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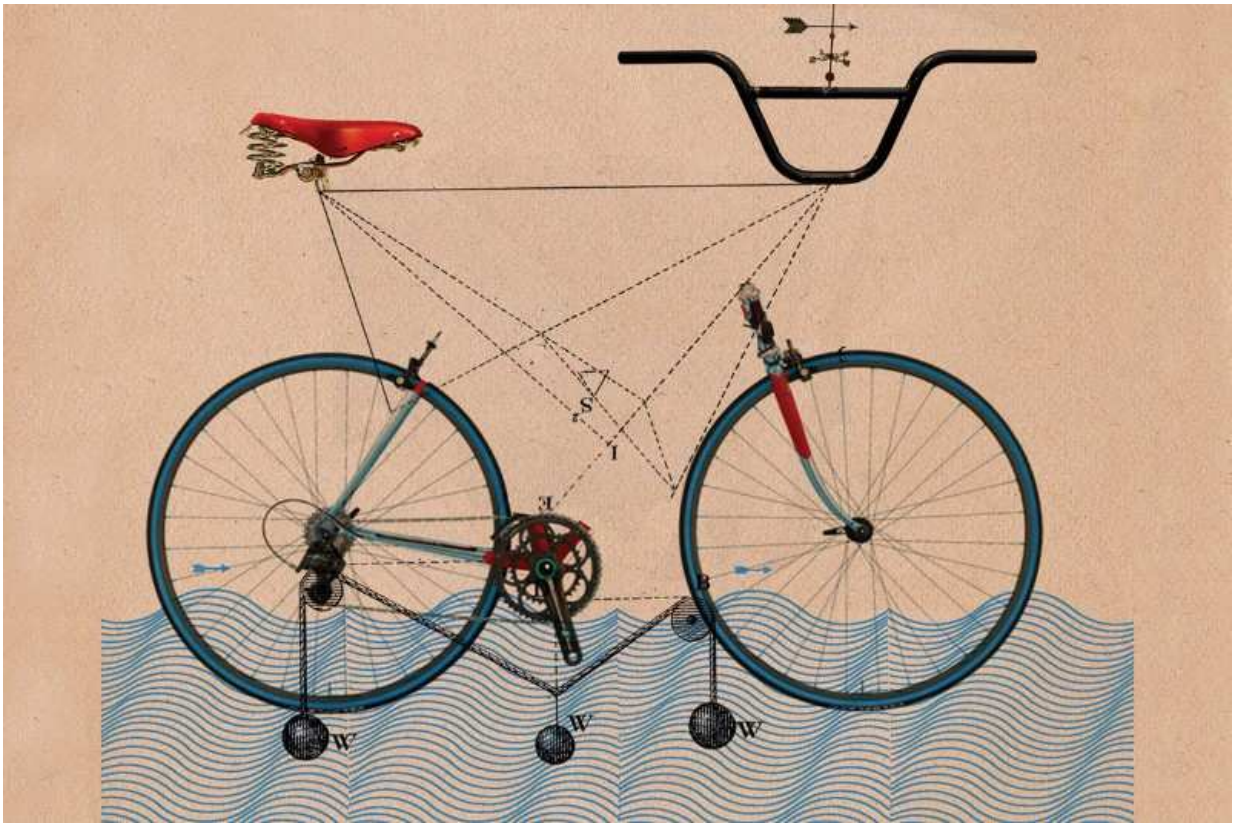
How does a bicycle stay upright?

We thought we knew the maths behind cycling. We were wrong - and our efforts to figure it out are leading to some weird and wonderful new bike designs



(Image: Matthew Richardson)

IN 2011, an international team of bi-pedal enthusiasts dropped the bombshell that, despite 150 years of analysis, no one knows how a bicycle stays upright. Across the world, riders dismounted and stared at their bikes in disbelief. What they had been doing for years was a feat inexplicable by science.

Well, sort of. “What we don’t know are the simple, necessary or sufficient conditions for a bicycle to be self-stable,” says Andy Ruina, an engineer at Cornell University in Ithaca, New York.

We have relied on trial-and-error engineering to construct stable bikes that aren't prone to toppling while in motion. Explaining how they work mathematically requires around 25 variables, such as the angle of the front forks relative to the road, weight distribution and wheel size.

Before 2011, researchers had reduced this profusion to two things. One was the size of the "trail", the distance between where the front wheel touches the road and where a straight line through the forks would meet the ground. The other was the gyroscopic restoring force that acts on a spinning wheel to keep it upright.

Ruina and his colleagues, including Arend Schwab of the Delft University of Technology in the Netherlands and Jim Papadopoulos of the University of Wisconsin-Stout at Menomonie, not only revisited this mathematics, but also skewed the trail and gyroscopic forces in prototype bikes to make them technically unrideable. To everyone's surprise, the bikes were still stable (*Science*, vol 332, p 339).

The researchers haven't been resting on their saddles since. Last year Ruina unveiled a "bricycle", a cross between a bicycle and a tricycle with spring-loaded stabilising wheels that can be adjusted to vary the rider's perception of contact with the ground. By studying the influence this has on how the rider steers and remains stable, he hopes to gain new insights that might lead to more easily controllable bicycles.

It's still an uphill struggle. "I think the real understanding of bikes requires a mix of what we did, plus some kind of brain science," says Papadopoulos. Human riders act in extremely complex yet intuitive ways to keep a bike balanced and on track. At very low speeds, for example, we recognise that the handlebars become useless for steering, and instead direct the bike by wobbling our knees.

Why? "We don't know," says Schwab. Yet another bike-based mystery that could be around long after we've worked out the origins of the universe.

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