

Computer Science NEA 2025

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1 Analysis

1.1 Problem Identification

Often times in physics, complex circuit diagrams have to be drawn and understood, and the opportunity to actually build them is not always available. A solution that could handle custom circuits as well as model and log different attributes quickly, accurately, and efficiently in order to help with building intuition in regard to how complex electrical systems function would be a useful tool that could help solve this issue.

1.2 Identification of why this problem is solvable by computational methods

The key requirements stated above (accuracy, haste, and clarity) lend themselves very well to using computational methods. Computers are able to make calculations orders of magnitude faster than by hand or by analogue machine, and to a virtually arbitrary degree of accuracy. Many modern central processing units (CPUs) are also able capable of making use of concurrent processing, further increasing the advantage that a computer would have over a human. Graphical processing units (GPUs) are specifically designed for parallel processing, making them especially useful for graphics, which would allow for high quality renders for the user to be able to see. Any data that you would need to consider can be displayed in a clear and user-friendly fashion, making it highly customisable to fit the individual persons needs and for many attributes to be studied at the same time.

1.3 Description of the Current System

Without using computer simulations, the usual process is to produce a handful of equations by hand that would model the attributes of an object, for example the path it takes in three-dimensional space. This has the benefit of giving exact values and equations that are very useful when trying to understand the underlying reasons for an event happening. For example when considering a pendulum, it is clear from the equation

$$T = 2\pi\sqrt{\frac{L}{g}}$$

that the period of the pendulum T does not depend on the mass of the object doing the swinging. However, when running computer simulations, such relationships may not be as obvious, and as computers aren't able to analytically solve problems (i.e. through the use of rigorous mathematics), this is a drawback that I will have to consider. A computer model of a circuit can only be so accurate, as there aren't enough resources or time in order to model every single electron, proton, and neutron and all the intricate interactions they have with each other in real time.

1.4 Identification of Stakeholders

After considering the problem I identified the following groups that could use a solution to this problem, as well as having useful insight on how a program like this should function.

- **University Students** often have to deal with complex systems and a way of visualising them would be very beneficial. I have been able to contact a student at the University of Aberdeen doing a masters in electrical and mechanical engineering. Their name is Hugo, and they are 21-years-old.
- **A-Level Students**, specifically students taking physics, would be able to greatly further their understanding of core concepts and be able to explore new ideas on their own. I

have been able to communicate with Daniel, a year 12 physics student, about being a stakeholder for this project.

- **Teachers** of A-Level and below could make great use of simulation software in order to make learning much easier with models and demonstrations that are clear and easy to understand. I have been able to contact Mr Waters about being a stakeholder for this project, who teaches physics at Invicta Grammar School.

1.5 Identification of User Needs and Acceptable Limitations

Summary of key takeaways from interviews:

- My stakeholders are people who generally enjoy doing physics and find it enjoyable, although they all acknowledge how much work it can be. As such, decreasing workload without completely eliminating need for human input would be important, as that would make it less enjoyable.
- People struggle with abstract concepts, and a common topic seems to be electricity and electricals systems, as well as visualising some key concepts in physics such as waves. Considering a way to visualise circuits and the physics going on in those would be useful all of my stakeholders.
- Two out of three of my stakeholders said that they enjoyed astrophysics, so considering some sort of astro-mechanics simulation could be of use to them, as visualising large bodies moving in space is difficult.
- People find graphs very useful in visualisation and aiding intuition. Some sort of real-time graphing of attributes could be something useful to consider in the final product.
- All my stakeholders are competent in using simulation software, or don't mind spending time to learn how to use one properly. This would mean that accuracy and functionality could be prioritised over general user experience if necessary.

1.6 Existing Solutions

1.6.1 Analytic Methods

Analytic methods are very common as they require little cost or set-up and their effectiveness only depends on how well you understand the physics that you are doing. Since my stakeholders enjoy doing physics and are also quite good at it, they are all well versed in spending time going through calculations in order to achieve a set of mathematical equations that describe the system being modelled.

Handwritten mathematical derivations for the deflection of a light ray by a massive object. The steps are as follows:

- Start with the Schwarzschild metric for a light ray ($ds^2 = 0$):

$$-c^2 dt^2 + \frac{R_s}{c^2(1-\frac{R_s}{r})} \frac{dr^2}{r^2} = 0$$
- Rearrange to find $\frac{dr}{dt}$:

$$\frac{dr}{dt} = \pm c \sqrt{1 - \frac{R_s}{r}}$$
- Introduce the impact parameter b and the distance of closest approach r_0 . The trajectory is given by:

$$r = \frac{R_s}{2} \left(1 + \frac{1}{\cos^2 \theta} \right)$$
- Calculate the deflection angle α by integrating the trajectory from $\theta = 0$ to $\theta = \pi$:

$$\alpha = \pi - 2 \int_0^{\pi/2} \frac{d\theta}{\cos^2 \theta} = \pi - 2 \left[\tan \theta \right]_0^{\pi/2} = \pi - 2 \left[\frac{1}{\cos \theta} \right]_0^{\pi/2} = \pi - 2 \left[\frac{1}{0} - 1 \right] = \pi - 2 \left[\frac{1}{0} \right]$$
- Final result for the deflection angle:

$$\alpha = \frac{4R_s}{b}$$

Figure 1: A sample of Daniel's working out

Advantages:

- Very versatile. Paper and pen allows for great customisation in the layout of the work including diagrams and annotations, which allows the user to be able to do things the way they want to do.
- Cheap and easy to use. Little equipment is required and there isn't a need to install anything.
- Writing things physically on paper usually results in the writer being able to remember it easier, which would help in remembering things when learning.
- To get effective with analytic methods you require a lot of practice, which develops core skills like manipulation of various equations to achieve a desired result.
- Ability to get exact answers and relationships between objects and attributes. Computers can only approximate exact answers and being able to see the equations of what is happening can greatly aid intuition when tackling future problems.
- Doing hard work to get to a result is rewarding and relaxing. Offloading a lot of that work to a computer would reduce the enjoyment from this process.

Disadvantages:

- Difficult to organise. You can't save paper notes in a way that is easily shareable and easy to organise on a computer (other than scanning them as PDF files which can take a lot of time and my clients find annoying). It may also be hard to stay consistent with formatting due to how versatile it is, as seen in Figure 1.
- Getting accurate graphs beyond simple sketches is difficult. Performing numerical methods by hand is very time-consuming which decreases the amount of time that can be spent on doing actual work.
- Scope of problems that can be approached is limited. Not all systems can be solved using analytic methods and sometimes numerical methods are necessary, depending on how simple or complex you choose to make your model.
- Some problems are much harder to approach as the effectiveness of analytic methods is dependent on your ability to manipulate and work with equations, as well as general mathematical ability. Human's also make mistakes and are far less consistent than a computer at doing the same or similar calculations repeatedly.

1.7 Success Criteria of the Proposed System

The solution **should**:

1. Be able to handle **10 or fewer** components in a single circuit (excluding multimeters and wires)
2. Have **at least** the following components:
 - **Cell** with customisable E.M.F. and internal resistance
 - **Wire** with customisable resistivity and diameter
 - **Filament Bulb** with customisable resistance
 - **Resistor** with customisable resistance
 - **Multimeter** with customisable type
 - **Switch**
3. Have general attributes of the circuit displayed, such as total resistance, current, potential difference, and electro-motive forces
- 4.