Presentation Outline

• Application scenario
• Introduction to symbolic prediction
• CABA$^2$L
• Discrete Auto-Regressive Hidden Markov Models
• Experimental evaluation of CABA$^2$L
• Conclusion and future works
Application scenario
Verbal Impairments

- Verbal impairments represent a social problem:
  - Social exclusion
  - Seclusion
Verbal Impairments

• Verbal impairments represent a social problem:
  ◦ Social exclusion
  ◦ Seclusion

• Millions of verbal impaired people live in the world (e.g., more than 2 millions in USA) suffering:
  ◦ Autism
  ◦ Dysphasia
  ◦ Intellectual impairments
  ◦ Motor impairments
ISAAC

- International Society for Augmentative and Alternative Communication (1983, USA)

- Objectives:
  - Development of languages usable by verbal impaired people (AAC languages)
  - Development of communicative aids (AAC aids)
ISAAC

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- Objectives:
  - Development of languages usable by verbal impaired people (AAC languages)
  - Development of communicative aids (AAC aids)

- Why Augmentative:
  - Non verbal communication modes do not necessarily substitute the natural language
  - They enhance residual capabilities

- Why Alternative:
  - Codes alternative to speech (figures, drawings, symbols, etc.)
AAC Language Examples

Bliss

PCS

PIC

PICSYM
AAC Software Aids

Communication Software

• Provide an electronic version of AAC tables
• Provide a number of device to select symbols
• Aid the verbal impaired to compose messages
• Provide extra features:
  ○ Vocal synthesis
  ○ Message exchangament services
  ○ etc.

(example of communication software)
Motor Disorders and Message Composition

60% of verbal impaired people suffer motor disorders

• They have difficulties to compose messages (the composition of a single message can take several minutes)
• They need particular input devices
• They need an automatic scansion of the symbol table
• They need special human-computer interfaces

(examples ad-hoc input devices)
An highlight moves autonomously on an AAC symbol table according to a strategy

**Linear** sequentially (it is not useful with a high number of symbols)

**Row-Column** at first rows are scanned, then columns, or vice versa (it is not useful with a high number of symbols)

**At subgroups** in groups fewer and fewer (it is not adopted by people suffering mental impairments)

**Predictive** from the most probable the user will use to continue the sentence according to a linguistic model of the user (currently lacking in literature)
Automatic Symbol Scansion (2)

- Non predictive automatic scansion strategies are not effective enough (time spent to compose sentences too long)
- Intelligent scansion strategies are required:
  - **Predictive** able to predict the linguistic behavior of the user embedding the peculiar user linguistic model
  - **Adaptive** able to adapt itself on the peculiar user intellectual and motor capabilities
Introduction to symbolic prediction
Symbolic Prediction

- In literature mainly alphabetical prediction
- Alphabetical prediction techniques do not suite with symbolic prediction issue

Main Differences

<table>
<thead>
<tr>
<th>Alphabetical prediction</th>
<th>Symbolic prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strict set of items (22 signs)</td>
<td>Variable set of items (from 50 to 300 symbols and over)</td>
</tr>
<tr>
<td>Organized in sequence of signs (words) known <em>a priori</em></td>
<td>Variable sequences of symbols</td>
</tr>
</tbody>
</table>
Traditional Predictive Techniques and AAC

- **Statistical**: do not take into account the peculiar AAC language
- **Syntactic and strong syntactic**: do not take into account the peculiar AAC language
- **Semantic**: do not take into account the variability related to the residual capabilities
- **Hybrid**: ...
**CABA²L**

Composition Assistant for Bliss Augmentative and Alternative Language

- Hybrid predictor (semantic-statistic) that takes into account:
  - Language peculiarities (linguistic and syntactic categories)
  - User linguistic behavior (probability that a symbol is selected given the last selected symbol and the related linguistic category)

- Adaptive scansion rate of the $n$ most probable symbols
Hybrid Predictor

- Semantic network formalism to identify linguistic categories:
  - 6 syntactic categories (verbs, adverbs, adjectives, substantives, people, punctuation)
  - 30 semantic subcategories
- Identification process accomplished in collaboration with experts in verbal rehabilitation
- Note: a symbol could belong more than one category
Hidden Markov Models

- Variation of a classical Hidden Markov Models (HMM)

- Example of classical HMMs:
  - States: $S_1, S_2, S_3$
  - Symbols: $\nu_1, \nu_2, \nu_3, \nu_4$
  - Transition probability: $a_{11}, a_{12}, a_{21}, \ldots$
  - Emission probability: $b_{11}, b_{12}, b_{21}, \ldots$
Hidden Markov Models and Symbols

Classical HMMs do not map completely symbolic prediction issue:

- Traditional HMMs allow the description of:
  - States (linguistic subcategories)
  - Symbols
  - Emission probabilities of a particular symbol in a particular state
  - Transition probabilities between states

- Traditional HMMs do not allow the description of:
  - Emission probabilities of a particular symbol conditioned to the last selected symbol
HMM vs. AR-HMM

- Regression takes into account previous emissions: Auto-Regressive Hidden Markov Models

(Comparison between HMM and AR-HMM)

- AR-HMMs are adopted in continuous systems
DAR-HMM
Symbol emission is a discrete event, a discretization of AR-HMM is required: Discrete Auto-Regressive Hidden Markov Models
DAR-HMM Parameters

