FIT2004 Data Structures and Algorithms
Assignment 1 - Semester 1 2025

DEADLINE:
Clayton cohort: 16^{th} April 2025 23:55:00 AEST.
Malaysia cohort: 16^{th} April 2025 23:55:00 MYT.

LATE SUBMISSION PENALTY: 5% penalty per day. Submissions more than 7 calendar days late will receive a score of 0. The lateness is measured in whole days, rounded up — for example, a submission that is 5 seconds late counts as 1 day late, and one that is 24 hours and 1 second late counts as 2 days late.

For special consideration, please visit the following page and fill out the appropriate form: `https://forms.monash.edu/special-consideration`.

The deadlines in this unit are strict, last minute submissions are at your own risk.

PROGRAMMING CRITERIA: It is required that you implement this exercise strictly using the **Python programming language** (version should not be earlier than 3.5). This practical work will be marked on the time complexity, space complexity and functionality of your program, and your documentation.

Your program will be tested using automated test scripts. It is therefore critically important that you name your files and functions as specified in this document. If you do not, it will make your submission difficult to mark, and you will be penalised.

SUBMISSION REQUIREMENT: You will submit a single Python file containing all of the questions you have answered, `assignment1.py`. Moodle will not accept submissions of other file types.

ACADEMIC INTEGRITY: The assignments will be checked for plagiarism and collusion using an advanced detector(s). In previous semesters, many students were detected and almost all got zero mark for the assignment (or even zero marks for the unit as penalty) and, as a result, the large majority of those students failed the unit. Helping others to solve the assignment is NOT ACCEPTED. Please do not share your solutions partially or completely to others. Even after the deadline, your solutions/approaches should not be shared before the grades and feedback are released by the teaching team. Using contents from the Internet, books etc without citing is plagiarism (if you use such content as part of your solution and properly cite it, it is not plagiarism; but you wouldn't be getting any marks that are possibly assigned for that part of the task as it is not your own work).

The use of generative AI and similar tools for the completion of your assignment is not allowed in this unit! In fact they often hallucinate bad solutions.

Learning Outcomes

This assignment achieves the Learning Outcomes of:

- Analyse general problem solving strategies and algorithmic paradigms, and apply them to solving new problems;
- Prove correctness of programs, analyse their space and time complexities;
- Compare and contrast various abstract data types and use them appropriately;
- Develop and implement algorithms to solve computational problems.

In addition, you will develop the following employability skills:

- Text comprehension.
- Designing test cases.
- Ability to follow specifications precisely.

Assignment timeline

In order to be successful in this assessment, the following steps are provided as a **suggestion**. This is an approach which will be useful to you both in future units, and in industry.

Planning

1. Read the assignment specification as soon as possible and write out a list of questions you have about it.
2. Try to resolve these questions by viewing the FAQ on Ed, or by thinking through the problems over time.
3. As soon as possible, start thinking about the problems in the assignment.
    - It is strongly recommended that you **do not** write code until you have a solid feeling for how the problem works and how you will solve it.
4. Writing down small examples and solving them by hand is an excellent tool for coming to a better understanding of the problem.
    - As you are doing this, you will also get a feel for the kinds of edge cases your code will have to deal with.
5. Write down a high-level description of the algorithm you will use.
6. Determine the complexity of your algorithm idea, ensuring it meets the requirements.

Implementing

1. Think of test cases that you can use to check if your algorithm works.
    - Use the edge cases you found during the previous phase to inspire your test cases.
    - It is also a good idea to generate large random test cases.
    - Sharing test cases **is** allowed, as it is not helping solve the assignment.
2. Code up your algorithm, and test it on the tests you have thought of.
3. Try to break your code. Think of what kinds of inputs you could be presented with which your code might not be able to handle.
    - Large inputs
    - Small inputs
    - Inputs with strange properties
    - What if everything is the same?
    - What if everything is different?
    - etc...

