Eye to eye with computers

Our eyes are our window on the world, but they also reveal a lot about us. **Andreas Bulling** and his team at the **Max Planck Institute for Informatics** in Saarbruecken and at the University of Stuttgart exploit this by teaching computers to interpret our gaze. Ultimately, their aim is to enable robots or avatars to communicate with us eye to eye.

TEXT **PETER HERGERSBERG**

Pay more attention to your eye movements," says Andreas Bulling with a laugh as he leaves. That's good advice. My discussion with him has made one thing clear: viewing the world, we also allow the world to view us. Our eye movements can reveal our character or the social dynamics in a group, to name just two aspects of Bulling's research. A computer scientist who heads a research group at the Max Planck Institute for Informatics in Saarbruecken, he has now been made a professor at the University of Stuttgart.

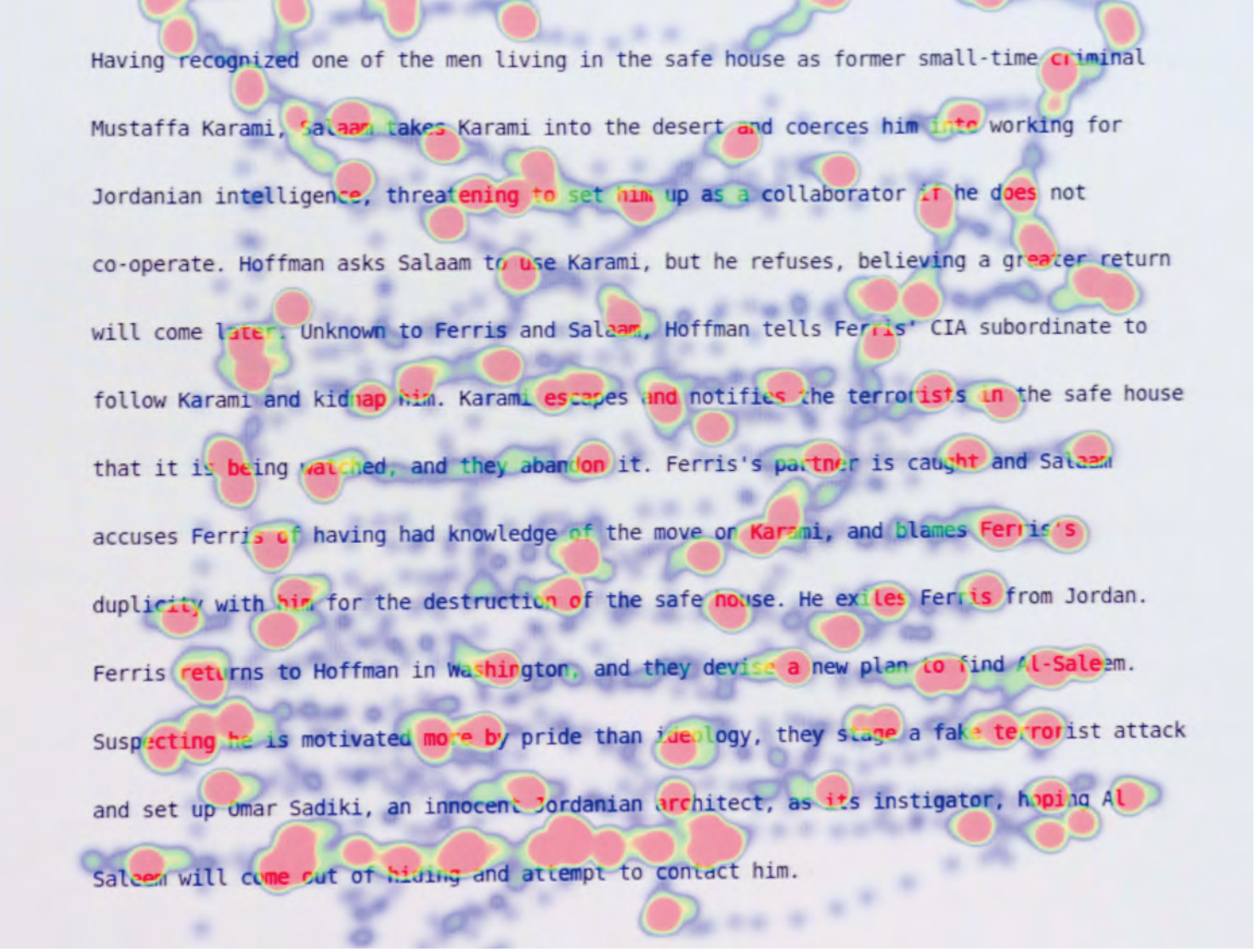
"We humans direct and analyze such signals subconsciously," says Andreas Bulling. "It's something some of us, such as people with autism, can't do." At times, they'll stare right through you in an unconnected way, while conversely, they often have trouble reading other peoples gazes. "It can be very disconcerting," says Bulling.

