Complex systems and linguistics
Outline

● The many faces of language
  ○ History
  ○ Context

● Language as a Complex Adaptive Systems
  ○ Concepts and similarities
  ○ Examples and applications

● The evolutionary language game
What is language?
Plato (428 b.c.e. – 348 b.c.e.) **Etymology**

Cratylus: “Everything changes and nothing remains still.”

Hermogenes: “A name is not whatever people call a thing by agreement, [...] there is a kind of inherent correctness in names, which is the same for all men”

Socrates: “And if different rule-setters do not make each name out of the same syllables, we mustn't forget that different blacksmiths, [...] , don't all make it out of the same iron. But as long as they give it the same form the tool will be correct.”
“The Sanscrit language, [...] more perfect than the Greek, more copious than the Latin, [...] yet bearing to both of them a stronger affinity, [...] than could possibly have been produced by accident;

So strong indeed, that no philologer could examine them all three, without believing them to have sprung from some common source.
Saussure set out to model language in *purely linguistic* terms, free of psychology, sociology, or anthropology.

Language can be viewed as a *game of chess*, where the history of past moves is irrelevant to the players.

**Language as a system**
Noam Chomsky (1928-present) Generativism

Chomsky wanted to explain the speed with which children acquire a language, and its astonishing fecundity, our ability to create an endless supply of grammatically correct sentences without apparently knowing the rules.

Universal grammar or context free grammar
How many colors are there in a rainbow?
Sapir-Whorf Hypothesis

The structure of a language affects the ways in which its speakers conceptualize their world.

Eskimos have **100 words for snow**.

The Hopi Indians of Arizona do not use **spatial metaphors for time**, and have no past tense as such.

The Piraha of the Amazon use only three words to count: **one, two, many**.

**Lojban**, constructed, syntactically **unambiguous** human language.

**Toki pona**, constructed **minimal** language.
Ludwig Wittgenstein

“The limits of my language mean the limits of my world.”

“Whereof one cannot speak, thereof one must be silent.”
Functionalistic perspective

Language is used as a communication tool

Evolved in a complex social context

Allows for a CAS approach
Why complicate language?

Dynamic properties of language

- **Active process**
  
  “A language is to be identified with a living capability by which speakers produce and understand utterances, not with the observed products of the acts of speaking and writing”
  - Robins 1967

- **Growth and change**

Actually, it’s even more complex: Language changes as it is used!
Emergence of language

Language is not the product of grammatical rules; grammatical rules are used to describe language!

Language emerges from local interactions of individuals (agents) based on

- Experience
- Social interaction
- Cognitive processes
Evidence for usage-based grammar

Grammar seen as a network built on categorization of experiences

Conventional ways of phrasing

“I want to marry you” vs “I want marriage with you”

Co-occurrence of words

I’m, She’s, They’re, …

“Be going to” → “Gonna”
Fractal structures within languages

Different languages share archetypical and core phonological patterns similar to “strange” attractors in complex systems.

Fractal structure

- Change at all levels
- Self-similarity

Example: Zipf’s power law
Zipf’s law

The relative frequency of a word is inversely proportional to its rank.

Ex: The second most used word occurs half as many times as the most used word etc.
Applications of the CAS approach within linguistics

The evolution of language
Historical linguistics
First and second language acquisition
Cognitive linguistics
Sociolinguistics

Computational modelling allows for quantified research over long timescales.
“Basic evolutionary language game”

- A community trying verbal communication
- m sounds and n objects
- Speaking matrix P and hearing matrix Q

\[
P = \begin{pmatrix}
p_{1,1} & p_{1,2} & \cdots & p_{1,m} \\
p_{2,1} & p_{2,2} & \cdots & p_{2,m} \\
\vdots & \vdots & \ddots & \vdots \\
p_{n,1} & p_{n,2} & \cdots & p_{n,m}
\end{pmatrix}
\]

\[
Q = \begin{pmatrix}
q_{1,1} & q_{1,2} & \cdots & q_{1,m} \\
q_{2,1} & q_{2,2} & \cdots & q_{2,m} \\
\vdots & \vdots & \ddots & \vdots \\
q_{n,1} & q_{n,2} & \cdots & q_{n,m}
\end{pmatrix}
\]
“Basic evolutionary language game”

- Communication between individual A and B speaking languages L and L'
- Payoff from both speaking and listening
- Accumulating payoff is interpreted as fitness in the game

\[ P(i) = \sum_{j=1}^{m} p_{ij} q_{ji} \]
- 100 individuals
- 5 objects
- 5 sounds
“Updated evolutionary language game”

- The whole community speaks the same language
- Each round a slightly different language is introduced

- Additional concepts
  - Misunderstandings
  - Object ranking
- 20 objects
- 40 sounds
- 10,000 rounds
- Stable after 4000 rounds
Word formation and basic grammatical rules

- Word formation can overcome the “error limit”
- Essentially unlimited potential for different object references
- Grammar combines words into sentences
- Grammar arises if communication about many different events is needed
Summary
Thank you for listening!
Questions

● Zipf’s law can easily be empirically verified, but can you try to give a theoretical motivation to it?
● “The limits of my language mean the limits of my world.” Does the language shape the way we think or is it the opposite?
● Obviously there are great synergies in a globally common language. Should one try to enforce teaching Lojban in school worldwide?
● Systems like Siri obviously depend heavily speech recognition. Will a human be able to easily distinguish if it’s talking to a machine in the future?