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2 strategies: basic (strategy 1) and advance (strategy 2)

- Strategy 1 (the example strategy in the assignment description): "The elevator starts on the ground floor and moves all the way to the top floor, stopping at every floor in between. When the elevator reaches the top floor, it changes direction and moves all the way back down to the ground floor, again stopping at every floor in between. On every floor where the elevator stops, any passengers who want to get off leave and any passengers who want to get on enter, as long as there is space in the elevator. If the elevator is full, passengers on that floor have to wait. Upon reaching the ground floor, the elevator repeats the cycle of moving all the way up and all the way down the building." (CS166 Assignment 1 - Elevator simulation)

- Strategy 2: The elevator has the current direction (up = True, down = False).
- At each run, the elevator will go to the nearest floor that it can drop off people or the closest person it can pick up that in the same direction it is currently moving, whichever is the closest.
- The algorithm can be represented as step-by-step as:
    - The elevator will go up if:
        - The current passengers in the elevator have people going up (which implies the current direction of the elevator is going up, and the elevator is not empty).
        - The building has the people to be picked up upstairs (to either go up or down). The priority is given to those who also want to go up (have the same direction with the current direction of the elevator).
        - The elevator will move to the closest among the two above options.
    - The elevator will go down if:
        - The current passengers in the elevator have people going down (which implies the current direction of the elevator is going down, and the elevator is not empty).
        - The building has the people to be picked up downstairs (to either go up or down). The priority is given to those who also want to go down (have the same direction with the current direction of the elevator).
        - The elevator will move to the closest among the two above options.
    - The elevator stops when all the people reach their floors.

Efficiency test:
We measure the time in our hotel's elevator and approximate that the loading/unloading passenger = 3 * the time moving on each floor. Also, we assume that the time moving each floor is the same (not accounting for accelerating/decelerating).

We consider moving one floor costs 1 unit, whereas each load/unload passengers costs 3 units.

The efficiency value
= total cost for the elevator to put everyone in the correct location
= the cost of the floors that the elevator move + the cost of the elevator load/unload passengers
= the time of the floors that the elevator move + 3*(the number of times the elevator load/unload passengers).

Initialization:
The building with 30 floors.
Random passenger initialization: the passengers are randomly located in the building: discrete uniform distribution.
The base case is 200 passengers.
For testing purposes, we use the values from 100 to 2000, with step size = 100.

Results:
The advanced strategy (strategy 2) outperforms the basic strategy (strategy 1) in terms of the efficiency value (defined above). This result is reasonable because the advance strategy requires much less load/unload passengers as we do not need to open the door on each floor. Also, the advance method does not go to unnecessary floors (e.g., the top floors).

Also, we learn that having only one elevator for a building with 200+ people is not efficient because the average cost for the basic method is 2608 steps and 1704 steps for the advance method, which is we relate to seconds unit (1 cost unit = 1 second): 43.5 minutes and 28.4 minutes, respectively.

When we increase the number of passengers (linearly), the costs also increase (linearly). As we can see from Figure 3 below, the trend is linearly increasing with the increasing passenger.

Our next step would be to implement a 2+ elevators model.

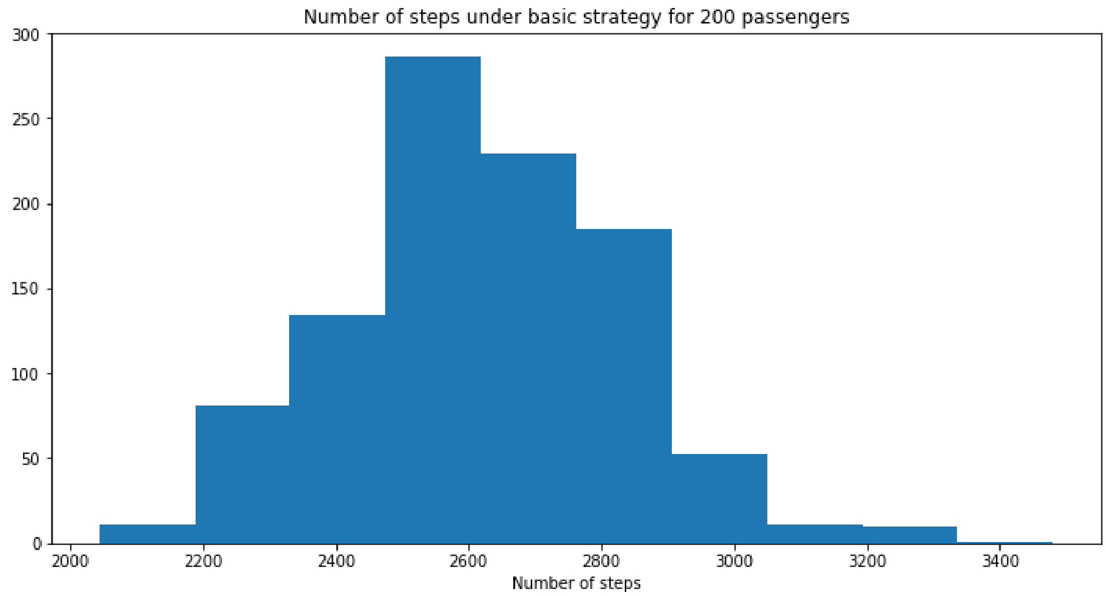


Fig. 1: The number of steps (cost) under the basic strategy for 200 passengers.
The mean number of steps is: 2620.728
The median number of steps is: 2608.0
The 95% confidence interval is from: 2268.0 to 3020.0

