Thesis Title

Thesis Subtitle

Author Name

B.Sc. Final Year Dissertation

Cardiff School of Mathematics

CARDIFF UNIVERSITY

PRIFYSGOL CAERDYDD

Acknowledgments

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Chapter 1

Introduction

1.1 Introduction

There is this data that is pretty awesome, I'm going to plot it and show it to you in sections 1.2 and 1.3.

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1.2 The data

In Figure 1.1 we see data that was generated using (1.2):

$$x \in \{x \in \mathbb{Z} | 1 \leq x \leq 1999\} \tag{1.1}$$

$$y = 2(1 + \epsilon)x + 5 \tag{1.2}$$

where $\epsilon \in (-0.5, 0.5)$ is a random number.

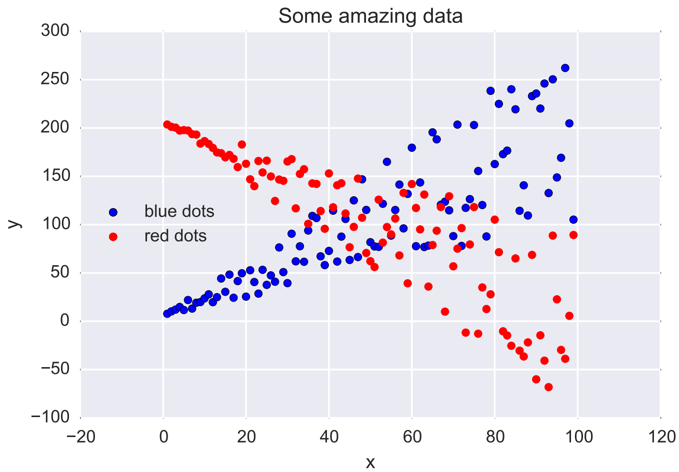

Figure 1.1: The great data

1.3 The distribution of the data

Figure shows the distribution of the data.

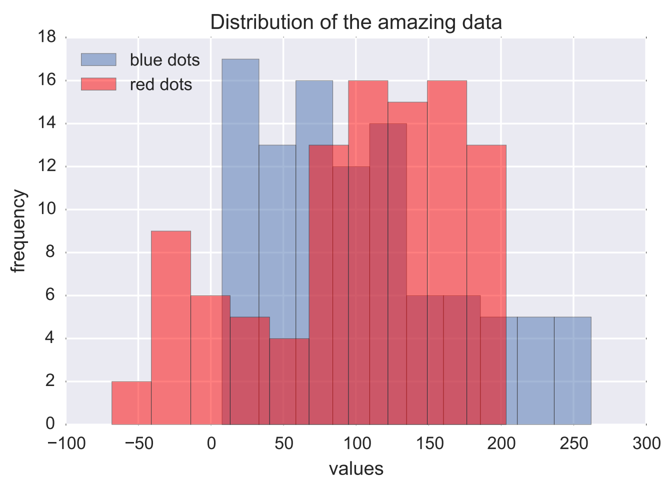

Figure 1.2: The distribution of the great data

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1.4 Conclusion

This chapter was amazing, here is a reference to a paper [5].

Chapter 2

Literature Review

2.1 Background

- Explain Prisoner's Dilemma

- Axelrod's original tournament

- Work to reproduce Axelrod's tournament [5]

Year	Reference	Number of Strategies	Type
1979		13	Standard
1979		64	Standard
1984		64	Evolutionary
1991		13	Noisy
2005		223	Varied
2012		13	Standard

Table 2.1: An overview of published tournaments

is often used to model systems in biology [6], sociology [3], psychology [4], and economics [2].

2.2 Fingerprinting

Definition 1 *If A is a strategy for playing the iterated prisoner's dilemma, then the **Joss-Anne of A**, $JA(A, x, y)$ is a transformation of that strategy. Instead of the original behaviour, it makes move C with probablility x, move D with probability y, and otherwise uses the response appropriate to strategy A (if $x + y < 1$).*

The notation JA comes from the initials of the names Joss and Anne. Joss was a strategy submitted to one of Axelrods original tournaments and it would occasionally defect without provocation in the hopes of a slight improvement in score. Anne is the first name of A. Stanley who suggested the addition of random cooperation (refs from ashlock paper) instead of random defection [1]. When $x+y=1$, the original strategy is not used, and the resulting behavior is a random strategy with probabilities (x, y). In more general terms, a JA strategy is an alteration of a strategy A that causes the strategy to be played with random noise inserted into the responses.

