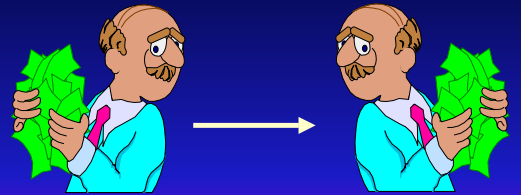


Evolution of cooperation and fairness

Martin Nowak
Institute for Advanced Study, Princeton

What is cooperation ?



Donor
pays a cost, c

$$c < b$$

Recipient
gets a benefit, b

Natural selection is based on competition.
How can natural selection lead to cooperation?



Social insects

- Workers do not reproduce, but raise the offspring of another individual, the queen.
- How can evolution design such altruistic behavior ?



Cooperation between relatives

Hamilton's rule

$$r > c / b$$



r ... coefficient of relatedness
 c ... cost of cooperation
 b ... benefit of cooperation

Cooperation between relatives

- 'I jump into the river to save 2 brothers or 8 cousins'

J.B.S Haldane



Evolutionary transitions require cooperation.

- Genes cooperate in a genome.
- Cells cooperate in an organism.
- Individuals cooperate in societies.

The architecture of complexity is based on cooperation.

How to get cooperation between non-relatives ?

Game Theory

John von Neumann
Oskar Morgenstern



Evolutionary game theory

- Successful strategies spread by natural selection.



John Maynard Smith

Prisoner's Dilemma

cooperate: **C**

defect: **D**

C - C 3 : 3

D - C 5 : 0

C - D 0 : 5

D - D 1 : 1

Rational players choose defection

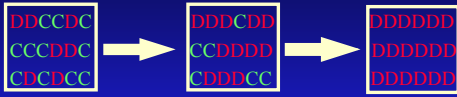
D - D 1 : 1

but cooperation would have been better for both:

C - C 3 : 3

Cooperation is 'irrational'.

Natural selection chooses defection



D wins against C

3 possibilities for the evolution of cooperation

- Direct reciprocity
- Indirect reciprocity
- Spatial reciprocity

Direct reciprocity

I help you,
but I expect we will meet again.
Then you can help me.

Repeated Prisoner's Dilemma

Player 1 : C D C D C C C
Player 2 : D C D D C C C

Repeated Prisoner's Dilemma

Player 1 : C D C D C C C
Player 2 : D C D D C C C

What is a good strategy for the repeated Prisoner's Dilemma?

Robert Axelrod

Tit-for-tat

- If you cooperate, then I will cooperate.
- If you defect, then I will defect.

Anatol Rapaport

Tit-for-tat is too unforgiving

Errors destroy cooperation

Tit-for-tat : CCCCDCDCDCDDDDDD....

Tit-for-tat : CCCDCDCDCDDDDDD....

