Scientists from the Max Planck Institute for Biological Cybernetics will soon be sending their test subjects through the streets of ancient Pompeii. Using the virtual scenario that researchers at ETH Zurich programmed, project leader Marc Ernst and the institute’s director Heinrich Bülthoff want to research the interplay between perception and movement. The trick: the test subjects can move in any direction on a treadmill that was developed at the TU Munich and controlled by the University of Rome.
The room is dark and empty, about as tall as a gym and almost as long and as wide. A chest-high stage takes up nearly the entire hall. A set of stairs leads up to it. From up here, the dark walls seem even more bare. The voices sound subdued. The hall is lined with black painted fiberboards that absorb the sound. The floor, too – a large, empty, black surface with a square cut out in the center, home to a conveyor belt with a rough, non-slip covering, four meters across. A room could hardly be more clinical or less stimulating. No objects to draw one’s attention. They don’t want anything to distract the subjects when they step onto the conveyor. They are to focus entirely on their own bodies and, above all, do one thing: walk, walk, walk.

Under the floor, it begins to rumble. The electric motors start. The conveyor belt begins to move. It glides along at walking speed. Marc Ernst takes a large step on the walking surface and moves swiftly forward. He walks in place, just like at the fitness studio. But this treadmill is different. It reacts to Ernst’s movements. If he goes left, it moves to the right. If he turns around, it reverses direction. Ernst strides confidently forward, although he sees nothing. He is wearing a helmet and glasses. On the helmet are four posts with balls on their tips. These enable the four cameras in the far corners of the room to track the position of the subject on the CyberCarpet. A monitor in the glasses displays the virtual scenarios.

Marc Ernst’s helmet bears four posts with balls on their tips. These enable the four cameras in the far corners of the room to track the position of the subject on the CyberCarpet. A monitor in the glasses displays the virtual scenarios.
This disk with a bar attached to a central axis is reminiscent of a child's merry-go-round. The subject holds onto the bar while walking against the disk's rotation direction.

scientific tool. Together with their colleagues, the two neighboring buildings at the Max Planck Institute for the Human Brain (MPI) house the CyberCarpet project, which is one of the most natural human walking systems. The CyberCarpet is ready for operation. Carpet – that almost sounds a bit trivializing, considering the 11-ton engine under the walking surface. Here, there are four large electric motors at work that could just as easily drive a full-blown department store escalator. Although researchers have been working on such a system for years, the CyberCarpet is the world's first functioning omnidirectional machine that offers so much walking freedom.

Creating Conflicts Between the Senses

The CyberCarpet slows to a halt. Ernst takes off the glasses and helmet and descends the stairs from the stage with the walking surface in its center. He bends down and crawls under the main girder to reach the engine. It looks like the oversized chain of an excavator and works in much the same way. Such a track chain moves in one direction from front to back. In an excavator, the chain links are usually made of elongated metal plates that claw into the ground and propel the machine forward. In contrast, in the CyberCarpet, these links are themselves belts that move at right angles to the track chain. In this way, forward, backward and sideways motions add up to a conveyor belt whose surface moves in all directions. This allows test subjects to walk in place more naturally than ever before.

Behavioral researchers, psychologists and psychophysicists have only been studying the interplay between perception and walking in greater detail for about ten years. Experiments have shown that people can assess distances very well while walking. When subjects are asked to aim for a goal some 20 meters away and then walk toward it blindfolded, almost everyone reaches it perfectly; if they miss it, then never by more than a meter. Of course these experiments do not reveal just what enables people to estimate distances so well. To do that, the subjects' perception must first be tricked slightly, or as the researchers call it, "creating conflicts between the senses."

A neighboring building at the Max Planck Institute in Tübingen houses a second large walking platform – a virtual world for creating conflicts. While walking, the subject holds onto a bar that extends from the center of the disk to its edge and rotates at a different speed than the disk. If the platform moves quickly, but the bar slowly, then the sensory-motor receptors in the legs report a high speed, while the inner ear reports low acceleration values. The subject judges his walking speed inaccurately. By continuously varying the experimental conditions, the researchers can find out which of the senses likely has the greater influence.

