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GENETIC ALGORITHMS

Labs

Tutorial

for master's degree holders

according to the educational program "Software engineering of computer systems»
specialties 121 "Software engineering"

according to the educational program "Computer systems and networks»
specialty 123 "Computer engineering"

according to the educational program "Information management systems and technologies»
specialties 126 "Information systems and technologies»

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Lab 1 - Introduction to Genetic Algorithms - OneMax problem

(short version with Hall of Fame) based on (C) Eyal Wirsansky work

In this lab we introduce **DEAP** – a **powerful and flexible evolutionary computation** framework capable of solving real-life problems using **genetic algorithms (GA)**.

Brief Content:

- introduction,
- installation,
- main modules: *creator* and *toolbox*,
- components needed for the GA workflow,
- the simplest example, *the OneMax problem*, so called the Hello World of genetic algorithms.

By the end of this lab you will know:

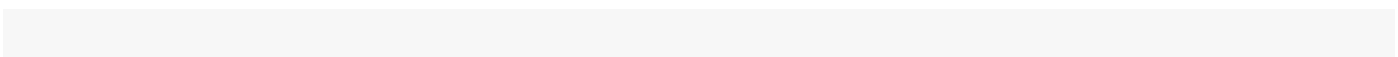
- the DEAP framework and its modules,
- the concepts of creator and toolbox in the DEAP framework,
- the simplest example of GA,
- how to create a GA solution using the DEAP framework,
- how to use the DEAP framework's built-in algorithms to produce concise code
- how to solve the OneMax problem using a GA coded with the DEAP framework,
- how to experiment with various settings of the GA and interpret the differences in the results.

▼ Installation and import of libraries

In these and other labs, we will use various Python packages:

- [NumPy](#)
- [Matplotlib](#)
- [Seaborn](#)

They are already pre-installed in Colab. Let's import them by the following code.



```
# Import all necessary standard libraries
import random
import numpy
import matplotlib.pyplot as plt
import seaborn as sns
```

Install DEAP by *pip* with the following code:

```
# Install DEAP
!pip install deap
```

```
Requirement already satisfied: deap in /usr/local/lib/python3.6/dist-packages
Requirement already satisfied: numpy in /usr/local/lib/python3.6/dist-package
```

```
# Import DEAP
from deap import base
from deap import creator
from deap import tools
from deap import algorithms
```

▼ Example: OneMax problem

▼ Constants

```
# Let's declare constants that set the parameters for the problem and control the l

# problem constants:
ONE_MAX_LENGTH = 100 # length of bit string to be optimized

# GA constants:
POPULATION_SIZE = 200
P_CROSSOVER = 0.9 # probability for crossover
P_MUTATION = 0.1 # probability for mutating an individual
MAX_GENERATIONS = 50
```

▼ Reproducibility of Results

One important aspect of the GA is the use of probability, which introduces a random element to the behavior of the algorithm.

However, **for reproducibility of results**, when experimenting with the code, we may want to be able to run the same experiment several times and get repeatable results.

To accomplish this, we set the random function seed to a constant number of some value, as shown in the following code:

```
# set the random seed:
RANDOM_SEED = 42
random.seed(RANDOM_SEED)
```

▼ Toolbox class

The **Toolbox** class is used as a container for functions (or operators), and enables us to create new operators by aliasing and customizing existing functions.

```
toolbox = base.Toolbox()
```

```
# For example, suppose we have a function, multiply() , defined as follows:
def multiply(a, b):
    return a*b
```

```
# Using toolbox, we can now create a new operator, incrementByFive(),
# which customizes the sumOfTwo() function as follows:
toolbox.register("MultiplyBy", multiply, b=5)
```

```
# examples:
A = toolbox.MultiplyBy(10)
print('toolbox.MultiplyBy(10) =', A)
B = multiply(10,5)
print('multiply(10,5) =', B)
```

```
    toolbox.MultiplyBy(10) = 50
    multiply(10,5) = 50
```

Let's create the *zeroOrOne* operator, which customizes the *random.randint(a, b)* function.

This function normally returns a random integer N such that $a \leq N \leq b$.

By fixing the two arguments, a and b , to the values 0 and 1 the *zeroOrOne* operator will randomly return either the value 0 or the value 1 when called later in the code.

```
# create an operator that randomly returns 0 or 1:
toolbox.register("zeroOrOne", random.randint, 0, 1)
```

```
# examples:
A = toolbox.zeroOrOne()
print('zeroOrOne =', A)
B = toolbox.zeroOrOne()
print('zeroOrOne =', B)
C = toolbox.zeroOrOne()
print('zeroOrOne =', C)
D = toolbox.zeroOrOne()
print('zeroOrOne =', D)
```

```
    zeroOrOne = 0
```

```
zeroOrOne = 0
zeroOrOne = 1
zeroOrOne = 0
```

▼ Fitness class

Next, we need to create the *Fitness* class. Since we only have one objective here—the sum of digits—and our goal is to maximize it, we choose the *FitnessMax* strategy, using a weights tuple with a single positive weight, as shown in the following code.

```
# define a single objective, maximizing fitness strategy:
creator.create("FitnessMax", base.Fitness, weights=(1.0,))
```

```
A = base.Fitness.weights
print(A)
```

```
None
```

In DEAP, the *Individual* class is used to represent each of the population's individuals. This class is created with the help of the creator tool. In our case, *list* serves as the base class, which is used as the individual's chromosome. The class is augmented with the fitness attribute, initialized to the *FitnessMax* class that we defined earlier

```
# create the Individual class based on list:
creator.create("Individual", list, fitness=creator.FitnessMax)
#creator.create("Individual", array.array, typecode='b', fitness=creator.FitnessMax)
```

Next, register the *individualCreator* operator, which creates an instance of the *Individual* class, filled up with random values of either 0 or 1 . This is done by customizing the previously defined *zeroOrOne* operator.

Since the objects generated by the *zeroOrOne* operator are integers with random values of either 0 or 1 , the resulting *individualCreator* operator will fill an *Individual* instance with 100 randomly generated values of 0 or 1.

```
# create the individual operator to fill up an Individual instance:
toolbox.register("individualCreator", # Register the individualCreator operator,
                tools.initRepeat,    # The initRepeat operator is customized here
                creator.Individual,  # The container type (Individual) in which
                toolbox.zeroOrOne,    # The function used to generate objects (=
                ONE_MAX_LENGTH)      # The number of objects we want to generate
```

Register the *populationCreator* operator that creates a list of individuals.

```
# create the population operator to generate a list of individuals:
toolbox.register("populationCreator", # Register the populationCreator operator,
                tools.initRepeat,    # The initRepeat operator is customized here
                list,                 # The container type (list) in which the results are stored
                toolbox.individualCreator) # The function used to generate objects
```

Define the function *oneMaxFitness* that computes the number of 1s in the individual.

```
# fitness calculation:
# compute the number of '1's in the individual
def oneMaxFitness(individual):
    return sum(individual), # return a tuple,
                        # fitness values in DEAP are represented as tuples,
                        # and therefore a comma needs to follow when a single value is returned
```

Define the *evaluate* operator as an alias to the *oneMaxFitness()* function we defined earlier.

```
# create the evaluate alias for calculating the fitness (by a DEAP convention)
toolbox.register("evaluate", oneMaxFitness)
```

▼ Genetic operators

The genetic operators are typically created by aliasing existing functions from the tools module and setting the argument values as needed.

Note: The *mutFlipBit* function iterates over all the attributes of the individual, a list with values of 1s and 0s in our case, and for each attribute will use the argument value (*indpb* parameter) as the probability of flipping (applying the not operator to) the attribute value. This value is independent of the mutation probability, which is set by the *P_MUTATION* constant that we defined earlier and has not yet been used. The mutation probability serves to decide if the *mutFlipBit* function is called for a given individual in the population.

```
# genetic operators:

# Tournament selection with tournament size of 3:
toolbox.register("select", tools.selTournament, tournsize=3)

# Single-point crossover:
toolbox.register("mate", tools.cxOnePoint)

# Flip-bit mutation:
# indpb: Independent probability for each attribute to be flipped
toolbox.register("mutate", tools.mutFlipBit, indpb=1.0/ONE_MAX_LENGTH)
```

▼ GA workflow

```
# create initial population (generation 0):
population = toolbox.populationCreator(n=POPULATION_SIZE)
```

▼ Short version with 'Hall of Fame' (HoF)

Let's consider the additional feature of the built-in *algorithms.eaSimple* method - the hall of fame (HoF). It is implemented as *HallOfFame* class that can be used to retain the best individuals that ever existed in the population during the evolution, even if they have been lost at some point due to selection, crossover, or mutation. HoF is continuously sorted so that the first element is **the first individual** that had **the best fitness value** ever seen.

```
# prepare the statistics object:
stats = tools.Statistics(lambda ind: ind.fitness.values)
stats.register("max", numpy.max)
stats.register("avg", numpy.mean)

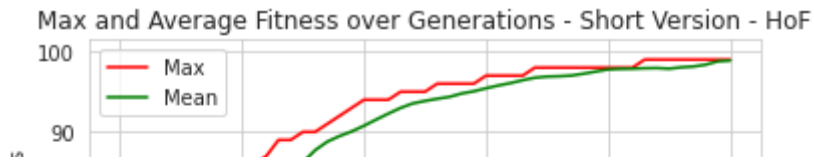
# define the hall-of-fame object:
HALL_OF_FAME_SIZE = 10
hof = tools.HallOfFame(HALL_OF_FAME_SIZE)

# perform the Genetic Algorithm flow with hof feature added:
population, logbook = algorithms.eaSimple(population, toolbox, cxpb=P_CROSSOVER, mu
                                         ngen=MAX_GENERATIONS, stats=stats, hof=hof)

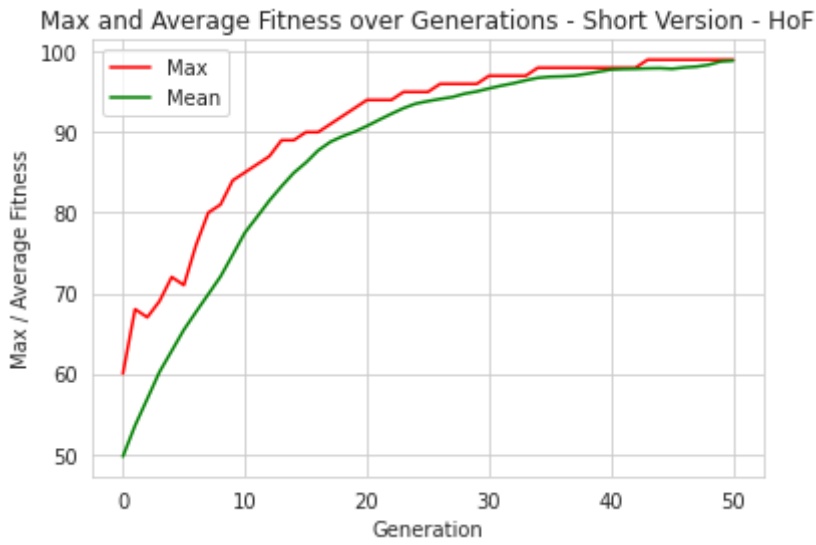
# print Hall of Fame info:
print("Hall of Fame Individuals = ", *hof.items, sep="\n")
print("Best Ever Individual = ", hof.items[0])

# Genetic Algorithm is done - extract statistics:
maxFitnessValues, meanFitnessValues = logbook.select("max", "avg")
```

gen	nevals	max	avg
0	200	60	49.705
1	190	68	53.56
2	175	67	56.87
3	179	69	60.21
4	175	72	62.825
5	184	71	65.45
6	178	76	67.68
7	187	80	69.865
8	189	81	72.055
9	184	84	74.765
10	185	85	77.515
11	181	86	79.485
12	190	87	81.49
13	181	89	83.27
14	184	89	84.94
15	189	90	86.22
16	176	90	87.725
17	176	91	88.79



You should get the following output:



Evolutionary Algorithms (EA) Basics

Lab 2 - Applications of EA based on (C) Eyal Wirsansky work

Brief Content:

- DEAP installation (**every time after start of Colab VM!**),
- main modules: *creator* and *toolbox*,
- components needed for the GA workflow,
- *Knapsack problem*,
- *Traveling Salesperson Problem*.

By the end of this lab you will know:

- again, how to use the DEAP framework's built-in algorithms to produce concise code
- how to solve the Knapsack problem using a GA coded with the DEAP framework,
- how to experiment with various settings of the GA and interpret the differences in the results.

▼ Installation and import of libraries

IMPORTANT: Mount your Google Drive!

At left sidebar -> click "Files" icon, then click "Mount Drive" icon with Google Drive logo, follow instructions.

```
# Copy all lab-related materials from Google Drive to your current location at Goo
! cp -r /content/drive/MyDrive/COLAB_EVO/EVO_Lab01/* .
```

```
# Check the folders/files copied
! ls
```

```
drive          EVO_Lab01          knapsack.py      tsp.py
elitism.py     EVO_Lab01_A_bag.ipynb  sample_data     vrp.py
```

In these and other lectures, we will use various Python packages:

- [NumPy](#)
- [Matplotlib](#)

- [Seaborn](#)

They are already pre-installed in Colab. Let's import them by the following code.

```
# Import all necessary standard libraries
import random
import numpy as np

import matplotlib.pyplot as plt
import seaborn as sns
```

Install DEAP by *pip* with the following code:

```
# Install DEAP
!pip install deap
```

```
Requirement already satisfied: deap in /usr/local/lib/python3.6/dist-packages
Requirement already satisfied: numpy in /usr/local/lib/python3.6/dist-package
```

```
# Import DEAP
from deap import base
from deap import creator
from deap import tools
from deap import algorithms
```

-
- ▼ Here the difference is started for these new examples!
 - ▼ Example 1: Knapsack problem (0-1 type)

[Rosetta Code's Description:](#)

A tourist wants to make a good trip at the weekend with his friends.

They will go to the mountains to see the wonders of nature, so he needs to pack well for the trip.

He has a good knapsack for carrying things, but knows that he can carry a maximum of only 4kg in it, and it will have to last the whole day.

He creates a list of what he wants to bring for the trip but the total weight of all items is too much.

He then decides to add columns to his initial list detailing their weights and a numerical value representing how important the item is for the trip.

The tourist can choose to take any combination of items from the list, but only one of each item is available.

He may not cut or diminish the items, so he can only take whole units of any item.

Task

Show which items the tourist can carry in his knapsack so that their total weight does not exceed 400 dag [4 kg], and their total value is maximized. Note: [dag = decagram = 10 grams]

```
# knapsack example-specific library
import knapsack
```

▼ Constants

```
# Let's declare constants that set the parameters for the problem and control the
# problem constants:
# create the knapsack problem instance to be used:
knapsack = knapsack.Knapsack01Problem()

# GA constants:
POPULATION_SIZE = 50
P_CROSSOVER = 0.9 # probability for crossover
P_MUTATION = 0.1 # probability for mutating an individual
MAX_GENERATIONS = 50
```

▼ Reproducibility of Results

One important aspect of the GA is the use of probability, which introduces a random element to the behavior of the algorithm.

However, **for reproducibility of results**, when experimenting with the code, we may want to be able to run the same experiment several times and get repeatable results.

To accomplish this, we set the random function seed to a constant number of some value, as shown in the following code:

```
# set the random seed:
RANDOM_SEED = 42
random.seed(RANDOM_SEED)
```

▼ Toolbox class

The **Toolbox** class is used as a container for functions (or operators), and enables us to create new operators by aliasing and customizing existing functions.

```
toolbox = base.Toolbox()
```

```
# For example, suppose we have a function, multiply() , defined as follows:
def multiply(a, b):
    return a*b

# Using toolbox, we can now create a new operator, incrementByFive(),
# which customizes the sumOfTwo() function as follows:
toolbox.register("MultiplyBy", multiply, b=5)

# examples:
A = toolbox.MultiplyBy(10)
print('toolbox.MultiplyBy(10) =', A)
B = multiply(10,5)
print('multiply(10,5) =', B)

    toolbox.MultiplyBy(10) = 50
    multiply(10,5) = 50
```

Let's create the *zeroOrOne* operator, which customizes the *random.randint(a, b)* function.

This function normally returns a random integer N such that $a \leq N \leq b$.

By fixing the two arguments, a and b , to the values 0 and 1 the *zeroOrOne* operator will randomly return either the value 0 or the value 1 when called later in the code.

```
# create an operator that randomly returns 0 or 1:
toolbox.register("zeroOrOne", random.randint, 0, 1)

# examples:
A = toolbox.zeroOrOne()
print('zeroOrOne =', A)
B = toolbox.zeroOrOne()
print('zeroOrOne =', B)
C = toolbox.zeroOrOne()
print('zeroOrOne =', C)
D = toolbox.zeroOrOne()
print('zeroOrOne =', D)

    zeroOrOne = 0
    zeroOrOne = 0
    zeroOrOne = 1
    zeroOrOne = 0
```

▼ Fitness class

Next, we need to create the *Fitness* class. Since we only have one objective here—the sum of digits—and our goal is to maximize it, we choose the *FitnessMax* strategy, using a weights tuple with a single positive weight, as shown in the following code.

```
# define a single objective, maximizing fitness strategy:
creator.create("FitnessMax", base.Fitness, weights=(1.0,))
```

```
A = base.Fitness.weights
print(A)
```

None

In DEAP, the *Individual* class is used to represent each of the population's individuals. This class is created with the help of the creator tool. In our case, list serves as the base class, which is used as the individual's chromosome. The class is augmented with the fitness attribute, initialized to the *FitnessMax* class that we defined earlier

```
# create the Individual class based on list:
creator.create("Individual", list, fitness=creator.FitnessMax)
```

```
/usr/local/lib/python3.6/dist-packages/deap/creator.py:141: RuntimeWarning: A
RuntimeWarning)
```

Next, register the *individualCreator* operator, which creates an instance of the *Individual* class, filled up with random values of either 0 or 1 . This is done by customizing the previously defined *zeroOrOne* operator.

Since the objects generated by the *zeroOrOne* operator are integers with random values of either 0 or 1 , the resulting *individualCreator* operator will fill an *Individual* instance with 100 randomly generated values of 0 or 1.

```
# create the individual operator to fill up an Individual instance:
toolbox.register("individualCreator", # Register the individualCreator operator,
                tools.initRepeat,   # The initRepeat operator is customized he
                creator.Individual, # The container type (Individual) in which
                toolbox.zeroOrOne,   # The function used to generate objects (=
                len(knapsack))      # The number of objects we want to generate
```

Register the *populationCreator* operator that creates a list of individuals.

```
# create the population operator to generate a list of individuals:
toolbox.register("populationCreator", # Register the populationCreator operator,
                tools.initRepeat,   # The initRepeat operator is customized he
                list,               # The container type (list) in which the r
                toolbox.individualCreator) # The function used to generate object
```

▼ Fitness function

Define the function *knapsackValue* that computes the fitness.

```
# fitness calculation:
# compute the number of '1's in the individual
```

```
def knapsackValue(individual):
    return knapsack.getValue(individual), # return a tuple,
                                           # fitness values in DEAP are represented
                                           # and therefore a comma needs to follow
```

Define the *evaluate* operator as an alias to the *knapsackValue()* function we defined earlier.

```
# create the evaluate alias for calculating the fitness (by a DEAP convention)
toolbox.register("evaluate", knapsackValue)
```

▼ Genetic operators

The genetic operators are typically created by aliasing existing functions from the tools module and setting the argument values as needed.

Note: The *mutFlipBit* function iterates over all the attributes of the individual, a list with values of 1s and 0s in our case, and for each attribute will use the argument value (*indpb* parameter) as the probability of flipping (applying the not operator to) the attribute value. This value is independent of the mutation probability, which is set by the *P_MUTATION* constant that we defined earlier and has not yet been used. The mutation probability serves to decide if the *mutFlipBit* function is called for a given individual in the population.

```
# genetic operators:

# Tournament selection with tournament size of 3:
toolbox.register("select", tools.selTournament, tournsize=3)

# Single-point crossover:
toolbox.register("mate", tools.cxOnePoint)

# or
# Two-point crossover:
# toolbox.register("mate", tools.cxTwoPoint)

# Flip-bit mutation:
# indpb: Independent probability for each attribute to be flipped
toolbox.register("mutate", tools.mutFlipBit, indpb=1.0/len(knapsack))
```

GA workflow

▼ Create population of individual solutions

```
# create initial population (generation 0):
population = toolbox.populationCreator(n=POPULATION_SIZE)
```