Definition 2 *A **Fingerprint** $F_A(S, x, y)$ with $0 \leq x, y \leq 1$, $x + y \leq 1$ for strategy S and probe A, is the function that returns the expected score of strategy S against $JA(A, x, y)$ for each possible (x, y).*

Definition 3 *The **Double Fingerprint** $F_{AB}(S, x, y)$ with $0 \leq x, y \leq 1$ returns the expected score of strategy S against $JA(A, x, y)$ if $x + y \leq 1$, and $JA(B, 1 - y, 1 - x)$ if $x + y \geq 1$.*

Definition 4 *Strategy A' is said to be the **Dual** of strategy A if A and A' can be written as finite-state machines that are identical except that their responses are reversed.*

An alternative wording is that, given a history for an opponent, the responses of the original strategy and the dual would be opposite. It's important to note that this is different to taking a strategy and flipping it's responses. The dual relies on knowledge of the underlying state of the original strategy, whereas the flip does not This is shown in Table 2.2.

Pavlov	Dual	Flip	Opponent
C	D	D	C
C	D	C	D
D	C	C	D
C	D	C	C
C	D	D	C
C	D	C	D
D	C	C	C
D	C	D	D
C	D	D	

Table 2.2: The different responses of Pavlov, Pavlov's Dual and Flipped Pavlov

The subtle difference between Dual and Flip can be highlighted further by inspecting each row individualy.

<u>Row 1</u> - Pavlov always plays C on the first go. Flip will change this to D. Dual knows that Pavlov always plays C and so swaps to D.

<u>Row 2</u> - In the previous round for Pavlov the strategies played (C, C), and so Pavlov plays C again. For Flip, the preceding interaction was (D, C), in this instance Pavlov would play D again, so this gets flipped to C. The previous turn for Dual was (D, C) so it infers that Pavlov had (C, C). It knows that Pavlov would play C and so plays D.

<u>Row 3</u> - In the previous round for Pavlov the strategies played (C, D), and so Pavlov would change to play D. For Flip, the preceding interaction was (C, D), in this instance Pavlov would change to D, so this gets flipped to play C again. The previous turn for Dual was (D, D) so it infers that Pavlov had (C, D). It knows that Pavlov would play D in this instance and so plays C.

Theorem 1 *If A and A' are dual strategies, then $F_{AA'}(S,x,y)$ is identical to the function $F_A(S,x,y)$ extended over the unit square.*

2.3 Example Fingerprint Construction

There are several steps to constructing the Fingerprint of a strategy a basic familiarity of Markov Chains is required. An outline of the steps is as follows:

1. Build the markov chain for IPD between the strategy and probe strategy.
2. Construct the corresponding transition matrix.
3. Find the steady state distribution.
4. Calculate the overall expected score by taking the dot product of the steady state distribution with the payoff vector given in .
5. Plot the resulting function.

We will now apply this process in order to obtain a fingerprint for the strategy Win-Stay-Lose-Shift (sometimes referred to as Pavlov) when probed by Tit-For-Tat.

Step 1 - Build the markov chain.

Step 2 - Construct the transition matrix.

$$T = \begin{array}{c} \\ (C,C) \\ (C,D) \\ (D,C) \\ (D,D) \end{array} \begin{array}{c} \begin{array}{cccc} (C,C) & (C,D) & (D,C) & (D,D) \end{array} \\ \begin{pmatrix} 1-y & 0 & 0 & x \\ y & 0 & 0 & 1-x \\ 0 & 1-y & x & 0 \\ 0 & y & 1-x & 0 \end{pmatrix} \end{array} \tag{2.1}$$

Step 3 - Find the steady state distribution.

$$\pi = \begin{bmatrix} \dfrac{x(1-x)}{2y(1-x)+x(1-x)+y(1-y)}, \\ \dfrac{y(1-x)}{2y(1-x)+x(1-x)+y(1-y)}, \\ \dfrac{y(1-y)}{2y(1-x)+x(1-x)+y(1-y)}, \\ \dfrac{y(1-x)}{2y(1-x)+x(1-x)+y(1-y)} \end{bmatrix} \tag{2.2}$$

Step 4 - Calculate the expected score.

$$F = \pi \cdot \begin{bmatrix} 3 \\ 0 \\ 5 \\ 1 \end{bmatrix} = \frac{3x(1-x) + y(1-x) + 5y(1-y)}{2y(1-x) + x(1-x) + y(1-y)} \tag{2.3}$$

Step 5 - Plot the resulting function.

