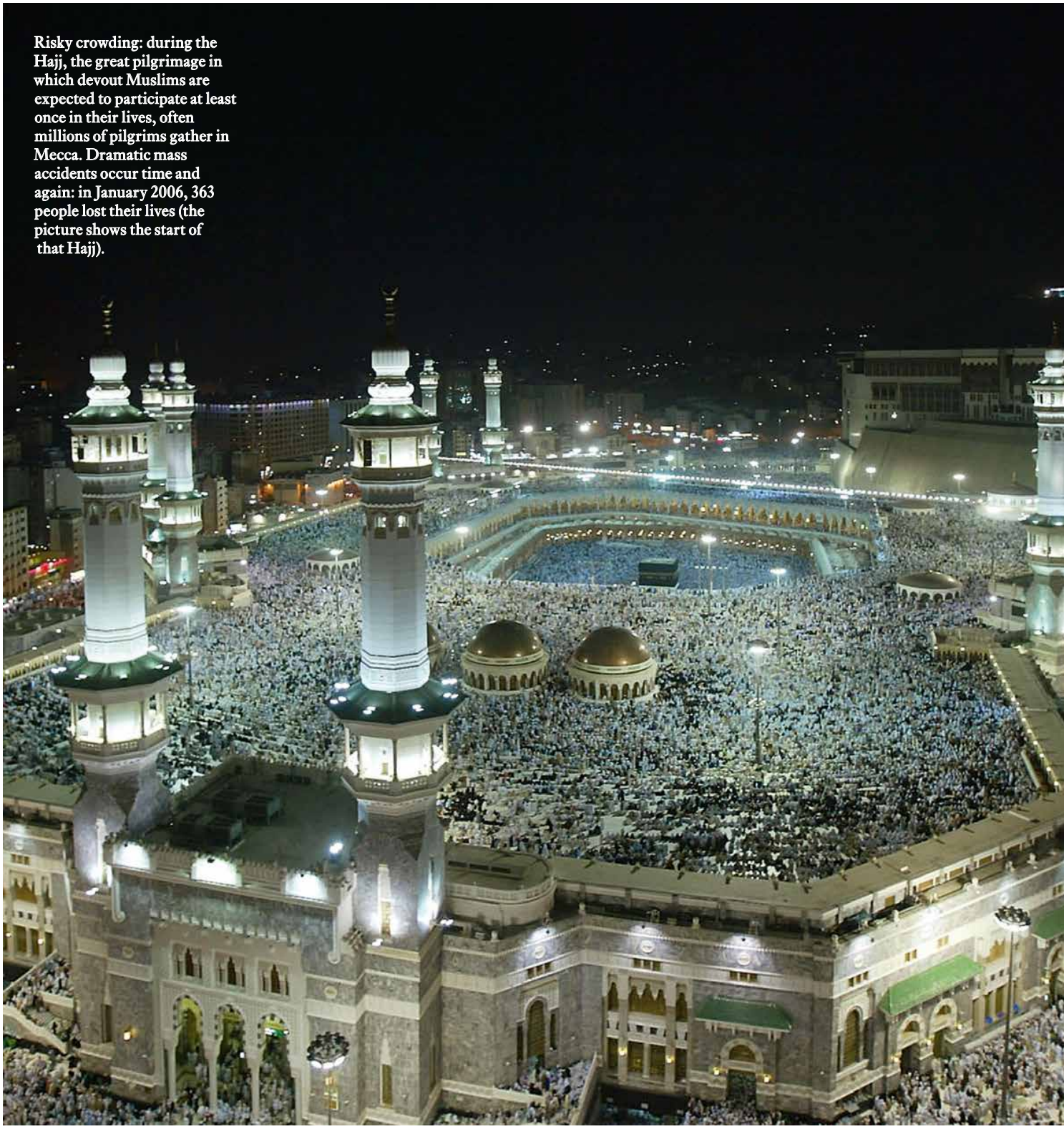


Risky crowding: during the Hajj, the great pilgrimage in which devout Muslims are expected to participate at least once in their lives, often millions of pilgrims gather in Mecca. Dramatic mass accidents occur time and again: in January 2006, 363 people lost their lives (the picture shows the start of that Hajj).

