Developing Computational Methods of Modelling Quantum Gravity

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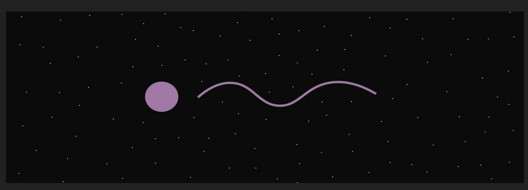
Theory of Quantum Gravity

In order to agree with the known theories of gravity, a "Graviton" must have certain properties:

- Massless
- Quantum spin of 2
- Electrically neutral

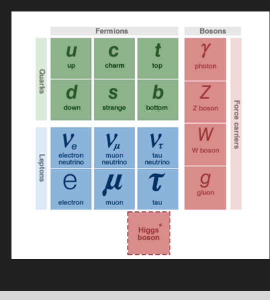


- Speculative" elementary particle called Graviton
- Far too small and weak to observe
- Existence predicted using the same concept electromagnetism uses to predict that a photon exists
- To agree with other theories of gravity, graviton must:

⇒ Be massless (like to a photon)
⇒ Have a quantum spin or 2
⇒ Be electrically neutral

Forces:

Current understanding of gravity based on theory of Relativity (a classical system).
Other fundamental forces of Physics employ quantum theories.



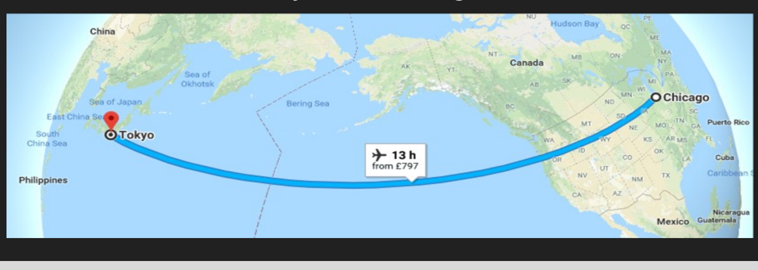
Standard Model includes all known particle interactions/forces except gravity

- Current understanding of gravity is Einstein's theory of Relativity
- The other fundamental forces of nature are described by Quantum mechanics and Quantum Field Theory
- Argued that quantum description is needed as classical and quantum theories can't be compatible

Planck length = 1.6 $\times 10^{-35}$ metres

$$l_p = \sqrt{\frac{G\hbar}{c^3}}$$

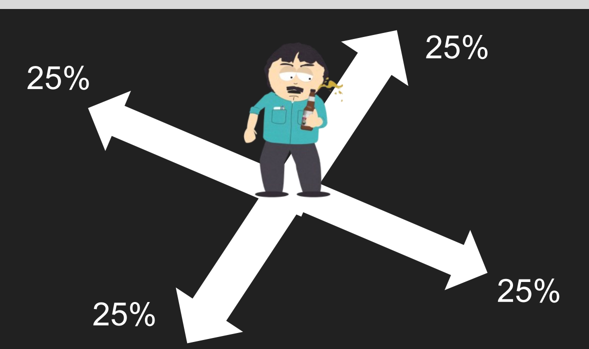
If we scaled a proton up to the size of the observable universe, the Planck length would be a trip from Tokyo to Chicago



- Planck established a set of units based on fundamental constants of nature.
- This includes Planck length, time, mass, temperature and charge.
- Planck scale consists of these magnitudes
- The scale also defines the meeting point of gravity, quantum mechanics, time and space.
- They are the universes limits to simplify the physical laws.

- In science, where something is individual or detached, it is discrete.
- Discreteness is the opposite of continuous.

- A fundamental postulate of quantum gravity is that space time is made of discrete points
- We want to model the effect of this discreteness on the motion light from discrete stars.

