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1 Introduction

1.1 General Introduction

This paper aims to replicate, to an essential degree, the seminal paper on the emergence of cooperation, cf. Santos and Pacheco (2005). The secondary goal of this research is to provide the publicly available code allowing replication of the original results.

Tutaj jest drugi akapit.

—

either prove or disprove the research paper with title **"Scale-Free Networks Provide a Unifying Framework for the Emergence of Cooperation"** written by F.C. Santos and J. M. Pacheco and published in Physical Review Letters nr 95 (later on reffered to as "The Paper"). Regardless of the outcome this work is going to be useful because the above mentioned authors did not provide the code that was used to conduct the necessary simulations. Therefore goal is not only to disprove the above mantioned paper but also to provide readers with clear and easy to follow code.

1.2 Description of The Paper

The Paper was published in "Physical Review Letters" on 26th August 2005 and according to Google Scholar has been since cited over 1600 times. It clearly shows the magnitude of said paper and its groundbreaking character. This paper is presenting the results of simulations conducted by the authors and its implications for evolutionary game theory. The crucial thing to understand is that the authors of The Paper changed the approach to modelling such games by applying Scale Free Networcs of Contacts (later on refferd to as "SF NOC's"). Its innovativeness lies in the never used before degree distribution of said graph. Before used graphs had a degree distribution with a single peak. It means that every "player" could interact only with a fixed number of other "players". SF NOC's is said to perform better at modelling the actual, existing societies and networks. It complies with the rules of growth and preferential attachment (rich gets richer). If we analyse some actual networks - for example Twitter network, we observe that those with bigger count of "followers" are more likely to gain new ones than accounts with low count of "followers".

One of the goals of The Paper was to compare results of simulations on different kinds of graphs. According to The Paper, players that occupy vertices of SF NOC are much more likely to cooperate than of any other graph. Those results came up both in Snowdrift game (later on reffered to as SG) and Prisoners Dilemma game (later on reffered to as PD).

1.3 A brief description of Snowdrift game and Prisoners Dilemma game

Prisoners Dilemma Game . The Prisoners Dillema game is a widely known problem in game theory and decision analysis. It shows that there exist situations in which the outcome is not optimal, even though players act in their own best interest. In the scope of our analysis, it is important to note that in the PD game, the best strategy is to defect, regardless of the opponent's choice. The game is parametrized as follows:

	C	D
C	R, R	S, T
D	T, S	P, P

where the values are given as follows:

$$T = b > 1,$$
$$R = 1,$$
$$P = 0,$$
$$S = 0,$$
$$1 < b \leq 2.$$

We see that the above restrictions order the parameters as follows:

$$T > R > P = S$$

Snowdrift Game. The Snowdrift game represents a metaphore for cooperative interactions between players. Contrary to PD, the Snowdrift game stimulates the cooperative behaviour amongst players. It doesn't make the deflection strategy totally inapplicable, but payoffs of this game favourizes cooperative behaviours more than the PD. The optimal strategy is to cooperate when the other defects and to defect when the other cooperates.

	C	D
C	R, R	T, S
D	S, T	P, P

Where the parametrisation is as follows:

$$T = \beta > 1$$
$$R = \beta - \tfrac{1}{2}$$
$$S = 1 - \beta$$
$$P = 0$$

$$T > R > P > S$$

1.4 Simulations description

Because of the nature of this paper (an attempt to clone the results of The Paper) our simulations must be conducted in a strickt accordance with the methods outlined in The Paper. Therefore it is only natural that we must follow each step with the utmost care and diligence. According to The Paper we must conduct 100 simulations for each parametrisation. Each simulation is performed following those steps:

1. Setting up the parameters which are needed to create SF NOC's (such as number of final vertices (population size), the avarage connectivity etc.).

2. Choosing the parameters of game which is to be simulated (either PD or SG).

3. Creating the randomly generated SF NOC (we use Barabasi - Albert model to do that). The SF NOC must be created in compliance with preferential attachment and growth rules.

4. Randomly distributing strategies amongst the population (SF NOC in this particular case). Each vertex can either get a cooperation or deflection strategy.

