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Book Scanning

Artificial Intelligence

2020/2021

3MIEIC02

01/04/2021

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Project Specification

Input file	Description
6 2 7	There are 6 books, 2 libraries, and 7 days for scanning.
1 2 3 6 5 4	The scores of the books are 1, 2, 3, 6, 5, 4 (in order).
5 2 2	Library 0 has 5 books, the signup process takes 2 days, and the library can ship 2 books per day.
0 1 2 3 4	The books in library 0 are: book 0, book 1, book 2, book 3, and book 4.
4 3 1	Library 1 has 4 books, the signup process takes 3 days, and the library can ship 1 book per day.
3 2 5 0	The books in library 1 are: book 3, book 2, book 5 and book 0.

Figure 1. Example of a input data set

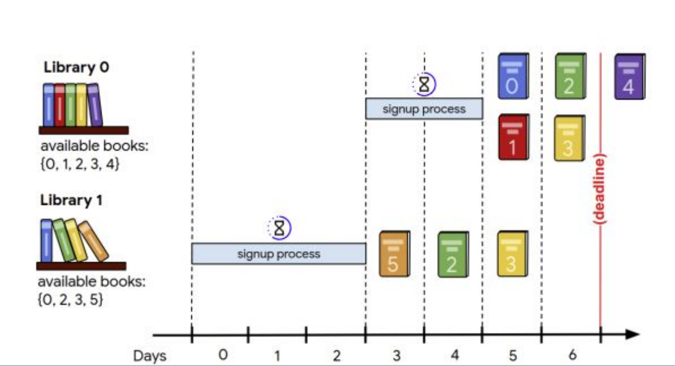


Figure 2. Based on the input data set of Figure 1, books 0, 1, 2, 3, and 5 are scanned by Day 6, and the total score is 16.

This project consists of solving an optimization problem: book scanning.
Given a description of a set of libraries (L) and books available (B), there is the need to plan which books to scan from which library to maximize the total score of all scanned books, taking into account that each library needs to be signed up before it can ship books and all books must be scanned within D days.

Read all the information about this problem in
https://storage.googleapis.com/coding-competitions.appspot.com/HC/2020/hashcode_2020_online_qualification_round.pdf

Formulation of the optimization problem

Solution Representation

The solution describes which books to ship from which library and the order in which libraries are signed up. In the output files, the first line contains the number of libraries to sign up and the following lines describe the libraries in the order to be signed up in two lines each - the first line containing the library id and the number of books sent, the second line containing the IDs of the books to scan from the library.

Rigid Constraints

- Many libraries can have a copy of the same book, but we only need to scan each book once;
- If the same book is shipped from multiple libraries, the solution will be accepted but the score for the book will be awarded only once;
- Only one library at a time can be going through the signing process;
- Each library must be described only once;
- You don't need to scan all books from a library you describe;
- If a library signup process finishes after D days, its description will be ignored;
- Books shipped after D days will be ignored;
- the signup process for a library can start only when no other signup processes are running;
- The libraries can be signed up in any order.

Evaluation Function

```python
def calculate_total_score(books_dict, scores):
    all_books = set()
    for id in books_dict:
        all_books.update(books_dict[id])
    return score(list(all_books), scores)
```

The evaluation function iterates through the library books saving them on a set (to eliminate the duplicate books) and then add the score of all those books producing the library score.

Neighborhood Function

```python
def find_best_neighbour(choosen_libraries, choosen_books, libraries, scores, n_days):
    best_score = calculate_total_score(choosen_books, scores)
    best_libraries = copy.deepcopy(choosen_libraries)
    best_books = copy.deepcopy(choosen_books)
    found_better = False

    for current_lib in choosen_libraries:
        day = 0
        new_list = []
        scanned_books_dict = dict()
        scanned_books_set = set()
        all_libraries = copy.deepcopy(libraries)
        for lib in choosen_libraries:
            if lib == current_lib:
                all_libraries.remove(lib)
                break
            else:
                new_list.append(lib)
                scanned_books_dict[lib.id] = lib.get_books(n_days-day)
                scanned_books_set.update(scanned_books_dict[lib.id])
                all_libraries.remove(lib)
                day += lib.signup_days


        while day < n_days and len(all_libraries) > 0:
            id = choose_best_score(n_days - day, all_libraries, scores, scanned_books_set)
            if id == -1:
                break
            for lib in all_libraries:
                if lib.id == id:
                    scanned_books_dict[lib.id] = lib.get_books(n_days-day)
                    scanned_books_set.update(scanned_books_dict[lib.id])
                    new_list.append(lib)
                    day += lib.signup_days
                    all_libraries.remove(lib)

        new_score = calculate_total_score(scanned_books_dict, scores)
        if new_score > best_score:
            found_better = True
            best_libraries = copy.deepcopy(new_list)
            best_books = copy.deepcopy(scanned_books_dict)
            best_score = new_score
            print("better!")
        else:
            print("not better :(")

    return found_better, best_libraries, best_books, best_score
```

```python
if new_score > best_score:
    found_better = True
    best_libraries = copy.deepcopy(new_list)
    best_books = copy.deepcopy(scanned_books_dict)
    best_score = new_score
    print("better!")
    return found_better, best_libraries, best_books, best_score
```

The find_first_neighbour function is the same as the find_best_neighbour, simply returning the first better neighbour it encounters.

