Mathematically Optimizing Rock Climbing

Owen McGlynn
College of Mathematics and Natural Sciences,
University of Massachusetts,
Amherst, MA 01003
omcglynn@umass.edu

July 24, 2025

1 Abstract

Rock climbing is both a physical and mental discipline, requiring climbers to make rapid decisions about movement and body position in real time. This paper proposes a mathematical model of route optimization in climbing using graph theory and pathfinding algorithms. By representing climbing routes as weighted graphs—where holds are nodes and potential moves are edges—this model will allow for the analysis of "optimal" climbing paths based on difficulty, efficiency, and energy expenditure. Different weighted graph search algorithms will be implemented to compare their outputs against real climbing decisions made by experienced climbers. The primary goal of this project is to investigate whether mathematical algorithms can successfully model human climbing behavior and to what extent optimal paths differ from actual climbed sequences. This project will blend mathematical theory with a real-world application, aiming to contribute to both sports science and applied mathematics. Overall this paper will hold a main focus on the climbing disciple of *Bouldering* as I have very little experience with other forms so I do not feel confident in speaking on them.

2 A Brief Introduction to Climbing

2.1 Ancient Origins

Rock climbing is an extremely self explanatory, ancient activity. The compulsion to venture to the highest vista possible has been evolutionarily ingrained into not only humans but many other animal species. Primally, it serves many very important purposes, from providing a sense of safety by providing a good vantage point to survey your surroundings for threats, to establishing social hierarchy. Such characteristics of the preference for height can still be seen quite commonly; for example, the top office of an office building oftentimes is reserved for the person holding the highest position within the business.

Outside of an instinctual sense, humans are actually extremely well acclimated for climbing in general, in fact, we may have specifically evolved to be good at it[4]. As you may know, human's most closely related DNA relative is the chimpanzee, whom we share 99% of our genetic make up. Well, chimpanzees are a tree-dwelling species, and thus have a body perfectly suited for traversing the arboreal environment. They have a very high proportion of fast-twitch muscle fibers which are specialized for quick contractions and generating bursts of force which is necessary for explosive movement in swinging across branches [3], and a shallow ball-and-socket shoulder that allows for a greater range of movement which are just a couple examples of their evolutionary advantage in climbing expertise[1].

Though we have evolved to no longer hold a particular resemblance to our primate brethren, and have lost many traits in our biped endeavors, we still retain quite a few traits that allow us to run and climb more effectively than most animals. Our shoulders and elbows still hold the same design as that of a chimpanzee's and began as a kind of de facto braking system for down-climbing to slow the descent from trees, furthermore, the *palmaris longus* muscle in your wrist is a muscle specifically devoted to helping with wrist flexion and gripping and supporting excessive strain on the wrist[6]. Interestingly, some people lack a palmaris longus as apparently evolution no longer considers it necessary.

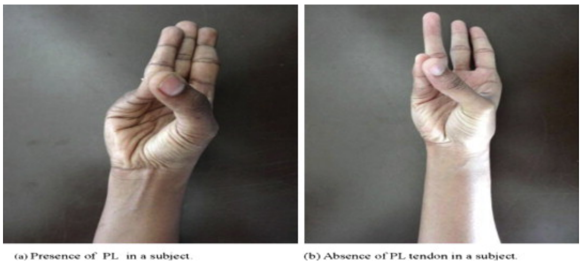

Figure 1: palmaris longus[2]

2.2 Modernity

Aside from primal urges and necessities though, just as we have gone from cooking purely to satiate hunger to coming up with new novel flavors to surprise our pallet, climbing has gone from something required to avoid ground-fairing predators and access our homes to something done out of the fundamental love for the activity.

Now-a-days, the colloquial definition of rock climbing is somewhat separated from simply venturing up any rocky face. It now generally refers to the climbing of "technical-terrain" or ways of traversing an almost vertical plane involving physical techniques, equipment, and oftentimes a predefined sequence of moves[7]. These routes do not even exist solely outside; the advent of climbing gyms has allowed for indoor, human set climbs with man made holds often made of plastic or wood rather than rock. The difficulty is measured not just by the steepness or height of the wall, but by the intricacy of movements required, the shape and quality of the holds, and the climber's physical and mental endurance. Climbers now analyze beta (the optimal sequence of moves), strategize rests, and calculate the most efficient paths, turning each climb into not just a test of strength, but a problem to be solved. It's in this rich mix of physical challenge and cognitive planning that mathematics begins to naturally emerge.

The format of rock climbing that this report will cover is called *bouldering*, a discipline that involves walls typically only ten to twenty feet in height, no ropes or harnesses, and an emphasis on short sections of technically challenging moves rather than long stamina based routes with numerous sections of varying difficulty.

While its primal roots may have served survival and social purposes, today's rock climbing is deeply recreational, athletic, and even competitive. Yet, the ancient desire to ascend, though transformed, and refined, is still very much present.

2.3 Terminology

Just for my own sake in writing this, there are some terms I will be using over the course of this paper that are in the common climbing vernacular but may sound like nonsense to most people. They are as follow

- **Beta** - A term referring to information about a climb, whether it be the route itself, how to do a specific move, etc.
- **Flash** - When you complete a climb first try
- **Words for specific holds**
  - **Jug** - A large hold with a big in-cut you can fit all your fingers in
  - **Pinch** - A hold that requires pinching between the thumb and forefingers
  - **Crimp** - A small hold only thick enough to accommodate part of a single digit of one or more fingers.
  - **Sloper** - A hold held on to purely by friction with nothing to grab on
  - **Pocket** - A hold with a hole to insert fingers in
  - **Undercling** - A jug like hold that is flipped upside down.
  - **Foot Chip/Jib** - A hold not intended to put your hands on, only feet.