2.4 Finite State Machines

Figure 2.1 and figure 2.2 show the Finite State Machine (FSM) representations for Tit-For-Tat and Pavlov respectively. Nodes represent the previous action taken by the strategy and the opponent, ie node (D, C) implies that is the preceding turn, the strategy chose to Defect and the opponent chose to co-operate. Arcs represent the choice made by the opponent at the current turn, and lead us to the state of the next turn.

It should be noted that these figures are not necessarily the simplest representation of their corresponding strategy. For example, Tit-For-Tat requires no knowledge of its own previous moves, but they have been included for completeness.

In figure 2.3 we have a more complex FSM for the strategy Majority which plays in the following way:

- If the opponent has cooperated the majority of the time, Majority will cooperate
- If the opponent has defected the majority of the time, Majority will defect
- Note - the strategy shown is technically Soft Majority, if the opponents cooperations and defections are equal it will cooperate. Hard Majority would defect in this situation.

This implies that the strategy Majority requires knowledge of all previous states, and therefore could not be represented as an FSM. However in Theorem 2 it is shown that if the number of turns in a game is known, any strategy can be represented as an FSM. A formal defintion of a Finite State Machine is given by Definition 5 but first we will outline some motivating key characteristics of a system that can be modeled with a FSM:

- The system must be describable by a finite set of states.
- The system must have a finite set of inputs that can trigger transitions between states.
- The behavior of the system at a given point in time depends upon the current state and the input that occurs at that time.
- For each state the system may be in, behavior is defined for each possible input.
- The system has a particular initial state.

Definition 5 *A* ***Deterministic Finite State Machine*** *M is a tuple $(S, \sigma, \delta, s_0, F)$ where*

- *σ is the set of symbols representing the input of M.*

- S *is the set of states of* M.
- $s_0 \in S$ *is the starting state.*
- $F \subseteq S$ *is the set of final states of* M.
- $\delta : S \times \sigma \to S$ *is the transition function.*

Theorem 2 *Given a determenistic strategy* α *and 2 histories* h_1, h_2, *then for all games of length* $n \in 1, 2, 3, ...$ *there exists a FSM such that* $\alpha(h_1, h_2)$ *can be obtained from the FSM.*

Proof 1 *Let* $\sigma = \{C, D\}$ *and*

$$S = \bigcup_{i=0}^{n+1} \{C, D\}^i \times \{C, D\}^i \delta((h_1, h_2), a) = ()$$

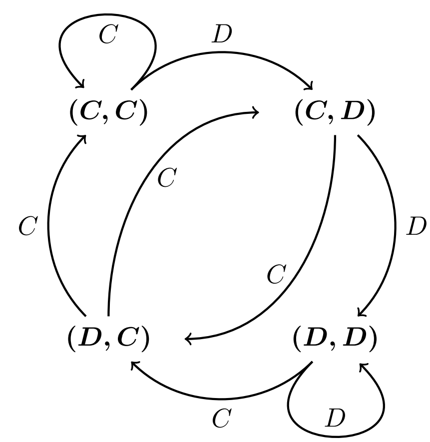

Figure 2.1: FSM for TitForTat

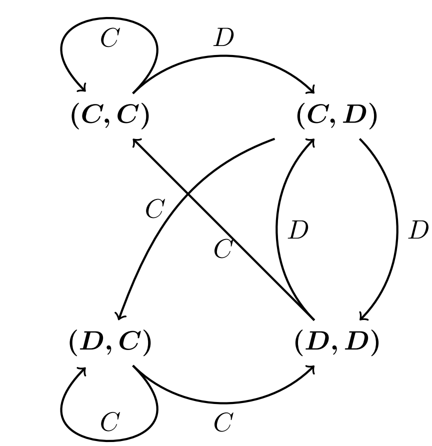

Figure 2.2: FSM for Pavlov (Win-Stay Lose-Shift)

