electromagnetism[10], where the particle and current densities are spatial densities. They can, however, be represented as a tensor field, the so-called 4-current, and this makes the Maxwell theory compatible with Einstein's theory of relativity. The same remark applies to all Yang–Mills gauge theories[11,12], both quantum and non-quantum.

Now, because the velocity of light is finite, a given observer at each point $P(t)$ on his or her world line — the path on which the observer travels trough spacetime — will never have access to the whole 3D region $R(t)$, but only to the interior of their past lightcone; this is a 4D subdomain of the 4D spacetime, and its intersection with $R(t)$ is reduced to $P(t)$. As a consequence, considering fields defined over $R(t)$ and densities with respect to a 3D volume element defined over $R(t)$ may not seem really physical. Dunkel, Hänggi and Hilbert[4] therefore suggest that $R(t)$ should be replaced by the 3D past lightcone of the observer at point $P(t)$. (This past lightcone reduces to $R(t)$ when c tends to infinity, as is the case in the Galilean regime.)

This idea seems indeed reasonable and it has the advantage of being arguably more physically sound than the conventional procedure. But still, it remains to be seen where this suggestion will lead us. Among the open issues are the following: first, from a purely mathematical or physical perspective, there is no problem whatsoever with integrating on a lightcone. However, it is impossible to average on a lightcone in an intrinsic, observer-independent manner (this is because lightcones are so-called null surfaces[13], on which the normal vectors are also tangent vectors — remember that the relativistic line-element is not necessarily positive). All lightcone averages therefore involve an extra structure, typically the choice of an observer, and it is not clear if this constitutes a severe limitation or not. Second, when following in the footsteps of Dunkel, Hänggi and Hilbert[4], it is tempting to revisit all Yang–Mills theories and connect them with lightcone densities. Will this be possible? And will it have any influence on how we view quantization? The future will tell. ❐

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SAND SWIMMERS

In silica *in silico*

Swimming and flying are complicated processes to model, but at least the laws of fluid dynamics are known. In contrast, sand is a trickier medium to understand than water or air, because it can behave as a solid or as a fluid. Moreover, the presence of a 'swimmer' — such as the sand skink *Plestiodon reynoldsi* (pictured), seeking refuge from the heat of the Sun — changes the local properties of the sand, creating pockets of air and affecting the force chains between the granules. Consequently, there are no analytical equations of motion. To better understand the mechanism of swimming through a solid yet shifting medium, Takashi Shimada and colleagues have simulated the locomotion of a sand swimmer (*Phys. Rev. E* **80,** 020301; 2009), using a 'push-me-pull-you' model (pictured moving to the right) introduced by Joseph Avron and colleagues (*New J. Phys.* **7,** 234; 2005).

In essence, the push-me-pull-you model describes two disks connected by a spring. The disks inflate and shrink. To move forwards in fluid-like sand, the smaller anterior disk inflates as the spring lengthens. The initially fully inflated posterior disk acts as an anchor in solid-like sand. Once the anterior disk is fully inflated, it then acts as the anchor while the posterior disk shrinks and moves forwards as the spring contracts. To complete the move, the posterior disk inflates again, ready for the next stroke. Thus, a sand swimmer must deal with solidification near the anchor and fluidization near the moving disk at the same time.

The simulation's surprising result is that the optimal swimming frequency for maximum velocity is different from that for maximum efficiency. For example, if the swimmer moves too fast, the large voids created cause the swimmer to lose traction and slip. Hence the most efficient swimmer swims slowly. But move too slowly and the sand re-solidifies before any forward motion can be completed. Unexpectedly, the simulation also provides information on the fundamental time scales associated with granular packing.

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