

A Glimpse of Game Theory

WALLY, THESE PEER REVIEWS
ARE LIKE THE FAMOUS
"PRISONER'S DILEMMA."



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S. Adams

IF YOU RAT ON ME BUT
I SAY GOOD THINGS
ABOUT YOU, YOU GET THE
BIGGEST RAISE. BUT IF
WE PRAISE EACH OTHER
WE CAN BOTH GET A
SMALL RAISE.



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WALLY, IF YOU RAT HIM
OUT, I'LL LET YOU LOOK AT
MY "VICTORIA'S SECRET"
CATALOG.



THIS IS EXACTLY
WHY THERE ARE
NO COED
PRISONS.



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Games and Game Theory

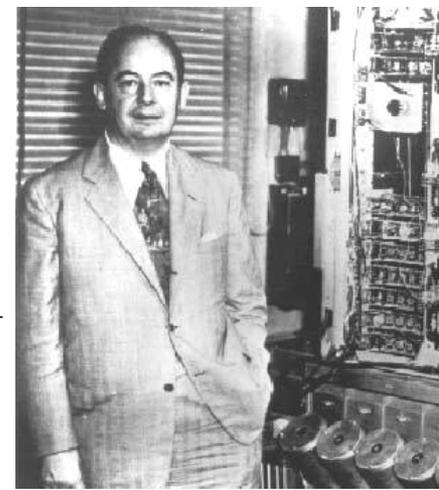
- Much effort to develop computer programs for artificial games like chess or poker commonly played for entertainment
- Larger issue: account for, model and predict how agents (human or artificial) interact with other agents
- **Game theory** accounts for mixture of cooperative and competitive behavior
- Applies to zero-sum and non-zero-sum games

Basic Ideas of Game Theory

- Game theory studies how strategic interactions among **rational players** produce **outcomes** with respect to the players' **preferences** (or utilities)
 - Outcomes might not have been intended
- Game theory offers a general theory of strategic behavior
- Generally depicted in mathematical form
- Plays important role in economics, decision theory and multi-agent systems

Game Theory

- Defined by **von Neumann & Morgenstern**
von Neumann, J., and Morgenstern, O., (1947).
The Theory of Games and Economic Behavior.
- Covers a wide range of situations for both cooperative and non-cooperative situations
- Developed and used in economics and in the past 20 years been used to model artificial agents
- Provides a powerful model and practical tools to think about interactions among a set of autonomous agents
- Used to model strategic policies (e.g., arms race)



Zero Sum Games



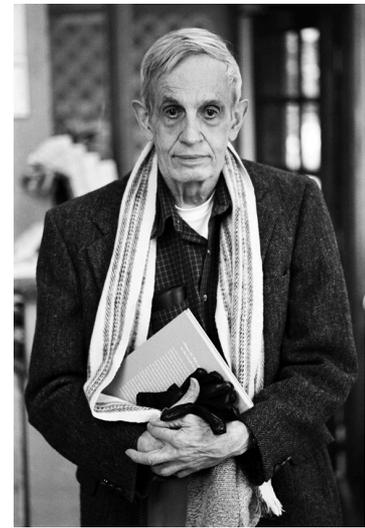
- **Zero-sum:** participant's gain/loss exactly balanced by losses/gains of the other participants
- Total gains of participants minus total losses = 0
Poker is zero sum game: money won = money lost
- Commercial trade is not a zero sum game
If a country with an excess of bananas trades with another for their excess of apples, both may benefit
- Non-zero sum games more complex to analyze
- More non-zero sum games as world becomes more complex, specialized and interdependent

Rules, Strategies, Payoffs & Equilibrium

Situations are treated as games:

- **Rules** of game: who can do what, and when they can do it
- Player's **strategy**: plan for actions in each possible situation in the game
- Player's **payoff**: amount that the player wins or loses in a particular situation in a game
- Player has a **dominant strategy** if her best strategy doesn't depend on what others do

