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# Evolutionary Language Games

## A brief analysis

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**Edinburgh - May, 28th 2004**

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# Evolutionary games theory

## John Maynard Smith

| Classical games theory | Evolutionary context |
|---|---|
| Rationality | Population dynamics |
| Self-interest | Darwinian fitness |

- Game theory in evolutionary biology
  - species playing a game against nature
  - species playing a game against each other

# Evolutionary games theory

## John Maynard Smith cont.

- A strategy is a behavioural phenotype, i.e. a specification of what an individual will do in any situation in which it may find itself
- An ESS is a strategy such that, if all members of a population adopt it, then no mutant strategies could invade the population under the influence of natural selection

# Language games

## Ludwig Wittgenstein

- The whole process of using words by which children learn their native language
- A language game is both
  - the language
  - the actions needed to deal with it
- He did not consider language games to have an evolutionary dimension

# Evolutionary language games

## Luc Steels

- A language is the consequence of the distributed behaviour of a large group of agents
- A language game is a complete interaction in which all linguistic levels are implied, as well as a context and social relations between speaker and hearer
- Experiments with robotic and software agents (**talking heads**)

# Evolutionary language games

## Luc Steels cont.

- Many different games can be defined

  **Discrimination games** to create meaning

  **Language games** to build up a lexicon

  **Imitation games** to evolve phonology

# Evolutionary language games

## Martin Nowak

- How protolanguages can evolve in a nonlinguistic society
- Language evolved as a mean of communicating information between individuals
- Outline the major principles that guided language evolution in terms of **mathematical models** of evolutionary dynamics and game theory

# Evolutionary language games

## Simon Kirby

- Language emerges at the intersection of three complex adaptive systems

  **Learning** children adapt their knowledge of language in response to the environment

  **Cultural evolution** languages changes during time

  **Biological evolution** the learning mechanisms adapt in response to selection pressure from the environment

- General approach to explore the transmission over time of observationally learned behaviour (**iterated learning model**)

# Evolutionary language games

## Simon Kirby cont.

- Language exists and persists via two form of representation

  **I-language** the language that exists internally as patterns of neural connectivity

  **E-language** the external form of language as sets of utterances

- For a language to persist from one generation (of language users) to the next, it must be mapped
  - I-language $\Rightarrow$ E-language $\rightsquigarrow$ *use*
  - E-language $\Rightarrow$ I-language $\rightsquigarrow$ *learning*

## Simulation & modelling

### The Swarm tool

- The Swarm project was started in 1994 at the Santa Fe Institute in New Mexico
- Swarm is a collection of software libraries which provide support for simulation programming
- The Swarm libraries provide a number of convenient pieces of code that will facilitate the design of an agent-based model
- Swarm is free software, and the current distribution is released under the GNU General Public License (GPL)

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- Nowak's work
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- Conclusion

# Nowak's model

## Definitions

- $n$ objects and $m$ sounds ($n = m$)
- Association matrix $A$ $(n \times m)$

  $a_{i,j}$ specifies how often an individual has observed one or several other individuals referring to object $i$ by producing sound $j$
- Active matrix $P$ $(n \times m)$

  $p_{i,j}$ specifies the probability that for the speaker object $i$ is associated with sound $j$
- Passive matrix $Q$ $(m \times n)$

  $q_{j,i}$ specifies the probability that for the hearer sound $j$ is associated with object $i$

## Nowak's model

### Definitions cont.

$$A_0 \xrightarrow{(*)} P_0 \xrightarrow{k} A_1 \longrightarrow P_1 \longrightarrow \cdots$$

$(*)$

$$p_{i,j} = \frac{a_{i,j}}{\sum_{k=1}^{m} a_{i,k}} \qquad q_{j,i} = \frac{a_{i,j}}{\sum_{k=1}^{n} a_{k,j}}$$

$k$ is the number of sampling from parent's matrix

- each individual form its association matrix by recording $k$ responses of its parent to each object

## Nowak's model

### Fitness function

$$F(A, A') = \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{m} (p_{i,j} q'_{j,i} + p'_{i,j} q_{j,i})$$

- At each round, every language (agent) plays with every other, and the accumulated payoffs, i.e. the fitness of the game for each language, are summed up
- Individuals with higher fitness leave more offspring, who learn the language of their parent by sampling its matrix

# Nowak's model

## Pros & Cons

- Simple
  - Population size constant (and small)
  - Each individual has only one parent
  - Small vocabulary
- Not realistic
  - Too many simplifications
  - Too few and too small values for $k$
  - No *external* influence

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# My research

## Present

- What I've already done
  - reproduced Nowak basic results
  - introduced world in Nowak's model
- What I'm working on
  - use distance between individuals to change the fitness function
  - make a distinction between individuals, i.e. members of a population, and languages (spoken or not)
  - introduce multiple parents

## My research

### Future

- Language contact and interaction
- Emergence of pidgin and creole languages
- Multi-linguism
- Adult learning

# My models

## Without & with world

- Without world
  - in order to reproduce Nowak results, the first version of the model has the same features, and follows the same behaviour, of Nowak's model
- With world
  - in this first stage, the world only influences the positioning of agents
  - initially, agents are placed at random in the world, that is represented as a square grid where each cell is occupied by a language
  - newborn individuals are placed in their parent cell or in the neighboring ones (at random)
  - fitness function is calculated as before

# My model

## Without world

`LangGame` represent the game entity, so it has to take care about the objects (languages) that will play in itself, in particular

- creates the lists of current, newborn, and dead languages
- creates offsprings
- lets each language plays against every other

`Language` is the language entity in itself, and therefore it needs to perform those actions that are intrinsic to the language

- creates associative, active, and passive matrices, the first time at random and in the next epochs by sampling matrices from previous languages
- actually perfoms the language game, i.e. calculates fitness

# My model

## With world

`LangGameBatchSwarm` is the batch observer for the model

- creates the model and activates it

`LangGameObserverSwarm` is the GUI observer for the model

- creates the graphical display and objects representing the world and languages respectively
- creates the model and activates it

`LangGameModelSwarm` is what `LangGame` was in the model without the world, and therefore it performs the same actions, in addition

- it takes care to put the objects it creates in their right place in world

# My model

## With world cont.

Language is what it was in the model without world, therefore it performs the same actions, in addition

- it needs to be aware of the world where it lives, so it has to set its coordinates, its color, and finally to draw itself in the world

LangSpace is the world entity, at the present time it just performs actions to add and delete languages from itself

# Some results

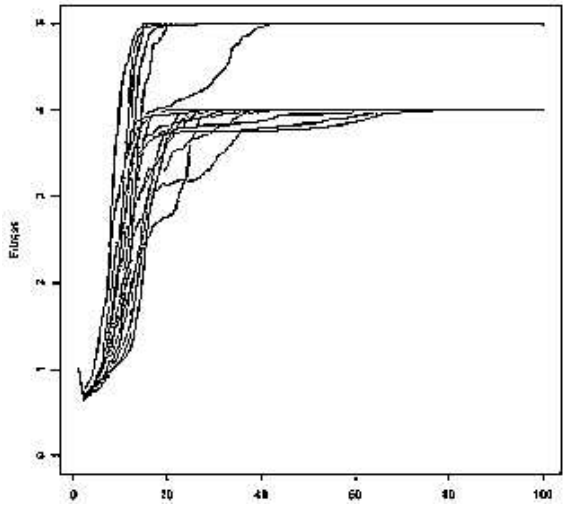
## Without & with world

- The tests were run under the same conditions described by Nowak in his paper *The evolutionary language game*
  - $k$ values in the set $\{1,4,7,10\}$
  - 20 rounds for each value of $k$
  - 100 epochs for each round
- The tests run with the model with world, at this stage of the project, do not present any particular feature, and results are quite the same as in the model without world

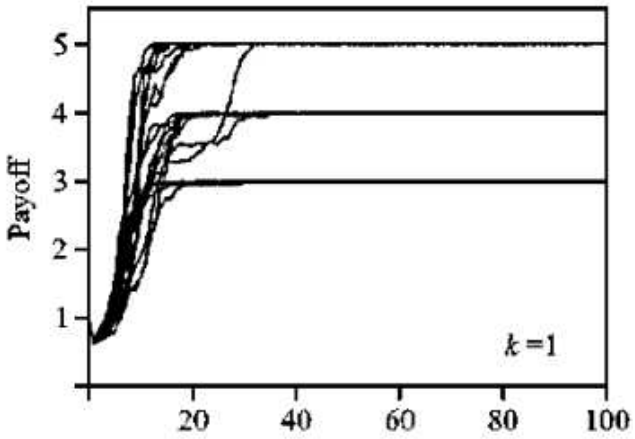
# Some results

## Without world - k=1

Mine



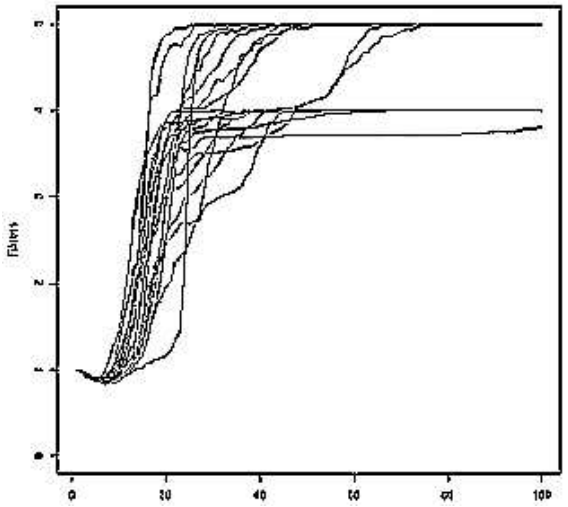
Nowak



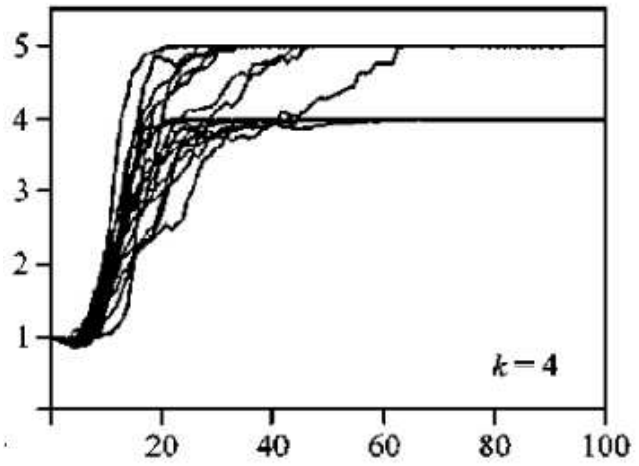
# Some results

## Without world - k=4

Mine



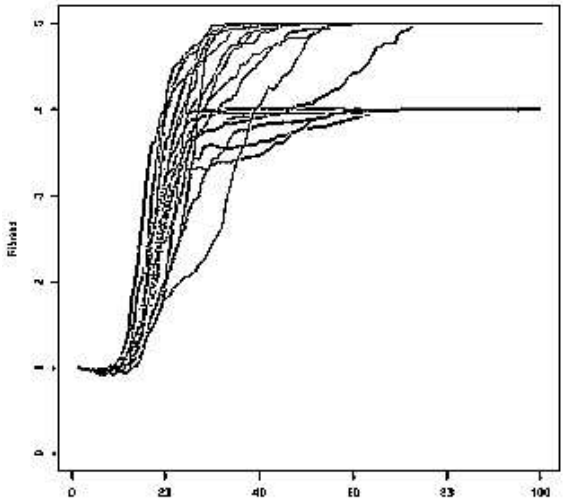
Nowak



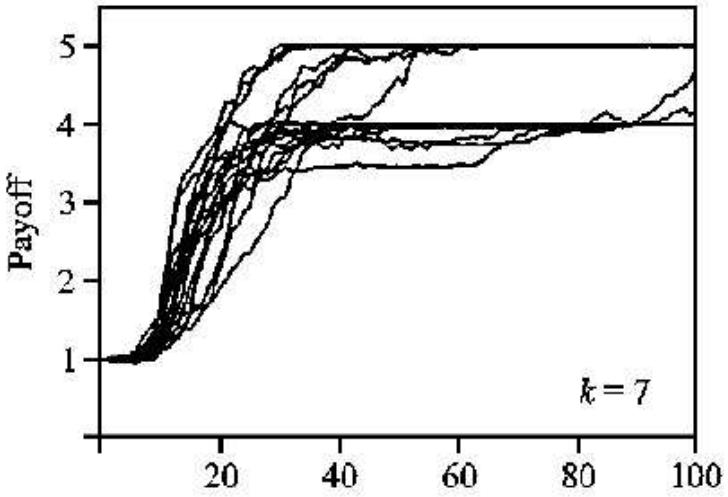
# Some results

## Without world - k=7

Mine



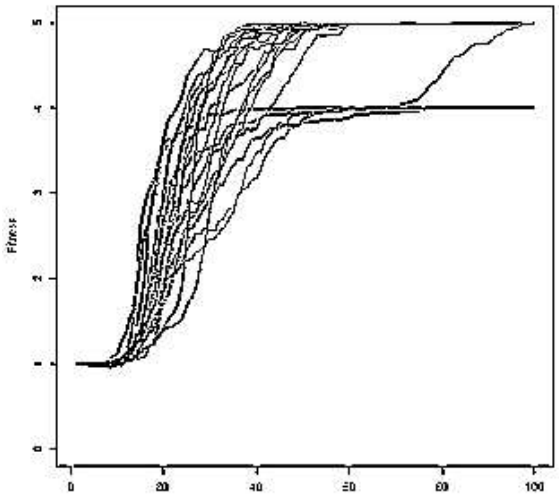
Nowak



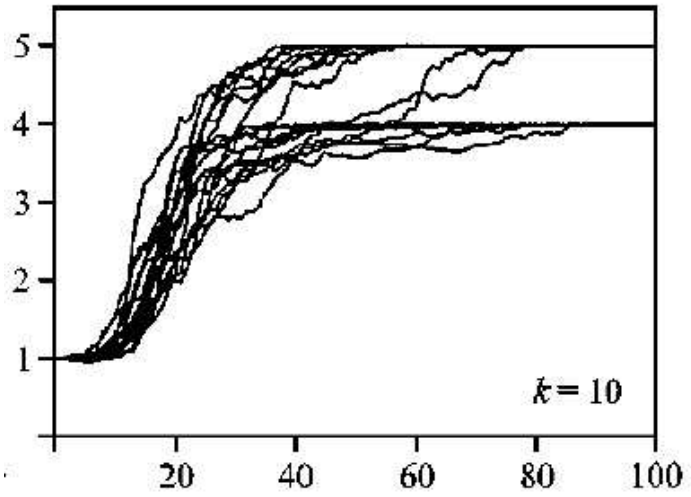
# Some results

## Without world - k=10

Mine

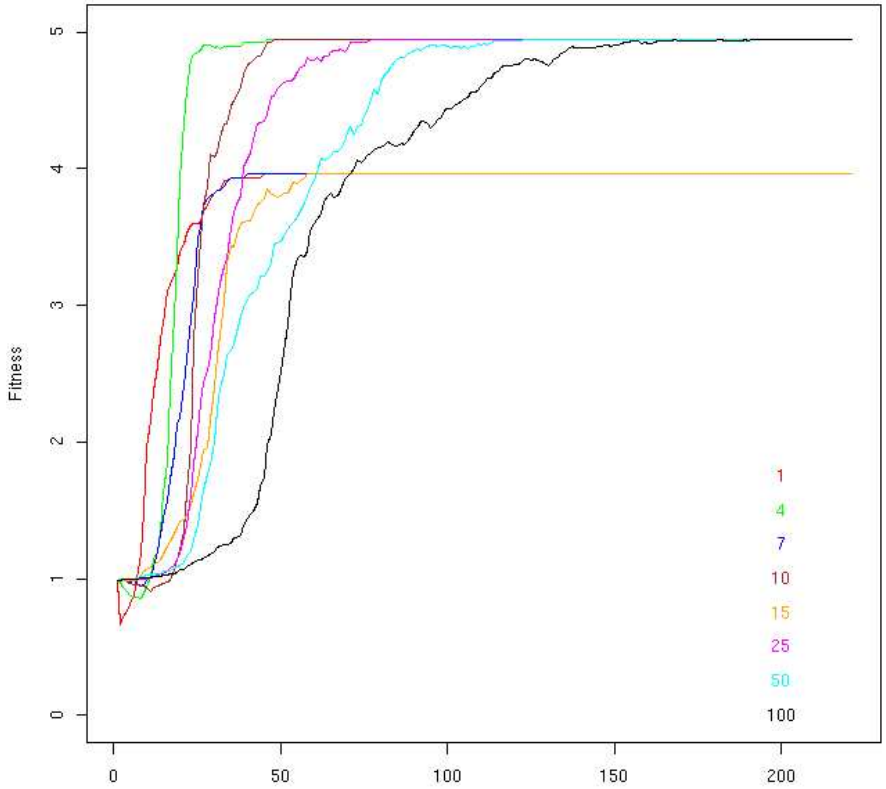


Nowak



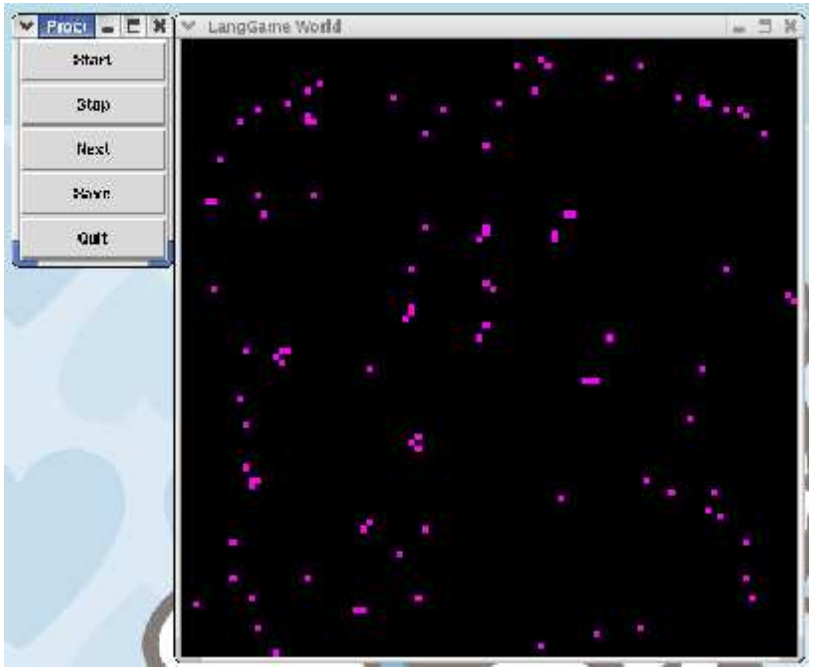
# Some results

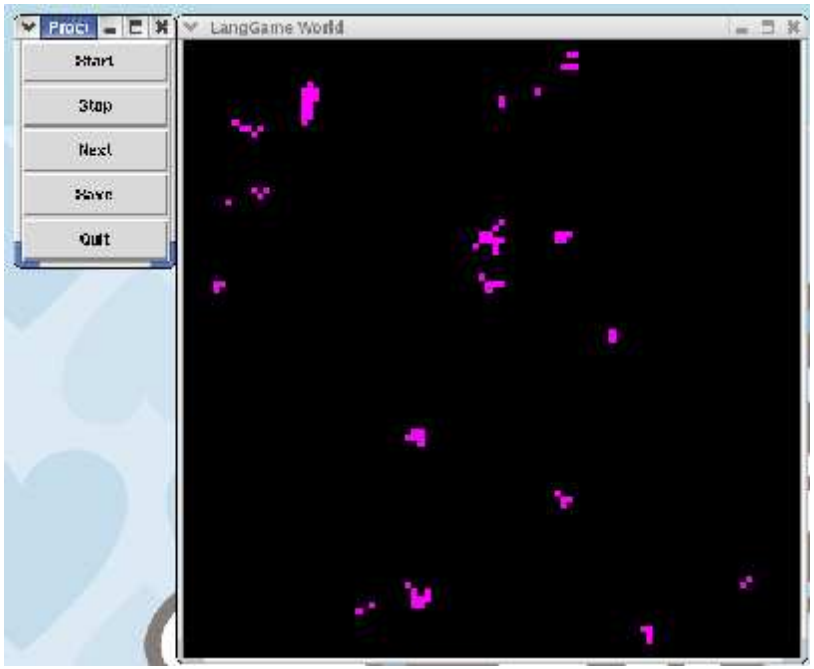
## With world - Test on k



# Some results

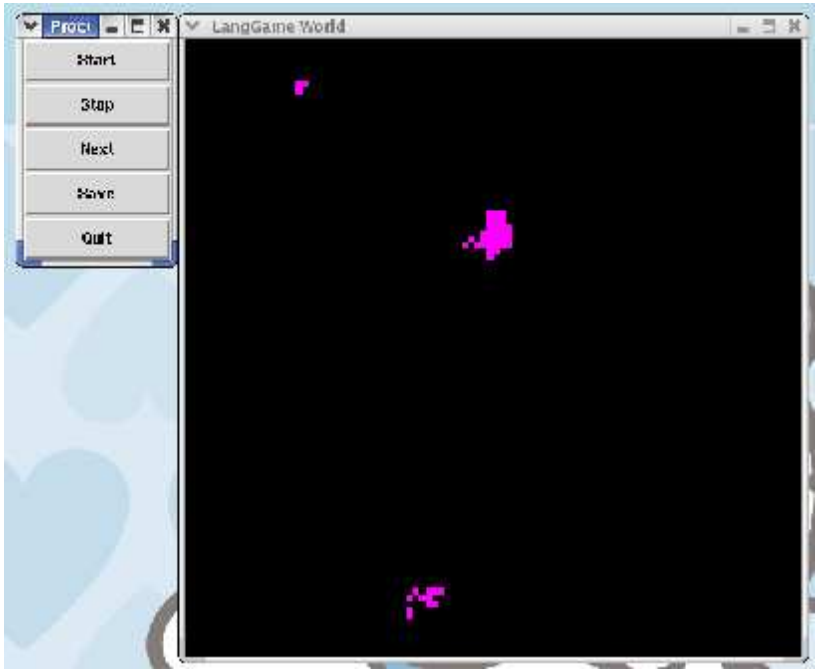
## With world - Screenshot

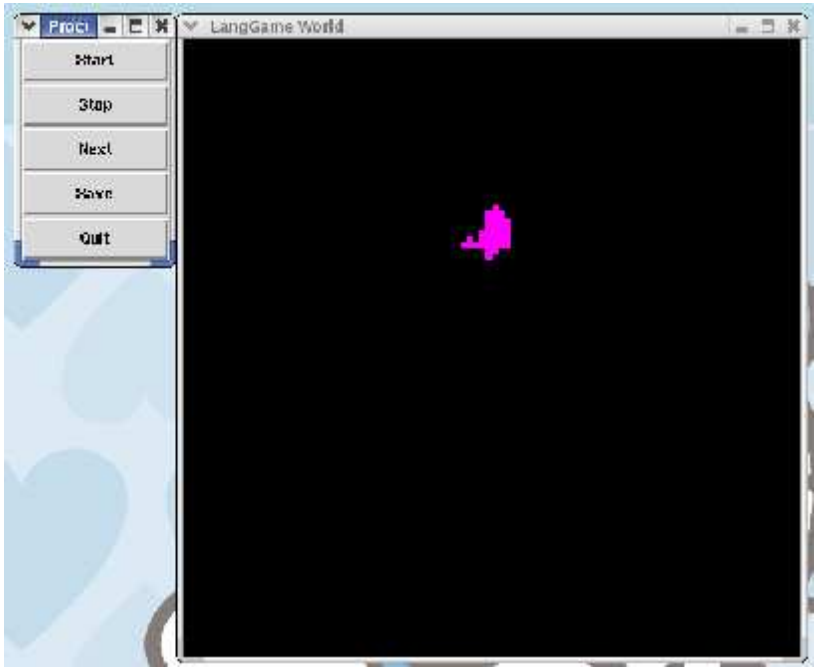


# Some results

## With world - Screenshot cont.



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# Conclusion

- Brief overview on evolutionary language games and on what I consider the three main approaches to them

  **Luc Steels** robotic agents

  **Martin Nowak** mathematical model

  **Simon Kirby** iterated learning method

- Analysis of the basic Nowak's language game model
- My present work
- My future ideas

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[8] Ludwig Wittgenstein, ”Philosophical investigation”, 1953