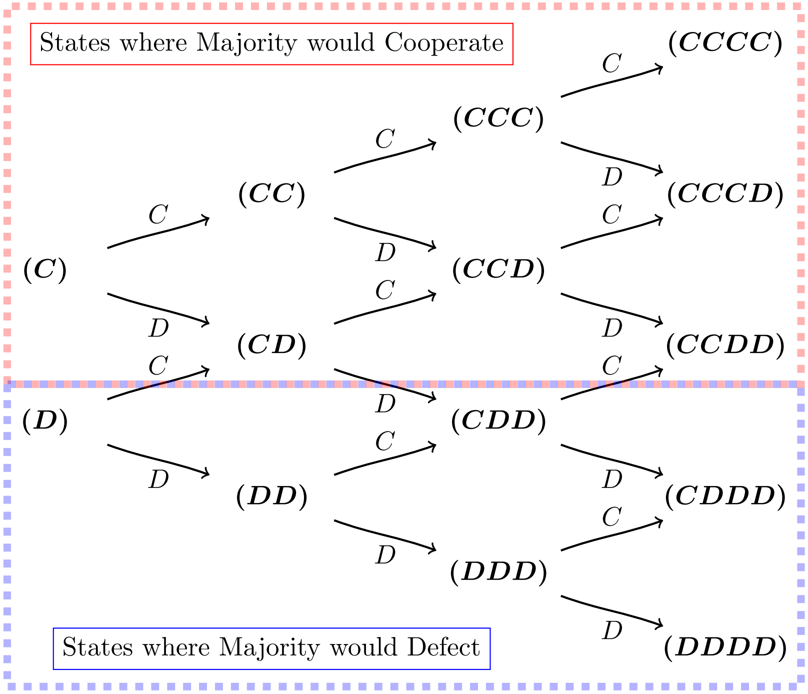

Figure 2.3: FSM for Majority in a game with 4 Turns

	0.0	0.2	0.4	0.6	0.8
0.0	(C, C): (1.00, nan)	(C, C): (0.00, 0.00)	(C, C): (0.00, 0.00)	(C, C): (0.00, 0.00)	(C, C): (0.00, 0.00)
	(C, D): (0.00, nan)	(C, D): (0.36, 0.36)	(C, D): (0.38, 0.38)	(C, D): (0.41, 0.42)	(C, D): (0.45, 0.45)
	(D, C): (0.00, nan)	(D, C): (0.29, 0.29)	(D, C): (0.23, 0.23)	(D, C): (0.18, 0.17)	(D, C): (0.09, 0.09)
	(D, D): (0.00, nan)	(D, D): (0.36, 0.36)	(D, D): (0.39, 0.38)	(D, D): (0.41, 0.42)	(D, D): (0.46, 0.45)
0.2	(C, C): (1.00, 1.00)	(C, C): (0.27, 0.25)	(C, C): (0.14, 0.15)	(C, C): (0.12, 0.12)	(C, C): (0.09, 0.10)
	(C, D): (0.00, 0.00)	(C, D): (0.24, 0.25)	(C, D): (0.31, 0.31)	(C, D): (0.35, 0.35)	(C, D): (0.40, 0.40)
	(D, C): (0.00, 0.00)	(D, C): (0.25, 0.25)	(D, C): (0.24, 0.23)	(D, C): (0.18, 0.18)	(D, C): (0.12, 0.10)
	(D, D): (0.00, 0.00)	(D, D): (0.24, 0.25)	(D, D): (0.31, 0.31)	(D, D): (0.35, 0.35)	(D, D): (0.40, 0.40)
0.4	(C, C): (1.00, 1.00)	(C, C): (0.38, 0.38)	(C, C): (0.22, 0.25)	(C, C): (0.20, 0.20)	(C, C): (0.17, 0.18)
	(C, D): (0.00, 0.00)	(C, D): (0.19, 0.19)	(C, D): (0.26, 0.25)	(C, D): (0.30, 0.30)	(C, D): (0.32, 0.35)
	(D, C): (0.00, 0.00)	(D, C): (0.25, 0.25)	(D, C): (0.27, 0.25)	(D, C): (0.21, 0.20)	(D, C): (0.18, 0.12)
	(D, D): (0.00, 0.00)	(D, D): (0.19, 0.19)	(D, D): (0.26, 0.25)	(D, D): (0.30, 0.30)	(D, D): (0.32, 0.35)
0.6	(C, C): (1.00, 1.00)	(C, C): (0.41, 0.43)	(C, C): (0.29, 0.30)	(C, C): (0.26, 0.25)	(C, C): (0.23, 0.23)
	(C, D): (0.00, 0.00)	(C, D): (0.14, 0.14)	(C, D): (0.20, 0.20)	(C, D): (0.24, 0.25)	(C, D): (0.27, 0.31)
	(D, C): (0.00, 0.00)	(D, C): (0.30, 0.29)	(D, C): (0.31, 0.30)	(D, C): (0.26, 0.25)	(D, C): (0.22, 0.15)
	(D, D): (0.00, 0.00)	(D, D): (0.14, 0.14)	(D, D): (0.20, 0.20)	(D, D): (0.24, 0.25)	(D, D): (0.28, 0.31)
0.8	(C, C): (1.00, 1.00)	(C, C): (0.41, 0.40)	(C, C): (0.35, 0.29)	(C, C): (0.27, 0.25)	(C, C): (0.26, 0.25)
	(C, D): (0.00, 0.00)	(C, D): (0.10, 0.10)	(C, D): (0.16, 0.14)	(C, D): (0.20, 0.19)	(C, D): (0.24, 0.25)
	(D, C): (0.00, 0.00)	(D, C): (0.38, 0.40)	(D, C): (0.33, 0.43)	(D, C): (0.32, 0.38)	(D, C): (0.26, 0.25)
	(D, D): (0.00, 0.00)	(D, D): (0.10, 0.10)	(D, D): (0.16, 0.14)	(D, D): (0.20, 0.19)	(D, D): (0.24, 0.25)

Chapter 3

Conclusion

3.1 Introduction

This chapter will just show you a picture drawn in tikz shown in Figure 3.1.

3.2 Conclusion

The end.

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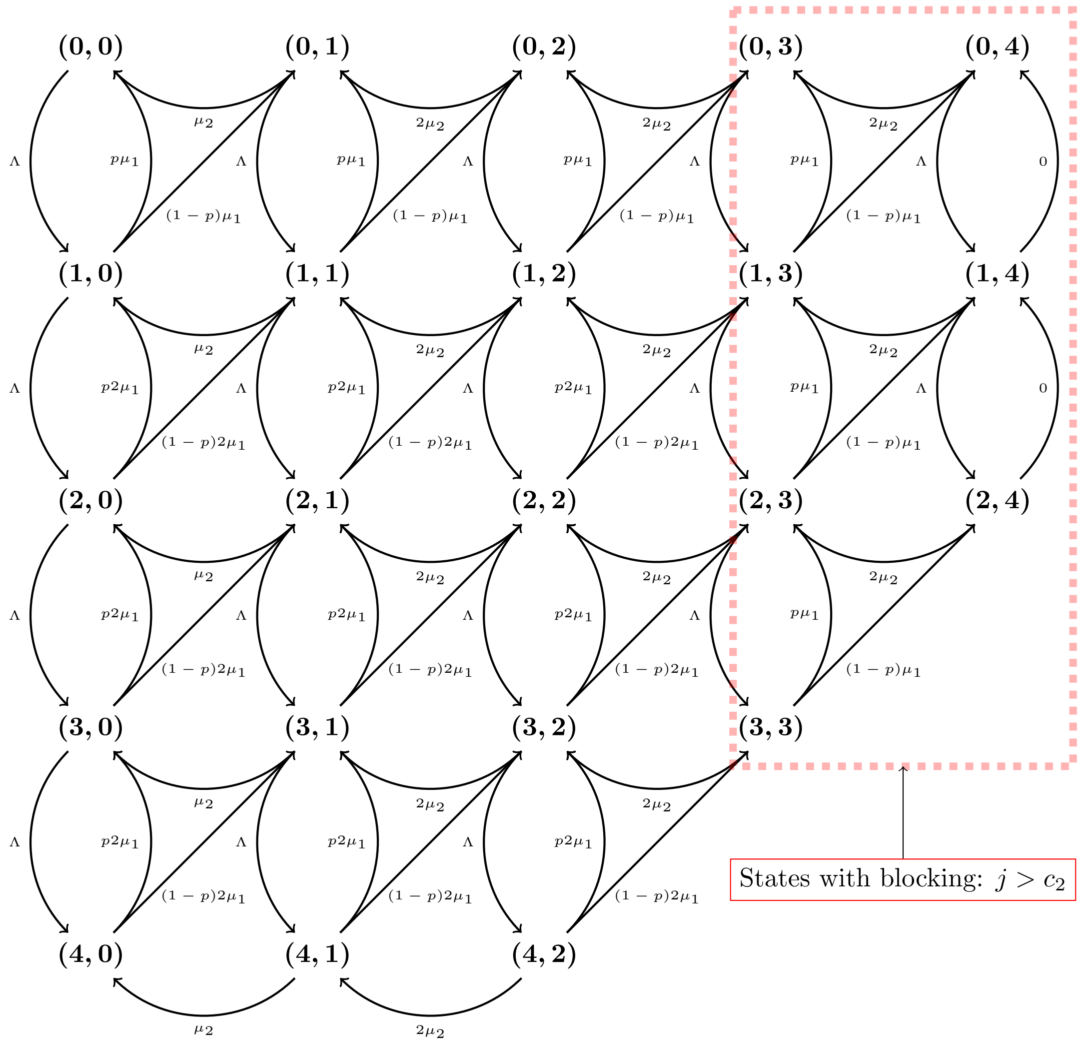

Figure 3.1: A Markov chain

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