PHOTO: MUHANNAD FALA'AH/GETTY IMAGES

NINE PER SQUARE METER

TEXT: MARTIN TSCHECHNE

How do individuals orient themselves in a crowd? How does hate spread on the internet? And what does one have to do with the other? At the Max Planck Institute for Human Development in Berlin, Mehdi Moussaid studies people in motion and explains why this sometimes leads to disaster.

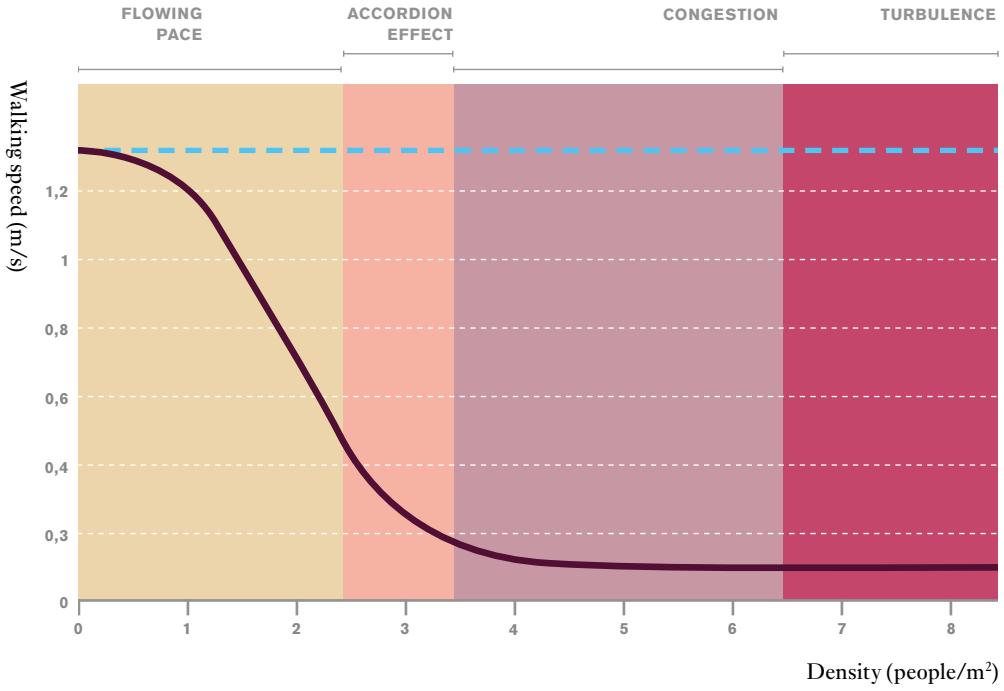
It was a moment when human existence passed into another state. Quite literally. In which it transcended the boundaries of its own corporeality and disintegrated into the flow of the masses. A moment when all hell broke loose.

January 12, 2006. Like every year, more than two million devout Muslims from all over the world made their way to Mecca to symbolically stone Satan and circle the Kaaba, the black shrine in the courtyard of the Great Mosque, seven times. And like every year, pilgrims pushed their way across bridges and through wide corridors towards the holy place, densely packed and hardly able to move on their own. There have repeatedly been deaths – in bad years, several hundred, or even more than one thousand, who succumbed to the masses and were trampled to death. Or those who simply suffocated in the crowd. The Saudi overseers of the ritual were at a loss to find a solution. Someone had to figure out exactly how such disasters occur. And how they can be prevented.

So it came to pass that Anders Johansson, a Swedish engineer and physicist, was able to film for the first time how the mass of pilgrims surged back and forth between the walls of the access roads like an ocean during a hurricane. How it surged up into wave crests, crashed against walls, and buried anyone who wasn't lucky enough to be squeezed out on top. No football stadium or rock concert has anywhere near as many people crowding into one place as the Hajj, the annual pilgrimage to Mecca. By the end of that ill-fated day in January 2006, 363 people had lost their lives.

