Fighting Plagiarism: A Game Theoretic Approach

Mohammad Yaghini
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February 2014
Outline

- Motivation
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- Motivation
- Introduction to Bayesian Games
- Definitions
- Equilibrium
- Expected Utility

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Plagiarism and cheating are rampant among students, be it in:

1. High School
2. Undergraduate
3. Graduate

While prevalent, it's not dominant Code of Ethics, Mostly in the Ivy League: Caltech, MIT, Stanford, etc.

Student Supervisory Councils

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And last but not least,

- Personal Experience:

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Fighting Plagiarism: A Game Theoretic Approach
Why Game Theory?

Plagiarism can be highly strategic:

- **Players:**
  - Rational Students vs. Professor
  - Student vs. Student

- **Strategies:**
  - Cheating/Not Cheating
  - Stricter/More Lenient Grading

- **Outcomes:**
  - Scores
  - Credibility
  - Reputation
  - Stature

Numerical payoffs can be assigned.
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Why Game Theory?

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Why Game Theory?

Motivation
Introduction to Bayesian Games
Game Modelling
Conclusion and Future Works

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- **Numerical payoffs can be assigned.**
Why Bayesian Games?

Bayesian Games = Games of Incomplete Information

- While the **type** of the professor might be previously known, the type of student isn’t.
- Professors can change grading policies.
- Through **learning** students and professor receive **signals** about each other’s types and therefore the **state** of the game.

∴ Bayesian games are suitable choices.
This is a test.
Outline

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- Introduction to Bayesian Games
- Definitions
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Fighting Plagiarism: A Game Theoretic Approach
Main Assumptions

- All possible games have the same number of agents and the same strategy space for each agents.
- Common-prior Assumption

In Bayesian Games there are two sources of uncertainty

- Mixed Strategies
- Types of players

Three definitions, based on:

- Information Sets
- Extensive Form with Chance Moves
- Epistemic Types
Definition 1

A Bayesian game is a tuple \((N, G, P, I)\) where:

- \(N\) is a set of agents;
- \(G\) is a set of games with \(N\) agents each such that if \(g, g' \in G\) then for each agent \(i \in N\) the strategy space in \(g\) is identical to the strategy space in \(g'\);
- \(P \in \Pi(G)\) is a common prior over games, where \(\Pi(G)\) is the set of all probability distributions over \(G\); and
- \(I = (I_1, ..., I_N)\) is a tuple of partitions of \(G\), one for each agent.
Definition 2: Extensive Form With Chance Moves

- **Nature:**
  - A special agent who makes probabilistic choices
  - Has a constant utility function
  - Has the unique strategy of randomizing in a commonly known way

- **Agents receive individual signals about Nature's choice.**
  - No additional information: agents make their choices without knowing the choices of others
Definition 3: Types

A Bayesian game is a tuple \((N, A, p, u)\) where:

- \(N\) is a set of agents;
- \(A = A_1 \times \cdots \times A_n\), where \(A_i\) is the set of actions available to player \(i\);
- \(\Theta = \Theta_1 \times \cdots \times \Theta_n\), where \(\Theta_i\) is the type space of player \(i\);
- \(p : \Theta \mapsto [0, 1]\) is a common prior over types; and
- \(u = (u_1, \ldots, u_n)\), where \(u_i : A \times \Theta \mapsto \mathbb{R}\) is the utility function for player \(i\).

Assumptions:

- All of this is common knowledge among the players
- Each agent knows his own type:
  - his private payoff function,
  - his beliefs about other agents payoffs,
  - their beliefs about his own payoff,
  - ...
- the type encapsulates all the information possessed by the agent that is not common knowledge.
**Bayes-Nash Equilibrium**

A Bayes-Nash equilibrium is a mixed-strategy profile $s$ that satisfies

$$\forall i \; s_i \in BR_i(s_i).$$

**Best response in a Bayesian game**

The set of agent $i$'s best responses to mixed-strategy profile $s_i$ are given by

$$BR_i(s_{-i}) = \arg\max \; EU_i(s_i', s_{-i})$$

Generic? the difference lies within Expected Utility $EU_i$. 

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The story of three EUs

In a Bayesian game, three ways of computing utility is conceivable:

- **Ex post** expected utility: based on all agents’ actual types.

- **Ex interim** expected utility: based on agent’s type but not others.