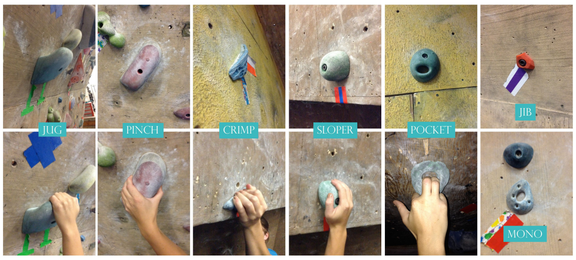

Figure 2: Hold Types[5]

  - **Note:** add ỹ to any of these words to make them an adjective
- **Dyno** - A climbing move involving lunging or leaping to a hold
- **Campus** - A term describing moves done without feet supporting you
- **Grading** - A value indicating difficulty of the climb
- **Slab** - Referring to climbs on a wall with a decline (¿=90° with the floor)
- **Incline** - Opposite of slab, walls with an incline angle
- **Top Out** - Term used for completion of a climb where you put both hands on the finish hold

It is also very important to understand the way overall difficulty of climbs is depicted. Generally, the American style of grading boulder problems by using a "v" followed by some number. For instance, the very easiest climbs possible are called v0's or vB's and the hardest boulder ever completed is a v17. These grades are somewhat arbitrarily given based on the setter or community's assumed difficulty. Some gyms, like the one this research will be conducted in, also use a taping system where a color of tape can denote a range of grades (e.g. v3-v4, v5-v6, etc...).

3 Research Questions

Now that you have an effective understanding of what exactly we are studying, let's take a look at the questions we will actually be asking. As mentioned briefly in the previous section, the climber's optimization of the route they take is extremely important for successfully completing a climb, especially in the discipline of bouldering. Unlike longer rope climbs, bouldering problems are often short, intense, and unforgiving. In gym settings especially, climbs are intentionally designed to push the climber to their limit by the end, eliminating obvious resting spots, limit grip variety to overuse the same muscles, and require a very specific sequence of movements to succeed. In many cases, a single misstep can mean failure.

Because of this, climbers must be able to "read" the climb before even stepping onto the wall. This means mentally parsing out the most energy-efficient sequence of movements, or "beta," from start to finish. Some of these decisions are quite obvious like the order in which to move their limbs between holds, or where to shift body weight. But at a more advanced level, it could involve much smaller details such as the exact angle a hold should be grabbed, or how much time to spend on a particular move. The ability to choose the optimal beta can be what separates a completion from a failure.

So, the main question at the heart of this paper is:

> *Can we find a mathematical method to calculate the most efficient beta for a climb? And how does our mathematically derived beta compare to the beta intended by the route setter, or the beta actually used by real climbers?*

This question is multifaceted though. Finding an "optimal" route is not as simple as drawing a straight line from the bottom hold to the top. That's not only physically impossible for humans, but frankly, it's not meaningful from the perspective of a climber or this research. So, if we want to optimize a path, we first need to break it down into the individual transitions between holds. We then need to evaluate those transitions to determine which ones are the most efficient.

That leads us to the first major technical question: *how do we calculate the "cost" of a move?* In other words, what exactly makes one movement more difficult or energy-draining than another? There are many possible factors that might influence the cost of a move, including but not limited to:

- The physical distance between two holds
- The type of hold being moved to
- The direction of movement (e.g., upward vs. lateral)
- The angle or steepness of the wall at that section
- The positioning of the climber before and after the move

Each of these variables contributes to the real-world challenge of a climb, but they don't all carry the same weight. So the next big question becomes: *how do we represent all of these variables in a single cost function that reflects actual climbing difficulty?* In other words, how do we combine these values in a way that mimics how climbers intuitively assess a route?

Even if we can create that function, there's still more to ask: how do we determine what attributes should matter more than others? Should a far move be weighted equally with a grip transition from a jug to a sloper? Should a small reach be considered easier than a large, awkward body repositioning? And how do we model the fact that fatigue is cumulative?

These are the kinds of questions that will guide the structure of this paper. By thinking about climbing not just as a sport, but as a problem-solving exercise, we can begin to break down the intuitive logic of beta into something mathematical and measurable. The ultimate goal is to build a model that mirrors how climbers solve problems on the wall but with numbers, functions, and algorithms instead of gut instinct.

4 Methodology

Unfortunately, I do not think it is feasible to create a perfect function that will fit every single individual. There is far too much variation between people to account for. For instance, how tall they are will change the weights of reach distance as will the length of their arms, how strong their stamina is will effect how quickly difficulty builds, their weight, muscle makeup, and working strength affect almost everything. Thus, for the sake of this report, I will be standardizing these measurements to fit myself, as I am the easiest test subject to use as well. If you would like to adapt my end result to fit yourself, my quantifiable measurements are below.