Before submission

- Make sure that the input/output format of your code matches the specification.
- Make sure your filenames match the specification.
- Make sure your functions are named correctly and take the correct inputs.
- Remove print statements and test code from the file you are going to submit.

Documentation

For this assignment (and all assignments in this unit) you are required to document and comment your code appropriately. Whilst part of the marks of each question are for documentation, there is a baseline level of documentation you must have in order for your code to receive marks. In other words:

Insufficient documentation might result in you getting 0 for the entire question for which it is insufficient.

This documentation/commenting must consist of (but is not limited to):

- For each function, high-level description of that function. This should be a two or three sentence explanation of what this function does.
- Your main function in the assignment should contain a generalised description of the approach your solution uses to solve the assignment task.
- For each function, specify what the input to the function is, and what output the function produces or returns (if appropriate).
- For each function, the appropriate Big-O or Big-Θ time and space complexity of that function, in terms of the input size. Make sure you specify what the variables involved in your complexity refer to. Remember that the complexity of a function includes the complexity of any function calls it makes.
- Within functions, add comments where appropriate. Generally speaking, you would comment complicated lines of code (which you should try to minimise) or a large block of code which performs a clear and distinct task (often blocks like this are good candidates to be their own functions!).

A suggested function documentation layout would be as follows:

```
def my_function(argv1, argv2):
    """
    Function description:

    Approach description (if main function):

    :Input:
        argv1:
        argv2:
    :Output, return or postcondition:
    :Time complexity:
   :Time complexity analysis:
    :Space complexity:
   :Space complexity analysis:
    """
    # Write your codes here.
```

There is a documentation guide available on Moodle in the Assignment section, which contains a demonstration of how to document code to the level required in the unit.

Warning

For all assignments in this unit, you may **not** use python **dictionaries** or **sets**. This is because the complexity requirements for the assignment are all deterministic worst-case requirements, and dictionaries/sets are based on hash tables, for which it is difficult to determine the deterministic worst-case behaviour.

Please ensure that you carefully check the complexity of each in-built python function and data structure that you use, as many of them make the complexities of your algorithms worse. Common examples which cause students to lose marks are **list slicing**, inserting or deleting elements **in the middle or front of a list** (linear time), using the `in` keyword to **check for membership** of an iterable (linear time), or building a string using **repeated concatenation** of characters. Note that use of these functions/techniques is **not forbidden**, however you should exercise care when using them.

Please be reasonable with your submissions and follow the coding practices you've been taught in prior units (for example, modularising functions, type hinting, appropriate spacing). While not an otherwise stated requirement, extremely inefficient or convoluted code will result in mark deductions.

These are just a few examples, so be careful. **Remember that you are responsible for the complexity of every line of code you write!**

1 Locomotion Commotion (10 marks, including 2 marks for documentation)

In this assignment, you are expected to develop and implement an efficient algorithm to determine the least cost path to intercept a moving passenger on a train loop.

You have a long-awaited reunion with your friend, who has just arrived in the city. They are a passionate train enthusiast and have decided to ride the city's newly built high-speed train loop. They are so excited about the ride that they refuse to exit the train unless you are at the train station. However, due to the high volume of passengers and the ongoing development of parking infrastructure, the city imposes strict pick-up times, where you are not allowed to stop and wait at any location. Therefore, in order to pick up your friend, you must simultaneously arrive/intercept them at some train station.

The city is organised into various locations connected by roads and a one-way high-speed train loop. To navigate effectively, you have obtained a city map which has two sub-maps: a detailed road map of the city and a train network map.

The road map

- There are two types of locations: regular locations or train stations. Whilst all train stations are locations, not all locations are regular locations.
- There are $|L|$ total locations in the city, denoted by ℓ_0 to $\ell_{|L|-1}$.
- Roads connect locations, and every road has a travel cost representing the expenses of travelling along the road such as fuel or tolls.
- Every road also has an associated travel time in minutes representing how long it takes to travel down the road.
- There are a total of $|R|$ roads shown in the map, from r_0 to $r_{|R|-1}$.
- All locations have at least one outgoing road to another location.

