Combinatorial Optimization labolatory

Artificial Intelligence 2021 sem. 3

labolatory

Library Book Assignment

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Requirements

python version 3.7.6

numpy 1.18.5

ortools Version: 8.1.8487

Implementation

Note: in this notebook program read from list of files to show scores on the example input files. Program itself read from standard input.

In [1]:
```
import numpy as np
import matplotlib.pyplot as plt
import time
import random
from math import sqrt
import copy

# Max flow Max cost solver
from ortools.graph import pywrapgraph
```

Library class definition

Every library has its id, size, signup_time, books_pre_day (how many libraries a day it can scan) and a set of book_ids. We chose a set to efficiently remove previously chosen books.

In [2]:
```python
class Library:
    def __init__(self, index, N, T, M):
        self.id = index
        self.size = N
        self.signup_time = T
        self.books_per_day = M
        self.book_ids = set()

    def add_book(self, book):
        self.book_ids.add(book)

    def remove_book(self, book):
        self.book_ids.remove(book)

    def __str__(self):
        return str(self.__class__) + ": " + str(self.__dict__)
```

Reading a file

Except from reading book values and library data with book assignments, we also have a table with sets of library_ids for eevery book. So that in how many libraries book is stored, and so we can quickly update it in our greedy interval solver.

In [3]:
```python
# Loads data from files into the class Library Objects
def process_file(filePath):
    with open('../data/'+filePath, 'r') as file:
        content = file.read().split('\n')[:-1]
        B, L, D = content[0].split()
        B, L, D = int(B), int(L), int(D)

    book_libraries = [set() for i in range(0, B)]
    book_values = [int(n) for n in content[1].split()]
    libraries = []

    for i in range(L):
        N, T, M = content[2 + 2 * i].split()
        N, T, M = int(N), int(T), int(M)
        book_ids = set(int(id_) for id_ in content[2 + 2 * i + 1].split())
        library = Library(i, N, T, M)

        for book_id in book_ids:
            book_libraries[book_id].add(i)
            library.add_book(book_id)
        libraries.append(library)
    return (B, L, D), book_values, book_libraries, libraries
```

Terminology

individual - a tuple of ordered ids

solution - a list of libraries with correctly assigned books

Scoring

scoring function simply sums up scores fo books in every library

In [4]:
```python
def score_solution(libraries, book_values):
    score = 0
    for library in libraries:
        for book_id in library.book_ids:
            score += book_values[book_id]
    return score
```

Check function

this function checks if generated sollution is valid:

- no library duplicated
- no book duplicates in library
- if number of books is correct
- if no library is signued up after the deadline

In [5]:
```python
def check_solution(D, libraries):
    days = 0
    prev_books = set()
    lib_ids = [lib.id for lib in libraries]
    # checking if there are no duplicates of libraries in the solution
    assert (len(lib_ids) == len(set(lib_ids)))

    for library in libraries:
        days += library.signup_time

        # checking if library sends correct number of books
        if len(library.book_ids) > (D - days) * library.books_per_day:
            print("Library sends more books, than it is allowed to:", len(library.book_ids),
                  (D - days) * library.books_per_day)

        # checking if there is no repetition of books
        assert (len(library.book_ids) == len(set(library.book_ids)))
        assert (not any([(book in prev_books) for book in library.book_ids]))
        prev_books.update(library.book_ids)

    # checking if we do not go over the deadline
    assert (days < D)
```

In [6]:
```python
def save_solution_to_file(solution, file_path, flag=False):
```

```python
    lines = [str(len(solution)) + "\n"]
    for library in solution:
        lines.append(f"{str(library.id)} {len(library.book_ids)}\n")
        aString = ""
        for book_id in library.book_ids:
            aString += f"{str(book_id)} "
        aString = aString.strip() + "\n"
        lines.append(aString)
    if flag:
        with open(file_path, "w+") as file:
            file.flush()
            file.writelines(lines)
    else:
        with open(f"{str(file_path[:-4])}_solution.txt", "w+") as file:
            file.flush()
            file.writelines(lines)
```

Problem Solver

It is an bastract class of almost every solver that we use. It has already defined get_solution function which transforms individual into solution. It does so by assignint best books from library than were not chosen before.

In [7]:

```python
class ProblemSolver:
    def __init__(self, B, L, D, book_values, book_libraries, libraries):
        self.B, self.L, self.D = B, L, D
        self.book_values = book_values
        self.libraries = libraries
        self.book_libraries = copy.deepcopy(book_libraries)

    def book_score(self, book):
        return self.book_values[book]

    def get_n_best_books(self, lib, n):
        return sorted(lib.book_ids, key=self.book_score, reverse=True)[:n]

    def get_solution(self, selected_lib_ids=None):
        if not selected_lib_ids:
            selected_lib_ids = self.get_individual()
        day = 0
        selected_libraries = [copy.deepcopy(self.libraries[i]) for i in selected_lib_ids]
        it = 0
        already_scanned_books = set()
        while it < len(selected_libraries):
            next_library = selected_libraries[it]
            day += next_library.signup_time
            if day >= self.D:
                break
            next_library.book_ids = next_library.book_ids - already_scanned_books
            next_library.book_ids = sorted(next_library.book_ids, key=self.book_score, reverse=True)[
```

```
                                    :(self.D - day) * next_library.books_per_day]
            already_scanned_books.update(next_library.book_ids)
            it += 1
        return selected_libraries[:it]

    def get_individual(self):
        pass
```