Nash Equilibrium



- Occurs when each player's strategy is optimal, given strategies of the other players
- Strategy profile where no player benefits by unilaterally changing her strategy, while others stay fixed
- Every finite game has at least one Nash equilibrium in either pure or mixed strategies (proved by John Nash)
 - J. F. Nash. 1950. Equilibrium Points in n-person Games. Proc. National Academy of Science, 36
 - Nash won 1994 Nobel Prize in economics for this work
 - Read [A Beautiful Mind](#) by Sylvia Nasar (1998) and/or see the [2001 film](#)

Prisoner's Dilemma

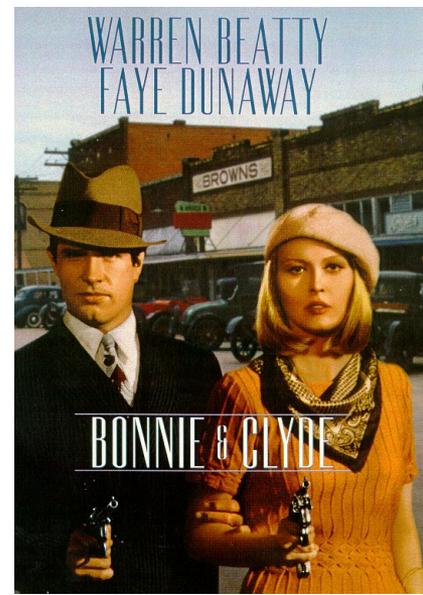
- Famous example of game theory
- Strategies must be undertaken without the full knowledge of what other players will do
- Players adopt dominant strategies, but they don't necessarily lead to the best outcome
- Rational behavior leads to a situation where everyone is worse off



Will the two prisoners cooperate to minimize total loss of liberty or will one of them, trusting the other to cooperate, betray him so as to go free?

Bonnie and Clyde

Bonnie and Clyde are arrested and charged with crimes. They're questioned in separately, unable to communicate. They know how it works:



- If both proclaim mutual innocence (cooperating), they will be found guilty anyway and get a three year sentences for robbery
- If one confesses (defecting) and the other doesn't (cooperating), the confessor is rewarded with a light, one-year sentence and the other gets a severe 8-year sentence
- If both confess (defecting), then the judge sentences both to a moderate 4 years in prison

What should Bonnie do? What should Clyde do?

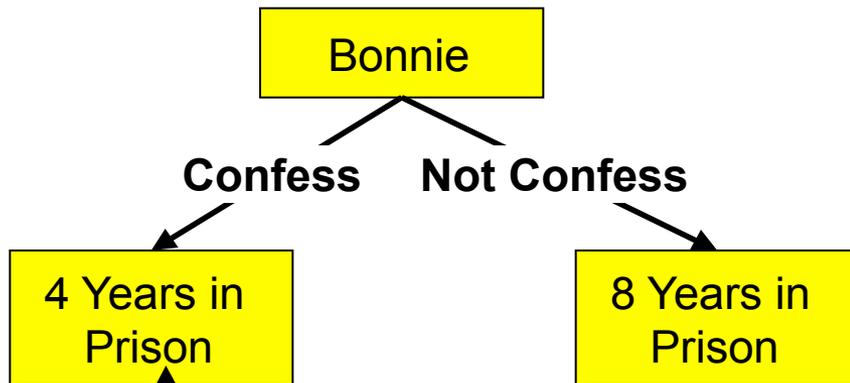
The payoff matrix

		CLYDE	
		Confess	Not Confess
BONNIE	Confess	4 years each	1 year for Bonnie and 8 years for Clyde
	Not Confess	8 years for Bonnie and 1 year for Clyde	3 years each