The train network map

- The train network consists of a single circular loop with one train travelling continuously in a designated direction.
- There are $|T|$ total train stations in the city but due to budget constraints the network designer could only create a maximum of 20 stations, thus $2 \leq |T| \leq 20$.
- All $|T|$ stations are included within the $|L|$ locations in the road map.
- Since it is a high-speed rail, the travel time between any two consecutive stations ranges between 1 minute to 5 minutes.
- The train only makes brief stops at each station to maximise the number of passengers it can transport throughout the day, effectively having no delay at each station.

You start to manually plan out a route to precisely intercept your friend as you know which station they will begin at and where you will begin driving from. However, as you proceed, you find the task quickly becomes complicated and tedious. To make matters worse, you find out that you actually find several city maps, representing different proposed versions of the road map and the train network throughout the new city's development. You are unsure which city map is the latest and current version and want to find an optimal route based on each one. You realise this has now turned into a complex problem that would take too long to manually do, so you turn to your algorithmic and coding prowess in hopes of getting out of this train-wreck of a situation.

Your goal is to develop an algorithm that determines how to intercept your friend at the **lowest possible cost** based on a given road map and train network map. The algorithm should return the total cost incurred and the sequence of locations you must traverse, beginning at your starting point and ending at the station where you intercept your friend.

1.1 Optimal Interception Planning

You must create a function in Python by considering how the optimal valid route along with the optimal pickup location can be calculated with the provided road and train network maps. The function should return the total cost of intercepting your friend, the total time spent driving, and the list of locations you have to drive through, doing so in a way that achieves the minimum possible total cost. If it is impossible to directly intercept your friend, the function should simply return `None`.

You will need to implement the function, `intercept(roads, stations, start, friendStart)`. This function accepts four arguments:

- `roads` is a list of roads where each road is represented as a tuple (ℓ_u, ℓ_v, c, t) where:
  - $\ell_u \in \{\ell_0, \ell_1, \ldots, \ell_{|L|-1}\}$ is the starting location of the road,
  - $\ell_v \in \{\ell_0, \ell_1, \ldots, \ell_{|L|-1}\}$ is the ending location of the road,
  - c is the positive integer cost of travelling down the road from ℓ_u to ℓ_v,
  - t is the time in minutes as a positive integer required to travel from ℓ_u to ℓ_v.

  Each road is a directed road meaning a road from ℓ_u to ℓ_v does not necessarily imply there is a road from ℓ_v to ℓ_u.

- `stations` is a list of train stations where each station is represented as a tuple (ℓ_{TS}, t) where:
  - $\ell_{TS} \in \{\ell_0, \ell_1, \ldots, \ell_{|L|-1}\}$ is a train station,
  - $t \in \{1, 2, 3, 4, 5\}$ is the time in minutes to travel from ℓ_{TS} to the next train station in the train loop,
  - the number of stations, $|T|$, will be bounded such that $2 \leq |T| \leq 20$.

  The tracks are provided in the order of the train loop, such that the train travels from `stations[i]` to `stations[i + 1]`. The final station, `stations[|T| - 1]`, would loop back to `stations[0]`.

- `start` $\in \{\ell_0, \ell_1, \ldots, \ell_{|L|-1}\}$ is the location from where you start the trip.
- `friendStart` $\in \{\ell_0, \ell_1, \ldots, \ell_{|L|-1}\}$ is the train station from where your friend starts their journey. It will always be referring to a valid train station in `stations`. You can assume that `friendStart` will always be different to `start`.

Both you and your friend start the journey simultaneously.

There can be multiple valid routes that will take you from `start` to a train station to intercept with your friend, however, your task is to find the route that **minimises the total cost**. In the event there are multiple such routes, the function must return the one with the **least amount of driving time** as the second criteria. In the event there are multiple routes with the same optimal cost and minimum driving time, return any of the possible routes.