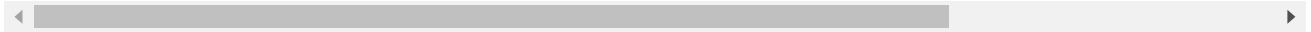
```
# let's check the population created...
population
```

```
[[1, 0, 1, 0, 0, 0, 1, 0, 0, 1, 0, 1, 1, 1, 1, 1, 1, 0, 0, 0, 1, 0],
 [0, 0, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 1, 0, 0, 0, 1, 0, 1, 1, 0, 1],
 [0, 0, 0, 1, 0, 1, 1, 1, 0, 0, 0, 1, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1],
 [1, 1, 0, 1, 1, 1, 1, 1, 1, 0, 0, 1, 1, 0, 0, 1, 1, 1, 0, 0, 0, 0],
 [0, 0, 0, 0, 0, 1, 0, 0, 1, 1, 1, 0, 1, 0, 1, 0, 0, 0, 1, 1, 0, 0],
 [0, 0, 1, 0, 1, 0, 0, 0, 1, 1, 0, 0, 0, 1, 0, 1, 0, 0, 1, 1, 1, 1],
 [1, 0, 1, 0, 0, 0, 0, 0, 1, 0, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 1],
 [0, 0, 1, 0, 1, 1, 1, 1, 1, 0, 0, 1, 0, 0, 0, 1, 0, 0, 0, 1, 1, 1],
 [1, 0, 1, 1, 0, 0, 0, 0, 1, 1, 1, 0, 1, 0, 0, 1, 0, 0, 1, 0, 1, 0],
 [0, 1, 0, 0, 1, 0, 1, 1, 1, 1, 0, 0, 0, 1, 1, 0, 1, 1, 1, 0, 1, 1],
 [0, 0, 0, 1, 1, 0, 1, 1, 1, 0, 0, 0, 1, 1, 0, 0, 1, 0, 1, 0, 0, 1],
 [0, 1, 0, 0, 0, 1, 0, 1, 0, 0, 0, 1, 0, 0, 0, 1, 0, 0, 0, 1, 1, 0],
 [0, 0, 1, 0, 1, 0, 0, 1, 1, 1, 0, 0, 0, 1, 1, 0, 1, 1, 1, 0, 0, 0],
 [0, 1, 0, 1, 1, 1, 1, 0, 0, 0, 1, 0, 1, 1, 0, 0, 0, 1, 1, 0, 1, 0],
 [1, 1, 1, 0, 1, 0, 1, 0, 0, 1, 0, 1, 0, 1, 1, 0, 1, 1, 0, 0, 1, 0],
 [0, 1, 0, 1, 1, 1, 1, 0, 0, 0, 1, 0, 1, 1, 0, 0, 0, 1, 1, 0, 1, 0],
 [1, 1, 1, 0, 1, 0, 1, 0, 0, 1, 0, 1, 0, 1, 1, 0, 1, 0, 0, 1, 1, 0],
 [1, 1, 1, 0, 1, 1, 0, 1, 1, 1, 0, 0, 1, 1, 1, 1, 0, 1, 1, 1, 1, 1],
 [0, 0, 0, 0, 0, 1, 1, 0, 1, 0, 1, 0, 0, 1, 0, 1, 0, 0, 1, 0, 1, 1],
 [1, 0, 1, 0, 0, 1, 1, 1, 0, 1, 1, 0, 0, 1, 1, 0, 1, 1, 0, 0, 1, 1],
 [0, 1, 0, 0, 0, 1, 0, 1, 0, 0, 0, 1, 0, 0, 0, 1, 0, 0, 0, 1, 1, 1],
 [0, 0, 1, 0, 1, 1, 1, 0, 0, 0, 1, 1, 1, 1, 1, 1, 0, 1, 0, 1, 0, 0],
 [1, 1, 0, 0, 0, 1, 1, 1, 0, 0, 1, 1, 1, 1, 0, 0, 0, 0, 1, 1, 0, 0],
 [0, 1, 1, 1, 1, 1, 0, 1, 0, 0, 1, 1, 1, 1, 1, 0, 0, 0, 1, 1, 1, 0],
 [0, 0, 1, 0, 1, 1, 0, 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 1, 0, 1, 1, 0],
 [1, 1, 0, 0, 1, 0, 1, 1, 0, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 0, 0],
 [0, 0, 0, 1, 1, 1, 0, 1, 0, 1, 0, 0, 1, 0, 0, 1, 1, 1, 1, 0, 1, 1],
 [1, 1, 0, 0, 1, 1, 1, 0, 0, 0, 0, 1, 0, 1, 0, 1, 1, 0, 0, 0, 1, 1],
 [0, 1, 0, 1, 1, 1, 0, 0, 1, 1, 1, 1, 0, 1, 1, 0, 0, 0, 0, 1, 1, 0],
 [0, 0, 0, 1, 0, 1, 1, 1, 0, 1, 0, 0, 0, 1, 1, 0, 0, 1, 1, 0, 0, 0],
 [1, 0, 0, 1, 1, 0, 0, 0, 1, 0, 1, 1, 0, 1, 0, 0, 1, 0, 0, 0, 1, 0],
 [0, 1, 0, 0, 1, 0, 1, 0, 0, 1, 0, 1, 0, 0, 0, 0, 0, 1, 0, 1, 1, 0],
 [0, 1, 1, 0, 1, 1, 1, 0, 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 0, 1, 0, 0],
 [1, 0, 1, 0, 0, 0, 0, 1, 1, 0, 0, 1, 1, 0, 0, 0, 1, 1, 0, 1, 1, 1],
 [0, 1, 0, 1, 0, 1, 1, 1, 0, 1, 1, 0, 0, 1, 1, 0, 1, 0, 1, 0, 1, 1],
 [1, 0, 0, 1, 1, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 0, 1, 1, 0, 0, 0, 0]]
```

```
# let's check the items that we should put in the knapsack
# ... the items in the population created...
```

```
# the 1st individual solution is ...
knapsack.printItems(population[0])
```

```
- Adding map: weight = 9, value = 150, accumulated weight = 9, accumulated va
- Adding water: weight = 153, value = 200, accumulated weight = 162, accumul
- Adding banana: weight = 27, value = 60, accumulated weight = 189, accumul
- Adding beer: weight = 52, value = 10, accumulated weight = 241, accumulat
- Adding camera: weight = 32, value = 30, accumulated weight = 273, accumul
- Adding t-shirt: weight = 24, value = 15, accumulated weight = 297, accumul
- Adding trousers: weight = 48, value = 10, accumulated weight = 345, accumul
- Adding waterproof trousers: weight = 42, value = 70, accumulated weight = 3
- Adding socks: weight = 4, value = 50, accumulated weight = 391, accumulated
- Total weight = 391, Total value = 595
```



```
# the last individual solution is ...
knapsack.printItems(population[-1])
```

```
- Adding map: weight = 9, value = 150, accumulated weight = 9, accumulated va
- Adding sandwich: weight = 50, value = 160, accumulated weight = 59, accumul
- Adding glucose: weight = 15, value = 60, accumulated weight = 74, accumul
- Adding banana: weight = 27, value = 60, accumulated weight = 101, accumul
- Adding apple: weight = 39, value = 40, accumulated weight = 140, accumulate
- Adding cheese: weight = 23, value = 30, accumulated weight = 163, accumul
- Adding suntan cream: weight = 11, value = 70, accumulated weight = 174, acc
- Adding camera: weight = 32, value = 30, accumulated weight = 206, accumul
- Adding t-shirt: weight = 24, value = 15, accumulated weight = 230, accumul
- Adding trousers: weight = 48, value = 10, accumulated weight = 278, accumul
- Adding umbrella: weight = 73, value = 40, accumulated weight = 351, accumul
- Adding waterproof overclothes: weight = 43, value = 75, accumulated weight
- Total weight = 394, Total value = 740
```



▼ Short version with 'Hall of Fame' (HoF)

Let's consider the additional feature of the built-in *algorithms.eaSimple* method - the hall of fame (HoF). It is implemented as *HallOfFame* class that can be used to retain the best individuals that ever existed in the population during the evolution, even if they have been lost at some point due to selection, crossover, or mutation. HoF is continuously sorted so that the first element is **the first individual** that had **the best fitness value** ever seen.

```
# define the hall-of-fame object:
HALL_OF_FAME_SIZE = 1
hof = tools.HallOfFame(HALL_OF_FAME_SIZE)
```

```
# let's check the initial state of HoF
hof.items
```

```
[]
```

▼ Start workflow

```
# prepare the statistics object:
stats = tools.Statistics(lambda ind: ind.fitness.values)
stats.register("max", numpy.max)
stats.register("avg", numpy.mean)

# perform the Genetic Algorithm flow with hof feature added:
population, logbook = algorithms.eaSimple(population, toolbox, cxpb=P_CROSSOVER, m
                                         ngen=MAX_GENERATIONS, stats=stats, h

# print Hall of Fame info:
print("Hall of Fame Individuals = ", *hof.items, sep="\n")
print("Best Ever Individual = ", hof.items[0])

print("-- Knapsack Items = ")
knapsack.printItems(hof.items[0])

# Genetic Algorithm is done - extract statistics:
maxFitnessValues, meanFitnessValues = logbook.select("max", "avg")
```

gen	nevals	max	avg
0	50	790	555.56
1	42	890	663.56
2	40	890	752.36
3	44	900	802.64
4	50	900	836.84
5	41	925	868.4
6	44	925	865.1
7	42	960	892.2
8	42	925	901.74
9	48	925	912.7
10	46	925	913.34
11	48	925	918.3
12	41	925	917.2
13	45	925	921.1
14	46	925	920.4
15	46	925	918.9
16	46	925	917.7
17	48	925	918.2
18	44	925	924
19	50	925	912.9
20	46	925	910.5
21	50	925	914.5
22	47	925	918.2
23	40	970	924.5
24	45	970	918.9
25	46	970	923.8
26	50	970	935.3
27	45	970	950.8
28	45	970	955.8
29	46	970	963
30	42	970	970
31	46	970	966.8
32	43	970	961.5
33	49	970	960.1
34	49	970	964.8

```

35      38      970      970
36      42      970      962.6
37      46      970      963.6
38      44      970      960.4
39      43      970      966.5
40      48      970      960.8
41      46      970      970
42      46      970      964.1
43      46      970      954.3
44      48      970      964.1
45      42      970      968.1
46      50      970      958.8
47      41      970      963.5
48      50      970      962.4
49      50      970      965
50      44      970      965.8

```

```
Hall of Fame Individuals =
```

```
[1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1, 0, 1, 1, 1, 0, 1, 1]
```

```
Best Ever Individual = [1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1, 0, 1, 1,
```

```
-- Knapsack Items =
```

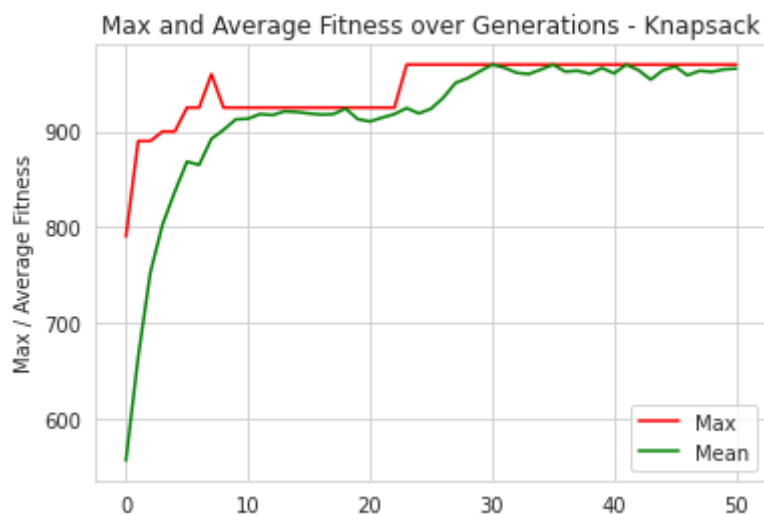
```
- Adding man: weight = 9 value = 150 accumulated weight = 9 accumulated
```

Plot results

```

# Plot statistics:
sns.set_style("whitegrid")
plt.plot(maxFitnessValues, color='red', label='Max')
plt.plot(meanFitnessValues, color='green', label='Mean')
plt.xlabel('Generation')
plt.ylabel('Max / Average Fitness')
plt.title('Max and Average Fitness over Generations - Knapsack')
plt.legend()
plt.show()

```



▼ Example 2: Traveling Salesman Problem

[Wikipedia Description](#)

"Given a list of cities and the distances between each pair of the cities, find the shortest possible path that goes through all the cities, and returns to the starting city."

Details

City coordinates are read from an online file and distance matrix is calculated. The data is serialized to disk. The total distance can be calculated for a path represented by a list of city indices. A plot can be created for a path represented by a list of city indices.

```
# tsp example-specific library
import tsp
```

▼ Constants

```
# Let's declare constants that set the parameters for the problem and control the
# problem constants:
# create the desired traveling salesman problem instance:
TSP_NAME = "bayg29" # name of problem
tsp = tsp.TravelingSalesmanProblem(TSP_NAME)

# GA constants:
POPULATION_SIZE = 300
P_CROSSOVER = 0.9 # probability for crossover
P_MUTATION = 0.1 # probability for mutating an individual
MAX_GENERATIONS = 200
```

▼ Reproducibility of Results

One important aspect of the GA is the use of probability, which introduces a random element to the behavior of the algorithm.

However, **for reproducibility of results**, when experimenting with the code, we may want to be able to run the same experiment several times and get repeatable results.

To accomplish this, we set the random function seed to a constant number of some value, as shown in the following code:

```
# set the random seed:
RANDOM_SEED = 42
random.seed(RANDOM_SEED)
```

▼ Toolbox class

The **Toolbox** class is used as a container for functions (or operators), and enables us to create new operators by aliasing and customizing existing functions.

```
toolbox = base.Toolbox()
```

▼ Fitness class

Next, we need to create the *Fitness* class. Since we only have one objective here—the sum of digits—and our goal is to maximize it, we choose the *FitnessMax* strategy, using a weights tuple with a single positive weight, as shown in the following code.

```
# define a single objective, minimizing fitness strategy:  
creator.create("FitnessMin", base.Fitness, weights=(-1.0,))
```

In DEAP, the *Individual* class is used to represent each of the population's individuals. This class is created with the help of the creator tool. In our case, *list* serves as the base class, which is used as the individual's chromosome. The class is augmented with the fitness attribute, initialized to the *FitnessMax* class that we defined earlier

```
import array  
# create the Individual class based on list:  
creator.create("Individual", array.array, typecode='i', fitness=creator.FitnessMin)
```

```
# create an operator that generates randomly shuffled indices:  
toolbox.register("randomOrder", random.sample, range(len(tsp)), len(tsp))
```

```
# create the individual creation operator to fill up an Individual instance with s  
toolbox.register("individualCreator", tools.initIterate, creator.Individual, toolb
```

Register the *populationCreator* operator that creates a list of individuals.

```
# create the population operator to generate a list of individuals:  
toolbox.register("populationCreator", # Register the populationCreator operator,  
                tools.initRepeat,    # The initRepeat operator is customized he  
                list,                 # The container type (list) in which the r  
                toolbox.individualCreator) # The function used to generate object
```

▼ Fitness function

Define the function *knapsackValue* that computes the fitness.

```
# fitness calculation:
# compute the total distance of the list of cities represented by indices:
def tpsDistance(individual):
    return tsp.getTotalDistance(individual), # return a tuple,
                                             # fitness values in DEAP are represented
                                             # and therefore a comma needs to follow
```

Define the *evaluate* operator as an alias to the *knapsackValue()* function we defined earlier.

```
# create the evaluate alias for calculating the fitness (by a DEAP convention)
toolbox.register("evaluate", tpsDistance)
```

▼ Genetic operators

The genetic operators are typically created by aliasing existing functions from the tools module and setting the argument values as needed.

Note: The *mutFlipBit* function iterates over all the attributes of the individual, a list with values of 1s and 0s in our case, and for each attribute will use the argument value (*indpb* parameter) as the probability of flipping (applying the not operator to) the attribute value. This value is independent of the mutation probability, which is set by the *P_MUTATION* constant that we defined earlier and has not yet been used. The mutation probability serves to decide if the *mutFlipBit* function is called for a given individual in the population.

```
# genetic operators:

# Tournament selection with tournament size of 3:
toolbox.register("select", tools.selTournament, tournsize=3)

# Ordered crossover
toolbox.register("mate", tools.cxOrdered)

# Shuffle mutation:
toolbox.register("mutate", tools.mutShuffleIndexes, indpb=1.0/len(tsp))
```

GA workflow

▼ Create population of individual solutions

```
# create initial population (generation 0):
population = toolbox.populationCreator(n=POPULATION_SIZE)
```

```
# let's check the population created...
#population
```

▼ Short version with 'Hall of Fame' (HoF)

Let's consider the additional feature of the built-in `algorithms.eaSimple` method - the hall of fame (HoF). It is implemented as `HallOfFame` class that can be used to retain the best individuals that ever existed in the population during the evolution, even if they have been lost at some point due to selection, crossover, or mutation. HoF is continuously sorted so that the first element is **the first individual** that had **the best fitness value** ever seen.

```
# define the hall-of-fame object:
HALL_OF_FAME_SIZE = 1
hof = tools.HallOfFame(HALL_OF_FAME_SIZE)
```

```
# let's check the initial state of HoF
hof.items
```

```
[]
```

▼ Start workflow

```
# prepare the statistics object:
stats = tools.Statistics(lambda ind: ind.fitness.values)
stats.register("min", np.min)
stats.register("avg", np.mean)

# perform the Genetic Algorithm flow with hof feature added:
population, logbook = algorithms.eaSimple(population, toolbox, cxpb=P_CROSSOVER, m
                                         ngen=MAX_GENERATIONS, stats=stats, h

# print Hall of Fame info:
best = hof.items[0]
print("Hall of Fame Individuals = ", best, sep="\n")
print("Best Ever Individual = ", best.fitness.values[0])

# Genetic Algorithm is done - extract statistics:
minFitnessValues, meanFitnessValues = logbook.select("min", "avg")
```

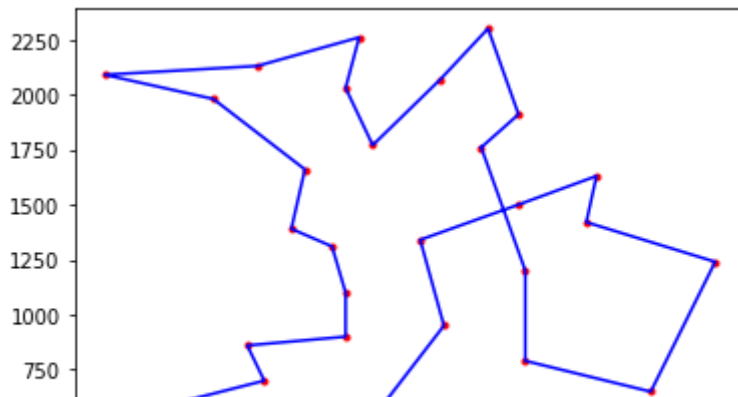
gen	nevals	min	avg
0	300	21103.3	26457
1	279	19562.4	25128.9
2	275	19456.5	24267.3
3	279	19760.9	23592
4	278	19406.4	22963.5
5	276	19105.2	22480.7
6	281	17802.4	22129.9
7	279	18160.2	21581.5

8	274	17691.3	21253.6
9	277	16011.9	20877.8
10	268	16011.9	20597.9
11	279	15878.8	20413.2
12	269	14589.1	20188.2
13	272	14589.1	19987.8
14	281	15182.9	19910.4
15	276	15836.2	19437
16	276	15687.4	19117.2
17	282	15426.5	19039.4
18	282	14905.2	18696.7
19	269	15020.4	18614.9
20	275	13346.3	18424
21	276	14711.4	18330.1
22	275	13139.1	18312
23	274	13139.1	18005
24	278	13002.5	17725.6
25	262	12203.5	17543.2
26	274	13157.3	17285.2
27	260	12918.6	16946.3
28	271	12918.6	16646
29	262	12918.6	16441
30	279	12652.9	16194.2
31	265	12652.9	15910.6
32	278	12565.6	15942.4
33	278	12520.5	15682
34	283	12436.1	15569.5
35	272	12214	15441.9
36	265	12278.3	15353.6
37	271	12302.9	15371.8
38	273	12037.5	15182
39	271	11969.4	14974.3
40	267	12081.2	14825
41	266	11785.8	14612.3
42	282	11477	14591.8
43	269	10869.8	14446
44	270	11475	14452.8
45	277	11796.8	14491.9
46	277	11262.8	14324.7
47	277	11333.1	14183.2
48	281	11311	14135.4
49	271	10921.8	14212.2
50	274	11172.8	14137.9
51	279	11295.1	13945
52	280	10870.6	14044.3
53	278	11225.2	14167.9
54	270	11336.3	13993.6
55	268	10473.0	13886.4

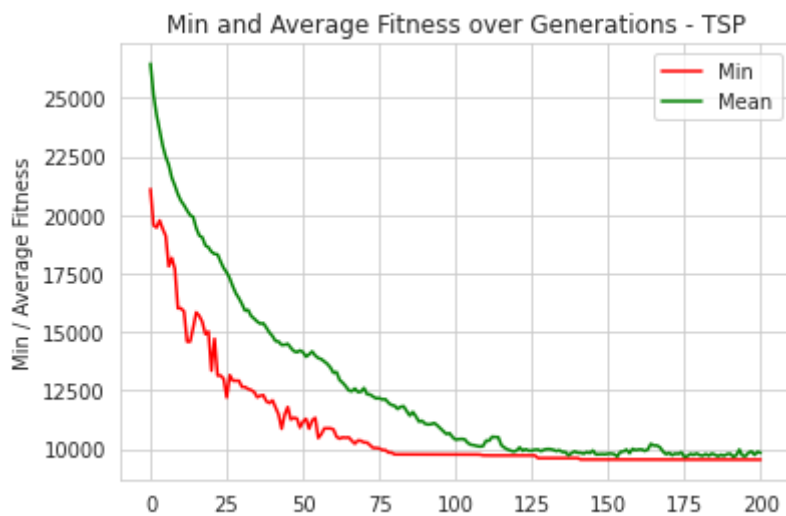
▼ Plot results

```
# plot best solution:  
plt.figure(1)  
tsp.plotData(best)
```

```
<module 'matplotlib.pyplot' from '/usr/local/lib/python3.6/dist-packages/matplotlib/pyplot.py'>
```



```
# Plot statistics:  
plt.figure(2)  
sns.set_style("whitegrid")  
plt.plot(minFitnessValues, color='red', label='Min')  
plt.plot(meanFitnessValues, color='green', label='Mean')  
plt.xlabel('Generation')  
plt.ylabel('Min / Average Fitness')  
plt.title('Min and Average Fitness over Generations - TSP')  
plt.legend()  
plt.show()
```



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Lab 3 - Applications of EA for ML

based on (C) Eyal Wirsansky work

Brief Content:

- DEAP installation (**every time after start of Colab VM!**),
- main modules: *creator* and *toolbox*,
- components needed for the GA workflow,
- *regression problem*,
- *classification problem*.

By the end of this lab you will know:

- again, how to use the DEAP framework's built-in algorithms to produce concise code
- how to solve the *regression* and *classification* problems using a GA coded with the DEAP framework,
- how to experiment with various settings of the GA and interpret the differences in the results.

▼ Installation and import of libraries

IMPORTANT: Mount your Google Drive!

