Kent Denver Innovative Scholars Program
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Physics and Mathematics
Mr. Saunders

RELATIVITY

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TOPIC

This poster documents one year of independent study in special relativity, an early 20th century physical theory that describes objects moving at speeds near the speed of light; it fundamentally changed the concepts of absolute distance and time. Time was also spent on the mathematical background for general relativity, which describes objects in a gravitational field.

LEARNING GOALS

At its most basic, the goal of this year's studies was to acquire an intuitive sense for the most important aspects of relativity and to develop sufficient mathematical and conceptual background to teach and produce work on the subject.

In particular, the study aimed to examine the more abstract mathematical structures associated with relativity, primarily Minkowski geometry and tensors. In addition to being a primary subject of interest, this would provide background for my capstone.

We also hoped to use computational models and thinking to prepare skills for my capstone, described below in Future Learning.

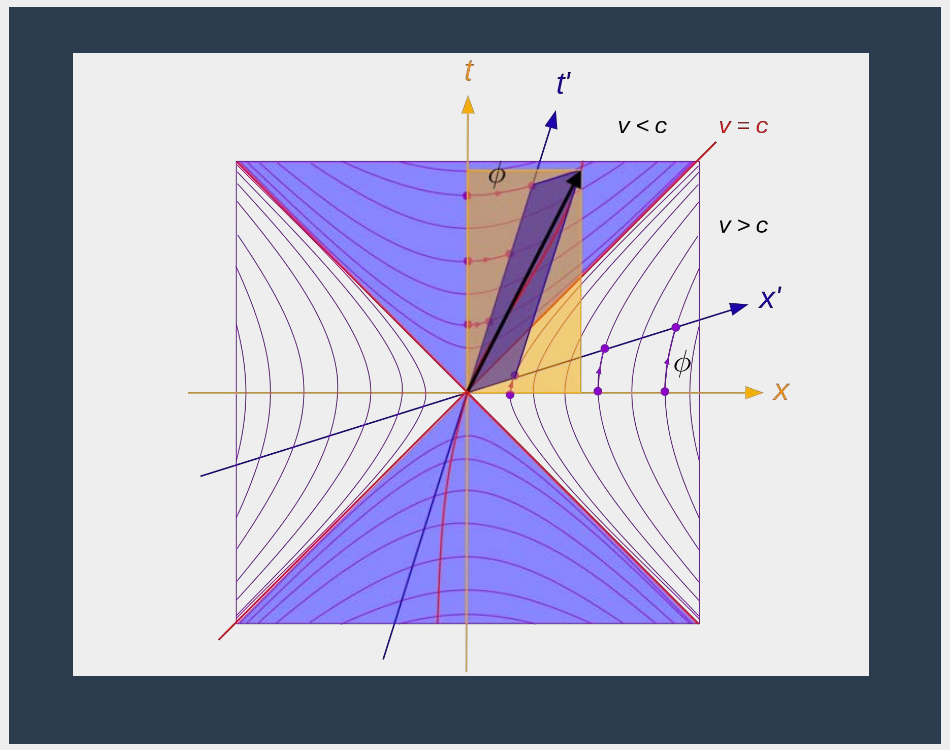

FIGURE 1: A Minkowski diagram depicting two reference frames with the worldlines of accelerating observers in purple.

PROCESS

We began with the basics of special relativity, including its motivation under the disagreement between the earlier Galilean Transformations and Maxwell Equations, the postulates of relativity, the fundamental effects (simultaneity, time dilation, and length contraction), Minkowski diagrams, and relativistic velocity addition.