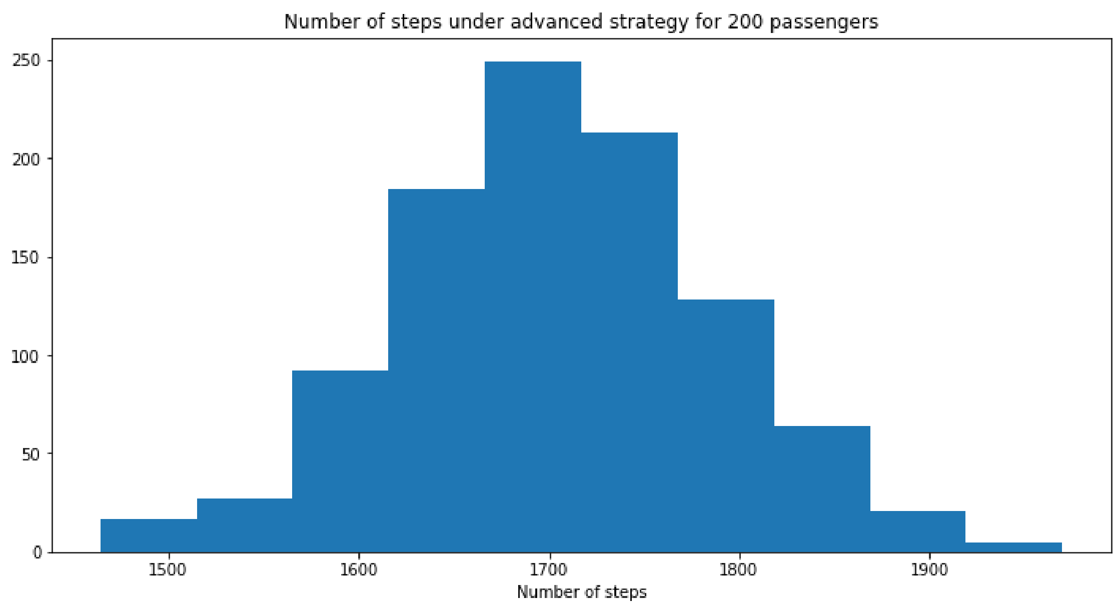


Fig. 2: The number of steps (cost) under the advance strategy for 200 passengers.
The mean number of steps is: 1704.205
The median number of steps is: 1703.5
The 95% confidence interval is from 1534.9750000000001 to 1869.0

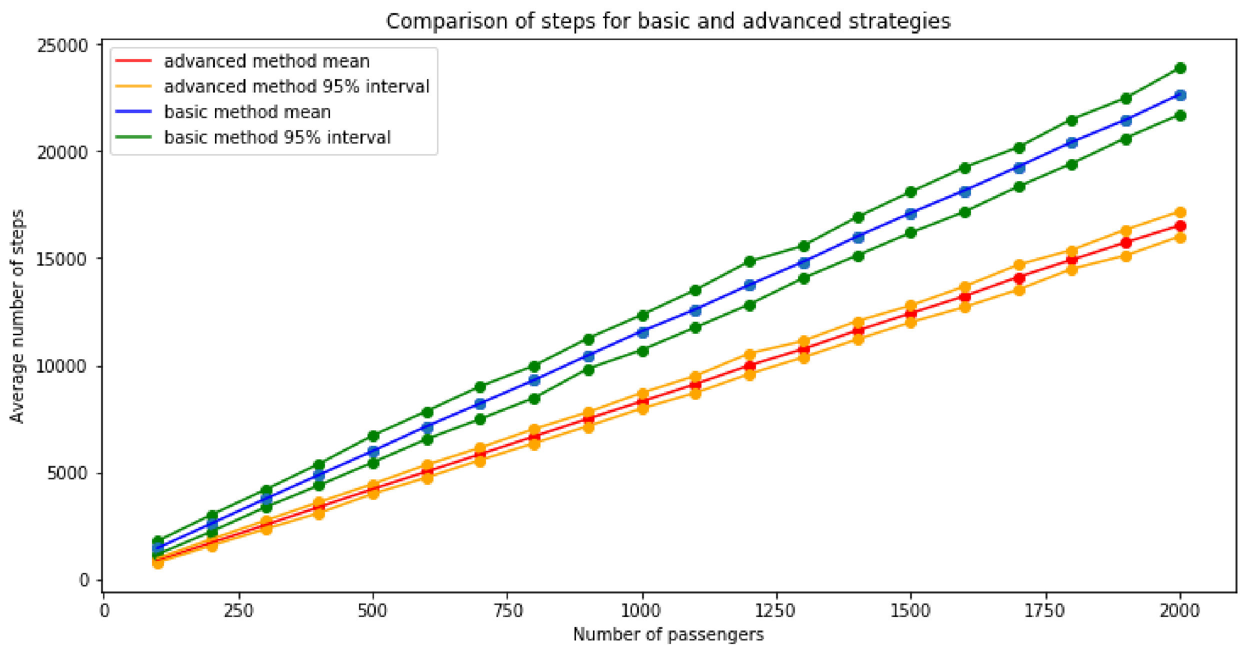


Fig. 3: The comparison between the costs (the smaller the better) between 2 strategies. As we can see, the basic method has much higher costs, which implies inefficiency.

