Physics Hackathon 2018 – project ideas

If you're stumped trying to think up a project for the hackathon, check out this some of these ideas for inspiration! Having trouble putting your ideas into code? Just ask around in our slack chatroom or grab a mentor at the event and ask them for advice! We strongly recommend you take a look at last years submissions at `https://physics-hackathon-2017-5733.devpost.com/submissions` to get an idea of what projects are like.

Contents

New projects

1   Observing elementary particles

Physics Concepts:

- Particle physics

- statistics

Prerequisites:

- Elementary knowledge of particle physics

1.1   Introduction

The ATLAS and CMS experiment made some of their data available online, so anyone can look for elementary particles! You can start getting by following this tutorial. `http://opendata.cern.ch/record/50`

1.2   Goal

The goal is to understand how observations are made in particle physics. Chose a process you would like to observe in the data and differentiate background from signal events. You will need to understand what particles can be observed in the detectors, which particles are unstable and in what they decay. Can you observe:

- The Z boson in data?

- The W boson in data?

- Top quark pair production?

2   Snowball earth

Physics Concepts:
- Climatology

- Energy conservation

Prerequisites:

- High School or CEGEP level physics

2.1 Introduction

The Snowball earth hypothesis proposes that Earth's surface became entirely frozen at least once it its history. One of the main arguments opposing this hypothesis is the difficulty of escaping an all-frozen condition. Could the earth have been completely frozen in its history? Create a climate model to find out.

2.2 Goal

The goal of this project is to create an elementary climate model to understand climate instability and feedback loops by studying the snowball earth hypothesis.

- You can start with a simple energy balance model as explained here :
  https://www.shodor.org/master/environmental/general/energy/index.html

- Can you reproduce Aron Faegre results? How many stable climates can you get?
  https://journals.ametsoc.org/doi/pdf/10.1175/1520-0450%281972%29011%3C0004%3AAIMOTE%3E2.0.CO%3B2

- You can add accuracy to your model by adding more feedback loops. Would they enable a snowball earth to return to our present climate?

3 Higgs Machine learning challenge

Physics Concepts:
- Particle physics

Prerequisites:

- Machine learning

3.1 Introduction

This is an advanced project for competitors with a solid background in machine learning. The goal is to identify Higgs boson using machine learning techniques

3.2 Goal

The challenge was issued by CERN and the full description of the project can be found here: http://opendata.cern.ch/record/328

4 Plant's Exploding Fruits

Physics Concepts:
- Classical mechanics

- Aerodynamics

Prerequisites:

- High School or CEGEP level physics

4.1 Introduction

Seed dispersal is a crucial phase of plant development and some plants have evolved to have impressively efficient seed dispersion methods. We propose to study the Ruellia ciliatiflora (Acanthaceae) plant which explosively launches its seeds at velocities over 15 m/s.

4.2 Goal

Model and stimulate the propulsion of the hairyflower wild petunia to understand the aerodynamics of flat discs, effects of drag on the seed's orientation, and the forces acting on the spinning top.

Resources:
http://rsif.royalsocietypublishing.org/content/15/140/20170901
https://www.nytimes.com/2018/03/09/science/hairyflower-wild-petunia-seeds.html

5 A light-induced THz photonic crystal

5.1 Introduction

A photonic crystal is a periodic modulation of an index of refraction in space. They have the property where there are certain energy gaps where light is forbidden to propagate. By illuminating a semiconductor with light, it's possible to change the index of refraction wherever the light shines. Patterning the illumination creates a light-induced photonic crystal that can be used to control another long wavelength pulse of light called a THz pulse.

5.2 Goal

Objectives:

- Understand how to propagate light numerically by using the Yee algorithm and finite difference time domain software provided.

- Understand how light can change the index of refraction of a semiconductor.

- Set up numerical conditions to model a photonic crystal by inducing a periodic modulation of the index of refraction.

- Model pulse propagation and map the "photonic band structure" of this light-induced photonic crystal.

- Bonus: Explore dynamic switching of a photonic band structure by turning it on while the pulse is inside. Trap a photon.

6 Pattern formation on animals

Physics Concepts:
- Diffusion

- Chemical reactions

Prerequisites:

- Partial differential equations

6.1 Introduction

Animals on many different scales exhibit beautiful and incredibly varied patterns on their skin (snake, frogs), scales (zebrafish, tropical fish), wings (butterfly, lady bug), coat (big cats, zebras and giraffe), etc. Such patterns have developed over time due to evolutionary forces. It is remarkable that diverse patterns across many species can be explained by simple reaction-diffusion models, first proposed by Alan Turing in 1952.

6.2 Goal

The goal of the project is to simulate the pattern formation of your favorite animal.

- You can start by setting up partial different equations and solving them in space and time.

- Explore different initial conditions

- Explore parameter regimes and the corresponding patterns. Can you find the patterns that match a given animal?

