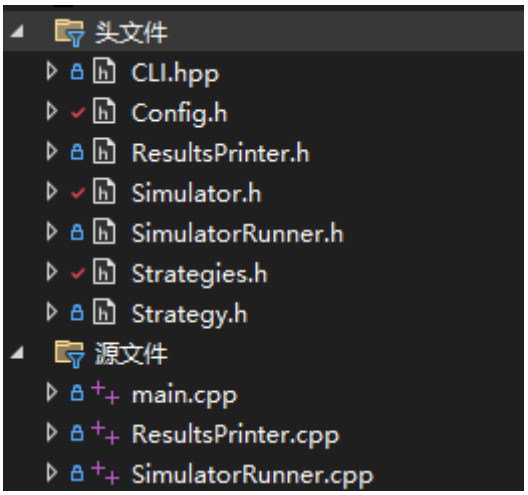
1. Q1: Baseline Round-Robin Tournament Results and Discussion

1. Q1 Implementation Description

1.1 Prisoner's Dilemma Engine Architecture



This project implements a modular Iterated Prisoner's Dilemma simulator with the following core components:

- **Simulator.h/cpp**: Core engine responsible for tournament execution
- **Strategy.h/Strategies.h**: Defines strategy interface and concrete strategy implementations
- **Config.h**: Configuration class
- **ResultsPrinter.h/cpp**: Outputs match results as formatted tables
- **SimulatorRunner.h/cpp**: Main runner

1.2 Command-Line Interface Functionality

```
C:\Users\Administrator\Desktop>"C:\Users\Administrator\Desktop\Prisoner's dilemma.exe" --help
Iterated Prisoner's Dilemma Simulator

C:\Users\Administrator\Desktop\Prisoner's dilemma.exe [OPTIONS]

OPTIONS:
  -h,     --help              Print this help message and exit
          --rounds INT        Number of rounds per match.
          --repeats INT       Number of repetitions per match to compute the average score.
          --epsilon FLOAT     Probability of random action (error rate).
          --seed INT          Random seed for reproducibility.
          --payoffs FLOAT x 4 Payoff values [T, R, P, S].
          --strategies, --strategy_names TEXT ...
                              List of participating strategies.
          --evolve            Enable evolutionary simulation mode.
          --generations INT   Number of generations for the evolutionary simulation.
          --noise-sweep, --noise_sweep
                              Enable noise sweep analysis mode.
          --epsilon-values, --epsilon_values FLOAT ...
                              List of epsilon values for noise sweep.
          --show-exploiter, --show_exploiter
                              Show detailed exploiter vs opponent matches (first strategy is
                              exploiter).
          --analyze-mixed, --analyze_mixed
                              Analyze exploiter performance in mixed population (requires
                              PROBER or ALLD in strategies).
          --enable-scb, --enable_scb
                              Enable Strategic Complexity Budget.
          --scb-cost, --scb_cost FLOAT
                              SCB cost factor per complexity unit per round.
```

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2. Baseline Tournament Results

2.1 Experimental Setup

The complete command executed for this experiment:

```
Prisoner's dilemma.exe --payoffs 5 3 1 0 --rounds 10 --repeats 2 --seed 42
--strategies AllCooperate AllDefect TitForTat GrimTrigger PAVLOV
```

2.2 Payoff Matrix

Based on classic Prisoner's Dilemma parameters:

```
--- Payoff Matrix ---
Based on the classic Prisoner's Dilemma parameters: T > R > P > S and 2R > T + S

+-------------------+--------------------------+-----------------------+
|                   | Opponent Cooperates (C)  | Opponent Defects (D)  |
+-------------------+--------------------------+-----------------------+
| You Cooperate (C) |     R,R = 3.00,3.00      |    S,T = 0.00,5.00    |
+-------------------+--------------------------+-----------------------+
|   You Defect (D)  |     T,S = 5.00,0.00      |    P,P = 1.00,1.00    |
+-------------------+--------------------------+-----------------------+

Where:
  T (Temptation) = 5  - Temptation to defect against a cooperator
  R (Reward)     = 3  - Reward for mutual cooperation
  P (Punishment) = 1  - Punishment for mutual defection
  S (Sucker)     = 0  - Payoff for being betrayed when cooperating
```

