The weirdness of time zones

Time zones are weird. Any child who's entered the Channel Tunnel in Calais and exited in Dover half an hour earlier can testify to that. As an adult you aren't allowed to admit it's confusing. But what if you were correct, as a child, to lose your head?

Here's another weird thing. A game. Extend your right arm straight in front of you, with your thumb pointing up. The first rule is that you have to keep your arm locked straight, and the second is that you're not allowed to rotate your thumb about the arm. You can only move the arm rigidly. Keeping your arm straight and pivoting it about your shoulder joint will force your thumb to move over the surface of a sphere with you at the centre.

If you imagine this sphere as the Earth, with you at the core, we can say your hand starts off pointing to the intersection of the Greenwich Meridian and the equator (i.e. just west of Equatorial Guinea). Now, the second rule says you mustn't change the angle of your thumb relative to the North Pole. You can't tilt it towards Russia in the east or the US in the west. The aim of the game is to take your hand on a journey over the surface of the Earth so that when it gets back to the start, your thumb no longer points north, but instead points west. Give it a go!

You might think it's an impossible game to win. At every stage of the journey the thumb has to keep pointing north, parallel to its starting angle, so it must still be pointing north upon its return. The weird thing, though, is that it *is* possible to win. First take your hand straight up, along the Greenwich Meridian, to the North Pole. Your arm will now be pointing to the ceiling, with your thumb pointing behind you. From there, take your hand straight down to your right, to the equator, passing through New Orleans on the way. Your arm will be pointing to your right, your thumb pointing behind you. Now move your hand horizontally along the equator back to the start. If everything went as planned your thumb will be back near Equatorial Guinea but will be pointing west rather than north. It's picked up a "geometric phase".

Time zones and the thumb game have a deeper connection than just both being weird. Imagine now that you're on a jet, flying west along the equator. You're a fastidious timekeeper and want your watch to stay correct relative to the time zone underneath you. Periodically, then, you have to wind your watch backwards an hour. The angle of the hour hand jumps backwards each time, picking up a phase. So if you travel once around the whole Earth, it seems you return with the date on your watch one day earlier than if you'd never left. So which date is correct? In fact, the time jumped *forwards* 24 hours when you crossed the International Date Line somewhere in the Pacific Ocean. Without that you'd have picked up a 24-hour geometric phase on your watch.

Why did your thumb rotate when it traversed that loop in the original game? Because your hand is constrained by the rules of the game to sit on a sphere, and a sphere is *curved*. By fixing the thumb's angle relative to the North Pole, you made the angle undefined on the pole itself: if you're standing exactly on the North Pole and someone asks you to point south, what do you do? If you wanted to play a non-weird game, you could instead have constrained your hand to move on a flat plane, say by putting the back of your hand on a table with your thumb pointing to the table's north edge. If the rule is, again, that you can't rotate your hand relative to north, then however you move your hand, your thumb will always point north. This serves as a nice demonstration that any flat atlas must be flawed. As a game, though, it is admittedly of limited appeal.

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Why does the hour hand on your watch pick up a phase as you move through time zones? Because the Earth is (approximately) a sphere, and a sphere is curved. If the Earth were a plane, then as soon as the Sun came up over the edge everyone would agree it was morning. We could call that event 8 a.m., say. In reality, the Sun comes up at different times on different longitudes. In an attempt to have it come up at 8 a.m. everywhere, we had to invent time zones. And in order to stop people flying around the world very fast from east to west and going back in time – like in *Superman: the Movie* – we had to invent the International Date Line.

The question gets to the heart of what it means to transport something, keeping it parallel, when space itself is curved – to keep your head when all about you are losing theirs. This question of "parallel transport" comes up in all areas of physics. It's why general relativity took Einstein a decade longer to formulate than special relativity. It's how you're able to park in a space only a couple of centimetres longer than your car (although it might require a 68-point turn). It characterizes defects in crystals. It's how a cat can begin falling upside down with no angular momentum and end up landing on its feet, and how microscopic organisms are able to swim without causing any net movement of the water. It might even be how we can construct a real time machine – *if* proposals to traverse closed loops around cosmic strings work out.

The moral? If you can keep your head when all about you are losing theirs, well, then, I suppose yours is the Earth and everything that's in it. But getting thoroughly confused also has its advantages.

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