Your function `intercept(roads, stations, start, friendStart)` should return a tuple `(totalCost, totalTime, route)` where:

- `totalCost` is the total cost of the journey along the optimal valid route. This should be a positive integer.
- `totalTime` is the total time driven of the journey along the optimal valid route. This should be a positive integer.
- `route` is the route you can use to drive from `start` to the train station you intercept your friend at. This should be a list of integers in the range of 0 to $|L| - 1$, that represent the locations you travel along the route, ending with the intercepting train station.

If it is impossible to intercept your friend, your function should return `None`.

1.2 Complexity

The function must run in $O(|R| \log |L|)$ time complexity and $O(|L| + |R|)$ auxiliary space complexity.

1.3 Examples

In this section we provide some examples for you to gain a better understanding of the intended behaviour and the output of `intercept(roads, stations, start, friendStart)` function.

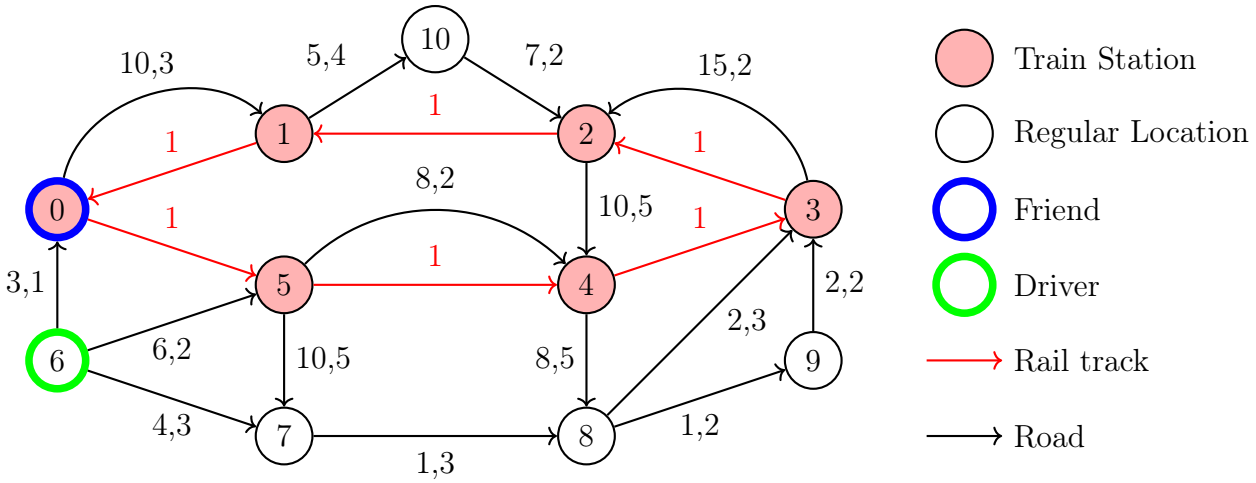
Note that this list is not exhaustive and passing the following examples does not imply your function is correct and within complexity.

Example 1: Simple

```
# Example 1, Simple

roads = [(6,0,3,1), (6,7,4,3), (6,5,6,2), (5,7,10,5), (4,8,8,5), (5,4,8,2),
(8,9,1,2), (7,8,1,3), (8,3,2,3), (1,10,5,4), (0,1,10,3), (10,2,7,2),
(3,2,15,2), (9,3,2,2), (2,4,10,5)]
stations = [(0,1), (5,1), (4,1), (3,1), (2,1), (1,1)]
start = 6
friendStart = 0
>>> intercept(roads, stations, start, friendStart)
(7, 9, [6,7,8,3])
```

