Project 2: Dynamic programming

COT 4400, Fall 2022

Due November 11, 2022

1 Overview

For this project, you will develop two algorithms to evaluate the cost to produce two kinds of products. Designing and implementing these algorithms will require you to model the problem using dynamic programming, then understand and implement your model.

You are only allowed to consult the class slides, the textbook, the TAs, and the professor. In particular, you are not allowed to use the Internet. This is a group project. The only people you can work with on this project are your group members. This policy is strictly enforced.

In addition to the group submission, you will also evaluate your teammates' cooperation and contribution. These evaluations will form a major part of your grade on this project, so be sure that you respond to messages promptly, communicate effectively, and contribute substantially to your group's solution. Details for your team evaluations are in Section 9.2. You will submit the peer evaluations to another assignment on Canvas, labelled "Project 2 (peer evaluation)."

A word of warning: this project is team-based, but it is quite extensive and a nontrivial task. You are highly encouraged to start working on (and start asking questions about) this project early; teams who wait to start until the week before the due date may find themselves unable to complete it in time.

2 Problem Description

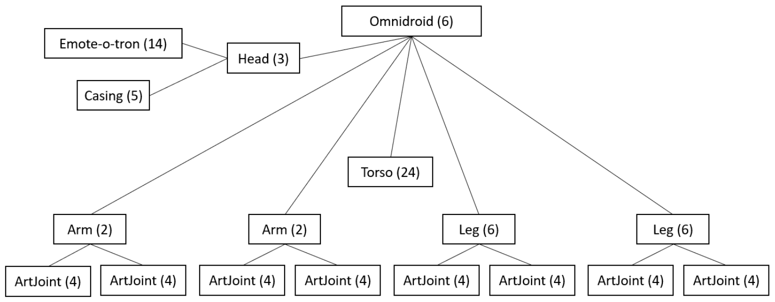
For this project, you will be given an input file describing how to assemble one of two different kinds of robots, omnidroids and robotomata, and all of the intermediate products required to construct them, and you will need to compute the total cost required to make them.

3 Constructing robotomata

The schematic for building an omnidroid will include a list of parts that need to be combined to assemble the omnidroid as well as the number of *sprockets* required to attach that part. *Sprockets* represent the main material component of robots, and the cost for a robot should be computed in terms of sprockets used. Parts for omnidroids come in two varieties, *basic* and *intermediate*. *Basic* parts of constructed by combining together some number of sprockets in the correct configuration, whereas *intermediate* parts are constructed via their own assembly process, where other basic and/or intermediate parts are attached to the construct via sprockets.

For example, omnidroid model T9001 is constructed by combining a head assembly, torso assembly, and two arm assemblies, and two leg assemblies using 6 sprockets. Head assemblies are constructed by combining an Emote-o-tron computer (14 sprockets) and skull casing (5 sprockets) using 3 sprockets. The torso is a basic part constructed from 22 sprockets. Arms and legs are built from two articulating joint assemblies (4 sprocket each), using 2 sprockets for arms and 6 sprockets for legs. In total, each T9001 omnidroid is built from 100 sprockets.

A diagram describing how to build the omnidroids appears below:

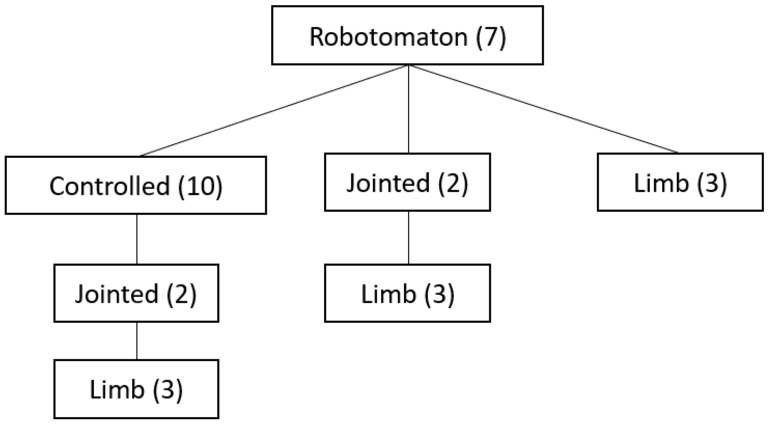


4 Constructing robotomata

The schematic for building a robotomaton is a much more constrained version of an omnidroid. Robotomata are constructed on an conveyor belt where the belt will carry a supply of sprockets and the intermediate parts required to construct them. The intermediate parts required to build a robotomaton are arranged on the belt so that each part can be constructed from the parts immediately in front of it on the belt, plus some number of sprockets. Unlike the omnidroids, parts used to construct a robotomaton will not require multiples of the same part; they only need some number of the parts immediately before them on the belt, with no gaps or duplicates.

