# Evolution of Cooperation

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# What is the Prisoner's Dilemma?

- Two prisoners must choose between remaining silent or betraying the other
  - Cooperate (C) vs Defect (D)

- 4 possible outcomes to the game:
  - Both cooperate: 2 years in prison for both
  - Both defect: 5 years in prison for both
  - 1 cooperate and 1 defect: Defector goes free, cooperator serves 10 years in prison

- Rationally, cooperation makes no sense
  - Iterative version introduces multiple rounds with random round counts; cooperation now makes sense sometimes

| Prisoner B / Prisoner A | Prisoner B stays silent (*cooperates*) | Prisoner B betrays (*defects*) |
|---|---|---|
| Prisoner A stays silent (*cooperates*) | Each serve 2 years | Prisoner A: 10 years<br>Prisoner B: goes free |
| Prisoner A betrays (*defects*) | Prisoner A: goes free<br>Prisoner B: 10 years | Each serve 5 years |

# Why is it Interesting?

- Examines human biases towards cooperation
- Why do we trust each other even when it makes no logical sense to do so?
- When do the benefits of betrayal outweigh the negatives for humans?
- *The Dark Knight (2008)*

# Literature Review

# Regarding the Prisoner's Dilemma

Effective Choice in the Prisoner's Dilemma (Axelrod 1980)

- Social Psychology
  - The Prisoner's Dilemma encapsulates the struggle between individual and group rationality in humans
    - Individual Rationality of selfishness to be able to reap the most benefit
    - Group Rationality of mutual cooperation to benefit all actors
  - Applications of Iterative variations of the Prisoner's Dilemma to analyze the concept of "Effective Choice" in:
    - Relationships between conflicting entities
    - The effects of Westernization in Central Africa
    - The difference in effects of learning using abstract vs concrete thinking styles

# An Overview of the First Axelrod Tournament

Effective Choice in the Prisoner's Dilemma (Axelrod 1980)

- Tournament Details
  - 15 Submitted Strategies by economists, psychologists, sociologists, mathematicians, and political scientists
  - Tournament itself was styled as a Round Robin Competition, meaning that each strategy competed against each other at some point of the tournament
  - Each match between strategies were 200 rounds
  - Point Breakdown:
    - 3 points for Mutual Cooperation (**C**, **C**)
    - 1 point for Mutual Defection (**D**, **D**)
    - 5 points for a successful Defection (**D**, C)
    - 0 points for an unsuccessful Cooperation (D, **C**)

# A Look Into Successful Strategies in the First Tournament

## Effective Choice in the Prisoner's Dilemma (Axelrod 1980)

- Strategies that were the most successful in the Tournament were:
  - **Nice** in that they did not Defect (D) during the first turn or were not the first strategy to Defect (D) before the match ended
  - **Effective when in a match with special strategies**
    - DOWNING was a strategy that attempted to predict the opponent's move based on its own previous move
    - GRAASKAMP was a strategy that played Tit-For-Tat for the first 50 turns, Defects (D) once, and then attempts to determine whether it's playing against itself, Tit-For-Tat or some similar variant, or the Random strategy
  - **Forgiving** in that they did not excessively punish an opponent after the opponent Defects (D)

- Out of all of the strategies, the basic Tit-For-Tat strategy won the tournament, even against opponents who made variations to attempt to improve Tit-For-Tat
  - Strategy Cooperates (C) with the opponent until the opponent Defects (D). Tit-For-Tat then Defects (D) next turn and goes back to Cooperating (C) following turns

# Observations from other Prisoners' Dilemma Strategy Papers

Probabilistic Tit-for-Tat Strategy vs Nash Equilibrium for Infinitely Repeating Games (Madhumidha et al. 2017)

- Nash Equilibrium - concept that every player within a game has selected a strategy and cannot perform better by changing the strategy
  - When players obtain equal end results in a game or repeated game, Nash Equilibrium becomes less optimal
  - Does not provide conclusive results when multiple solutions to Nash Equilibria are found
- The Tit-for-Tat strategy is not optimal when "noise" caused by players deviating from their typical behavior due to mistakes and misconceptions exists

# Observations from other Prisoners' Dilemma Strategy Papers (Continued)

No Strategy Can Win in the Repeated Prisoner's Dilemma: Linking Game Theory and Computer Simulations (García and Veelen 2018)

- Argues that cooperation is inherently unstable due to mutants and deviations

Evolution of cooperation through cumulative reciprocity (Li et al. 2022)

- Traditional models of cooperation use strategies with restricted memory.
- Strategies where players only remember the last encounter they had are mathematically convenient, but they miss important aspects of human reciprocity, where defections can have lasting effects.