Bonnie's Decision Tree

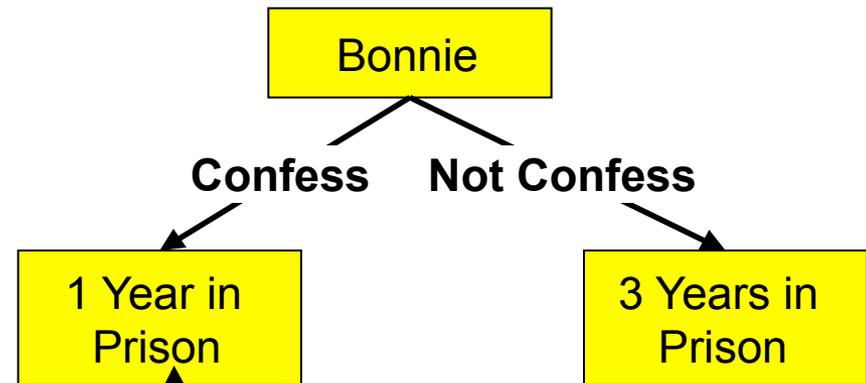
There are two cases to consider

If Clyde Confesses



Best Strategy

If Clyde Does Not Confess



Best Strategy

The dominant strategy for Bonnie is to confess (defect) because no matter what Clyde does she is better off confessing.

So what?

- It seems we should always defect and never cooperate
- No wonder Economics is called the dismal science

Some PD examples

- There are lots of examples of the Prisoner's Dilemma situations in the real world
- It makes it difficult for “players” to avoid the bad outcome of both defecting
 - Cheating on a cartel
 - Trade wars between countries
 - Arms races
 - Advertising
 - Communal coffee pot
 - Class team project

Cheating on a Cartel

Cartel: association of manufacturers or suppliers with purpose of maintaining prices at a high level and restricting competition

- Cartel members' possible strategies range from abiding by their agreement to cheating
- Cartel members can charge the monopoly price or a lower price
- Cheating firms can increase profits
- The best strategy is charging the low price

Trade Wars Between Countries

- Free trade benefits both trading countries
- Tariffs can benefit one trading country
- Imposing tariffs can be a dominant strategy and establish a Nash equilibrium even though it may be inefficient

Advertising

- Advertising is expensive
- All firms advertising tends to equalize the effects
- Everyone would gain if no one advertised
- But firms increase their advertising to gain advantage
- Which makes their competition do the same
- It's an arms race

Games Without Dominant Strategies

- In many games players have no dominant strategy
- Player's strategy depends on others' strategies
- If player's best strategy depends on another's strategy, she has no dominant strategy

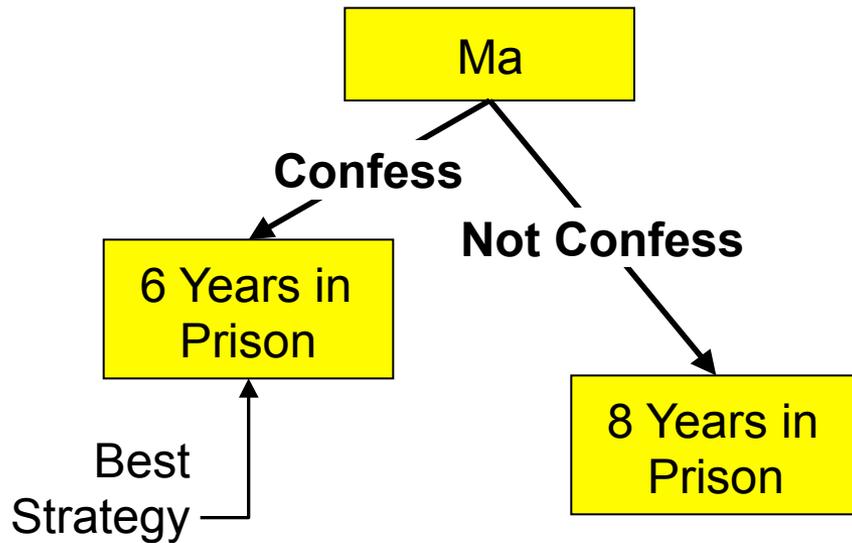


Pa

		Pa	
		Confess	Not Confess
Ma	Confess	6 years for Ma 1 year for Pa	5 years for Ma 3 years for Pa
	Not Confess	8 years for Ma 0 years for Pa	4 years for Ma 2 years for Pa

Ma's Decision Tree

If Pa Confesses



If Pa Does Not Confess



Ma has no explicit dominant strategy, but there is an *implicit* one since Pa does have a dominant strategy. (What is it?)

