MYP Personal Project - Writing a physics simulator from scratch in C++

Objective A: Planning

My Learning Goal - Learning how a physics engine/simulator works

Ever since I was a child, I have been intrigued by the sciences and the way they allow us to understand the physical world better. I have always loved the logic behind math and the sciences, and how you could always use it to find the answer to a question. I have been fascinated by how all of the sciences are related and connected in various ways, and how knowledge of one can apply to another. Of the numerous sciences, my favorites are computer science and physics. I wanted my project to combine my interests in these sciences in a way that would be interesting and challenging for me, while still having some kind of real-world application.

I realized that a perfect way to combine these interests would be to create a physics simulator, a computer program that could simulate interactions between various physical objects in real time using the laws of physics. For example, it could calculate and display the outcome if two objects with complex shapes collide, are thrown off their paths by the collision, and then bounce off walls and repeatedly re-collide, all in real time. This would require me to understand the mathematical equations that govern our physical world and find ways to implement them in a computer program. Such physics computer simulations are rare, and are generally developed by large companies such as Nvidia that produce advanced graphics processors for computers.

My learning goal for this project is to learn how a physics engine works by making one. It will require me to learn the mechanics of real-time simulations, how to utilize multithreading, or the multiple computational units available in computer processors, how physics equations can be implemented into code, and how to organize code in a way that the different parts can work hand in hand with each other and can be easily expanded upon in the future. I have never worked on a project this large before with this many different parts working together.

This project will help me further my knowledge and understanding of physics, specifically dynamics, forces and torque. It will help teach me the use of mathematics in physics as well as develop my understanding of linear algebra, using vectors that can represent points in space and matrices which describe transformations on these points. It will also teach me technical skills, including computer coding with the C++ language, which is used in many commercial applications and computer operating systems, and improve my overall skills as a programmer.

Product - Physics simulator

To gain a deeper insight into how physics engines work, I will be writing my own physics engine and simulator to get hands-on experience with them. A physics simulator refers to only the code that calculates the actual physics and transformations, while a physics engine includes other systems too such as a graphics renderer.

I decided to write this simulator using a previous project of mine as a foundation. That project was a 3D rendering engine that uses ray tracing, a computer program that simulates the interaction of light rays to realistically render, or display, images on a computer screen. This rendering engine, however, could only display spheres, so I needed to improve it to be able to handle any kind of polyhedra, or solid shape, made from a 3D model.

The project will be written in C++ along with Vulkan, a graphics API system which allows for high control of the rendering process. I aim for this physics simulator to be able to simulate simple elements of physics such as collisions, forces, torque, conservation of momentum, conservation of angular momentum, and linear and angular inertia.

To make sure my learning goal is realistic, I will limit it to just simple dynamics so as to not overwhelm myself with the number of different things I could choose to simulate. I will not include a user interface (UI) for changing different starting conditions and instead will have them hard coded, or directly written into the code, as I feel that coding a UI for this would take time and does not directly contribute to my learning goal, which is to better understand how physics engines and physics simulations work.

By changing various starting parameters – such as number of objects, the 3D model of each object, the initial velocity, the initial angular velocity, the mass, the center of mass, and the inertia tensor – I will be able to change the outcome of the simulation and change the scenario being simulated. I also want this program to be able to be run at real-time speeds so that someone can watch the objects interact in real-time.

The C++ programming language is used in most professional desktop computer applications due to its large feature-set and its ability to have higher control of the computer. However, these benefits come with a large drawback, being a very difficult and complex programming language to use.

Since few computer physics engines have been created, finding resources relating to this project will be quite difficult, and pairing this with the complex C++ programming language will make this a difficult and challenging project.

Product success criteria

I have prepared the following criteria to evaluate how successful I am in creating my product. My goal for the product is to have a real-time physics simulation, which will require it to be optimized so that it can run at real-time speeds, have accurate and realistic physics, and for me to be able to change what's being simulated.