At left sidebar -> click "Files" icon, then click "Mount Drive" icon with Google Drive logo, follow instructions.

```
# Copy all lab-related materials from Google Drive to your current location at Goo
! cp -r /content/drive/MyDrive/COLAB_EV0/EV0_Lecture03/* .
```

```
# Check the folders/files copied
! ls
```

```
01-solve-friedman.py  elitism.py  __pycache__
02-solve-zoo.py      EVO_Lecture03_ML_examples.ipynb  sample_data
drive                 friedman.py  zoo.py
```

In these and other lectures, we will use various Python packages:

- [NumPy](#)
- [Matplotlib](#)
- [Seaborn](#)

They are already pre-installed in Colab. Let's import them by the following code.

```
# Import all necessary standard libraries

import numpy as np
from pandas import read_csv
import random

# for Friedman1 problem data generation
from sklearn import datasets

# for ML training/testing
from sklearn import model_selection

# for Regression example
from sklearn.ensemble import GradientBoostingRegressor

# for Classification example
from sklearn.tree import DecisionTreeClassifier

# for MSE metrics
from sklearn.metrics import mean_squared_error

# for plotting
import matplotlib.pyplot as plt
import seaborn as sns
```

▼ Example: Regression

▼ Classic Solution

```
class Friedman1Test:
    """This class encapsulates the Friedman1 regression test for feature selection
    """

    VALIDATION_SIZE = 0.20
    NOISE = 1.0

    def __init__(self, numFeatures, numSamples, randomSeed):
        """
        :param numFeatures: total number of features to be used (at least 5)
        :param numSamples: number of samples in dataset
        :param randomSeed: random seed value used for reproducible results
        """

        self.numFeatures = numFeatures
        self.numSamples = numSamples
        self.randomSeed = randomSeed
```

```

# generate test data:
self.X, self.y = datasets.make_friedman1(n_samples=self.numSamples, n_feat
                                         noise=self.NOISE, random_state=se

# divide the data to a training set and a validation set:
self.X_train, self.X_validation, self.y_train, self.y_validation = \
    model_selection.train_test_split(self.X, self.y, test_size=self.VALIDA

self.regressor = GradientBoostingRegressor(random_state=self.randomSeed)

def __len__(self):
    """
    :return: the total number of features
    """
    return self.numFeatures

def getMSE(self, zeroOneList):
    """
    returns the mean squared error of the regressor, calculated for the valida
    using the features selected by the zeroOneList
    :param zeroOneList: a list of binary values corresponding the features in
    represents selecting the corresponding feature, while a value of '0' means
    :return: the mean squared error of the regressor when using the features s
    """

# drop the columns of the training and validation sets that correspond to
# unselected features:
zeroIndices = [i for i, n in enumerate(zeroOneList) if n == 0]
currentX_train = np.delete(self.X_train, zeroIndices, 1)
currentX_validation = np.delete(self.X_validation, zeroIndices, 1)

# train the regression model using th etraining set:
self.regressor.fit(currentX_train, self.y_train)

# calculate the regressor's output for the validation set:
prediction = self.regressor.predict(currentX_validation)

# return the mean square error of prediction vs actual data:
return mean_squared_error(self.y_validation, prediction)

```

```

%time
# create a test instance of Friedman1Test class:
test = Friedman1Test(numFeatures=15, numSamples=60, randomSeed=42)
test

```

```

CPU times: user 4 µs, sys: 0 ns, total: 4 µs
Wall time: 22.2 µs
<__main__.Friedman1Test at 0x7f2f2bc47518>

```

```
test
```

```
<__main__.Friedman1Test at 0x7f2f2bc47518>
```

```
scores = []  
# calculate MSE for 'n' first features:  
for n in range(1, len(test) + 1):  
    nFirstFeatures = [1] * n + [0] * (len(test) - n)  
    score = test.getMSE(nFirstFeatures)  
    print("%d first features: score (MSE) = %f" % (n, score))  
    scores.append(score)
```

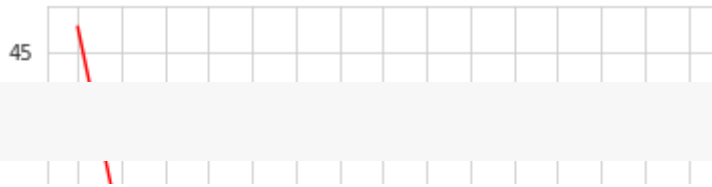
```
1 first features: score (MSE) = 47.553993  
2 first features: score (MSE) = 26.121143  
3 first features: score (MSE) = 18.509415  
4 first features: score (MSE) = 7.322589  
5 first features: score (MSE) = 6.702669  
6 first features: score (MSE) = 7.677197  
7 first features: score (MSE) = 11.614536  
8 first features: score (MSE) = 11.294010  
9 first features: score (MSE) = 10.858028  
10 first features: score (MSE) = 11.602919  
11 first features: score (MSE) = 15.017591  
12 first features: score (MSE) = 14.258221  
13 first features: score (MSE) = 15.274851  
14 first features: score (MSE) = 15.726690  
15 first features: score (MSE) = 17.187479
```

```
# Find the MINIMAL MSE and the correspondent number of features  
index_min = np.argmin(scores)  
print("MIN score (MSE) = %f, for %d first features" % (min(scores), index_min+1))
```

```
MIN score (MSE) = 6.702669, for 5 first features
```

```
# plot graph:  
sns.set_style("whitegrid")  
plt.plot([i + 1 for i in range(len(test))], scores, color='red')  
plt.xticks(np.arange(1, len(test) + 1, 1.0))  
plt.xlabel('n First Features')  
plt.ylabel('MSE')  
plt.title('MSE over Features Selected')  
plt.show()
```

MSE over Features Selected



▼ GA Solution



Install DEAP by *pip* with the following code:



```
# Install DEAP
!pip install deap
```

```
Requirement already satisfied: deap in /usr/local/lib/python3.6/dist-packages
Requirement already satisfied: numpy in /usr/local/lib/python3.6/dist-package
```



```
from deap import base
from deap import creator
from deap import tools
```

```
import elitism
```

```
NUM_OF_FEATURES = 15
NUM_OF_SAMPLES = 60
```

```
# Genetic Algorithm constants:
POPULATION_SIZE = 30
P_CROSSOVER = 0.9 # probability for crossover
P_MUTATION = 0.2 # probability for mutating an individual
MAX_GENERATIONS = 30
HALL_OF_FAME_SIZE = 5
```

```
# set the random seed:
RANDOM_SEED = 42
random.seed(RANDOM_SEED)
```

```
# create the Friedman-1 test class:
friedman = Friedman1Test(NUM_OF_FEATURES, NUM_OF_SAMPLES, RANDOM_SEED)
```

```
toolbox = base.Toolbox()
```

```
# define a single objective, minimizing fitness strategy:
creator.create("FitnessMin", base.Fitness, weights=(-1.0,))
```

```
# create the Individual class based on list:
creator.create("Individual", list, fitness=creator.FitnessMin)
```

```
# create an operator that randomly returns 0 or 1:
```



```

toolbox.register("zeroOrOne", random.randint, 0, 1)

# create the individual operator to fill up an Individual instance:
toolbox.register("individualCreator", tools.initRepeat, creator.Individual, toolbox)

# create the population operator to generate a list of individuals:
toolbox.register("populationCreator", tools.initRepeat, list, toolbox.individualCreator)

# fitness calculation
def friedmanTestScore(individual):
    return friedman.getMSE(individual), # return a tuple

toolbox.register("evaluate", friedmanTestScore)

# genetic operators for binary list:
toolbox.register("select", tools.selTournament, tournsize=2)
toolbox.register("mate", tools.cxTwoPoint)
toolbox.register("mutate", tools.mutFlipBit, indpb=1.0/len(friedman))

# create initial population (generation 0):
population = toolbox.populationCreator(n=POPULATION_SIZE)

# prepare the statistics object:
stats = tools.Statistics(lambda ind: ind.fitness.values)
stats.register("min", np.min)
stats.register("avg", np.mean)

# define the hall-of-fame object:
hof = tools.HallOfFame(HALL_OF_FAME_SIZE)

# perform the Genetic Algorithm flow with hof feature added:
population, logbook = elitism.eaSimpleWithElitism(population, toolbox, cxpb=P_CROSSOVER,
                                                ngen=MAX_GENERATIONS, stats=stats)

# print best solution found:
best = hof.items[0]
print("Best Ever Individual = ", best)
print("Best Ever Fitness = ", best.fitness.values[0])

```

gen	nevals	min	avg
0	30	13.4946	30.2123
1	20	13.4946	22.9373
2	22	11.1869	19.0558
3	23	11.1869	17.0366
4	24	11.1869	14.0624
5	21	10.8123	13.2361
6	20	10.5603	12.3547
7	21	10.5603	12.8725
8	21	9.67682	12.0955
9	23	9.67682	11.2473
10	20	9.67682	10.8749
11	16	9.67682	10.8527
12	22	7.45319	10.5706
13	22	7.45319	10.1786

```

14      22      7.45319 10.1176
15      22      7.26529 11.4639
16      23      7.26529 10.8954
17      23      6.70267 9.41857
18      24      6.70267 10.9443
19      23      6.70267 10.3826
20      24      6.70267 9.28936
21      23      6.70267 8.39784
22      25      6.70267 9.43918
23      24      6.70267 7.29398
24      19      6.70267 7.57122
25      19      6.70267 6.88776
26      24      6.70267 7.48048
27      24      6.70267 7.96912
28      19      6.70267 7.23222
29      22      6.70267 7.67753
30      24      6.70267 8.10665
Best Ever Individual = [1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]
Best Ever Fitness = 6.702668910463276

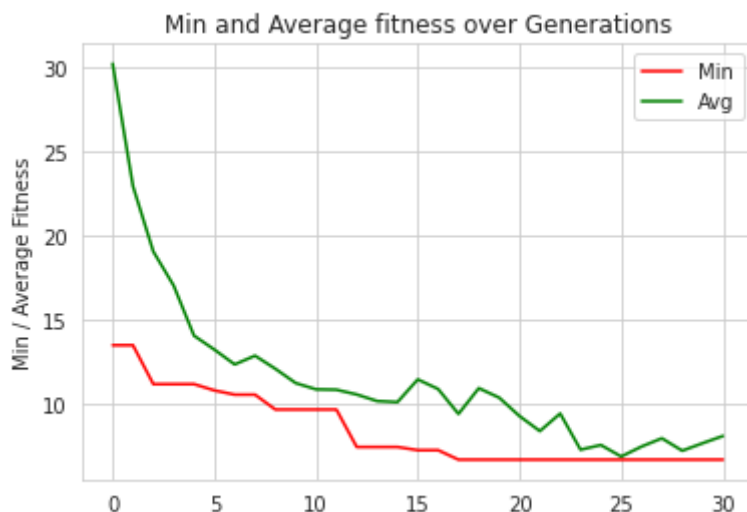
```

```

# extract statistics:
minFitnessValues, meanFitnessValues = logbook.select("min", "avg")

# plot statistics:
sns.set_style("whitegrid")
plt.plot(minFitnessValues, label='Min', color='red')
plt.plot(meanFitnessValues, label='Avg', color='green')
plt.xlabel('Generation')
plt.ylabel('Min / Average Fitness')
plt.title('Min and Average fitness over Generations')
plt.legend()
plt.show()

```



▼ Example: Classification

```

class Zoo:
    """This class encapsulates the Friedman1 test for a regressor

```

```

"""

DATASET_URL = 'https://archive.ics.uci.edu/ml/machine-learning-databases/zoo/z
NUM_FOLDS = 5

def __init__(self, randomSeed):
    """
    :param randomSeed: random seed value used for reproducible results
    """
    self.randomSeed = randomSeed

    # read the dataset, skipping the first columns (animal name):
    self.data = read_csv(self.DATASET_URL, header=None, usecols=range(1, 18))

    # separate to input features and resulting category (last column):
    self.X = self.data.iloc[:, 0:16]
    self.y = self.data.iloc[:, 16]

    # split the data, creating a group of training/validation sets to be used
    self.kfold = model_selection.KFold(n_splits=self.NUM_FOLDS, random_state=s

    self.classifier = DecisionTreeClassifier(random_state=self.randomSeed)

def __len__(self):
    """
    :return: the total number of features used in this classification problem
    """
    return self.X.shape[1]

def getMeanAccuracy(self, zeroOneList):
    """
    returns the mean accuracy measure of the classifier, calculated using k-fol
    using the features selected by the zeroOneList
    :param zeroOneList: a list of binary values corresponding the features in
    represents selecting the corresponding feature, while a value of '0' means
    :return: the mean accuracy measure of the classifier when using the featur
    """

    # drop the dataset columns that correspond to the unselected features:
    zeroIndices = [i for i, n in enumerate(zeroOneList) if n == 0]
    currentX = self.X.drop(self.X.columns[zeroIndices], axis=1)

    # perform k-fold validation and determine the accuracy measure of the clas
    cv_results = model_selection.cross_val_score(self.classifier, currentX, se

    # return mean accuracy:
    return cv_results.mean()

```

▼ Classic Solution

```
# create a zoo instance of Zoo class:
```

```
zoo = Zoo(randomSeed=42)
```

```
/usr/local/lib/python3.6/dist-packages/sklearn/model_selection/_split.py:296:  
FutureWarning
```

```
allOnes = [1] * len(zoo)  
#print("For all features selected: ", allOnes, ", accuracy = ", round(zoo.getMeanA  
print("For all features selected: ", allOnes, ", accuracy = ", zoo.getMeanAccuracy
```

```
For all features selected: [1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]
```

▼ GA Solution

```
from deap import base  
from deap import creator  
from deap import tools
```

```
import elitism
```

```
# Genetic Algorithm constants:  
POPULATION_SIZE = 50  
P_CROSSOVER = 0.9 # probability for crossover  
P_MUTATION = 0.2 # probability for mutating an individual  
MAX_GENERATIONS = 50  
HALL_OF_FAME_SIZE = 5
```

```
FEATURE_PENALTY_FACTOR = 0.001
```

```
# set the random seed:  
RANDOM_SEED = 42  
random.seed(RANDOM_SEED)
```

```
# create the Zoo test class:  
zoo = Zoo(RANDOM_SEED)
```

```
/usr/local/lib/python3.6/dist-packages/sklearn/model_selection/_split.py:296:  
FutureWarning
```

▼ Genetic Algorithm - tools

```
toolbox = base.Toolbox()
```

```
# define a single objective, maximizing fitness strategy:  
creator.create("FitnessMax", base.Fitness, weights=(1.0,))
```

```

# create the Individual class based on list:
creator.create("Individual", list, fitness=creator.FitnessMax)

# create an operator that randomly returns 0 or 1:
toolbox.register("zeroOrOne", random.randint, 0, 1)

# create the individual operator to fill up an Individual instance:
toolbox.register("individualCreator", tools.initRepeat, creator.Individual, toolbox.zeroOrOne)

# create the population operator to generate a list of individuals:
toolbox.register("populationCreator", tools.initRepeat, list, toolbox.individualCreator)

# fitness calculation
def zooClassificationAccuracy(individual):
    numFeaturesUsed = sum(individual)
    if numFeaturesUsed == 0:
        return 0.0,
    else:
        accuracy = zoo.getMeanAccuracy(individual)
        return accuracy - FEATURE_PENALTY_FACTOR * numFeaturesUsed, # return a tuple

toolbox.register("evaluate", zooClassificationAccuracy)

# genetic operators:mutFlipBit

# Tournament selection with tournament size of 2:
toolbox.register("select", tools.selTournament, tournsize=2)

# Single-point crossover:
toolbox.register("mate", tools.cxTwoPoint)

# Flip-bit mutation:
# indpb: Independent probability for each attribute to be flipped
toolbox.register("mutate", tools.mutFlipBit, indpb=1.0/len(zoo))

```

```

/usr/local/lib/python3.6/dist-packages/deap/creator.py:141: RuntimeWarning: /
RuntimeWarning)
/usr/local/lib/python3.6/dist-packages/deap/creator.py:141: RuntimeWarning: /
RuntimeWarning)

```

▼ Genetic Algorithm - workflow

```

# create initial population (generation 0):
population = toolbox.populationCreator(n=POPULATION_SIZE)

# prepare the statistics object:
stats = tools.Statistics(lambda ind: ind.fitness.values)
stats.register("max", np.max)
stats.register("avg", np.mean)

```

```

# define the hall-of-fame object:
hof = tools.HallOfFame(HALL_OF_FAME_SIZE)

# perform the Genetic Algorithm flow with hof feature added:
population, logbook = elitism.eaSimpleWithElitism(population, toolbox, cxbp=P_CROS
                                                ngen=MAX_GENERATIONS, stats=

```

gen	nevals	max	avg
0	50	0.931	0.854475
1	41	0.931	0.888799
2	42	0.932476	0.898603
3	39	0.939	0.908676
4	38	0.939	0.915697
5	41	0.939	0.908824
6	43	0.947	0.915913
7	39	0.947	0.919742
8	36	0.947	0.922974
9	41	0.947	0.922894
10	44	0.949	0.923587
11	41	0.949	0.928286
12	42	0.949	0.931107
13	37	0.961	0.929126
14	44	0.961	0.932577
15	42	0.961	0.934937
16	38	0.961	0.931545
17	43	0.961	0.92797
18	44	0.961	0.928183
19	42	0.961	0.92835
20	40	0.961	0.935627
21	40	0.961	0.934047
22	38	0.961	0.929953
23	42	0.962	0.937037
24	39	0.962	0.936218
25	41	0.963	0.935186
26	40	0.964	0.936786
27	42	0.964	0.940153
28	34	0.964	0.948788
29	41	0.964	0.947346
30	44	0.964	0.952076
31	37	0.964	0.954729
32	43	0.964	0.955279
33	43	0.964	0.953498
34	42	0.964	0.955269
35	38	0.964	0.953825
36	42	0.964	0.951685
37	38	0.964	0.954197
38	39	0.964	0.954385
39	41	0.964	0.95778
40	41	0.964	0.95672
41	44	0.964	0.957848
42	43	0.964	0.954497
43	42	0.964	0.953987
44	39	0.964	0.955858
45	40	0.964	0.957407
46	43	0.964	0.957788
47	44	0.964	0.956839
48	41	0.964	0.959409

```

49      41      0.964      0.95912
50      44      0.964      0.957408

```

```

# print best solution found:
print("Best solutions are:")
for i in range(HALL_OF_FAME_SIZE):
    print(i, ": ", hof.items[i], " fitness =", round(hof.items[i].fitness.values[0],6)
          " accuracy =", round(zoo.getMeanAccuracy(hof.items[i]),6), " features =", s

# extract statistics:
maxFitnessValues, meanFitnessValues = logbook.select("max", "avg")

```

```

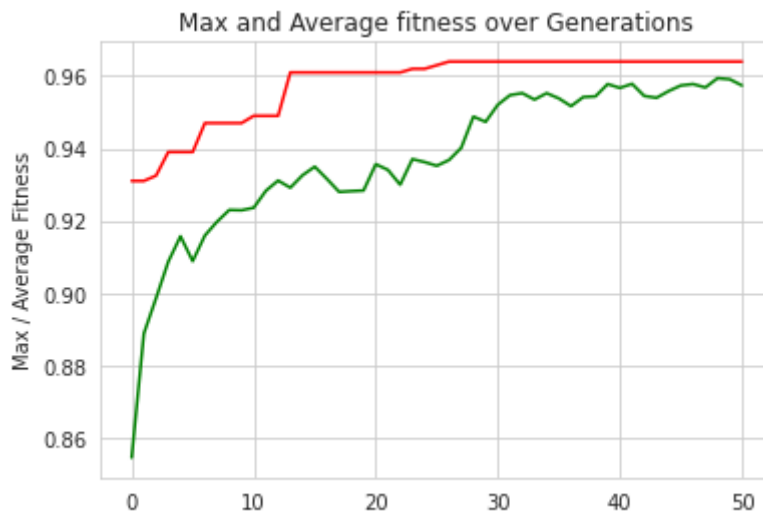
Best solutions are:
0 : [0, 1, 0, 1, 1, 0, 0, 0, 1, 0, 0, 1, 0, 1, 0, 0] fitness = 0.964 accur
1 : [0, 1, 0, 1, 1, 0, 0, 0, 1, 0, 0, 1, 0, 1, 0, 1] fitness = 0.963 accur
2 : [0, 1, 0, 1, 1, 0, 0, 0, 1, 0, 1, 1, 0, 1, 0, 0] fitness = 0.963 accur
3 : [1, 1, 0, 1, 1, 0, 0, 0, 1, 0, 0, 1, 0, 1, 0, 0] fitness = 0.963 accur
4 : [0, 1, 0, 1, 1, 0, 0, 0, 1, 0, 0, 1, 0, 1, 1, 0] fitness = 0.963 accur

```

```

# plot statistics:
sns.set_style("whitegrid")
plt.plot(maxFitnessValues, color='red')
plt.plot(meanFitnessValues, color='green')
plt.xlabel('Generation')
plt.ylabel('Max / Average Fitness')
plt.title('Max and Average fitness over Generations')
plt.show()

```



population

```

[[0, 1, 0, 1, 1, 0, 0, 0, 1, 0, 0, 1, 0, 1, 0, 0],
 [0, 1, 0, 1, 1, 0, 0, 0, 1, 0, 0, 1, 0, 1, 0, 0],
 [0, 1, 0, 1, 1, 0, 0, 0, 1, 0, 0, 1, 0, 1, 0, 0],
 [0, 1, 0, 1, 1, 0, 0, 0, 1, 0, 0, 1, 0, 1, 0, 0],
 [0, 1, 0, 1, 1, 0, 0, 0, 1, 0, 0, 1, 0, 1, 0, 0],
 [0, 1, 0, 1, 1, 0, 0, 0, 1, 0, 0, 1, 0, 1, 0, 0],
 [0, 1, 0, 1, 1, 0, 0, 0, 1, 0, 0, 1, 0, 1, 0, 0],
 [0, 1, 0, 1, 1, 0, 0, 1, 1, 0, 0, 1, 0, 1, 0, 0],
 [0, 1, 0, 0, 1, 0, 0, 0, 1, 0, 0, 1, 0, 1, 0, 0],

```


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Lab 4 - Applications of EA for ML hyperparameter tuning

based on (C) Eyal Wirsansky work

Brief Content:

- DEAP installation (**every time after start of Colab VM!**),
- components needed for the GA workflow,
- *classification problem*
 - classic solution
 - sklearn-based solution,
 - DEAP-based solution with finetuning.

By the end of this lab you will know:

- again, how to use the DEAP framework's built-in algorithms to produce concise code
- how to solve the *classification* problem using a classic and GA-based solutions with the SKLEARN and DEAP frameworks,
- how to experiment with various settings of the GA and interpret the differences in the results.