Height	5'11"
Weight	140 lbs
Wingspan	75 in
Avg. Climbing Session	1.5-2 hrs
Age	20
Skills	Pinches, Crimps, Footwork
Level of Climber	v7-v8

Table 1: Standard Measurements Used in Report

All of the actual practical research will occur at University of Massachusetts - Amherst's *Ascend* climbing gym. I chose to complete this research in a gym environment because it offers a significantly more controlled environment where factors such as wetness, temperature and season are so variable. The gym environment also means that the climbs were all set by people so they have defined intended beta which I will be able to compare with our calculated result at the end of the report. The access to setters of the climbs that will be tested, and in general provides me with the ability to ask questions about intended difficulty of certain moves, thoughts on how to weight difficulty, and overall just provide an awesome source of experienced information. Furthermore, this gym is on campus so it provides easy access to do research across multiple days.

For the actual research itself, graphs corresponding to each climb that is tested will of course have to be generated. While one approach could be to just put every hold connected to each other, I think a more effective approach would be to rule out any hold out of jumping distance, or anything that is clearly not feasible given the graded difficult of the climb (i.e. on a v4, a dyno to a tiny crimp). Since the graphs will be created manually, during the testing phase I will explain if I believe a move is not feasible if it is not immediately obvious.

Determining weighting and factors to consider will be a more ambiguous process. As I have previously mentioned, the difficulty of a move is not very explicit in most cases. You could have the same move with the same holds in two separate climbs and depending on numerous factors that move could be exponentially harder in one than the other. Just for example lets say this move is a 2.5 ft span from a jug to a half-finger crimp, if this move is at the very beginning of the climb, the climb is on a slab wall, and you have really good feet, this could be incredibly easy. On the other hand, if the this move is the final move of the climb so you're very tired, the climb is on an incline wall, and you have to do it campus, its going to be ridiculously difficult. Therefore, in order to try to come up with a relatively general solution, I am going to consult with the setters and experience climbers at Ascend, and get their opinions on how much factors such as level of incline, number of moves already made, and body position affect difficulty of moves.

Finally, for the actual computation of a route, there is a few decisions needed to make about method. We will be using weighted graphs and thus will be using a shortest path algorithm, but which one is the best for our use-case? Ultimately, I have landed on the A* search algorithm. I chose this one because, firstly, I is the search algorithm I have the most experience with. Secondly, It is quite well optimized for this problem as there will be no negative path weights and making a heuristic will be quite easy (using distance).

Now, all of this computation would take tens of hours for each climb if it were to be done by hand. I would have to calculate the cost of every single combination of every single possible move, which I am just not willing to do. To solve this issue, I decided to use my actual major and make a computer program to do the heavy lifting for me. In this program, all that you need to do is plug in the positions and information of all the holds in the climb and then plug in the climbers measurements along with the holds each limb is starting on and run it. It sounds like a lot of work but compared to running the complicated formula a few hundred times per climb.

4.1 Creating the Cost Function

After consulting with some of the setters and well seasoned climbers at Ascend I have decided on the following cost function (as of the first draft, all calculations are entirely tentative):

$$T = (w_1 E + w_2 H + w_3 I + w_4 (1 - C_1) + w_5 (1 - C_2) - \lambda (D_{\text{before}} - D_{\text{after}})) \cdot (1 + \alpha \cdot \log(1 + F)) \tag{1}$$

Below are the values of each of the variables

1. **Effort** - The effort value (E) is a measure of exactly how much effort the climber must exert to make a given move.

$$E = \sum_{l \in \text{moved limbs}} \left(\frac{\|p^l_{\text{start}} - p^l_{\text{end}}\| \cdot u}{L_l} \right)^2 \tag{2}$$

2. **Hold Difficulty** - (H) The difficulty of the hold being moved to is calculated as follows

$$H = \sum_{l \in \text{moved limbs}} D^{\text{new}}_{\text{grip}}(l) - D^{\text{old}}_{\text{grip}}(l) \tag{3}$$

$$D_{\text{grip}} = \text{base} \cdot \left(1 + \frac{\text{incline}}{100}\right) \cdot \text{size\_scale} \cdot \text{angle\_penalty} \tag{4}$$

3. **Incline** - Incline (I) is a major component of difficulty in many climbs and in our formula is just represented as

$$I = 1 + \frac{\text{incline}}{90} \tag{5}$$

4. **Comfort** - Comfort (C) is our measure of how comfortable the climbers body is in a given position on the wall. It appears twice in our formula, in the first instance showing comfort level prior to the move and in the second, after.

$$C = 1 - (0.4R + 0.25T + 0.15B + 0.2X) \tag{6}$$

   (a) **Reach Strain** - In this formula, reach strain (R) is how far extended the climbers body is

$$R = \frac{1}{k} \sum_{l \in \text{limbs}} \left(\frac{\|p_l - p_{\text{center}}\| \cdot u}{L_l} \right)^2 \tag{7}$$

$$p_{\text{center}} = \frac{1}{k} \sum_{l \in \text{limbs}} p_l \tag{8}$$

      i. k is the number of limbs on the wall, p is the position of each limb, u is conversion from grid to meters (for use in the coded portion of my research) and L is the max reach of that limb (half wingspan or leg length).

   (b) **Tension** - Tension (T) is the measure of how much tension is holding the climber on the wall

$$T = \begin{cases} 1, & \text{if both feet are off and both hands are on bad holds} \\ 0.5, & \text{if one foot is off} \\ 0, & \text{if both feet are on} \end{cases} \tag{9}$$

   (c) **Balance Asymmetry** - How unbalanced you are (B) is a major issue in climbing as it is one of the most unsuspecting ways to lose your grip on the wall

$$B = \left| \frac{w_{\text{left}} - w_{\text{right}}}{w_{\text{left}} + w_{\text{right}}} \right| \tag{10}$$

$$w_i = \sum_{\text{i limbs}} \text{support score} \tag{11}$$

      i. support score is a value 1 or 0 given as to whether the given limb is on the wall

   (d) **Contortion** - (C) The difficulty to make moves is greatly increased if your body is contorted in a strange position

      i.