- **Ex ante** expected utility: without anyone’s knowledge of any type.
The story of three EUs

In a Bayesian game, three ways of computing utility is conceivable:

- **Ex post** expected utility: based on all agents’ actual types

  \[ EU_i(s, \theta) = \sum_{a \in A} \left( \prod_{j \in N} s_j(a_j|\theta_j) \right) u_i(a, \theta). \]

- **Ex interim** expected utility: based on agent’s type but not others.

  \[ EU_i(s, \theta_i) = \sum_{\theta_{-i} \in \Theta_{-i}} p(\theta_{-i}|\theta_i) \sum_{a \in A} \left( \prod_{j \in N} s_j(a_j|\theta_j) \right) u_i(a, \theta_{-i}, \theta_i). \]

- **Ex ante** expected utility: without anyone’s knowledge of any type.

  \[ EU_i(s) = \sum p(\theta) \sum_{a \in A} \left( \prod_{j \in N} s_j(a_j|\theta_j) \right) u_i(a, \theta). \]
Professor vs. Short-sighted Student

Put another way, any given assignment could be rejected either because of plagiarism (in case a student cheats and gets caught) or because of insufficiency of the answers provided (in case the student does not cheat).

**B. Rewards and Punishments**

1. A student is rewarded 1 unit of reward if her assignment is accepted, regardless of how she has obtained her answers.
2. Turning in authentic work (= NC) has a cost of 1 unit. Cheating, on the other hand only costs 0.5 unit.
3. Most naturally, there is a system of reputation in the game, so by cheating and getting caught, the wrong doer not only suffers the total loss of the score of the aforementioned assignment but she also suffers a disgrace cost equal to 0.5 units.
4. Students, who do not plagiarize, enjoy a deeper understanding of the subject which in turn, helps them in their midterm or final exam's preparations. Thus a reward of 0.5 unit is assumed.

**For a long-sighted student:**

the above stays the same, except that she receives a higher payoff for not plagiarizing (1 instead of 0.5) she places more emphasis on the role of assignments as preparation for exams.

**For a strict professor,** who is an idealist, who expects every student to enjoy his course as much as she does; we assume the following:

1. Being tricked by a cunning student fills her with indignation; for this she suffers 1 unit.
2. She feels triumphant catching a wrong doer; thus a reward of 1 unit.
3. She is deeply concerned with the course and her presentation; therefore:
   - When facing a cheater, she is somewhat let down: a cost of 0.5 unit.
   - On the contrary, when she encounters an honest student who takes genuine interest in her course and succeeds, she receives a payoff of 0.5 unit.

**For a lenient professor,** who is trying to keep everyone satisfied, cheating is a misdemeanor. She would rather everyone received a good grade, than having angry students swarming her office asking for better grades. Thus the following:

1. Being tricked by a student, doesn’t provoke indignation, although she feels tricked. Thus a cost of 0.5 unit.
2. There is no triumph in catching a cheater.
3. Whenever an assignment gets accepted, she is rewarded 1 unit; regardless of whether it’s been genuine or not.

**C. Game Matrices:**

1) For the case of a Professor vs. Short-sighted Student the matrices for the Bayesian game follows:

<table>
<thead>
<tr>
<th>Student\Professor</th>
<th>Accept</th>
<th>Reject</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copy</td>
<td>0.5,0.5</td>
<td>-1,0</td>
</tr>
<tr>
<td>Not Copy</td>
<td>0.5,1</td>
<td>-0.5,0</td>
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</tbody>
</table>

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</tr>
</tbody>
</table>

Professor is Lenient ($\pi$)

- Players: Lenient Professor, Severe Professor, The Student
- Strategies: $S_{Student} = \{C, NC\}$ and $S_{Professor} = \{A, R\}$
- Preferences: Ordinal as indicated
We add that, since the type of professor is unknown to the Student, she has to calculate her expected payoff given her belief that her professor is Lenient (with probability $\frac{1}{4}$) or severe ($1 - \frac{1}{4}$); thus we have the following table:

<table>
<thead>
<tr>
<th>Student\Professor (Lenient Type, Severe Type)</th>
<th>(A,A)</th>
<th>(A,R)</th>
<th>(R,A)</th>
<th>(R,R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.5</td>
<td>$1.5\pi - 1$</td>
<td>$0.5\pi + 0.5$</td>
<td>-1</td>
</tr>
<tr>
<td>NC</td>
<td>0.5</td>
<td>$\pi - 0.5$</td>
<td>$-\pi + 0.5$</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

Table 2 - Short-Sighted Student's Expected Payoffs

For finding the Bayesian Nash equilibria we construct best response functions. For Professor, we use Table 1 and for Student, Table 2.

In calculations of Table 4, note that:

$1 - \frac{1}{4} > 1.5\pi - 1 \Rightarrow 0.5\pi < 0.5$ always true

And $0.5 > 0.5\pi - 1 \Rightarrow 0.5 > -\pi + 0.5$ always true

So in 8 possible pure-strategy equilibriums, considering the above BRs we omit those that contain non-BR strategies; first Professor’s BR:

- $(C; A; A)$
- $(C; A; R)$
- $(C; R; A)$
- $(C; R; R)$
- $(NC; A; A)$
- $(NC; A; R)$
- $(NC; R; A)$
- $(NC; R; R)$

Now Student’s BR:

- $(C; A; R)$
- $(NC; A; A)$

So the only possible Bayesian NE is: $(NC, A, A)$ which is a weak NE.