Contribution:

- Ivanna and I created the efficiency testing part.
- I also debug the final code to make it run properly, without syntactical and logical errors.
- Discuss the strategies with others.

What I've learned:

- For simulations, it will be very challenging if we are not familiar with the syntax. In our group, there were some errors in the syntax (split the line but forgot to add "\"; find the max of an empty list)
- Writing simulation with objects needs a systematic mindset because there are so many components to coordinate and interact with others. I found it helpful to have a Google Doc to keep track of all the methods and classes.
- It is essential to have a readable, well-commented code, especially in group-setting. My code might seem trivial to me now, but not trivial to others and my future self. Hence, having readable code helps others learn and build upon our work more efficiently.

The code:

Link to Colab:
https://colab.research.google.com/drive/1GnD-dKJqCwd5yaPIl6Ub-nH85ZVcg6jZ

Link to Github:
https://github.com/katjadellalibera/ElevatorSimulationAssignment/blob/master/Elevator_Simulation.ipynb

```
import numpy as np
import matplotlib.pyplot as plt
import time
```

```
class Passenger():

    def __init__(self, start, end, name):
        # variables describing the state of the passenger
        self.current = start
        self.end = end
        self.reached = self.current == self.end
        self.direction = self.determine_direction()
        self.name = name

    def determine_direction(self):
      # direction is True if passenger needs to go up,
      # False if needs to go down
        if self.end > self.current:
            return True
        else:
            return False

    def move_floor(self, direction):
        # change their floor when moving up or down
        # (first strategy)
        if direction:
            self.current += 1
        else:
            self.current -= 1
        # update whether the goal is reached
        self.reached = self.current == self.end

    def move_to_floor(self, floor):
      # move to a given floor when moving up or down
      # (second strategy)
        self.current = floor
        self.reached = self.current == self.end
```

```python

    def __str__(self):
        # define the str method
        return self.name

    def __repr__(self):
      # representation
        return self.name
```

```python
class Elevator():
    #describing the elevator class
    def __init__(self, location = 0, direction = True, passengers = None, capacity = 6):
        self.location = location
        self.direction = direction
        self.passengers = self.initialize_passengers(passengers)
        self.capacity = capacity
        self.step = 0

    def initialize_passengers(self, passengers):
        if passengers == None:
            return []
        else:
            return passengers

    # method for moving an elevator a single floor up or down
    # depending on the direction
    def move_floor(self):
        self.step += 1
        if self.direction:
            self.location += 1
        else:
            self.location -= 1
        # when the elevator moves a floor, so do all the passengers in it
        for passenger in self.passengers:
              passenger.move_floor(self.direction)

    # method for directly moving the elevator to a given floor
    # rather than going in increments of 1
    def move_to_floor(self, goal):
```

```
    def move_to_floor(self, goal):
        if goal != None:
          self.step += abs(goal - self.location)
          # takes a goal floor and moves to that floor
          # change the direction if necessary:
          if goal < self.location and self.direction:
              self.direction = False
          elif goal > self.location and not self.direction:
              self.direction = True
          # move to the floor
          self.location = goal
          for passenger in self.passengers:
              passenger.move_to_floor(goal)

    # method to change elevator's direction
    def change_direction(self):
        if self.direction:
            self.direction = False
        else:
            self.direction = True

    # method to load and unload passengers
    def load_passengers(self, building):
        self.step += 3
        #Check if anyone wants to get off
        for person in self.passengers:
            if person.reached:
                # remove from the elevator, add to the floor
                building.add_passenger(self.location,person)
                self.passengers.remove(person)
                # 1 open space left
                self.capacity +=1

        # check if there is capacity and if anyone wants to get on
        if self.capacity > 0:
            for person in building.floor_lists[self.location]:
                if self.capacity > 0:
                    if person.direction == self.direction and not person.reached:
                        # remove from the floor, add to the elevator
                        self.passengers.append(person)
```

```
                        self.passengers.append(person)
                        building.remove_passenger(self.location,person)
                        self.capacity -= 1

    # method to find the next floor to visit
    def next_floor(self, building):
        # In cases where elevator is going up:
        if self.direction == True:
            # Case 1: if there are people going up
            # (either in elevator or to be picked up)
            going_up = []
            for person in self.passengers:
                if person.end > self.location:
                    going_up.append(person.end)
            for x in range(self.location + 1, building.n_floors):
                if any(person.direction == self.direction and not person.reached for person in building.floor_lists[x]):
                    going_up.append(x)
            # pick the closest one if the list is not empty
            if going_up != []:
                return min(going_up)

            # Case 2: people upstairs (or on the same floor) are going down
            upstairs_going_down = []
            for x in range(self.location, building.n_floors):
                for person in building.floor_lists[x]:
                    if person.direction != self.direction and not person.reached:
                        upstairs_going_down.append(x)
            # pick the highest
            if upstairs_going_down != []:
                # turn around since the person will be going down
                self.direction = False
                return max(upstairs_going_down)

            # Case 3: there's no reason to go up
            # find the closest floor downstairs to drop off
            # or the next floor where people need to be picked up going down
            going_down = []
            for person in self.passengers:
                if person.end < self.location:
```

```
                    going_down.append(person.end)
            for x in range(self.location + 1):
                for person in building.floor_lists[x]:
                    if person.direction != self.direction and not person.reached:
                        going_down.append(x)
            # pick the closest of the two
            if going_down != []:
                # turn around if you are picking someone up downstairs
                self.direction = False
                return max(going_down)

            # Case 4: there are only people going up that are downstairs
            else:
                cur = [person.current for floor in building.floor_lists for person in floor if not person.reached]
                if cur != []:
                  return max(cur)
            # pick up person at lowest floor

        # Same process if going down, but opposite
        if self.direction == False:
            # if there are people going down (either in elevator or to be picked up)
            going_down = []
            for person in self.passengers:
                if person.end < self.location:
                    going_down.append(person.end)
            for x in range(self.location):
                if any(person.direction == self.direction and not person.reached for person in building.floor_lists[x]):
                    going_down.append(x)
            # pick the closest one if the list is not empty
            if going_down != []:
                return max(going_down)

            # if there are people going up that are downstairs
            downstairs_going_up = []
            for x in range(self.location + 1):
                for person in building.floor_lists[x]:
                    if person.direction != self.direction and not person.reached:
                        downstairs_going_up.append(x)
            # pick the lowest one
```

```
            if downstairs_going_up != []:
                # turn around since the person will be going up
                self.direction = True
                return min(downstairs_going_up)

            # if there's no reason to go down
            # find the closest floor upstairs to drop off
            # or the next floor where people need to be picked up going up
            going_up = []
            for person in self.passengers:
                if person.end > self.location:
                    going_up.append(person.end)
            for x in range(self.location + 1, building.n_floors):
                for person in building.floor_lists[x]:
                    if person.direction != self.direction and not person.reached:
                        going_up.append(x)
            # pick the closest
            if going_up != []:
                # turn around since the person will be going up
                self.direction = True
                return min(going_up)

            # in case there's only people going down that are downstairs
            else:
                cur = [person.current for floor in building.floor_lists for person in floor if not person.reached]
                if cur != []:
                  return max(cur)
            # pick up person at highest floor