For example, robotomaton model R4096 is built in 4 stages. In stage 1, 3 sprockets are fashioned into limbs, and in stage 2, these limbs are combined with 2 more sprockets into jointed limbs. In stage 3, 10 sprockets are used to add a control system to jointed limbs. In stage 4, limbs produced in stages 2 and 3 are combined together using the basic limbs produced in stage 1 and 7 sprockets into the finished robotomaton (uses all 3 previous stages). In total, each R4096 robotomaton is built from 30 sprockets.

A diagram illustrating how to build this robotomaton appears below:



5 Input format

Your program should read its input from the file `input.txt`, in the following format. The first line of the file contains an integer indicating the number of robots defined in the file, and the rest of the file will describe the requirements for those robots. Each robot's requirements will be separated by a blank line (including a blank line between the number of robots and the first robot's requirements). Further, the first line of each robot's requirements will be the string "omnidroid" or "robotomaton", indicating the kind of robot being built.

5.1 Omnidroids

For an omnidroid, the second line of the robot specification will have two positive integers n and m, indicating the number of parts in the assembly and the number of assembly dependencies, respectively. The next m lines will have two nonnegative integers i and j, representing that part i is used in the assembly of part j. For convenience, the parts are numbered 0 to $n-1$ instead of being identified by names like "Emote-o-tron", with part $n-1$ representing the finished omnidroid. Every intermediate part will appear as the second entry in at least one line, while basic parts will not appear as the second entry in a line. The n lines following the part dependencies will have a single integer indicating how many sprockets are used to create an omnidroid part outside of any other parts used in the construction (in order, part 0 to part $n-1$).

For example, if we label the 8 parts used the omnidroid T9001 as: 0 articulated joint, 1 arm assembly, 2 leg assembly, 3 torso, 4 Emote-o-tron, 5 skull casing, 6 head assembly, and 7 omnidroid, the input for T9001 would be as follows:

```
omnidroid
8 12
0 1
0 1
0 2
0 2
4 6
5 6
1 7
1 7
2 7
2 7
3 7
6 7
4
2
6
24
14
5
3
6
```

Note: as in this example, the same part may be used multiple times in the construction of another part. Also (not shown in this example), parts with larger ID values may be used as inputs to parts with smaller ID values. You may assume the assembly instructions will never be impossible to satisfy (e.g., part 1 is constructed from part 2, which is constructed from part 1), and the overall omnidroid (ID $n - 1$) will not be used to build any other part.

5.2 Robotomaton

For a robotomaton, the second line will have a positive integer n representing the number of stages in the construction (with the last stage being the completed robotomaton). The following n lines will have two nonnegative integers, s and p, representing the number of sprockets needed for this stage and the number of previous stages that are used to assemble this stage. You may assume that the number of previous stages needed will never exceed the number of previous stages defined.

For example, the input file below would represent the requirements to construct robotomaton R4096:

```
robotomaton
4
3 0
2 1
10 1
7 3
```

5.3 Output

Your program should write its output to the file `output.txt`. For each problem, your program should output the total number of sprockets needed for each robot, one answer per line, in the order the robots were defined in the input file. For example, if the input file described omnidroid T9001 and robotomaton R4096, the output file should contain:

```
100
30
```

Implementation note: when solving these robot construction problems, the number of sprockets used to construct a robot may exceed 2^{32}, but it will be less than 2^{64}. All of the numbers in the input files will be smaller than 2^{32}.

6 Modelling the problem recursively

In order to write a dynamic programming algorithm for this problem, you will need to develop recurrence to solve both versions of the problem. I recommend that you start by developing a recurrence to solve the omnidroid construction problem first. Be sure that your solution to this problem is based on a recursive algorithm with repeating subproblems; other algorithms for solving the problems will likely receive less credit.

