Contingent interaction with a human, and reinforcement learning as a mechanism for language acquisition in robots

Caroline Lyon¹, Britta Wrede²
and Chrystopher L. Nehaniv¹

1. Adaptive Systems research Group, University of Hertfordshire
2. Research Institute for Cognition and Robotics, Bielefeld University

Research conducted through the italk project

ICPC York June 2011
Scenario for current work
Babbling-to-words experiments

- Focus on the “essential continuity between babbling and first words”

- Rationale behind learning a few word forms:
  - stage on the way to learning word meanings
  - contribution of anchor words to segmentation of an utterance

- Neuroscientific evidence of two types of learning:
  (i) statistical patterns, word forms without meaning: dorsal stream
  (ii) referential, association of word form and meaning: ventral stream

This work addresses (i).
Context

• Inspired by language acquisition in human infants

• Starting point: partly analogous to infants of 6 – 12 months that produce babble without meaning

• Explores the role of contingent interaction between teacher and learner, through proto-conversations with robot DeeChee. (See work by Kuhl and others)

• Naive participants are asked to teach DeeChee the names of shapes and colours in their own unscripted words
Hypotheses

1. DeeChee can acquire word form recognition through interaction with a human teacher

2. Recognition is augmented by contingent reinforcement, if the teacher makes an approving comment when a proper word is uttered

Participants

• Volunteers, unconnected with our research, asked to teach DeeChee the names of shapes and colours, talking naturally

• 14 participants recruited

• Participants engaged in 2 consecutive sessions, each a 4 minute “conversation”
Assumptions

• DeeChee acts autonomously but is influenced by what it hears

• It practices turn taking in a proto-conversation

• It can perceive phonemes (analogous to human infants)

• It can produce syllabic babble without articulatory constraints (not always analogous to human infants)

• It is sensitive to the statistical distribution of phonemes

• It reacts positively to reinforcement. A list of approving comments (“well done”, “good” etc) is assumed known.
Hypothesis 1

Word form learning can be achieved through interaction with a human

Method of investigation

Experiments in which participants have a proto-conversation with iCub DeeChee

Initially DeeChee produces random syllabic babble
Participant tries to teach the names of shapes and colours
Does DeeChee’s babble begin to include real syllables / one syllable words?
**Hypothesis 2**
Learning can be augmented through reinforcement

**Method of investigation**
Participants are asked to make an approving comment if DeeChee chances to produce a proper word.

If DeeChee “hears” this comment, then the word is stored in its lexicon

Is random babble interspersed with words from the lexicon?
Overview of process

- Initially DeeChee produces random syllabic babble

  Syllables are of 4 types: V, CV, CVC, VC
  V is a vowel, C is a consonant or cluster of consonants

  Most syllables allowable in English have a chance of being uttered

- As the teacher talks with DeeChee, his / her speech is processed by and “heard” by DeeChee as a stream of phonemes.

- Overlapping syllables are extracted and stored by DeeChee in frequency tables for each syllable type
  e.g. <a star> → <a>, <a st>, <st a>, <st a r> etc
Overview of process - continued

- DeeChee’s random babble becomes biased towards teacher’s speech: perceived syllables are more likely to be produced

- If the teacher hears DeeChee utter, by chance, a proper (single syllable) word he/she may make an approving comment.

- DeeChee may pick up this approving comment, reinforcement, and the word is then lodged in its lexicon
The learning engine

Age

Productions

random babbling

Memory contents

own language syllables

Perceptions

syllables in speech

learning engine

A

D

U

L

T

K

words without meaning mixed with other syllables

lexicon with word forms

more adult word forms

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The learning engine

Age

Productions

random babbling

sylablic babbling biased towards adult patterns

words without meaning mixed with other syllables

Memory contents

own language syllables

patterns of adult’s syllabic output

lexicon with word forms

Perceptions

syllables in speech

patterns of adult’s syllabic output

more adult word forms

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Age

Productions

- random babbling
- syllabic babbling biased towards adult patterns
- chance production of a word form
- words without meaning mixed with other syllables

Memory contents

- own language syllables
- patterns of adult’s syllabic output
- syllabic patterns and a few word forms without meaning
- lexicon with word forms