Let natural selection design a strategy

Random

Let natural selection design a strategy

Always defect



Random

Let natural selection design a strategy

Tit-for-tat



Always defect



Random

Let natural selection design a strategy

Tit-for-tat → Generous Tit-for-tat



Always defect

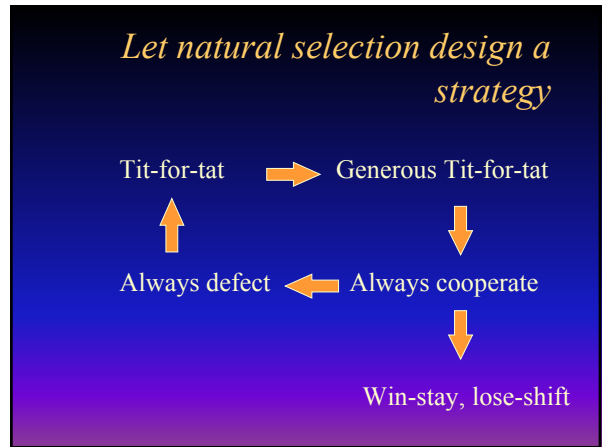
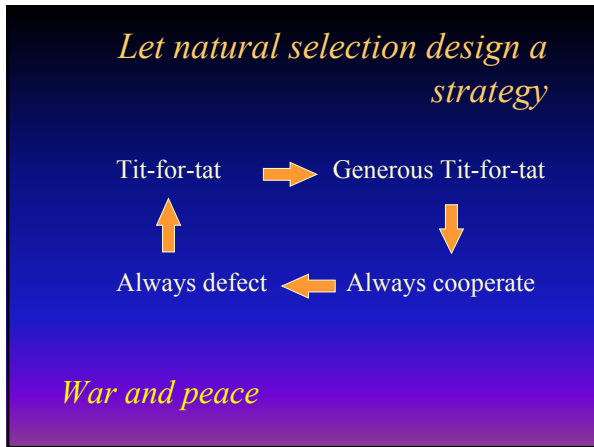
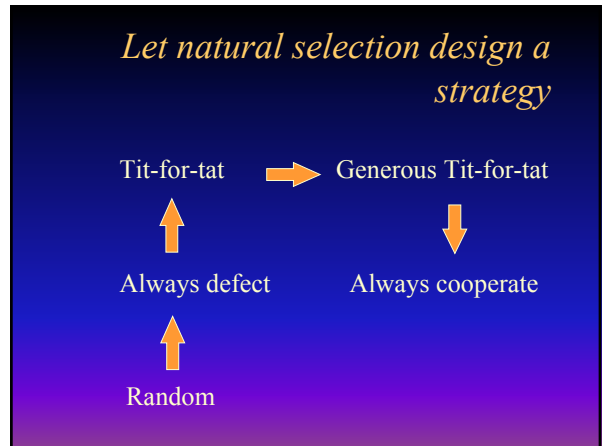
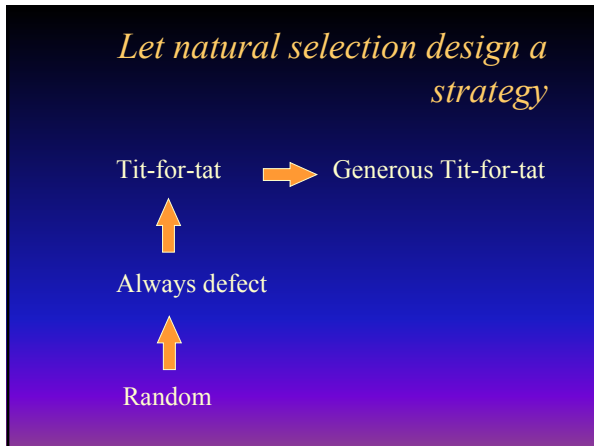


Random

Generous Tit-for-tat

- If you cooperate, then I will cooperate.
- If you defect, then I will cooperate with probability 1/3.

*Never forget a good move.
Sometimes forgive a bad move.*



Win-stay, lose-shift

Win - stay :

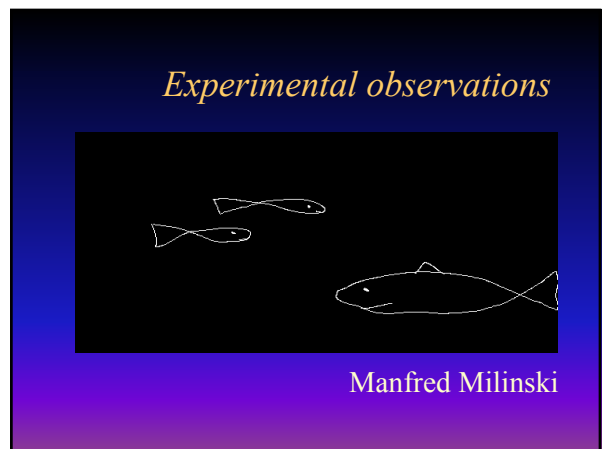
C (3) C D (5) D

C C

Lose - shift :

C (0) D D (1) C

D D



Direct reciprocity

'I help you, you help me.'

Indirect reciprocity

'I help you, somebody else helps me.'