▼ Installation and import of libraries

```
! pip install deap
```

```
Requirement already satisfied: deap in /usr/local/lib/python3.6/dist-packages  
Requirement already satisfied: numpy in /usr/local/lib/python3.6/dist-packages
```

```
! pip install sklearn-deap
```

```
Requirement already satisfied: sklearn-deap in /usr/local/lib/python3.6/dist-  
Requirement already satisfied: deap>=1.0.2 in /usr/local/lib/python3.6/dist-p  
Requirement already satisfied: scipy>=0.16.0 in /usr/local/lib/python3.6/dist  
Requirement already satisfied: scikit-learn>=0.18.0 in /usr/local/lib/python3  
Requirement already satisfied: numpy>=1.9.3 in /usr/local/lib/python3.6/dist-  
Requirement already satisfied: joblib>=0.11 in /usr/local/lib/python3.6/dist-
```

but this is not the end, we will use various Python packages:

Saved successfully! ✕

- [Matplotlib](#)

- [Seaborn](#)

They are already pre-installed in Colab. Let's import them by the following code.

```
# Import all necessary standard libraries

import numpy as np
from pandas import read_csv
import random

# for Friedman1 problem data generation
from sklearn import datasets

# for ML training/testing
from sklearn import model_selection

# for Regression example
from sklearn.ensemble import GradientBoostingRegressor

# for Classification example
from sklearn.tree import DecisionTreeClassifier

# for MSE metrics
from sklearn.metrics import mean_squared_error

# for plotting
import matplotlib.pyplot as plt
import seaborn as sns
```

▼ Example - Dataset Description

[UCI Wine Data Set](#)

- These data are the results of a chemical analysis of wines grown in the same region in Italy but derived from 3 different cultivars. The analysis determined the quantities of 13 constituents found in each of the three types of wines.
- The attributes are (donated by Riccardo Leardi, riclea@anchem.unige.it):

1. Alcohol
2. Malic acid
3. Ash
4. Alcalinity of ash
5. Magnesium
6. Total phenols
7. Flavonoids

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9. Proanthocyanins

10. Color intensity
11. Hue
12. OD280/OD315 of diluted wines
13. Proline

- Number of Instances:
 - class 1: 59
 - class 2: 71
 - class 3: 48
- Number of Attributes: 13

```
import numpy as np
import time
import random

from sklearn import model_selection
from sklearn.ensemble import AdaBoostClassifier
from sklearn.model_selection import GridSearchCV

from pandas import read_csv
from evolutionary_search import EvolutionaryAlgorithmSearchCV

accuracy_classic_solution = 0
accuracy_sklearn_deap_solution = 0
accuracy_DEAP_solution = 0

class HyperparameterTuningGrid:

    NUM_FOLDS = 5

    def __init__(self, randomSeed):

        self.randomSeed = randomSeed
        self.initWineDataset()
        self.initClassifier()
        self.initKfold()
        self.initGridParams()

    def initWineDataset(self):
        url = 'https://archive.ics.uci.edu/ml/machine-learning-databases/wine/wine

        self.data = read_csv(url, header=None, usecols=range(0, 14))
        self.X = self.data.iloc[:, 1:14]
        self.y = self.data.iloc[:, 0]

    def initClassifier(self):
        self.classifier = AdaBoostClassifier(random_state=self.randomSeed)

        self.kfold = model_selection.KFold(n_splits=self.NUM_FOLDS,
                                         random_state=self.randomSeed)
```

Saved successfully!



```

def initGridParams(self):
    self.gridParams = {
        'n_estimators': [10, 20, 30, 40, 50, 60, 70, 80, 90, 100],
        'learning_rate': np.logspace(-2, 0, num=10, base=10),
        'algorithm': ['SAMME', 'SAMME.R'],
    }

def getDefaultAccuracy(self):
    cv_results = model_selection.cross_val_score(self.classifier,
                                                self.X,
                                                self.y,
                                                cv=self.kfold,
                                                scoring='accuracy')

    return cv_results.mean()

def gridTest(self):
    print("Classic grid search is STARTED ...")

    gridSearch = GridSearchCV(estimator=self.classifier,
                              param_grid=self.gridParams,
                              cv=self.kfold,
                              scoring='accuracy',
                              iid='False',
                              n_jobs=4)

    gridSearch.fit(self.X, self.y)
    print("Best parameters: ", gridSearch.best_params_)
    print("Score (after gridSearch): ", gridSearch.best_score_)
    accuracy_classic_solution = gridSearch.best_score_
    print("Classic grid search is FINISHED.")
    return accuracy_classic_solution

def geneticGridTest(self):
    print("Genetic grid search was STARTED ...")

    gridSearch = EvolutionaryAlgorithmSearchCV(estimator=self.classifier,
                                              params=self.gridParams,
                                              cv=self.kfold,
                                              scoring='accuracy',
                                              #verbose=True,
                                              iid='False',
                                              n_jobs=4,
                                              verbose=1,
                                              population_size=20,
                                              gene_mutation_prob=0.30,
                                              #gene_crossover_prob=0.5,
                                              tournament_size=2,
                                              generations_number=5)

    gridSearch.fit(self.X, self.y)
    print("Best parameters: ", gridSearch.best_params_)
    print("Score (after geneticGridTest): ", gridSearch.best_score_)
    print("Genetic grid search is FINISHED.")
    return accuracy_classic_solution

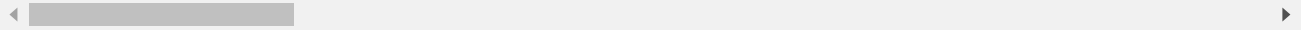
```

Saved successfully!



```
print("Genetic grid search is FINISHED.")
return gridSearch.best_score_, gridSearch.best_params_, gridSearch.all_log
```

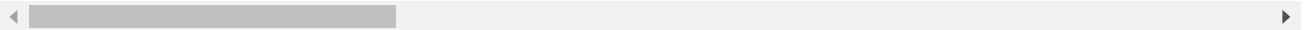
```
/usr/local/lib/python3.6/dist-packages/sklearn/utils/deprecation.py:144: FutureWarning: warn(message, FutureWarning)
```



```
RANDOM_SEED = 42
random.seed(RANDOM_SEED)
```

```
# create a problem instance:
test = HyperparameterTuningGrid(RANDOM_SEED)
```

```
/usr/local/lib/python3.6/dist-packages/sklearn/model_selection/_split.py:296: FutureWarning
```



▼ Classic Solutions

▼ DEMO 1. Default Hyperparameter Values

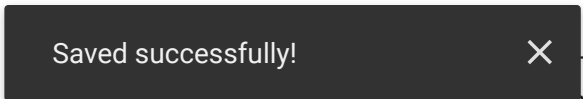
```
print('*****')
start = time.time()
print("Default Classifier Hyperparameter values:")
print(test.classifier.get_params())
print("Score (with default values) = ", test.getDefaultAccuracy())
end = time.time()
print("Time Elapsed = ", end - start)
```

```
*****
Default Classifier Hyperparameter values:
{'algorithm': 'SAMME.R', 'base_estimator': None, 'learning_rate': 1.0, 'n_estimators': 10}
Score (with default values) = 0.6457142857142857
Time Elapsed = 0.4167492389678955
```



▼ DEMO 2. Extensive Grid Search

```
print('*****')
start = time.time()
accuracy_classic_solution = test.gridTest()
end = time.time()
print("Time Elapsed = ", end - start)
```



```
*****
Best parameters: {'algorithm': 'SAMME.R', 'learning_rate': 0.359381366380462}
Score (after gridSearch): 0.9325842696629213
```

```
Classic grid search is FINISHED.  
Time Elapsed = 74.51628732681274  
/usr/local/lib/python3.6/dist-packages/sklearn/model_selection/_search.py:823:  
  "removed in 0.24.", FutureWarning
```

▼ GA Solutions

▼ DEMO 3. GA-driven Grid Search

based on sklearn-deap

```
print('*****')  
start = time.time()  
best_score_, best_params_, logbook_GA_sklearn = test.geneticGridTest()  
print(best_score_, best_params_)  
end = time.time()  
print("Time Elapsed = ", end - start)  
  
# extract statistics:  
maxFitnessValues_GA_sklearn, meanFitnessValues_GA_sklearn = logbook_GA_sklearn[0].  
  
*****  
Genetic grid search was STARTED ...  
Types [1, 2, 1] and maxint [9, 9, 1] detected  
--- Evolve in 200 possible combinations ---  
gen      nevals  avg          min           max           std  
0        20      0.708427     0.117978     0.910112     0.265992  
1        13      0.865169     0.662921     0.926966     0.0717915  
2        15      0.887921     0.646067     0.926966     0.0571676  
3        12      0.896348     0.679775     0.926966     0.0526256  
4        16      0.918539     0.88764      0.926966     0.0110233  
5        9       0.911517     0.730337     0.926966     0.0425958  
Best individual is: {'n_estimators': 60, 'learning_rate': 0.5994842503189409,  
with fitness: 0.9269662921348315  
0.9269662921348315  
{'n_estimators': 60, 'learning_rate': 0.5994842503189409, 'algorithm': 'SAMME  
[{'gen': 0, 'nevals': 20, 'avg': 0.7084269662921348, 'min': 0.11797752808988  
Genetic grid search is FINISHED.  
0.9269662921348315 {'n_estimators': 60, 'learning_rate': 0.5994842503189409,  
Time Elapsed = 24.287983655929565
```

▼ DEMO 4. Direct GA

based on DEAP

Saved successfully!



```
from deap import creator  
from deap import tools
```

```

from deap import algorithms

import random
import numpy

import matplotlib.pyplot as plt
import seaborn as sns

```

▼ Genetic Tools

```

from sklearn import model_selection
from sklearn.ensemble import AdaBoostClassifier

from pandas import read_csv

class HyperparameterTuningGenetic:

    NUM_FOLDS = 5

    def __init__(self, randomSeed):

        self.randomSeed = randomSeed
        self.initWineDataset()
        self.kfold = model_selection.KFold(n_splits=self.NUM_FOLDS, random_state=s

    def initWineDataset(self):
        url = 'https://archive.ics.uci.edu/ml/machine-learning-databases/wine/wine

        self.data = read_csv(url, header=None, usecols=range(0, 14))
        self.X = self.data.iloc[:, 1:14]
        self.y = self.data.iloc[:, 0]

    # ADABOOST [n_estimators, learning_rate, algorithm]:
    # "n_estimators": integer
    # "learning_rate": float
    # "algorithm": {'SAMME', 'SAMME.R'}
    def convertParams(self, params):
        n_estimators = round(params[0]) # round to nearest integer
        learning_rate = params[1] # no conversion needed
        algorithm = ['SAMME', 'SAMME.R'][round(params[2])] # round to 0 or 1, the
        return n_estimators, learning_rate, algorithm

    def getAccuracy(self, params):
        n_estimators, learning_rate, algorithm = self.convertParams(params)
        self.classifier = AdaBoostClassifier(random_state=self.randomSeed,
                                             n_estimators=n_estimators,
                                             learning_rate=learning_rate,
                                             algorithm=algorithm
                                             )

        cv_results = model_selection.cross_val_score(self.classifier,

```

Saved successfully!




```

        self.X,
        self.y,
        cv=self.kfold,
        scoring='accuracy')

    return cv_results.mean()

def formatParams(self, params):
    return "'n_estimators'=%3d, 'learning_rate'=%1.3f, 'algorithm'=%s" % (self

```

▼ Elitism Tools

```

# boundaries for ADABOOST parameters:
# "n_estimators": 1..100
# "learning_rate": 0.01..100
# "algorithm": 0, 1
# [n_estimators, learning_rate, algorithm]:
BOUNDS_LOW = [ 1, 0.01, 0]
BOUNDS_HIGH = [100, 1.00, 1]

NUM_OF_PARAMS = len(BOUNDS_HIGH)

# Genetic Algorithm constants:
POPULATION_SIZE = 20
P_CROSSOVER = 0.9 # probability for crossover
P_MUTATION = 0.5 # probability for mutating an individual
MAX_GENERATIONS = 5
HALL_OF_FAME_SIZE = 5
CROWDING_FACTOR = 20.0 # crowding factor for crossover and mutation

# set the random seed:
RANDOM_SEED = 42
random.seed(RANDOM_SEED)

```

```

def eaSimpleWithElitism(population, toolbox, cxpb, mutpb, ngen, stats=None,
                        halloffame=None, verbose=__debug__):
    """This algorithm is similar to DEAP eaSimple() algorithm, with the modificati
    halloffame is used to implement an elitism mechanism. The individuals containe
    halloffame are directly injected into the next generation and are not subject
    genetic operators of selection, crossover and mutation.
    """
    logbook = tools.Logbook()
    logbook.header = ['gen', 'nevals'] + (stats.fields if stats else [])

    # Evaluate the individuals with an invalid fitness
    invalid_ind = [ind for ind in population if not ind.fitness.valid]
    toolbox.evaluate, invalid_ind)

    (ind, fitnesses):

```

Saved successfully!



```

if halloffame is None:
    raise ValueError("halloffame parameter must not be empty!")

halloffame.update(population)
hof_size = len(halloffame.items) if halloffame.items else 0

record = stats.compile(population) if stats else {}
logbook.record(gen=0, nevals=len(invalid_ind), **record)
if verbose:
    print(logbook.stream)

# Begin the generational process
for gen in range(1, ngen + 1):

    # Select the next generation individuals
    offspring = toolbox.select(population, len(population) - hof_size)

    # Vary the pool of individuals
    offspring = algorithms.varAnd(offspring, toolbox, cxpb, mutpb)

    # Evaluate the individuals with an invalid fitness
    invalid_ind = [ind for ind in offspring if not ind.fitness.valid]
    fitnesses = toolbox.map(toolbox.evaluate, invalid_ind)
    for ind, fit in zip(invalid_ind, fitnesses):
        ind.fitness.values = fit

    # add the best back to population:
    offspring.extend(halloffame.items)

    # Update the hall of fame with the generated individuals
    halloffame.update(offspring)

    # Replace the current population by the offspring
    population[:] = offspring

    # Append the current generation statistics to the logbook
    record = stats.compile(population) if stats else {}
    logbook.record(gen=gen, nevals=len(invalid_ind), **record)
    if verbose:
        print(logbook.stream)

return population, logbook

```

```

# create the classifier accuracy test class:
test = HyperparameterTuningGenetic(RANDOM_SEED)

toolbox = base.Toolbox()

# define a single objective, maximizing fitness strategy:
creator.create("FitnessMax", base.Fitness, weights=(1.0,))

```

Saved successfully!



used on list:
t, fitness=creator.FitnessMax)

```

# define the hyperparameter attributes individually:

```

```

for i in range(NUM_OF_PARAMS):
    # "hyperparameter_0", "hyperparameter_1", ...
    toolbox.register("hyperparameter_" + str(i),
                    random.uniform,
                    BOUNDS_LOW[i],
                    BOUNDS_HIGH[i])

# create a tuple containing an attribute generator for each param searched:
hyperparameters = ()
for i in range(NUM_OF_PARAMS):
    hyperparameters = hyperparameters + \
        (toolbox.__getattr__("hyperparameter_" + str(i)),)

# create the individual operator to fill up an Individual instance:
toolbox.register("individualCreator",
                tools.initCycle,
                creator.Individual,
                hyperparameters,
                n=1)

# create the population operator to generate a list of individuals:
toolbox.register("populationCreator", tools.initRepeat, list, toolbox.individualCr

# fitness calculation
def classificationAccuracy(individual):
    return test.getAccuracy(individual),

toolbox.register("evaluate", classificationAccuracy)

# genetic operators:mutFlipBit

# genetic operators:
toolbox.register("select", tools.selTournament, tournsize=2)
toolbox.register("mate",
                tools.cxSimulatedBinaryBounded,
                low=BOUNDS_LOW,
                up=BOUNDS_HIGH,
                eta=CROWDING_FACTOR)

toolbox.register("mutate",
                tools.mutPolynomialBounded,
                low=BOUNDS_LOW,
                up=BOUNDS_HIGH,
                eta=CROWDING_FACTOR,
                indpb=1.0 / NUM_OF_PARAMS)

```

```

/usr/local/lib/python3.6/dist-packages/sklearn/model_selection/_split.py:296:
FutureWarning
/usr/local/lib/python3.6/dist-packages/deap/creator.py:141: RuntimeWarning: A
RuntimeWarning)
/usr/local/lib/python3.6/dist-packages/deap/creator.py:141: RuntimeWarning: A

```

Saved successfully!



```

def eaSimpleWithElitism(population, toolbox, cxpb, mutpb, ngen, stats=None,

```

```

        halloffame=None, verbose=__debug__):
    """This algorithm is similar to DEAP eaSimple() algorithm, with the modificati
    halloffame is used to implement an elitism mechanism. The individuals containe
    halloffame are directly injected into the next generation and are not subject
    genetic operators of selection, crossover and mutation.
    """
    logbook = tools.Logbook()
    logbook.header = ['gen', 'nevals'] + (stats.fields if stats else [])

    # Evaluate the individuals with an invalid fitness
    invalid_ind = [ind for ind in population if not ind.fitness.valid]
    fitnesses = toolbox.map(toolbox.evaluate, invalid_ind)
    for ind, fit in zip(invalid_ind, fitnesses):
        ind.fitness.values = fit

    if halloffame is None:
        raise ValueError("halloffame parameter must not be empty!")

    halloffame.update(population)
    hof_size = len(halloffame.items) if halloffame.items else 0

    record= stats.compile(population) if stats else {}
    logbook.record(gen=0, nevals=len(invalid_ind), **record)
    if verbose:
        print(logbook.stream)

    # Begin the generational process
    for gen in range(1, ngen + 1):

        # Select the next generation individuals
        offspring = toolbox.select(population, len(population) - hof_size)

        # Vary the pool of individuals
        offspring = algorithms.varAnd(offspring, toolbox, cxpb, mutpb)

        # Evaluate the individuals with an invalid fitness
        invalid_ind = [ind for ind in offspring if not ind.fitness.valid]
        fitnesses = toolbox.map(toolbox.evaluate, invalid_ind)
        for ind, fit in zip(invalid_ind, fitnesses):
            ind.fitness.values = fit

        # add the best back to population:
        offspring.extend(halloffame.items)

        # Update the hall of fame with the generated individuals
        halloffame.update(offspring)

        # Replace the current population by the offspring
        population[:] = offspring

        # Append the current generation statistics to the logbook
        record= stats.compile(population) if stats else {}
        logbook.record(gen=gen, nevals=len(invalid_ind), **record)
        if verbose:
            print(logbook.stream)

```

Saved successfully!



```
return population, logbook
```

▼ GA workflow

```
# create initial population (generation 0):
population = toolbox.populationCreator(n=POPULATION_SIZE)

# prepare the statistics object:
stats = tools.Statistics(lambda ind: ind.fitness.values)
stats.register("max", numpy.max)
stats.register("avg", numpy.mean)

# define the hall-of-fame object:
hof = tools.HallOfFame(HALL_OF_FAME_SIZE)

print('*****')
start = time.time()
# perform the Genetic Algorithm flow with hof feature added:
population, logbook = eaSimpleWithElitism(population,
                                           toolbox,
                                           cxpb=P_CROSSOVER,
                                           mutpb=P_MUTATION,
                                           ngen=MAX_GENERATIONS,
                                           stats=stats,
                                           halloffame=hof,
                                           verbose=True)

end = time.time()
print("Time Elapsed = ", end - start)

# print best solution found:
print("- Best solution is: ")
print("params = ", test.formatParams(hof.items[0]))
print("Accuracy = %1.5f" % hof.items[0].fitness.values[0])

# extract statistics:
maxFitnessValues, meanFitnessValues = logbook.select("max", "avg")

*****
gen      nevals  max      avg
0        20      0.92127  0.841024
1        14      0.943651  0.900603
2        13      0.943651  0.912841
3        14      0.943651  0.922476
4        15      0.949206  0.929468
5        13      0.949206  0.938563
Time Elapsed = 46.62226867675781
- Best solution is:
params = 'n_estimators'= 69, 'learning_rate'=0.628, 'algorithm'=SAMME.R
Accuracy = 0.949206
```

Saved successfully!



▼ Comparison Plot

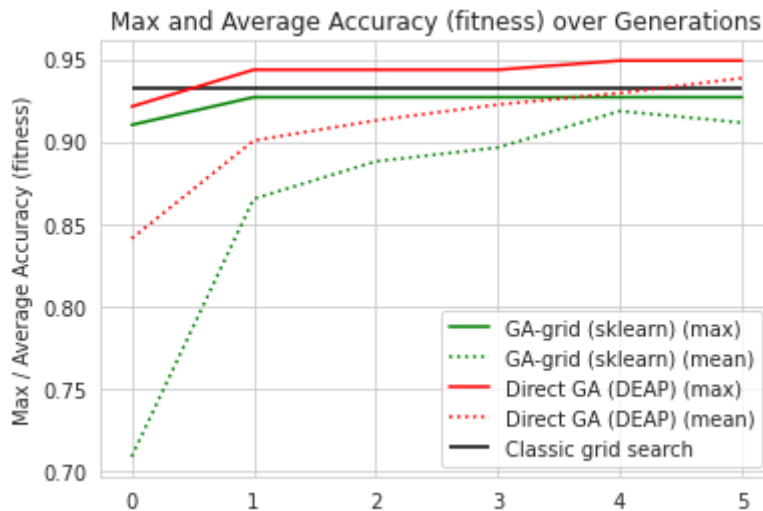
```
sns.set_style("whitegrid")

# Classic grid search solution
plt.hlines(accuracy_classic_solution, 0, 5, linestyle = 'solid', label='Classic gr

# GA_deap_sklearn solution
plt.plot(maxFitnessValues_GA_sklearn, color='green', label='GA-grid (sklearn) (max)
plt.plot(meanFitnessValues_GA_sklearn, color='green', linestyle = 'dotted', label=

# GA_DEAP solution
plt.plot(maxFitnessValues, color='red', label='Direct GA (DEAP) (max)')
plt.plot(meanFitnessValues, color='red', linestyle = 'dotted', label='Direct GA (D

plt.xlabel('Generation')
plt.ylabel('Max / Average Accuracy (fitness)')
plt.title('Max and Average Accuracy (fitness) over Generations')
plt.legend()
plt.show()
```



Saved successfully!



Colab paid products - Cancel contracts here



Saved successfully!



Lab 5 - Applications of EA (actually GA here) for DL tuning (architecture + hyperparameters)

based on (C) Varoquaux, Grobler, Wirsansky work

Brief Content:

- DEAP installation (**every time after start of Colab VM!**),
- components needed for the GA workflow,
- *classification problem*
 - Neural Network (NN) Architecture Tuning
 - NN Hyperparameter Tuning,
 - NN Architecture + NN Hyperparameter Tuning
- performance comparison (accuracy and run time).

By the end of this lab you will know:

- again, how to use the DEAP framework's built-in algorithms to produce concise code
- how to solve the *classification* problem using a GA-based solutions for NN architecture tuning, NN hyperparameter tuning, and their combination,
- how to experiment with various settings of the GA and interpret the differences in the results.