```

```
class Building():
    #defining building class based on PCW criteria
    def __init__(self, n_floors = 10, n_passengers = 100):
        self.n_floors = n_floors
        self.floor_lists = self.initialize_floorlists(n_passengers)
        self.n_reached = self.count_reached()

    def initialize_floorlists(self,n_passengers):
        # generate n random passengers and put them into their initial floors
```

```
        initial_positions = np.random.randint(self.n_floors,size = (n_passengers,2))
        initial_lists = [[] for i in range(self.n_floors)]
        for index,init in enumerate(initial_positions):
            initial_lists[init[0]].append(Passenger(init[0],init[1],str(index)))
        return initial_lists

    def count_reached(self):
        # count the number of passengers at their goal
        count = 0
        for floor in self.floor_lists:
            for person in floor:
                if person.reached:
                    count += 1
        return count

    # to add passenger to the floor - remove from elevator
    def add_passenger(self, location, person):
        self.floor_lists[location].append(person)
        if person.reached:
            self.n_reached += 1

    # to remove passengers from the floor
    def remove_passenger(self,location, person):
        self.floor_lists[location].remove(person)
        if person.reached:
            self.n_reached -= 1
```

```
# Basic algorithm from assigment instructions

building = Building(10,50)
elevator = Elevator()

# run this algorithm until everyone reaches their floor
def basic_method(building,elevator,n_passengers):
    # run this until all passengers have reached their destination
    # this line makes sure the initial position doesn't fulfill the requirements
    while building.n_reached != n_passengers:
        # display the steps taken and number of completed passengers aftr every step
```

```
        print("number of people reached: ",building.n_reached)
        print("Steps taken: ", elevator.step)
        # if the elevator is at an end point, turn around
        if elevator.direction and elevator.location == building.n_floors-1:
            elevator.change_direction()
        elif not elevator.direction and elevator.location == 0:
            elevator.change_direction()
        # otherwise, load passengers and move by one floor
        else:
            elevator.load_passengers(building)
            elevator.move_floor()
        # once everyone has arrived, complete the simulation
            if building.n_reached == n_passengers:
                print("number of people reached: ",building.n_reached)
                print("Steps taken: ", elevator.step)
                return "Everyone arrived!"

basic_method(building,elevator,50)
```

```
# this algorithm uses the next_floor method of the elevator class to skip over
# floors that don't need a pick-up or drop-off.
def advanced_method(building,elevator,n_passengers):
    # run while not all passengers have arrived
    while building.n_reached != n_passengers:
        # display the state of the simulation
        print("number of people reached: ",building.n_reached)
        print("Steps taken: ", elevator.step)
        # load and unload passengers and move to the appropriate floor
        elevator.load_passengers(building)
        elevator.move_to_floor(elevator.next_floor(building))
        #print(elevator.passengers, [person.end for person in elevator.passengers])
        #print(elevator.direction,[person.direction for person in building.floor_lists[elevator.location] if not person.reached])
        if building.n_reached == n_passengers:
            print("number of people reached: ",building.n_reached)
            print("Steps taken: ", elevator.step)
            return "Everyone arrived!"

# create a building and run the simulation
building = Building(10,50)
```

