COMP3160 Artificial Intelligence
Assignment 2 (Weight: 20%)
Evolutionary Algorithms for Adversarial Game Playing

Draft Submission Due: 11:55pm, Oct 29, 2021 (Friday, Week 12)
Final Submission Due: 11:55pm, Nov 05, 2021 (Friday, Week 13)

The goal of this assignment is to appreciate the efficacy of Evolutionary Algorithms, specifically Genetic Algorithm (GA), in the context of game theory. You will be using the DEAP package for Genetic Algorithm in order to evolve strategies for repeatedly playing variants of *The Tragedy of the Commons* (TC). Basically, there is a group of farmers (herdsman) in a village, and there is a community grazing area ("Commons"). If the farmers limit the number of cows that each of them is allowed to graze in the Commons, everyone prospers. If a few farmers flout the convention, they benefit at some cost to others. But if too many farmers flout the convention, then everyone suffers due to over-grazing. This game is quite pertinent to the sustainability issue. It is interesting in this context to read the obituary, Elinor Ostrom: An uncommon woman for the commons, that Kenneth J Arrow and colleagues wrote for an unusual *political scientist* who received Nobel Prize in economics.

The Tragedy of the Commons is originally described by Hardin[1] as follows:

> As a rationale being, each herdsman seeks to maximize his gain. Explicitly or implicitly, more or less consciously, he asks, "what is the utility to me of adding one more animal to my herd?" This utility has a negative and a positive component.
>
> 1. The positive component is a function of the increment of one animal. Since the herdsman receives all the proceeds from the sale of the additional animal, the positive utility is nearly $+1$.
>
> 2. The negative component is a function of the additional overgrazing created by one more animal. Since, however, the effects of overgrazing are shared by all [. . .], the negative utility for any particular decision-making herdsman is only a fraction of 1.
>
> Adding together the component particular utilities, the rational herdsman concludes that the only sensible course for him to pursue is to add another animal to his herd. And another; and another... But this is the conclusion reached by each and every rational herdsman sharing a commons. Therein is the tragedy. Each man is locked into a system that compels him to increase his herd without limit – in a world that is limited. Ruin is the destination towards which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all.

We will look at two very simplistic models of this imagined scenario. Both of them are two-player games.

In the first model (TC_1), we assume a small grazing common land that can comfortably support two cows altogether, and each cow brings 5 units of utility to its owner. If one more

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[1]Hardin, G. "The Tragedy of the Commons." *Science* 1968, 162, 1243–1248.

cow is allowed to graze, the cows are not adequately fed, and the benefit from each cow reduces by 1. If instead two more cows are allowed in, the feed is fully inadequate for every cow because of overgrazing, and they bring zero benefit each to their owners. It is assumed that there is a tacit understanding between the two farmers that they will *cooperate*, that is, will allow in only one cow each. The payoff matrix for this model is given as follows:

Table 1: **The Tragedy of the Commons: TC$_1$**

ROW

		C	D
COLUMN	C	(5, 5)	(4, 8)
	D	(8, 4)	(0, 0)

Payoffs to: (Column, Row)

The second model (TC$_2$) changes the narrative to some extent. The local council decides that the two farmers can take a lease of part of the "commons" for a nominal fee, and use that part exclusively for grazing their own cows. However there is a constraint: each can take an independent decision of whether to lease $\frac{1}{3}$ of the commons, or $\frac{1}{4}$. Either way, part of the commons will be left un-leased, and they will have equal grazing right over that un-leased part. Here we assume that the total commons has an area of 24, and each unit area provides one unit of benefit. Again there is the tacit understanding that the two farmers will *cooperate*, that is each will take out a lease on $\frac{1}{4}$ of the commons. However there is incentive to defect, as the payoff matrix shows below. For instance, if one farmer cooperates, and the other defects, the cooperator receives $\frac{24}{4} + \frac{24-(\frac{24}{4}+\frac{24}{3})}{2} = 11$ units of benefit, while the defector will receive $\frac{24}{3} + \frac{24-(\frac{24}{4}+\frac{24}{3})}{2} = 13$ units.

Table 2: **The Tragedy of the Commons: TC$_2$**

ROW

		C	D
COLUMN	C	(12, 12)	(11, 13)
	D	(13, 11)	(12, 12)

Payoffs to: (Column, Row)

Task Specification

The main issue is the representation of a strategy for playing a game like TC_1 or TC_2 as a bit string. Two papers are provided in the Assignment folder that will help you with this. You are recommended to start with the paper, an easy read, by Adnan Haider. You might want to also read the paper by Golbeck, if you find the topic interesting.

A code template is being provided to help you with your Python code (Task 2). Although it is possible to represent players/strategies in very many different ways, for parity in marking, you are strongly advised to employ the following representation:
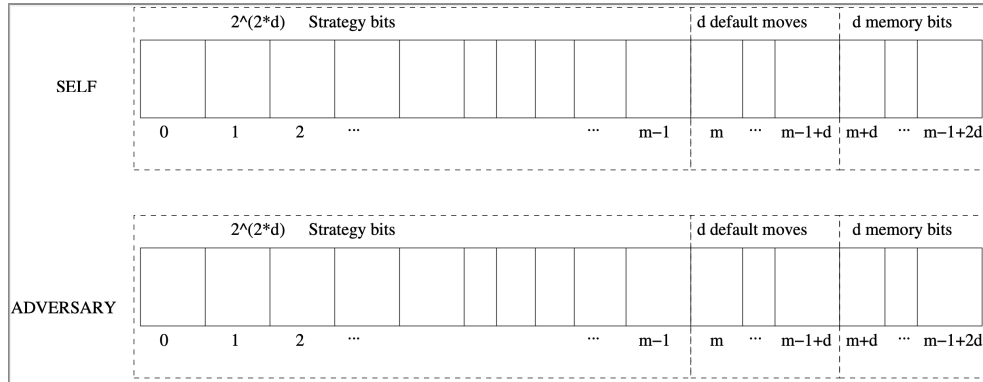

Figure 1: Representation of two players. With d as the memory depth, $m = 2^{2d}$. Total length of a player/chromosome: $2^{2d} + 2d$.