5. Each pair of cooperator - deflector engages in a round of given game. In compliance with replicatory dynamics we keep track of cumulative payoffs for both strategies so that "players" can adjust their strategies throughout the population. This step is repeated 11 000 times, each time is called "generation". The first 10 000 is so called "transient time".

6. We collect results (equilibrium frequencies of cooperators and defectors) by avarag-ing over the last 1 000 generations.

1.5 Replicatory dynamics

In our analysis we consider replicator to be a strategy in a game. The general idea is that replicators compete for dominance throughout the population. Payoffs of their strategies represent their "fitness". It is important to note that each player can alter their strategy through inheritance. Attempt of inheritance occurs whenever on of the sites is updated. For the sake of an example lets say that the site that was just updated is a site x. The procedure is as follows:

1. The site x is updated.

2. A neighbour y is drawn at random among all k_x neighbours

3. if cumulative payoffs of y (P_y) is greater than cumulative payoffs of x (P_x), the chosen neighbour takes over site x with probability (P_i) given below.

$$P_i = \frac{(P_y - P_x)}{Dk_>}$$

Where P_i is the probability of the chosen neighour taking over the site x, P_y is a cumulated payoffs of strategies y, P_x is a cumulated payoffs of strategies x, $k_>$ is the largest between k_y and k_x (k_y is a number of neighbours with a strategy y, k_x is a number of neighbours with a strategy x), D depends on the game (it is equal to either T-S for PD or T-P for SG).

2 Basic things

2.1 Compiling LaTeXfiles

The `.tex` file is just a plain text file. It contains the LaTeXformatting codes together with the content of a paper. To get a `.pdf` file you have to compile the `.tex` file using a sequence `pdflatex`, `biblatex`, `pdflatex`, `pdflatex`. This sequence is a default in most editors designed for use with LaTeX.

2.2 Basic formatting for a text

Paragraphs are coded by an empty line. That is is you want to start a new paragraph it is enough to leave an empty line and start typing like that:

```
This is the first paragraph.

This is the next paragraph.
```

Everything about the paragraph is formatted for you including all indents and spacings. Again, you don't have to take care of it manually.

Basic text formatting, e.g. bold face and italic, is achieved with the following commands: `\textbf{}`, `\textit{}`, `\underline{}`, producing **text**, *text*, text. I suggest not overusing those commands!

Alignment is done through environments `center`, `flushleft` and `\flushright` giving the following examples.

This is centered.

This is aligned to the left.

This is aligned to the right.

In other environments it is possible to use `\centering` to center content of that environment (like in `figure` or `table` environments).

2.3 Fonts and fonts' sizes

You do not change fonts and fonts' sizes! Technically it can be done but I will reject this.

3 Mathematics

This is testing footnotes[1].

3.1 Basic mathematics

There are two types of mathematics inside a LaTeX document. The first one is the in-line mathematics and the displayed mathematics. The first one looks like this: $F(x) = \int_{-\infty}^{x} f(\omega)d\omega$ with the code looking like this: `\( F(x) = \int_{-\infty}^{x} f(\omega) d\omega \)`. The displayed mathematics looks like that

$$F(x) = \int_{-\infty}^{x} f(\omega)d\omega$$

with the code

```
\[
F(x) = \int_{-\infty}^{x} f(\omega) d\omega
\]
```

As you can see the same code is formatted differently depending on the type of mathematics.

3.2 Referencing mathematics and other things

To reference mathematics (only displayed formulas) you use the `equation` environment with a `\label{}` within. The reference is done through the `\ref{}` command. The example is

$$F(x) = \int_{-\infty}^{x} f(\omega)d\omega. \tag{1}$$

To reference the equation you use the `\ref{}` command giving (1). The `\label{}` / `\ref{}` pair works for anything that can be referenced.

[1]This is a footnote. We can put some math here $x^2 - f(x) = g(x^2)$ which is not encouraged but sometimes necessary. The other thing we can do is to put here an URL `https://tex.stackexchange.com/questions/249415/set-font-size-for-footnotes`.