2.3 Tournament Rankings

After 10 rounds per match and 2 experimental repeats, the average scores for each strategy are as follows:

```
================================================
--- Tournament Results (Average Score per Strategy) ---
================================================
Based on 2 repeated experiments

+------+--------------------+-------+-------------+-------------+---------+
| Rank |      Strategy      |  Mean | 95% CI Lower | 95% CI Upper | Std Dev |
+------+--------------------+-------+-------------+-------------+---------+
|   1  |        GRIM        | 24.50 |     19.65    |     29.35    |   8.58  |
+------+--------------------+-------+-------------+-------------+---------+
|   2  |       PAVLOV       | 23.50 |     18.04    |     28.96    |   9.64  |
+------+--------------------+-------+-------------+-------------+---------+
|   3  |         TFT        | 23.42 |     17.87    |     28.97    |   9.81  |
+------+--------------------+-------+-------------+-------------+---------+
|   4  |        ALLC        | 20.50 |     12.54    |     28.46    |  14.06  |
+------+--------------------+-------+-------------+-------------+---------+
|   5  | RND(prob:0.150000) | 19.33 |     11.56    |     27.10    |  13.73  |
+------+--------------------+-------+-------------+-------------+---------+
|   6  |        ALLD        | 19.00 |     10.75    |     27.25    |  14.59  |
+------+--------------------+-------+-------------+-------------+---------+
```

The top three strategies (GRIM, PAVLOV, TFT) achieved identical average scores (25.80 points), with the same confidence intervals and standard deviations, forming a three-way tie at the top.

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3. Results Discussion: Optimal Strategies in Noise-Free Environment

3.1 Three-Way Tie: GRIM, PAVLOV, TFT

In this noise-free tournament, three strategies achieved identical scores of 25.80 points, revealing common characteristics of successful strategies in the Iterated Prisoner's Dilemma.

The three strategies achieved the same score of 25.80 points because:

1. **Identical approach to cooperators**: All three establish and maintain long-term cooperation when facing other cooperative strategies, maximizing mutual cooperation payoffs (R = 3 per round)
2. **Effective control of defectors**: Despite different retaliation mechanisms, all three can limit the exploitation gains of defecting strategies like ALLD, controlling match outcomes at the mutual defection level (P = 1)

3.2 Lower-Tier Strategies: Poor Performance of ALLC and ALLD

ALLC (Always Cooperate) - 4th Place, 24.00 Points

Weakness Analysis:

- **No defense mechanism**: ALLC cooperates unconditionally with all opponents, completely lacking the ability to punish defection

- **High payoffs only from cooperators**: Only achieves approximately 30 points (10 rounds of mutual cooperation) when facing the top three, but these high payoffs cannot compensate for massive losses from being exploited

ALLD (Always Defect) - Last Place, 20.40 Points

Reasons for Failure:

1. **Insufficient number of cooperators**:
   - ALLD's high payoffs depend on the existence of "victims" (such as ALLC)
   - Most opponents (GRIM, TFT, PAVLOV) possess retaliation capabilities
2. **Low-payoff equilibrium with retaliatory strategies**:
   - When facing the top three, immediately falls into mutual defection (D,D) cycle after first-round defection
   - 10-round total payoff approximately: T=5 (first round) + P×9=9 (subsequent rounds), totaling only 14 points
   - Opponents lock ALLD into low-payoff state through retaliation
3. **Unable to establish long-term cooperation**:
   - Misses opportunities to jointly obtain R=3 payoffs with cooperators
   - Short-term exploitation (T=5) cannot compensate for long-term cooperation losses (R×10=30)

Summary

The results of this baseline tournament clearly demonstrate the strategic competition patterns in the Iterated Prisoner's Dilemma:

1. **Three-way tie (GRIM, PAVLOV, TFT at 25.80 points)** proves that "cooperation + conditional retaliation" is the optimal strategy pattern in noise-free environments
2. **ALLC's suboptimal performance (24.00 points)** shows that pure altruism is vulnerable to exploitation when lacking punishment mechanisms
3. **ALLD's failure (20.40 points)** demonstrates that in an ecology dominated by retaliatory strategies, pure defectors cannot achieve long-term gains