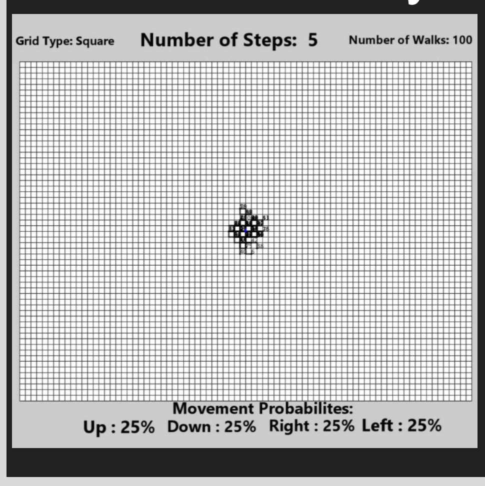


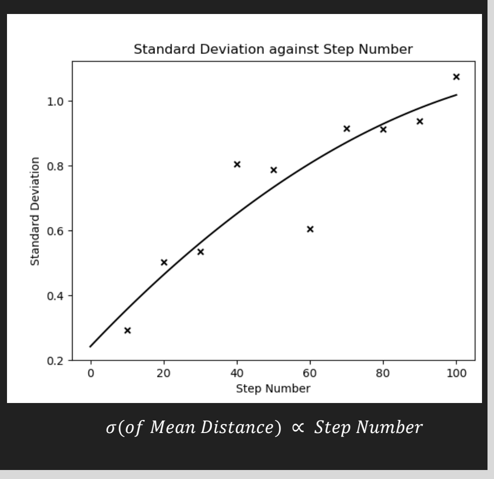
Random Walk

This drunk person has an equal probability of going in any direction

- We chose to focus on developing the required computational techniques to model the discreteness of space
- In order to do this we used random walks, which is a path made up of a series of steps that are determined through probability.
- Our first random walk was made up of equal probability the light had an equal chance of going left, right, up or down.

Theory vs Results



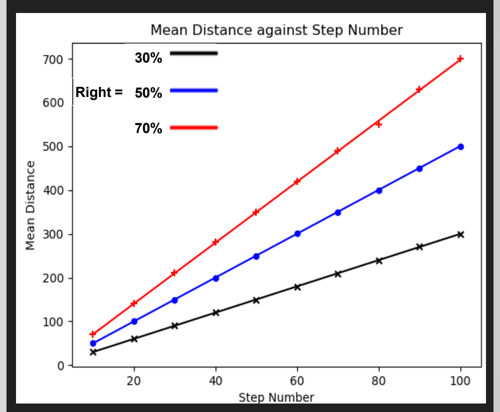


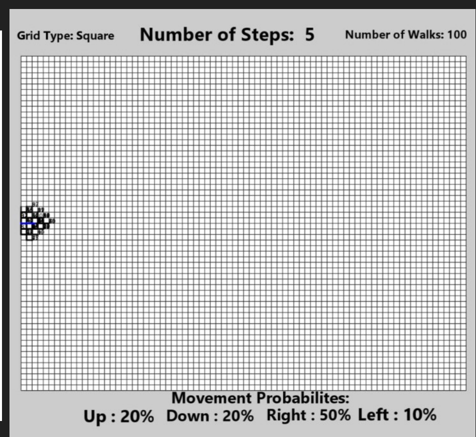
$\sigma(\text{of Mean Distance}) \propto \text{Step Number}$

- We used this equally likely simulation to gather some results.
- By increasing number of steps that each random walk takes, you can see that the walk on average travels a longer distance.
- We programmed the simulation to calculate and store the mean distance from the start to the end position of each walk.
- We were presented with this graph when we plotted the standard deviation of them against step number.

- The standard deviation of the mean distance of the walks is proportional to the step number.
- This is a result that we expected and so shows that we are investigating this correctly.