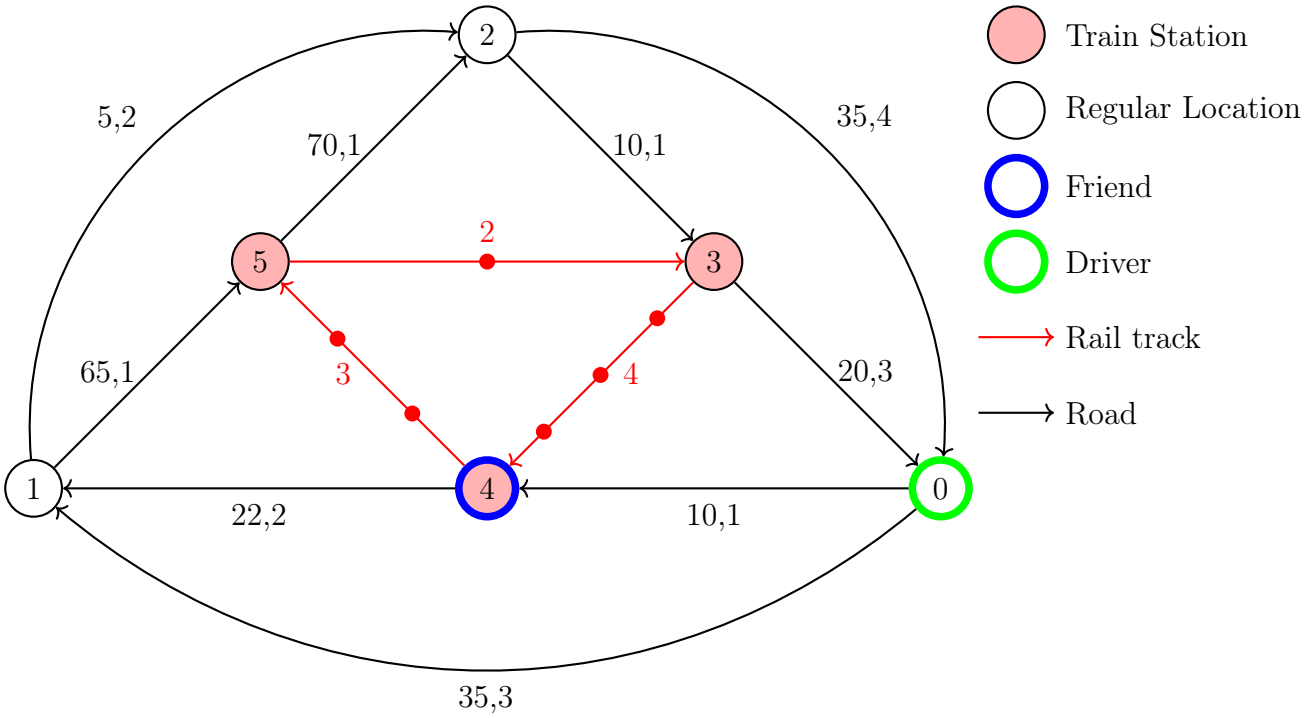
Your friend begins at location 0 and you begin at location 6. Notice, if you choose to move to location 7, 3 minutes would have passed and your friend would have appropriately moved 3 minutes forward, going from station 0 to station 5, then to station 4, and then finally having arrived at station 3. Alternatively, you could go to location 0, but since this takes 1 minute, your friend moves to location 5, therefore, you have missed them. Since you cannot wait at a location, you must then move to location 1. There is a possible interception route of $6 \to 0 \to 1 \to 10 \to 2$ with a cost of 25 but this is a larger cost than the optimal route of $6 \to 7 \to 8 \to 3$ which has a cost of 7.

