Annabell, a cognitive system able to learn different languages

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Abstract. ANNABELL is a cognitive system entirely based on a large-scale neural architecture capable of learning to communicate through natural language starting from a *tabula rasa* condition. In order to shed light on the level of cognitive development required for language acquisition, in this work the model is used to study the acquisition of a new language, namely Albanian, in addition to English. The aim is to evaluate in a completely different and more complex language the ability of the model to acquire new information through several examples introduced in the new language and to process the acquired information, answering questions that require the use of different language patterns. The results show that the system is capable of learning cumulatively in either language and to develop a broad range of language processing functionalities in both languages.

Keywords. ANNABELL, cognitive system, natural language acquisition, bilingual system.

1. Introduction

Suitable modelling of the cognitive foundations of language processing and representation of statistical regularities in natural language are facilitated using neural-networks language models [1-3]. Natural language processing (NLP) techniques make good use of these models, demonstrating superior performances over conventional approaches in next-word prediction and other standard NLP tasks. The recent blooming of recurrent neural networks (RNNs) based deep learning techniques have proven successful for several NLP tasks, including speech recognition [4], parsing [5, 6] machine translation [7] and sentiment analysis of text [8]. Originally biologically inspired, these models have now become essential engineering solutions to specific problems in NLP. However, relatively little work has been done on integrating neural models of language into comprehensive cognitive models compatible with current knowledge on how storing and processing of the verbal information happens in the brain. Miikkulainen [3, 9] and Fidelman et al. [10] presented a cognitive neural architecture able to parse script-based stories, to store them in episodic memory, to generate paraphrases of the narratives, and to answer questions about them. Their model was

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tested on a small corpus of nine scripts, each of which consisted of 4-7 sentences. Dominey and Hinaut [11,12] proposed a neural model of brain areas involved in language processing, able to learn grammatical constructions and to generalize the acquired knowledge to novel constructions. Golosio et al [13], proposed a cognitive architecture ANNABELL, based on a very large scale neural network, designed to help and understand the cognitive process involved in the early language development.

The ability to understand and identify nuances of natural language is complex but fundamental for a wide area of applications. IBM Watson [14], by bringing a cognitive learning approach to the absorption of data, has made it possible for computer systems to understand spoken language. Rather than pattern matching, Watson is taught to understand the structure of languages, through a combination of natural language processing and machine learning being able to parse - to identify the verb, nouns, adjectives and other parts of speech in as much as nine different languages. Mikel Artetxe et al [15] show that neural networks can learn to translate with no parallel texts, through unsupervised machine learning. In the case of languages that have strong similarities in the word clustering, it is easier for artificial linguistic systems to map-out language co-occurrences, like a usual road atlas with words for cities where maps of different languages resemble each other just with different names, in a form of a bilingual dictionary.

In this work, we present a cognitive system able to learn different languages, by adding to the capabilities of the model ANNABELL the processing and production of a second language, completely different and more complex than the English language, with no change in the system's architecture and procedural knowledge in language elaboration. Section 2 describes an overview of the ANNABELL system followed by an extension on the dataset used, in section 3. In section 4, the Albanian language involvement is introduced, and method of training is explained. Results of the validation are presented in section 4, leading to the work being concluded in section 5.

2. Overview of the ANNABELL model

The ANNABELL system (Artificial Neural Network with Adaptive Behaviour Exploited for Language Learning) [13] is a cognitive system entirely based on a large-scale neural architecture (with over 2M neurons) intended to help comprehend the cognitive processes associated with early language development, skilful in memorising thousands of words and sentences, and summing up hundreds of novel sentences, beginning from a supposed clean slate or *tabula rasa*, i.e. having no *a priori* knowledge on the structure of phrases or meaning and clustering of words [13,16]. This model provided a significant advancement in the qualitative and quantitative scaling-up of neural system models of language learning.

The system architecture is globally organised based on a multi-component working memory model [17]. Figure 1 presents the four main components comprised in the model: a verbal short-term memory (STM), a verbal long-term memory (LTM), a central executive (CE) and a reward structure. In the STM are included a phonological store, a focus of attention, a goal stack and a comparison structure. The phonological store serves for maintaining the working phrase, which can be either acquired from verbal input or retrieved from LTM. The focus of attention is a structure able to hold up to four words. Goal chunks that contribute to decision-making processes are stored within the goal stack.