Indirect reciprocity

	donor	recipient	donor's reputation
cooperate	-c	+b	+1
defect	0	0	-1

Natural selection chooses

strategies that base their decision to cooperate on the **reputation** of the recipient: 'help those who have helped others'

Give and you shall receive.

How it works:

You help someone and increase thereby your reputation in society and the chance that you will receive help.

A rule for indirect reciprocity

$$q > c / b$$

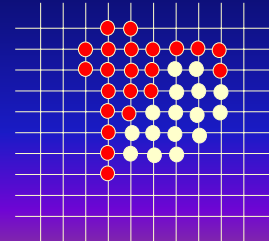
- q ... probability to know someone's reputation
- c ... cost of cooperation
- b ... benefit of cooperation

A universal constant of nature

- 0.7380294688... is the maximum fraction of people who can be bad in the beginning such that everyone will be good in the end

Another possibility for the evolution of cooperation

Spatial game dynamics



Cooperators
Defectors

Fairness

Ultimatum Game



\$1,000,000



Proposer
makes an offer.

Ultimatum Game



\$1,000,000



Proposer
makes an offer.

Responder
says yes or no.

Ultimatum Game



\$100



Proposer
makes an offer.

Responder
says yes or no.

What does game theory suggest?

- A 'rational' responder should prefer \$1 to \$0.
- Therefore, a 'rational' proposer should offer \$1 and keep almost the whole sum.

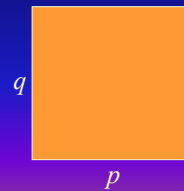
What do the experiments show?

- People are not 'rational'.
- Most proposers offer 30-50%.
- Most responders reject offers below 30%.

Evolutionary ultimatum

Evolutionary ultimatum

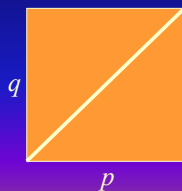
Strategies $S(p,q)$
 p ...offer when proposer
 q ...minimum acceptance level when responder



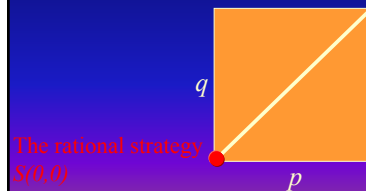
Evolutionary ultimatum

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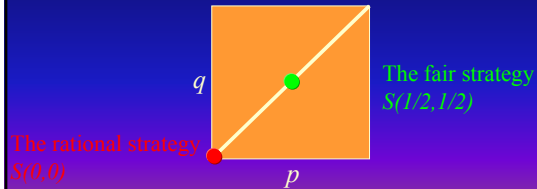


Evolutionary ultimatum

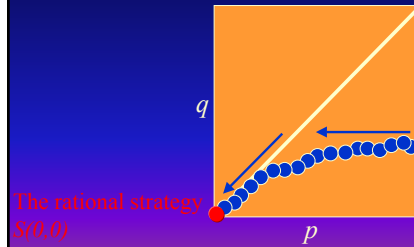
Strategies $S(p,q)$

p ... offer when proposer

q ... minimum acceptance level when responder



Evolutionary simulations



Natural selection chooses

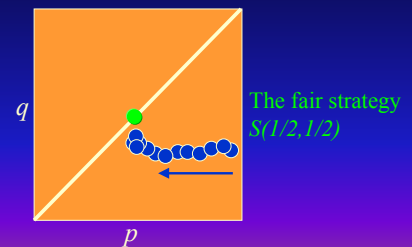
- ... low offers, low demands.
- It costs to reject offers, therefore low acceptance levels are favored.
- If acceptance levels decline, then offers will decline too.

How can we explain the evolution of fairness?

Reputation !

- Suppose there is a chance that it will become known what offer a person has accepted.
- Accepting low offers increases the probability of receiving reduced offers in the future.
- Rejecting low offers is costly, but buys the reputation of being someone who demands a fair share.

Evolutionary simulations



People

- Karl Sigmund (Vienna)
- Karen Page (London)
- Robert May (Oxford)