Success criteria	Details	Method of evaluation
Function What will my project do? How will my simulation function? What functions will my simulation have? What is the purpose of the project?	My product will be a physics simulator, able to simulate simple physics such as dynamics, forces, momentum, inertia, angular momentum, and torque. You will be able to change the simulation start conditions to change the outcome of the simulation.	Is the simulator able to simulate simple physics? Can it simulate collisions? Can it simulate dynamics? Can it simulate forces? Can it simulate inertia? Can it simulate angular momentum? Can it simulate torque?
Optimization Can my simulation run at real-time speeds while maintaining accuracy? Is my project's speed able to linearly scale with more objects? How much time will be spent on optimization?	My simulation will be able to run at real-time speeds, even though there will be a greater emphasis on accuracy. The speed of the simulation should be faster than $O(N^2)$ (collision checks require checking every object with every other object). Around a week will be spent on optimizing the system to make it faster.	Does it run at real-time speeds? Does its speed scale quadratically with the number of objects? Is it visually appealing to watch at real-time speeds?
Accuracy How accurate is my simulation? How accurate do I want my simulation to be? How much speed do I want to sacrifice for accuracy?	Most of the time on this project will be spent increasing the accuracy of the simulation, as well as increasing the capabilities of the simulator. It will be as accurate as my computer will allow while running at real-time speeds.	Did I make a physically accurate physics simulation? Is my simulator accurate? Was I able to balance speed with accuracy?
Realism How realistic is the simulation? How accurate is the simulation?	My product will use accurate physics while running at real-time speeds, with an emphasis on realism. I will improve the rendering system that I previously created to allow for more realism.	Does the physics appear realistic? Is it able to have accurate results? Does it run in real-time? Does it use the equations that govern our physical world?
Features What can it simulate? Is it easily usable to simulate something? How user-friendly will it be?	My simulator should be able to simulate simple dynamics, forces, torque, inertia, angular momentum, and real-life lighting and do this at real-time speeds. There will not be much emphasis on user-friendliness as I will be the only user and any simulation will just be hard coded.	Is it able to simulate different kinds of physics? Can the starting conditions be changed? Does it show an understanding of the topic?

Action plan

Task	Success Criteria	Due Date	Status (if completed not on time, provide the date completed)
Supervisor selection	Report/Form	8th Sept	Completed
Research how physics engines work	Function	25th Sept	Completed
First meeting	Function/features	6th Oct	Completed
Finish rudimentary physics simulation for spheres and dynamics	Features/accuracy	15th Oct	Completed
Second meeting	Realism/Features	10th Nov	Completed
Add collision detection for any polyhedra	Features/accuracy	15th Nov	Completed late,15th Dec
Add collision dynamics for any polyhedra (no angular momentum)	Features/accuracy	18th Dec	Completed late, 24th Dec
Add angular momentum dynamics for any polyhedra	Features/accuracy	30th Dec	Completed
Third meeting	Function/Features	12th Jan	Completed
Optimization	Optimization/realism	15th Jan	Completed
Product due date	Function	22nd Jan	Completed

Objective B: Applying skills

Self-management/time management

One of the most important skills that I needed for this project was self-management. Since this was a long-term project, I needed to make sure that I could stay on top of deadlines and did not have to cram all my work into the last couple of weeks which would lower the quality of my work and make it a less enjoyable experience for me. I often struggle with keeping track of the things I need to do, which was something I wanted to improve this year. I planned to do this by making sure that I keep up to date with my personal project by keeping track of what I need to do and by using tools such as Notion to track deadlines.

There were many times in this project where I felt discouraged when things were not working as I wanted them to but I knew I had to manage my time and myself well so that I would not be overwhelmed. Furthermore, this project required me to have to learn things on my own without much help from the internet, meaning I had to organize all my research and findings myself.

This all is exacerbated by the fact that this entire project has to be done in one's own time, with no allocated time in school, so I had to manage my personal project alongside my other school work, while also having enough time for myself to not feel burnt out or overly tired. This was highly difficult as I already struggled with finding time for myself with many extracurricular activities and lots of school work. This required me to use my self-management and time-management skills to make sure I could get everything done in a timely manner while not getting burnt out or overwhelmed.

Even with my improved time management, there were unforeseen problems that impacted my personal project and caused delays in my plan. For example, code that was harder than expected to write and make work properly, or external factors like having other parts of my life conflict with parts of my personal project. These unforeseen circumstances caused me to have to manage my time even more effectively so that I could finish what I needed to do in an even shorter time period. It also meant I had to use my self-management skills to manage myself so that when these unexpected circumstances arose, I would still be able to manage everything I needed to do and get everything done.

Research

A major skill that was required for this project was my research skills. As real-time physics simulation is potentially a massive project, I needed to research what would be the optimal way for me to accurately yet efficiently simulate physics on my computer. I also needed to figure out what parts of physics I would like to simulate such as dynamics, stresses, fluids, or kinematics. I needed to deepen my understanding of physics, as well as understand how to implement physics in a physics simulator. My research was split into several different parts: background information on real-time physics simulation, kinematics, and dynamics with spheres, collision detection with polyhedra, impulse-based dynamics, and transference of both angular and linear velocity.