The comparison structure can evidence similarities between words included in the phonological store, in the focus of attention and within the goal stack and additionally aids the decision-making processes. The memorizing of working phrases happens in a dedicated structure included in LTM, while a retrieval structure retrieves memorized phrases using the focus of attention as a cue. The whole decision-dependent processes are controlled by the CE. It consists of a state-action association system, a set of action neurons and a set of gatekeeper neurons. The state-action association system is a neural network that is trained to associate mental actions to the internal states of the system through a reward procedure.

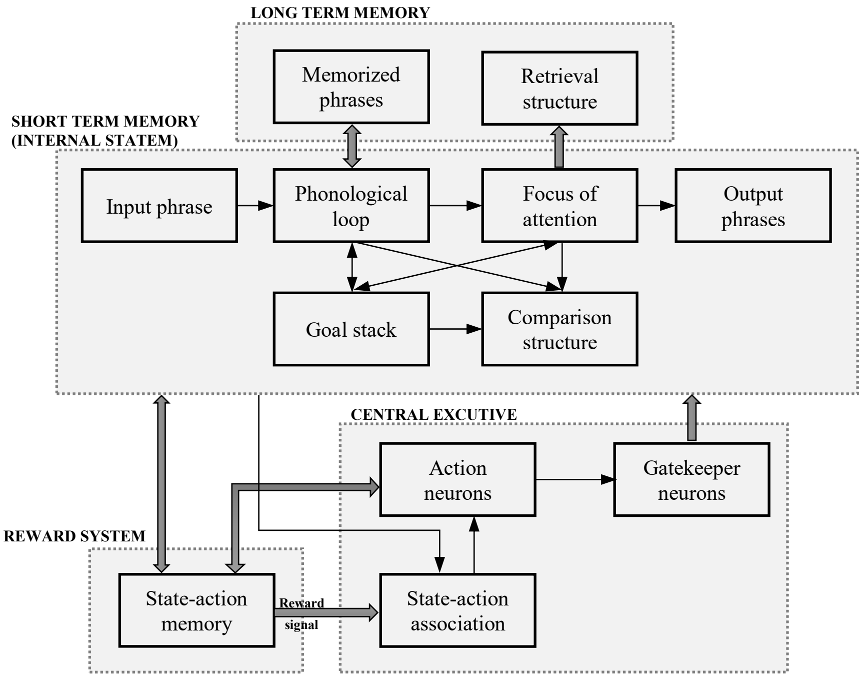

Figure 1 Schematic diagram of ANNABELL

3. Dataset

The training procedure and evaluation of the system's response to the Albanian language is performed using the *People* dataset, described in [13]. 28 conversation test examples from this dataset were considered, being firstly translated and adapted according to the linguistic structures of the new language (database *people_albanian*). Using similar declarative sentences (how-to sentences), prescriptions on specific tasks accomplishments are provided. The system is trained for language and reasoning skills, in the use of different pronouns and the rules they apply to when in a sentence, answering yes/no or multiple-choice questions, counting and comparing numbers, all from previously acquired information through given examples.

Table 1 lists some of the sentences used to describe the social environment of the dataset *People* (or *people_albanian*). It has to be highlighted that there is not difference in meaning to the simulated environment when going from English to Albanian, unless linguistic rules force changes in gender, plurals or sentence order. Thus, the concept of the dataset *People* detailed in [13] remains true even when implementing Albanian as a validating language.

Table 1: Sentences of the dataset *people_albanian.*

Sentence structures	Parents	Sister	Friend	Grand parents	Aunts / uncles	Total
<person> is your <relationship>	2	1	1	4	4	12
You have <number> <relationship> (s)	2	1	1	2	2	8
<person> is a woman/man/girl/boy	2	1	1	4	4	12
<person> has a <noun>	2	1	1	0	0	4
<person> does not have a <noun>	2	1	1	0	0	4
<person> is <number> years old	2	1	1	4	4	12
You do not have a <noun>	-	-	-	-	-	4
Women/men/girls/boys like to…	-	-	-	0	0	7
How-to sentences	-	-	-	-	-	
Other sentences	-	-	-	-	-	
					Total	128

4. Methods

The aim is to evaluate the ability of ANNABELL to memorize through several examples introduced in a completely different and unknown language and later process the information learned, answering questions that require the use of different language patterns. The linguistic competences of the system in the use of articles, nouns, verbs, adjectives and pronouns are targeted for performance comparison with respect to syntactic and semantic correctness with the previously successfully validated system output in the English language [13].