Heurystic Solver

An abstract class than defines a way than every heurystic solver creates an individual. It does so by sorting libraries according to its heurystic and chossing best one till there is no library that can fit in the time left. Default heuristic function is f = S/signup_time

Terminology for heurystic solvers

- S - sum of best books
- signup_time - library signup time
- var(S) - variance of S
- book_score - book score
- book_libraries - number of libraries that have a book
- D number of days *n length of N best books

In [8]:

```
class HeuristicSolver(ProblemSolver):
    def library_score(self, lib_id):
        lib = self.libraries[lib_id]
        delta_time = self.D - lib.signup_time
        n_best_books = self.get_n_best_books(lib, delta_time * lib.books_per_day)
        sum_of_best_book_scores = sum([self.book_values[book] for book in n_best_books])
        return sum_of_best_book_scores / lib.signup_time

    def get_individual(self):
        lib_ids = [i for i in range(len(self.libraries))]
        lib_ids.sort(key=self.library_score, reverse=True)
        day = 0
        chosen = []
        for i in range(len(lib_ids)):
            if day + self.libraries[lib_ids[i]].signup_time >= self.D:
                continue
            day += self.libraries[lib_ids[i]].signup_time
            chosen.append(lib_ids[i])
        return tuple(chosen)
```

Power Solver

Heurystic solver with a given function f = S/(signup_time)^(1+signup_time/D)

In [9]:
```python
class PowerSolver(HeuristicSolver):
    def library_score(self, lib_id):
        lib = self.libraries[lib_id]
        delta_time = self.D - lib.signup_time
        n_best_books = self.get_n_best_books(lib, delta_time * lib.books_per_day)
        sum_of_best_book_scores = sum([self.book_values[book] for book in n_best_books])
        return sum_of_best_book_scores / lib.signup_time ** (1 + lib.signup_time / self.D)
```

SimpleScoreVarianceSolver

Heurystic solver with a given function f = S/var(S)

In [10]:
```python
class SimpleScoreVarianceSolver(HeuristicSolver):
    def library_score(self, lib_id):
        lib = self.libraries[lib_id]
        delta_time = self.D - lib.signup_time
        n_best_books = self.get_n_best_books(lib, delta_time * lib.books_per_day)
        best_scores = [self.book_values[book] for book in n_best_books]
        sum_of_best_book_scores = sum(best_scores)
        book_variance = max(0.001, np.var(best_scores))
        return sum_of_best_book_scores / book_variance
```

SquareScoreVarianceSolver

Heurystic solver with a given function f = (S^2)/(signup_time^2 * sqrt(var(S))

In [11]:
```python
class SquareScoreVarianceSolver(HeuristicSolver):
    def library_score(self, lib_id):
        lib = self.libraries[lib_id]
        delta_time = self.D - lib.signup_time
        n_best_books = self.get_n_best_books(lib, delta_time * lib.books_per_day)
        best_scores = [self.book_values[book] for book in n_best_books]
        sum_of_best_book_scores = sum(best_scores)
        book_variance = max(0.001, np.var(best_scores))
        return sum_of_best_book_scores ** 2 / (lib.signup_time * lib.signup_time * sqrt(book_variance))
```

BookNumbersSolver

Heurystic solver with a given function f = S^2/(var(S)*n*signup_time)

In [12]:
```python
class BookNumbersSolver(HeuristicSolver):
    def library_score(self, lib_id):
        lib = self.libraries[lib_id]
        delta_time = self.D - lib.signup_time
        n_best_books = self.get_n_best_books(lib, delta_time * lib.books_per_day)
        best_scores = [self.book_values[book] for book in n_best_books]
        sum_of_best_book_scores = sum(best_scores)
```

```
        book_variance = max(0.001, np.var(best_scores))
        return sum_of_best_book_scores ** 2 / (book_variance * len(n_best_books) * lib.signup_time)
```

ScoreSquareSolver

Heurystic solver with a given function f = S^2/(signup_time)

In [13]:
```
class ScoreSquareSolver(HeuristicSolver):
    def library_score(self, lib_id):
        lib = self.libraries[lib_id]
        delta_time = self.D - lib.signup_time
        n_best_books = self.get_n_best_books(lib, delta_time * lib.books_per_day)
        sum_of_best_book_scores = sum([self.book_values[book] for book in n_best_books])
        return sum_of_best_book_scores ** 2 / lib.signup_time
```

BookCountSolver

Heurystic solver with a book score function = book_value-length(book_libraries)

In [14]:
```
class BookCountSolver(HeuristicSolver):
    def book_score(self, book):
        return self.book_values[book] - 0.7 * len(self.book_libraries[book])
```

BookCountPowerSolver

Power solver with a book score function = book_value-length(book_libraries)

In [15]:
```
class BookCountPowerSolver(PowerSolver):
    def book_score(self, book):
        return self.book_values[book] - 0.7 * len(self.book_libraries[book])
```

RandomSolver

Shuffles library ids and selects them till the library singnup time is longer than time left

In [16]:
```
class RandomSolver(ProblemSolver):
    def get_individual(self):
        lib_ids = [i for i in range(len(self.libraries))]
        random.shuffle(lib_ids)
        day = 0
        for i in range(len(lib_ids)):
            day += self.libraries[lib_ids[i]].signup_time
            if day >= self.D:
                return tuple(lib_ids[:i])
        return tuple(lib_ids)
```

GreedyIntervalSolver

Essentially a BookCountSolver. However it sorts libraries repatedly every 25 iterations. Due to the fact that it needs to create a complete sollution while creating individual, it does not inherit from Problem Solver. Instead it implements a method get_individual_from_solution, which returns an individual from sollution.

