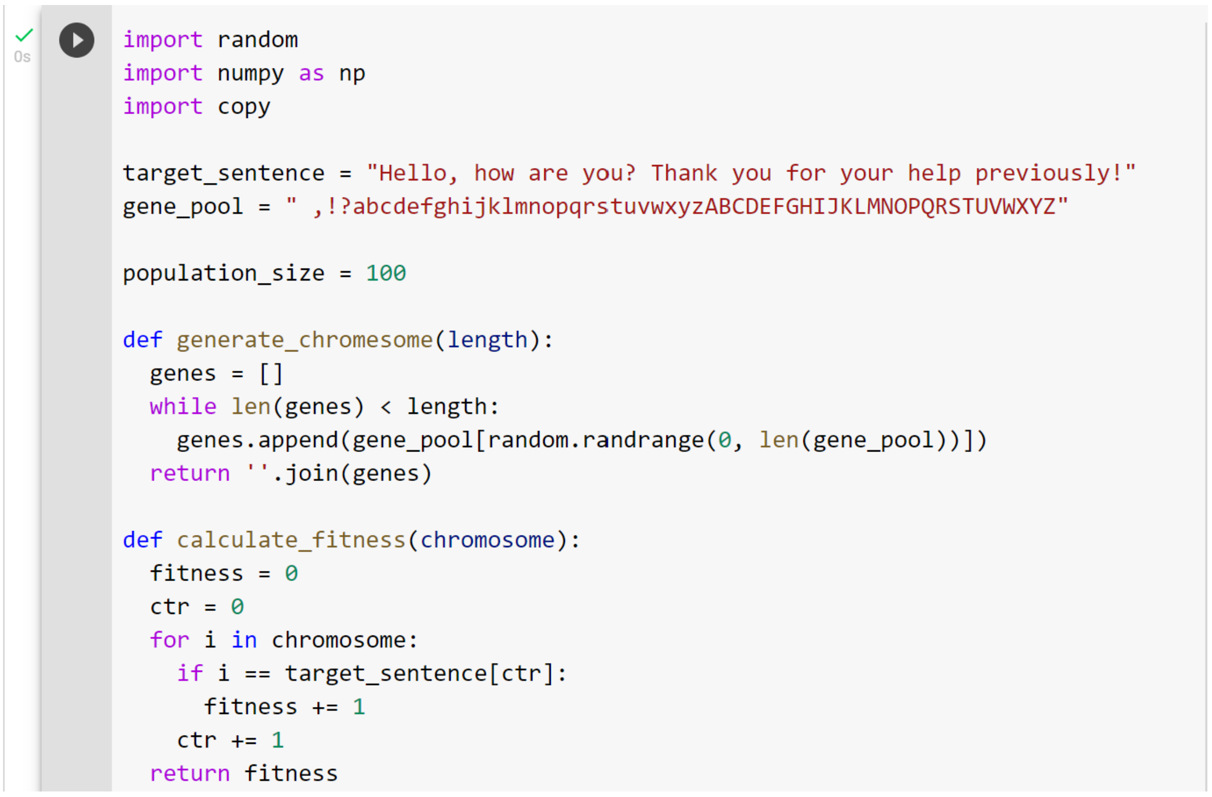
Homework4

Modify the program:

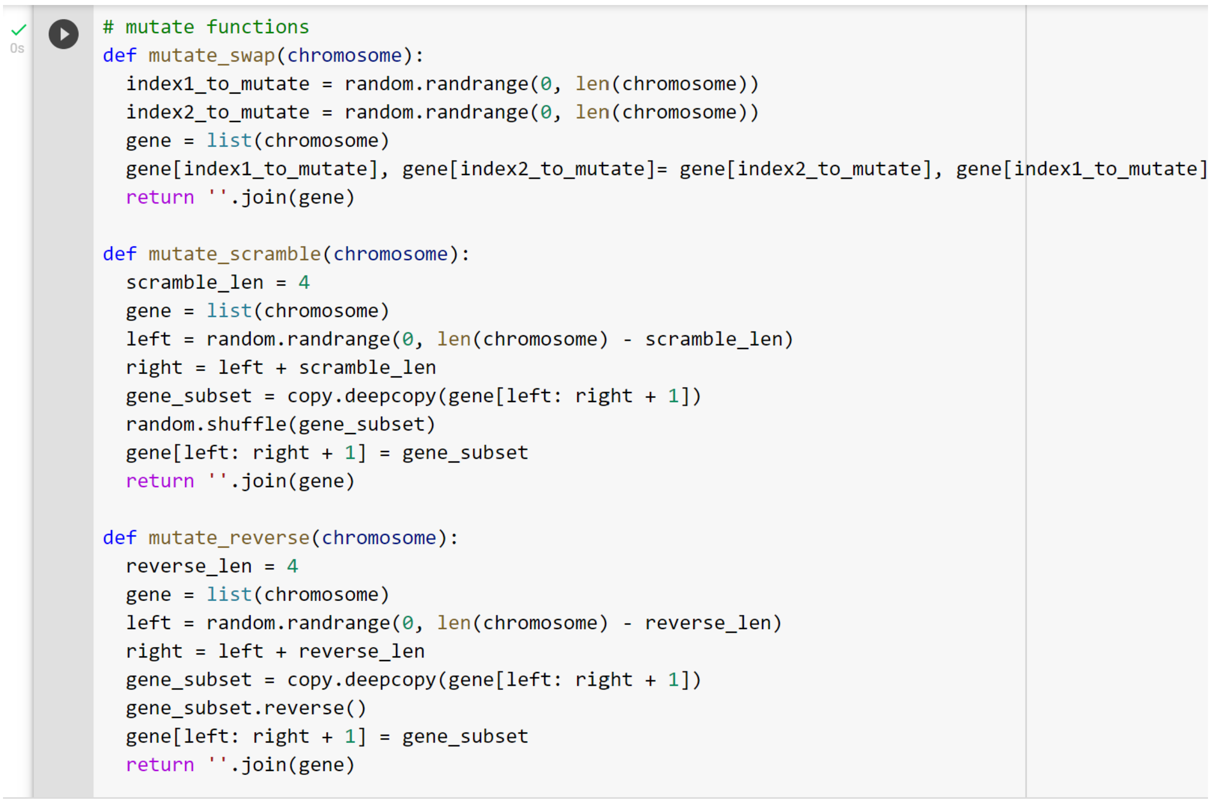
1. Create a crossover function
   - With any parents selection method
   - Split anywhere of your choice
2. Call the crossover function before mutating the chromosome
3. Insert the resulting crossover chromosomes into population

