A multi-agent approach to language acquisition, language grounding and language evolution

Paul Vogt
http://ilk.uvt.nl/~pvogt
p.a.vogt@uvt.nl

Why this course?

- AI in the sense of using computer models to understand human intelligence benefits from interaction with other disciplines
- Evolution of language is such a discipline
- The study of language evolution deals with systems that are so complex that they need to be modeled with computers
- Linguists/paleontologists appreciate modeling, but are usually no good with computers themselves

Why this course?

- To understand how languages evolved requires one to understand how languages are acquired and grounded
- Understanding how these can be modelled does not only increase our scientific knowledge on the nature & nurture of language, but has impact on AI engineering as well

Aims

- To explain and practice techniques on modelling language evolution, grounding & acquisition (LEGA)
- Multi-agent systems and robotics
- Social interactions and dynamics of MAS
- Cognitive mechanisms
- Learning word-meaning mappings
- Learning simple compositional languages
• Day 1:
  • Introduction:
    • Language evolution
    • Modelling language evolution and language acquisition

• Day 2:
  • Lexicon formation
    • Grounding
    • Various language games
    • Cross-situational learning

• Day 3:
  • Two-word phase
    • Modelling joint attention
    • Iterated learning model
    • Hybrid IL-LG model

• Day 4:
  • Emergence of compositionality
    • Overextensions
    • Cumulative cultural evolution
    • Group size effects

• Day 5:
  • Case study: NEW TIES
  • Wrap-up
  • Discussion

Hands-on exercises

• Programming own language evolution model, or use existing toolkit (THSim), and carry out small research studying one or more aspects of language evolution using THSim

  • Work in small groups (2-3 persons)
  • Hand in final report on Friday

Practical details

• Lectures 10:00 - 12:30
• Lunch: 12:30 - 14:00
• Practical exercises: 14:00 - 16:00

• Course website:
  http://ilk.uvt.nl/~pvogt/lega.html
Dude - who are you and what the **** are you doing here??

- Day 1:
  - Introduction:
    - Language evolution
    - Modelling language evolution and language acquisition

Early Scientific Experiments

- Pharaoh Psamtik I
- Frederick II von Hohenstaufen
- James IV of Scotland
And speculation…

- Jespersen’s critique
- Bow-wow theory
- Pooh-pooh theory
- Ding-dong theory
- Yo-he-ho theory
- But his own theory:
  - La-la theory

As a result:

- Also: Chomsky considered it impossible (and uninteresting) to study language evolution

Can we do better today?

- 1990: Pinker & Bloom “Natural Language and Natural Selection”
- Since 1996 biannual Evolang Conference
  - Palaeontology
  - Archaeology
  - Anthropology
  - Linguistics
  - Biology
  - Ethology
  - Etc…
  - And of course: Computer modelling

Why language?

- Interesting and difficult question
  - Many factors play a role (including chance), complex dynamics
  - Possibilities for modelling
Communication in Animals
Humans are not the only ones with complex communication

Relation with primates
- Chimpanzees are very smart
  - But do not learn how to speak
  - And only learn sign language with difficulty
- Apes do communicate vocally
  - But more comparable with involuntary human cries of pain, joy, laughter etc.
- Neural structures in ape and monkey brains for manipulation and vocalization are analogues of human brain structures for speech

What evolved?
- Very specific mechanisms?
  - “Universal Grammar”
  - Principles and Parameters
- More general learning mechanisms, some specialised for communication?
- Completely general mechanisms
  - Language itself evolved culturally
  - “Nature versus nurture”

Modern Language
- Are there primitive languages?
  - No, not if native
  - No data on language evolution
  - But data on possibilities of language
- But: pidgin-languages
  - Jergens, second language etc.
  - And creolisation
- Or emergence of new language
  - New-american sign language
  - Idea: proto-language
  - Bickerton
Jackendoff

- Pre-existing primate conceptual structure
- Use of symbols in non-situation-specific fashion
- Use of an open, unlimited class of symbols
- Concatenation of symbols
- Development of a phonological combinatorial system to enlarge open, unlimited class of symbols
- Use of symbol position to convey basic semantic relations
- (Protolanguage about here)
- Hierarchical phrase structure
- Symbols that explicitly encode abstract semantic relations
- Grammatical categories
- System of inflections to convey semantic relations
- System of grammatical functions to convey semantic relations
- Modern language

Complex adaptive systems
(Kirby & Hurford, 2002)

- Biological evolution
- Social learning
- Cultural evolution

- Cultural evolution
  - no innate Universal Grammar; universal tendencies emerge through cultural transmission
- Individual & social learning
  - learning mechanisms are likely innate
- Self-organisation
  - a global structure – language – emerges from local interactions

Complex dynamical adaptive systems (Steels)