In [17]:

```
class GreedyIntervalSolver:
    def __init__(self, B, L, D, book_values, book_libraries, libraries):
        self.B, self.L, self.D = B, L, D
        self.book_values = book_values
        self.libraries = copy.deepcopy(libraries)
        self.book_libraries = copy.deepcopy(book_libraries)

    def book_score(self, book_id):
        return self.book_values[book_id] - 0.7 * len(self.book_libraries[book_id])

    def get_n_best_books(self, lib, n):
        return sorted(lib.book_ids, key=self.book_score, reverse=True)[:n]

    def library_score(self, lib_id, current_day):
        lib = self.libraries[lib_id]
        delta_time = self.D - current_day - lib.signup_time
        n_best_books = self.get_n_best_books(lib, min(delta_time * lib.books_per_day, len(lib.book_ids)))
        sum_of_best_book_scores = sum([self.book_values[book] for book in n_best_books])
        sum_of_best_book_scores /= lib.signup_time
        return sum_of_best_book_scores

    def get_solution(self):
        remaining_libraries = set(lib.id for lib in self.libraries)
        day = 0
        chosen_libraries = []
        it = 0
        interval = 25
        while len(remaining_libraries) > 0:
            if it % interval == 0:
                library_scores = [(self.library_score(lib_id, day), lib_id) for lib_id in remaining_libraries]
            it += 1
            max_el = max(library_scores, key=lambda x: x[0])
            library_scores.remove(max_el)
            score, lib_id = max_el
            remaining_libraries.remove(lib_id)
            library = self.libraries[lib_id]
            if day + library.signup_time >= self.D:
                break
            day += library.signup_time
            books_to_take = (self.D - day) * library.books_per_day
            sorted_books = sorted(library.book_ids, key=self.book_score, reverse=True)
            for book_id in sorted_books[:books_to_take]:
                for lib_id in self.book_libraries[book_id]:
```

```
                if lib_id != library.id:
                    self.libraries[lib_id].remove_book(book_id)

            for book_id in sorted_books[books_to_take:]:
                self.book_libraries[book_id].remove(library.id)

            library.book_ids = sorted_books[:books_to_take]
            chosen_libraries.append(library)
        return chosen_libraries

    def get_individual_from_solution(self, solution):
        return tuple([lib.id for lib in solution])
```

GeneticSolver

It is a problem solver that implements a genetic algorithm. Slver stores scores fo all individuals in a dictionary, so if individuals repeat it does not need to recalulate socore. This algorithm generates its initial population using all previous solvers. Then it calculates their scores and performs the following operations till it runs out of time.

- create a new population
- preserve a defined percentage of population by selecting them by means of tournament, add them to new population
- while new population size is smaller than defined perform the following steps:
-
  - with propability 50% either mutate those 2 individuals or make a crossover
-
  - add them both to population After time runs out select best individual from the dictionary an return it

Muation

The mutation works in 2 ways with 50% probaility each.

- local mutation - 4 times swaps 2 random libraries
- external mutation - seletcs 4 random libraries with probability equal to its score. Than it inserts them at random places After external mutation cut operation is performed to make sollution correct if it is too long.

Crossover

First from 2 individuals it selects common and different ids. Than it creates children by taking indexes of common ids from one parent and placing "different ids" from second parent at places where previously were "different ids" from the first parent.

Example:

parent1: 12453

parent2: 36172

child1: 12673

child2: 34152

In [18]:

```
class GeneticSolver(ProblemSolver):
    def __init__(self, B, L, D, book_values, book_libraries, libraries,start_time, deadline = 240,pop_size=20, p_mutate=
                 tournament_size=3):
        super().__init__(B, L, D, book_values, book_libraries, libraries)
        num = 1
        length_of_libraries = len(libraries)
        while num < pop_size and length_of_libraries != 1:
            num *= length_of_libraries
            length_of_libraries -= 1
        self.pop_size = min(pop_size, num)
        self.p_mutate = p_mutate
        self.tournament_size = min(self.pop_size, tournament_size)
        self.survival_rate = surv_rate
        self.book_values = book_values
        self.individual_scores = dict()
        self.lib_ids = [i for i in range(len(libraries))]
        self.lib_scores = [self.lib_score(lib) for lib in self.libraries]
        self.start_time = start_time
        self.deadline = deadline

    def lib_score(self, lib):
        delta_time = self.D - lib.signup_time
        n_best_books = self.get_n_best_books(lib, delta_time * lib.books_per_day)
        sum_of_best_book_scores = sum([self.book_values[book] for book in n_best_books])
        return sum_of_best_book_scores / lib.signup_time

    def mutate(self, individual):
        new_one = list(individual)
        if random.random() <= 0.5:
            # internal mutation
            length = len(new_one)
            for i in range(4):
                a, b = random.sample(range(length), 2)
                new_one[a], new_one[b] = new_one[b], new_one[a]
            return tuple(individual)
        else:
            # external mutation
            additional = random.choices(self.lib_ids, k=4, weights=self.lib_scores)
            unique = set(additional)
            for un in unique:
                new_one.insert(random.randrange(0, len(new_one)), un)
            return self.cut(new_one)

    def cut(self, new_one):
        day = 0
        chosen = set()
```

```python
        solution = []
        for i in range(len(new_one)):
            if new_one[i] not in chosen:
                day += self.libraries[new_one[i]].signup_time
                if day >= self.D:
                    continue
                solution.append(new_one[i])
                chosen.add(new_one[i])
        return tuple(solution)

    def crossover(self, indiv_1, indiv_2):
        set1 = set(indiv_1)
        set2 = set(indiv_2)
        common = set1.intersection(set2)
        max_length = max(len(indiv_1), len(indiv_2))
        child1, child2, = [-1] * max_length, [-1] * max_length
        only1, only2 = [], []
        for i in range(len(indiv_1)):
            if indiv_1[i] in common:
                child1[i] = indiv_1[i]
            else:
                only1.append(indiv_1[i])
        for i in range(len(indiv_2)):
            if indiv_2[i] in common:
                child2[i] = indiv_2[i]
            else:
                only2.append(indiv_2[i])
        for i in range(max_length):
            if child1[i] == -1 and len(only2) > 0:
                child1[i] = only2.pop(0)
            if child2[i] == -1 and len(only1) > 0:
                child2[i] = only1.pop(0)
        child1 = [i for i in child1 if i != -1]
        child2 = [i for i in child2 if i != -1]

        child1 = self.cut(child1)
        child2 = self.cut(child2)
        if random.random() <= self.p_mutate:
            child1 = self.mutate(child1)
        if random.random() <= self.p_mutate:
            child2 = self.mutate(child2)
        return child1, child2

    def tournament(self, indivs):
        return max(indivs, key=self.individual_scores.get)

    def get_initial_population(self):
        solvers_cls = [HeuristicSolver, PowerSolver, SimpleScoreVarianceSolver, SquareScoreVarianceSolver,
                       BookNumbersSolver, ScoreSquareSolver, BookCountSolver, BookCountPowerSolver]
        solvers = [cl(self.B, self.L, self.D, self.book_values, self.book_libraries, self.libraries) for cl in
                   solvers_cls]
```

```
        population = [solver.get_individual() for solver in solvers]
        greedyIntervalSolver = GreedyIntervalSolver(self.B, self.L, self.D, self.book_values, self.book_libraries,
                                                    self.libraries)
        greedyIntervalSolution = greedyIntervalSolver.get_solution()
        gis_individual = greedyIntervalSolver.get_individual_from_solution(greedyIntervalSolution)
        population.append(gis_individual)
        self.individual_scores[gis_individual] = score_solution(greedyIntervalSolution, self.book_values)
        print("Greedy interval score: ", self.individual_scores[gis_individual],"time:", time.time()-self.start_time)
        randomSolver = RandomSolver(self.B, self.L, self.D, self.book_values, self.book_libraries, self.libraries)
        while len(population) < self.pop_size:
            population.append(randomSolver.get_individual())
        return population

    def get_individual(self):
        population = self.get_initial_population()
        for indiv in population:
            sol = self.get_solution(indiv)
            self.individual_scores[indiv] = score_solution(sol, self.book_values)
        progress = []
        times = []
        while True:
            progress.append(max(self.individual_scores.values()))
            times.append(time.time() - self.start_time)
            if time.time() - self.start_time > self.deadline:
                break
            new_population = [self.tournament(random.sample(population, self.tournament_size)) for i in
                              range(int(self.pop_size * self.survival_rate))]
            while len(new_population) < self.pop_size:
                individual_1 = self.tournament(random.sample(population, self.tournament_size))
                individual_2 = self.tournament(random.sample(population, self.tournament_size))
                if random.random() <= 0.5:
                    new_child1 = self.mutate(individual_1)
                    new_child2 = self.mutate(individual_2)
                else:
                    new_child1, new_child2 = self.crossover(individual_1, individual_2)
                if new_child1 not in self.individual_scores:
                    self.individual_scores[new_child1] = score_solution(self.get_solution(new_child1), self.book_values)
                if new_child2 not in self.individual_scores:
                    self.individual_scores[new_child2] = score_solution(self.get_solution(new_child2), self.book_values)
                new_population.append(new_child1)
                new_population.append(new_child2)
            population = tuple(new_population)
        min_ = min(progress)
        plt.title("Progress of score from: " + str(min_) + " to " + str(max(progress)))
        plt.plot(times, progress, color="blue", label="Progress", alpha=0.5, linewidth=2)
        plt.plot(times, [min_ for x in range(0, len(times))], linestyle="--", linewidth=1, color="red",
                 label="Base level", alpha=0.5)
        plt.xlabel("time [s]")
        plt.ylabel("score [-]")
        plt.legend()
        plt.show()
```

```
        print("Genetic Progress:", max(progress) - min_)
        print("Score from GA:", max(progress))
        return max(self.individual_scores, key=self.individual_scores.get)
```

MutationHillClimbingSolver

After receiving result from GeneticSolver it performs sort of "randomized hill climbing". It does it by performing the very same mutations as in GeneticSolver. Using this mutations it creates a neighbourhood of size 10, and than selects best individual. It this individual is better than current best individual it becomes our individual.