This discipline, which aims to describe how the mind understands the physical world, is called psychophysics. It is a relatively old discipline. The question of how environmental stimuli are processed in such a way that a rational action results out of which of the senses likely has the greater influence.

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The bar and the disk can move at different speeds. Subjects can then no longer judge their own walking speed correctly.
Ernst's work is full of these kinds of conflicts. One of them even got him into the journal Nature a few years ago. However, it didn't yet have anything to do with walking. Ernst had developed a lab setup with which one can assess the size of a virtual object on a computer monitor optically and haptically. In this experiment, the image of a virtual post is projected onto a mirror. Behind the mirror, and thus exactly behind the virtual object, there are two straps into which the subject inserts the thumb and forefinger of one hand and one end of a virtual object on a computer monitor which one can assess the size of a virtual post. The trick: one time, the object was easily visible, and another time, the image of a virtual post on the mirror, and thus exactly behind the virtual object, there are two straps into which the subject inserts the thumb and forefinger of one hand and one end of a virtual object, there are two straps into which the subject inserts the thumb and forefinger of one hand. The straps, in turn, are connected with three electric motors each that counter the movement of the fingers. Such a force feedback device produces resistance and leads the test person to believe that they are touching a virtual object.

The subjects were given the task of comparing the size of two bars projected onto the screen in succession. The trick: one time, the object was easily visible, and another time, the researchers had it float in a virtual fog. By gently varying the size of the objects of comparison, the scientists incorporated errors. This allowed them to ascertain whether the subjects relied more on their eyes or on their feeling.

**CHOOSING A DIRECTION – WHERE TO?**

The findings were very interesting, providing the first proof that the brain combines stimulus data in a statistically optimal fashion. If the image was clear, the visual information prevailed. If it was obscured, the subjects relied more on their feeling. So the brain combines data from the various sensors and weights the information according to how reliable it is. "Viewed mathematically, the brain proceeds like a statistician integrating data of varying quality using the maximum likelihood method," says Ernst. As he proved, the brain is occasionally wrong. By and large, however, humans apparently make their way through the world fairly well with this method.

The team in Tübingen now has a pretty good idea of how the different human senses combine to form, for example, an impression of speed. But what they still don't know is how people orient themselves in space. What they were lacking was a large CyberCarpet that offers enough space to walk curves. The researchers have been pursuing this goal for some time in their labs – in Virtual Tübingen, an artificial downtown with shops and cigarette machines, stretching across a curved panorama screen like a film in a 3-D cinema. In the collection of images, the scientists move churches and supermarket landmarks from right to left to examine how their subjects gain their bearings. The trick to this experiment is that it is not the subject who moves, but rather the image.

Unlike with the CyberCarpet, on a walk through Virtual Tübingen, the subjects themselves do not move, but rather Tübingen’s downtown traverses the curved panorama screen, much like a 3-D movie.

The CyberCarpet gives navigation research a new quality. "We can even send subjects through empty deserts and see whether they really do walk in circles – and if so, which of the senses leads them astray," says Souman. The advantage of the CyberCarpet world is that orientation aids such as the position of the sun and the direction of the wind are eliminated. The CyberCarpet turns on again.

The gentle and intelligent control of the treadmill was the contribution of the Roman project partners, while the 11-ton hardware comes from the TU Munich. The team in Tübingen had submitted a request for support to the Institute of Applied Mechanics three years ago. The Bavarians are known for their clever machines. In 2005, at the Hanover Trade Fair, they sent their walker Johnnie through an obstacle course, to great acclaim – Johnnie, the first biped machine to overcome hurdles and manage ramps.

The TU team agreed to help the scientists in Tübingen and brought Martin Schwaiger on board for the CyberWalk project – an experienced engineer who normally develops warehouse management and logistics systems for forklift manufacturer Jungheinrich in Moosburg. Schwaiger realized that every conveyor belt principle had already been conceived at some time, somewhere in the world. But there was not a single functioning system. Japanese researchers had devised a similar conveyor belt in the lab, but the belt jerked and clattered. "A nice idea – but not practicable," they concluded.