Mehdi Moussaid has the horrific scenes displayed on his screen. Shrugging, he admits that it is first-class research material. He was still a student when he joined the research team led by Johansson and Dirk Helbing, a physicist and sociologist teaching in Zurich. Moussaid is now 40. And as bad luck would have it: on 24 July 2010, only a few days after he defended his doctoral thesis on the origin of turbulence in crowds at the University of Toulouse, 21 participants of the Love Parade in Duisburg were crushed and trampled to death, and 652 others were injured, some seriously. "With six or seven people per square meter," says Moussaid, "the critical limit is reached and exceeded." In Mecca, there were sometimes nine people per square meter.

He clicks another image onto his screen: bright red grape tomatoes in a wooden frame. Pretty to look at. In time lapse, increasingly more tomatoes are added. It gets increasingly tighter until the first fruits burst and red juice oozes out of them. What began harmlessly ends in disaster. The parallels are abundantly clear. The people in the mass are pushed and fall, every gap closes immediately, and every impulse is passed on and builds up to a powerful surge. "We tend to blame such events on personal shortcomings," says Moussaid. "Youthful recklessness, religious fanaticism, alcohol, and drugs. All nonsense! What happens here follows the laws of hydrodynamics, fluid mechanics, and me-



The denser, the slower: the number of people per square meter determines how fast someone can move. Even with one or two people per square meter, people have to avoid each other and the pace slows down. If the crowd becomes denser, the so-called accordion effect develops, for the only way to move is stop-and-go. If the crowd becomes even tighter, people have to move with the crowd. It becomes dangerous when people are so close that even small movements can cause turbulence.

GRAPHIC: GCO ACCORDING TO MEHDI MOUSSAID/MPI FOR EDUCATIONAL RESEARCH

Grape tomatoes as a model: a tomato almost exactly reproduces the outline of a human body. On an area of 15 square meters, two to three people can stay at a corona distance of 1.5 meters (1). Even with two people per square meter, progress is slow (2). On the S-Bahn, when trains are canceled during rush hour, there are often five people per square meter (3). This crowding is not yet dangerous, as impacts are absorbed by the bodies. A density of eight people per square meter (4), on the other hand, can be life-threatening: at the 2010 Love Parade in Duisburg, 21 people died at this density.

PHOTOS: GCO ACCORDING TO MEHDI MOUSSAID/MPI FOR EDUCATIONAL RESEARCH

chanics alone. Pure physics. It's about formulas. As simple as that."

As an engineer, he came to the interface of disciplines: computer science. But after six months as a programmer and data analyst in the industry, the allure had faded. He wanted to do research. So he studied bees and ants, swarms of birds and insects, and fish at the Behavioral Research Laboratory in Toulouse, worked at the ETH in Zurich at the interface between physics and social sciences, and finally came to Berlin to the Max Planck Institute for Human Development. Director Ralph Hertwig is a psychologist. "I fit in well there," says Moussaid, laughing. "I'm not a specialist in psychology or even computer science or biology – but I am quite adept at moving between these subjects."

How can a school of fish turn in another direction at the same moment? And what is the dynamic of a wave of hate on the internet? How does information about a threat propagate through a phone chain? Like waves in a liquid. Sometimes he almost has to laugh at how far the laws of natural science determine the everyday life of a highly civilized society. But then he gets very serious at the thought of the possibilities of remote control this opens up. It's then about the subtle (and not so subtle) mechanisms of social influence and manipulation. What influence does another's confident demeanor have on one's own judgment? Or the conviction of a large majority? When do people flee their homes? How do people move through a narrow network of corridors? And what influences the choice of an escape route? According to Moussaid, the patterns are remarkably similar. The findings from one field can be transferred to another. The scientist speaks of fouloscopy (derived from the French "la foule" meaning "the crowd" or "the mass"): what the mass says about us.