3.3 Some more mathematical formulas

Here are slightly more complex formulas. Let A be a matrix

$$A = \left(\begin{bmatrix} 1 & \alpha^2 \\ 2 & \sqrt{\pi} - \log(x - \sin(y)) \end{bmatrix}^2 - \begin{bmatrix} 1 & f(x) \\ 2 & g(y) \end{bmatrix} \cdot \begin{bmatrix} x \\ y \end{bmatrix} \right),$$

where

$$f(x) = \begin{cases} \dfrac{1}{x} & \text{for } x < -\dfrac{1}{2}, \\ \dfrac{1}{1+x^2} & \text{for } x \geq -\dfrac{1}{2} \end{cases}$$

and

$$g(y) = \sin\left(\frac{\mathbf{E}(X)}{\cos(y) + \log(y)} \right), \quad \text{where } X \sim \mathrm{N}(0, \sigma).$$

It is very easy to typeset a normal form game. Below is an example of such a game.

	L	M	H
L	$16, 9$	$3, 13$	$0, 3$
M	$21, 1$	$10, 4$	$-1, 0$
H	$9, 0$	$5, -4$	$-5, -15$

4 Figures and tables

Both figures and tables use the same ideas. To insert a table you use the `table` environment. This is an example of a simple table.

Table 1: This is an example of a table.

Name	property 1	property 2	property 3
Michael	23	34	–
John	34	–	28
Mr. Niceguy	123	231	312

Table 1 is a very simple table and much more is possible.

To insert a figure you need to have a figure. In the catalog there are two figures and the following is an example of the `figure` environment.

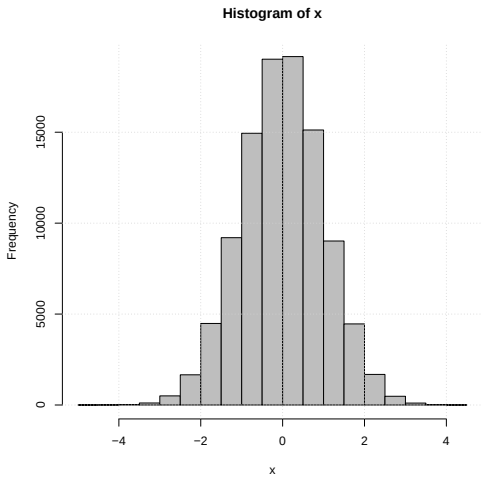
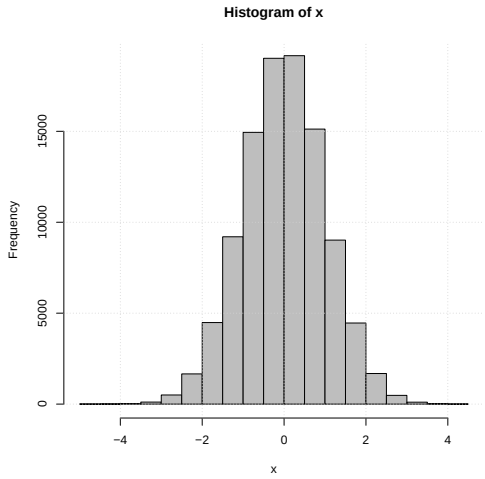
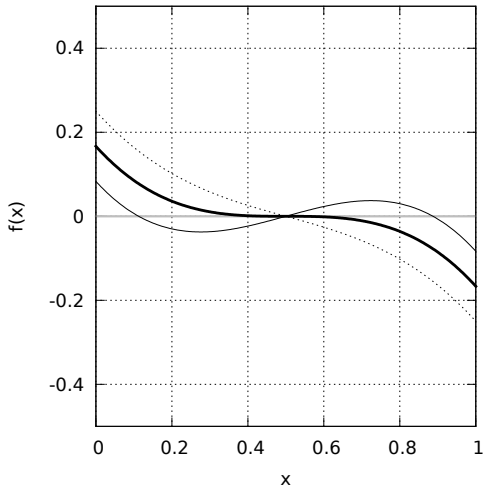


Figure 1: This is just an example. *Source:* own calculations.