Progress so far ...

The project is being developed in Python 3, with a text interface.
The development environment is Visual Studio Code.
For the most part of the project, the data structures used are arrays, sets, lists and classes.
The structure of the files is:

- src: where the source code is located;
- input: where all the libraries data is stored;
- output: where the output files of the program are stored;
- docs: where the documents are kept, such as this document.

At this point, it was implemented a greedy algorithm to find the solution.
The program has to be run with a single argument, specifying the input file where the libraries data is stored (for example, running the command *python bookscanning.py a_example.txt*).

So far, the best results for each file are:

File name	Total score
a_example.txt	21
b_read_on.txt	5 822 900
c_incunabula.txt	5 689 822
d_tough_choices.txt	5 028 530
e_so_many_books.txt	4 212 457
f_libraries_of_the_world.txt	5 283 965
Total	26 037 695

Approach

Evaluation function:

```
def score(books, scores):
    return sum([scores[b] for b in books])
```

It receives the scanned books and the map of the books to the respective scores and calculates the total score.

Heuristic:

This function iterates through all libraries, calculates their score if all the books were to be scanned and divides these scores for the number of days that it takes for the library to be signed up. If this heuristic is better than the previous library, it replaces the best with the new one, returning the best of all libraries.

```
def choose_best_score(days, libraries, scores, scanned_books):
    best_score = 0
    best_books = []
    best_lib = None
    for library in libraries:
        if library.signup_days > days: continue
        books = library.get_books(days, scanned_books)
        s = score(books, scores) /library.signup_days
        if s > best_score:
            best_lib = library.id
            best_score = s
            best_books = books

    if best_lib == None:
        return -1, best_books

    return best_lib, best_books
```

Implemented algorithms

Greedy: Starting with an empty solution, while there are still left days, it chooses the best library at the moment, that has not been signed yet, and adds it to the final solution.

Local Search:

- **First neighbour** - based on basic "hill climbing", generates neighbours until it finds a better evaluated one and applies it. The algorithm stops when no better neighbours are found;
- **Best neighbour** - based on "steepest ascent", generates all neighbours and applies the best-evaluated one. The algorithm stops when no better neighbours are found;
- **Random neighbour** - from a known solution, it generates a random neighbour solution.

Simulated Annealing: Starting with a high temperature (100) and using an exponential cooling function, chooses a random neighbour and accepts it if it is an improving move or if it is a deteriorating move with some probability.

Genetic algorithm: Based on the mechanics of biological evolution, a random initial population is generated and the solutions.

Experimental results

File	Best Score	Algorithm used
a_example	21	Greedy
b_read_on	5 822 900	Greedy
c_incunabula	5 690 054	Random Neighbor
d_tough_choices	5 028 530	Greedy
e_so_many_books	5 037 291	Genetic
f_libraries_of_the_world	5 329 948	Simulated annealing using heuristic

For the overall files, the greedy approach was found to be the best one, because there was not a huge variation in solutions and its implementation is very optimized taking into consideration the problem restrictions. Hence, when starting the local search algorithms with a random solution instead of a greedy solution, the scores reached wouldn't even get closed to the ones starting with greedy.

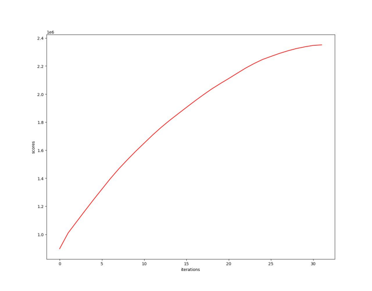
For the c and d files, since the initial input of libraries and the number of days were so big that made all search really slow and very hard to get results without taking a big amount of time to obtain them.

Most of the search algorithm implementations use our heuristic in order to optimize even more the choice made.