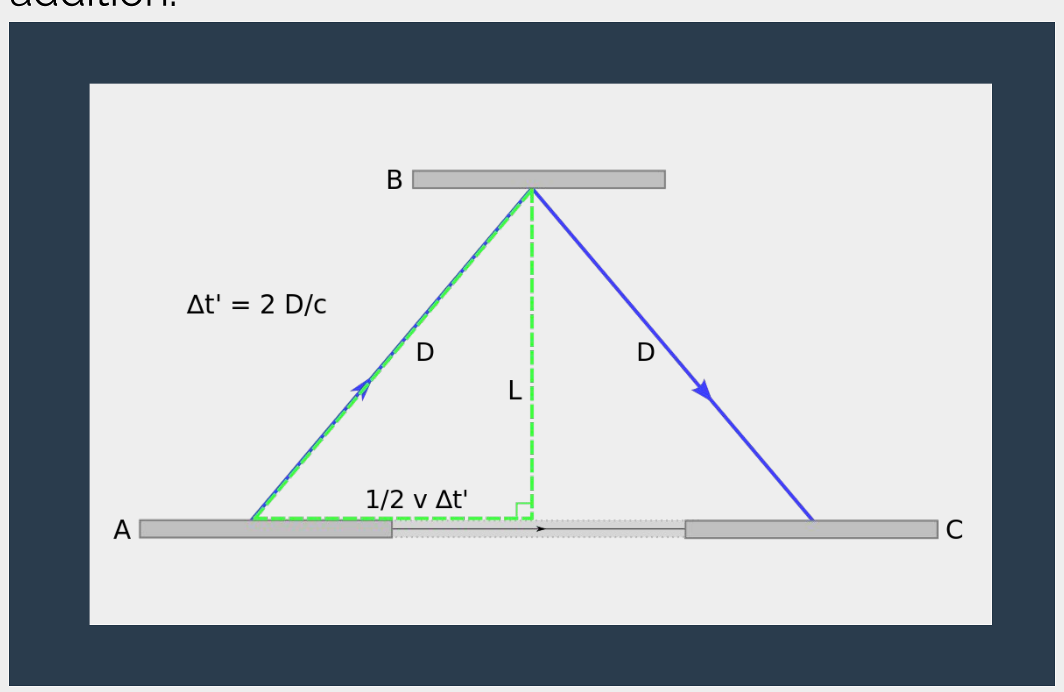

FIGURE 2: A depiction of the derivation of time dilation using a light clock – A, B, and C, are portions of the moving clock as time passes.

This learning occupied the entirety of the first semester and was facilitated by lessons with Mr. Saunders and readings from texts such as Morin's *Special Relativity For the Enthusiastic Beginner*, Susskind's *Special Relativity and Classical Field Theory*, and the Feynman lectures.

During the second semester, we began to delve into the prerequisite mathematics for more complex relativity, such as 4-vectors, hyperbolic trigonometry, and tensors. This and the conceptual background for GR were achieved via lessons, research, Susskind's GR lectures at Stanford, and Nearing's *Mathematical Tools for Physics.*

DELIVERABLES

At the conclusion of the first semester, I reviewed and compiled my learning into approximately 1 hour of lecture video split into 12 videos of varying length. A link to the folder containing my lectures is below:

https://drive.google.com/drive/u/0/folders/1gkiOxyQQsWj-CoGXKEOMZnun5yTdXIMc

Additionally, I programmed several physics simulations in a module called VPython; many were unrelated to relativity with such topics as a spring and a trinary star system, but one explores the movement of a relativistic particle.