5. **Distance to Finish** - Distance to finish (D) is a value that is not really so much a cost but a bonus, retracting from the cost to reinforce the search algorithms tendency to move towards the finish.

$$D = \frac{1}{n} \sum_{i=1}^{n} \min_j \left(\|p_i - f_j\| \cdot u \right) \tag{12}$$

(a) in this case, p is the position of the limb, f is the position of the finish hold, n is the number of limbs on holds, and u is once again our conversion factor

6. **Fatigue Penalty -** Finally, the fatigue penalty (F) is to simulate a climber's fatigue. As the path goes on, the fatigue increments, dissuading the search algorithm from taking long, circular routes.

$$\text{FatiguePenalty} = 1 + \alpha \cdot \log(1 + F) \tag{13}$$

(a) F is the cost of the route so far.

4.2 Modeling climbs

To get a feel for the accuracy of this methodology, we of course need to get some climbs to test it out on. I have ultimately decided to test it on 5 separate climbs. Of these climbs, three of them will purely be chosen based on difficulty, either on a vertical or incline wall and the remaining two will be based on technical skill, something unable to be modeled by our cost function. The two technical climbs will be different from each other as well, one will be on a slab which requires balance and careful movement and the other will be dynamic, requiring large powerful moves like jumps. Both of these types of climbs are areas where I can for-see problems arising with our search algorithm and cost function.

5 Hypothesis

Climbing is an incredibly variable sport. Regardless of all the things we are taking into account, even if we were to add more, I do not think there is any way to effectively quantify the difficulty of moves on a climb, at least purely using graph theory. As I constructed this report, it became more and more evident to me the absurd amount of factors and calculations that would need to contribute to the equation in order for it to provide an accurate optimal route. In any case, my research will push on, and I will continue to try my best to produce a usable end product.

6 Process

Now that we have taken all the provisional measures required to effectively ensure understanding of the topic, present our methodology, and introduce a hypothesis, we can finally move on to the actual analysis of climbs.

6.1 Creating the Graphs

I went to Ascend on April 20th, 2025 to collect climbs for this study. As of right now, the currently set climbs are scaled on a number system rather than the traditional v# style of grading. This is because there was a recently held competition with 42 climbs set so they are graded with 1 as the easiest to 42 as the most difficult. All of the climbs I actually expect the algorithm to perform on with some accuracy are graded on this systems and then the two I do not are not. One of those non-numbered climbs is a v7 (slabby with some jumps) and the other is a finalist climb for the women competing (slabby with strange moves such as one requiring the climber to go upside down).

To create the graphs, I labeled them with the starting hand holds and the finish holds. All foot holds that are just infeasible to use as hands are labeled with an "F" and then for ease of use when running the algorithm, each hold is labeled with an arbitrary number.

For clarity to the reader, I did some photo-shopping to remove other climbs from the wall and since my photoshop skills are not quite the best, the positions of the bolt holds I will be using for measurement are not correct in the images in the document.