In [19]:

```
class MutationHillClimbingSolver(ProblemSolver):
    def __init__(self, B, L, D, book_values, book_libraries, libraries, individual_scores,start_time, deadline = 260, ne
        super().__init__(B, L, D, book_values, book_libraries, libraries)
        self.neighbourhood_size = neighbourhood_size
        self.individual_scores = individual_scores
        self.lib_ids = [i for i in range(len(libraries))]
        self.lib_scores = [self.lib_score(lib) for lib in self.libraries]
        self.deadline = deadline
        self.start_time = start_time

    def lib_score(self, lib):
        delta_time = self.D - lib.signup_time
        n_best_books = self.get_n_best_books(lib, delta_time * lib.books_per_day)
        sum_of_best_book_scores = sum([self.book_values[book] for book in n_best_books])
        return sum_of_best_book_scores / lib.signup_time

    def mutate(self, individual):
        new_one = list(individual)
        if random.random() <= 0.5:
            # internal mutation
            length = len(new_one)
            for i in range(4):
                a, b = random.sample(range(length), 2)
                new_one[a], new_one[b] = new_one[b], new_one[a]
            return tuple(individual)
        else:
            # external mutation
            additional = random.choices(self.lib_ids, k=4, weights=self.lib_scores)
            unique = set(additional)
            for un in unique:
                new_one.insert(random.randrange(0, len(new_one)), un)
            return self.cut(new_one)

    def cut(self, new_one):
        day = 0
        chosen = set()
        solution = []
        for i in range(len(new_one)):
            if new_one[i] not in chosen:
```

```
                day += self.libraries[new_one[i]].signup_time
                if day >= self.D:
                    continue
                solution.append(new_one[i])
                chosen.add(new_one[i])
        return tuple(solution)

    def get_individual(self, start_individual):
        cur_best = copy.copy(start_individual)
        cur_best_score = self.individual_scores[cur_best]
        progress = [cur_best_score]
        while time.time() - self.start_time < self.deadline:
            neighbourhood = []
            n_scores = []
            for i in range(self.neighbourhood_size):
                new_one = self.mutate(cur_best)
                if new_one not in self.individual_scores:
                    new_solution = self.get_solution(new_one)
                    new_score = score_solution(new_solution, self.book_values)
                    self.individual_scores[new_one] = new_score
                else:
                    new_score = self.individual_scores[new_one]
                neighbourhood.append(new_one)
                n_scores.append(new_score)
            new_max_score = max(n_scores)
            new_max_score_index = n_scores.index(new_max_score)
            if new_max_score > cur_best_score:
                cur_best = neighbourhood[new_max_score_index]
                cur_best_score = new_max_score
            progress.append(cur_best_score)
        print("Climber progress:", max(progress)-self.individual_scores[start_individual])
        return cur_best
```

Max Flow Max Cost

After MutationHillClimbingSolver returns an individual we are going to look for the best book to library assignment for a given library ordering. We are going to use google ortools to solve first max flow and than max cost problem. To do so, we are going to create a flow graph. It will consist of source vertex(node). For each library we are going to create a node a connect it to source with an edge with flow = (D-day_when_lib_signup_completed)*books_per_day and cost = 0. For each book we are going to create a node, this node is connected to every library than has book with edge with flow = 1 and cost = 0. There is also an edge from book node to a sink with flow =1 and cost = -book_value. (we are using -book_value, because our solver solves min cost problem, so this way we will get max cost simply max book value).

First we are going to use max_flow solver from ortools to find what is the maximum number of books that can be scanned by all libraries. Then we can use that flow as a value of flow for source node (with + sign0 and for sink node (with - sign). Than we can use min cost solver from ortools, that really solves transportation problem (but assigning flow value to just sink and source makes it just min cost problem), to see which books are going to give us the most value.

Note:

we can use max flow (and not anything smaller), because in our graph there are no edges with cost of different sign (+,-), so no book has a negative effect. It is also due to the fact that, edges to and from books have unit flow.

In [20]:
```
#max flow functions
def generate_book_to_node_assignment(number_of_libraries, all_book_ids):
    book_to_node = dict()
    node_to_book = dict()
    counter = 1
    for book_id in all_book_ids:
        node_nr = number_of_libraries + counter
        book_to_node[book_id] = node_nr
        node_to_book[node_nr] = book_id
        counter += 1
    return book_to_node, node_to_book


def lib_to_node(lib_id):
    return lib_id + 1


def node_to_lib(node):
    return node - 1
```

