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Mathematical time law governs crowd flow

Pedestrians avoid bumping into each other by anticipating when their paths would collide.

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Walking in crowds means predicting the future. When navigating heavily trafficked areas, people adjust their paths after subconsciously calculating how long it would take to collide with another person.

Researchers have come to this conclusion by analysing videos of crowds. They say that it could lead to safer design of public spaces and help in the development of crowd-monitoring methods to prevent deadly stampedes.

Brian Skinner, a physicist at the Argonne National Laboratory in Lemont, Illinois, and his colleagues will publish the work in an upcoming *Physical Review Letters*[1].

When scientists study crowd movement, they often model people as moving particles that repel each other, similarly to electrostatic charges of the same sign. Skinner and his colleagues expected that the 'repulsive force' would depend on the separation in space between the pedestrians, making them change trajectory when they get too close, so as to avoid collisions.

If the electrostatic analogy were correct, the strength of the force would be proportional to the inverse square of the mutual distance, with the repulsion becoming rapidly stronger as two people approach each other. Instead the team found that the force is proportional to the inverse square of the anticipated time to the next collision. In particular, the researchers point out, if two people walk side-by-side — and therefore do not anticipate bumping together — they can do so at very close distance without feeling the need to put more distance in between.

"What's exciting is not so much the understanding of one person navigating through a crowd, but the promise of predicting what crowds do by using one simple rule," says Skinner.

This rule accurately described the motion of people navigating university campuses in Israel and of participants in crowd experiments in Germany, both captured in videos. In addition, simulations showed that the simple time law also reproduced many known properties of crowd interactions (see video above), such as cramming around narrow passages and spontaneously forming lanes.

But the team’s model breaks down if the anticipated time to the next collision is longer than three seconds, Skinner says. This may reflect the possibility that people in a crowd do not concern themselves with what will happen beyond that interval, he says.

Mehdi Moussaid, who studies crowd behaviour at the Max Planck Institute for Human Development in Berlin, says: “The nice thing about this paper is that it is based on empirical observations, and that the result is clean: the exact same power law emerges from different data sets.” The model could also help to “fine-tune predictions of crowd movements during mass events, such as the Mecca pilgrimage,” adds Moussaid, who has studied the motion of the immense crowds that converge on the Saudi Arabian city during the Hajj. “But when it comes to crowd accidents and crowd disasters, the open question is whether the same rule is still valid under high-stress conditions, for instance during panics and emergency evacuations.”

The authors admit that the time dependence they found cannot account for the stop-and-go of crowds in which people are so close that they press against each other, or for the onset of chaotic motion, or ‘turbulence’, that has been observed in extremely dense crowds[2]. In such situations, the model may need modification, Skinner says, because people can no longer rely on the projected time to next collision to navigate. However, the current model may be able to warn when such dangerous crowd situations are about to arise, he adds.

Indeed, the team’s next step, says study co-author Stephen Guy of the University of Minnesota in Minneapolis, is to combine modelling with data from surveillance cameras and other pedestrian-tracking systems to detect the current state of a crowd and predict how it will change over time. “Identifying crowd problems before they even happen has the real potential to save lives,” he says.

Skinner also hopes to test whether the model applies to highway traffic. Igor Aronson, a physicist who is also at Argonne National Laboratory but was not part of the study, adds that the rule might also be applicable to other groups of animals, such as birds or fish.

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References

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