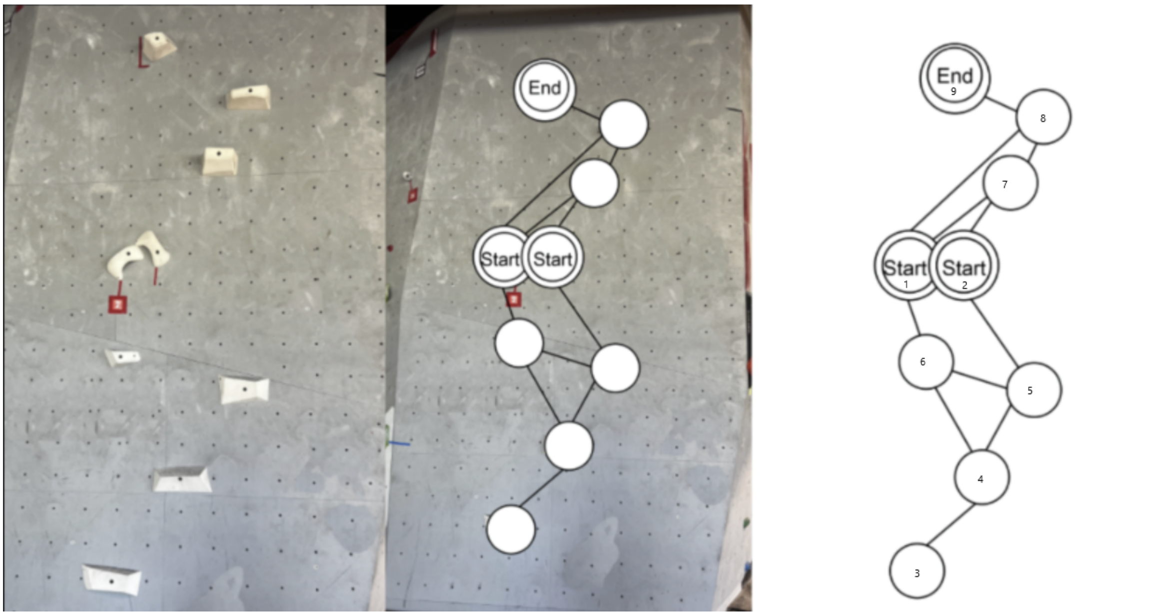

Figure 3: Easy Climb, Difficulty 2

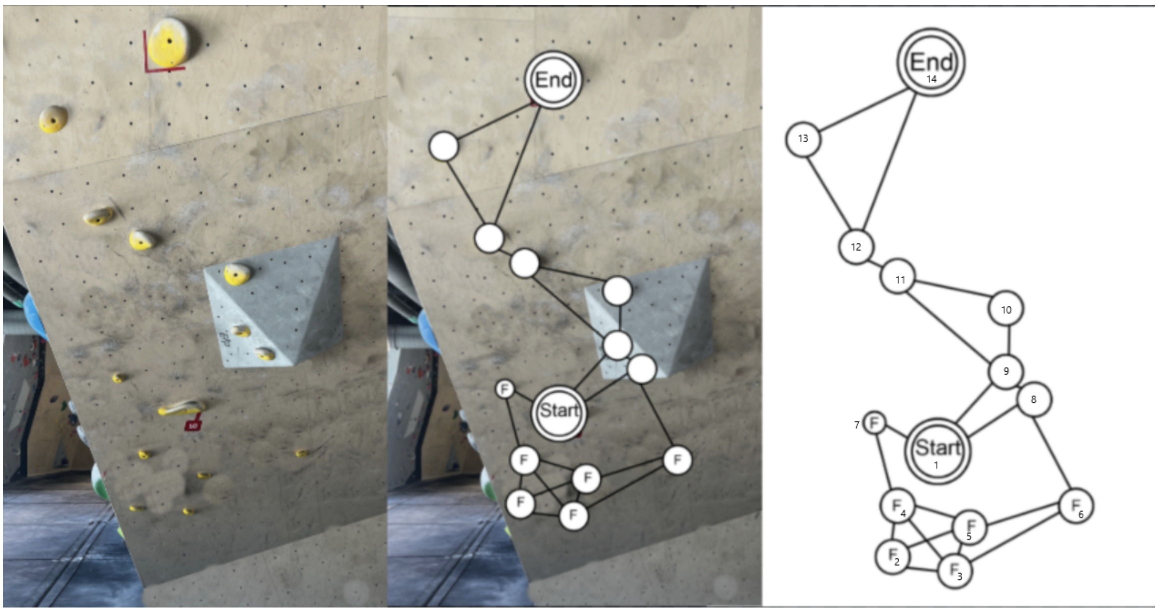

Figure 4: Medium Climb, Difficulty 10

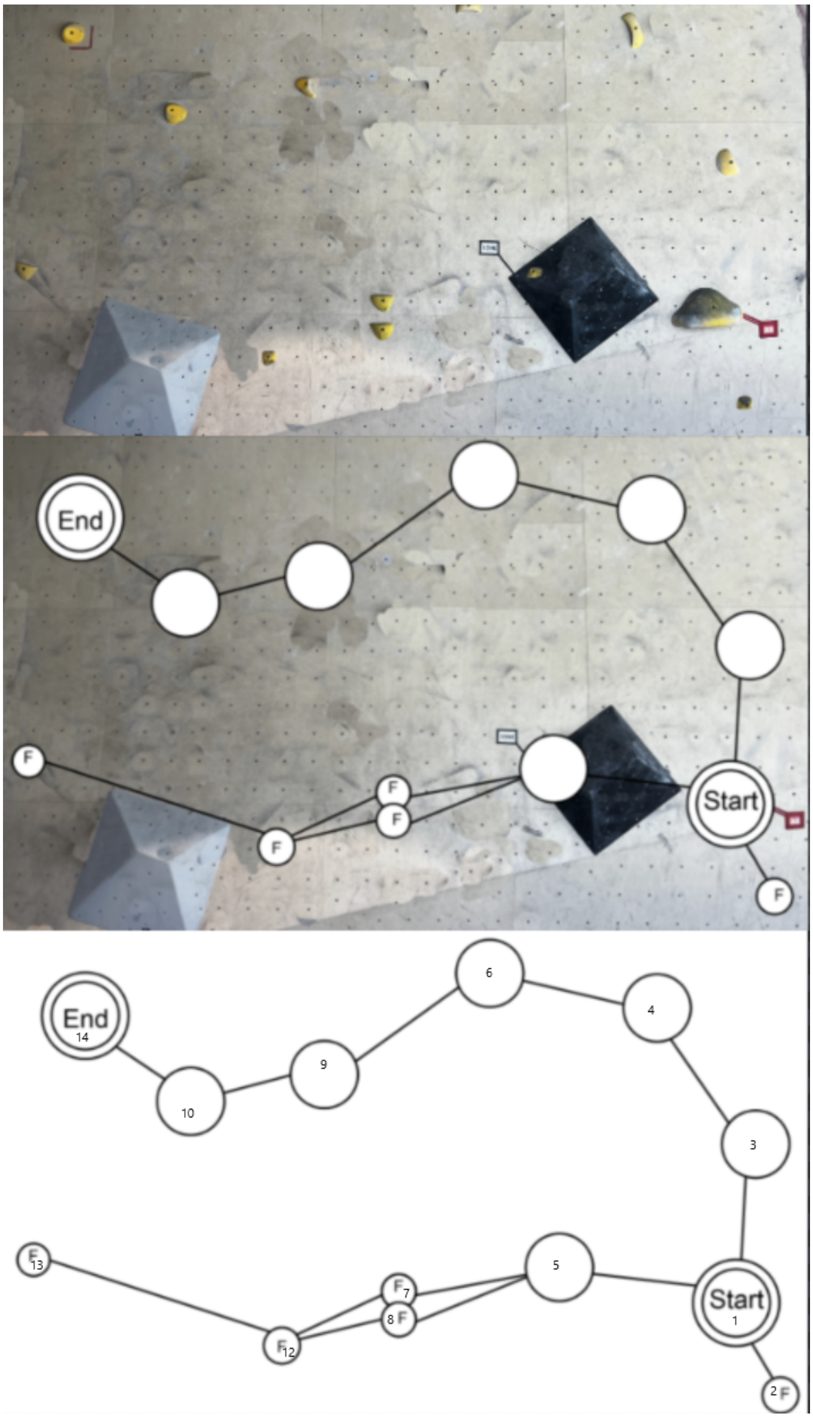

Figure 5: Difficult Climb, Difficulty 27

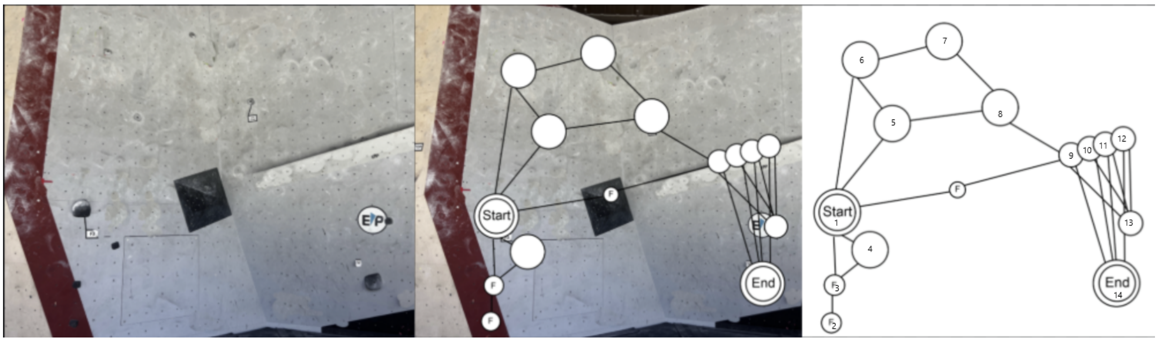

Figure 6: Slabby Dynamic Climb

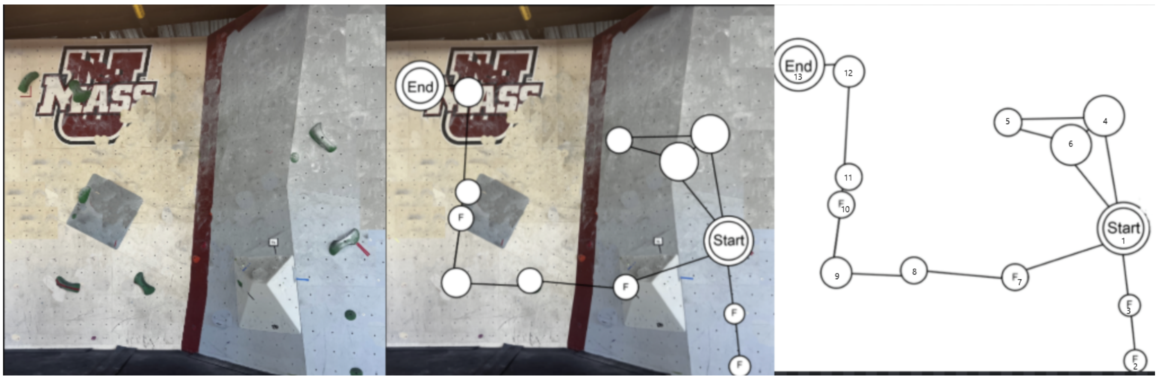

Figure 7: Women's Finalist Climb

6.1.1 Utilizing the Program

Very fortunately for me, the distance measurements between holds is extremely easy due to the way climbing walls are made. For the setters ease of use, the climbing wall is dotted with holes uniformly separated by 6 inches. Thus, we can use this grid to easily plot the locations of the holds. Once I handled that, the rest was quite trivial.

7 Results

All in all, the program was able to generate paths for four out of five of the climbs. This actually surpassed my expectations as I had intentionally included two that I did not think it would be able to process.

For sake of visualization, I took the liberty of animating both the actual way I climbed each in real life, and the routes that were generated by the program. I did this because looking at the movements of each limb is very hard to visualize just by imagining someone making that move, and it makes it extremely hard to tell whether or not that move is actual feasible for a real human being working under actual physics. In this paper I will only be including the sequences of frames in the animations but you can access the GIF at the following link:

Figure 8: https://drive.google.com/drive/folders/1eR1WLsnSPslHlVkTj9jZpDFcmZy_TOgJ?usp=sharing

7.1 Climb (2)

This climb was easily the simplest of them all. Just about anyone with a couple months of climbing under their belt would be able to do it without hands at all, so I had high hopes for the program, and these hopes were satisfied. Not only did the program successfully generate a route, but it actually may have been more efficient than the one I did myself. Not only did it complete the climb in fewer moves, but it did an amazing job balancing the climber's center of mass and ensuring they were not spanning too far.