# Design

# Axelrod API

- Python library created by Dr. Vince Knight at Cardiff University (Wales, UK).
- Research tool for the iterated Prisoner's Dilemma.
  - Includes strategies from literature and Axelrod's tournament.
- Generates reproducible results of iterative round robin tournaments.
- Features tools to model population dynamics with the tournaments.
  - Strategies that perform better reproduce more between iterations
  - Players are randomly removed between iterations.
  - Better performing strategies are more likely to "survive"
- Documentation with examples of the library's capabilities.
- Lack of intuitive output format and difficult to add custom strategies.

# Project Scope

- **Goal: Create a UI that makes the Axelrod API much easier to use for those without coding experience**
  - Curated list of strategies with strategy explanations that remove the need to look at the algorithm
  - Tournament output that is less confusing and presented in a cleaner way
  - User control over various parameters like number of rounds, strategy selected, number of participants, etc.
  - Ability to code a custom strategy and add it to the game
  - Allow user to run multiple tournaments back to back without restarting the program
  - Inclusion of “Advanced Mode” that expands the strategy list and adds more complex parameters for the user to manipulate, as well as more detailed output

# Design Decisions

- Built off of the Axelrod API as a foundation
  - Originally had intended to create our own tournament program from scratch
  - Discovery of the API meant we had an opportunity to improve upon the large amount of work already done
- Chose to use Python as our programming language
  - Originally had intended on using Java for its greater focus on object-oriented programming and classes, but switched focus to Python upon discovering the exhaustive Axelrod API
- User Experience focused direction
  - Experimentation with the API revealed that it’s clunky to use and difficult to understand for non-programmers
  - Streamlining the experience would allow for a greater range of access to researchers and enthusiasts

# Custom Strategy Implementation

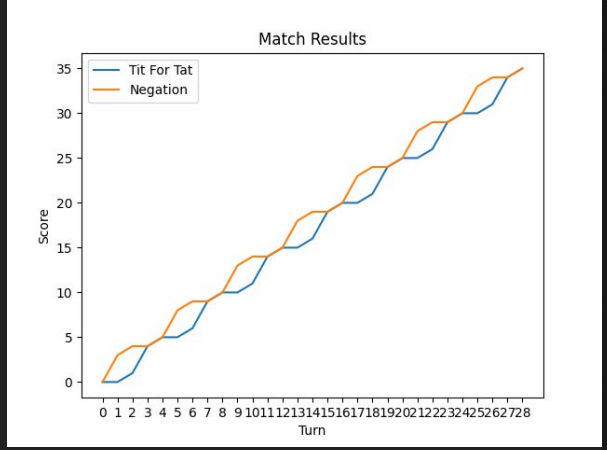
```
def strategy(self, opponent):
    """This is where you define the strategy"""
    # First move
    if not self.history:            # If the length of history is 0, i.e. the first round
        return C
    # The rest of your moves
    if opponent.history[-1] == D:   # If the opponent's last move was D
        return D                    # Defect
    return C                        # Otherwise cooperate.
```

# Algorithms Involved

- Algorithms classified by properties
  - Depth of memory
  - Randomization (stochasticity)
  - Strategies that are known to increase tournament run-time
- Tit-for-tat: Simple strategy with a memory depth of 1
  - Only looks at the opponent’s last move
  - Strategy wasn’t dominant in every match it played but scored well on average
  - Variations of Tit-for-tat: Tit-for-2-tats, 2-tits-for-tat, dynamic
- Custom strategies: Creatable by users
  - Chaotic Clairvoyant: Demonstrates higher memory depth usage.
  - FibTitForTat: Tit for Tat with random chance to defect based on fibonacci sequence.