Evolve (feel free to experiment with the number of generation loop) and print the result



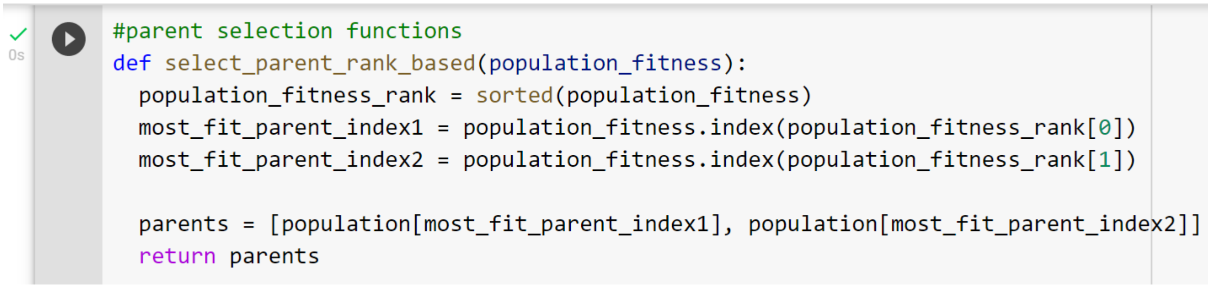
```python
import random
import numpy as np
import copy

target_sentence = "Hello, how are you? Thank you for your help previously!"
gene_pool = " ,!?abcdefghijklmnopqrstuvwxyzABCDEFGHIJKLMNOPQRSTUVWXYZ"

population_size = 100

def generate_chromesome(length):
  genes = []
  while len(genes) < length:
    genes.append(gene_pool[random.randrange(0, len(gene_pool))])
  return ''.join(genes)

def calculate_fitness(chromosome):
  fitness = 0
  ctr = 0
  for i in chromosome:
    if i == target_sentence[ctr]:
      fitness += 1
    ctr += 1
  return fitness
```

There are three mutate functions, but I used the same mutate() function as the slide in the generation loop in order to compare the results of generation and figure out how crossover functions affect the results of generation.