▼ Installation and import of libraries

```
! pip install deap
```

```
Requirement already satisfied: deap in /usr/local/lib/python3.7/dist-packages  
Requirement already satisfied: numpy in /usr/local/lib/python3.7/dist-package
```

In these and other lectures, we will use various Python packages:

- [NumPy](#)
- [Matplotlib](#)
- [Seaborn](#)

They are already pre-installed in Colab. Let's import them by the following code.

```
# Import all necessary standard libraries
```



```

import numpy as np
from pandas import read_csv
import random

# for Friedman1 problem data generation
from sklearn import datasets

# for ML training/testing
from sklearn import model_selection

# for Regression example
from sklearn.ensemble import GradientBoostingRegressor

# for Classification example
from sklearn.tree import DecisionTreeClassifier

# for MSE metrics
from sklearn.metrics import mean_squared_error

# for plotting
import matplotlib.pyplot as plt
import seaborn as sns

from sklearn import model_selection
from sklearn import datasets
from sklearn.neural_network import MLPClassifier

from sklearn.exceptions import ConvergenceWarning
from sklearn.utils.testing import ignore_warnings

import numpy as np
import time
import random
from pandas import read_csv

import random
import numpy

```

▼ Part 1. Neural Network Architecture Tuning

Wine Classification Example

▼ Wine Dataset

▼ Description

[UCI Wine Data Set](#)

- These data are the results of a chemical analysis of wines grown in the same region in Italy but derived from 3 different cultivars. The analysis determined the quantities of 13 constituents found in each of the three types of wines.
- The attributes are (donated by Riccardo Leardi, riclea@anchem.unige.it):
 1. Alcohol
 2. Malic acid
 3. Ash
 4. Alcalinity of ash
 5. Magnesium
 6. Total phenols
 7. Flavanoids
 8. Nonflavanoid phenols
 9. Proanthocyanins
 10. Color intensity
 11. Hue
 12. OD280/OD315 of diluted wines
 13. Proline
- Number of Instances:
 - class 1: 59
 - class 2: 71
 - class 3: 48
- Number of Attributes: 13

```
import matplotlib.pyplot as plt
from sklearn import datasets

# import Wine dataset
wine_dataset = datasets.load_wine()
X = wine_dataset.data[:, :2] # we only take the first two features.
y = wine_dataset.target
```

▼ Features and Targets

```
list(wine_dataset.target_names)

['class_0', 'class_1', 'class_2']
```

```
list(wine_dataset.feature_names)

['alcohol',
 'malic_acid',
```

```
'ash',
'alcalinity_of_ash',
'magnesium',
'total_phenols',
'flavanoids',
'nonflavanoid_phenols',
'proanthocyanins',
'color_intensity',
'hue',
'od280/od315_of_diluted_wines',
'proline']
```

▼ Plot Some Features

```
x_min, x_max = X[:, 0].min() - .5, X[:, 0].max() + .5
y_min, y_max = X[:, 1].min() - .5, X[:, 1].max() + .5

plt.figure(2, figsize=(8, 6))
plt.clf()

# Plot the training points
scatter = plt.scatter(X[:, 0], X[:, 1], c=y, cmap=plt.cm.Set1)
                #edgecolor='k')
plt.xlabel(wine_dataset.feature_names[0])
plt.ylabel(wine_dataset.feature_names[1])

plt.xlim(x_min, x_max)
plt.ylim(y_min, y_max)
plt.xticks(())
plt.yticks(())
#plt.legend()
#plt.legend(*scatter.legend_elements())
classes = list(wine_dataset.target_names)
plt.legend(handles=scatter.legend_elements()[0], labels=classes)

plt.show()
```

▼ Neural Network

```
from deap import base
from deap import creator
from deap import tools
from deap import algorithms

class MlpLayersTest:

    NUM_FOLDS = 5

    def __init__(self, randomSeed, network_name):

        self.randomSeed = randomSeed
        self.initDataset(network_name)
        self.kfold = model_selection.KFold(n_splits=self.NUM_FOLDS, random_state=s

    def initDataset(self, network_name):

        if network_name == 'iris':
            self.data = datasets.load_iris()
        elif network_name == 'wine':
            self.data = datasets.load_wine()
        elif network_name == 'breast_cancer':
            self.data = datasets.load_breast_cancer()
        else:
            self.data = []
            print('ERROR: Wrong dataset name was used!')

        self.X = self.data['data']
        self.y = self.data['target']

    # params contains: [layer_1_size, layer_2_size, layer_3_size, layer_4_size]
    def convertParams(self, params):

        # transform the layer sizes from float (possibly negative) values into hid
        if round(params[1]) <= 0:
            hiddenLayerSizes = round(params[0]),
        elif round(params[2]) <= 0:
            hiddenLayerSizes = (round(params[0]), round(params[1]))
        elif round(params[3]) <= 0:
            hiddenLayerSizes = (round(params[0]), round(params[1]), round(params[2]
        else:
            hiddenLayerSizes = (round(params[0]), round(params[1]), round(params[2]

        return hiddenLayerSizes

    @ignore_warnings(category=ConvergenceWarning)
```

```

def getAccuracy(self, params):
    hiddenLayerSizes = self.convertParams(params)

    self.classifier = MLPClassifier(random_state=self.randomSeed,
                                    hidden_layer_sizes=hiddenLayerSizes)

    cv_results = model_selection.cross_val_score(self.classifier,
                                                self.X,
                                                self.y,
                                                cv=self.kfold,
                                                scoring='accuracy')

    return cv_results.mean()

def formatParams(self, params):
    return "'hidden_layer_sizes'={}".format(self.convertParams(params))

```

▼ GA Solution - max: 4 layers

```

# boundaries for layer size parameters:
# [layer_layer_1_size, hidden_layer_2_size, hidden_layer_3_size, hidden_layer_4_size]
BOUNDS_LOW = [ 5, -5, -10, -20]
BOUNDS_HIGH = [15, 10, 10, 10]

NUM_OF_PARAMS = len(BOUNDS_HIGH)

# Genetic Algorithm constants:
POPULATION_SIZE = 20
P_CROSSOVER = 0.9 # probability for crossover
P_MUTATION = 0.5 # probability for mutating an individual
MAX_GENERATIONS = 10
HALL_OF_FAME_SIZE = 3
CROWDING_FACTOR = 10.0 # crowding factor for crossover and mutation

```

▼ Genetic Tools

```

toolbox = base.Toolbox()

# define a single objective, maximizing fitness strategy:
creator.create("FitnessMax", base.Fitness, weights=(1.0,))

# create the Individual class based on list:
creator.create("Individual", list, fitness=creator.FitnessMax)

# define the layer_size_attributes individually:
for i in range(NUM_OF_PARAMS):
    # "layer_size_attribute_0", "layer_size_attribute_1", ...
    toolbox.register("layer_size_attribute_" + str(i),
                    random.uniform,

```

```

        BOUNDS_LOW[i],
        BOUNDS_HIGH[i])

# create a tuple containing an layer_size_attribute generator for each hidden layer
layer_size_attributes = ()
for i in range(NUM_OF_PARAMS):
    layer_size_attributes = layer_size_attributes + \
        (toolbox.__getattr__("layer_size_attribute_" + str(i)))

# create the individual operator to fill up an Individual instance:
toolbox.register("individualCreator",
                tools.initCycle,
                creator.Individual,
                layer_size_attributes,
                n=1)

# create the population operator to generate a list of individuals:
toolbox.register("populationCreator",
                tools.initRepeat,
                list,
                toolbox.individualCreator)

# fitness calculation
def classificationAccuracy(individual):
    return test.getAccuracy(individual)

toolbox.register("evaluate", classificationAccuracy)

# genetic operators:mutFlipBit

# genetic operators:
toolbox.register("select", tools.selTournament, tournsize=2)

toolbox.register("mate",
                tools.cxSimulatedBinaryBounded,
                low=BOUNDS_LOW,
                up=BOUNDS_HIGH,
                eta=CROWDING_FACTOR)

toolbox.register("mutate",
                tools.mutPolynomialBounded,
                low=BOUNDS_LOW,
                up=BOUNDS_HIGH,
                eta=CROWDING_FACTOR,
                indpb=1.0/NUM_OF_PARAMS)

```

/usr/local/lib/python3.7/dist-packages/deap/creator.py:141: RuntimeWarning: /usr/local/lib/python3.7/dist-packages/deap/creator.py:141: RuntimeWarning:

/usr/local/lib/python3.7/dist-packages/deap/creator.py:141: RuntimeWarning: /usr/local/lib/python3.7/dist-packages/deap/creator.py:141: RuntimeWarning:

▼ Elitism Tools

```
def eaSimpleWithElitism(population, toolbox, cxpb, mutpb, ngen, stats=None,
                        halloffame=None, verbose=__debug__):
    """This algorithm is similar to DEAP eaSimple() algorithm, with the modification
    halloffame is used to implement an elitism mechanism. The individuals contained
    halloffame are directly injected into the next generation and are not subject
    genetic operators of selection, crossover and mutation.
    """
    logbook = tools.Logbook()
    logbook.header = ['gen', 'nevals'] + (stats.fields if stats else [])

    # Evaluate the individuals with an invalid fitness
    invalid_ind = [ind for ind in population if not ind.fitness.valid]
    fitnesses = toolbox.map(toolbox.evaluate, invalid_ind)
    for ind, fit in zip(invalid_ind, fitnesses):
        ind.fitness.values = fit

    if halloffame is None:
        raise ValueError("halloffame parameter must not be empty!")

    halloffame.update(population)
    hof_size = len(halloffame.items) if halloffame.items else 0

    record = stats.compile(population) if stats else {}
    logbook.record(gen=0, nevals=len(invalid_ind), **record)
    if verbose:
        print(logbook.stream)

    # Begin the generational process
    for gen in range(1, ngen + 1):

        # Select the next generation individuals
        offspring = toolbox.select(population, len(population) - hof_size)

        # Vary the pool of individuals
        offspring = algorithms.varAnd(offspring, toolbox, cxpb, mutpb)

        # Evaluate the individuals with an invalid fitness
        invalid_ind = [ind for ind in offspring if not ind.fitness.valid]
        fitnesses = toolbox.map(toolbox.evaluate, invalid_ind)
        for ind, fit in zip(invalid_ind, fitnesses):
            ind.fitness.values = fit

        # add the best back to population:
        offspring.extend(halloffame.items)

        # Update the hall of fame with the generated individuals
        halloffame.update(offspring)

        # Replace the current population by the offspring
        population[:] = offspring

        # Append the current generation statistics to the logbook
        record = stats.compile(population) if stats else {}
```

```

        record = stats.compile(population) if stats else {}
        logbook.record(gen=gen, nevals=len(invalid_ind), **record)
        if verbose:
            print(logbook.stream)

    return population, logbook

```

▼ GA Workflow

```
# create the classifier accuracy test class:
```

```
RANDOM_SEED = 42
random.seed(RANDOM_SEED)
```

```
# dataset_name = 'iris'
# dataset_name = 'breast_cancer'
dataset_name = 'wine'
```

```
test = MlpLayersTest(RANDOM_SEED, dataset_name)
```

```

/usr/local/lib/python3.7/dist-packages/sklearn/model_selection/_split.py:296:
FutureWarning

```

```
# create initial population (generation 0):
```

```
population = toolbox.populationCreator(n=POPULATION_SIZE)
```

```
# prepare the statistics object:
```

```
stats = tools.Statistics(lambda ind: ind.fitness.values)
stats.register("max", numpy.max)
stats.register("avg", numpy.mean)
```

```
# define the hall-of-fame object:
```

```
hof = tools.HallOfFame(HALL_OF_FAME_SIZE)
```

```
print('*****')
```

```
start = time.time()
```

```
# perform the Genetic Algorithm flow with hof feature added:
```

```

population, logbook = eaSimpleWithElitism(population,
                                          toolbox,
                                          cxpb=P_CROSSOVER,
                                          mutpb=P_MUTATION,
                                          ngen=MAX_GENERATIONS,
                                          stats=stats,
                                          halloffame=hof,
                                          verbose=True)

```

```
end = time.time()
```

```
time_NNA = end - start
```

```
print("Time Elapsed = ", time_NNA)
```

```
# print best solution found:
```

```
print("Best solution is: ", test.formatParams(hof.items[0]))
```



```

print("Accuracy = %1.5f" % hof.items[0].fitness.values[0])

# extract statistics:
maxFitnessValues_NNA, meanFitnessValues_NNA = logbook.select("max", "avg")

*****
gen      nevals  max          avg
0        20      0.769841     0.284063
1         17      0.769841     0.473413
2         15      0.769841     0.606905
3         16      0.769841     0.659238
4         17      0.769841     0.673444
5         14      0.769841     0.703746
6         17      0.769841     0.739619
7         14      0.769841     0.70954
8         16      0.769841     0.686921
9         17      0.769841     0.689833
10        15      0.769841     0.680286
Time Elapsed = 82.1906521320343
Best solution is: 'hidden_layer_sizes'=(13, 4, 7)
Accuracy = 0.76984

```

▼ Problems?

▼ with various RANDOM_SEED

▼ Results for various RANDOM_SEEDs

```

# dataset = 'wine'
# RANDOM_SEED = 42

gen nevals  max          avg
0   20      0.769841     0.284063
1   17      0.769841     0.473413
2   15      0.769841     0.606905
3   16      0.769841     0.659238
4   17      0.769841     0.673444
5   14      0.769841     0.703746
6   17      0.769841     0.739619
7   14      0.769841     0.70954
8   16      0.769841     0.686921
9   17      0.769841     0.689833
10  15      0.769841     0.680286
Best solution is: 'hidden_layer_sizes'=(13, 4, 7)
Accuracy = 0.76984

```

```

# dataset = 'wine'
# RANDOM_SEED = 666

*****

```

```

gen nevals  max      avg
0   20      0.647937  0.31354
1   17      0.647937  0.41869
2   15      0.647937  0.478095
3   16      0.647937  0.418651
4   17      0.647937  0.503325
5   12      0.647937  0.492421
6   17      0.647937  0.435524
7   16      0.647937  0.503032
8   16      0.647937  0.466016
9   16      0.647937  0.51246
10  17      0.647937  0.572524
Time Elapsed = 93.69340062141418
Best solution is: 'hidden_layer_sizes'=(14, 3, 4, 4)
Accuracy = 0.64794

```

```

# dataset = 'wine'
# RANDOM_SEED = 1042
*****
gen nevals  max      avg
0   20      0.520159  0.289151
1   15      0.520159  0.322095
2   12      0.520159  0.42246
3   17      0.541587  0.419079
4   14      0.541587  0.41527
5   17      0.541587  0.471929
6   15      0.541587  0.457198
7   16      0.541587  0.472865
8   17      0.541587  0.493143
9   16      0.541587  0.45669
10  13      0.541587  0.488968
Time Elapsed = 84.34443235397339
Best solution is: 'hidden_layer_sizes'=(9, 9, 5)
Accuracy = 0.54159

```

RESUME

For various RANDOM_SEED we can obtain NNs with the **very different**:

- **performance** (accuracy),
- **the number of nodes** in layers,
- **the number of layers**.

The reason is the stochastic (so-called **non-gradient**) manner of parameter change during evolution. There is a possibility that all models for different RANDOM_SEEDs can reach the different **local** (not **global**) the maximum value of fitness function (accuracy here).

▼ ... with various datasets ...

(let's try it as a self-guided learning!)

It takes a small change in `dataset_name` variable.

▼ Iris dataset

```
import matplotlib.pyplot as plt
from sklearn import datasets

# import dataset
data = datasets.load_iris()
X = data.data[:, :2] # we only take the first two features.
y = data.target
```

▼ Features and Targets

```
list(data.target_names)

['setosa', 'versicolor', 'virginica']
```

```
list(data.feature_names)

['sepal length (cm)',
 'sepal width (cm)',
 'petal length (cm)',
 'petal width (cm)']
```

▼ Plot Some Features

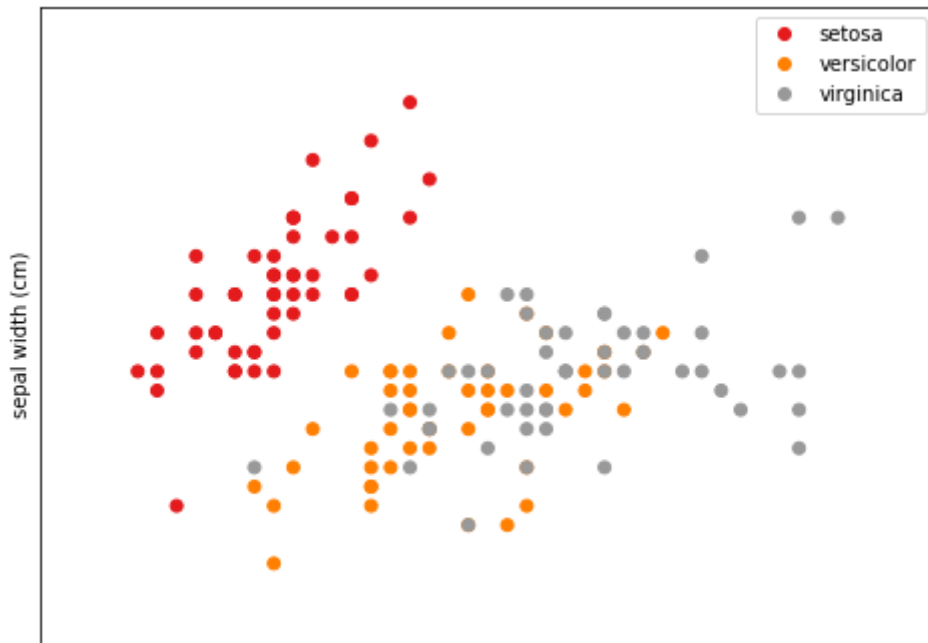
```
x_min, x_max = X[:, 0].min() - .5, X[:, 0].max() + .5
y_min, y_max = X[:, 1].min() - .5, X[:, 1].max() + .5

plt.figure(2, figsize=(8, 6))
plt.clf()

# Plot the training points
scatter = plt.scatter(X[:, 0], X[:, 1], c=y, cmap=plt.cm.Set1)
                    #edgecolor='k')
plt.xlabel(data.feature_names[0])
plt.ylabel(data.feature_names[1])

plt.xlim(x_min, x_max)
plt.ylim(y_min, y_max)
plt.xticks(())
plt.yticks(())
#plt.legend()
#plt.legend(*scatter.legend_elements())
classes = list(data.target_names)
plt.legend(handles=scatter.legend_elements()[0], labels=classes)

plt.show()
```



▼ Breast cancer dataset

```
import matplotlib.pyplot as plt
from sklearn import datasets

# import dataset
data = datasets.load_breast_cancer()
X = data.data[:, :2] # we only take the first two features.
y = data.target
```

▼ Features and Targets

```
list(data.target_names)
```

```
['malignant', 'benign']
```

```
list(data.feature_names)
```

```
['mean radius',
 'mean texture',
 'mean perimeter',
 'mean area',
 'mean smoothness',
 'mean compactness',
 'mean concavity',
 'mean concave points',
 'mean symmetry',
 'mean fractal dimension',
 'radius error',
 'texture error',
 'perimeter error',
 'area error',
```

```
'smoothness error',
'compactness error',
'concavity error',
'concave points error',
'symmetry error',
'fractal dimension error',
'worst radius',
'worst texture',
'worst perimeter',
'worst area',
'worst smoothness',
'worst compactness',
'worst concavity',
'worst concave points',
'worst symmetry',
'worst fractal dimension']
```

▼ Plot Some Features

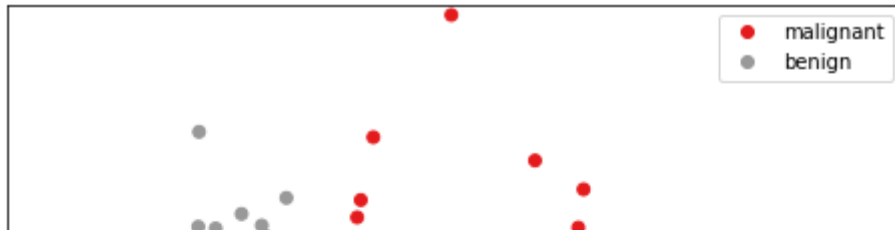
```
x_min, x_max = X[:, 0].min() - .5, X[:, 0].max() + .5
y_min, y_max = X[:, 1].min() - .5, X[:, 1].max() + .5

plt.figure(2, figsize=(8, 6))
plt.clf()

# Plot the training points
scatter = plt.scatter(X[:, 0], X[:, 1], c=y, cmap=plt.cm.Set1)
                #edgecolor='k')
plt.xlabel(data.feature_names[0])
plt.ylabel(data.feature_names[1])

plt.xlim(x_min, x_max)
plt.ylim(y_min, y_max)
plt.xticks(())
plt.yticks(())
#plt.legend()
#plt.legend(*scatter.legend_elements())
classes = list(data.target_names)
plt.legend(handles=scatter.legend_elements()[0], labels=classes)

plt.show()
```



▼ Results for various datasets

```
### wine
# RANDOM_SEED = 42

gen nevals  max      avg
0   20      0.769841  0.284063
1   17      0.769841  0.473413
2   15      0.769841  0.606905
3   16      0.769841  0.659238
4   17      0.769841  0.673444
5   14      0.769841  0.703746
6   17      0.769841  0.739619
7   14      0.769841  0.70954
8   16      0.769841  0.686921
9   17      0.769841  0.689833
10  15      0.769841  0.680286
- Best solution is: 'hidden_layer_sizes'=(13, 4, 7) , accuracy = 0.7698412698412
```

```
### iris
# RANDOM_SEED = 42

gen nevals  max      avg
0   20      0.666667  0.416333
1   17      0.693333  0.487
2   15      0.76      0.537333
3   14      0.76      0.550667
4   17      0.76      0.568333
5   17      0.76      0.653667
6   14      0.76      0.589333
7   15      0.76      0.618
8   16      0.866667  0.616667
9   16      0.866667  0.666333
10  16      0.866667  0.722667
- Best solution is: 'hidden_layer_sizes'=(15, 5, 8) , accuracy = 0.8666666666666666
```

```
### breast_cancer
# RANDOM_SEED = 42

gen nevals  max      avg
0   20      0.927946  0.808865
1   15      0.929669  0.889953
2   15      0.929669  0.893562
3   15      0.929669  0.893683
```

4	16	0.934932	0.839395
5	17	0.934932	0.912204
6	14	0.934932	0.895351
7	16	0.934932	0.908839
8	17	0.934932	0.900869
9	16	0.934932	0.845574
10	15	0.934932	0.900429

- Best solution is: 'hidden_layer_sizes'=(15, 8, 10, 4) , accuracy = 0.934932463

RESUME

Again ... for various DATASETS we can obtain NNs with the **very different**:

- **performance** (accuracy),
- **the number of nodes** in layers,
- **the number of layers**.

The reason is evident here: the different number of features and their different contribution to fitness function.

▼ with various MAX number of layers ...

(let's try it as a self-guided learning!)