Perceptions

- syllables in speech
- patterns of adult’s syllabic output
- adults approval of word form reinforcement
- more adult word forms

The learning engine
Teacher

Real time recognition of teacher’s speech (SAPI 5.1)

phoneme stream

Process utterances

Frequency tables

Lexicon

DEECHEE

Capture approving terms

Reinforcement

Produce syllabic babble and one syllable words

Espeak speech synthesizer

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### Excerpt from CVC frequency table

*built up from 8 minute conversation of CC in video clip above*

<table>
<thead>
<tr>
<th>Rank</th>
<th>Frequency</th>
<th>CMU</th>
<th>Word</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>gr iy n</td>
<td>green</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>hh ah t</td>
<td>heart</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>m uw n</td>
<td>moon</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>k ah l</td>
<td>from colour</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>s ih z</td>
<td>from 'this is'</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>r eh d</td>
<td>red</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>dh ih s</td>
<td>this</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>kr ao s</td>
<td>cross</td>
</tr>
</tbody>
</table>

List continues: entries 28 to 96 have frequency 1

**Zipfian type distribution**
Frequency of CVC syllables from participant CC, 8 min dialog with iCub
**Excerpt from CVC frequency table**

*built up from batch process of 8 teachers’ speech, about 8,000 words (previous experiments)*

<table>
<thead>
<tr>
<th>Rank</th>
<th>Frequency</th>
<th>Phonemic form</th>
<th>Word</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>215</td>
<td>y uw s</td>
<td>from 'you see'</td>
</tr>
<tr>
<td>2</td>
<td>165</td>
<td>hh aa rt</td>
<td>heart</td>
</tr>
<tr>
<td>3</td>
<td>144</td>
<td>g aa t</td>
<td>get</td>
</tr>
<tr>
<td>4</td>
<td>143</td>
<td>skw eh r</td>
<td>square</td>
</tr>
<tr>
<td>5</td>
<td>138</td>
<td>s er k</td>
<td>from 'circle'</td>
</tr>
<tr>
<td>6</td>
<td>136</td>
<td>s iy dh</td>
<td>from 'see the', 'see this’</td>
</tr>
<tr>
<td>14</td>
<td>106</td>
<td>sh ey p</td>
<td>shape</td>
</tr>
<tr>
<td>15</td>
<td>97</td>
<td>s ah n</td>
<td>sun</td>
</tr>
<tr>
<td>16</td>
<td>96</td>
<td>dh ih s</td>
<td>this</td>
</tr>
<tr>
<td>17</td>
<td>95</td>
<td>m uw n</td>
<td>moon</td>
</tr>
</tbody>
</table>
Frequency of CVC syllables from batch data, 8K words

- you s[ee] (1, 215)
- heart (2, 165)
- get (3, 144)
- square (4, 143)
- sun (15, 100)
- this (16, 96)
- moon (17, 95)
Results from 14 participants
7 standard mode, 7 in filtered “syllabifier” mode

Phoneme recognition
median correct 83%, range 15-100%, average 78.36%

Salient words uttered by DeeChee, picked up by teacher, reinforced
Standard mode: 4 total from all 7 participants
Syllabifier mode: 4 total from all 7 participants

Salient words uttered by DeeChee, missed by teacher
Standard mode: 20 total from all 7 participants
Syllabifier mode: 2 total from all 7 participants
Conclusions and Discussion

Re Hypothesis 1:

Word forms can be learnt in only a few minutes using a real time, interactive approach

Analyzing teacher’s speech shows a Zipfian distribution of syllables
• salient words occur prominently among all syllables
• they are picked up by DeeChee and occur in its future productions

This is in line with research showing that salient words are likely to be associated with canonical phonemic form and prosodic prominence
Conclusion and Discussion continued

Re Hypothesis 2:

Augmentation of learning through reinforcement, can confirm the learning process.

However, currently, many participants find it hard to notice words produced by DeeChee in among its babble.

Filter “syllabifier” excludes many possible candidate words. But it may be easier for participants to pick up salient words from a smaller set.

Technical problems, such as DeeChee hearing its own babble, prevented us from implementing dynamic turn-taking so far.
Future work

We have a good basis on which to further explore reinforcement and the role of non-verbal feedback signals in regulating interaction and supporting learning.