- Co-evolution of language & meaning
  - emergence of semantic structures give rise to the emergence of syntactic structures and v.v.
- Level formation
  - increasing complexity evolves in steps (levels), which can interact back on previously evolved levels
Language acquisition

- No language specific language acquisition device
- Usage-based / cognitive linguistics approach
- General associative learning mechanisms
- Straightforward pattern recognition methods

Language grounding

- Language is about something real
- Meaning needs to be grounded in reality
- Humans have to learn meanings of words and how these relate to reality
- Cognitive & social process

Modelling

- Learning from dictionary or corpora does not allow agents to ground language
- Human-robot interactions
- Multi-agent/robot interactions

Day 1:

- Introduction:
  - Language evolution
  - Modelling language evolution and language acquisition
Multi-agent systems
- ‘Autonomous’ agents
- Homogeneous
- Heterogeneous
- Goals
- Behaviour
- Interaction
  - protocols
  - language
  - ...

Artificial life
- Modelling life
  - as it is
  - as it could
- Techniques:
  - Evolutionary modelling
  - Artificial chemistry
  - Cultural evolution
- Purpose
  - to understand life & how it came to be
  - to build artifacts with life-like properties

Adaptive Behaviour
- Building adaptive systems
  inspired by adaptive systems from nature
  - insects
  - ...
  - reptiles
  - ...
  - humans

Techniques
- Optimization
- Genetic Algorithms
- Agent-based models
- Mathematical analysis
Agent-based models (1)

- Two aspects of language/linguistics
  - Individual
    - Psycholinguistics, language acquisition, speech errors...
    - "performance", "parole"
  - Collective
    - Historical linguistics, general linguistics
    - "competence", "langue"
- These aspects influence each other
  - Individual performance based on group conventions
  - Collective behaviour caused by individuals
- This link is difficult to investigate
  - Complex feedback
  - Non-linear behaviour (influences are not separable)
  - Difficult to understand with "pen-and-paper"

Agent-based models (2)

- Computer simulations have no problems with complex systems
  - Ideal to investigate interaction of individual and collective levels
- Model a population of individuals
  - Individual: learning behavior, language behavior
  - Population: interactions, population dynamics

Architecture of an individual

- Language
- Learning
- Perception
- Production
- Social behaviour
- Speech, vision, ...
- Chromosomes
- Age

The population

- Social interaction
- Language interaction
- Mating

Spatial structure
- Add to population
- Remove from population
Agent-based paradigms

- Iterated learning model (Edinburgh)
- Vertical transmission (Transfer over generations)
- Small populations
- Language game model (Brussels)
- Horizontal transmission (Transfer within generations)
- Larger population
- Sometimes the differences are accentuated, but we would like to stress the similarities

Language games (Steels, 1996)

Lexicon

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Interpretation

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### Score adaptation - success

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### Score adaptation - failure

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- Increasing (success)
  \[ \sigma_{ij} = \eta \sigma_{ij} + 1 - \eta \]
- Decreasing (failure & lateral inhibition)
  \[ \sigma_{ij} = \eta \sigma_{ij} \]
- \( \eta \) constant learning rate between 0 & 1
- I use \( \eta = 0.9 \)
- Variant: \( \sigma_{ij} = \sigma_{ij} \pm \delta \)
  - possibly bounded by 0 & 1
### Invention

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### Adoption

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Communicative success

No. of words

Self-organisation

- Local one-to-one interactions
- Positive feedback loop
- Emergent structure

Beyond the naming game

- Adding
  - embodiment & situatedness (robots)
  - meaning construction (grounding)
  - social interactions (joint attention)
  - learning constraints (mutual exclusivity)
  - grammar (compositionality)
Beyond the naming game

• Varying
  • learning mechanisms
  • parameters
  • environments

Summary

Language evolution

• Long history of speculation and 'scientific' research
• Since 1970s novel and improved tools
  • e.g., comparative psychology / biology, archaeology, linguistics, ..., and AI

Nature vs Nurture

• What language mechanisms have evolved?
  • Specific language acquisition device?
  • General usage-based learning mechanisms?
• If not LAD & UG, what else has evolved?
  • Theory of Mind?
  • Symbolism?
  • Sociality?
Complex adaptive systems

Biological evolution  Social learning  Cultural evolution

Modelling
- Agent-based systems
  - modelling populations
  - modelling individuals
- Machine learning
  - Evolutionary computation, neural networks, reinforcement learning, associative learning,...
- Iterated learning vs Language game
  - vertical vs horizontal transmission
  - small vs large populations

Language games

Speaker  Hearer

Encoding  Decoding
Select meaning  Identify meaning
Utterance

gotcha

Sensing  Preprocessing  Feature vectors
Categorisation
Meaning  Encoding  Utterance
Adaptation

Sensing  Preprocessing  Feature vectors
Categorisation
Meaning  Encoding  Utterance
Adaptation