Mass hysteria stems from imitation

In the shopping mall at Alexanderplatz in Berlin, there is a balcony that offers an unobstructed view of how streams of people meet and glide past each other quite easily and almost elegantly. Moussaid thought he had found an optimal place for his analysis of the highly complex, collectively coordinated patterns of movement right on his doorstep – until the security guards came and escorted him out along with his video camera. They spoke of data protection. Of the right to one's own image. As if he were targeting individuals.

So he developed an experimental set-up, a kind of computer game, in which he sends avatars, proxies simulated on the screen, into a crowd that can be varied at will. The virtual creatures look like wooden mannequins. At the click of a mouse, they can be navigated through winding corridors and narrow passages. Signposts light up, and others push their way forward. The living participants of his studies sit in the same room, each in front of their screens with the other players in sight. Some form of contact must be provided if interaction is to be observed. It's about validity.

As he found out, the jerky, yet fascinatingly synchronous change of direction of a school of herring is not that far removed from the behavior of people in larger groups. The movement of the closest neighbor is a very important stimulus. One knows where to go, and the others follow. Decisive behavior convinces others. Mass hysteria comes from imitation. Increased reward, punishment, a flashing red light, or time pressure creates stress; if the density increases, crowding in front of a narrow exit quickly turns to panic. And of course, the

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PHOTO: DAVID AUSSERHOFER FOR MPG

Committed communicator: Mehdi Moussaid works at the Max Planck Institute for Human Development. In his spare time, he produces YouTube videos in his native language, French, in which he clearly explains his research area.

SUMMARY

The movements of individuals in dense crowds conform to physical laws. Appropriate calculations can help control large gatherings and avoid mass disasters.

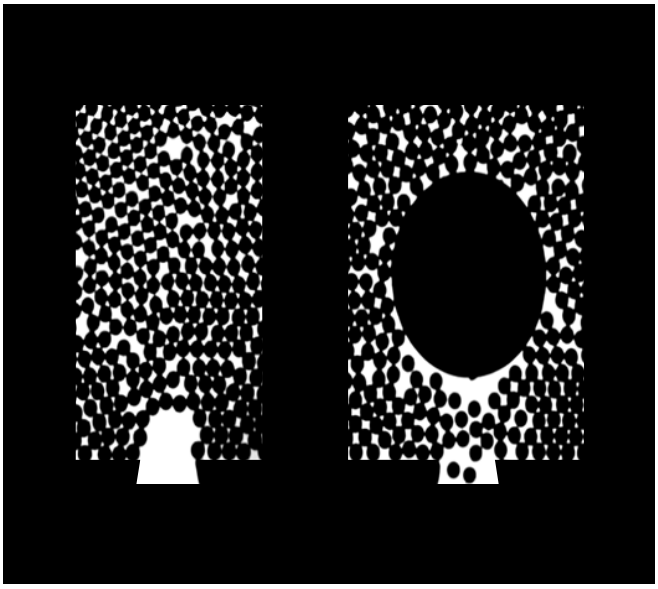
In less dense crowds, psychological factors play the essential role in the behavior of individuals and thus in the behavior of the crowd.

wider the gate, the quicker people are able to escape. Moussaid calls up another image on his screen. There are two funnels into which someone is pouring dry rice: on the right in a surging gush and on the left in a slow and steady flow. And while the grains flows unhindered into the bowl on the left, the grains clog the narrow bottom on the right.

A new film appears on the screen: sheep crowded in their pen in front of a narrow exit. And indeed, the more violently the animals are driven, the greater their fear and the more restless the flock becomes. And the longer it takes them to pass through the exit. "Pure physics," Moussaid says again, but who thinks about the zipper-merging process when deadly danger threatens from behind? He reels off the disasters that have all followed a similar pattern: Heysel in Belgium, Hillsborough in England, and the Jewish festival Lag BaOmer in 2021 in Israel with 39, 97, and 45 fatalities, respectively.