1. BACKGROUND KNOWLEDGE ASSESSMENT [5 marks]

   (a) Consider the *Cryptocurrency Mining*. You may want to read this New Yorker article about the environmental impact of Bitcoin mining. Which of the two models of the Tragedy of the Commons, **TC_1** and **TC_2**, is closer in spirit to this situation? **Answer this question in no more than 50 words.**

   (b) Find all *Dominant Strategy Equilibria*, *Nash Equilibria* and *Pareto Optimal Strategy Profiles* for the game **TC_1**.

   (c) Find all *Dominant Strategy Equilibria*, *Nash Equilibria* and *Pareto Optimal Strategy Profiles* for the game **TC_2**.

   (d) Analyse the results you obtained in items 1b and 1c above. Describe any interesting difference you noted between them. Why did you find those differences interesting? **Answer this question in no more than 50 words.**

   (e) Axelrod's tournaments of Iterated Prisoner's Dilemma show that co-operation among players can emerge in a world of selfish agents. What do you expect would happen if different strategies were to play Iterated **TC_1** (henceforth (**ITC_1**) instead? What would you expect in the case of Iterated **TC_2** (henceforth (**ITC_2**)? **Explain your answer in no more than 50 words.** Give particular attention to any difference in what you woudl expect in these two cases.

2. IMPLEMENTATION IN PYTHON [10 marks]

(a) Implement the function:

```
payoff_to_player1(player1, player2, game):
returns payoff
```

Note: `player2` is the adversary, and `payoff` is determined by latest moves obtained from respective appropriate memory locations and the payoff matrix for the relevant game ($\mathbf{TC}_1$ or $\mathbf{TC}_2$). Assume memory-depth of 2.

(b) Implement the function:

```
next_move(player1, player2, round):
returns player1's move
```

Note: `player1`'s next move is based on both the players' earlier moves and `player1`'s strategy (encoded in `player1`'s chromosome). The move to be returned can be `C/D` or `0/1` depending on your representation. Note that in early rounds some default moves are made. Assume memory-depth of 2.

(c) Implement the function:

```
process_move(player, move, memory_depth):
returns success / failure
```

Note: `player`'s relevant memory bits are updated based on its latest move `move` and its `memory depth`.

(d) Implement the function:

```
score(player1, player2,  m_depth, n_rounds, game):
returns score to player1
```

Note: `player1` iteratively plays the game `game` against `player2` for `n_rounds` number of rounds, and its score is returned.

(e) You will be using the DEAP package for genetic evolution of strategies. Assume a memory depth of 2.
   i. Implement genetic evolution of strategies for playing $\mathbf{ITC}_1$.
   ii. Modify the code you wrote as part of Task 2(e)i above so as to genetically evolve strategies for playing $\mathbf{ITC}_2$.

3. ANALYSIS [5 marks]

    (a) What is the best ITC_1-strategy that you generated in Task 2(e)i via GA? What parameters (fitness function, type of crossover, mutation rate, etc.) did you use, and why?

    (b) Describe in English the behaviour of that ITC_1-strategy (that you identified in Task 3a above). Does it align with the prediction you outlined in Task 1e earlier? **Explain in no more than 50 words.**

    (c) What is the best ITC_2-strategy that you generated in Task 2(e)ii via GA? What parameters (fitness function, type of crossover, mutation rate, etc.) did you use, and why?

    (d) Describe in English the behaviour of the ITC_2-strategy (that you identified in Task 3c above). Does it align with the prediction you outlined in Task 1e earlier? **Explain in no more than 50 words.**

    (e) Take an appropriate sustainability issue, and outline in no more than 50 words the implications that your results have in that context.

What to Submit, and When

You will submit two files:

1. `<yourLastname_yourFirstname>_code.py`

2. `<yourLastname_yourFirstname>_report.pdf`.

Your code file should include all the Python codes you wrote for this assignment.

Your report file should include all the answers (including the Python codes copied-and-pasted). It must be submitted in the pdf format. It must have as cover page the one that has been supplied (as part of the document template), duly filled and signed. Also, if relevant, note in the last section anything relevant that is worth noting.

You will submit the files in two stages. In the first stage you must submit two draft files (that you will be able to update) by 11:55pm, Friday Week 12:

  (a) of the program file `<yourLastname_yourFirstname>_code.py` including at least the implementation of functions specified in Tasks 2a and 2b.

  (b) of your report file `<yourLastname_yourFirstname>_report.pdf` with answers to Tasks 1a-1e. You can modify these files while preparing your final version. However, failure to submit the two draft files by the required date will attract a penalty of 2 marks. The final version of these three files must be submitted by 11:55pm, Friday Week 13.