Figure 2 is a slightly more complex than just a simple figure but it is useful to have such template. It is possible to refrence subfigures as 2a and 2b.



(a) This is a caption for the first figure. This caption is wrapped at the right width and the hight is being compensated.



(b) This is another caption.

Figure 2: This is the main caption and it is below the figures. *Source:* own calculations

5 Bibliography

The content for the bibliography is in a different file named `refs.bib`. You can change the name but then you have to change the information in this file from `\bibliography{refs}` to `\bibliography{new-name}` where `new-name` is the name of your file. The file `refs.bib` contains some examples for books and papers.

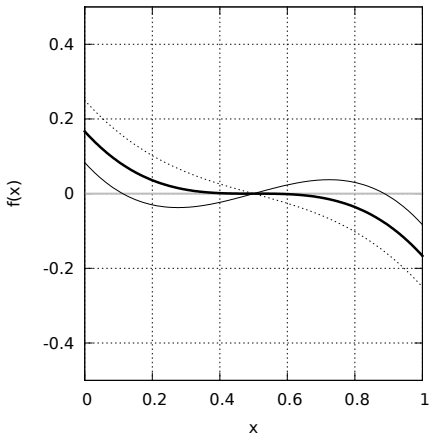


Figure 3: This is how one can wrap a text around a figure. *Source:* own calculations

The process of citation is simple. The command `\cite{garland2010}` gives this Tucker (2010) and puts all information into the bibliography section at the end. Everything is sorted and formatted for you so that you don't have to worry about this. An example of a paper with many authors is Benaim and Weibull (2003) or Osborne and Rubinstein (1998).

Table 2: Binary variables used in the VAR model

t	year	elections	crises	tax cuts
1	1961	0	0	0
2	1962	0	0	0
3	1963	0	0	0
4	1964	1	0	0
5	1965	0	0	1
6	1966	0	0	0
7	1967	0	0	0
8	1968	1	0	0
9	1969	0	0	0
10	1970	0	0	0
11	1971	0	0	0

Continued on next page

Table 2 – *Continued from previous page*

t	year	elections	crises	tax cuts
12	1972	1	0	0
13	1973	0	0	0
14	1974	0	1	0
15	1975	0	1	0
16	1976	1	0	0
17	1977	0	0	0
18	1978	0	0	0
19	1979	0	0	0
20	1980	1	0	0
21	1981	0	0	0
22	1982	0	1	1
23	1983	0	0	0
24	1984	1	0	0
25	1985	0	0	0
26	1986	0	0	1
27	1987	0	0	0
28	1988	1	0	0
29	1989	0	0	0
30	1990	0	0	0
31	1991	0	1	0
32	1992	1	0	0
33	1993	0	0	0
34	1994	0	0	0
35	1995	0	0	0
36	1996	1	0	0
37	1997	0	0	0
38	1998	0	0	0
39	1999	0	0	0

Continued on next page

Table 2 – *Continued from previous page*

t	year	elections	crises	tax cuts
40	2000	1	0	0
41	2001	0	1	1
42	2002	0	0	1
43	2003	0	0	1
44	2004	1	0	0
45	2005	0	0	0
46	2006	0	0	0
47	2007	0	0	0
48	2008	1	1	0
49	2009	0	1	1
50	2010	0	0	1
51	2011	0	0	0
52	2012	1	0	0
53	2013	0	0	0
54	2014	0	0	0
55	2015	0	0	0

A Appendix: Some important stuff

This appendix contains all the necessary important stuff, blah, blah, blah ...