Some games have no simple solution

In the following payoff matrix, neither player has a dominant strategy. There is no non-cooperative solution

		Player B	
		1	2
Player A	1	1, -1	-1, 1
	2	-1, 1	1, -1

Repeated Games

- A repeated game is a game that the same players play more than once
- Repeated games differ from one-shot games because a player's current actions can depend on the past behavior of other players
- Cooperation is encouraged

Payoff matrix for the generic two person dilemma game

(A' s payoff,
B' s payoff)

		Player B	
		cooperate	defect
Player A	cooperate	(CC,CC) reward for mutual cooperation	(CD,DC) sucker' s payoff and temptation to defect
	defect	(DC,CD) temptation to defect and sucker' s payoff	(DD,DD) punishment for mutual defection

Payoffs

- Four payoffs are involved
 - CC: Both players cooperate
 - CD: You cooperate, other defects (aka “sucker’s payoff”)
 - DC: You defect, other cooperates (aka “temptation to defect”)
 - DD: Both players defect
- Assigning values to these induces an ordering, with 24 possibilities (4!); three lead to “dilemma” games
 - Prisoner’s dilemma: $DC > CC > DD > CD$
 - Chicken: $DC > CC > CD > DD$
 - Stag Hunt: $CC > DC > DD > CD$

Chicken

- DC > CC > CD > DD
- Rebel without a cause scenario
 - Cooperation: swerving
 - Defecting: not swerving
- Optimal move: do exactly the opposite of other player



Stag Hunt

- $CC > DC > DD > CD$
- Two players on a stag hunt
 - Cooperating: keep after the stag
 - Defecting: switch to chasing the hare
- Optimal play: do exactly what the other player(s) do



Prisoner's dilemma

- $DC > CC > DD > CD$
- Optimal play: always defect
- Two rational players will always defect.
- Thus, (naïve) individual rationality subverts their common good



More examples of the PD in real life

- **Communal coffeepot**

- Cooperate by making new pot of coffee if you take last cup
- Defect by taking last cup and not making new pot, depending on the next coffee seeker to do it
- $DC > CC > DD > CD$

- **Class team project**

- Cooperate by doing your part well and on time
- Defect by slacking, hoping other team members will come through and sharing benefits of good grade
- (Arguable) $DC > CC > DD > CD$

Iterated Prisoner's Dilemma

- Game theory shows that rational players should always defect when engaged in a PD situation
- In real situations, people don't always do this
- Why not? Possible explanations:
 - People aren't rational
 - Morality
 - Social pressure
 - Fear of consequences
 - Evolution of species-favoring genes
- Which of these make sense? How can we formalize?

Iterated Prisoner's Dilemma

- **Key idea:** We often play more than one “game” with a given player
- Players have complete knowledge of past games, including their choices and other players' choices
- Your choice when playing against a player can be based on whether she's been cooperative in the past
- A simulation was first done by Robert Axelrod (Michigan) in which computer programs played in a round-robin tournament
(DC=5,CC=3,DD=1,CD=0)
- The simplest program won!

Some possible strategies

- Always defect
- Always cooperate
- Randomly choose
- Pavlovian (win-stay, lose-switch)
 - Start always cooperating, switch to always defecting when “punished” by other’s defection, switch back and forth at every such punishment
- Tit-for-tat (TFT)
 - “Be nice, but punish any defections”. Starts cooperating and, after that always does what the other player did on the previous round
- Joss
 - A sneaky TFT that defects 10% of the time
- In an idealized (noise free) environment, TFT is both a very simple and a very good strategy

Characteristics of Robust Strategies

Axelrod analyzed entries and identified characteristics

Nice: never defects first

Provocable: responds to defection by promptly defecting.