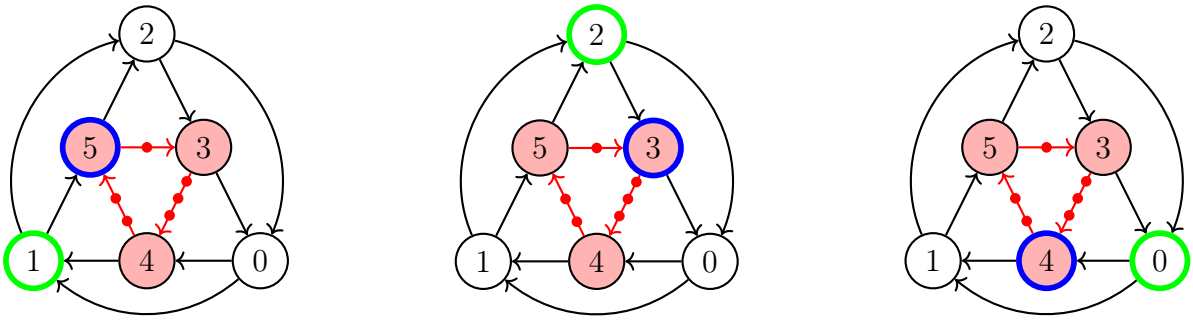


Example 2: Unsolvable

```
# Example 2, Unsolvable
roads = [(0,1,35,3), (1,2,5,2), (2,0,35,4), (0,4,10,1), (4,1,22,2),
(1,5,65,1), (5,2,70,1), (2,3,10,1), (3,0,20,3)]
stations = [(4,3), (5,2), (3,4)]
start = 0
friendStart = 4
>>> intercept(roads, stations, start, friendStart)
None
```

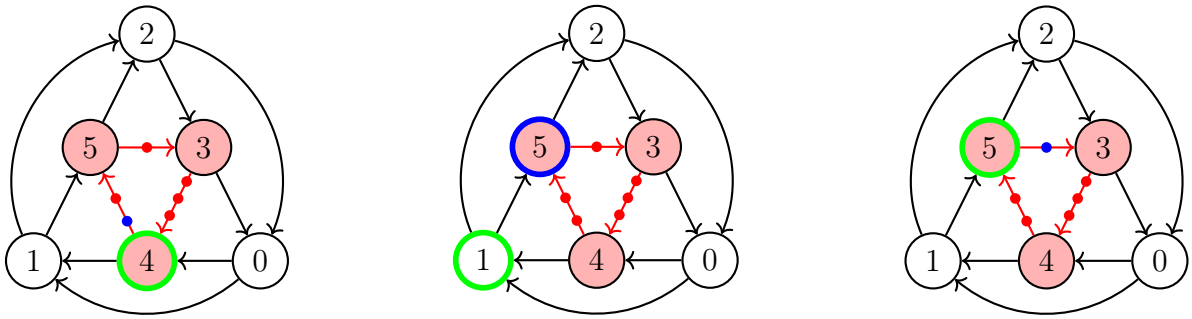
In the following example there is no way to reach your friend. Notice that each time you travel in the outer most ring, your friend also progresses to the next station. So if you travel from location 0 to location 1, your friend travels from location 4 to location 5. This pattern is highlighted in Figure 1. Anytime you attempt to intercept at a station, 1 minute passes and your friend will be ahead of you along the train track. This is shown visually where the red dots along the trail tracks represent where your friend could be along the track. This is just because when you travel to an adjacent location, your friend will not always necessarily be at a train station. The blue highlighted dot on the track just represents where your friend currently is part way along a track. Returning back to the example, after attempting to intercept and then travelling back to the outer ring "resets" the state as if you remained there. For example, travelling from location 0 to location 4, your friend is now slightly ahead. Then travelling from location 4 to location 1, your friend is now at location 5, which gives you the exact same state as if you just travelled directly to 1 from 0. This is highlighted in Figure 2.