For the case of a Professor vs. Long-sighted Student; analysis is much the same. Corresponding tables follow:

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<tbody>
<tr>
<td>C</td>
<td>0.5</td>
<td>$1.5\pi - 1$</td>
</tr>
<tr>
<td>NC</td>
<td>0.5</td>
<td>$\pi - 0.5$</td>
</tr>
</tbody>
</table>

Professor is Lenient ($\frac{1}{4}$) Professor is Severe ($1 - \frac{1}{4}$)

Table 3 - BR for Professor

Table 5 - Strategic Form Representation (Professor vs. Long-Sighted Student)
Best Response Calculation

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<td>-0.5,0</td>
</tr>
</tbody>
</table>

Professor is Lenient ($\pi$)

<table>
<thead>
<tr>
<th>Student \ Professor</th>
<th>(A,A)</th>
<th>(A,R)</th>
<th>(R,A)</th>
<th>(R,R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.5</td>
<td>1.5\pi - 1</td>
<td>0.5\pi + 0.5</td>
<td>-1</td>
</tr>
<tr>
<td>NC</td>
<td>0.5</td>
<td>\pi - 0.5</td>
<td>-\pi + 0.5</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

Figure: BR for Student

Professor is Severe (1 - $\pi$)

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</tbody>
</table>

Figure: BR for Professor
Solution Concept: Elimination of not BRs

- in 8 possible pure-strategy equilibriums, considering the above BRs we omit those that contain non-BR strategies; first Professors BR:

\[
\{ (C, A, A), (C, A, R), (C, R, A), (C, R, R), (NC, A, A), (NC, A, R), (NC, R, A), (NC, R, R) \}
\]

- Now Student BR:

\[
\{ (C, A, R), (NC, A, A) \}
\]

So the only possible Bayesian NE is: \((NC, A, A)\).
Professor vs. Long-sighted Student

<table>
<thead>
<tr>
<th>Student</th>
<th>Professor (Lenient Type, Severe Type)</th>
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<th>(A,R)</th>
<th>(R,A)</th>
<th>(R,R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.5</td>
<td>1.5π - 1</td>
<td>0.5π + 0.5</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>NC</td>
<td>1</td>
<td>π</td>
<td>1 - π</td>
<td>0</td>
<td></td>
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</tbody>
</table>

**Figure:** BR for Student
Roles Reversed: Student vs. Lenient Professor

Professor’s type is unknown to the student.

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Short-Sighted Student(µ)

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<tbody>
<tr>
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</tr>
<tr>
<td>Reject</td>
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<td>0,0</td>
</tr>
</tbody>
</table>

Far-Sighted Student (1- µ)

**Figure:** Student vs. Lenient Professor Game in Strategic Form

<table>
<thead>
<tr>
<th>Professor\Student (Short-Sighted Type, Long-Sighted Type)</th>
<th>(C,C)</th>
<th>(C,NC)</th>
<th>(NC,C)</th>
<th>(NC,NC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.5</td>
<td>0,5µ</td>
<td>0.5µ+0.5</td>
<td>0</td>
</tr>
<tr>
<td>R</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Figure:** Lenient Professor’s Expected Payoffs

two Bayesian Nash Equilibria: (A;C;NC) and (A;NC;NC)
Student vs. Severe Professor

Professor’s type is unknown to the student.

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<tbody>
<tr>
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<td>0.5</td>
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<tr>
<td>Reject</td>
<td>0.5</td>
<td>-1</td>
</tr>
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</table>

Short- Sighted Student ($\mu$)

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<tr>
<td>Reject</td>
<td>0.5, -1</td>
<td>0, -0.5</td>
</tr>
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</table>

Far- Sighted Student ($1-\mu$)

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<tr>
<td>Reject</td>
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</tbody>
</table>

**Figure:** Student vs. Lenient Professor Game in Strategic Form

<table>
<thead>
<tr>
<th>Student \ Professor (Short-Sighted Type, Long-Sighted Type)</th>
<th>(C,C)</th>
<th>(C,NC)</th>
<th>(NC,C)</th>
<th>(NC,NC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-1.5</td>
<td>-2$\mu$+0.5</td>
<td>2$\mu$ - 1.5</td>
<td>0.5</td>
</tr>
<tr>
<td>R</td>
<td>0.5, $\mu$</td>
<td>0.5,0.5</td>
<td>0.5 - 0.5$\mu$</td>
<td>0</td>
</tr>
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</table>

**Figure:** Lenient Professor’s Expected Payoffs
The Double Blind Game

The game can be thought of as a complete information game of four player.