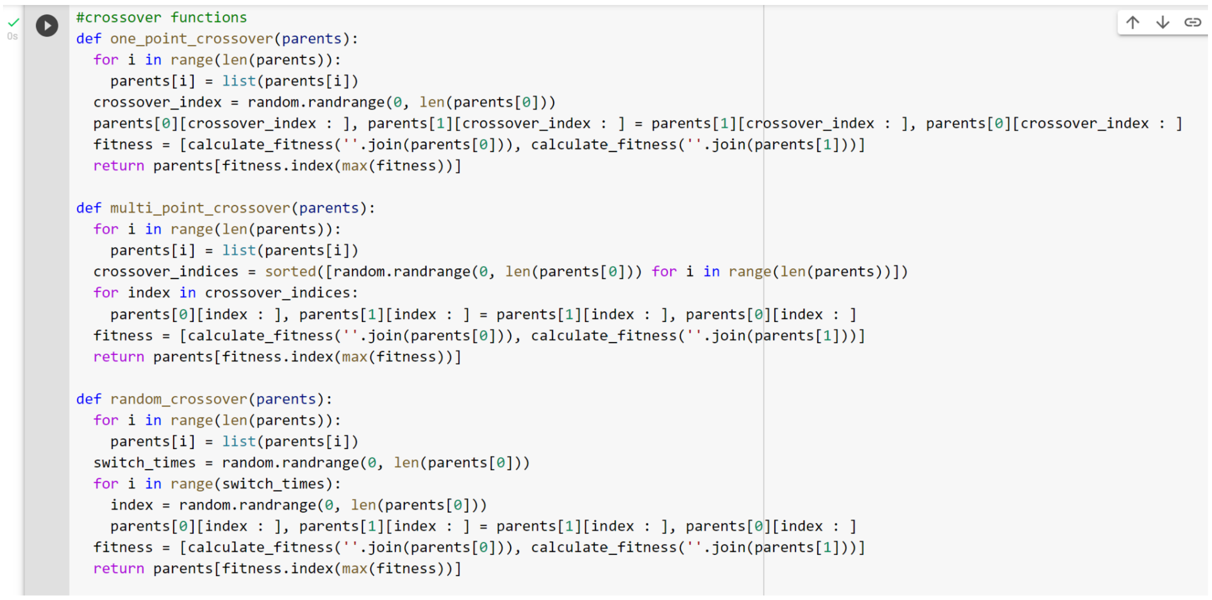
```python
# mutate functions
def mutate_swap(chromosome):
  index1_to_mutate = random.randrange(0, len(chromosome))
  index2_to_mutate = random.randrange(0, len(chromosome))
  gene = list(chromosome)
  gene[index1_to_mutate], gene[index2_to_mutate]= gene[index2_to_mutate], gene[index1_to_mutate]
  return ''.join(gene)

def mutate_scramble(chromosome):
  scramble_len = 4
  gene = list(chromosome)
  left = random.randrange(0, len(chromosome) - scramble_len)
  right = left + scramble_len
  gene_subset = copy.deepcopy(gene[left: right + 1])
  random.shuffle(gene_subset)
  gene[left: right + 1] = gene_subset
  return ''.join(gene)

def mutate_reverse(chromosome):
  reverse_len = 4
  gene = list(chromosome)
  left = random.randrange(0, len(chromosome) - reverse_len)
  right = left + reverse_len
  gene_subset = copy.deepcopy(gene[left: right + 1])
  gene_subset.reverse()
  gene[left: right + 1] = gene_subset
  return ''.join(gene)
```

Parents select functions based on rank.

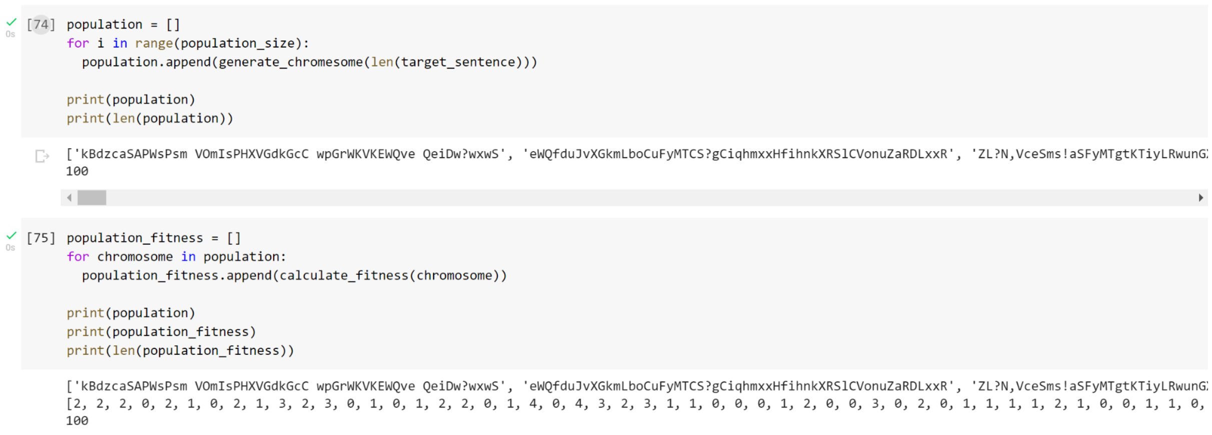


```python
#parent selection functions
def select_parent_rank_based(population_fitness):
  population_fitness_rank = sorted(population_fitness)
  most_fit_parent_index1 = population_fitness.index(population_fitness_rank[0])
  most_fit_parent_index2 = population_fitness.index(population_fitness_rank[1])

  parents = [population[most_fit_parent_index1], population[most_fit_parent_index2]]
  return parents
```

There are three crossover functions, including one_point_crossover(), multi_point_crossover(), and random_crossover(). The generation results by adopting different crossover methods are shown on the last page.