▼ Part 2. NN Hyperparameter Tuning

```

from sklearn import model_selection
from sklearn import datasets
from sklearn.neural_network import MLPClassifier

from sklearn.exceptions import ConvergenceWarning
from sklearn.utils.testing import ignore_warnings

from math import floor

class MlpHyperparametersTest:

    NUM_FOLDS = 5

    # Only hyperparameters!
    HIDDEN_LAYER_SIZES = [13, 4, 7]

    def __init__(self, randomSeed):

        self.randomSeed = randomSeed
        self.initDataset()

```

```

self.kfold = model_selection.KFold(n_splits=self.NUM_FOLDS, random_state=s

def initDataset(self):
    self.data = datasets.load_iris()

    self.X = self.data['data']
    self.y = self.data['target']

# params contains floats representing the following:
# 'hidden_layer_sizes': up to 4 positive integers
# 'activation': {'tanh', 'relu', 'logistic'},
# 'solver': {'sgd', 'adam', 'lbfgs'},
# 'alpha': float,
# 'learning_rate': {'constant', 'invscaling', 'adaptive'}
def convertParams(self, params):

    # transform the layer sizes from float (possibly negative) values into hid
#     if round(params[1]) <= 0:
#         hiddenLayerSizes = round(params[0]),
#     elif round(params[2]) <= 0:
#         hiddenLayerSizes = (round(params[0]), round(params[1]))
#     elif round(params[3]) <= 0:
#         hiddenLayerSizes = (round(params[0]), round(params[1]), round(params[
#     else:
#         hiddenLayerSizes = (round(params[0]), round(params[1]), round(params[

#     activation = ['tanh', 'relu', 'logistic'][floor(params[4])]
#     solver = ['sgd', 'adam', 'lbfgs'][floor(params[5])]
#     alpha = params[6]
#     learning_rate = ['constant', 'invscaling', 'adaptive'][floor(params[7])]

activation = ['tanh', 'relu', 'logistic'][floor(params[0])]
solver = ['sgd', 'adam', 'lbfgs'][floor(params[1])]
alpha = params[2]
learning_rate = ['constant', 'invscaling', 'adaptive'][floor(params[3])]

#return hiddenLayerSizes, activation, solver, alpha, learning_rate
return activation, solver, alpha, learning_rate

@ignore_warnings(category=ConvergenceWarning)
def getAccuracy(self, params):
    #hiddenLayerSizes, activation, solver, alpha, learning_rate = self.convert
activation, solver, alpha, learning_rate = self.convertParams(params)

self.classifier = MLPClassifier(random_state=self.randomSeed,
                                #hidden_layer_sizes=hiddenLayerSizes,
                                hidden_layer_sizes=self.HIDDEN_LAYER_SIZES
activation=activation,
solver=solver,
alpha=alpha,
learning_rate=learning_rate)

cv_results = model_selection.cross_val_score(self.classifier,
                                             self.X,

```



```

        self.y,
        cv=self.kfold,
        scoring='accuracy')

    return cv_results.mean()

def formatParams(self, params):
    #hiddenLayerSizes, activation, solver, alpha, learning_rate = self.convert
    activation, solver, alpha, learning_rate = self.convertParams(params)
#    return "'hidden_layer_sizes'={}\n " \
    return "'activation'='{}'\n " \
           "'solver'='{}'\n " \
           "'alpha'={}\n " \
           "'learning_rate'='{}'\n" \
           .format(activation, solver, alpha, learning_rate)
    #.format(hiddenLayerSizes, activation, solver, alpha, learning_rate)

```

```

from deap import base
from deap import creator
from deap import tools

import random
import numpy

# boundaries for all parameters:
# 'hidden_layer_sizes': first four values
# 'activation': ['tanh', 'relu', 'logistic'] -> 0, 1, 2
# 'solver': ['sgd', 'adam', 'lbfgs'] -> 0, 1, 2
# 'alpha': float in the range of [0.0001, 2.0],
# 'learning_rate': ['constant', 'invscaling', 'adaptive'] -> 0, 1, 2
#BOUNDS_LOW = [ 5, -5, -10, -20, 0, 0, 0.0001, 0 ]
#BOUNDS_HIGH = [15, 10, 10, 10, 2.999, 2.999, 2.0, 2.999]

# Only hyperparameters!
BOUNDS_LOW = [0, 0, 0.0001, 0 ]
BOUNDS_HIGH = [2.999, 2.999, 2.0, 2.999]

NUM_OF_PARAMS = len(BOUNDS_HIGH)

# Genetic Algorithm constants:
POPULATION_SIZE = 20
P_CROSSOVER = 0.9 # probability for crossover
P_MUTATION = 0.5 # probability for mutating an individual
MAX_GENERATIONS = 10
HALL_OF_FAME_SIZE = 3
CROWDING_FACTOR = 10.0 # crowding factor for crossover and mutation

# set the random seed:
RANDOM_SEED = 42
random.seed(RANDOM_SEED)

```

```

# create the classifier accuracy test class:
test = MlpHyperparametersTest(RANDOM_SEED)

toolbox = base.Toolbox()

# define a single objective, maximizing fitness strategy:
creator.create("FitnessMax", base.Fitness, weights=(1.0,))

# create the Individual class based on list:
creator.create("Individual", list, fitness=creator.FitnessMax)

# define the layer size attributes individually:
for i in range(NUM_OF_PARAMS):
    # "attribute_0", "attribute_1", ...
    toolbox.register("attribute_" + str(i),
                    random.uniform,
                    BOUNDS_LOW[i],
                    BOUNDS_HIGH[i])

# create a tuple containing an attribute generator for each param searched:
attributes = ()
for i in range(NUM_OF_PARAMS):
    attributes = attributes + (toolbox.__getattr__("attribute_" + str(i)),)

# create the individual operator to fill up an Individual instance:
toolbox.register("individualCreator",
                tools.initCycle,
                creator.Individual,
                attributes,
                n=1)

# create the population operator to generate a list of individuals:
toolbox.register("populationCreator",
                tools.initRepeat,
                list,
                toolbox.individualCreator)

# fitness calculation
def classificationAccuracy(individual):
    return test.getAccuracy(individual),

toolbox.register("evaluate", classificationAccuracy)

# genetic operators:mutFlipBit

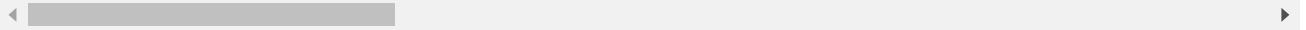
# genetic operators:
toolbox.register("select", tools.selTournament, tournsize=2)

toolbox.register("mate",
                tools.cxSimulatedBinaryBounded,
                low=BOUNDS_LOW,
                up=BOUNDS_HIGH,
                eta=CROWDING_FACTOR)

```

```
toolbox.register("mutate",
                 tools.mutPolynomialBounded,
                 low=BOUNDS_LOW,
                 up=BOUNDS_HIGH,
                 eta=CROWDING_FACTOR,
                 indpb=1.0/NUM_OF_PARAMS)
```

```
/usr/local/lib/python3.7/dist-packages/sklearn/model_selection/_split.py:296:
FutureWarning
/usr/local/lib/python3.7/dist-packages/deap/creator.py:141: RuntimeWarning: A
RuntimeWarning)
/usr/local/lib/python3.7/dist-packages/deap/creator.py:141: RuntimeWarning: A
RuntimeWarning)
```



```
# create initial population (generation 0):
population = toolbox.populationCreator(n=POPULATION_SIZE)

# prepare the statistics object:
stats = tools.Statistics(lambda ind: ind.fitness.values)
stats.register("max", numpy.max)
stats.register("avg", numpy.mean)

# define the hall-of-fame object:
hof = tools.HallOfFame(HALL_OF_FAME_SIZE)

print('*****')
start = time.time()
# perform the Genetic Algorithm flow with hof feature added:
population, logbook = eaSimpleWithElitism(population,
                                           toolbox,
                                           cxpb=P_CROSSOVER,
                                           mutpb=P_MUTATION,
                                           ngen=MAX_GENERATIONS,
                                           stats=stats,
                                           halloffame=hof,
                                           verbose=True)

end = time.time()
time_HYP = end - start
print("Time Elapsed = ", time_HYP)

# print best solution found:
print("Best solution is: ", test.formatParams(hof.items[0]))
print("Accuracy = %1.5f" % hof.items[0].fitness.values[0])

# extract statistics:
maxFitnessValues_HYP, meanFitnessValues_HYP = logbook.select("max", "avg")
```

```
*****
```

gen	nevals	max	avg
0	20	0.946667	0.362
1	15	0.946667	0.599667
2	16	0.946667	0.864333

3	16	0.946667	0.927333
4	17	0.946667	0.944667
5	14	0.946667	0.887
6	15	0.946667	0.944667
7	14	0.946667	0.946
8	16	0.946667	0.907667
9	15	0.946667	0.945
10	17	0.946667	0.946

Time Elapsed = 92.3740484714508
 Best solution is: 'activation'='logistic'
 'solver'='lbfgs'
 'alpha'=0.17139833879055075
 'learning_rate'='invscaling'
 Accuracy = 0.94667

▼ Part 3. NN Architecture + Hyperparameter Tuning

```

from sklearn import model_selection
from sklearn import datasets
from sklearn.neural_network import MLPClassifier

from sklearn.exceptions import ConvergenceWarning
from sklearn.utils.testing import ignore_warnings

from math import floor

class MlpHyperparametersTest:

    NUM_FOLDS = 5

    def __init__(self, randomSeed):

        self.randomSeed = randomSeed
        self.initDataset()
        self.kfold = model_selection.KFold(n_splits=self.NUM_FOLDS, random_state=s

    def initDataset(self):
        self.data = datasets.load_iris()

        self.X = self.data['data']
        self.y = self.data['target']

    # params contains floats representing the following:
    # 'hidden_layer_sizes': up to 4 positive integers
    # 'activation': {'tanh', 'relu', 'logistic'},
    # 'solver': {'sgd', 'adam', 'lbfgs'},
    # 'alpha': float,
    # 'learning_rate': {'constant', 'invscaling', 'adaptive'}
    def convertParams(self, params):

        # transform the layer sizes from float (possibly negative) values into hid
        if round(params[1]) <= 0:

```

```

        hiddenLayerSizes = round(params[0]),
    elif round(params[2]) <= 0:
        hiddenLayerSizes = (round(params[0]), round(params[1]))
    elif round(params[3]) <= 0:
        hiddenLayerSizes = (round(params[0]), round(params[1]), round(params[2])
    else:
        hiddenLayerSizes = (round(params[0]), round(params[1]), round(params[2])

    activation = ['tanh', 'relu', 'logistic'][floor(params[4])]
    solver = ['sgd', 'adam', 'lbfgs'][floor(params[5])]
    alpha = params[6]
    learning_rate = ['constant', 'invscaling', 'adaptive'][floor(params[7])]

    return hiddenLayerSizes, activation, solver, alpha, learning_rate

@ignore_warnings(category=ConvergenceWarning)
def getAccuracy(self, params):
    hiddenLayerSizes, activation, solver, alpha, learning_rate = self.convertP

    self.classifier = MLPClassifier(random_state=self.randomSeed,
                                    hidden_layer_sizes=hiddenLayerSizes,
                                    activation=activation,
                                    solver=solver,
                                    alpha=alpha,
                                    learning_rate=learning_rate)

    cv_results = model_selection.cross_val_score(self.classifier,
                                                self.X,
                                                self.y,
                                                cv=self.kfold,
                                                scoring='accuracy')

    return cv_results.mean()

def formatParams(self, params):
    hiddenLayerSizes, activation, solver, alpha, learning_rate = self.convertP
    return "'hidden_layer_sizes'={}\n " \
           "'activation'='{}'\n " \
           "'solver'='{}'\n " \
           "'alpha'={}\n " \
           "'learning_rate'='{}'\n " \
           .format(hiddenLayerSizes, activation, solver, alpha, learning_rate)

```

```

from deap import base
from deap import creator
from deap import tools

```

```

import random
import numpy

```

```

# boundaries for all parameters:
# 'hidden_layer_sizes': first four values
# 'activation': ['tanh', 'relu', 'logistic'] -> 0, 1, 2

```

```

# 'solver': ['sgd', 'adam', 'lbfgs'] -> 0, 1, 2
# 'alpha': float in the range of [0.0001, 2.0],
# 'learning_rate': ['constant', 'invscaling', 'adaptive'] -> 0, 1, 2
BOUNDS_LOW = [ 5, -5, -10, -20, 0, 0, 0.0001, 0 ]
BOUNDS_HIGH = [15, 10, 10, 10, 2.999, 2.999, 2.0, 2.999]

NUM_OF_PARAMS = len(BOUNDS_HIGH)

# Genetic Algorithm constants:
POPULATION_SIZE = 20
P_CROSSOVER = 0.9 # probability for crossover
P_MUTATION = 0.5 # probability for mutating an individual
MAX_GENERATIONS = 10
HALL_OF_FAME_SIZE = 3
CROWDING_FACTOR = 10.0 # crowding factor for crossover and mutation

# set the random seed:
RANDOM_SEED = 42
random.seed(RANDOM_SEED)

# create the classifier accuracy test class:
test = MlpHyperparametersTest(RANDOM_SEED)

toolbox = base.Toolbox()

# define a single objective, maximizing fitness strategy:
creator.create("FitnessMax", base.Fitness, weights=(1.0,))

# create the Individual class based on list:
creator.create("Individual", list, fitness=creator.FitnessMax)

# define the layer size attributes individually:
for i in range(NUM_OF_PARAMS):
    # "attribute_0", "attribute_1", ...
    toolbox.register("attribute_" + str(i),
                    random.uniform,
                    BOUNDS_LOW[i],
                    BOUNDS_HIGH[i])

# create a tuple containing an attribute generator for each param searched:
attributes = ()
for i in range(NUM_OF_PARAMS):
    attributes = attributes + (toolbox.__getattr__("attribute_" + str(i)),)

# create the individual operator to fill up an Individual instance:
toolbox.register("individualCreator",
                tools.initCycle,
                creator.Individual,
                attributes,
                n=1)

# create the population operator to generate a list of individuals:
toolbox.register("populationCreator",
                tools.initRepeat,
                list,

```



```

stats=stats,
halloffame=hof,
verbose=True)

end = time.time()
time_NNA_HYP = end - start
print("Time Elapsed = ", time_NNA_HYP)

# print best solution found:
print("Best solution is: ", test.formatParams(hof.items[0]))
print("Accuracy = %1.5f" % hof.items[0].fitness.values[0])

# extract statistics:
maxFitnessValues_NNA_HYP, meanFitnessValues_NNA_HYP = logbook.select("max", "avg")

*****
gen      nevals  max      avg
0        20      0.94     0.448
1        16      0.94     0.633
2        15      0.94     0.737667
3        16      0.946667 0.842
4        17      0.946667 0.889667
5        15      0.946667 0.937667
6        16      0.946667 0.939
7        16      0.946667 0.875
8        16      0.946667 0.876333
9        14      0.946667 0.942333
10       16      0.946667 0.902667
Time Elapsed = 83.84976434707642
Best solution is: 'hidden_layer_sizes'=(8, 7)
'activation'='relu'
'solver'='lbfgs'
'alpha'=0.563775972907702
'learning_rate'='adaptive'
Accuracy = 0.94667

```

▼ Comparison Plots

▼ Accuracy

```

sns.set_style("whitegrid")

# Classic grid search solution
#plt.hlines(accuracy_classic_solution, 0, 5, linestyle = 'solid', label='Classic g

# NN architecture
plt.plot(maxFitnessValues_NNA, color='green', label='NNA (max)')
plt.plot(meanFitnessValues_NNA, color='green', linestyle = 'dotted', label='NNA (m

# NN hyperparameter
plt.plot(maxFitnessValues_HYP, color='blue', label='hyper (max)')

```

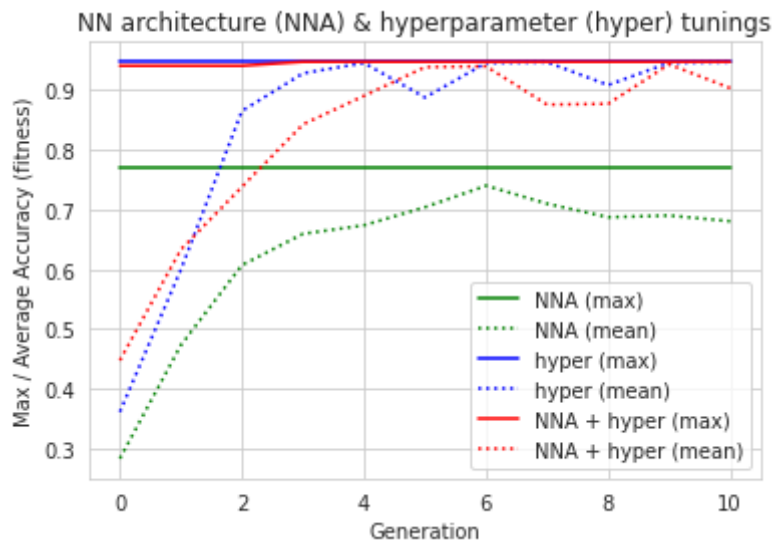


```

plt.plot(meanFitnessValues_HYP, color='blue', linestyle = 'dotted', label='hyper (
# NN architecture + hyperparameter
plt.plot(maxFitnessValues_NNA_HYP, color='red', label='NNA + hyper (max)')
plt.plot(meanFitnessValues_NNA_HYP, color='red', linestyle = 'dotted', label='NNA

plt.xlabel('Generation')
plt.ylabel('Max / Average Accuracy (fitness)')
plt.title('NN architecture (NNA) & hyperparameter (hyper) tunings')
plt.legend()
plt.show()

```



▼ Time

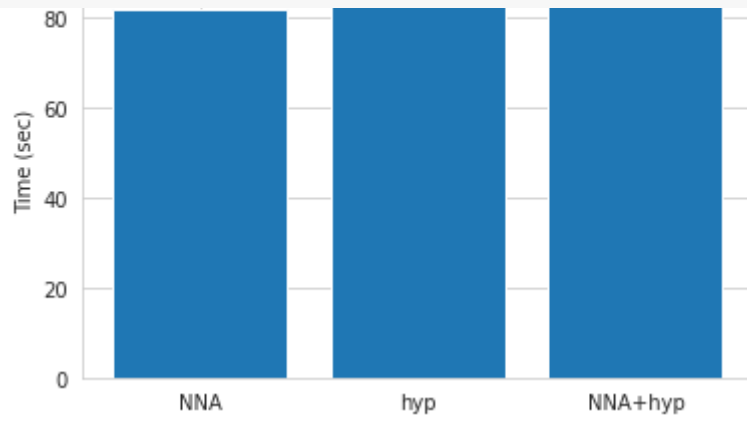
```

import matplotlib.pyplot as plt

x = ['NNA', 'hyp', 'NNA+hyp']
y = [time_NNA, time_HYP, time_NNA_HYP]
plt.bar(x, y)
plt.ylabel('Time (sec)')
plt.title('Workflow Time')
plt.show()

```

Workflow Time



[Colab paid products - Cancel contracts here](#)

It supports teaching agents everything from walking to playing games like Pong or Pinball.

```
! pip install gym
```

```
Requirement already satisfied: gym in /usr/local/lib/python3.7/dist-packages  
Requirement already satisfied: pygame<=1.5.0,>=1.4.0 in /usr/local/lib/python3.7/dist-packages  
Requirement already satisfied: numpy>=1.10.4 in /usr/local/lib/python3.7/dist-packages  
Requirement already satisfied: scipy in /usr/local/lib/python3.7/dist-packages  
Requirement already satisfied: cloudpickle<1.7.0,>=1.2.0 in /usr/local/lib/python3.7/dist-packages  
Requirement already satisfied: future in /usr/local/lib/python3.7/dist-packages
```

▼ Libraries to Render OpenAI Gym Environments in Colab

It is possible to visualize the activities performed in Gym (game your agent is playing), even on Colab. This section provides information on how to generate a video in Colab that shows you an episode of the game your agent is playing.

```
%%time  
!pip install gym pyvirtualdisplay > /dev/null 2>&1  
!apt-get install -y xvfb python-opengl ffmpeg > /dev/null 2>&1
```

```
CPU times: user 42.1 ms, sys: 11.1 ms, total: 53.2 ms  
Wall time: 12.3 s
```

```
%%time  
!apt-get update > /dev/null 2>&1  
!apt-get install cmake > /dev/null 2>&1  
!pip install --upgrade setuptools > /dev/null 2>&1  
!pip install ez_setup > /dev/null 2>&1  
!pip install gym[atari] > /dev/null 2>&1
```

```
Collecting setuptools  
  Downloading https://files.pythonhosted.org/packages/60/6a/dd9533a  
    |████████████████████████████████████████| 788kB 4.4MB/s  
ERROR: datascience 0.10.6 has requirement folium==0.2.1, but you'll  
Installing collected packages: setuptools  
  Found existing installation: setuptools 54.0.0  
  Uninstalling setuptools-54.0.0:  
    Successfully uninstalled setuptools-54.0.0  
  Successfully installed setuptools-54.1.1  
CPU times: user 81.7 ms, sys: 32.5 ms, total: 114 ms
```

- ▼ **IMPORTANT:** you should restart runtime!

▼ Functions to visualize Gym-game-scenarios in Colab

Next we define functions used to show the video by adding it to the Colab notebook.

```
import gym
from gym.wrappers import Monitor
import glob
import io
import base64
from IPython.display import HTML
from pyvirtualdisplay import Display
from IPython import display as ipythondisplay

display = Display(visible=0, size=(1400, 900))
display.start()

"""
Utility functions to enable video recording of gym environment
and displaying it.
To enable video, just do "env = wrap_env(env)"
"""

def show_video():
    mp4list = glob.glob('video/*.mp4')
    if len(mp4list) > 0:
        mp4 = mp4list[0]
        video = io.open(mp4, 'r+b').read()
        encoded = base64.b64encode(video)
        ipythondisplay.display(HTML(data='''<video alt="test" autoplay
            loop controls style="height: 400px;">
                <source src="data:video/mp4;base64,{0}" type="video/mp4" />
            </video>'''.format(encoded.decode('ascii'))))
    else:
        print("Could not find video")

def wrap_env(env):
    env = Monitor(env, './video', force=True)
    return env
```

▼ Part 2. GA Solution for RL problem - MountainCar-v0

MountainCar - Problem Description

A car is on a one-dimensional track, positioned between two "mountains".

The **goal** is to drive up the mountain on the right; however, the car's engine is not strong enough to scale the mountain in a single pass. Therefore, the only way to succeed is to drive back and forth to build up momentum.