Resources:
http://science.sciencemag.org/content/sci/329/5999/1616.full.pdf

7   Nuclear radiation

Physics Concepts:
- Diffusion

- Climate

- Decay and half-life

Prerequisites:

- Partial differential equations

7.1   Introduction

The tsunami resulting from the 2011 earthquake in Tōhoku, Japan, magnitude 9.1 on the scale of Richter, caused nuclear accidents, most notably the meltdown of reactors in the Fukushima Daiichi Nuclear Power Plant. Radiation levels inside and outside the plant shot up to alarming rates. Even now, 7 years after the event, radiation is up, as can be seen on `http://safecast.org/tilemap/`. Why is all this radiation still there?

7.2   Goal

The goal of the project is to recreate the Fukushima event via diffusion, winds and decay of radioactive nuclei given a source of radiation. To what extend can you retrieve the current radiation patterns? Think of adding the following variables into your model.

- Prevailing winds

- Rain

- Source strength

- Radiation

Which variables do you need to take such patterns into account? How strongly does each of these influence the current radiation patterns? Are there more events whose aftermath you can simulate?

8   Grow a crystal

Physics Concepts:
- Phase transition

- Diffusion

Prerequisites:

- Solid state physics

- Partial differential equations

- Numerical methods

8.1 Introduction

Crystals exist in all shapes and are made up of the most diverse material (ice, rock, salt, metal, etc.). Fascinating patterns are generated when atoms become arranged in such an orderly fashion. Growing crystals is a tough job, both experimentally and computationally. For example, even with modern computing resources it is incredibly difficult to simulate the growth of the simplest ice crystal.

8.2 Goal

The goal of this project is to simulate the growth of a crystal. As this is a computationally advanced project, we encourage you to seek help from Nikolas Provatas whose daily job it is to grow crystals on the computer, and who co-authored this introductory book.

Resources:
`http://www.physics.mcgill.ca/~provatas/papers/Phase_Field_Methods_text.pdf`

9   Immuneural network

Physics Concepts:
- Biophysics

- Nonlinear dynamics

Prerequisites:

- None (but machine learning is useful)

9.1 Introduction

In a recent paper published by one of the organizers (Thomas) is claimed that cellular decision-making (to respond to a stimuli or not) is equal to one-dimensional classification by machine learning algorithms, specifically in relation to ways these decision-makers can be deceived. An immune cell has evolved such that small, specific perturbations to the input will not affect the output (effectively removing strong ligand antagonism). On the other hand, imperceptible perturbations do have a strong effect on neural networks, making them vulnerable to so-called adversarial attacks.

9.2 Goal

The goal of the project is to emulate robust decision-making by an immune cell with a neural network, effectively creating the first immune-inspired neural network, which is robust to adversarial examples (unlike any other neural network). The hard part is to incorporate the nonlinearities into the neural network. When you consider doing this project, you are encouraged to ask Thomas for specific approaches.

Resources:
https://arxiv.org/abs/1807.04270

Past projects

10   Fidget spinners

Physics Concepts:

- Angular momentum

- Rotational Energy

Prerequisites:

- High School or CEGEP level physics

10.1   Introduction

Considered to be fun and relaxing, or annoying and useless, or everything in between, fidget spinners are ubiquitous. Some claim that they can treat anxiety or even improve mental focus(great for hackathons?). Regardless, we would like to better understand how these curious devices work.

When struck, they continue spinning in the same direction for a long time because the ball bearing in the center reduces the friction between the body of the fidget spinner and its central axis. The ball bearings on the sides however are there just to add more weight.

10.2   Goal

Design a fidget spinner simulation or app. It can be as elaborate or simple as you like. Here is a list of things you could consider including in your simulation or simply use as inspiration. Remember, these are just suggestions.

- Create a virtual fidget spinner app that's fun, fidgetty, and educational.

- Use an Arduino or something similar to analyze the motion of a real fidget spinner. Plot the angular velocity versus time. Does your simulation behave the same way? What could be some reasons for the differences?

- Make your simulation 3D and include all the gyroscopic forces

11   Impressing dinner guests

Physics Concepts:
- Thermodynamics

- Heat transfer, convection

Prerequisites:

- differential equations

11.1 Introduction

Your butcher claims that you should cook a roast beef in an oven for 15 minutes per pound of flesh. Is this scaling law plausible?

11.2 Goal

Design a simulation that calculates the ideal temperature and cooking time for cooking food items. For example, searing a steak, baking a sweet potato, barbecuing a sausage and so on. Make approximations and assumptions as necessary. In your simulation, we suggest you adopt the following definition of "cooked": i. the center of the food item is at a certain temperature and ii. the rest of item is as close to this temperature as possible (i.e. "uniform doneness"). Your simulation should take into account the shape, type, and weight of the food item in question. Here are some suggestions of features for inspiration:

- Very low cooking temperatures for very long times are not recommended by the BC centre for disease control because the meat may not heat fast enough to stop bacteria from growing. Can you impose this as a restriction in your simulation?