Background Information
What is a physics simulator? How does a physics simulator work? What physics simulators already exist? What is needed to make a physics simulator?
Dynamics
How can the equations of motion be implemented into C++? How does a numerical differential equation solver work?
Collision detection with polyhedra
How can the angular equations of motion be implemented for any shape? How can angular momentum be calculated for any shape?
Impulse-based dynamics
How can impulse-based dynamics be implemented into C++?

What is impulse-based dynamics?
Angular velocity
How can angular velocity be implemented in C++? How do you calculate torque? How does torque get converted into angular velocity? What is an inertia tensor? What are rotation matrices?

Many of the necessary parts of my product and work I needed to do to complete my learning goal required me to do research to understand the topic and what I would need to do. To start working on my physics engine, I needed to figure out exactly what physics engines and simulators did and how they worked. I did research on how previous ones have been made and how they worked, what is needed to make one, and how I could make my own. This would be the first step to fulfilling my product plan and learning goal.

After I had gotten a basic understanding of existing physics simulators and how they worked, I had to research the physics equations that would govern how the objects moved and interacted. This required me to use lots of my research skills to make sure I understood the equations so I could later implement them into my code. My main sources of research consisted of different programmers who documented their coding process on YouTube, repositories of code on GitHub, and several developer's blogs. Since not many people have created a physics engine application based on their own custom rendering engine, it was quite difficult for me to find resources and conduct research so that I could fulfill my product success criteria and complete my learning goal.

While writing the code for this project, I encountered many bugs and issues that I needed to fix, such as different errors, the app crashing, the app becoming unresponsive, etc. This all required me to do research to figure out what went wrong and how to fix it. I looked at forums such as StackOverflow to see if anyone else has had similar problems and searching up error codes in Google would also help me in overcoming any coding issues. I had to use my research skills to find out what had gone wrong and if anyone else had encountered any similar issues and if they had, then looking into how they fixed it, and if they had not, looking into code documentation to see what the error code meant.

Thinking

A large part of this project involved figuring out how to properly implement different equations and algorithms into my program. This process requires a lot of thinking on how to best implement a certain algorithm, and figuring out how to do it efficiently and effectively. Math, physics, and computer science are all complex subjects which meant I needed to do a lot of thinking as my project was a collection of all three of these subjects. Additionally, another major portion of my time was spent debugging and rewriting code and figuring out why certain parts were not working as expected, which also uses a lot of thinking.

Throughout this process, I needed to implement various different algorithms such as the GJK and EPA algorithms, Verlet integration, and ray triangle intersection algorithm. The GJK and EPA algorithms, the algorithms used to detect collisions, required the most thinking to help me figure out what was not working and find ways to make it work, which ended up helping me complete my product. It gave me deeper insight and understanding into how the algorithms worked which contributed to my learning goal. Specifically with the GJK and EPA algorithms, they both drastically helped me with my understanding of programming and how math and linear algebra can be applied to computer science. Implementing the ray triangle intersection algorithm also required a lot of thinking. It required me to spatially understand how the mathematics behind the algorithm worked, requiring a lot of thinking, which helped contribute to the final product.

Additionally, figuring out how to implement the physics equations for my physics simulation in my code required me to use my thinking skills to determine how the objects in my simulation would move and interact with each other. Using my thinking skills was required for me to complete my product, and for me to complete my learning goal. Implementing the physics equations was highly necessary for my product to be complete, and using my thinking skills greatly helped me gain a better understanding of how physics simulations work and of math, physics, and computer science overall.

Objective C: Reflecting

Throughout this project, I have learned many new things, developing as a person and furthering my knowledge and understanding. As I worked my way towards completing my project and reaching my learning goal, I encountered many challenges, and as I encountered these challenges, I had to learn how to face and overcome them to complete my learning goal and product. Encountering and overcoming these challenges taught me many valuable lessons in computer science, math, physics, about myself, and as a learner as a whole.

Content-wise, I learned many new things during this project, in math, physics, and computer science. I deepened my understanding of physics and the equations that govern physical bodies and the interactions between them, such as how energy is transferred in elastic collisions and how to calculate impulses. I also got to learn the math behind many algorithms that are used for calculating collisions such as the GJK and EPA algorithms and generally improved my knowledge and understanding of linear algebra which is used for representing points and transformations in 3D space. This project has also improved my programming skills and ability. Working on a large project like this has taught me how different systems can work together and how to write code that can allow these different systems to work together. Furthermore, this project has improved my understanding of how mathematical equations and systems can be represented, created, and simulated on a computer. This new knowledge and understanding of these subjects can help me in the future with similar projects and will impact my methods of learning and developing my understanding of new topics.