Figure 9: Climb 2 Generated Route

Figure 10: Climb 2 Actual Route

7.2 Climb (10)

This climb was also relatively simple but had the advent of being conducted on an incline. This fact changed the cost calculation for moves on certain holds, making crimps and pinches more difficult. Regardless, yet again, the program still managed to create a relatively decent route. This one however was not as optimized as I would have liked. It seemed to show a very strong tendency to match hands when possible. Though it avoided spanning, matching every hold is by no means necessary and introduces a lot of unnecessary fatigue to the climber in real world situations. The second to last move it did was also not advisable in real world scenarios, involving the climber crossing their left arm over their right when it could just have easily used their right in the first place. In any case, the route generated was completely feasible.

Figure 11: Climb 10 Generated Route

Figure 12: Climb 10 Actual Route

7.3 Climb (27)

This climb was very slabby and involved utilizing good balance, and precise movement. This is also where things started to fall apart. Though the route generated was possible if you are a very strong climber, it was significantly more difficult than necessary. It involved matching feet in places that would be very difficult to do so, poor handling of center of gravity, large spans, and a preference for making hand moves over foot ones. Though the actual route involved more moves, in the real world it would be less taxing and more efficient for any climber.

Figure 13: Climb 27 Generated Route

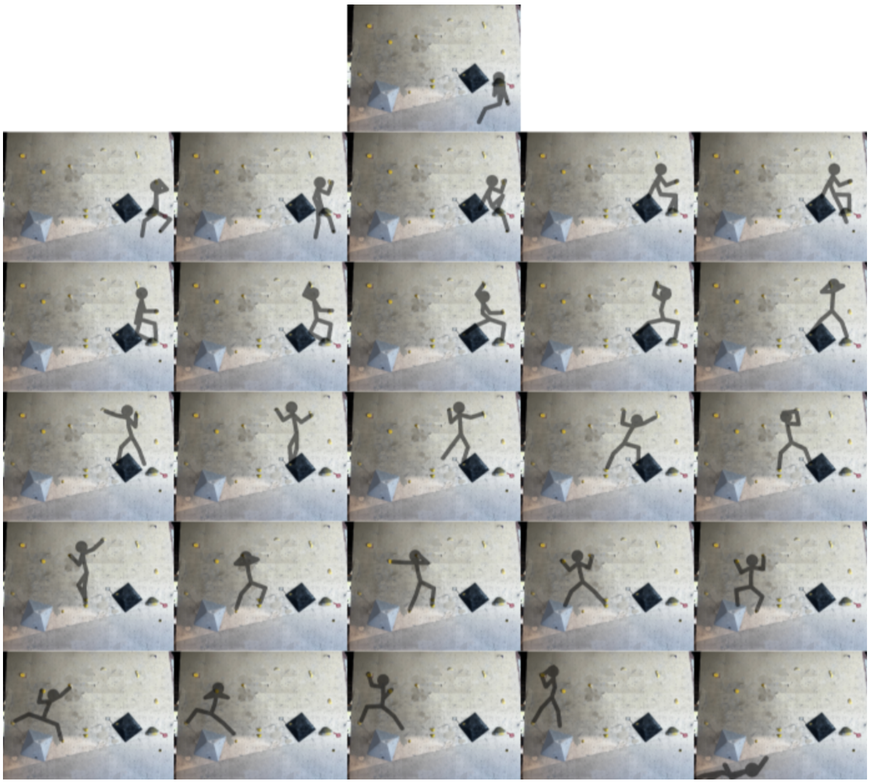

Figure 14: Climb 27 Actual Route

7.4 Climb F3

Now we begin to get into the climbs intended to break the algorithm. This one in particular was very slabby and not only involved precise movement and center of gravity management like the previous climb, but also going completely upside-down which I made no prior considerations for in generating the cost function and program as a whole. Despite intentionally introducing this climb to break the program, to my surprise it still managed to output a route for me. This route however, would be completely impossible for any climber in real life. The algorithm decided to take going upside down to the extreme, forcing the climber to be upside-down for more than 75% of the climb and contorting their body in ways not quite humanly possible. Even though the program surpassed expectations and managed to spit out a route for this climb, I would not call its result satisfactory or optimized by any definition of the word.