- Vector of parameters: $\langle \Pi^0, A, B \rangle$
- Vector of initial subcategory probabilities: $\Pi^0 = (\pi_z(0))$
- Matrix with subcategory transition probabilities: $A[N][N] = (a_{zw})$
- Emission matrix: $B[N][M][M + 1] = (b_{zw}^x y)$
Emission rules (1)

First observed symbol:

\[ \hat{O}(0) = \arg \max_{\nu_w^{(x)}} \left( P(O(0) = \nu_w^{(x)}|\lambda) \right) \]

\[ = \arg \max_{\nu_w^{(x)}} \left( P(O(0)|Q(0),\lambda) P(Q(0)) \right) \]

\[ = \arg \max_{\nu_w^{(x)}} \left( b_w^x \cdot \pi_x(0) \right) \]
Emission rules (2)

Recalling that we can compute the probability of the current (hidden) state as:

\[
P(Q(t)) = \sum_{x=1}^{N} P(Q(t)|Q(t-1)) P(Q(t-1)) = \sum_{x=1}^{N} \pi_y(t-1)a_{xy} = \pi_y(t)
\]

we obtain a recursive form for symbol prediction at time \( t \):

\[
\hat{O}(t) = \arg \max_{v(z^{(x)})} \left( b_{zw}^{xy} \cdot \sum_{y=1}^{N} \pi_y(t-1)a_{xy} \right)
\]
Parameter estimation (1)

- Baum-Welch algorithm adapted for DAR-HMM adopting sentence dataset

- Initialization
  - Uniform distribution for $\Pi^0$
  - In $A^0$ the arcs between symbols and states that are not connected in semantic network have a very low probability
  - $B^0$ is more critical (Segmental k-Means and Viterbi)
Parameter estimation (2)

- *Baum-Welch*
- Stopping criterion based on *generalization error* adopting *K-fold cross validation* technique
  - Generalization loss:
    \[
    GL(t) \triangleq 100 \left( \frac{Err_{Val}(t)}{Err_{Opt}(t)} - 1 \right)
    \]
    \[
    GL(t) > \tau
    \]
Parameter estimation (3)

(synthesis of the training process)
Language model production

AAC language model (syntactic categories, semantic subcategories, symbols, probability matrices)

Purging

User dictionary symbols

Reduced AAC language model

Training and residua probability scaling

User sentence corpus

User AAC language model

(synthesis of the language model production procedure)
Experimental evaluation
Evaluation Indexes

Indexes:

- **Training error**
  - Express the effectiveness of the learning
  - Obtained comparing the suggestions of $CABA^2_L$ during the composition of sentences belonging the training dataset

- **Generalization error**
  - Express the effectiveness of the prediction system
  - Obtained comparing the suggestions of $CABA^2$ during the composition of sentences not presented during the training phase
Case Study

1. Dataset of 20 sentences with 4 sub-categories and 7 symbols (person unskilled in Bliss utilization)
2. Dataset of 80 sentences with 18 sub-categories and 120 symbols (person skilled in Bliss utilization without mental deficiency)
Evaluation Results (Training Error)

Probability that the requested symbol is in the first four predicted symbols according to the datasets adopted to train the DAR-HMM

<table>
<thead>
<tr>
<th>Predictions</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std. Dev.</td>
</tr>
<tr>
<td>1 symbol</td>
<td>0.343</td>
<td>0.055</td>
</tr>
<tr>
<td>2 symbols</td>
<td>0.563</td>
<td>0.074</td>
</tr>
<tr>
<td>3 symbols</td>
<td>0.778</td>
<td>0.067</td>
</tr>
<tr>
<td>4 symbols</td>
<td>0.908</td>
<td>0.056</td>
</tr>
<tr>
<td>not suggested</td>
<td>0.092</td>
<td>0.056</td>
</tr>
</tbody>
</table>
## Evaluation Results (Generalization Error)

Probability that the requested symbol is in the first four predicted symbols according to the datasets not adopted to train the DAR-HMM

<table>
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<tr>
<td></td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>Mean</td>
<td>Std. Dev.</td>
</tr>
<tr>
<td>1 symbol</td>
<td>0.202</td>
<td>0.082</td>
<td>0.185</td>
<td>0.089</td>
</tr>
<tr>
<td>2 symbols</td>
<td>0.438</td>
<td>0.146</td>
<td>0.252</td>
<td>0.073</td>
</tr>
<tr>
<td>3 symbols</td>
<td>0.666</td>
<td>0.181</td>
<td>0.304</td>
<td>0.070</td>
</tr>
<tr>
<td>4 symbols</td>
<td>0.887</td>
<td>0.067</td>
<td>0.357</td>
<td>0.077</td>
</tr>
<tr>
<td>not suggested</td>
<td>0.113</td>
<td>0.067</td>
<td>0.643</td>
<td>0.077</td>
</tr>
</tbody>
</table>
Evaluation Results (Other Issues)

- Sentence composition time reduction: 60%
- Training required time: a few minutes according to dataset size (in our case study: (1) less a minute, (2) between 10 and 15 minutes)
- Prediction required time: < 1s (real time)
Conclusions

• Analysis of the AAC table symbol scansion issue
• Design of symbolic prediction model (semantic-statistical)
• Design of DAR-HMM: formalism, ad-hoc emission rules, training, etc.
• Experimental evaluation
Future works

- Refining the prediction model introducing:
  - Specific syntactic analysis of symbolic languages (AAC languages)
  - On-line adaption to the linguistic behavior of the user and the related evolution
- Analysis of the semantic/probabilistic model to study relationships between disabilities and verbal impairments