

## Seeing and Experiencing Relativity — A New Tool for Teaching?

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# Seeing and Experiencing Relativity – A New Tool for Teaching?

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“What would you see if you were riding a beam of light?” This thought experiment, which Einstein reports to have “conducted” at the age of 16,<sup>1</sup> of course has no sensible answer: as Einstein published a decade later, you could never reach the speed of light.<sup>2</sup> But it does make sense to ask what you would see if you were traveling close to the speed of light, and one of the first physicists to embark on this effort was George Gamow in his *Mr. Tompkins in Wonderland*.<sup>3</sup> His protagonist is speeding on a bicycle through a city where the speed of light is lower, thus ingeniously taking advantage of the fact that special relativity scales with  $v/c$ : for it to kick in, you either have to move very fast (in rather unfamiliar territory), or light has to be slow (in which case special relativity kicks in at everyday velocities in everyday situations). Gamow provides drawings of what Mr. Tompkins and people at the curb would see in this slow-light city, at least, what they would see if one only took into account two of the effects: length contraction and time dilation.<sup>4</sup>

Gamow unfortunately neglected or was unaware of some nagging issues that were first identified by Lampa: what you would see is different from what you would measure.<sup>5</sup> It took almost two decades after Gamow before the topic would get picked up again, namely by Terrell<sup>6</sup> and Penrose,<sup>7</sup> this time taking into account the finite runtime of light: light that was emitted at a farther distance actually comes from the past. As a result, length contraction is not always visible as a contraction, and interestingly, spheres always appear spherical. In addition, two more effects need to be taken into account to get the full picture: Doppler shift and relativistic aberration (“searchlight effect”), leading to phenomena like the familiar “red shift” and the fact that more photons hit you from the direction into which you are traveling.

Illustrating all of these effects in concert requires more than the pencil and paper even of a Mr. Gamow: it takes a computer to get it right. Foundations for this visualization were laid four decades later by Weiskopf,<sup>8</sup> which led to a number of computer-generated movies,<sup>9</sup> including (in reference to Gamow) a bicycle ride through the German city of Tübingen.<sup>10</sup> These visualizations are available online at [www.spacetime.travel.org/](http://www.spacetime.travel.org/), as well as on a DVD published by the Deutsches Museum.<sup>11</sup> Due to the high computation requirements, these renderings were not distributed in an interactive format—the viewer cannot control the movement. However, the asynchronous nature of these visualizations allows for expanding beyond special relativity into the computationally even more intense general relativity realm.<sup>12</sup>

The first interactive first-person visualization of relativity was provided by Savage et al. as Real Time Relativity,<sup>13</sup> which has since been used for teaching purposes at the Australian National University and elsewhere.<sup>14</sup> The philosophy of this project is slightly different in that it does not slow down light, but moves the viewer into space, where he or she actually travels fast. However, the movement of the first-person viewer is completely controllable, and different effects can be switched on and off in order to see their visual impact. The Real Time Relativity engine does not include third-party movement, which poses significant challenges in tracing the “history” of an object to find out when it would have emitted photons that are momentarily visible to the viewer.

Another approach was taken by Doat et al. Their virtual billiards game tracks the motion of a limited number of third-party objects and takes place in a virtual reality cave. An advantage of this approach is that the same scenario can be viewed asynchronously from different frames of reference.<sup>15</sup> The current version of this billiards game does not take into account Doppler and searchlight effects. The long-term goal of their efforts is again in the educational realm.

Recently, our group released a game that is based on a new first-person relativity visualization engine, which includes simple third-party movement: third-party objects can be generated and destroyed at fixed points in the environment, as long as they are moving uniformly along a straight line in between. Our game, *A Slower Speed of Light*, can be downloaded for PC and Mac from [gamelab.mit.edu/games/a-slower-speed-of-light/](http://gamelab.mit.edu/games/a-slower-speed-of-light/). Figure 1 shows a screen shot of this game,

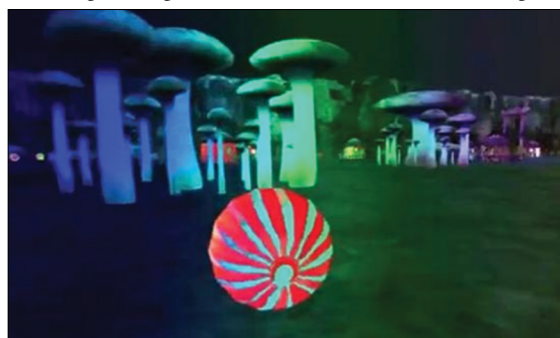


Fig. 1. Screen shot from *A Slower Speed of Light*.

which is based on a simple object collection paradigm—a task that becomes increasingly more difficult as light slows down. The underlying OpenRelativity engine, which in turn is based on the Unity 3D game engine, is available in source code at <http://gamelab.mit.edu/research/openrelativity/>.

We hope that the current game is only the first of a number of games based on this engine, some of which could be “lab experiments” in university physics courses. Of particular interest would be a “level editor,” in which predefined relativistic objects can be assembled to generate new educational challenges and puzzles. Today’s students are quite used to operating in environments with randomly modified physics, for example, through Portal<sup>16</sup> or Quantum Conundrum,<sup>17</sup> so we have high hopes that they would find their way through an environment in which the physics is actually altered *correctly*. As opposed to Doat et al., the OpenRelativity engine currently does not implement a “history buffer” to keep track of where the objects were when they emitted light, which, given the complexity of our environment, would have posed significant storage challenges. Implementation of such a buffer would however allow for “instant replay” of situations, as seen from different frames of reference.

What’s next? Maybe Gamow’s next visualization project, *Mr. Tompkins Explores the Atom*,<sup>18</sup>—instead of lowering the speed of light, we could increase the Planck constant and see what happens.

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