This problem was first described by Andrew Moore in his PhD thesis:

A. Moore, Efficient Memory-Based Learning for Robot Control, PhD thesis, University of Cambridge 1990 **Cited in 363 sources**

▼ Import Python libraries

In these and other lectures, we will use various Python packages:

- [NumPy](#)
- [Matplotlib](#)
- [Seaborn](#)

They are already pre-installed in Colab. Let's import them by the following code.

```
import gym
import time
import pickle
import random
import numpy

# for plotting
import matplotlib.pyplot as plt
import seaborn as sns
```

```
# If you run this notebook again, please, clean the local directory.
! rm -r ./video
! rm ./.*pickle
```

```
rm: cannot remove './video': No such file or directory
rm: cannot remove './.*pickle': No such file or directory
```

▼ Actors - Car

```
MAX_STEPS = 200
FLAG_LOCATION = 0.5

class MountainCar:
```

```

def __init__(self, randomSeed):

    #self.env = gym.make('MountainCar-v0')
    self.env = wrap_env(gym.make("MountainCar-v0"))
    self.env.seed(randomSeed)

def __len__(self):
    return MAX_STEPS

def getScore(self, actions):
    """
    calculates the score of a given solution, represented by the list of actions
    by initiating an episode of the Mountain-Car environment and running it with
    Lower score is better.
    :param actions: a list of actions (values 0, 1, or 2) to be fed into the environment
    :return: the calculated score value
    """

    # start a new episode:
    self.env.reset()

    actionCounter = 0

    # feed the actions to the environment:
    for action in actions:
        actionCounter += 1

        # provide an action and get feedback:
        observation, reward, done, info = self.env.step(action)

        # episode over - either the car hit the flag, or 200 actions processed
        if done:
            break

    # evaluate the results to produce the score:
    if actionCounter < MAX_STEPS:
        # the car hit the flag:
        # start from a score of 0
        # reward further for a smaller amount of steps
        score = 0 - (MAX_STEPS - actionCounter)/MAX_STEPS
    else:
        # the car did not hit the flag:
        # reward according to distance from flag
        score = abs(observation[0] - FLAG_LOCATION) # we want to minimize the distance

    return score

def saveActions(self, actions):
    """
    serializes and saves a list of actions using pickle
    :param actions: a list of actions (values 0, 1, or 2) to be fed into the environment
    """
    savedActions = []
    for action in actions:
        savedActions.append(action)

```

```

        pickle.dump(savedActions, open("mountain-car-data.pickle", "wb"))

def replaySavedActions(self):
    """
    deserializes a saved list of actions and replays it
    """
    savedActions = pickle.load(open("mountain-car-data.pickle", "rb"))
    self.replay(savedActions)

def replay(self, actions):
    """
    renders the environment and replays list of actions into it, to visualize
    :param actions: a list of actions (values 0, 1, or 2) to be fed into the m
    """

    # start a new episode:
    observation = self.env.reset()

    # start rendering:
    self.env.render()

    actionCounter = 0

    # replay the given actions by feeding them into the environment:
    for action in actions:

        actionCounter += 1
        self.env.render()
        observation, reward, done, info = self.env.step(action)
        print(actionCounter, ": -----")
        print("action = ", action)
        print("observation = ", observation)
        print("distance from flag = ", abs(observation[0] - 0.5))
        print()

        if done:
            break
        else:
            time.sleep(0.02)

    self.env.close()

def replayVideo(self):
    #self.env.close()
    show_video()

```

```

# Set the random seed
# for reproducibility of results:
RANDOM_SEED = 42
random.seed(RANDOM_SEED)

```



```
# Create the instance of the MountainCar class:
```

▼ GA Solution

```
from deap import base
from deap import creator
from deap import tools
from deap import algorithms
```

```
# Genetic Algorithm constants:
POPULATION_SIZE = 100
P_CROSSOVER = 0.9 # probability for crossover
P_MUTATION = 0.5 # probability for mutating an individual
MAX_GENERATIONS = 80
HALL_OF_FAME_SIZE = 20
```

▼ Genetic Tools

```
toolbox = base.Toolbox()

# define a single objective, minimizing fitness strategy:
creator.create("FitnessMin", base.Fitness, weights=(-1.0,))

# create the Individual class based on list:
creator.create("Individual", list, fitness=creator.FitnessMin)

# create an operator that randomly returns 0, 1 or 2:
toolbox.register("zeroOneOrTwo", random.randint, 0, 2)

# create an operator that generates a list of individuals:
toolbox.register("individualCreator",
                 tools.initRepeat,
                 creator.Individual,
                 toolbox.zeroOneOrTwo,
                 len(car))

# create the population operator to generate a list of individuals:
toolbox.register("populationCreator", tools.initRepeat, list, toolbox.individualCr

# fitness calculation
def getCarScore(individual):
    return car.getScore(individual), # return a tuple

toolbox.register("evaluate", getCarScore)

# genetic operators for binary list:
toolbox.register("select", tools.selTournament, tournsize=2)
toolbox.register("mate", tools.cxTwoPoint)
toolbox.register("mutate", tools.mutUniformInt, low=0, up=2, indpb=1.0/len(car))
```

▼ Elitism Tools

```
def eaSimpleWithElitism(population, toolbox, cxpb, mutpb, ngen, stats=None,
                        halloffame=None, verbose=__debug__):
    """This algorithm is similar to DEAP eaSimple() algorithm, with the modificati
    halloffame is used to implement an elitism mechanism. The individuals containe
    halloffame are directly injected into the next generation and are not subject
    genetic operators of selection, crossover and mutation.
    """
    logbook = tools.Logbook()
    logbook.header = ['gen', 'nevals'] + (stats.fields if stats else [])

    # Evaluate the individuals with an invalid fitness
    invalid_ind = [ind for ind in population if not ind.fitness.valid]
    fitnesses = toolbox.map(toolbox.evaluate, invalid_ind)
    for ind, fit in zip(invalid_ind, fitnesses):
        ind.fitness.values = fit

    if halloffame is None:
        raise ValueError("halloffame parameter must not be empty!")

    halloffame.update(population)
    hof_size = len(halloffame.items) if halloffame.items else 0

    record = stats.compile(population) if stats else {}
    logbook.record(gen=0, nevals=len(invalid_ind), **record)
    if verbose:
        print(logbook.stream)

    # Begin the generational process
    for gen in range(1, ngen + 1):

        # Select the next generation individuals
        offspring = toolbox.select(population, len(population) - hof_size)

        # Vary the pool of individuals
        offspring = algorithms.varAnd(offspring, toolbox, cxpb, mutpb)

        # Evaluate the individuals with an invalid fitness
        invalid_ind = [ind for ind in offspring if not ind.fitness.valid]
        fitnesses = toolbox.map(toolbox.evaluate, invalid_ind)
        for ind, fit in zip(invalid_ind, fitnesses):
            ind.fitness.values = fit

        # add the best back to population:
        offspring.extend(halloffame.items)

        # Update the hall of fame with the generated individuals
        halloffame.update(offspring)

        # Replace the current population by the offspring
        population[:] = offspring
```

```

# Append the current generation statistics to the logbook
record = stats.compile(population) if stats else {}
logbook.record(gen=gen, nevals=len(invalid_ind), **record)
if verbose:
    print(logbook.stream)

return population, logbook

```

▼ GA Workflow

```

# create initial population (generation 0):
population = toolbox.populationCreator(n=POPULATION_SIZE)

# prepare the statistics object:
stats = tools.Statistics(lambda ind: ind.fitness.values)
stats.register("min", numpy.min)
stats.register("avg", numpy.mean)

# define the hall-of-fame object:
hof = tools.HallOfFame(HALL_OF_FAME_SIZE)

print('*****')
start = time.time()
# perform the Genetic Algorithm flow with hof feature added:
population, logbook = eaSimpleWithElitism(population,
                                           toolbox,
                                           cxpb=P_CROSSOVER,
                                           mutpb=P_MUTATION,
                                           ngen=MAX_GENERATIONS,
                                           stats=stats,
                                           halloffame=hof,
                                           verbose=True)

end = time.time()
time_GA = end - start
print("Time Elapsed = ", time_GA)

```

```

*****
gen      nevals  min          avg
0         100    0.659205    1.02616
1          78    0.659205    0.970209
2          77    0.659205    0.906442
3          76    0.659205    0.841666
4          74    0.659205    0.791741
5          78    0.581075    0.754467
6          76    0.581075    0.712045
7          77    0.551261    0.676387
8          74    0.455182    0.64108
9          76    0.455182    0.610402
10         79    0.455182    0.586111
11         77    0.441709    0.554078
12         75    0.415877    0.517882
13         78    0.415877    0.494984
14         77    0.36574     0.471906

```

15	79	0.36574	0.468517
16	80	0.362115	0.442253
17	74	0.34458	0.420221
18	77	0.325772	0.411453
19	75	0.325772	0.407308
20	77	0.325772	0.396775
21	76	0.312125	0.394258
22	73	0.312125	0.381892
23	74	0.276737	0.367306
24	79	0.276737	0.353065
25	75	0.263841	0.346514
26	73	0.262451	0.326677
27	75	0.241413	0.320918
28	79	0.241413	0.314168
29	73	0.241413	0.312155
30	76	0.224605	0.30864
31	76	0.224605	0.299474
32	77	0.224605	0.302423
33	78	0.20032	0.298204
34	76	0.20032	0.29605
35	75	0.20032	0.27704
36	78	0.196936	0.270632
37	76	0.196936	0.27497
38	73	0.196936	0.270335
39	75	0.194873	0.265736
40	76	0.192338	0.264394
41	70	0.116166	0.243454
42	74	0.0900748	0.256206
43	77	0.0694396	0.250983
44	75	0.0694396	0.244451
45	76	0.0694396	0.220137
46	78	0.0694396	0.208847
47	71	0.0400128	0.205876
48	74	0.0400128	0.186488
49	75	0.0400128	0.189645
50	77	0.0400128	0.199232
51	78	0.0400128	0.174549
52	75	0.0179342	0.152889
53	79	0.0179342	0.15147
54	79	0.00603528	0.139074
--	--	- - - - -	- - - - -

```

# print best solution found:
best = hof.items[0]
print("Best solution: ", best)
print("Best FitnessMin = %1.5f" % best.fitness.values[0])

# extract statistics:
minFitnessValues_GA, meanFitnessValues_GA = logbook.select("min", "avg")
print('History of minFitnessValues_GA =',minFitnessValues_GA)
print('History of meanFitnessValues_GA =',meanFitnessValues_GA)

# save best solution for a replay:
car.saveActions(best)

```

```

Best solution: [0, 1, 2, 0, 0, 1, 2, 2, 2, 2, 2, 2, 1, 1, 2, 2, 0, 1, 2, 1,
Best FitnessMin = -0.02000
History of minFitnessValues_GA = [0.6592052516766607, 0.6592052516766607, 0.6
History of meanFitnessValues_GA = [1.0261591751881378, 0.9702094529954302, 0.

```

```
# Replay the best solution - TEXT version
car.replaySavedActions()
```

```
1 : -----
action = 0
observation = [-0.54270019 -0.00086328]
distance from flag = 1.0427001917084184

2 : -----
action = 1
observation = [-0.54342029 -0.0007201 ]
distance from flag = 1.0434202917150182

3 : -----
action = 2
observation = [-5.42991818e-01  4.28473768e-04]
distance from flag = 1.0429918179471604

4 : -----
action = 0
observation = [-5.43417978e-01 -4.26160453e-04]
distance from flag = 1.0434179784000257

5 : -----
action = 0
observation = [-0.54469558 -0.0012776 ]
distance from flag = 1.0446955823976336

6 : -----
action = 1
observation = [-0.54581507 -0.00111948]
distance from flag = 1.0458150659568424

7 : -----
action = 2
observation = [-5.45768051e-01  4.70152879e-05]
distance from flag = 1.0457680506689189

8 : -----
action = 2
observation = [-0.54455489  0.00121316]
distance from flag = 1.0445548883672975

9 : -----
action = 2
observation = [-0.54218466  0.00237023]
distance from flag = 1.0421846587338575

10 : -----
action = 2
observation = [-0.53867511  0.00350955]
distance from flag = 1.0386751071930986

11 : -----
action = 2
observation = [-0.53405252  0.00462259]
distance from flag = 1.0340525217127836
```

```
12 : -----  
action = 2  
      0 500000000 0 000000000
```

```
car.replayVideo()
```



Part 3. What about the solution dependence on GA conditions?

- ▼ ... with various **RANDOM_SEED** ...

Results for various RANDOM_SEEDs

- ▼ RANDOM_SEED = 42

```
# Set the random seed  
# for reproducibility of results:  
RANDOM_SEED = 42  
random.seed(RANDOM_SEED)  
  
# Create the instance of the MountainCar class:  
car = MountainCar(RANDOM_SEED)
```

```

# create initial population (generation 0):
population = toolbox.populationCreator(n=POPULATION_SIZE)

# prepare the statistics object:
stats = tools.Statistics(lambda ind: ind.fitness.values)
stats.register("min", numpy.min)
stats.register("avg", numpy.mean)

# define the hall-of-fame object:
hof = tools.HallOfFame(HALL_OF_FAME_SIZE)

print('*****')
start = time.time()
# perform the Genetic Algorithm flow with hof feature added:
population, logbook = eaSimpleWithElitism(population,
                                           toolbox,
                                           cxpb=P_CROSSOVER,
                                           mutpb=P_MUTATION,
                                           ngen=MAX_GENERATIONS,
                                           stats=stats,
                                           halloffame=hof,
                                           verbose=True)

end = time.time()
time_42 = end - start
print("Time Elapsed = ", time_42)

```

```

*****
gen      nevals  min          avg
0        100    0.659205    1.02616
1         78    0.659205    0.970209
2         77    0.659205    0.906442
3         76    0.659205    0.841666
4         74    0.659205    0.791741
5         78    0.581075    0.754467
6         76    0.581075    0.712045
7         77    0.551261    0.676387
8         74    0.455182    0.64108
9         76    0.455182    0.610402
10        79    0.455182    0.586111
11        77    0.441709    0.554078
12        75    0.415877    0.517882
13        78    0.415877    0.494984
14        77    0.36574     0.471906
15        79    0.36574     0.468517
16        80    0.362115    0.442253
17        74    0.34458     0.420221
18        77    0.325772    0.411453
19        75    0.325772    0.407308
20        77    0.325772    0.396775
21        76    0.312125    0.394258
22        73    0.312125    0.381892
23        74    0.276737    0.367306
24        79    0.276737    0.353065
25        75    0.263841    0.346514
26        73    0.262451    0.326677
27        75    0.241413    0.320918
28        79    0.241413    0.314168

```

29	73	0.241413	0.312155
30	76	0.224605	0.30864
31	76	0.224605	0.299474
32	77	0.224605	0.302423
33	78	0.20032	0.298204
34	76	0.20032	0.29605
35	75	0.20032	0.27704
36	78	0.196936	0.270632
37	76	0.196936	0.27497
38	73	0.196936	0.270335
39	75	0.194873	0.265736
40	76	0.192338	0.264394
41	70	0.116166	0.243454
42	74	0.0900748	0.256206
43	77	0.0694396	0.250983
44	75	0.0694396	0.244451
45	76	0.0694396	0.220137
46	78	0.0694396	0.208847
47	71	0.0400128	0.205876
48	74	0.0400128	0.186488
49	75	0.0400128	0.189645
50	77	0.0400128	0.199232
51	78	0.0400128	0.174549
52	75	0.0179342	0.152889
53	79	0.0179342	0.15147
54	79	0.00603528	0.139074
55	71	0.00267502	0.130707

```
# print best solution found:
best = hof.items[0]
print("Best solution: ", best)
print("Best FitnessMin = %1.5f" % best.fitness.values[0])
#print("Best Fitness = ", best.fitness.values[0])

# extract statistics:
minFitnessValues_GA_42, meanFitnessValues_GA_42 = logbook.select("min", "avg")
print('History of minFitnessValues_GA =',minFitnessValues_GA_42)
print('History of meanFitnessValues_GA =',meanFitnessValues_GA_42)

Best solution: [0, 1, 2, 0, 0, 1, 2, 2, 2, 2, 2, 2, 1, 1, 2, 2, 0, 1, 2, 1,
Best FitnessMin = -0.02000
History of minFitnessValues_GA = [0.6592052516766607, 0.6592052516766607, 0.6
History of meanFitnessValues_GA = [1.0261591751881378, 0.9702094529954302, 0.
```

▼ RANDOM_SEED = 666

```
# Set the random seed
# for reproducibility of results:
RANDOM_SEED = 666
random.seed(RANDOM_SEED)

# Create the instance of the MountainCar class:
car = MountainCar(RANDOM_SEED)
```



```

# create initial population (generation 0):
population = toolbox.populationCreator(n=POPULATION_SIZE)

# prepare the statistics object:
stats = tools.Statistics(lambda ind: ind.fitness.values)
stats.register("min", numpy.min)
stats.register("avg", numpy.mean)

# define the hall-of-fame object:
hof = tools.HallOfFame(HALL_OF_FAME_SIZE)

print('*****')
start = time.time()
# perform the Genetic Algorithm flow with hof feature added:
population, logbook = eaSimpleWithElitism(population,
                                           toolbox,
                                           cxpb=P_CROSSOVER,
                                           mutpb=P_MUTATION,
                                           ngen=MAX_GENERATIONS,
                                           stats=stats,
                                           halloffame=hof,
                                           verbose=True)

end = time.time()
time_666 = end - start
print("Time Elapsed = ", time_666)

```

```

*****
gen      nevals  min          avg
0        100    0.824257     1.03458
1         80    0.768396     0.961691
2         76    0.695209     0.894844
3         75    0.631651     0.838345
4         75    0.601543     0.789886
5         74    0.572929     0.742351
6         72    0.577929     0.711419
7         77    0.577929     0.679999
8         72    0.534989     0.641107
9         72    0.534989     0.622413
10        75    0.512573     0.609433
11        78    0.439645     0.592019
12        74    0.439645     0.571789
13        72    0.437972     0.550431
14        79    0.418771     0.53019
15        77    0.418771     0.51943
16        76    0.41794      0.48955
17        76    0.410739     0.488176
18        77    0.372919     0.473319
19        79    0.372919     0.464156
20        77    0.252726     0.453411
21        72    0.252726     0.429531
22        71    0.252726     0.402247
23        77    0.252726     0.366217
24        78    0.23005      0.353316
25        74    0.211242     0.324498
26        76    0.211242     0.316425
27        78    0.20121      0.304086
28        79    0.20121      0.291859

```

29	76	0.197576	0.2995
30	76	0.197576	0.287731
31	73	0.173191	0.274362
32	77	0.173191	0.275585
33	79	0.173191	0.264559
34	75	0.173191	0.272344
35	77	0.168406	0.264175
36	77	0.162313	0.264218
37	74	0.162313	0.248879
38	72	0.162313	0.254829
39	72	0.162313	0.241994
40	79	0.1499	0.243321
41	78	0.148408	0.236391
42	77	0.148408	0.225184
43	75	0.131007	0.216867
44	75	0.123164	0.220414
45	77	0.123164	0.218808
46	74	0.108418	0.211137
47	72	0.106098	0.203032
48	77	0.106098	0.208214
49	71	0.0875458	0.202567
50	73	0.0875458	0.194274
51	77	0.0875458	0.197749
52	76	0.0875458	0.19476
53	77	0.0743577	0.196832
54	77	0.0743577	0.174699
55	70	0.0743577	0.180216

```
# print best solution found:
best = hof.items[0]
print("Best solution: ", best)
print("Best FitnessMin = %1.5f" % best.fitness.values[0])
#print("Best Fitness = ", best.fitness.values[0])
```

```
# extract statistics:
minFitnessValues_GA_666, meanFitnessValues_GA_666 = logbook.select("min", "avg")
print('History of minFitnessValues_GA =',minFitnessValues_GA_666)
print('History of meanFitnessValues_GA =',meanFitnessValues_GA_666)
```

```
Best solution: [2, 2, 1, 1, 0, 1, 0, 0, 1, 2, 2, 1, 1, 1, 1, 0, 2, 1, 2, 1,
Best FitnessMin = -0.01500
History of minFitnessValues_GA = [0.8242573388334045, 0.7683963861683756, 0.6
History of meanFitnessValues_GA = [1.0345837515118468, 0.9616914914820174, 0.
```

▼ RANDOM_SEED = 1042

```
# Set the random seed
# for reproducibility of results:
RANDOM_SEED = 1042
random.seed(RANDOM_SEED)

# Create the instance of the MountainCar class:
car = MountainCar(RANDOM_SEED)
```

```

# create initial population (generation 0):
population = toolbox.populationCreator(n=POPULATION_SIZE)

# prepare the statistics object:
stats = tools.Statistics(lambda ind: ind.fitness.values)
stats.register("min", numpy.min)
stats.register("avg", numpy.mean)

# define the hall-of-fame object:
hof = tools.HallOfFame(HALL_OF_FAME_SIZE)

print('*****')
start = time.time()
# perform the Genetic Algorithm flow with hof feature added:
population, logbook = eaSimpleWithElitism(population,
                                           toolbox,
                                           cxbp=P_CROSSOVER,
                                           mutpb=P_MUTATION,
                                           ngen=MAX_GENERATIONS,
                                           stats=stats,
                                           halloffame=hof,
                                           verbose=True)

end = time.time()
time_1042 = end - start
print("Time Elapsed = ", time_1042)

```

```

*****
gen      nevals  min          avg
0        100    0.758144     1.03179
1         75    0.713363     0.966288
2         75    0.713363     0.906746
3         75    0.639515     0.850049
4         78    0.577392     0.789484
5         77    0.577392     0.737554
6         78    0.513466     0.692913
7         75    0.513466     0.644129
8         79    0.482627     0.617077
9         75    0.405722     0.593555
10        75    0.405722     0.575717
11        75    0.383543     0.55207
12        74    0.378358     0.523467
13        78    0.359471     0.508689
14        79    0.349516     0.477198
15        75    0.349516     0.452328
16        74    0.349516     0.435158
17        79    0.349516     0.41954
18        76    0.34445      0.407666
19        76    0.296326     0.397487
20        78    0.296326     0.382383
21        77    0.271068     0.388545
22        72    0.260843     0.373072
23        79    0.260843     0.374041
24        73    0.260843     0.361229
25        75    0.260843     0.356421
26        74    0.218994     0.343781
27        77    0.218994     0.338026
28        76    0.218994     0.337831

```

29	77	0.197813	0.321685
30	76	0.160213	0.314113
31	80	0.160213	0.3191
32	80	0.160213	0.299479
33	76	0.160213	0.29697
34	73	0.160213	0.284896
35	78	0.155248	0.286583
36	72	0.160213	0.272549
37	78	0.14066	0.273315
38	77	0.14066	0.254534
39	79	0.134304	0.259926
40	73	0.134304	0.253324
41	77	0.108358	0.245759
42	79	0.108358	0.239136
43	75	0.108358	0.233271
44	74	0.108358	0.218148
45	78	0.108358	0.212218
46	75	0.102538	0.202415
47	76	0.102538	0.199431
48	77	0.102538	0.204366
49	76	0.0873598	0.20761
50	78	0.0711741	0.198609
51	77	0.0711741	0.186059
52	74	0.0584212	0.177664
53	75	0.0532709	0.166839
54	80	0.0532709	0.162786
55	74	0.037248	0.147070

```
# print best solution found:
best = hof.items[0]
print("Best solution: ", best)
print("Best FitnessMin = %1.5f" % best.fitness.values[0])
#print("Best Fitness = ", best.fitness.values[0])

# extract statistics:
minFitnessValues_GA_1042, meanFitnessValues_GA_1042 = logbook.select("min", "avg")
print('History of minFitnessValues_GA =',minFitnessValues_GA_1042)
print('History of meanFitnessValues_GA =',meanFitnessValues_GA_1042)
```

```
Best solution: [1, 0, 0, 2, 1, 2, 1, 2, 0, 2, 1, 2, 1, 2, 2, 2, 1, 2, 2, 1,
Best FitnessMin = -0.01500
History of minFitnessValues_GA = [0.7581441108997677, 0.713363151121015, 0.71
History of meanFitnessValues_GA = [1.031790151391004, 0.9662875012494746, 0.9
```

RESUME

For various RANDOM_SEED we can obtain **different**:

- **solutions** :) ... of course,
- **performance** (fitness function value),
- **history**.

The reason is the stochastic manner of parameter change during evolution.