His research could help. As a computer scientist, he teaches computers to understand human eye movements. The software he has been developing could also help people with autism to interpret the gaze of others and to control their own eye movements, for example by relaying helpful instructions via a pair of eyeglasses.

Andreas Bulling and his team are also aiming to enable machines to communicate eye to eye with us humans. In the long term, humanoid robots, for example, would be able to interpret our gazes even in a crowd, and control the movement of their camera eyes in such a way that we experience their own gaze as natural. Our eye movements

Eye contact: Max Planck researchers have developed a computer program that can detect whether a person is looking into the eyes of another person.

Photo: shutterstock



Reading prediction: researchers have been studying eye movements in reading since the 19th century. Andreas Bulling's team is now developing a model that, on the basis of the text alone, is able to predict which words readers will fixate on.

could also provide important information for driver assistance systems.

Bulling and his team are using computer-aided analysis of eye movements to achieve this – helped by a decisive technique. "We were the first to apply machine learning in the field." Artificial intelligence has opened up completely new ways for the research team to read our eyes.

Researchers first started investigating gaze behavior back at the end of the 19th century. The French ophthalmologist Louis Émile Javal was a pioneer, investigating how people read. He discovered that our eyes don't continuously wander along lines of text, but instead skip from word to word, mainly, as it turned out later, fixating on key words.

From the 20th century onwards, companies have also discovered the significance of eye movements. Newspaper and magazine publishers, for example, examine what we are looking at in an article, while marketers analyze where they should position adverts or print information on packaging to attract the attention of customers. And some web designers design Internet pages on the basis of eye movements to ensure that the gaze of readers linger where they want it to.

EYE MOVEMENTS AS A CHANNEL OF COMMUNICATION

Customer decision-making is just one of the mental processes that cognitive scientists study using gaze analysis. "We use eye movements as a kind of window on cognitive processes," says Peter König, a professor at the University of Osnabrueck. "They provide us with a paradigm for how the brain functions."

Computer scientists like Bulling now research eye movements both as a data source and as a communication channel. Bulling's group isn't just focused on cognitive processes, but also on our behavior, for example how we interact with our digital devices. Their first task is to teach computers to correctly recognize where we are looking, and not just from a perfectly illuminated face and in a constant laboratory environment, as was previously the case in computer-assisted gaze analysis.

Scientists have long relied on machine learning to do this. But, up until now, the data they relied on to train computers wasn't very relevant to everyday life. To rectify this, Bulling and his team installed software on the notebooks of 15 volunteers. Over a number of days while they worked on their computers, the volunteers were repeatedly prompted by the software to fixate on a chosen point on the monitor, and a photo was taken of them.

This provided the team with images in varying environments and often in poor light conditions. As they also knew where the volunteers were look-

Photo: Wolfram Scheible

ing, the researchers were able to create a comprehensive dataset, which they used to train a program to determine gaze directions, even in difficult conditions. "Our data set is much larger and more natural, making it more revealing than previous ones," says Bulling. "But it's still not optimal." During the training, the volunteers were only sitting in front of computers, which they looked at more or less frontally. The program still recognizes eye position extremely poorly if someone moves or targets a point out of the corner of their eye. "We're still trying to figure out how to generate even more realistic data sets."