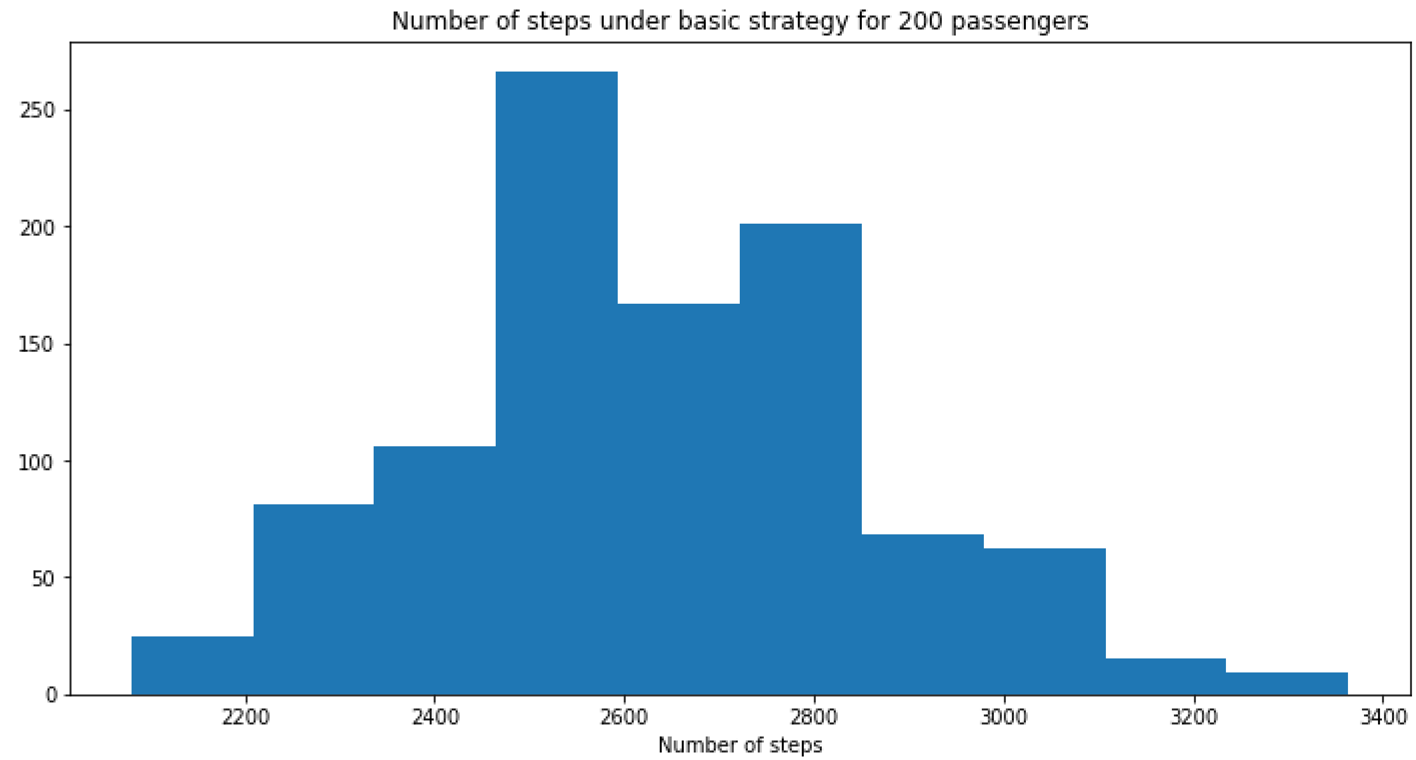
```
elevator = Elevator()
advanced_method(building,elevator, 50)
```

```
# Basic algorithm from assigment instructions

# run this algorithm until everyone reaches their floor
# this is the same as basic_method, just without the print statements
def basic_method_no_print(building,elevator,n_passengers):
    # run until everyone arrived
    while building.n_reached != n_passengers:
        # change direction as necessary
        if elevator.direction and elevator.location == building.n_floors-1:
            elevator.change_direction()
        elif not elevator.direction and elevator.location == 0:
            elevator.change_direction()
        # otherwise, load and move a floor
        else:
            elevator.load_passengers(building)
            elevator.move_floor()
            # finish the simulation
            if building.n_reached == n_passengers:
                return "Everyone arrived!"
```

```
# this algorithm uses the next_floor method of the elevator class to skip over
# floors that don't need a pick-up or drop-off.
def advanced_method_no_print(building,elevator,n_passengers):
    while building.n_reached != n_passengers:
        # load and unload passengers and move to the appropriate floor
        elevator.load_passengers(building)
        elevator.move_to_floor(elevator.next_floor(building))
        # finish the simulation if everyone arrived
        if building.n_reached == n_passengers:
            return "Everyone arrived!"
```

```
steps = []
passenger = 200

```

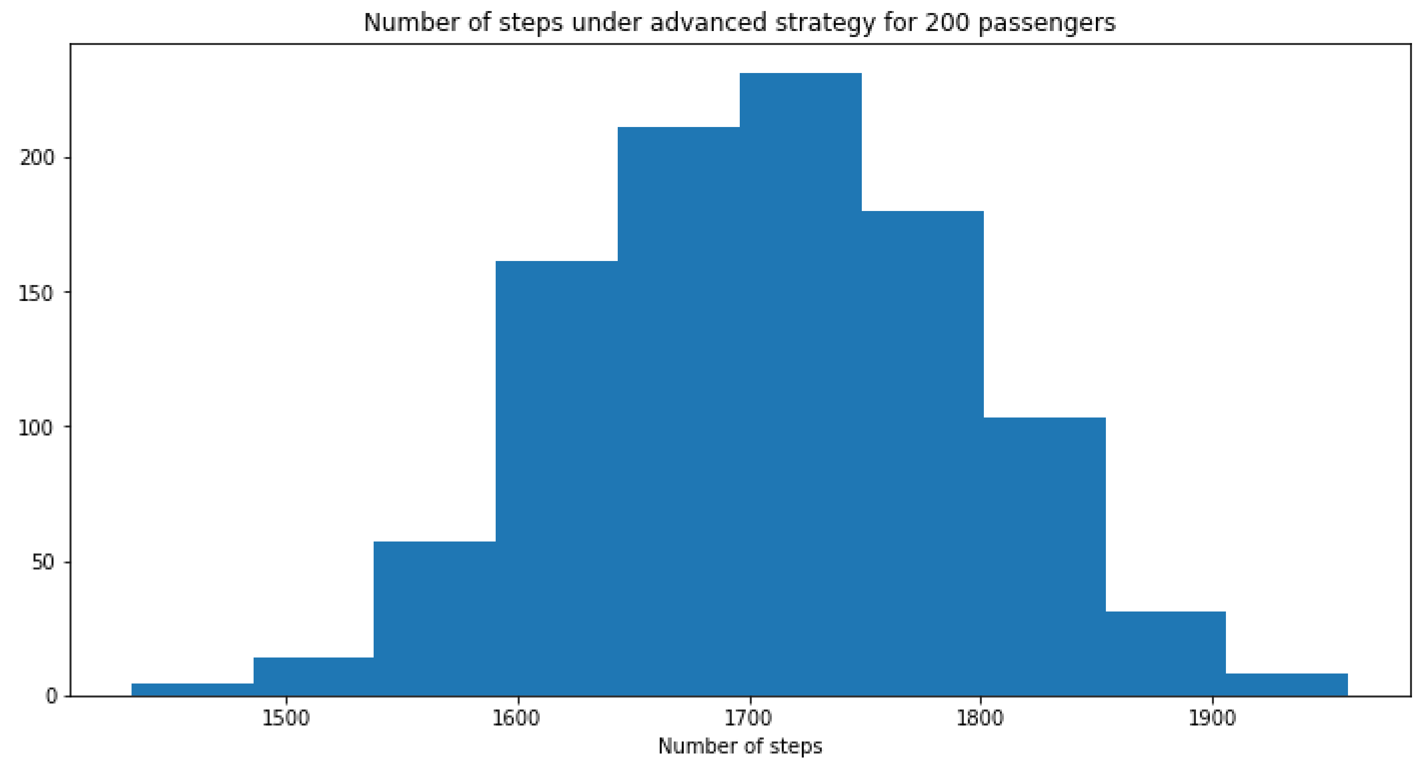
```
# run the simulation 1000 times and record the number of steps
for i in range(1000):
  building = Building(30, passenger)
  elevator = Elevator()
  basic_method_no_print(building,elevator, passenger)
  steps.append(elevator.step)

# plot the number of steps in a histogram
plt.figure(figsize= (12,6))
plt.hist(steps)
plt.title('Number of steps under basic strategy for 200 passengers')
plt.xlabel('Number of steps')
plt.show()
# find the mean, median and 95 interval
print("The mean number of steps is:", np.mean(steps))
print("The median number of steps is:", np.median(steps))
print("The 95% confidence interval is from:",np.quantile(steps,0.025),"to",np.quantile(steps,0.975))
```




```
The mean number of steps is: 2629.888
The median number of steps is: 2620.0
The 95% confidence interval is from: 2254.8 to 3080.4999999999995
```

```
steps = []
passenger = 200

# run the simulation with the advanced method 1000 times
for i in range(1000):
  building = Building(30, passenger)
  elevator = Elevator()
  advanced_method_no_print(building,elevator, passenger)
  steps.append(elevator.step)

# plot a histogram of the number of steps taken
plt.figure(figsize= (12,6))
plt.hist(steps)
```

```
plt.title('Number of steps under advanced strategy for 200 passengers')
plt.xlabel('Number of steps')
plt.show()


# find the mean, median and 95 interval
print("The mean number of steps is:", np.mean(steps))
print("The median number of steps is:", np.median(steps))
print("The 95% confidence interval is from:",np.quantile(steps,0.025),"to",np.quantile(steps,0.975))
```



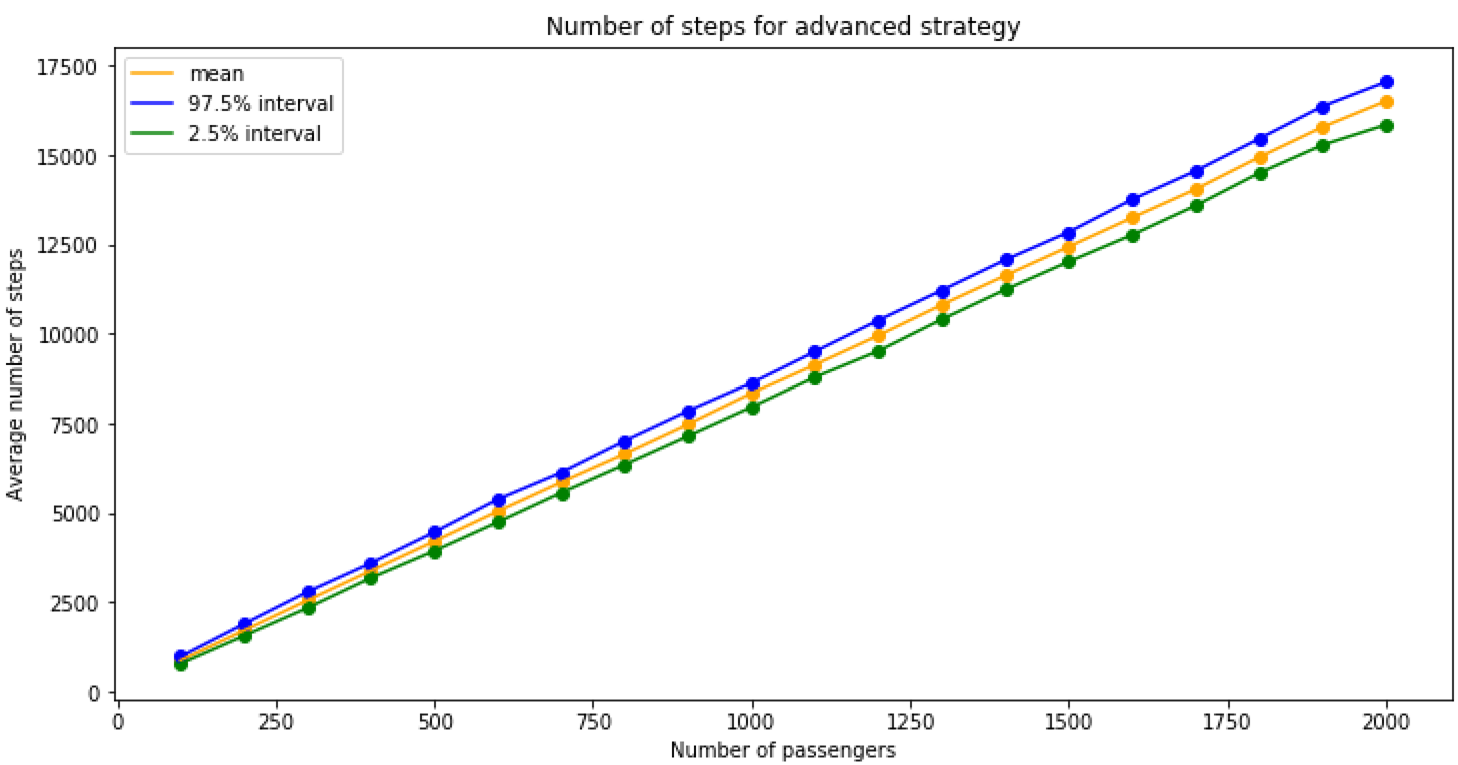

```
The mean number of steps is: 1707.85
The median number of steps is: 1708.0
The 95% confidence interval is from: 1554.9750000000001 to 1867.0500000000002
```

```
# variables to keep track of the advanced method
recorded_step_a = []
recorded_step_a_975 = []
recorded_step_a_025 = []
```

```

# variables to keep track of the basic method
recorded_step_b = []
recorded_step_b_975 = []
recorded_step_b_025 = []

# run the simulation for passenger numbers between 100 and 2000
for passenger in range(100, 2100, 100):
  steps = []
  # for every passenger number, run 100 times
  for i in range(100):
    building = Building(30, passenger)
    elevator = Elevator()
    advanced_method_no_print(building,elevator, passenger)
    steps.append(elevator.step)
  # add a datapoint about the average and 95% confidence interval
  recorded_step_a.append(np.mean(steps))
  recorded_step_a_975.append(np.quantile(steps, 0.975))
  recorded_step_a_025.append(np.quantile(steps, 0.025))

# do the same for the basic method
for passenger in range(100, 2100, 100):
  steps = []
  for i in range(100):
    building = Building(30, passenger)
    elevator = Elevator()
    basic_method_no_print(building,elevator, passenger)
    steps.append(elevator.step)
  # add a datapoint about the average and 95% confidence interval
  recorded_step_b.append(np.mean(steps))
  recorded_step_b_975.append(np.quantile(steps, 0.975))
  recorded_step_b_025.append(np.quantile(steps, 0.025))
```

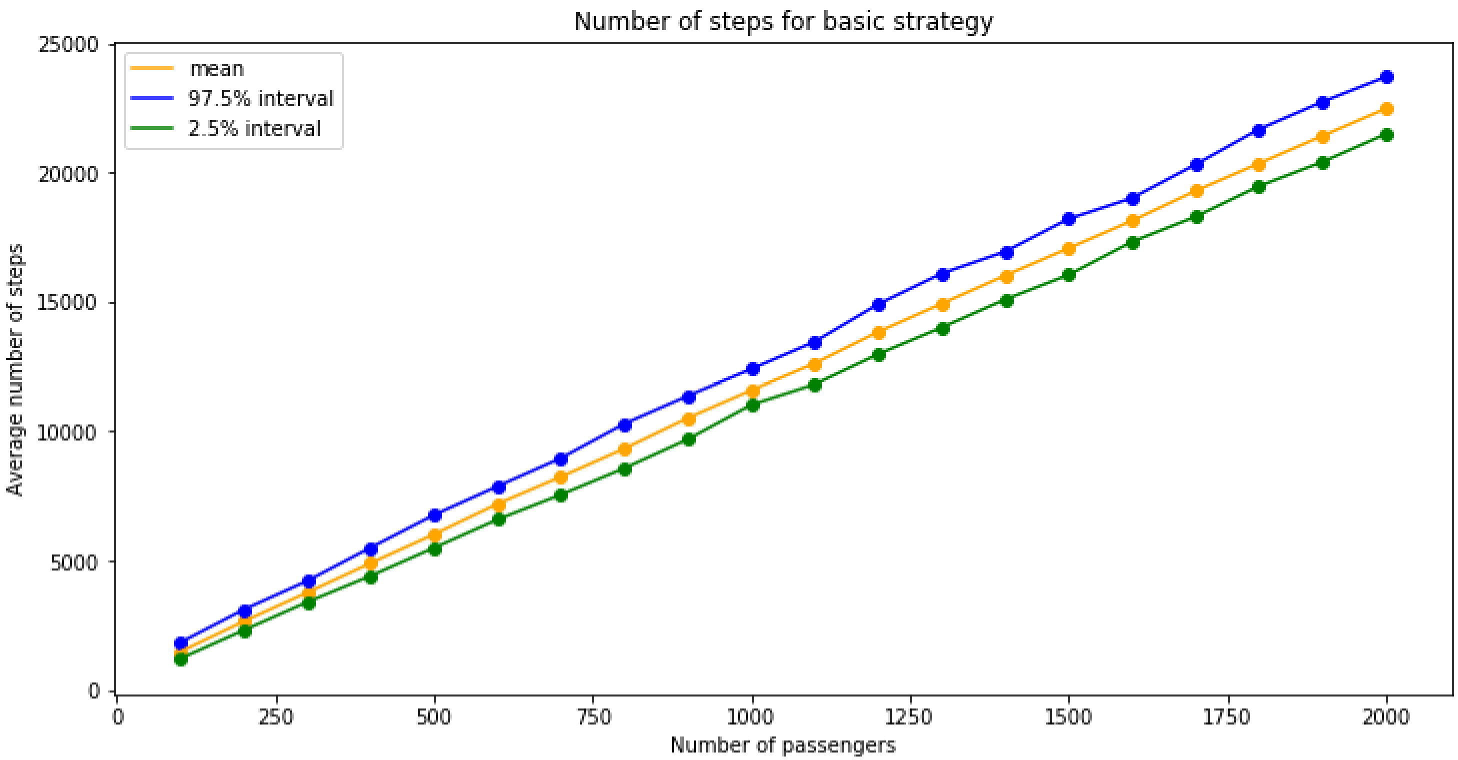
```
# plot all the findings on the same plot
plt.figure(figsize= (12,6))
plt.plot(range(100, 2100, 100), recorded_step_a, label = "mean", color = 'orange')
plt.plot(range(100, 2100, 100), recorded_step_a_975, label = "97.5% interval", color = 'blue')
plt.plot(range(100, 2100, 100), recorded_step_a_025, label = "2.5% interval", color = 'green')
plt.scatter(range(100, 2100, 100), recorded_step_a, color = 'orange')
```

```
plt.scatter(range(100, 2100, 100), recorded_step_a_025, color = 'green')
plt.scatter(range(100, 2100, 100), recorded_step_a_975, color = 'blue')
plt.legend()
plt.title('Number of steps for advanced strategy')
plt.xlabel('Number of passengers')
plt.ylabel('Average number of steps')
plt.show()
```




```

plt.figure(figsize= (12,6))
plt.plot(range(100, 2100, 100), recorded_step_b, label = "mean", color = 'orange')
plt.plot(range(100, 2100, 100), recorded_step_b_975, label = "97.5% interval", color = 'blue')
plt.plot(range(100, 2100, 100), recorded_step_b_025, label = "2.5% interval", color = 'green')
plt.scatter(range(100, 2100, 100), recorded_step_b, color = 'orange')
plt.scatter(range(100, 2100, 100), recorded_step_b_025, color = 'green')
plt.scatter(range(100, 2100, 100), recorded_step_b_975, color = 'blue')
plt.legend()
```

```
plt.title('Number of steps for basic strategy')
plt.xlabel('Number of passengers')
plt.ylabel('Average number of steps')
plt.show()
```




```
# compare the basic and advanced strategies

plt.figure(figsize= (12,6))

plt.plot(range(100, 2100, 100), recorded_step_a, label = "advanced method mean", color = 'red')
plt.plot(range(100, 2100, 100), recorded_step_a_975, label = "advanced method 95% interval", color = 'orange')
plt.plot(range(100, 2100, 100), recorded_step_a_025, color = 'orange')
plt.scatter(range(100, 2100, 100), recorded_step_a, color = 'red')
plt.scatter(range(100, 2100, 100), recorded_step_a_025, color = 'orange')
plt.scatter(range(100, 2100, 100), recorded_step_a_975, color = 'orange')

plt.plot(range(100, 2100, 100), recorded_step_b, label = "basic method mean", color = 'blue')
```

```
plt.plot(range(100, 2100, 100), recorded_step_b_975, label = "basic method 95% interval", color = 'green')
plt.plot(range(100, 2100, 100), recorded_step_b_025, color = 'green')
plt.scatter(range(100, 2100, 100), recorded_step_b, color = 'blue')
plt.scatter(range(100, 2100, 100), recorded_step_b_025, color = 'green')
plt.scatter(range(100, 2100, 100), recorded_step_b_975, color = 'green')
plt.scatter(range(100, 2100, 100), recorded_step_b)
plt.legend()
plt.title('Comparison of steps for basic and advanced strategies')
plt.xlabel("Number of passengers")
plt.ylabel("Average number of steps")
plt.show()
```