However, not all that I learned during this project was new content or a new subject, but rather about myself. This project has taught me many valuable lessons about myself and how I handle large projects and challenges. This is one of the largest projects that I have worked on and it has taught me how to better handle challenges, be responsible for my own learning, and be dedicated to a project

without someone else having to tell me what to do. This learning experience will change how I approach future projects and will help me carry them out. Being able to complete this project will impact many of my future decisions, including my decisions toward large projects and my own learning. It has taught me how to organize and be responsible for my own learning, and how to be dedicated and motivated, especially with challenges and feeling discouraged. The many challenges I faced during this project, whether it be code not working, not being able to find resources to learn from, or not having enough time, have helped me develop as a learner, teaching me that unforeseen obstacles will occur and come my way, and I will need to learn and adapt to these challenges.

This project has also helped many develop many of my learner profiles. As I worked on this project, I have become more knowledgeable, took more risks, and developed my thinking and inquiry skills. By working on this project, I have gained knowledge in mathematics, physics, and computer science, making me more knowledgeable in the respective fields. The project has also improved my ability to apply my knowledge, using my thinking to help solve problems and get past challenges. This new found knowledge and improved thinking will help me when I encounter new challenges in the future and will help me find solutions to these challenges. Additionally, this project has made me take many risks, trying new things with my code, and to take the risk of it not working, which will help me take risks in the future when overcoming challenges. I also took a risk when choosing this project as it is a fairly complex project and was worried that I wouldn't be able to complete it. Taking these risks have helped me take more risks with my learning, to try new things, and even if they don't work, it is okay because it will still have taught me something in the process. This project has also developed my inquiry skills, allowing me to ask questions about how different things work, and to figure out answers to these questions to complete my product and learning goal.

Impact of the project

This project has impacted me in many different ways, developing my skills and abilities, as well as teaching me more about myself as a person. This project has improved how I deal with projects and has helped me be more responsible for my own learning. Keeping track of my learning and documenting my challenges helped teach me how to push on through challenges and how to deal with challenges in the future. It has also taught me to be responsible for my own learning, overcoming challenges on my own and doing the research myself. This has helped me become a more responsible learner overall and will help me in learning new things.

The skills I've learned from this project will greatly impact my future learning and the decisions I make. In the future, when learning something new, I will apply the responsibility I gained for my own learning from this project to further my learning and accelerate my learning process. I will also apply the skills I gained dealing with challenges during this project in future projects, helping me deal with unforeseen obstacles. Furthermore, this project will help me make better decisions with my learning. For example, when dealing with challenges, I now have a better understanding of how to overcome them which will impact how I deal with them and the decisions I make to deal with them. This project will have also helped me when deciding how to go about learning something new. This project was like a test run on how to learn things on my own and how to complete them on my own, and the knowledge and skills I gained from this project can be applied to future projects and learning.

All the ways that this project has impacted me will help me in the future. This project has been beneficial in getting a taste of working on projects that I need to be responsible for and being responsible for my own learning, both skills that will help me greatly in the real world where there aren't teachers or mentors guiding me and where I need to be responsible for myself. The skills I've learned during this project can help me in nearly any endeavor of life, such as being a student, being responsible for myself, working in a job, or developing as a person. I've developed subject related knowledge and understanding which will help me with any future studies I have in those subjects. Additionally, keeping track of what I've learned will help me with future studies and will help me in being responsible for my actions and decisions.

Overall reflection

Overall, this project has taught me many valuable lessons, and has been a very valuable experience. It has taught me many things and given me many skills that can be applied to future learning, projects, or my life in general. The project gave me a taste of what the real world would be like, how to deal with challenges, how to investigate something I'm interested and passionate about, and how to do this without much external help and support. This project has fulfilled my original learning goal quite well, teaching me how physics engines work and how to create one, improving my overall coding skills and understanding of C++, as well as improved my understanding of physics and mathematical concepts. This project has been a valuable experience, teaching me many things about myself and about being independent, as well as deepening my understanding of the topic I chose as my learning goal.