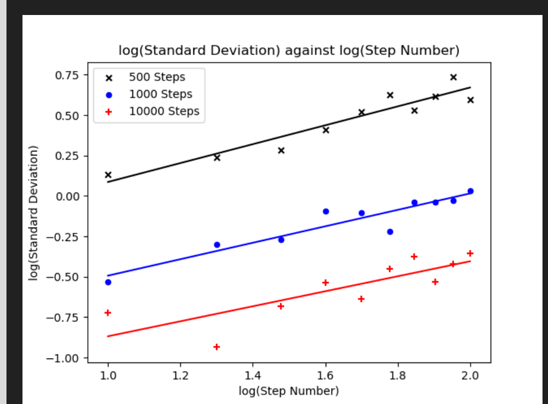
Theory vs Results

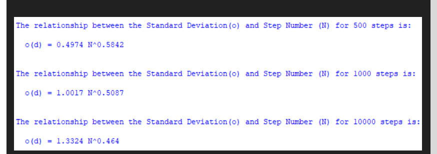




- We then went on to changing the probabilities of the light's movement.
- Plotted a graph of mean distance against step number for different probabilities of going right.
- This shows that the higher the step number and the higher the probability of travelling right, the further the walk travels on average.
- This is also a result that we expected and so once again shows that we are investigating this correctly.

Theory vs Results

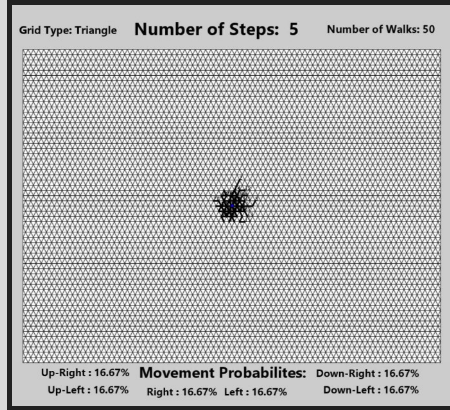




- Another way of showing that our simulation is providing correct results is by performing logarithmic functions on the results.
- Assuming that (the standard deviation of the mean distance) is related to (the mean step distance) by some power law.
- The gradient of this graph will be the power in the relationship and will give the multiplier.

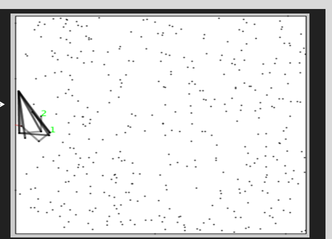
- We expect the power to be ½ from our previous findings of the relationship between the standard deviation of the mean distance and step number.
- When we plotted these graphs and calculated the power law dependencies, we discovered that, accounting for fluctuations, the power was ½, as expected.

Generalisations

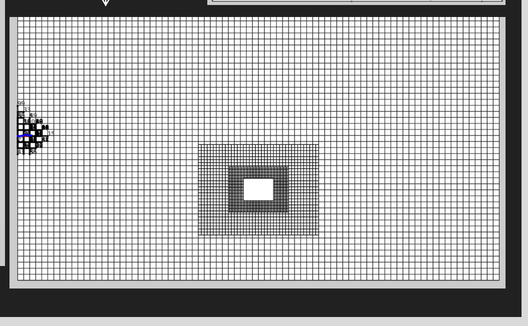


Isometric Grid

Random Grid



Random Walk with mass



- After this we decided to move onto investigate other types of grids.
- First we programmed an isometric grid, which now meant that the light had 6 directions it could travel in.
- We found that it produced the same results as the square grid, with differences only being due to fluctuations.
- We then undertook the task of programming a random grid.
- The concept behind this was to have randomly plotted points on a grid and have the light randomly pick a point near it and travel to it.

- Finally, we incorporated masses into our simulation to replicate planets
- From our understanding of gravitational lensing, it would be expected to see the light bending towards the planet when close to it.
- The blue average line shows that the planet's gravitational field, modelled by a denser region, bends the light when it is near the planet.

What did we do?

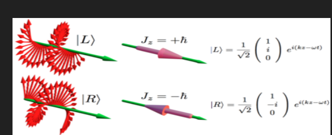
- Working model of spacetime ✔
- Experiment with different grids, probabilities, step number, etc. ✔
- Made it to be scalable and optimized ✔

To summarize:

- We have made a working model of discrete space-time
- It's scalable and optimized
- Various of modifications made to further explore the model:
- Different types of grids
- Varying number of steps
- Incorporating masses

What could we have done?

- Different photon spins



- Include extreme gravitational bodies

- Quantum interference

What more could we do if we had the time?

- Different photon spins and the interaction between two photons of opposing spin
- Much heavier and denser masses i.e. a black hole
- Integrating quantum interference
- The "moving window" method
- Spheres of influence