<table>
<thead>
<tr>
<th>Student\Professor</th>
<th>Accept</th>
<th>Reject</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copy</td>
<td>0.5,0.5</td>
<td>-1,0</td>
</tr>
<tr>
<td>Not Copy</td>
<td>0.5,1</td>
<td>-0.5,0</td>
</tr>
</tbody>
</table>

Professor is Lenient ($\pi$)

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Professor is Lenient ($\pi$)

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</tr>
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Professor is Severe ($1 - \pi$)

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<td>-0.5,0</td>
</tr>
</tbody>
</table>

Professor is Severe ($1 - \pi$)
### Calculations

#### Student vs Professor (Lenient Type, Severe Type)

<table>
<thead>
<tr>
<th>Student</th>
<th>Professor</th>
<th>(A,A)</th>
<th>(A,R)</th>
<th>(R,A)</th>
<th>(R,R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>(A,A)</td>
<td>0.5</td>
<td>1.5\pi - 1</td>
<td>0.5\pi + 0.5</td>
<td>-1</td>
</tr>
<tr>
<td>NC</td>
<td>(A,A)</td>
<td>0.5</td>
<td>\pi - 0.5</td>
<td>-\pi + 0.5</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

#### Professor vs Student (Lenient Type, Severe Type)

<table>
<thead>
<tr>
<th>Professor</th>
<th>Student</th>
<th>(A,A)</th>
<th>(A,R)</th>
<th>(R,A)</th>
<th>(R,R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>(A,A)</td>
<td>0.5</td>
<td>1.5\pi - 1</td>
<td>0.5\pi + 0.5</td>
<td>-1</td>
</tr>
<tr>
<td>NC</td>
<td>(A,A)</td>
<td>1</td>
<td>\pi</td>
<td>1 - \pi</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Professor vs Student (Short-Sighted Type, Long-Sighted Type)

<table>
<thead>
<tr>
<th>Professor</th>
<th>Student</th>
<th>(C,C)</th>
<th>(C,NC)</th>
<th>(NC,C)</th>
<th>(NC,NC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>(C,C)</td>
<td>0.5</td>
<td>1 - 0.5\mu</td>
<td>0.5\mu + 0.5</td>
<td>1</td>
</tr>
<tr>
<td>R</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Student vs Professor (Short-Sighted Type, Long-Sighted Type)

<table>
<thead>
<tr>
<th>Student</th>
<th>Professor</th>
<th>(C,C)</th>
<th>(C,NC)</th>
<th>(NC,C)</th>
<th>(NC,NC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>(C,C)</td>
<td>-1.5</td>
<td>-2\mu + 0.5</td>
<td>2\mu - 1.5</td>
<td>0.5</td>
</tr>
<tr>
<td>R</td>
<td>(C,C)</td>
<td>0.5</td>
<td>0.5\mu</td>
<td>0.5 - 0.5\mu</td>
<td>0</td>
</tr>
</tbody>
</table>
Calculations (cont.)

Crossing out profiles with non-BR strategies: first by Tables 7 and 8:

\[


Now, By Tables 9 and 10:

\[
\{(C, NC, A, A), (NC, NC, A, A), (NC, NC, A, R)\}
\]

Of the remaining two, \((NC, NC, A, A)\) is a no doubt a NE since it's a mutual best response, but \((C, NC, A, A)\) can be a Bayesian NE provided that a condition is satisfied:

\[(C, NC, A, A) \text{ is NE } \iff 0.5\mu \leq -2\mu + 0.5 \iff \mu \leq 0.2\]

So, for \(\mu > 0.2\) we only have \((C, NC, A, A)\) which is consistent with our result from section II. But for \(\mu \leq 0.2\) there are two possible Bayesian NE, \(\{(C, NC, A, A), (NC, NC, A, A)\}\). We interpret these results in section IV.
Outline

- Motivation
- Introduction to Bayesian Games
- Definitions
- Equilibrium
- Expected Utility
- Game Modelling
- Conclusion and Future Works
(NC;A;A) is an NE. the student does not copy whether she thinks her professor is severe or lenient.

This is the case for both short-sighted and long-sighted students.

In the reversed case, seemingly closest to the reality, two equilibria, namely (A;NC;NC) and (A;C;NC) provided $\mu < 0.2$

- More rational to stay truthful: short and long term gains.
- Imbecility overthrows that rationale beyond a certain point: $\mu > 0.2$
- In case of leniency on the professor’s side, not even imbecility is required.