▼ ... with various GA parameters ... like Crossover Probability

It takes a small change in $P_CROSSOVER$ variable.

▼ $P_CROSSOVER = 0.1$

```
P_CROSSOVER = 0.1 # probability for crossover
```

```
# Set the random seed
# for reproducibility of results:
RANDOM_SEED = 1042
random.seed(RANDOM_SEED)
```

```
# Create the instance of the MountainCar class:
car = MountainCar(RANDOM_SEED)
```

```
# create initial population (generation 0):
population = toolbox.populationCreator(n=POPULATION_SIZE)
```

```
# prepare the statistics object:
stats = tools.Statistics(lambda ind: ind.fitness.values)
stats.register("min", numpy.min)
stats.register("avg", numpy.mean)
```

```
# define the hall-of-fame object:
hof = tools.HallOfFame(HALL_OF_FAME_SIZE)
```

```
print('*****')
```

```
start = time.time()
```

```
# perform the Genetic Algorithm flow with hof feature added:
```

```
population, logbook = eaSimpleWithElitism(population,
                                           toolbox,
                                           cxpb=P_CROSSOVER,
                                           mutpb=P_MUTATION,
                                           ngen=MAX_GENERATIONS,
                                           stats=stats,
                                           halloffame=hof,
                                           verbose=True)
```

```
end = time.time()
```

```
time_1042_CR0p1 = end - start
```

```
print("Time Elapsed = ", time_1042_CR0p1)
```

```
*****
```

gen	nevals	min	avg
0	100	0.758144	1.03179
1	41	0.743802	0.964259
2	39	0.743802	0.915064
3	41	0.739214	0.865538
4	52	0.583381	0.830942
5	37	0.583381	0.78981
6	42	0.575982	0.754293
7	48	0.549486	0.728786
8	39	0.547788	0.703206

9	40	0.547788	0.658415
10	41	0.538602	0.629071
11	43	0.520597	0.600203
12	45	0.520597	0.581616
13	44	0.519325	0.566761
14	42	0.519325	0.556239
15	46	0.520321	0.558152
16	44	0.496319	0.551587
17	46	0.496319	0.552638
18	57	0.48621	0.555001
19	42	0.48621	0.5451
20	35	0.48621	0.541675
21	32	0.48621	0.533755
22	44	0.48621	0.536453
23	52	0.48621	0.538906
24	38	0.48621	0.527768
25	34	0.481001	0.521111
26	42	0.481001	0.521335
27	49	0.46186	0.520217
28	51	0.46186	0.522274
29	47	0.46186	0.520333
30	48	0.46186	0.513685
31	50	0.46186	0.515025
32	52	0.46186	0.512728
33	50	0.450984	0.502648
34	36	0.449244	0.492566
35	45	0.425699	0.490416
36	51	0.425699	0.485783
37	44	0.425699	0.484683
38	45	0.415825	0.477998
39	47	0.415751	0.472314
40	45	0.414466	0.473612
41	42	0.394263	0.460849
42	44	0.38147	0.452556
43	44	0.38147	0.453463
44	38	0.359843	0.445091
45	49	0.38147	0.442556
46	47	0.356461	0.434419
47	47	0.356461	0.438531
48	41	0.351673	0.429193
49	44	0.333198	0.420095
50	47	0.310826	0.418048
51	41	0.310826	0.404214
52	37	0.310826	0.398673
53	38	0.307904	0.392828
54	42	0.307904	0.385709
55	50	0.307904	0.378934

```
# print best solution found:
best = hof.items[0]
print("Best solution: ", best)
print("Best FitnessMin = %1.5f" % best.fitness.values[0])
#print("Best Fitness = ", best.fitness.values[0])

# extract statistics:
minFitnessValues_GA_1042_CR0p1, meanFitnessValues_GA_1042_CR0p1 = logbook.select("
print('History of minFitnessValues_GA =',minFitnessValues_GA_1042_CR0p1)
print('History of meanFitnessValues_GA =',meanFitnessValues_GA_1042_CR0p1)
```

Best solution: [1, 1, 2, 2, 1, 0, 1, 1, 1, 1, 1, 2, 2, 2, 2, 1, 2, 0, 1, 1,
Best FitnessMin = 0.25583
History of minFitnessValues_GA = [0.7581441108997677, 0.743802202262433, 0.74
History of meanFitnessValues_GA = [1.031790151391004, 0.9642592656875997, 0.9

▼ P_CROSSOVER = 0.2

```
P_CROSSOVER = 0.2 # probability for crossover
```

```
# Set the random seed  
# for reproducibility of results:  
RANDOM_SEED = 1042  
random.seed(RANDOM_SEED)
```

```
# Create the instance of the MountainCar class:  
car = MountainCar(RANDOM_SEED)
```

```
# create initial population (generation 0):  
population = toolbox.populationCreator(n=POPULATION_SIZE)
```

```
# prepare the statistics object:  
stats = tools.Statistics(lambda ind: ind.fitness.values)  
stats.register("min", numpy.min)  
stats.register("avg", numpy.mean)
```

```
# define the hall-of-fame object:  
hof = tools.HallOfFame(HALL_OF_FAME_SIZE)
```

```
print('*****')  
start = time.time()
```

```
# perform the Genetic Algorithm flow with hof feature added:  
population, logbook = eaSimpleWithElitism(population,  
                                           toolbox,  
                                           cxpb=P_CROSSOVER,  
                                           mutpb=P_MUTATION,  
                                           ngen=MAX_GENERATIONS,  
                                           stats=stats,  
                                           halloffame=hof,  
                                           verbose=True)
```

```
end = time.time()  
time_1042_CR0p2 = end - start  
print("Time Elapsed = ", time_1042_CR0p2)
```

```
*****
```

gen	nevals	min	avg
0	100	0.758144	1.03179
1	51	0.758144	0.963915
2	47	0.743435	0.90916
3	51	0.695507	0.859285

4	39	0.687698	0.819404
5	46	0.673627	0.787391
6	50	0.673627	0.752036
7	43	0.673627	0.730605
8	51	0.633845	0.717065
9	54	0.617011	0.699343
10	47	0.60558	0.682446
11	39	0.52083	0.665377
12	44	0.52083	0.642318
13	49	0.52083	0.631635
14	47	0.52083	0.619007
15	48	0.52083	0.605986
16	42	0.52083	0.594333
17	56	0.519022	0.586025
18	43	0.517601	0.582297
19	44	0.517601	0.572918
20	47	0.517601	0.566298
21	37	0.514145	0.561395
22	48	0.486861	0.555451
23	45	0.495736	0.552859
24	51	0.488352	0.553029
25	49	0.488352	0.547999
26	54	0.488352	0.549498
27	40	0.477017	0.538995
28	53	0.456922	0.535805
29	48	0.456922	0.53067
30	49	0.456922	0.52461
31	51	0.456922	0.519212
32	56	0.456922	0.515279
33	43	0.429074	0.509413
34	45	0.429074	0.502732
35	44	0.433134	0.500906
36	51	0.381015	0.492789
37	55	0.400434	0.494057
38	41	0.393918	0.484146
39	43	0.380597	0.463111
40	50	0.380597	0.457285
41	45	0.380597	0.446375
42	45	0.37735	0.436169
43	53	0.37735	0.4369
44	42	0.37735	0.433312
45	51	0.373786	0.433094
46	55	0.354377	0.425752
47	48	0.354377	0.42211
48	50	0.354377	0.42557
49	51	0.354377	0.429721
50	47	0.338672	0.427246
51	46	0.338672	0.417907
52	50	0.338672	0.414365
53	43	0.338672	0.412554
54	51	0.338672	0.408941
55	46	0.334169	0.405105

```
# print best solution found:
best = hof.items[0]
print("Best solution: ", best)
print("Best FitnessMin = %1.5f" % best.fitness.values[0])
#print("Best Fitness = ", best.fitness.values[0])
```



```
# extract statistics:
minFitnessValues_GA_1042_CR0p2, meanFitnessValues_GA_1042_CR0p2 = logbook.select("
print('History of minFitnessValues_GA =',minFitnessValues_GA_1042_CR0p2)
print('History of meanFitnessValues_GA =',meanFitnessValues_GA_1042_CR0p2)
```

```
Best solution: [1, 1, 2, 2, 1, 0, 0, 1, 1, 0, 1, 2, 2, 2, 2, 1, 1, 2, 2, 1,
Best FitnessMin = 0.27027
History of minFitnessValues_GA = [0.7581441108997677, 0.7581441108997677, 0.7
History of meanFitnessValues_GA = [1.031790151391004, 0.9639150575310811, 0.9
```

▼ P_CROSSOVER = 0.4

```
P_CROSSOVER = 0.4 # probability for crossover
```

```
# Set the random seed
# for reproducibility of results:
RANDOM_SEED = 1042
random.seed(RANDOM_SEED)
```

```
# Create the instance of the MountainCar class:
car = MountainCar(RANDOM_SEED)
```

```
# create initial population (generation 0):
population = toolbox.populationCreator(n=POPULATION_SIZE)
```

```
# prepare the statistics object:
stats = tools.Statistics(lambda ind: ind.fitness.values)
stats.register("min", numpy.min)
stats.register("avg", numpy.mean)
```

```
# define the hall-of-fame object:
hof = tools.HallOfFame(HALL_OF_FAME_SIZE)
```

```
print('*****')
```

```
start = time.time()
```

```
# perform the Genetic Algorithm flow with hof feature added:
```

```
population, logbook = eaSimpleWithElitism(population,
```

```
        toolbox,
        cxpb=P_CROSSOVER,
        mutpb=P_MUTATION,
        ngen=MAX_GENERATIONS,
        stats=stats,
        halloffame=hof,
        verbose=True)
```

```
end = time.time()
```

```
time_1042_CR0p4 = end - start
```

```
print("Time Elapsed = ", time_1042_CR0p4)
```

gen	nevals	min	avg
0	100	0.758144	1.03179
1	47	0.758144	0.96371
2	54	0.727386	0.912661
3	60	0.705355	0.857932
4	61	0.657006	0.811883
5	58	0.657006	0.769599
6	47	0.595538	0.736513
7	53	0.595538	0.718777
8	66	0.595538	0.696454
9	49	0.561895	0.670669
10	53	0.514064	0.650457
11	59	0.505097	0.616604
12	55	0.505097	0.592464
13	60	0.497067	0.572719
14	48	0.467229	0.557426
15	58	0.44677	0.542682
16	57	0.44677	0.538783
17	53	0.44441	0.519375
18	59	0.44441	0.512814
19	47	0.431716	0.496614
20	51	0.431798	0.492885
21	54	0.431798	0.484241
22	55	0.431798	0.481492
23	52	0.402477	0.473635
24	58	0.395013	0.464906
25	58	0.395979	0.460759
26	62	0.395979	0.455918
27	56	0.373773	0.441825
28	51	0.377606	0.442353
29	64	0.373032	0.440682
30	59	0.373032	0.436511
31	65	0.368091	0.428604
32	61	0.348563	0.427526
33	52	0.348563	0.403681
34	61	0.348563	0.403101
35	65	0.33754	0.403952
36	58	0.341745	0.399188
37	67	0.304036	0.398323
38	64	0.304036	0.394692
39	58	0.294635	0.381294
40	58	0.293038	0.379477
41	55	0.285197	0.375154
42	64	0.285197	0.374484
43	58	0.280692	0.360436
44	63	0.276096	0.356769
45	63	0.276096	0.344396
46	57	0.276096	0.343845
47	58	0.270799	0.328424
48	54	0.240293	0.323965
49	55	0.240293	0.331106
50	61	0.234587	0.324565
51	53	0.234587	0.314767
52	52	0.234587	0.319126
53	44	0.234587	0.313707
54	59	0.234587	0.314518
55	17	0.224587	0.298071

print best solution found:

```

best = hof.items[0]
print("Best solution: ", best)
print("Best FitnessMin = %1.5f" % best.fitness.values[0])
#print("Best Fitness = ", best.fitness.values[0])

# extract statistics:
minFitnessValues_GA_1042_CR0p4, meanFitnessValues_GA_1042_CR0p4 = logbook.select("
print('History of minFitnessValues_GA =',minFitnessValues_GA_1042_CR0p4)
print('History of meanFitnessValues_GA =',meanFitnessValues_GA_1042_CR0p4)

```

```

Best solution: [2, 2, 1, 0, 2, 2, 0, 2, 0, 1, 2, 0, 1, 2, 1, 2, 2, 1, 2, 0,
Best FitnessMin = 0.03568
History of minFitnessValues_GA = [0.7581441108997677, 0.7581441108997677, 0.7
History of meanFitnessValues_GA = [1.031790151391004, 0.963710243402782, 0.91

```

▼ P_CROSSOVER = 0.8

```
P_CROSSOVER = 0.8 # probability for crossover
```

```

# Set the random seed
# for reproducibility of results:
RANDOM_SEED = 1042
random.seed(RANDOM_SEED)

```

```

# Create the instance of the MountainCar class:
car = MountainCar(RANDOM_SEED)

```

```

# create initial population (generation 0):
population = toolbox.populationCreator(n=POPULATION_SIZE)

```

```

# prepare the statistics object:
stats = tools.Statistics(lambda ind: ind.fitness.values)
stats.register("min", numpy.min)
stats.register("avg", numpy.mean)

```

```

# define the hall-of-fame object:
hof = tools.HallOfFame(HALL_OF_FAME_SIZE)

```

```
print('*****')
```

```
start = time.time()
```

```
# perform the Genetic Algorithm flow with hof feature added:
```

```
population, logbook = eaSimpleWithElitism(population,
```

```

        toolbox,
        cxpb=P_CROSSOVER,
        mutpb=P_MUTATION,
        ngen=MAX_GENERATIONS,
        stats=stats,
        halloffame=hof,

```

verbose=True)

```
end = time.time()
time_1042_CR0p8 = end - start
print("Time Elapsed = ", time_1042_CR0p8)
```

gen	nevals	min	avg
0	100	0.758144	1.03179
1	68	0.758144	0.966299
2	70	0.752055	0.910033
3	69	0.691596	0.8756
4	70	0.691596	0.831427
5	78	0.608389	0.796644
6	73	0.608389	0.744301
7	72	0.537531	0.699397
8	74	0.513783	0.662102
9	74	0.480739	0.639031
10	71	0.480739	0.603637
11	77	0.480739	0.591893
12	68	0.480739	0.571104
13	75	0.464238	0.55785
14	72	0.399844	0.541363
15	72	0.399844	0.525015
16	75	0.399844	0.502956
17	77	0.393905	0.496615
18	74	0.377284	0.47752
19	72	0.377284	0.46305
20	69	0.370618	0.443473
21	69	0.339829	0.429576
22	76	0.319831	0.424963
23	75	0.319831	0.412669
24	69	0.290862	0.404008
25	74	0.312944	0.388373
26	76	0.254349	0.37347
27	71	0.254349	0.367373
28	67	0.254349	0.358663
29	71	0.254349	0.349505
30	72	0.248498	0.337288
31	74	0.246287	0.328025
32	71	0.243479	0.321194
33	79	0.191121	0.311822
34	70	0.167603	0.298414
35	76	0.167603	0.287305
36	74	0.161337	0.271923
37	76	0.137685	0.249659
38	77	0.116808	0.242038
39	68	0.116808	0.237632
40	69	0.0931239	0.222499
41	72	0.0931239	0.221872
42	76	0.0931239	0.222749
43	73	0.0774572	0.209579
44	69	0.0774572	0.203161
45	72	0.0774572	0.205266
46	70	0.0397077	0.195229
47	72	0.0397077	0.195742
48	70	0.0397077	0.18765
49	69	0.0397077	0.18707
50	73	0.0397077	0.183028
51	71	0.0397077	0.179607

52	75	0.0397077	0.17581
53	70	0.033631	0.160689
54	72	0.033631	0.164106
55	74	0.033631	0.157403

```
# print best solution found:
best = hof.items[0]
print("Best solution: ", best)
print("Best FitnessMin = %1.5f" % best.fitness.values[0])
#print("Best Fitness = ", best.fitness.values[0])

# extract statistics:
minFitnessValues_GA_1042_CR0p8, meanFitnessValues_GA_1042_CR0p8 = logbook.select("
print('History of minFitnessValues_GA =',minFitnessValues_GA_1042_CR0p8)
print('History of meanFitnessValues_GA =',meanFitnessValues_GA_1042_CR0p8)
```

```
Best solution: [1, 1, 0, 1, 2, 2, 1, 2, 1, 1, 1, 0, 2, 1, 2, 2, 1, 1, 2, 2,
Best FitnessMin = -0.00500
History of minFitnessValues_GA = [0.7581441108997677, 0.7581441108997677, 0.7
History of meanFitnessValues_GA = [1.031790151391004, 0.9662991740375603, 0.9
```

RESUME

Again ... for various $P_{\text{CROSSOVER}}$ we can obtain **different**:

- **solutions** :) ... of course,
- **performance** (fitness function value),
- **history**.

The reasons are

- the stochastic manner of parameter change during evolution,
- BUT ... more important ... different levels of gene exchange.

▼ ... with various GA parameters ... like Mutation Probability

(let's try it as a self-guided learning!)

It takes a small change in P_{MUTATION} variable.

▼ Comparison Plots

▼ Random Seed Dependence

▼ Fitness Function

```

sns.set_style("whitegrid")

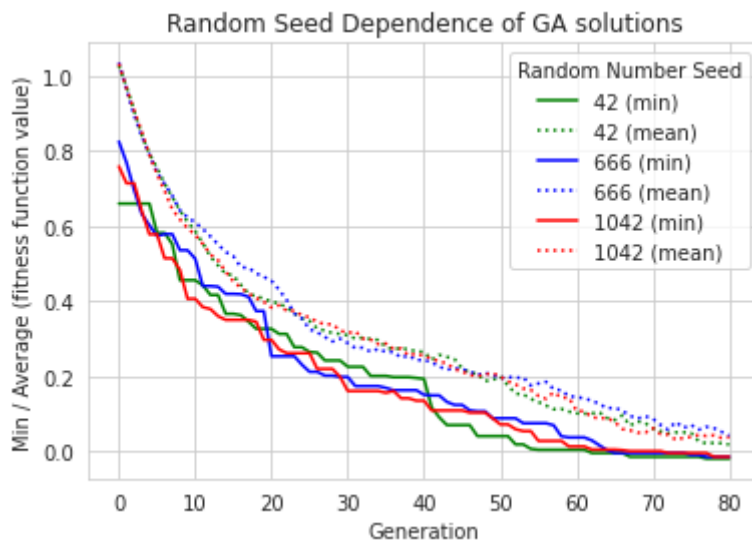
# RS=42
plt.plot(minFitnessValues_GA_42, color='green', label='42 (min)')
plt.plot(meanFitnessValues_GA_42, color='green', linestyle = 'dotted', label='42 (

# RS=666
plt.plot(minFitnessValues_GA_666, color='blue', label='666 (min)')
plt.plot(meanFitnessValues_GA_666, color='blue', linestyle = 'dotted', label='666

# RS=1042
plt.plot(minFitnessValues_GA_1042, color='red', label='1042 (min)')
plt.plot(meanFitnessValues_GA_1042, color='red', linestyle = 'dotted', label='1042

plt.xlabel('Generation')
plt.ylabel('Min / Average (fitness function value)')
plt.title('Random Seed Dependence of GA solutions')
plt.legend(title='Random Number Seed')
plt.show()

```



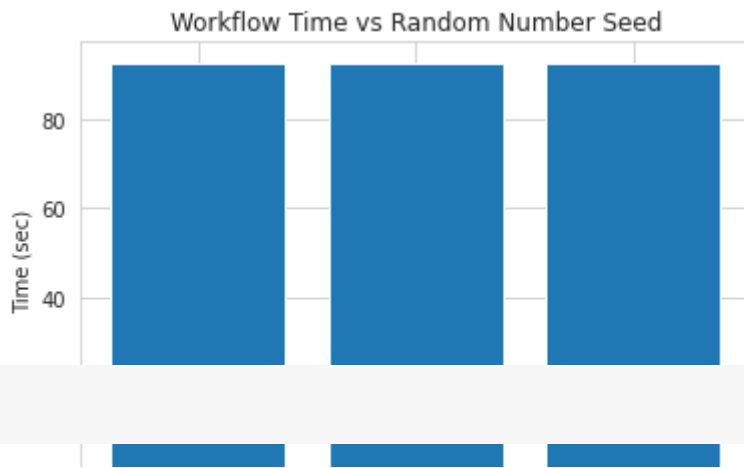
▼ Time

```

import matplotlib.pyplot as plt

x = ['42', '666', '1042']
y = [time_42, time_666, time_1042]
plt.bar(x, y)
plt.ylabel('Time (sec)')
plt.title('Workflow Time vs Random Number Seed')
plt.show()

```



▼ Crossover Probability Dependence

▼ Fitness Function

```
sns.set_style("whitegrid")

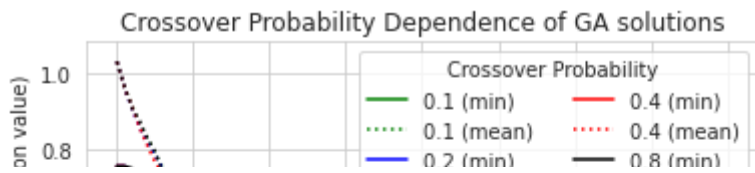
# CR=0.1
plt.plot(minFitnessValues_GA_1042_CR0p1, color='green', label='0.1 (min)')
plt.plot(meanFitnessValues_GA_1042_CR0p1, color='green', linestyle = 'dotted', label='0.1 (avg)')

# CR=0.2
plt.plot(minFitnessValues_GA_1042_CR0p2, color='blue', label='0.2 (min)')
plt.plot(meanFitnessValues_GA_1042_CR0p2, color='blue', linestyle = 'dotted', label='0.2 (avg)')

# CR=0.4
plt.plot(minFitnessValues_GA_1042_CR0p4, color='red', label='0.4 (min)')
plt.plot(meanFitnessValues_GA_1042_CR0p4, color='red', linestyle = 'dotted', label='0.4 (avg)')

# CR=0.8
plt.plot(minFitnessValues_GA_1042_CR0p8, color='black', label='0.8 (min)')
plt.plot(meanFitnessValues_GA_1042_CR0p8, color='black', linestyle = 'dotted', label='0.8 (avg)')

plt.xlabel('Generation')
plt.ylabel('Min / Average (fitness function value)')
plt.title('Crossover Probability Dependence of GA solutions')
plt.legend(title='Crossover Probability', ncol=2)
plt.show()
```



▼ Time



```
import matplotlib.pyplot as plt

x = ['0.1', '0.2', '0.4', '0.8']
y = [time_1042_CR0p1, time_1042_CR0p2, time_1042_CR0p4, time_1042_CR0p8]
plt.bar(x, y)
plt.ylabel('Time (sec)')
plt.title('Workflow Time vs Crossover Probability')
plt.show()
```