Cost = 35, Time = 3 Cost = 40, Time = 5 Cost = 75, Time = 9

Figure 1: Simulated path following outer loop of Example 2



Cost = 10, Time = 1 Cost = 32, Time = 3 Cost = 97, Time = 4

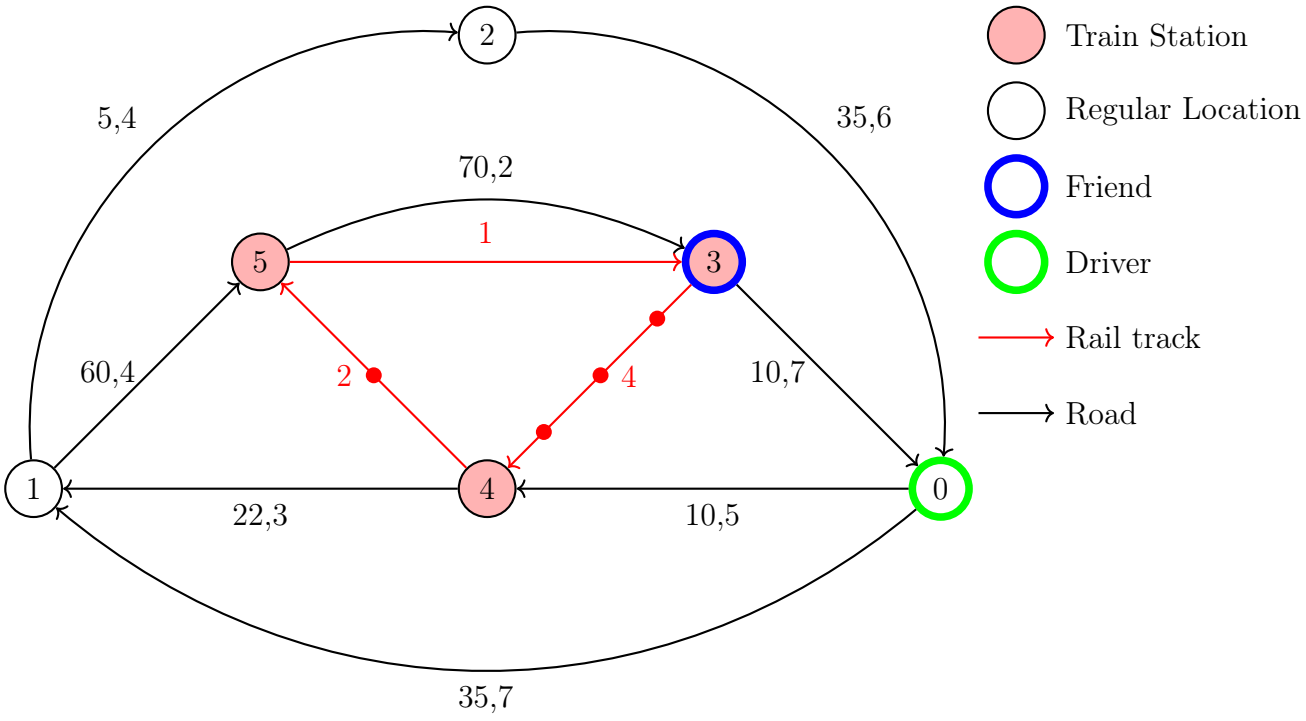
Figure 2: Simulated path attempting to intercept at station of Example 2

Example 3: Repeated Locations

```
# Example 3, Repeated Locations

roads = [(0,1,35,7), (1,2,5,4), (2,0,35,6), (0,4,10,5), (4,1,22,3),
(1,5,60,4), (5,3,70,2), (3,0,10,7)]
stations = [(4,2), (5,1), (3,4)]
start = 0
friendStart = 3
>>> intercept(roads, stations, start, friendStart)
(160, 39, [0,1,2,0,1,2,0,4])
```

In this example, the optimal solution requires you to revisit a location multiple times. Notice in this example, the first time you visit a location, attempting to go to an adjacent station would result in missing your friend and therefore not intercepting them. There is a route $0 \to 4 \to 1 \to 5 \to 3$ with a cost of 162 but this is a larger cost than the optimal route of $0 \to 1 \to 2 \to 0 \to 1 \to 2 \to 0 \to 4$ with a cost of 160.



Example 4: Same Cost, Different Time

```
# Example 4, Multiple routes with same cost but different total time

roads = [(0,1,10,7), (0,2,10,3), (2,0,1,4), (1,0,1,7)]
stations = [(2,4), (1,3)]
start = 0
friendStart = 1
>>> intercept(roads, stations, start, friendStart)
(10, 3, [0,2])
```

In this example, there are two possible interceptions with the same cost, $0 \to 1$ and $0 \to 2$. The latter will produce a path has a lower overall driving time.