Evaluation

Function :

Success criteria	**Details**	**Method of evaluation**	**Successful or not**
What will my project do? How will my simulation function? What functions will my simulation have? What is the purpose of the project?	My product will be a physics simulator, able to simulate simple physics such as dynamics, forces, momentum, inertia, angular momentum, and torque. You will be able to change the simulation start conditions to change the outcome of the simulation.	Is the simulator able to simulate simple physics?	Successful
		Can it simulate collisions?	Mostly successful
		Can it simulate dynamics?	Successful
		Can it simulate forces?	Successful
		Can it simulate inertia?	Successful
		Can it simulate angular momentum?	Successful
		Can it simulate torque?	Successful

My physics simulation was quite successful in accomplishing its functions. Through rigorous testing, I have made sure that my product works as expected and does what I intended it to. It is able to simulate nearly any collision between any two polyhedra, simulate the forces exchanged, the inertia of objects through the use of an inertia tensor, simulate angular momentum, and torque applied on the objects. However, there are some edge cases where collisions aren't handled properly which I believe to be a problem with the algorithm itself, not my implementation of it. Collisions aren't handled properly if an object is rotating "into" another object, especially if it hits another object on one of the edges as the algorithm can't figure out the collision normal, or the direction of the collision. However, this is just an edge case scenario and other than that, my simulator does as expected, fulfilling this success criteria.

Strengths:
It fulfilled this success criteria. The simulation is able to simulate most collisions, handle forces exchanged in collisions, handle transference of both linear and angular momentum, and simulate all this while accurately simulating inertia through the use of an inertia tensor. I am also able to change the starting conditions of the simulation by hard coding it, which could be difficult for some, but this was not an area of focus for me.

Weaknesses:
There are some edge cases that need to be dealt with. If I had more time to work on this project, I would try to find a way to resolve these edge cases to allow for a more stable simulation. The lack of an easy to use interface could also be a drawback for some, making it harder to be used in the real world. Furthermore, having many objects can cause the simulation to slow down leading to less accurate results.

Optimization :

Success criteria	**Details**	**Method of evaluation**	**Successful or not**
Can my simulation run at real-time speeds while maintaining accuracy? Is my project's speed able to linearly scale with more objects? How much time will be spent on optimization?	My simulation will be able to run at real-time speeds, even though there will be a greater emphasis on accuracy. The speed of the simulation should be faster than $O(N^2)$ (collision checks require checking every object with every other object). Around a week will be spent on optimizing the system to make it faster.	Does it run at real-time speeds?	Successful
		Does its speed scale quadratically with the number of objects?	Successful
		Is it visually appealing to watch at real-time speeds?	Successful

My physics simulation is able to run at real-time speeds, fulfilling this success criteria. However, with more objects, my renderer that uses a physically accurate simulation of light paths becomes the bottleneck of my simulation. This, however, was not the focus of the project, which was rather the collisions and force response simulation. Other than this, my simulation is easily able to run at real time speeds while maintaining an accurate simulation. Even with large amounts of objects, my

physics simulation performed very well. It scales quadratically with the number of objects, however this could be improved further by splitting up the 3D space with a system such as octrees, which splits up the 3D space into 8 sections which are each assigned a separate CPU thread for faster simulations. However, at this stage, I don't feel that to be necessary. I feel overall, I have fulfilled this success criteria quite well.

Strengths:
My physics simulator runs at real-time speeds, and has a lot of overhead for many objects. It's also able to simulate many objects and simulate all the collisions efficiently, scaling $O(N^2)$ with the number of objects. It is able to maintain a high degree of simulation accuracy while still being very performant.

Weaknesses:
Other parts of the code are bottlenecking the simulation, specifically the rendering system which has to calculate multiple rays of light per pixel of the screen to accurately physically represent how light works in the real world. If I were to continue working on this project, I would work on making the rendering code more efficient so it wouldn't bottleneck my simulation.

Accuracy :

Success criteria	**Details**	**Method of evaluation**	**Successful or not**
How accurate is my simulation? How accurate do I want my simulation to be? How much speed do I want to sacrifice for accuracy?	Most of the time in this project will be spent increasing the accuracy of the simulation, as well as increasing the capabilities of the simulator. It will be as accurate as my computer will allow while running at real-time speeds.	Did I make a physically accurate physics simulation?	Successful
		Is my simulator accurate?	Successful
		Was I able to balance speed with accuracy?	Successful

My simulation is able to accurately simulate collisions and forces except for a few edge cases which were discussed in the Function success criteria. Other than those edge cases, my simulation uses the actual physical equations that model our world to simulate interactions between different objects. These equations that I've implemented ensure an accurate simulation and ensure that my simulation models the real physical world. I've also tested my simulation in different scenarios to test for accuracy, to see if objects interact similarly to how they would in the real world. Overall, I think my project fulfills this success criteria quite well.

