An open reproducible framework for the study of the iterated prisoner's dilemma

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1   Introduction

This paper introduces a software package: the Axelrod python library [28]. The Axelrod-Python project has the following stated goals:

- To enable the reproduction of previous Iterated Prisoner's Dilemma research as easily as possible.

- To produce the de-facto tool for any future Iterated Prisoner's Dilemma research.

- To provide as simple a means as possible for anyone to define and contribute new and original Iterated Prisoner's Dilemma strategies.

This library is motivated by an ongoing discussion in the academic community about reproducible research [8, 14, 24, 25], and is:

- Open: all code is released under an MIT license;

- Reproducible: at the time of writing there is an excellent level of integrated tests with 99.59% coverage;

- Documented: all features of the library are documented for ease of use.

- Extensive: over 100 strategies are included.

Before describing the package in more detail in Section 1.2, an overview of some previous Iterated Prisoner's Dilemma research will be given.

1.1   Review of the literature

As stated in [5]: *"few works in social science have had the general impact of [Axelrod's study of the evolution of cooperation]"*. In 1980, Axelrod wrote two papers: [1, 2] which described a computer tournament that has been at the origin of a majority of game theoretic work [4, 5, 6, 7, 9, 10, 11, 12, 13, 15, 16, 17, 18, 20, 21, 22, 23, 26, 27]. As described in [5] this work has not only had mathematical impact but has also led to insights in biology (for example in [26], a real tournament where Blu Jays are the participants is described) and in particular to the study of evolution.

The tournament is based on an iterated game (see [19] or similar for details) where two players repeatedly play the normal form game of (1) in full knowledge of each others playing history to date. An excellent description of the *one shot* game is given in [12] which is paraphrased below:

Two players must choose between *Cooperate* (C) and *Defect* (D):

- If both choose C, they receive a payoff of R (**R**eward);

- If both choose D, they receive a payoff of P (**P**punishment);

- If one chooses C and the other D, the defector receives a payoff of T (**T**emptation) and the cooperator a payoff of S (**S**ucker).

$$\begin{pmatrix} R,R & S,T \\ S,S & P,P \end{pmatrix} \quad \text{such that } T > R > P > S \text{ and } 2R > T + S \tag{1}$$

The game of (1) is called the Prisoner's Dilemma. Numerical values of $(R, S, T, P) = (3, 0, 5, 1)$ are often used in the literature. Axelrod's tournaments (and further implementations of these) are sometimes referred to as Iterated Prisoner's Dilemma (IPD) tournaments, an overview of published tournaments is given in Table 1.

Year	Reference	Number of Strategies	Type	Source Code
1979	[1]	13	Standard	Not immediately available
1979	[2]	64	Standard	Not immediately available
1991	[5]	13	Noisy	Not immediately available
2002	[26]	16	Wildlife	Not applicable

Table 1: An overview of published tournaments

In [20] describes how incomplete information can be used to enhance cooperation, in a similar approach to the proof of the Folk theorem for repeated games [19]. This aspect of incomplete information is also considered in [21, 5, 17] where "noisy" tournaments randomly flip the choice made by a given strategy. In [22] incomplete information is considered in the sense of a probabilistic termination of each round of the tournament.

As mentioned before, IPD tournaments have been studied in an evolutionary context: [11, 17, 23, 27] consider this in a traditional evolutionary game theory context. These works investigates particular evolutionary contexts within which cooperation can emerge as stable. Often these works consider direct opposition to another strategy and disregard the population dynamics, for example in [17] a simple machine learning algorithm outperforms a strategy found in [23].

Further to these evolutionary ideas, [7, 9] are examples of using machine learning techniques to evolve particular strategies. In [3] Axelrod describes how similar techniques are used to genetically evolve a high performing strategy from a given set of strategies. Note that in his original work Axelrod only used a base strategy set of 12 strategies for this evolutionary study. This is noteworthy as [28] now boasts over 90 strategies that are readily available for a similar analysis.

1.2 Description of the Axelrod python package

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The library is written in Python (`http://www.python.org/`) which is a popular language in the academic community with libraries developed for a variety of uses including:

- Machine learning (`http://scikit-learn.org/`);

- Visualisation (`http://matplotlib.org/`);

- Mathematics (`http://www.sagemath.org/`);

- Astrophysics (`http://www.astropy.org/`);

- Data manipulation (`http://pandas.pydata.org/`).

Furthermore [15] Python is described as an appropriate language for the reproduction of Iterated Prisoner's dilemma tournaments due to it's object oriented nature and readability.

The library itself is available at `https://github.com/Axelrod-Python/Axelrod`. This is a hosted git repository which. Git is a popular version control system which is one of the recommended aspects of reproducible research [8, 25].

Figure 1 shows a very simple example of using the library to create a basic tournament with the graphical output shown in Figure 2.

```
>>> import axelrod
>>> strategies = [s() for s in axelrod.demo_strategies])
>>> tournament = axelrod.Tournament(strategies)
>>> results = tournament.play()
>>> plot = axelrod.Plot(results)
>>> plot.boxplot()
```