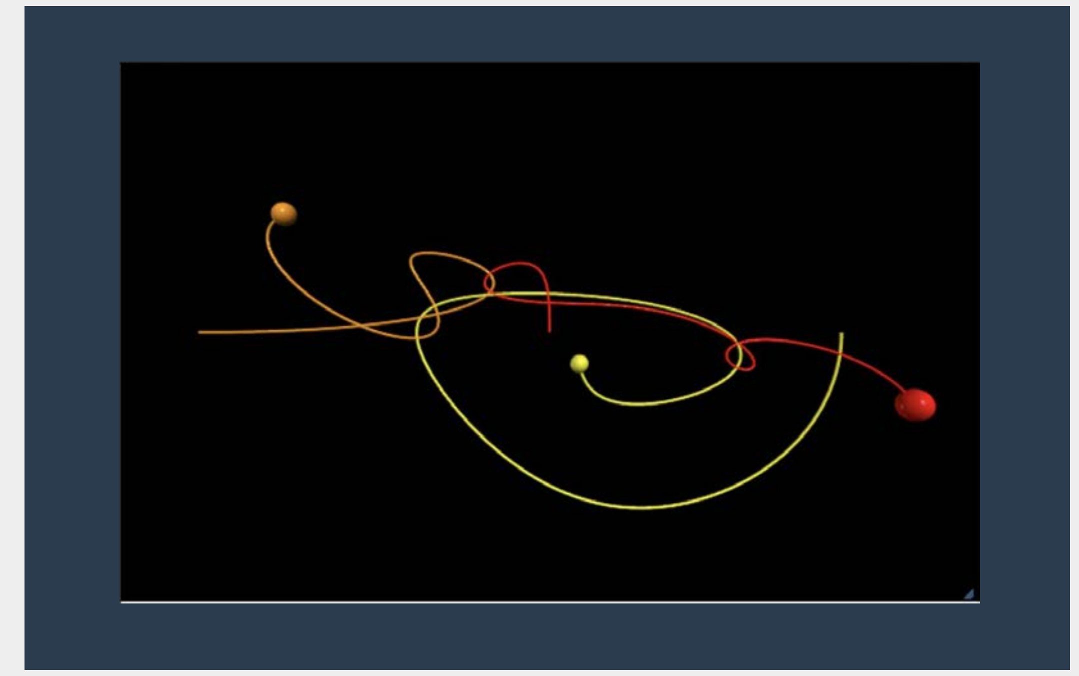

FIGURE 3: A screenshot from my simulation of a trinary star system. Each body experiences gravity, which determines the path via iteration.

Unlike these other simulations, the particle sim is not visual or 3D – it simply graphs iterations of the particle's position (cyan), momentum (purple), and gamma factor (green) onto a live graph. The gamma factor provides a relativistic adjustment to classical position and momentum; it is very near 1 at low velocity but approaches infinity at significant fractions of light speed.

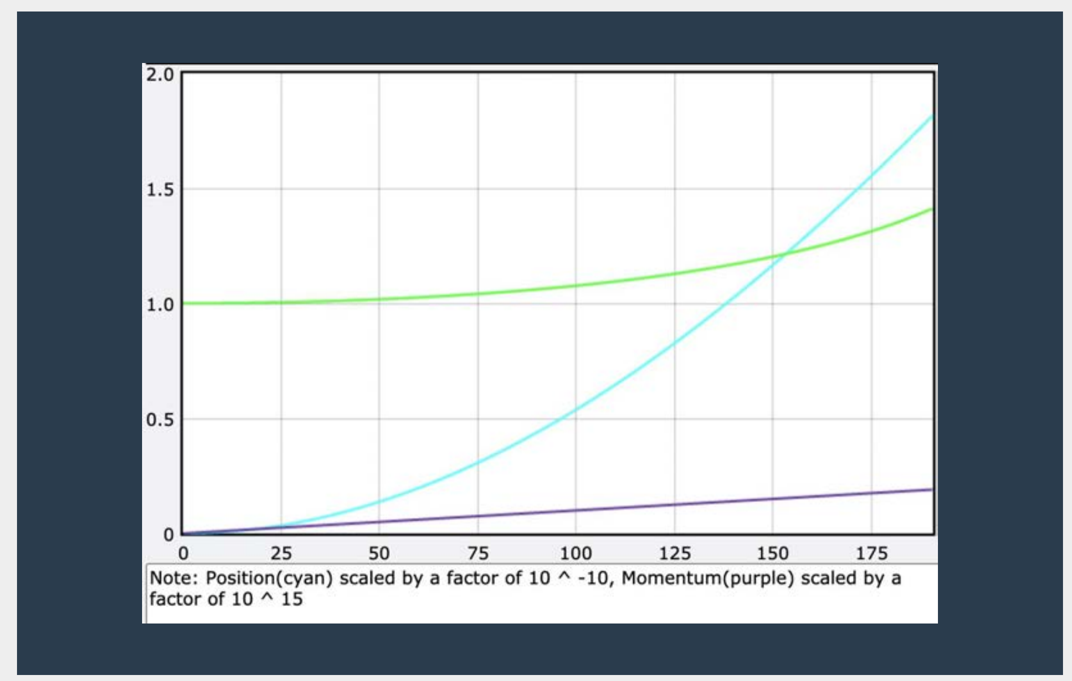

FIGURE 4: My graph of the motion of a relativistic particle, iterated from an initial velocity of 1 m/s and a constant applied force. See above for guide and note that this was taken from an in-progress sim.

CONCLUSION

This independent study worked quite well as an introduction to relativity, though I believe I should be more consistent about ongoing deliverables. I had plenty of reading material, but ought to have included selections of problems to fully learn the concepts. However, writing and filming the lectures helped my understanding immensely.

Next, I will continue to apply the mathematical knowledge I have gained to the complexities of relativity and fill in my current level of understanding. I will also begin work on my capstone using the knowledge I have built over the course of this year.

CAPSTONE

My capstone project will be a visual representation of special relativity, created using a currently undetermined software with the goal of depicting the beauty of the topic with shape and color. It should be interactive and assist in an intuitive understanding of special relativity. The exact focus has not yet been determined, but it is likely that it will examine invariance and the fundamental effects.