Strengths:
Accurately simulates physics using the equation to calculate impulse. It also accurately detects collisions between polyhedra using the GJK algorithm with the EPA algorithm for collision response. My simulation is accurate, being able to accurately calculate the transference of energy and momentum between objects, both translational and angular. I was able to make my simulations as

accurate as possible as I was able to optimize it to run real-time while still having a lot of headroom. Due to this, I didn't need to sacrifice any accuracy for speed.

Weaknesses:
As previously stated, there are a couple edge cases that need to be dealt with to ensure a complete and accurate simulation. Due to time constraints, these edge cases have not yet been resolved yet and if I had more time, I would work on this and try to find a way to resolve these edge cases.

Realism :

Success criteria	**Details**	**Method of evaluation**	**Successful or not**
How realistic is the simulation? How accurate is the simulation? Does it run at real-time speeds?	My product will use accurate physics while running at real-time speeds, with an emphasis on realism. I will improve the rendering system that I previously created to allow for more realism.	Does the physics appear realistic?	Successful
		Is it able to have accurate results?	Successful
		Does it run in real-time?	Successful

My simulation is quite realistic, accurately simulating physics using the equations that govern the physical world. I've tested many different scenarios for accuracy and all scenarios other than those edge cases previously mentioned have accurately simulated the interactions between objects. My simulation also is able to run at real-time speeds, adding to the perceived realism of the simulation. I would say I have fulfilled this success criteria quite well.

Strengths:
It has both accurate results and runs in real-time. The simulation is quite realistic, being both well optimized and having accurate simulation results. The simulation runs at real-time speeds, and has overhead for many objects and uses the physical equations that are used to calculate energy transference in collisions.

Weaknesses:
As previously stated, there are a few edge cases that need to be worked out to make the simulation complete and work stably for any interaction. Also, when simulating many objects, the simulation can become slower leading to less realistic looking simulations.

Features :

Success criteria	**Details**	**Method of evaluation**	**Successful or not**
What can it simulate? Is it easily usable to	My simulator should be able to simulate simple dynamics, forces, torque, inertia, angular momentum, and real-life lighting and do this at	Is it able to simulate different kinds of physics?	Successful

simulate something? How user-friendly will it be?	real-time speeds. There will not be much emphasis on user-friendliness as I will be the only user and any simulation will be hard coded.	Can the starting conditions be changed?	Successful
		Does it show an understanding of the topic?	Successful

My physics simulation is able to simulate collisions, forces, torque, angular and linear transference of energy, and rotational and translational inertia. It is able to do this all by setting a few starting parameters such as the mass, size and shape, initial velocity, initial angular velocity, location, and rotational inertia along each axis. These parameters can be changed in the code. However, this can be a bit difficult for someone unfamiliar with the code and if I were to continue working on this project, I might implement an easier way to adjust these parameters. However, ease of use was not a primary focus of this project. I would say this project and its features have demonstrated an understanding of the topic and shows that I have developed my knowledge and understanding of the topic. I feel that I have fulfilled this success criteria quite well.

Strengths:
It is able to simulate all of the different aspects of physics I was planning to with this project: simple dynamics, forces, torque, inertia, angular momentum, and real-life lighting. I also was able to do this at real-time speeds. I also added a fairly easy way to change the starting parameters if someone is familiar with the code.

Weaknesses:
The rendering system could be optimized a bit more. Additionally, having some more complex physics would allow for more interesting simulations.

Further exploration

Over the course of this project, I have been able to learn lots, but it has definitely not been long enough for me to properly learn the whole subject. The knowledge and skills I have gained can be applied to many different parts of my life: math, physics, computer science, school work, time management, and many more. I can further my knowledge of the topic by expanding my physics engine to be able to handle more complex physics such as simulating fluids or optimizing it to be able to run more complex systems such as simulating an engine or simulating more objects. I want to work on this project further in the future, implementing more features to make it a near real-life simulation such as improving my rendering system and graphics pipeline, procedurally generating worlds or terrain, and adding networking capabilities so that different people can be connected to the same “world”. I will keep working on my math, physics, and coding skills by working on different coding projects, and by furthering my math and physics knowledge.

Bibliography

Link to code repository on GitHub: https://github.com/Hibernathan1212/Personal-Project

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