Computer Science NEA 2025

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Centre Number:
Candidate Number:

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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, al-
  though 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.

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.
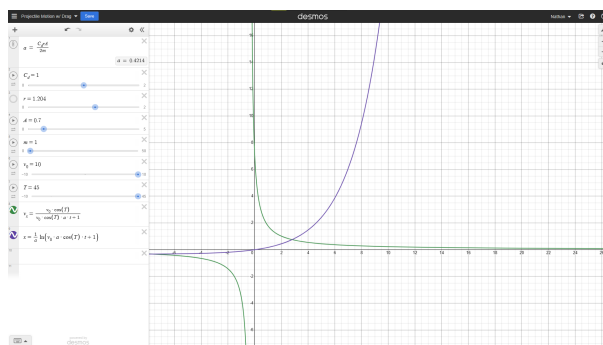
1.6.2   Desmos

Figure 2: Desmos graphing software

In Figure 2 below, Desmos has been used in order to see how attributes of an object change (specifically the x position and velocity with respect to time of an object experiencing drag). Desmos is great in order to aid intuition and view general trends, however you still need to work through equations in order to have something to graph, and Desmos won't give exact values for solutions, but the final visualisations are still very useful.

The simplicity of Desmos allows it to be very versatile, but that also means its more of a jack-of-all-trades and master of none, so it wouldn't be very good for a more specialised application (like the ones being considered).

Advantages:

- Desmos is a very versatile software which means that it can be used for a wide variety of problems.

- Free and easy to use. Desmos can be accessed by anyone with a computer or mobile device by going to their website, or by downloading the mobile app.

- Very customisable. Desmos allows for labels within the equation space, as well as changing the names of the labels on the axes. Which allows for some form of documentation within the graphs. The colours and line style are also changeable.

- Easy to share and work on on multiple devices. After you make an account, you are able to save graphs that you've done and access them on whatever device you're signed in on. Graphs can also be shared with links once they're saved which allows for collaboration on projects.

- As of quite recently, Desmos has released a beta for a 3D graphing mode, which is great for modelling some events happening in 3D, such as the trajectory of an object given some initial conditions.

Disadvantages:

- The versatility of Desmos means that in the case of a more specialised system with specific needs, it would be more beneficial to create custom software for that specific system. However, Desmos still manages to cover a wide variety of problems, just not in a lot of depth.

- The accuracy of Desmos is not very customisable, usually giving answers to two or three decimal places, and it is only able to give exact answers in some circumstances (values are usually given in terms of π when working with trigonometric functions).

- Circuits diagrams often end up messy and obviously not functional as they are on a piece of paper.

1.7 Success Criteria of the Proposed System

The solution **should:**

1. Model electricity accurately

2. Be able to handle **10 or fewer** components in a single circuit (excluding multimeters and wires)

3. 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**

4. Have general attributes of the circuit displayed, such as total resistance, current, potential difference, and electro-motive forces

5. Have a snapshot button that is able to log attributes of every multimeter and export to a CSV file or similar, which allows the user to perform the analysis individually

6. **Drag and drop** system for placement of components onto a grid

7. **Charge flow indicators** for the direction of charge flow (toggle between electron flow and conventional current)

8. Nameable components (for easier management)

The solution also **could:**

1. Have the capability to handle multiple **(two or three)** circuits simultaneously

2. Have the previously mentioned snapshot button be more customisable, including an option to automatically perform snapshots after a given time interval

3. Have custom themes with accessebility options (for example, for colourblind users)

4. Have the ability to export circuit arrangements which can then be shared with other collaborators