# Algorithm Demonstrations

- Strategies play each other in a round-robin tournament
- View data on how algorithms perform in a tournament or in head-to-head matches

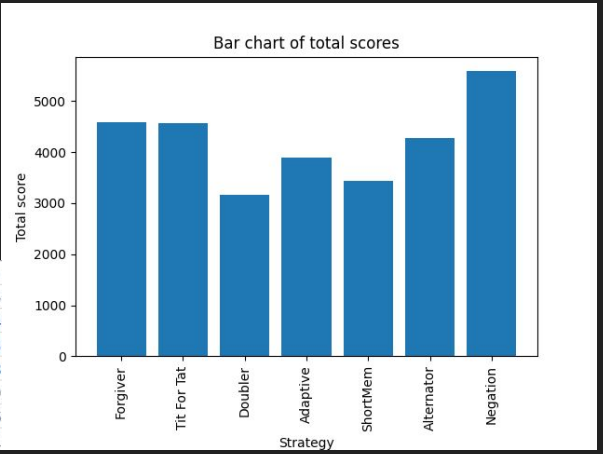



| Turn | Tit For Tat | Negation |
|---|---|---|
| 1 | C | D |
| 2 | D | D |
| 3 | D | C |
| 4 | C | C |
| 5 | C | D |
| 7 | D | C |
| 8 | C | C |
| 9 | C | D |
| 10 | D | D |
| 11 | D | C |
| 12 | C | C |
| 13 | C | D |
| 14 | D | D |
| 15 | D | C |
| 16 | C | C |
| 17 | C | D |
| 18 | D | D |
| 19 | D | C |
| 20 | C | C |
| 21 | C | D |
| 22 | D | D |
| 23 | D | C |
| 24 | C | C |
| 25 | C | D |
| 26 | D | D |
| 27 | D | C |
| 28 | C | C |

Individual Match Results

Full Tournament Results

| Rank | Name | Median_score | Cooperation_rating | Wins | Total score | Avg. score per turn | Score Std. | Normalised Score |
|---|---|---|---|---|---|---|---|---|
| 1 | Negation | 1.883928571 | 0.575 | 2 | 5590 | 19.96 | 1.05 | 2.85 |
| 2 | Forgiver | 3.327380952 | 0.574404762 | 3 | 4580 | 16.36 | 0 | 2.34 |
| 3 | Tit For Tat | 2.726190476 | 0.80952381 | 0 | 4560 | 16.29 | 0 | 2.33 |
| 4 | Alternator | 2.041666667 | 0.5 | 3 | 4278 | 15.28 | 1.55 | 2.18 |
| 5 | Adaptive | 2.553571429 | 0.517857143 | 4 | 3898 | 13.92 | 1.55 | 1.99 |
| 6 | ShortMem | 2.327380952 | 0.791666667 | 0 | 3442 | 12.29 | 1.55 | 1.76 |
| 7 | Doubler | 2.714285714 | 0.821428571 | 0 | 3163 | 11.3 | 3.33 | 1.61 |



# Workflow & Contributions

- Weekly agile structure used to adapt to project needs on a short-term basis
- Weekly meetings to check in on progress and alter direction/tasks
- Overall contributions:
  - Alex - Project leader, ensured tasks were completed and kept project on track, assisted with output and program logic
  - Marc - Implemented curated strategy list with explanations and assisted with program logic
  - Jaden - Created logic surrounding input of user parameters and chose which parameters to make available
  - Austin - Implemented the ability to add custom strategies and streamlined API output for readability

# Results & Future Development

- What do we have to show for it?
  - Much easier to use/simplified version of the Axelrod python API
  - Custom strategy implementation
- How can we continue to develop this project in the future?
  - Sleeker and further streamlined GUI
  - Custom strategy implementation that doesn’t require scripting knowledge
  - Further simplifying the output for easier interpretation
  - Adding additional games, like the closed-bag exchange or the Guardian’s Dilemma
  - Incorporation of randomized player evolution feature
  - Turning the tournament into a simple game that takes user input
    - Players input their moves each turn. See scores and which strategies their moves were most similar to

# Questions?