Mobile eye trackers are one possibility. They are fairly accurate, but up to now have been rather obtrusive: various cameras recording an individual's eye movement and field of view are attached to a device similar to a pair of eyeglasses, along with infrared LEDs whose reflections are captured by the cameras. The equipment makes subjects look like a cyborg – not exactly unobtrusive for onlookers.

Bulling's team has, therefore, developed a prototype eye tracker for everyday use with a handful of commercially available cameras that are only marginally larger than pin heads. Even though these cameras have a limited resolution, the researchers can compensate for this with the right training. Using data in which camera images have been linked with eye position, they train a computer to correctly interpret the poor-quality camera images. The Berlin start-up Pupil Labs, in which Andreas Bulling has a stake, is now marketing an eye tracker based on the concept of the Saarbruecken researchers that is almost comparable in accuracy to significantly more conspicuous eyeglass devices.

"We aren't yet using inconspicuous eye trackers in everyday communication, but we've already started employing them in market research and in virtual reality computer games," says Bulling. Primarily, however, they are of interest for research. "In studies involving social interaction, they allow participants to interact more naturally." In the future, they should also lend weight to the findings of Bulling's team on group dynamics.

WARNINGS FOR DISPLAY JUNKIES

The computer scientists have, nevertheless, already started to reveal some surprising insights using computer-assisted gaze analysis with conventional eye trackers. For instance, the researchers equipped 20 volunteers with the devices, and tracked their eye movements while using smart phones. They also identified the app that the participants were currently using and analyzed what was going on in their external environment.

As unlikely as it sounds, the hope was that such data could be used to predict whether, in the seconds that followed, the attention of smart phone users can be shifted to their surroundings and stay there. And, at least to some extent, that's just what the computer learned from the data.

Using such models, smart phone apps are potentially able to predict whether someone staring at their phone is about to walk into an obstacle, and give the display-fixated reader a timely warning. Attention analyses, a field which Andreas Bulling is now able to pursue with an ERC grant, could also provide clues as to how a person's focus can be held, for example, on a text. "We think we might be able to reverse the trend that people are becoming ever more prone to getting distracted from tasks," says the researcher.

Eye trackers can also help analyze the mood in group discussions as well as who is in charge. The crucial method involved was developed by Philipp Müller, a doctoral researcher at the Max Planck Institute for Informatics. From

Focused: Andreas Bulling (right), together with Sander Staal from the ETH in Zurich and others, are developing models of how our attention is controlled, for example to develop new ways of alerting computer users to incoming e-mails without interrupting their concentration.

Photo: Wolfram Scheible

An eye catcher for everyday life: based on work by Max Planck researchers in Saarbruecken, the Berlin-based company Pupil Labs has developed a mobile eye tracker that resembles normal eyeglasses.

regular camera shots of groups of people in discussions, his technique recognizes who is looking at whom and who is consistently looking beyond someone or everyone else. It can also read the mood of people from their faces. Combined with voice analysis, among other things, these characteristics can successfully reveal whether or not a discussion is progressing constructively, and who is emerging as the leader.

It's easy to understand how our gaze can tell us a lot about the dynamics of a group. The leader of a group tends to attract the gaze of everyone else, while if the mood of the group is poor, people tend to stare at the ground rather than seek eye contact. In future, computers should also be able to interpret such non-verbal signals.

Statistical analysis of gazes using machine learning isn't just limited to just concrete gaze patterns, however. If we want to analyze personality traits, for example, we need to be able to recognize highly subtle eye movement patterns. Using a combination of eye tracking and machine learning, Bulling and his team of researchers, together with colleagues from the University of South Australia, were able to make some reliable statements placing subjects into four character trait groups.

To achieve this, they asked 42 subjects at Saarbruecken University to complete a task, on average twelve minutes long, while simultaneously recording their eye movements. Some of the subjects also completed a standard psychological questionnaire, and this data was fed into a model. Trained in this way, the computer was able to read from the eyes of the other subjects how neurotic they were, how well they got along with others, whether their attitude to life was extroverted, and how conscientiously they completed tasks.