Schwaiger viewed things differently. He thought the principle was promising. First, he drafted a completely new belt configuration – and quickly noticed that the devil is in the detail. "Adjust one screw, and five new problems arise," he says. The belts collided at the inflection point of the "track chain" and the hydraulic lines lost so much oil that the pressure was then barely enough to move the mechanics. Schwaiger switched to electric motors. However, the danger remained that the entire construction would tip over if the motors weren’t driven at exactly the same speed.
Partnerships
In addition to the Max Planck Institute for Biological Cybernetics, the following partners collaborated on the EU CyberWalk project:

- The Institute of Applied Mechanics at the TU Munich (Martin Schwaiger, Dr. Thomas Thümmel, Prof. Heinz Ulbrich)
- The Computer Vision Laboratory at ETH Zurich (Simon Hägler, Michael Van den Bergh, Dr. Roland Kehl, Dr. Pascal Müller, Dr. Esther Koller-Meier, Prof. Luc van Gool)
- The Department of Computer and Systems Sciences at Sapienza University of Rome (Paolo Robuffo Giordano, Dr. Raffaella Mattone, Prof. Alessandro De Luca)
- The Institute of Automatic Control Engineering at the TU Munich (Chih-Chung Chen, Dr. Dirk Wollherr, Prof. Martin Buss)
- AFWO GmbH in Tübingen (Dr. Friederike Wolf-Oberhollenzer, Uta Paulsen)

One-Click Town Planning on the Computer
But the treadmill alone doesn’t yet make it psychophysics. It also takes realistic computer graphics and software that understands the subjects’ movements. The cooperation partners from ETH Zurich contributed both. The observation cameras are linked to an analysis program. It recognizes not only the position of the subjects, but also their gestures. They are recorded and analyzed online in just seconds. For example, the computer recognizes when someone turns the handle of a virtual door.

Pompeii is, of course, just one of many virtual worlds that the Tübingen-based scientists want to simulate for their subjects. The Swiss cooperation partners developed a visualization software with which, with just a few lines of code, they can quickly create an entire city or other psychophysical scenarios – from futuristic metropolises to ancient Pompeii. To draft a realistic image of the city on the Gulf of Naples, the computer scientists visited the excavation site, spoke with archaeologists and analyzed drawings and photos. It took only about four weeks from the first digital plans to the finished draft of the virtual city. The charm of the software is that it takes only a short key entry to change the draft. The computer experts can thus make, for example, all 8,500 Pompeian houses sprout up in just a few minutes.

For the team in Tübingen, however, this is just the beginning. The Cyberneum is a large black gym cube perched atop a hill overlooking Tübingen and glowing turquoise in the dark. In the basement, there are treadmills and an industrial robot that swings test subjects wearing a virtual reality headset through the air, but the CyberCarpet is definitely the start of a new era. Subjects walking around curves and darting sideways is new territory for biological cybernetics.

And there is one more thing that makes the CyberCarpet so interesting for Marc Ernst: “We have here a machine that can be used in an incredible number of areas – also beyond basic research.” Firefighters could train for dangerous deployments in burning corridors, or museum visitors could stroll through ancient Rome. And architects could take their clients on a tour through their future dream house. The future of the CyberCarpet is undoubtedly colorful and alive – even if the beginning is black and bare.

TIM SCHRÖDER
PHOTOS: AXEL GRIESCH (2)

With their green control lamps, the electronic drive units ensure that the electric motors of the cross-belts stay in sync – otherwise, the CyberCarpet would not flow so smoothly.

Part of the CyberWalk team (from left): Ilja Frissen, Michael Kerger, Marc Ernst and Jan Souman from Tübingen, Paolo Giordano from the University of Rome, and Simon Hägler and Michael Van den Bergh from ETH Zurich.

A year later, a small prototype was completed. He had stopped the clattering with special circular, so-called transition curves. And thanks to a lot of control electronics, the motors remained in sync. Then, finally, Schwaiger was able to start building the real CyberCarpet. A few weeks ago, the machine moved to Tübingen, part by part. For Schwaiger, the project is complete. Ph.D. in hand, he will now return to Moosburg from his excursion at the TU.