Figure 1: A simple set of commands to create a demonstration tournament. The output is shown in Figure 2.
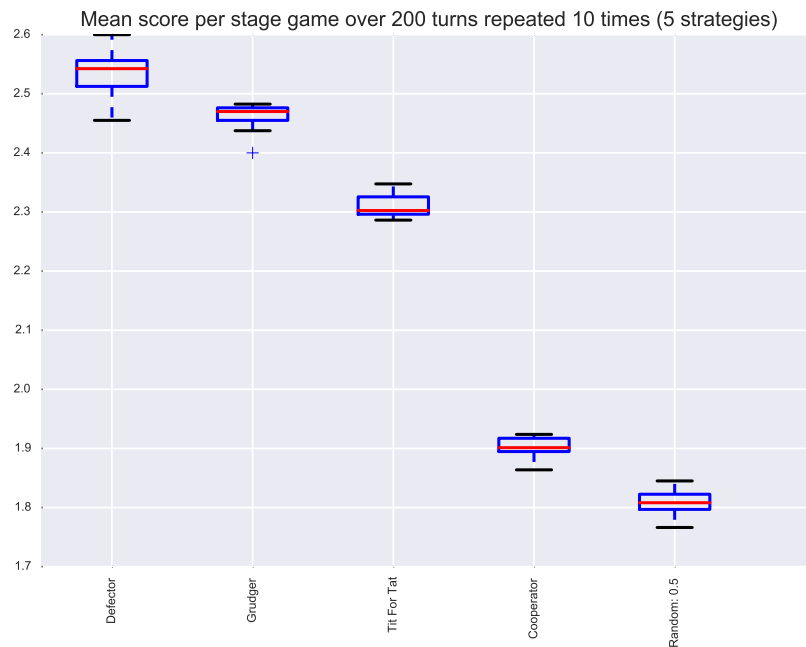

Figure 2: The results from a simple tournament.

This just shows the very basic utilisation of the library and further details can be found at the online documentation: `http://axelrod.readthedocs.org`. Some further implemented capabilities include:

- Noisy tournaments;
- Ecological tournaments;
- Full tournament history.

3

As stated in Section 1 one of the main goals of the library is to allow for the easy contribution of strategies. To do this requires the writing of a simple python class (which can inherit from other predefined classes). Full contribution guidelines can be found in the documentation. Figures 3 and 4 show the source code for the Grudger strategy as well as it's corresponding test.

```python
class Grudger(Player):
    """A player starts by cooperating however will defect if
       at any point the opponent has defected."""

    name = 'Grudger'
    classifier = {
        'memory_depth': float('inf'),   # Long memory
        'stochastic': False,
        'inspects_source': False,
        'manipulates_source': False,
        'manipulates_state': False
    }

    def strategy(self, opponent):
        """Begins by playing C, then plays D for the remaining
           rounds if the opponent ever plays D."""
        if opponent.defections:
            return D
        return C
```

Figure 3: Source code for the Grudger strategy.

You can see an overview of some of the source code in Figure 5.

To date the library has had contributions from 19 contributors from a variety of backgrounds. These contributions have both been in terms of strategies (one strategy is the creation of an undergraduate mathematics student with little prior knowledge of programming) as well as the architecture of the library itself.

Before discussing the novel insights obtained from the study of this library in Section 3 an overview of some tournaments that have been reproduced will be given in Section 2.

2 Reproducing previous tournaments

3 New strategies, tournaments and implications

4 Conclusion

References

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```
class TestGrudger(TestPlayer):

    name = "Grudger"
    player = axelrod.Grudger
    expected_classifier = {
        'memory_depth': float('inf'),  # Long memory
        'stochastic': False,
        'inspects_source': False,
        'manipulates_source': False,
        'manipulates_state': False
    }

    def test_initial_strategy(self):
        """
        Starts by cooperating
        """
        self.first_play_test(C)

    def test_strategy(self):
        """
        If opponent defects at any point then the player will defect forever
        """
        self.responses_test([C, D, D, D], [C, C, C, C], [C])
        self.responses_test([C, C, D, D, D], [C, D, C, C, C], [D])
```
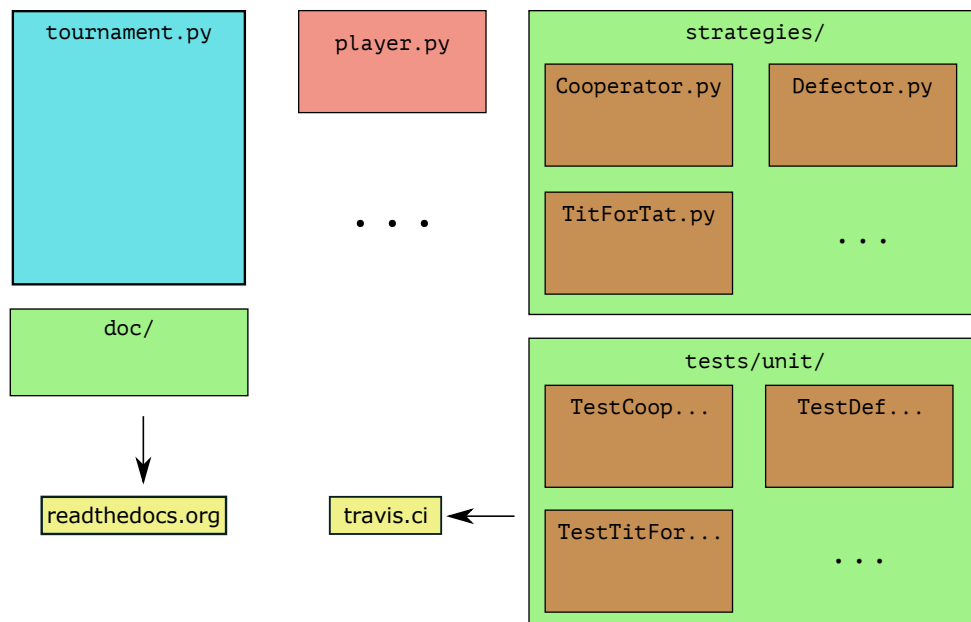
Figure 4: Test code for the Grudger strategy.

Figure 5: An overview of the source code.

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