For the robotomaton construction problem, I recommend using the omnidroid construction algorithm as a baseline. However, you should consider how to take advantage of the structure of the robotomaton construction problem to improve the complexity of your algorithm relative to a naïve implementation of the omnidroid algorithm. For full credit, your algorithm for robotomata should be more efficient than applying an omnidroid algorithm to the robotomaton construction requirements.

7 Project report

In your project report, you should include brief answers to 9 questions. Note that you must use dynamic programming to solve this problem; other solutions will not receive substantial credit.

1. How you can break down a problem instance of the omnidroid construction problem into one or more smaller instances? You may use $sprocket[t]$ to represent the number of sprockets used for part t, and you may use $req[t]$ and $use[t]$ to represent the collection of all parts required to build part t and all parts that part t is used to build, respectively. Your answer should include how the solution to the original problem is constructed from the subproblems.
2. What is the base cases of the omnidroid construction problem?
3. How you can break down a problem instance of robotomaton construction problem into one or more smaller instances? You should assume that you are given *sprocket* and *previous* arrays that indicate the number of sprockets required for each stage of construction and the number of previous stages used to construct a particular part. Your answer should include how the solution to the subproblems are combined together to solve the original problem.
4. What are the base cases of the robotomaton construction problem?
5. What data structure would you use to recognize repeated problems for each problem (two answers)? You should describe both the abstract data structures, as well as their implementations.
6. Give pseudocode for a memoized dynamic programming algorithm to calculate the sprockets needed to construct an omnidroid.
7. What is the *worst-case* time complexity of your memoized algorithm for the omnidroid construction problem?
8. Give pseudocode for a memoized dynamic programming algorithm to calculate the sprockets needed to construct a robotomaton.
9. Give pseudocode for an iterative algorithm to calculate the sprockets needed to construct a robotomaton. This algorithm does not need to have a reduced space complexity, but it should have asymptotically optimal time complexity.

8 Coding your solutions

In addition to the report, you should implement a dynamic programming algorithms that can find the number of sprockets used in omnidroids and robotomata. Your code may be iterative or recursive, but both solutions must use dynamic programming. Also, you may code your solution in C++ or Java, but it must compile and run in a Linux environment. If you are using C++ and compiling your code cannot be accomplished by the command

```
g++ -o robot *.cpp
```

you should include a Makefile that is capable of compiling the code via the `make` command.

If you choose to implement your code in Java, you should submit an executable jar file with your source. In either case, your source code may be split into any number of files.

Your code will not need to handle invalid input (e.g., omnidroid requirements that include invalid part IDs or robotomaton stages that require more previous stages than have been defined).

9 Submission

Your submission for this project will be in two parts, the group submission and your individual peer evaluations.

9.1 Group submission

The submission for your group should be a zip archive containing 1) your report (described in Section 7) as a PDF document, and 2) your code (described in Section 8). If your code requires more than a simple command to compile and run then you must also provide a Makefile and/or shell script. You should submit this zip archive to the "Project 2 (group)" assignment on Canvas.

Be aware that your project report and code will be checked for plagiarism.

9.2 Teamwork evaluation

The second part of your project grade will be determined by a peer evaluation. Your peer evaluation should be a text file that includes 1) the names of all of your teammates (including yourself), 2) the team member responsibilities, 3) whether or not your teammates were cooperative, 4) a numeric rating indicating the proportional amount of effort each of you put into the project, and 5) other issues we should be aware of when evaluating your and your teammates' relative contribution. The numeric ratings must be integers that sum to 30.

It's important that you be honest in your evaluation of your peers. In addition to letting your team members whether they do (or do not) need to work on their teamwork and communication skills, we will also evaluate your group submission in light of your team evaluations. For example, a team in which one member refused to contribute would be assessed differently than a team with three functioning members.

You should submit your peer evaluation to the "Project 2 (individual)" assignment on Canvas.

10 Grading

Report	**40 points**
Questions 1 and 3	9 each
Questions 6 and 9	5 each
Question 8	4
Questions 2, 4, 5, and 7	2 each
Code	**30 points**
Compiles	5
Uses correct input and output format	5
Computes correct answer	15
Good coding style	5
Teamwork	**30 points**

Note that if your algorithms are inefficient, you may lose points for both your pseudocode and your submission. Also, in extreme cases, the teamwork portion of your grade may become negative or greater than 30. In particular, if you do not contribute to your group's solution at all, you can expect to receive an overall grade of 0 on the project.