In [21]:
```
def solve_one_example_with_genetic_climber_max_flow(file_path, file_to, deadline_for_genetic, deadline_for_hill_climber,
                                                    flag=True):
    start_time = time.time()
    print("File:", str(file_path))
    (B, L, D), book_values, book_counts, libraries = process_file(file_path)
    libraries_backup = copy.deepcopy(libraries)
    genetic_solver = GeneticSolver(B, L, D, book_values, book_counts, libraries, start_time,
                                   deadline=deadline_for_genetic)
    individual = genetic_solver.get_individual()
    check_solution(D, genetic_solver.get_solution(selected_lib_ids=individual))
    score_from_genetic = score_solution(genetic_solver.get_solution(selected_lib_ids=individual), book_values)

    hill_climber_solver = MutationHillClimbingSolver(B, L, D, book_values, book_counts, libraries,
                                                     genetic_solver.individual_scores,start_time,
                                                     deadline=deadline_for_hill_climber)
    # Creating new individual with hill_climber
    individual = hill_climber_solver.get_individual(individual)
    climbed_solution = hill_climber_solver.get_solution(individual)
    check_solution(D, climbed_solution)
    climbed_score = score_solution(climbed_solution, book_values)
    print("Score after climbing:", climbed_score)

    libraries = libraries_backup

    all_book_ids = set()
```

```
    for lib_id in individual:
        all_book_ids.update(libraries[lib_id].book_ids)
    book_to_node, node_to_book = generate_book_to_node_assignment(len(individual), all_book_ids)

    start_nodes = []
    end_nodes = []
    capacities = []
    unit_costs = []

    source = 0
    sink = len(individual) + len(all_book_ids) + 1
    day = 0

    # from source to lib
    for i in range(len(individual)):
        day += libraries[individual[i]].signup_time
        start_nodes.append(source)
        end_nodes.append(lib_to_node(i))
        capacities.append((D - day) * libraries[individual[i]].books_per_day)
        unit_costs.append(0)

    # from lib to book
    for i in range(len(individual)):
        for book_id in libraries[individual[i]].book_ids:
            start_nodes.append(lib_to_node(i))
            end_nodes.append(book_to_node[book_id])
            capacities.append(1)
            unit_costs.append(0)

    # from book to sink
    for book_id in all_book_ids:
        start_nodes.append(book_to_node[book_id])
        end_nodes.append(sink)
        capacities.append(1)
        unit_costs.append(-book_values[book_id])

    max_flow = pywrapgraph.SimpleMaxFlow()
    # Add each arc.
    for i in range(0, len(start_nodes)):
        max_flow.AddArcWithCapacity(start_nodes[i], end_nodes[i], capacities[i])
    max_flow.Solve(0, sink)

    if max_flow.Solve(0, sink) != max_flow.OPTIMAL:
        raise Exception("Failed with max_flow", max_flow.OptimalFlow())

    optimal_flow = max_flow.OptimalFlow()

    supplies = [0 for i in range(sink + 1)]
    supplies[0] = optimal_flow
    supplies[-1] = -optimal_flow
```

```
    min_cost_flow = pywrapgraph.SimpleMinCostFlow()

    # Add each arc.
    for i in range(0, len(start_nodes)):
        min_cost_flow.AddArcWithCapacityAndUnitCost(start_nodes[i], end_nodes[i],
                                                    capacities[i], unit_costs[i])
    for i in range(0, len(supplies)):
        min_cost_flow.SetNodeSupply(i, supplies[i])

    if min_cost_flow.Solve() != min_cost_flow.OPTIMAL:
        print("Failed with max_flow_max_cost")

    solution = []
    for lib_id in individual:
        lib2 = copy.deepcopy(libraries[lib_id])
        lib2.book_ids = set()
        solution.append(lib2)
    for i in range(min_cost_flow.NumArcs()):
        from_node = min_cost_flow.Tail(i)
        to_node = min_cost_flow.Head(i)
        flow = min_cost_flow.Flow(i)

        if lib_to_node(0) <= from_node <= lib_to_node(len(individual) - 1) and flow == 1:
            lib_index = node_to_lib(from_node)
            book_id = node_to_book[to_node]
            solution[lib_index].book_ids.add(book_id)

    check_solution(D, solution)
    score = score_solution(solution, book_values)
    print("Score after optimizing book distribution:", str(score) + ".", "Progress:", score - score_from_genetic)
    print("Time elapsed:", time.time() - start_time)
    print()
    save_solution_to_file(solution, file_to, flag=flag)
    return score
```

Getting sollution

After running min_cost algoriithm we transform its output to get best book to library assignments and save/or print result in desired output format for this task and calculate score.

In [22]:

```
def solve_with_flow_and_genetic_and_hill_climber(file_paths, time_for_genetic, time_for_hill_climber):
    max_score = 0
    for file_path in file_paths:
        score = solve_one_example_with_genetic_climber_max_flow(file_path, "", time_for_genetic, time_for_hill_climber,
                                                                flag=False)
        max_score += score
    print("Sum of scores:", max_score)
```

```
file_paths = ['a_example.txt', 'b_read_on.txt', 'c_incunabula.txt', 'd_tough_choices.txt', 'e_so_many_books.txt',
```

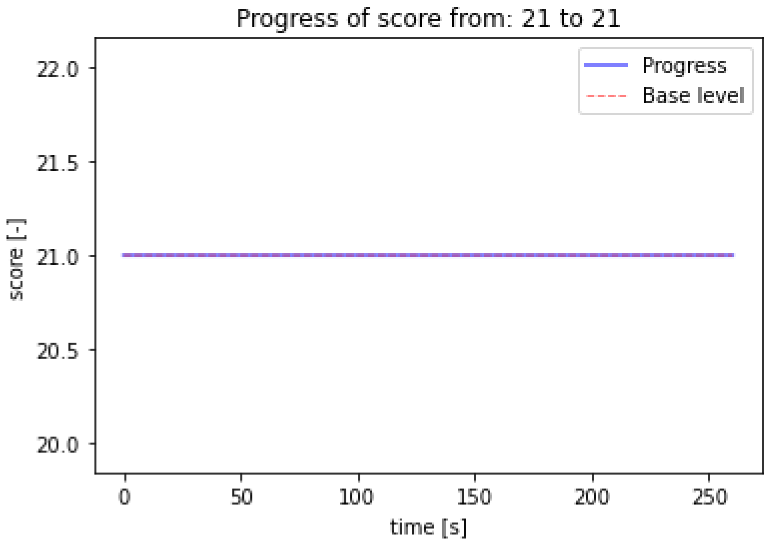
```
In [23]:              'f_libraries_of_the_world.txt']
```