The trauma of terrorist attacks continues to have an impact

The terrorist attack in Paris in November 2015 should be noted as well, when around 1,500 people crowded into the Bataclan concert hall as Islamist terrorists opened fire inside, causing 90 fatalities. A further 40 perished and hundreds were injured during attacks elsewhere in the city, with no escape. And it is hard to imagine what



GRAPHIC: MEHDI MOUSSAID/MPI FOR HUMAN DEVELOPMENT

Helpful obstacle: a barrier just before the exit causes the crowd to divide, making it easier to flow out.

would have happened if the bombers had also stormed the Stade de France football stadium, where 80,000 spectators at the international match between France and Germany heard only the muffled bang of detonating explosive devices. The trauma of the terrorist attacks continues to have an impact today. Sometimes people take flight because they think they have recognized signs of a new attack and sometimes just because others are also running away.

Moussaid is a communicator. He not only determines his findings in concrete situations but also disseminates them that way. He tells stories, illustrates them in vivid and sometimes shocking images, searches for catchy analogies, and lectures with rousing enthusiasm. He writes popular books and articles, enjoys appearing on radio, produces audio books, and runs a YouTube channel in his native France with 300,000 followers. In all honesty: is he perhaps applying his findings on the power of persuasion to his own content?

The routing in Mecca was redesigned

He laughs. His former teachers and colleagues now advise transportation planners and architects. The routing in Mecca was redesigned according to their specifications; a control center monitors the flow rate and density of the stream of pilgrims, and one-way streets divide it up. Bottlenecks in front of which the faithful had piled up like the grains of rice in a funnel were removed. The specialists curb inflow to mass events by opening and closing time windows. They limit access or, seemingly paradoxically, place an obstacle in front of a narrow exit. This obstacle acts like a kind of wave breaker in front of which the flowing mass divides and can then slip out more easily. The principle is similar to the formula used to design a wing to keep an airplane in the air. It is also helpful in preventing disasters.

Moussaid is now entering a research field in which events follow not only the laws of physics but also those of cognition and adaptive rationality, i.e., with fewer than three, four, or five people per square meter. "It's quite fascinating," he confirms as he points to the wooden figures in his virtual mazes. "The sheer number of people determines which scientific discipline provides the best explanations and predictions." Whether they block each other in the crowd or are free to decide for themselves how to behave. Whether they put their own interests before those of the group or give way to each other because they make quicker headway. Collective intelligence – even if someone shouts "Fire!" from behind. Density (also perceived or anticipated density) restricts any freedom of movement.

Did Napoleon really force the inhabitants of the countries he subjugated to swerve to the right side of the road when they encountered each other – so that they would not be able to swiftly draw their swords with their right hands and strike immediately? The person approaching could also be a soldier of the occupying power. "Nice story," says Moussaid, laughing again. "But, unfortunately, only a myth. And one that's hard to dispel." In fact, he says, the heuristic of swerving right or left is the result of a learning process in the social environment. There is a general consensus on which side people should swerve to. Quite simply because collisions cannot be avoided any other way. The rules of the road have some influence – but not a compelling one. It has been verified and proven many times that most people in Central Europe have the impulse to swerve to the right when in doubt. This can be seen nicely in the short film clip from the shopping mall at Alexanderplatz.

For almost 10 years, it seemed that the analysis and correction of the flow of pilgrims to Mecca had ended a chain of fateful misfortunes. Until September 24, 2015. On that day, a glitch in the process caused a panic unlike any seen before. Well over 2,000 people were killed. Was it because, as the Iranian press later claimed, Saudi Crown Prince Mohammed bin Salman had a barrier erected in order to make a convenient path for himself through the crowds? Moussaid is skeptical. For him, any attempt at prediction and prevention eventually reaches a limit. "Such events have many causes," he says. "Usually too many to even identify."

www.mpg.de/podcasts/schwarm (in German)