Prompt response is important; being slow to anger isn't a good strategy; some programs tried even harder to take advantage.

Forgiving: programs responding to single defections by defecting forever thereafter weren't successful. It's better to respond to a TIT with 0.9 TAT; might dampen some echoes and prevent feuds.

Clear: Clarity was an important feature. With TFT you know what to expect and what would/wouldn't work. With too much randomness or bizarre strategies in a program, competing programs could not analyze and began to always defect.

Implications of Robust Strategies

- Succeed not by "beating" others, but by allowing both to do well. TFT never "wins" a single turn! It can't. It can never do better than tie (all C).
- You do well by motivating cooperative behavior from others - the provocability part.
- Envy is counterproductive. It does not pay to get upset if someone does a few points better than you on any single encounter. For you to do well others must also do well, e.g., business and its suppliers.

Implications of Robust Strategies

- You don't have to be very smart to do well. You don't even have to be conscious! TFT models cooperative relations with bacteria and hosts.
- Cosmic threats and promises aren't necessary, although they may be helpful.
- Central authority is not necessary, although it may be helpful.
- Optimum strategy depends on environment. TFT is not necessarily the best program in all cases. It may be too unforgiving of JOSS and too lenient with RANDOM.

Required for emergent cooperation

- A non-zero sum situation.
- Players with equal power and no discrimination or status differences.
- Repeated encounters with another player you can recognize. Car garages that depend on repeat business versus those on busy highways. Gypsies. If you're unlikely to ever see someone again, you're back into a non-iterated dilemma.
- A temptation payoff that isn't too great. If, by defecting, you can become a millionaire, then you're likely to do it. "Every man has his price."

Ecological model

- Assume an ecological system can support N players
- Players accumulate or lose points on each round
- After each round, poorest players die and richest multiply
- *Noise* in the environment can model likelihood that an agent makes errors in following a strategy misinterpret another's choice
- A simple way of modeling this is described in [The Computational Beauty of Nature](#)

Evolutionary stable strategies

- Strategies do better or worse against other strategies
- Successful strategies should be able to work well in a variety of environments
 - E.g., ALL-C works well in an mono-culture of ALL-C' s but not in a mixed environment
- Successful strategies should be able to “fight off mutations”
 - E.g., an ALL-D mono-culture is very resistant to invasions by any cooperating strategies
 - E.g., TFT can be “invaded” by ALL-C