Results

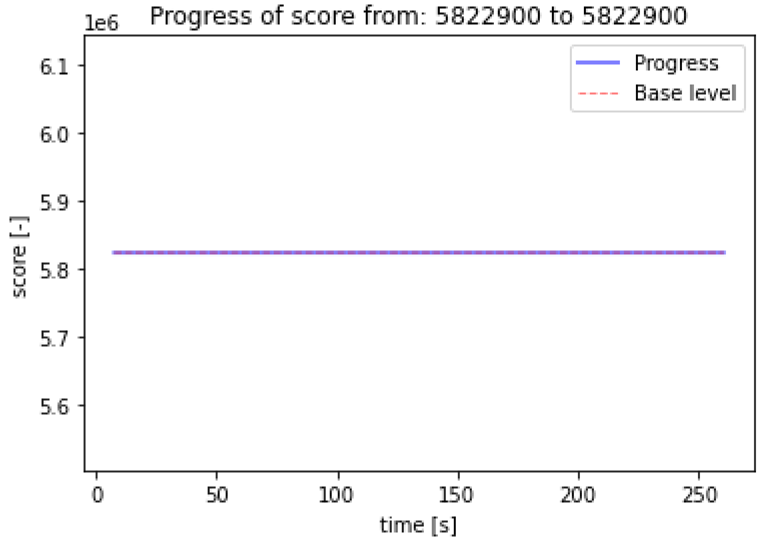
Now we run our algorithm and check the result. For every file we present value of output at different stages of computation, as well as graph that show progress during runtime of genetic algorithm. At the end be print sum of all scores. We decided that genetic algorithm should finish at 260s of computation and hill climbing at 280s of computation, because currently ortools functions run for up to 3s, but for larger examples they can run longer so 17 s is a safe buffor for us.

```
In [24]: solve_with_flow_and_genetic_and_hill_climber(file_paths, 260, 280)
```

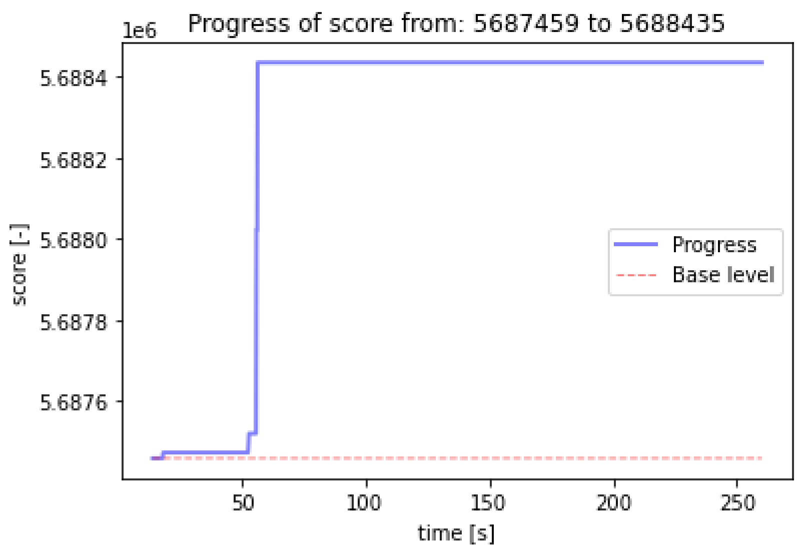
```
File: a_example.txt
Greedy interval score:  21 time: 0.0009160041809082031
```




```
Genetic Progress: 0
Score from GA: 21
Climber progress: 0
Score after climbing: 21
Score after optimizing book distribution: 21. Progress: 0
Time elapsed: 280.0020115375519

File: b_read_on.txt
Greedy interval score:  5822900 time: 6.146183490753174
```

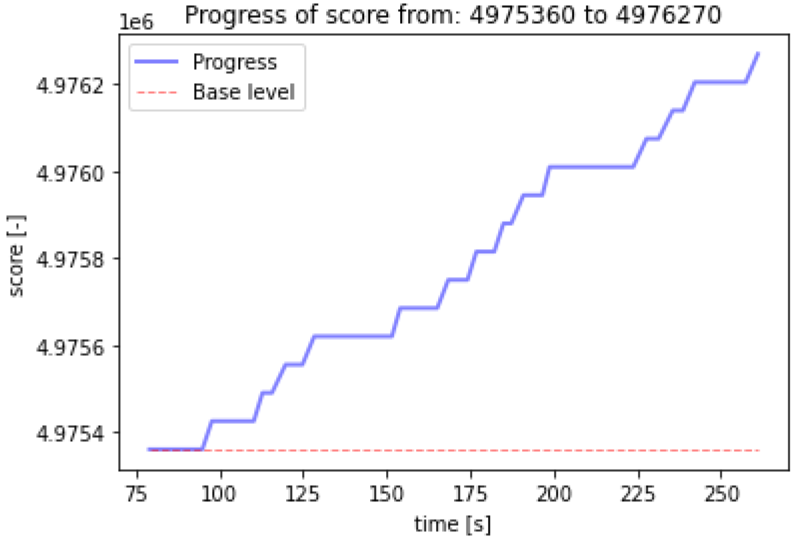



```
Genetic Progress: 0
Score from GA: 5822900
Climber progress: 0
Score after climbing: 5822900
Score after optimizing book distribution: 5822900. Progress: 0
Time elapsed: 280.63885164260864

File: c_incunabula.txt
Greedy interval score:  5687459 time: 13.100662231445312
```