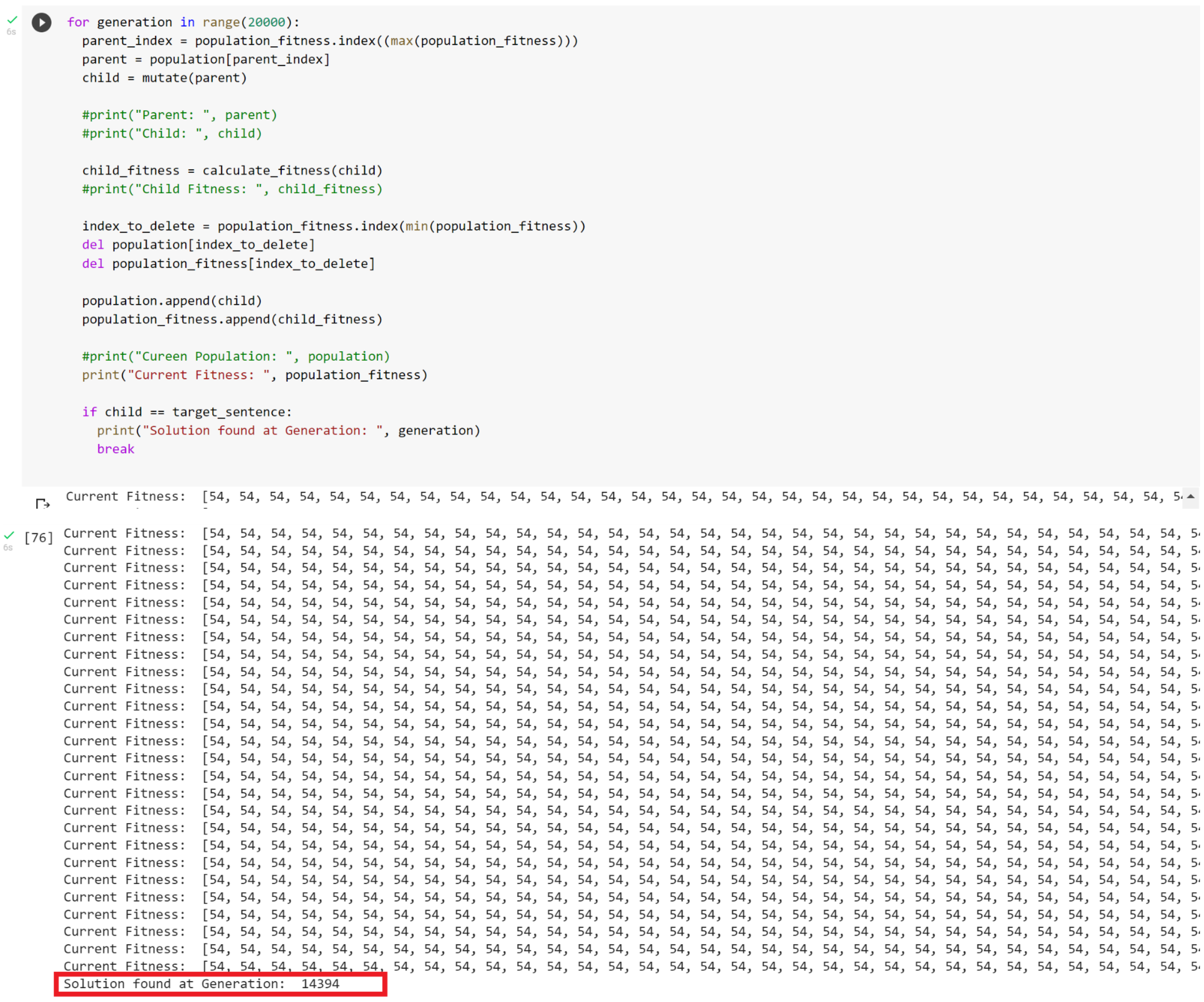


```python
#crossover functions
def one_point_crossover(parents):
  for i in range(len(parents)):
    parents[i] = list(parents[i])
  crossover_index = random.randrange(0, len(parents[0]))
  parents[0][crossover_index : ], parents[1][crossover_index : ] = parents[1][crossover_index : ], parents[0][crossover_index : ]
  fitness = [calculate_fitness(''.join(parents[0])), calculate_fitness(''.join(parents[1]))]
  return parents[fitness.index(max(fitness))]

def multi_point_crossover(parents):
  for i in range(len(parents)):
    parents[i] = list(parents[i])
  crossover_indices = sorted([random.randrange(0, len(parents[0])) for i in range(len(parents))])
  for index in crossover_indices:
    parents[0][index : ], parents[1][index : ] = parents[1][index : ], parents[0][index : ]
  fitness = [calculate_fitness(''.join(parents[0])), calculate_fitness(''.join(parents[1]))]
  return parents[fitness.index(max(fitness))]

def random_crossover(parents):
  for i in range(len(parents)):
    parents[i] = list(parents[i])
  switch_times = random.randrange(0, len(parents[0]))
  for i in range(switch_times):
    index = random.randrange(0, len(parents[0]))
    parents[0][index : ], parents[1][index : ] = parents[1][index : ], parents[0][index : ]
  fitness = [calculate_fitness(''.join(parents[0])), calculate_fitness(''.join(parents[1]))]
  return parents[fitness.index(max(fitness))]
```



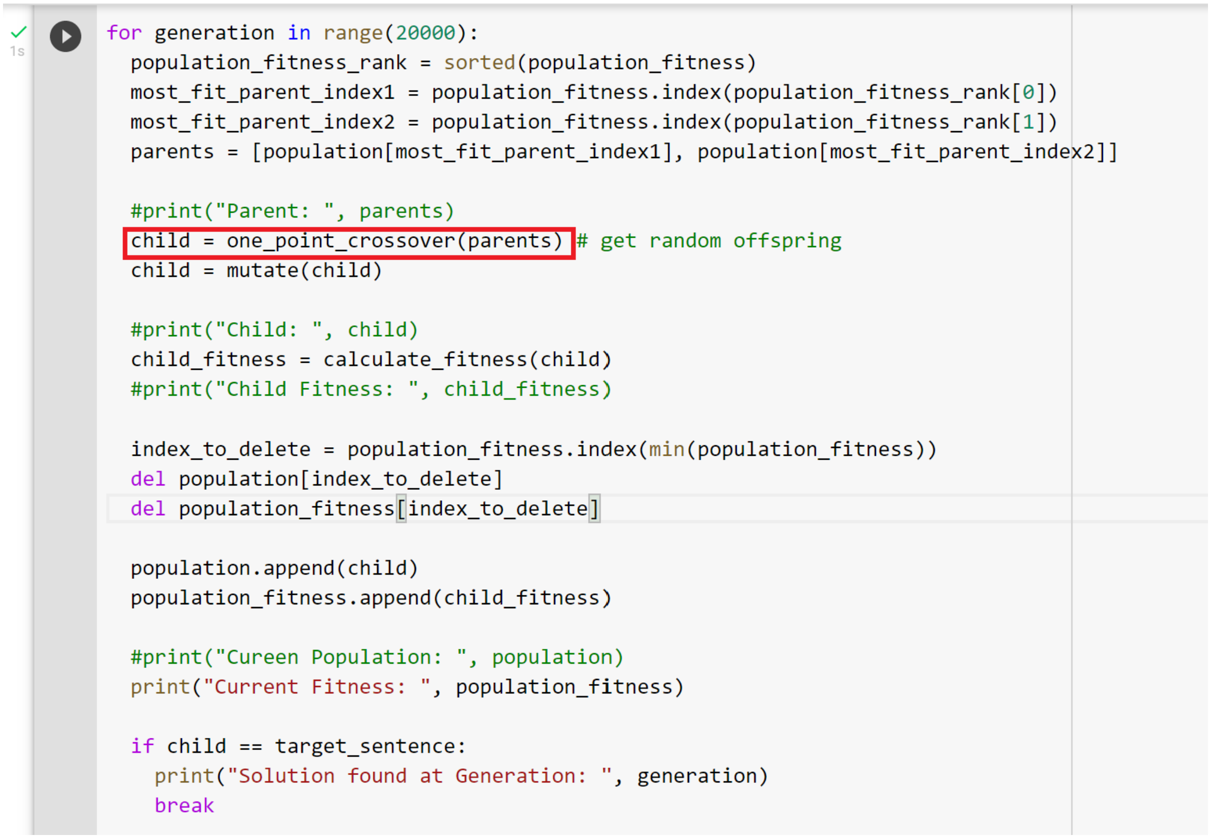
```
[74] population = []
     for i in range(population_size):
       population.append(generate_chromesome(len(target_sentence)))

     print(population)
     print(len(population))

     ['kBdzcaSAPWsPsm VOmIsPHXVGdkGcC wpGrWKVKEWQve QeiDw?wxwS', 'eWQfduJvXGkmLboCuFyMTCS?gCiqhmxxHfihnkXRSlCVonuZaRDLxxR', 'ZL?N,VceSms!aSFyMTgtKTiyLRwunG
     100

[75] population_fitness = []
     for chromosome in population:
       population_fitness.append(calculate_fitness(chromosome))

     print(population)
     print(population_fitness)
     print(len(population_fitness))

     ['kBdzcaSAPWsPsm VOmIsPHXVGdkGcC wpGrWKVKEWQve QeiDw?wxwS', 'eWQfduJvXGkmLboCuFyMTCS?gCiqhmxxHfihnkXRSlCVonuZaRDLxxR', 'ZL?N,VceSms!aSFyMTgtKTiyLRwunG
     [2, 2, 2, 0, 2, 1, 0, 2, 1, 3, 2, 3, 0, 1, 0, 1, 2, 2, 0, 1, 4, 0, 4, 3, 2, 3, 1, 1, 0, 0, 0, 1, 2, 0, 0, 3, 0, 2, 0, 1, 1, 1, 1, 2, 1, 0, 0, 1, 1, 0,
     100
```

The generation result without modifying the program.

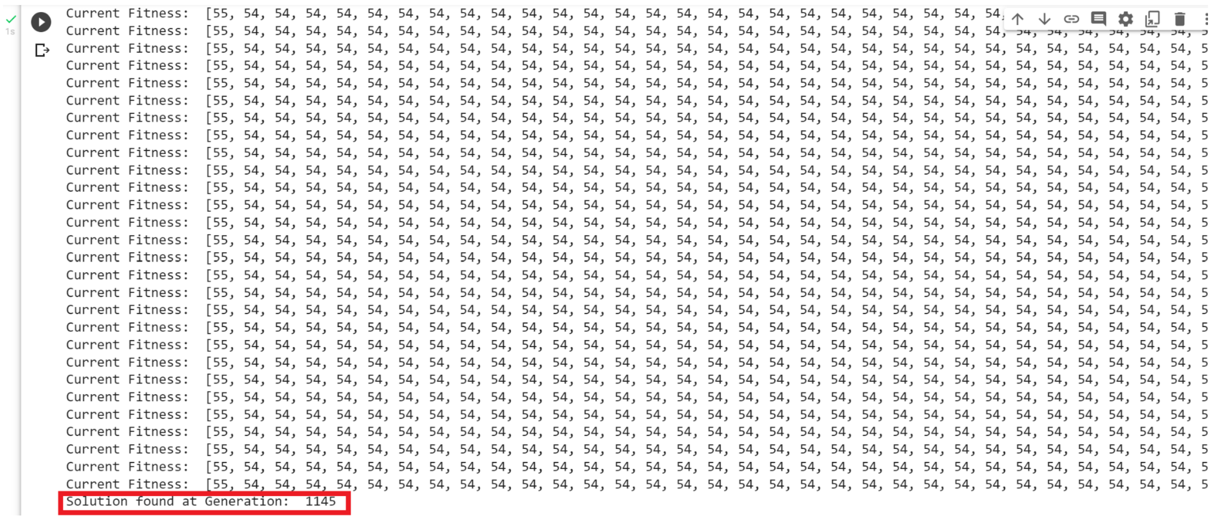


```
     for generation in range(20000):
       parent_index = population_fitness.index((max(population_fitness)))
       parent = population[parent_index]
       child = mutate(parent)

       #print("Parent: ", parent)
       #print("Child: ", child)

       child_fitness = calculate_fitness(child)
       #print("Child Fitness: ", child_fitness)

       index_to_delete = population_fitness.index(min(population_fitness))
       del population[index_to_delete]
       del population_fitness[index_to_delete]

       population.append(child)
       population_fitness.append(child_fitness)

       #print("Cureen Population: ", population)
       print("Current Fitness: ", population_fitness)

       if child == target_sentence:
         print("Solution found at Generation: ", generation)
         break

     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5

[76] Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Current Fitness:  [54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
     Solution found at Generation:  14394
```

The generation results by using one_point_crossover() function.

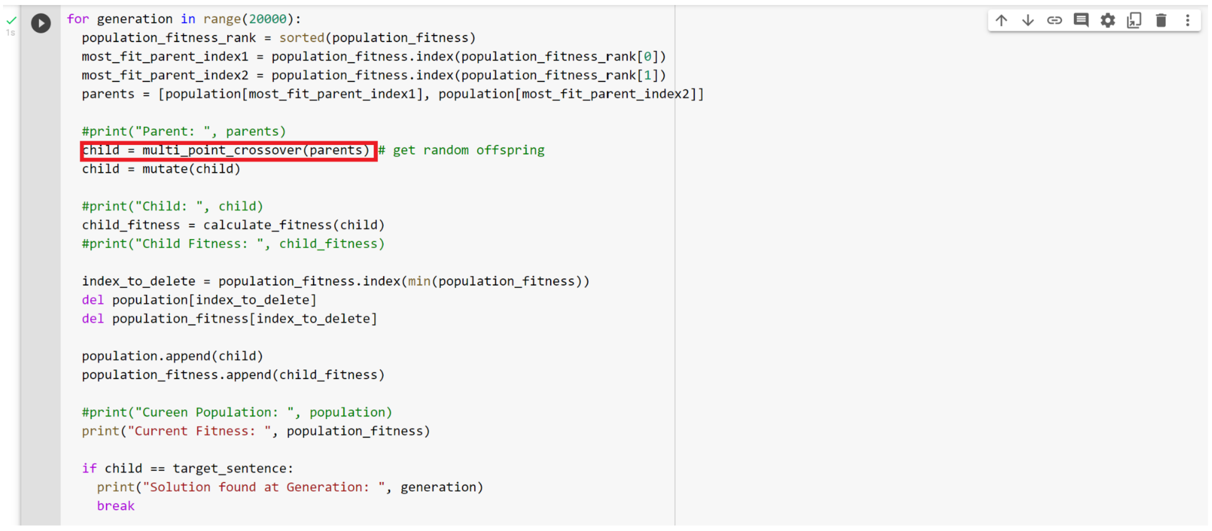


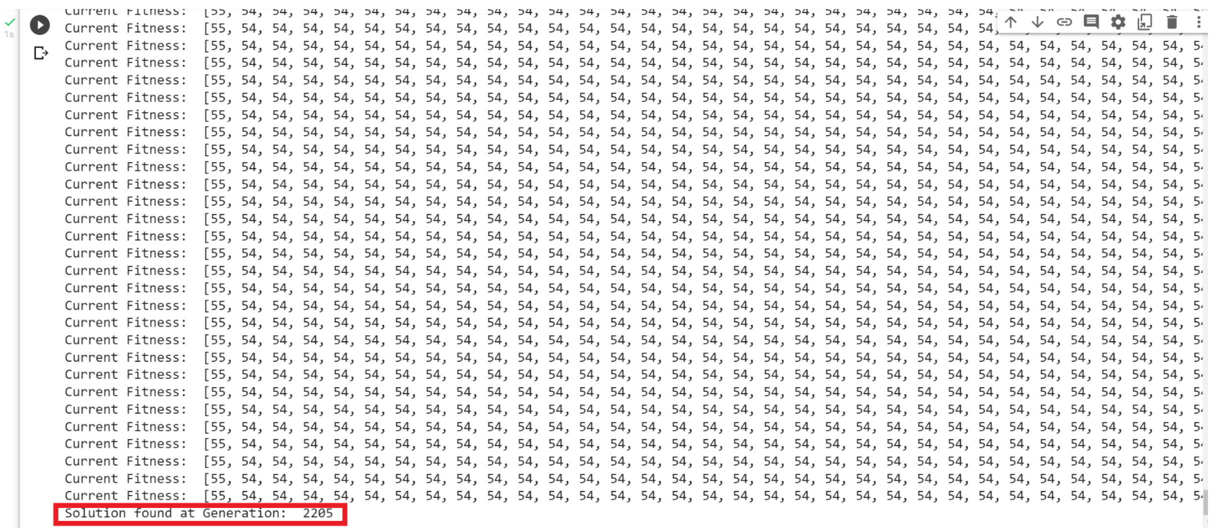
```python
for generation in range(20000):
  population_fitness_rank = sorted(population_fitness)
  most_fit_parent_index1 = population_fitness.index(population_fitness_rank[0])
  most_fit_parent_index2 = population_fitness.index(population_fitness_rank[1])
  parents = [population[most_fit_parent_index1], population[most_fit_parent_index2]]

  #print("Parent: ", parents)
  child = one_point_crossover(parents) # get random offspring
  child = mutate(child)

  #print("Child: ", child)
  child_fitness = calculate_fitness(child)
  #print("Child Fitness: ", child_fitness)

  index_to_delete = population_fitness.index(min(population_fitness))
  del population[index_to_delete]
  del population_fitness[index_to_delete]

  population.append(child)
  population_fitness.append(child_fitness)

  #print("Cureen Population: ", population)
  print("Current Fitness: ", population_fitness)

  if child == target_sentence:
    print("Solution found at Generation: ", generation)
    break
```



```
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54,
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54,
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
Solution found at Generation:  1145
```

The generation results by using multi_point_crossover() function.


```python
for generation in range(20000):
  population_fitness_rank = sorted(population_fitness)
  most_fit_parent_index1 = population_fitness.index(population_fitness_rank[0])
  most_fit_parent_index2 = population_fitness.index(population_fitness_rank[1])
  parents = [population[most_fit_parent_index1], population[most_fit_parent_index2]]

  #print("Parent: ", parents)
  child = multi_point_crossover(parents) # get random offspring
  child = mutate(child)

  #print("Child: ", child)
  child_fitness = calculate_fitness(child)
  #print("Child Fitness: ", child_fitness)

  index_to_delete = population_fitness.index(min(population_fitness))
  del population[index_to_delete]
  del population_fitness[index_to_delete]

  population.append(child)
  population_fitness.append(child_fitness)

  #print("Cureen Population: ", population)
  print("Current Fitness: ", population_fitness)

  if child == target_sentence:
    print("Solution found at Generation: ", generation)
    break
```


```
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54,
Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54,
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Current Fitness:  [55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 5
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Solution found at Generation:  2205
```
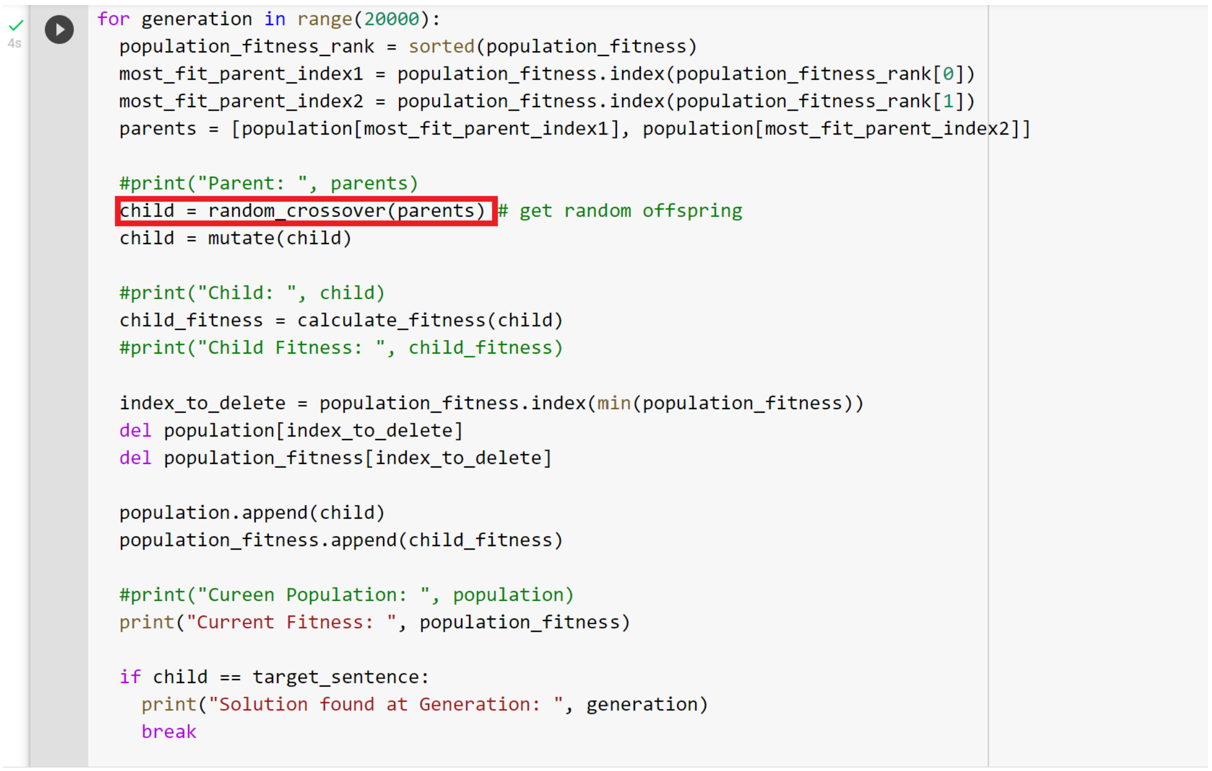

The generation results by using random_crossover() function.



```python
for generation in range(20000):
  population_fitness_rank = sorted(population_fitness)
  most_fit_parent_index1 = population_fitness.index(population_fitness_rank[0])
  most_fit_parent_index2 = population_fitness.index(population_fitness_rank[1])
  parents = [population[most_fit_parent_index1], population[most_fit_parent_index2]]

  #print("Parent: ", parents)
  child = random_crossover(parents) # get random offspring
  child = mutate(child)

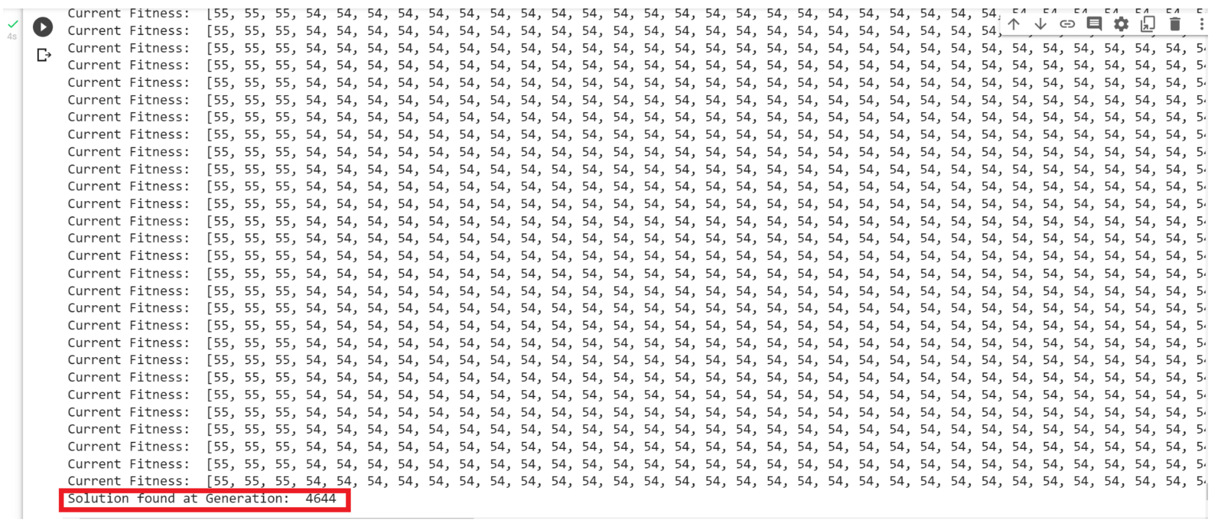
  #print("Child: ", child)
  child_fitness = calculate_fitness(child)
  #print("Child Fitness: ", child_fitness)

  index_to_delete = population_fitness.index(min(population_fitness))
  del population[index_to_delete]
  del population_fitness[index_to_delete]

  population.append(child)
  population_fitness.append(child_fitness)

  #print("Cureen Population: ", population)
  print("Current Fitness: ", population_fitness)

  if child == target_sentence:
    print("Solution found at Generation: ", generation)
    break
```



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Current Fitness:  [55, 55, 55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54,
Current Fitness:  [55, 55, 55, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54, 54,
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Solution found at Generation:  4644
```

The results show that the number of generation loops decreased after calling the crossover function before mutating the chromosome, and the performance of one_point_crossover() function is the best.