Population simulation

(a) TFT wins

(b) A noise free version with TFT winning

(c) 0.5% noise lets Pavlov win

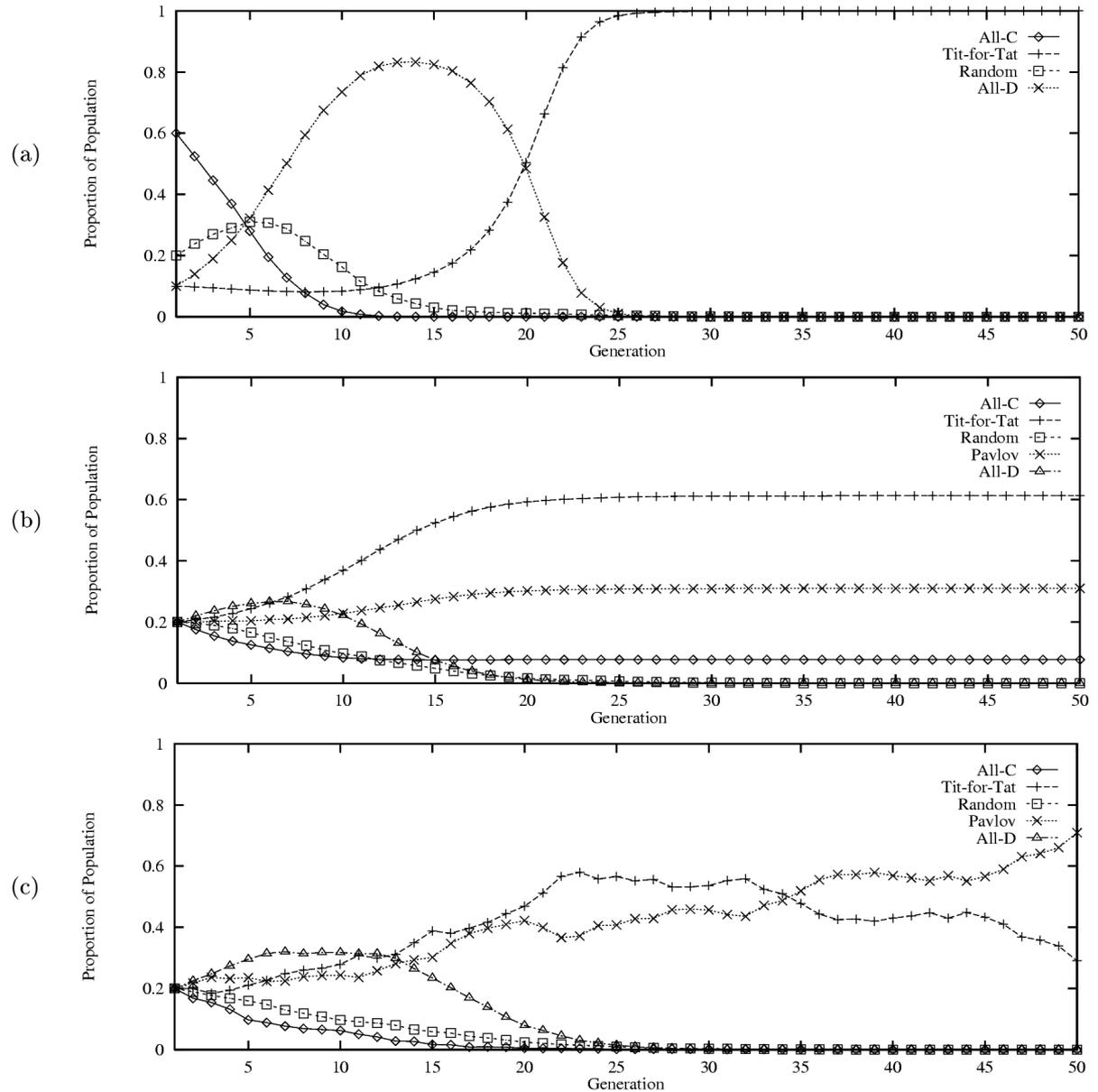


Figure 17.3 Population simulations of the ecological version of the iterated Prisoner's Dilemma: (a) an idealized version that illustrates the rise of **TFT**; (b) a noise-free simulation with **TFT** winning; (c) with 0.5 percent noise **PAV** wins

20th anniversary IPD competition (2004)

- [New Tack Wins Prisoner's Dilemma](#)
- [Coordinating Team Players within a Noisy Iterated Prisoner's Dilemma Tournament](#)
- U. Southampton bot team won using a covert channel to let “fellow travelers” recognize each other
- The 60 bots
 - Executed series of moves that signaled their ‘tribe’
 - Defect if other is known to be outside tribe, coordinate if in tribe
 - Coordination was not just cooperation, but master/slave : defect/cooperate

For more information

- Prisoner's Dilemma: John von Neumann, Game Theory, and the Puzzle of the Bomb, William Poundstone, Anchor Books, Doubleday, 1993.
- The Origins of Virtue: Human Instincts and the Evolution of Cooperation, Matt Ridley, Penguin, 1998.
- Games of Life : Explorations in Ecology, Evolution and Behaviour, Karl Sigmund, 1995.
- Nowak, M.A., R.M. May and K. Sigmund (1995). The Arithmetic of Mutual Help. Scientific American, 272(6).
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- The Computational Beauty of Nature: Computer Explorations of Fractals, Chaos, Complex Systems, and Adaptation, Gary _William Flake, MIT Press, 2000.
- [New Tack Wins Prisoner's Dilemma](#), By Wendy M. Grossman, Wired News, October 2004.

Hawk and Dove