Table 3: Tutaj jest tytuł tablicy

Nazwa atrybutu	Wartości	Opis
chk_acct	-	stan środków na rachunku bieżącym (jakościowa)
	A11	... <0 Marek Niemieckich
	A12	0 <... <200 Marek Niemieckich
	A13	... >200 Marek Niemieckich
	A14	brak rachunku bieżącego
duration	-	czas trwania kredytu w miesiącach (numeryczna)
history	-	przeszłość kredytowa (jakościowa)
	A30	brak kredytów w historii/wszystkie kredyty poprawnie spłacone
	A31	wszystkie kredyty poprawnie spłacone (zaciągnięte w tym banku)
	A32	kredyty poprawnie spłacane po dzień dzisiejszy
	A33	opóźnienia w poprzednich spłatach kredytu
	A34	konto krytyczne/zaciągnięte kredyty w innych bankach
purpose	-	cel (jakościowa)
	A40	nowy samochód
	A41	używany samochód
	A42	meble
	A43	telewizor
	A44	urządzenia gospodarstwa domowego
	A45	remont
	A46	edukacja
	A47	wakacje
	A48	przekwalifikowanie
	A49	biznes
	A410	inne

kontynuowane na następnej stronie

Table 3 – *kontynuacja z poprzedniej strony*

Nazwa atrybutu	Wartości	Opis
amount	-	kwota kredytu (numeryczna)
say_acct	-	saldo na rachunku oszczędnościowym/wartość posiadanych obligacji (jakościowa)
	A61	... <100 Marek Niemieckich
	A62	100 <= ... <500 Marek Niemieckich
	A63	500 <= ... <1000 Marek Niemieckich
	A64	... >= 1000 Marek Niemieckich
	A65	nieznane/ brak oszczędności
employment	-	czas zatrudnienia w obecnej pracy (jakościowa)
	A71	brak zatrudnienia
	A72	... <1 rok
	A73	1 <= ... <4 lata
	A74	4 <= ... <7 lat
	A75	... >= 7 lat
install_rate	-	wielkość raty jako procent rozporządzalnego przychodu (liczbowa)
pstatus	-	płeć i stan cywilny (jakościowa)
	A91	mężczyzna; rozwodnik/w separacji
	A92	kobieta; rozwiedziona/ w separacji/ mężatka
	A93	mężczyzna ; wolny
	A94	mężczyzna ; żonaty/ wdowiec
	A95	kobieta ; wolna
other_debtor	-	inni dłużnicy/ poręczyciele (jakościowa)
	A101	brak
	A102	współkredytobiorca
	A103	poręczyciel
property	-	własność/ mienie (jakościowa)

kontynuowane na następnej stronie

Table 3 – *kontynuacja z poprzedniej strony*

Nazwa atrybutu	Wartości	Opis
	A121	nieruchomość
	A122	(jeśli nie A121) umowa oszczędnościowa/ ubezpieczenie na życie
	A123	(jeśli nie A121/A122) samochód lub inne
	A124	nieznane
timer_resid	-	czas zamieszkania w aktualnym miejscu zamieszkania (liczbowa)
age	-	wiek w latach (liczbowa)
other_install	-	inne zobowiązania ratalne (jakościowa)
	A141	bank
	A142	sklepy
	A143	brak
housing	-	warunki mieszkaniowe (jakościowa)
	A151	wynajem
	A152	własność
	A153	zamieszkanie bez ponoszenia kosztów
other_credits	-	liczba aktualnych kredytów w tym banku (liczbowa)
job	-	praca (jakościowa)
	A171	bezrobotny/niewykwalifikowany; cudzoziemiec
	A172	niewykwalifikowany; rezydent
	A173	wykwalifikowany pracownik/urzędnik
	A174	menadżer/ samozatrudniony/ wysocewykwalifikowany/ wyższy urzędnik
num_depend	-	liczba osób na utrzymaniu (liczbowa)
telephone	-	telefon (jakościowa)
	A191	brak
	A192	tak, zarejestrowany pod nazwiskiem klienta
foreign	-	pracownik zagraniczny (jakościowa)

kontynuowane na następnej stronie

Table 3 – *kontynuacja z poprzedniej strony*

Nazwa atrybutu	Wartości	Opis
	A201	tak
	A202	nie
response	-	decyzja kredytowa
	1	tak
	2	nie

References

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Streszczenie

Tutaj zamieszczają Państwo streszczenie pracy. Streszczenie powinno być długości około pół strony.