However, the model failed to provide a useful assessment of three other character traits that psychologists use to characterize personality. "And the predictions are not yet accurate enough to be useful in practice," says Bulling. But the system is certain to become more reliable in the future. Such a complex task will require training sets of more than just a few dozen subjects. More data on eye movements will enable more accurate character analysis.

THE IMPORTANCE OF DATA PROTECTION

Such advances bode well for how we will be interacting with robots and avatars in the future. After all, computer systems should, in the long term, be able to interpret all of our verbal and non-verbal modes of communication. However, the fact that computers will be able to analyze our personality solely on the basis of our subconsciously controlled gaze behavior is cause for trepidation.

Bulling is aware that the software may make it possible to subject people to a computer-based personality test – a possibility that could be abused by companies or autocratic regimes, which, even today, have already started digitally analyzing people's behavior. However, the computer scientist stresses that the technology is a long way from being able to reliably determine an unwilling subject's personality. This is not least due to the eye trackers that people still need to wear right in front of their eyes.

And even if one day it does, indeed, become possible to identify someone's character remotely and with little effort using their eye movements, as with all inventions, such technology can be employed both for good and for bad. "Analyzing people's personalities, attitudes and intentions, for instance at a job interview, isn't new – as performed by person," says Bulling. "However, we're mostly not aware it's happening or take it for granted, because it's being done by a human."

Science can't prevent misuse of its advances in many fields, but it can contribute to preventing it. Data protection for eye-tracking is, therefore, one of Bulling's main concerns. "I think it's crucial. As with other digital platforms, in particular social media, we need to be mindful of privacy in eye-tracking," he

Photo: Pupil Labs

Promising prospects: Andreas Bulling is convinced that analysis of eye movements for non-verbal human-machine communication will easily provide enough material for his future research life.

says. "We're at the forefront of research in the field, and over the coming years we'll continue to drive it forward."

Informational self-determination, in other words, control over what happens with our data, is generally only considered a cause for concern when data is used for a specific purpose. However, non-existent data can't be misused. Bulling and his team have therefore investigated how data in the images taken of people's field of view by eye trackers can be kept confidential. The images can reveal not only where a person is looking, but also what they are seeing.

The images may accidentally include passwords or secret codes, and, naturally, other people, who are unlikely to want to be recorded without their consent. Gaze analysis and machine learning once again have a role to play in the solution. The scene camera can readily be used to determine whether we are accessing our bank account on the computer, entering a PIN at an ATM, or are facing a stranger. The researchers developed a highly analog solution to the problem: the software merely slides a cover over the lens of the camera. "As the scene can't subsequently be analyzed, we have to infer from eye movements if and when the subject has moved on from the sensitive situation," says Bulling.

The ability of the software to learn is helping us solve the problem of data protection. Sometimes, however, this ability itself becomes a problem. A well-trained program is able to read much more from eye movement patterns than we humans can, such as whether the eye tracker is being worn by a woman or a man. "However, only a portion of the eye tracker data can be used to determine gender," explains Bulling. "As this is not required for the other analyses we're interested in, we just fade it out." We can treat other information obtained from our eye movements in a similar way. "Which data to preserve and which to fade out will be left to the user to decide in the future."

As Bulling has shown, non-verbal communication with humans or machines, life-like virtual reality, utilizing digital devices, and data protection in gaze analysis can all benefit from analysis of eye movements using artificial intelligence. And he's sure it will stay that way: "It's a gold mine," Bulling says. "There is easily enough material here for me for a lifetime of research." ◀

https://www.mpg.de/podcasts/lernen/maschinelleslernen (in German)

SUMMARY

- Eye movements play a significant role in non-verbal communication. Researchers are hoping that such modes of communication will be utilized by computer systems such as robots or driver assistance systems in the future.
- Andreas Bulling's team is refining computer-aided techniques that gauge the direction of a person's gaze. They are also developing models with the help of machine learning that can identify the personality traits of individuals or the mood of a group from eye movements. This should also help computers, for instance, to learn how to control the movement of a robot's eyes to appear natural.
- The researchers are working on various technical solutions to ensure that data gathered when analyzing eye movements is protected.

Photo: Wolfram Scheible