- Suppose your food item is irregularly shaped. Can you import the precise shape using a 3D scanner and feed that into your simulation. (This could actually be very useful for other project ideas!).

12 Random walk

Physics Concepts:
- Diffusion

Prerequisites:

- None!

12.1 Introduction

Random walk simulations are important for modelling phenomena in many fields of science. In population genetics, random walk describes the statistical properties of genetic drift. In physics, random walks are used as simplified models of physical Brownian motion and diffusion such as the random movement of molecules in liquids and gases. In mathematical ecology, random walks are used to describe individual animal movements, to empirically support processes of biodiffusion, and occasionally to model population dynamics. In brain research, random walks and reinforced random walks are used to model cascades of neuron firing in the brain (wikipedia). Can you model a physical phenomenon using a random walk simulation?

12.2 Goal

Design a random walk simulation that models or predicts a natural phenomenon. For example, you could model a drop of food coloring that is injected in the center of a cup of water. How long does it take for all the water to appear the color of the dye? Can you visualize your simulation in a nice way?

- Easy: Suppose a particle can only move left or right. If every moment of time it chooses randomly which direction to go, and moves the same distance each step, what would its position look like as time passed? Make a graph of its position over time.

- Medium: Make the random walk simulation as in challenge 1. Run the simulation many times. Calculate the average position of the particle over all the different trials.

- Hard: Simulate a drop of food coloring that is injected in the center of a cup of water. How long does it take for all the water to appear the color of the dye?

13   End of the world

Physics Concepts:
- High School or CEGEP level physics

Prerequisites:

- None!

13.1 Introduction

A meteor of the same energy as the one that caused the extinction of the dinosaurs is approaching planet earth. Luckily, we detect it in advance. The UN contacts you and asks you to design a countermeasure.

13.2 Goal

Explore the many possibilities humanity has to deal with a situation like this. Write a simulation to see if they are plausible. Plot the trajectory of the asteroid with and without the countermeasure. Here are some below:

- Gravity tractor: drive some heavy spaceships (or a spaceship towing another asteroid) by the incoming asteroid. Over time, the gravitational interaction should push the asteroid off course. How heavy do the space ships need to be and how long does it need to be near the asteroid for?

- Solar sails: Install solar sails on the asteroid and wait for the solar wind to push it off course. Plot the trajectory of the asteroid with and without the solar sails.

- Laser sublimation: Direct beams of concentrated light on asteroid. Is it heats up, it will spew jets of debris and gas and change its course.

14   Planetary Motion

Physics Concepts:
- Basic mechanics

Prerequisites:

- None!

14.1   Introduction

Last year, planetary motion simulations were a popular choice. Take a look at last year's submissions at XXX.

14.2   Goal

Design a planetary motion simulation. You could make it as elaborate as you like. You could do a simple solar system model or something more elaborate like calculating transfer orbits or modelling a space ship doing a gravity sling shot to get to Jupiter. Here are some things you might want to implement as features if you are looking for inspiration. Try to come up with your own!

- Calculate the interaction forces of an asteroid with the different astronomical bodies and simulate its motion based on given initial position and speed. (You may choose to use just the 3 astronomical bodies that will have the greatest effect.) Can you find an initial condition which produces a stable orbit?

- Simulate a space ship solar sails. How fast are they? How light does the material need to be for them to be plausible?

15   Arduino

15.1   Introduction

There are several Arduino units, components, and other hardware available at the event. We encourage you to take advantage of them!

15.2 Goal

Use the available Arduino or other available hardware to model a physical phenomenon rather than writing a computer simulation. Here are a few things you could do if you are looking for inspiration:

- Using a photodetector, measure how the light's intensity of an LED depends on how far the observer is. Make a plot of light intensity vs distance.

- Build a device that demonstrates how the power is different for a series or parallel circuit.

- Build a machine that sorts Skittles by color.

16   Trajectories

Physics Concepts:
- Projectile motion

Prerequisites:

- High School or CEGEP level physics

16.1   Introduction

Can you come up with an interactive way to demonstrate the concepts of projectile motion?

16.2   Goal

Write a computer simulation of the trajectory of a projectile. Here are some ideas:

- Plot the the trajectory of a ball depending on its initial velocity and angle it was fired.

- Make a game that allows the player to move a box side-to-side to try to catch a ball that's launched at different angles.

- Make a game in which the player has to hit a target by adjusting the angle energy of the catapult.

17   Computer generated art

Physics Concepts:
- Various

Prerequisites:

- None!

17.1   Introduction

Last year, A computer algorithm analyzed all of Rembrandt's work to learn the Dutch master's style and technique, before re-creating it in a new painting: `https://www.livescience.com/54364-computer-creates-new-rembrandt-painting.html` Antony Gormley's Quantum Cloud sculpture in London was designed by a computer using a random walk algorithm. See YYY for more about random walks. Computer generated music of all genre's can also be found on youtube.

17.2   Goal

Create a piece of computer generated visual or musical art!