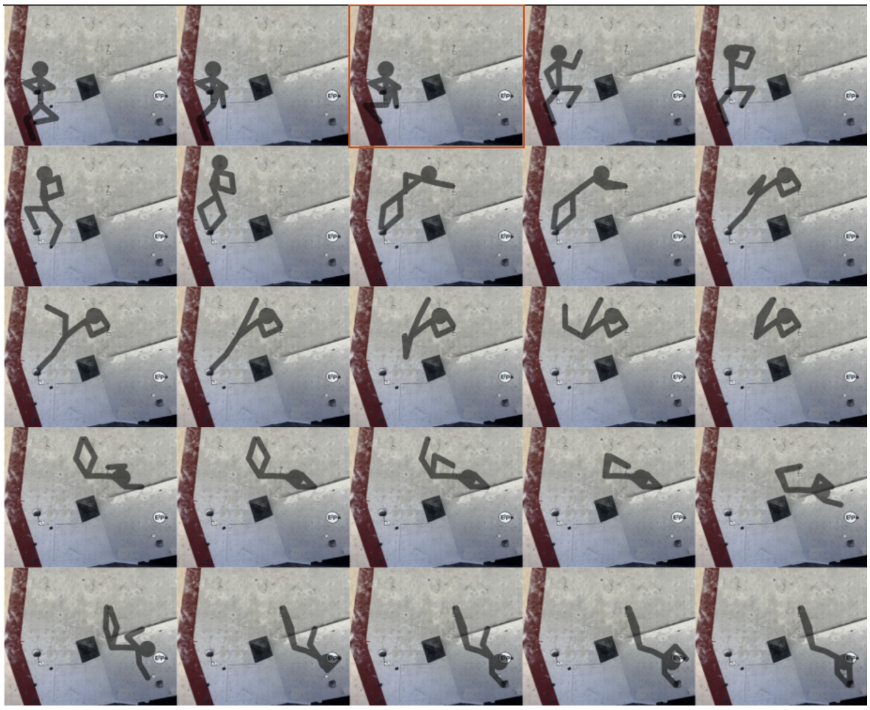

Figure 15: Climb F3 Generated Route

Figure 16: Climb F3 Actual Route

7.5 Climb Red

We finally have reached the last climb, and the one I had the least hope for. This climb involves multiple dynamic moves, including jumps, small falls, and going backwards. As I honestly expected, this climb broke the algorithm, leaving it unable to generate a route for it.

Figure 17: Climb Red Actual Route

8 Conclusion

8.1 Reflection

When I first began working on this project, frankly, I thought this project would be relatively easy; I climb every day, its not that hard for me and I have a good understanding of how things are done, so how hard could it really be to just model it mathematically. I quickly realized I had trivialized a problem that was significantly more difficult than I originally thought. The first issue I stumbled upon was creating the cost function. The more I worked on it, the further I felt I was from a working copy. Each time I introduced a variable, 3 more would pop up, requiring me to make new considerations and new calculations for each. Ultimately I decided to forgo a complete edition in favor of making a one that works at all.

Aside from the actual modeling of the climbs, I completely neglected to consider the difficulty of creating the program that would handle the search itself. When I began, I hadn't though very far past just using a search algorithm. The experience I had in the past with them only involved one agent navigating the graph so the thought of handing multiple didn't even cross my mind until I began working. Ultimately though, I am quite proud of my end result. It functions wonderfully and could easily be adapted for use in future, unrelated projects.

Lastly, I am extremely proud of my animations though they are not visible in their full glory in this document, I strongly encourage anyone reading this to check them out.

8.2 Notes for the Future

If I were to continue to work on this project, I would completely overhaul my cost function. The approach I took was a complete mess mathematically and in the code. Not only does it not work very effectively on climbs more difficult than the easiest ones imaginable, but it also fails to factor in things that are essential to climbing efficiently which was the entire point of this project.

Just as an idea, I think that machine learning would be a significantly better way to model optimal paths. I think that is the route I would go if I were to completely start from scratc.

I would try to implement considerations for dynamic moves and adjust it so it allows for releasing of limbs to allow for further spanning. As it stands, having fewer limbs on the wall is so heavily penalized that the algorithm only decided it was the optimal option once. I would also try to find some kind of way to better model center of gravity tracking as it is a much more important factor to climbing that I realized at the time of beginning this project.

Finally, I would like to find some way to make it so that the climbs can be multi-faced. Unfortunately, my program only models the climbs on a 2D plane, so, when you have a climb that goes around a corner, or an incline that increases or decreases the angle at some point in the climb, there is no way for it to effectively handle it.

8.3 Final Thoughts

I hand an amazing time working on this project. It revolved around a topic that I truly love and I think it really encouraged me to take a novel approach to a new project in coding which I really don't have very much experience with yet. Despite the fact that my final product was not quite satisfying, I hold no regret in taking on this endeavor and will probably continue to work on it.

References

[1] Dartmouth Arts and Sciences. *Our Shoulders and Elbows Began as Brakes for Climbing Apes.* Accessed: 2025-04-06. 2023. URL: https://faculty.dartmouth.edu/artsandsciences/news/2023/09/our-shoulders-and-elbows-began-brakes-climbing-apes.

[2] Various Authors. "Morphological Variations of the Human Wrist: A Cadaveric Study". In: *Journal of Clinical Orthopaedics and Trauma* (2014). Accessed: 2025-04-06. URL: https://www.sciencedirect.com/science/article/abs/pii/S0976001614001598.

[3] BBC News. *Fast-twitch Muscle Fibres: Evolutionary Advantage.* https://www.bbc.com/news/science-environment-40405026. Accessed: 2025-04-06. 2017. URL: https://www.bbc.com/news/science-environment-40405026.

[4] D. Scott Borden. *Are We Born to Climb?* Accessed: 2025-04-06. The Climbing Zine. n.d. URL: https://climbingzine.com/are-we-born-to-climb-by-d-scott-borden/.

[5] Uncarved Block Climbing. *What's in a Name? — Types of Holds Explained.* Accessed: 2025-04-06. n.d. URL: https://www.uncarvedblock.com.au/blog/whatsinaname.

[6] Hope Gangata. "Functional Anatomy of the Palmaris Longus Muscle". In: *National Institutes of Health (PMC)* (2014). Accessed: 2025-04-06. URL: https://pmc.ncbi.nlm.nih.gov/articles/PMC4059683/#:~:text=Having%20a%20strong%20palmaris%20longus,less%20important%20in%20other%20primates.

[7] National Geographic. *What Is Rock Climbing?* Accessed: 2025-04-06. n.d. URL: https://www.nationalgeographic.com/history/article/rock-climbing.