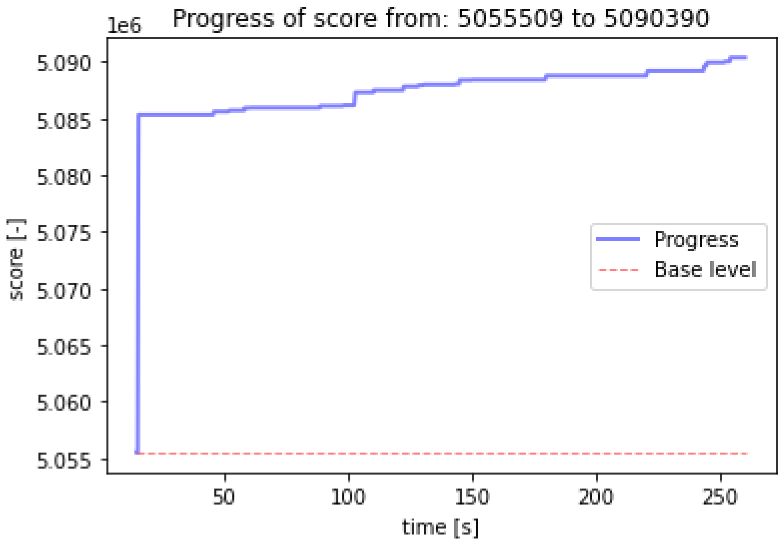



```
Genetic Progress: 976
Score from GA: 5688435
Climber progress: 0
Score after climbing: 5688435
Score after optimizing book distribution: 5688435. Progress: 0
Time elapsed: 280.3547029495239
```

```
File: d_tough_choices.txt
Greedy interval score:  4975360 time: 71.94074964523315
```

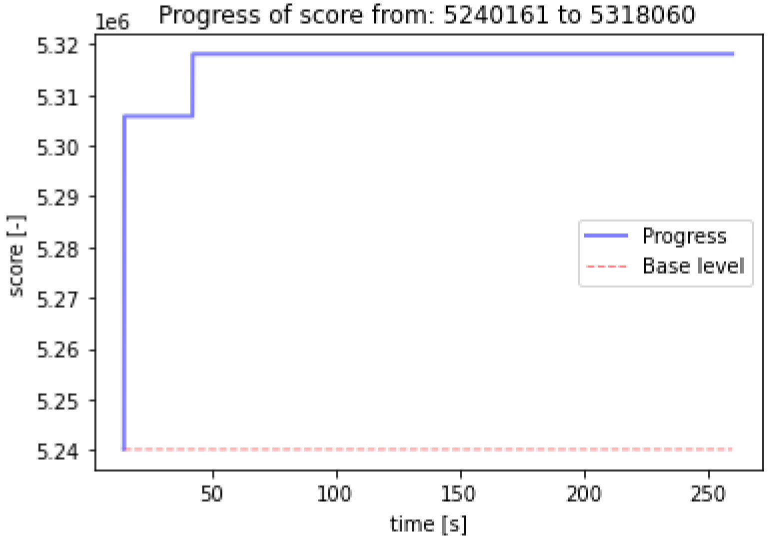



```
Genetic Progress: 910
Score from GA: 4976270
Climber progress: 130
Score after climbing: 4976400
Score after optimizing book distribution: 4976400. Progress: 130
Time elapsed: 281.7655248641968

File: e_so_many_books.txt
Greedy interval score:  5057067 time: 12.934185028076172
```




```
Genetic Progress: 34881
Score from GA: 5090390
Climber progress: 79
Score after climbing: 5090469
Score after optimizing book distribution: 5210401. Progress: 120011
```

```
Time elapsed: 280.70972299575806

File: f_libraries_of_the_world.txt
Greedy interval score:  5240157 time: 13.188772439956665
```




```
Genetic Progress: 77899
Score from GA: 5318060
Climber progress: 0
Score after climbing: 5318060
Score after optimizing book distribution: 5318060. Progress: 0
Time elapsed: 280.1358916759491

Sum of scores: 27016217
```

Conclusions

In our opinion our algorithm performs pretty well. It always scores above 27mln in total. From previous graphs and our previous experiments it is clearly visible that good initial population (and that way good interval greedy/ heurystic algorithms) is a key to succes. Our genetic algorithm gives us more or less +0.1mln in total score. What surprised us is that hill climbing algorithm barely improves results in most cases. That is why we decided o give just 20s of whole available time. However, when processing example g it gives us better results per unit of time than genetic algorithm, and that is why we decided to keep it. While for most cases our max flow min cost optimization does not improve results at all, it gives us around 0.1-0.15 mln improve in score, so it was definately a very good decision to use it.

Sources

During developing our algorithm we uses and developed ideas contained in the following articles:

- https://medium.com/@achille.nazaret/hashcode-2020-1e1ef62e1229
- https://medium.com/better-programming/google-hash-code-2020-how-we-took-98-5-of-the-best-score-e5b6fa4abc1b
- https://towardsdatascience.com/google-hash-code-2020-a-greedy-approach-2dd4587b6033

Link to ORTools:

https://developers.google.com/optimization

In [ ]: