Language, Games, and Evolution
Workshop ESSLLI 07

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Aspects of Language, Games, and Evolution

- Rationality in Language Use
  - Gricean Pragmatics
  - Alignment, Interaction and Language Structure
- Language Games
  - Credibility
  - Bounded rationality
- Language Evolution
  - Evolution of Typological Diversity
  - Studies of Grammaticalisation Phenomena
  - Micro-Dynamics of Language Evolution
  - Mathematical Models
Decision Theory

If a decision depends only on
- the state of the world,
- the actions to choose from and
- their outcomes

but not on
- the choice of actions by other agents,

then the problem belongs to decision theory.
“A game is being played by a group of individuals whenever the fate of an individual in the group depends not only on his own actions but also on the actions of the rest of the group.” (Binmore, 1990)
Two Varieties of Game Theory

- **Classical Game Theory**: Strong assumptions about the agents' rationality
  - common knowledge
  - logical omniscience

- **Evolutionary Game Theory**: Weak assumptions about agents' rationality.
  In its most radical interpretation:
  - no knowledge representation,
  - no reasoning capabilities.
In a very general sense we can say that we play a game together with other people whenever we have to decide between several actions such that the decision depends on:

- the choice of actions by others
- our preferences over the ultimate results.

Whether or not an utterance is successful depends on

- how it is taken up by its addressee
- the overall purpose of the current conversation.
Signalling Games
Simple Case [Lewis(1969)]

- $\mathcal{M}$: a set of meanings (states of the world).
- $\mathcal{F}$: a set of signals (linguistic forms).

Playing the game:
1. Only the speaker knows the state of the world $m \in \mathcal{M}$.
2. He chooses a form $f \in \mathcal{F}$ and sends it to the hearer.
3. The hearer has to guess what $m$ is.

The players are successful if the hearer can guess what $m$ is.
The strategies are:

- **speaker**: a function $S : \mathcal{M} \rightarrow \mathcal{F}$ that maps meanings to forms.
- **hearer**: a function $H : \mathcal{F} \rightarrow \mathcal{M}$ that maps forms to meanings.

Payoff:

$$u(m, f, m') = \begin{cases} 
1, & \text{if } m = m' \\
0, & \text{else}
\end{cases}.$$
Signalling Signalhood
Thomas C. Scott-Philipps, Simon Kirby & Graham Ritchie
(In Proceedings)

How can audiences know that signals are signals?

• the coordination of signalhood is non-trivial,
• in order to signal signalhood, signaller must deviate in some way from the audiences expectations of the signaller’s behaviour.

Experimental study
• involving a coordination problem with two agents,
• very restricted possibility of information flow between agents,
• no possibility to use conventional means of communication.
⇒ agents forced to create signals.
Aims at the isolation of the relative contribution of different types of signals.

Example
Subjects have to predict the behaviour of agents in the dictator game. How is this influenced by:

- way how information about agents is presented (pictures vs. videos),
- activities of the agents (kind of text they read in the video).

Experimental studies.
Rooted in evolutionary anthropology.
Why a New Framework?
The Example of Gricean Pragmatics

• Basic concepts of Gricean pragmatics are undefined, most notably the concept of relevance.
• On a purely intuitive level, it is often not possible to decide whether an inference of an implicature is correct or not.
A stands in front of his obviously immobilised car:

A: I am out of petrol.
B: There is a garage round the corner. \((G)\)
\(\Rightarrow\) The garage is open. \((H)\)
Set $H^* := \text{The negation of } H$.

1. B said that $G$ but not that $H^*$.
2. $H^*$ is relevant and $G \land H^* \Rightarrow G$.
3. Hence, if $G \land H^*$, then B should have said $G \land H^*$ (Quantity).
4. Hence, $H^*$ cannot be true, and therefore $H$. 

A possible Explanation
Problem: A Second Valid Explanation

Exchange $H$ and $H^*$

1. B said that $G$ but not that $H$.
2. $H$ is relevant and $G \land H \Rightarrow G$.
3. Hence, if $G \land H$, then B should have said $G \land H$ (Quantity).
4. Hence, $H$ cannot be true, and therefore $H^*$.
Game and Decision Theoretic Approaches to Gricean Pragmatics

Distinguish between approaches based on:

- Classical Game Theory
  - Radical Underspecification Approach [Parikh(2001), Ross(2006)]
- Evolutionary Game Theory [v. Rooij(2004), Jäger(2007)]
- Decision Theory
  - Argumentative View: [Merin(1999)]
  - Non-Argumentative View: [v. Rooij(2004), v. Rooij(2003)]
Example

1. If you are hungry, there are biscuits on the shelf. (NIC)
2. If the butler has not killed the baroness, the gardener has.

NIC:

1. Antecedent and consequent not logically related.
2. If antecedent is true, then consequent is relevant.

Licensing and logical properties investigated using decision theoretic measure of relevance.
Example

John or Mary came to the party.

- implicated (strong): Only one of the two came
- implicated (weak): all the speaker knows is that one of them came

- Observation: Strong implicature presupposes that the speaker is known to be expert.
- Dependency between weak/strong implicatures and speaker expertise investigated using signalling games.
Approaches to Diachrony

- Game theoretic:
  - “Discrete” Models,
  - Evolutionary Models

- Non-GT diachronic Simulations
Discrete Models

- Consist typically of a sequence of synchronic models.
- Each step in the model is the effect of e.g.:
  - change of some parameter value,
  - a learning process,
  - improvement of strategies.
Example: Partial Blocking

[Benz(2006a)]

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<td><strong>cause to die</strong></td>
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<td><strong>kill directly</strong></td>
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<td><strong>kill indirectly</strong></td>
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<td><strong>terminate a life</strong></td>
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Stage 0   Stage 1   Stage 2
Horn Strategies and Russian Aspect
Atle Grøn

- Considers meaning differences between Russian verb classes and their uses:
  - intransitive simplex verbs ($f_0$): čitat'
  - transitive simplex verbs ($f_1$): čitat’ pis’mo
  - prefixed verbs ($f_2$): pročitat’ pis’mo

<table>
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<td>čitat’</td>
<td>⇔ atelic activities</td>
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<tr>
<td>čitat’ pis’mo</td>
<td>⇔ ‘progressive’ accomplishments</td>
</tr>
<tr>
<td>pročitat’ pis’mo</td>
<td>⇔ ‘non-progressive’ accomplishments</td>
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- Considers meaning differences as blocking phenomenon.
- Uses diachronic model to explain blocking.
Semantic Change:  
- Generalisation: German *Sache*: issue of dispute $\Rightarrow$ thing.  
- Specialisation: German *Mut*: mood $\Rightarrow$ audacity.  
- Semantic Shift: German *Hammer*: stone, rock $\Rightarrow$ hammer.

Explained as equilibrium shift in Parikh’ian games of partial information.
Investigates:

- syntactic changes as the result of production pressure in dialogue;
- Case study: the diachronic development of clitic pronouns in modern Romance languages from Latin.
- Framework: Dynamic Syntax.
Evolutionary Game Theory

- Classical Game Theory: Strong assumption about rationality — sometimes seen to be unrealistic.
- Evolutionary Game Theory: Weak assumptions about rationality
  - Each strategy may be adopted by a certain proportion of an (infinite) population.
  - Successful strategies spread in the population, unsuccessful strategies diminish (survival of the fittest).
Different Interpretation of Evolutionary GT

- **Biological Interpretation:**
  - Strategies represent certain traits of a species,
  - payoff is defined by the species’ offspring.

- **Cultural interpretation:**
  - Strategies represent a certain regularity in behaviour,
  - strategies spread by learning and imitation.
  - the rate of learning and imitation is directly related to the success of a strategy.
Replicator dynamics

Simple Case

Basic parameters:

- \( s_i, i = 1, \ldots, n \): \( n \) different strategies.
- \( x^i \in [0, 1] \): proportion of population playing strategy \( s_i \).
- \( u(i, j) \): utility of strategy \( s_i \) against strategy \( s_j \).

Expected utility of strategy \( s_i \):

\[
\tilde{u}_i := \sum_{j=1}^{n} x_j u(i, j).
\]

Average expected utility of population:

\[
\tilde{u} := \sum_{i=1}^{n} x_i \tilde{u}_i.
\]
Replicator Equation

Expectations:

- If individual expected utility $\tilde{u}_i$ is higher than average expected utility $\tilde{u}$, then strategy $s_i$ should spread in the population.
- If individual expected utility $\tilde{u}_i$ is lower than average expected utility $\tilde{u}$, then strategy $s_i$ should diminish.
- Rate of growth is the higher, the higher the difference $\tilde{u}_i - \tilde{u}$.

Dynamic Interpretation:

- $x_i$ is a function of time $t$ with

$$\frac{dx_i}{dt} = x_i(\tilde{u}_i - \tilde{u}).$$
Replicator dynamics
Matrix Notation

Write utilities $u(i, j)$ into a matrix:

$$U = \begin{pmatrix}
  u(1, 1) & u(1, 2) & \cdots & u(1, n) \\
  u(2, 1) & u(2, 2) & \cdots & u(2, n) \\
  \vdots & \vdots & \ddots & \vdots \\
  u(n, 1) & u(n, 2) & \cdots & u(n, n)
\end{pmatrix}$$

Then, the expected utility and average expected utility can be written:

$$\tilde{u}_i := (Ux)_i, \quad \tilde{u} := x \cdot Ux.$$ 

The replicator equation becomes:

$$\frac{dx_i}{dt} = x_i ((Ux)_i - x \cdot Ux).$$
Utilities in Signalling Games

Symmetrised Game

Strategies:
- speaker: functions $s : \mathcal{M} \rightarrow \mathcal{F}$ that maps meanings to forms.
- hearer: functions $h : \mathcal{F} \rightarrow \mathcal{M}$ that maps forms to meanings.

Utilities (sending $f$ in $m$, interpreting $f$ as $m'$):

$$u(m, f, m') = \begin{cases} 1, & \text{if } m = m' \\ 0, & \text{else} \end{cases}.$$ 

Each member of population is speaker and hearer, hence:

- strategies are pairs $(s, h)$,
- utility of $(s, h)$ against $s', h'$ is:

$$\sum_{m \in \mathcal{M}} \frac{1}{2} u(m, s(m), h'(s(m))) + \frac{1}{2} u(m, s'(m), h(s(m)))$$
Linguistic Applications

- Evolution of typological diversity [Jäger(2006)]
A Graphical Representation of a Simulation
From [Jäger(2006)]
States of **perfect communication** in signalling game:

If $S(m) = f$, then $H(f) = m$, i.e. $H \circ S|_\mathcal{M} = \text{id}_\mathcal{M}$

- Under the replicator dynamics, a non-negligible proportion of strategies converges to **partial communication**.
- Looks at certain **perturbations** of the replicator dynamics in order to assess the significance of this result.
Language Regulation and Dissipation in Meaning
Andrew Stivers
(In Proceedings)

Studies the dynamics of language evolution when communication can proceed through two channels:
- Social Channel: fully aligned;
- Commercial channel: opposed.

Investigates credibility of signals when channels get confused.
Non-Game Theoretic Diachronic Models

- Game Theory: Dynamics depend on expected payoff of agent interactions.
- Others: Dynamics is determined by other (social) parameters & structures.
Agent-Based Model of Linguistic Diversity
Pieter de Bie & Bart de Boer

• Investigates the development of language borders and dialect continua.
• Example:
  • Continuum: Dutch-German
  • Border: Dutch-French in Belgium
• Simulations show the emergence of different patterns.
• Simulations based on social impact theory
Evolving Lexical Networks
Alexander Mehler

- Simulates the *terminological alignment* in a multi-agent community.
- Community model is a special kind of *agent network*.
- Interested in the evolution of lexical networks and their structural dependency on the community model.