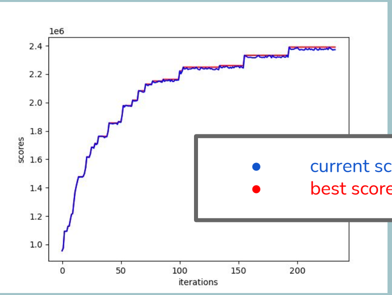
Experimental results *(cont.)*

using e_so_many_books.txt file as input, starting with a randomly generated solution

Local search evolution

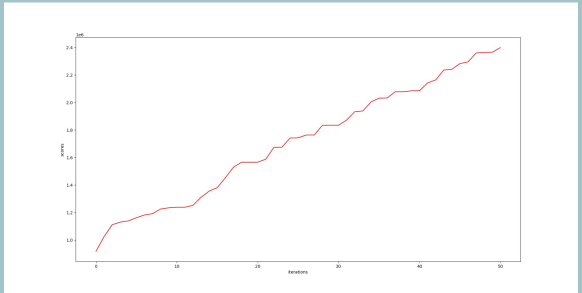


find_best_neighbor



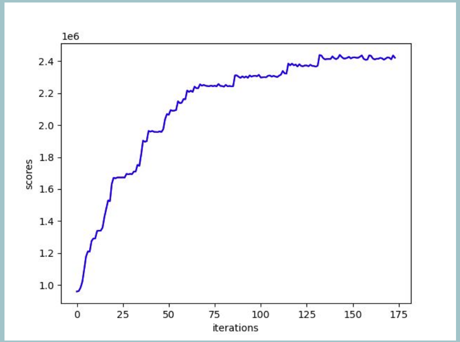
current score
best score

find_random_neighbor

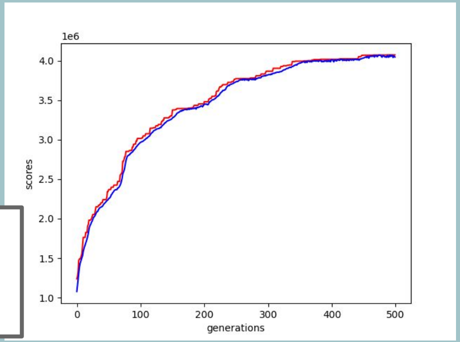


find_first_neighbor

Simulated annealing evolution



Genetic algorithm evolution



average population score
best score in population

Conclusions

The biggest challenge of this project was trying to make the runtime of the algorithms as acceptable as possible, whereas the amount of data of some input files were quite big making it a difficult computational task.

We implemented all algorithms presented during these course’s lessons. However, after a battery of tests, we narrowed our chosen algorithms to the ones that were found to be more relevant and improved the final scores.

We want to emphasize some important improvements we made to the algorithms that significantly improved the scores:

- in the **heuristic function**, we restrained the libraries from sending repeated books;
- in the **crossover function**, we switched from a single point crossover to a linear order crossover technique.

References and materials used

As this project consists of a hashcode qualification problem, the research made lead us to articles about the implemented solutions by some of the teams:

- https://medium.com/@kevinjohn1999/how-we-achieved-a-98-27-of-the-best-score-at-google-hashcode-2020-94314a904190
- https://towardsdatascience.com/google-hash-code-2020-a-greedy-approach-2dd4587b6033

Related topics:

- https://www.geeksforgeeks.org/0-1-knapsack-problem-dp-10/
- https://www.sciencedirect.com/topics/computer-science/local-search-algorithm

Annex

If the algorithms do not find a better solution, they return the initial solution.

The times for all algorithms beside greedy are only of the algorithm without the generation of the initial solution.

Labels

ps - population size
g - generations
mp - mutation prob
sp - swap prob
pv - population variation

	Greedy	First neighbor	Best neighbor	Random neighbor	Simulated annealing w/ heuristic	Simulated annealing wo/ heuristic	Genetic	Genetics params
a_example.txt	**21**	21	21	21	21	21	---	---
	00:00:00	0:00:00.003001	0:00:00.003994	0:00:00.010048	0:00:00.363199	0:00:00.361562	---	
b_read_on.txt	**5822900**	5822900	5822900	5822900	5822900	5822900	5822900	50 1000 0.2 0.2 0.2
	0:00:00.472789	0:00:01.054852	0:00:00.987204	0:00:00.328252	0:00:08.352748	0:00:04.563797	0:00:08.785825	
c_incunabula.txt	5689822	5689822	5689822	**5690054**	5689822	5689822	5689822	10 10 0.05 0.05 0.01
	0:01:00.857248			0:07:01.999125				
d_tough_choices.txt	**5028530**	5028530	5028530	5028530	5028530	5028530	5028530	10 10 0.05 0.05 0.001
	0:21:55.779328						0:19:39.209910	
e_so_many_books.txt	5034888	5035273	5035457	5035031	5034888	5034888	**5037291**	20 500 0.2 0.2 0.2
	0:00:14.194703	0:00:02.568339	0:00:08.783084	0:00:00.436051	0:00:14.464738	0:00:06.177446	0:11:07.193176	
f_libraries_of_the_world.txt	5308034	5308034	5308034	5308034	**5329948**	5308034	5308034	20 100 0.2 0.2 0.2
	0:00:02.332154	0:00:02.694138	0:00:00.462567	0:00:00.889916	0:00:17.215107	0:00:09.768772	0:00:44.930076	