4.1. Albanian language training

Sentences in the Albanian language follow the *<subject> <verb> <object>* order. In comparison with the English patterns used for training and validation from the dataset *People* [13], no changes are introduced in the general sentence structures when Albanian is applied. However, being a more complex language, the following challenges are met:

1. Special characters of the Albanian alphabet, such as *"ç", "ë"* be translated as *"c", "e"* and double letters *"dh, gj, ll, nj, rr, sh, th, xh, zh"* be recognized as two separate characters.
2. The plural in Albanian, as contrary to English, is generally irregular. Many words result in significant changes and are encountered both in singular and plural within the training/testing sentences, thus being it a necessity to describe a rule that can unite their meaning but distinguish among them. As a solution, it is proposed that the root word be singular and followed by a preposition for the word formation of the plural, despite it not being a correct linguistic structure, i.e. similar to the use of the form "stem -suffix", a standard approach in many linguistic systems. For example, the Albanian equivalent of "*brother -> brother -s"* is "*vell**a** -> vell**e**zer*". To the question *"? how many brother -s do you have"* (Albanian: *? sa vellezer ke ti*), the system must reply *"I don't have a brother"* (Albanian: *une nuk kam nje vella*). If used as such, the system is unable

to understand that the relationship remains the same and mistakes the answer. With the solution proposed, the plural of brother in Albanian is written *"vella -ezer"*, where *"vella"* is the root word (same as the singular) and *"-ezer"* the preposition of the plural (*vellezer* = *vella -ezer*). After validation, the results in Albanian (left) and their equivalent in English (right) are obtained, as shown in Figure 2. The system is capable of replying correctly to the first three questions, as appropriate to the conversation while maintaining the sentence structure and having the exact same meaning in both languages. However, to the last example (grey-highlighted), there is no response in Albanian and an incorrect answer is outputted in English. Thus, it can be concluded it not being a language issue but a limited system's capability to process the acquired information in either language.

```
? a ke ti nje vella
.cx
 -> jo une nuk kam
 ...  -> nje vella
+
jo une nuk kam nje vella

? sa vella -ezer ke ti
.cx
 -> une nuk kam
 ...  -> nje vella
+
une nuk kam nje vella

? a ka mami nje vella
.cx
 -> po
 ...  -> ajo
 ...  -> ka
+
po ajo ka

? a ka mami yt nje vella
.cx
```

```
? do you have any brother -s
.cx
 -> no I do not
 ...  -> have a brother
+
no I do not have a brother

? how many brother -s do you have
.cx
 -> I do not
 ...  -> have a brother
+
I do not have a brother

? does Mum have a brother
.cx
 -> yes
 ...  -> she
 ...  -> does
+
yes she does

? does your mother have a brother
.cx
 -> ,
 ...  -> you
 ...  -> do not have a brother
+
, you do not have a brother
```

Figure 2 Simplification of the plural for brother *"vella -ezer"*, where *"vella"* is a root word (same as the singular) and *"-ezer"* the suffix of the plural. Validation results have proven successful in most cases, unless grey-highlighted (remark 2).

Similar adjustments are made for plural formation of other Albanian words that appear irregular. Validation results prove the proposed method of equivalence from singular to plural be successful in most cases.

3. The possessive pronouns in Albanian as contrary to English come after the noun and not only do they change according to the gender of the subject that introduces the possession, but to the object they refer as well. For example, for a feminine subject the possessive pronoun would be her, despite the object (her sister, her brother). While the Albanian equivalent would be "*motra e saj, vellai i saj*" with a change in the article. In some cases, there are more prominent changes in the pronoun pattern such as the following: "*my*" may be either "*im*" (masculine object) "*ime*" (feminine object) or "*e mi*" (plural masculine object),

"*e mia*" (plural feminine object); "*yours*" may be either "*yt*" (masculine object), "*jote*" (feminine object) or "*e tu*" (plural masculine object), "*e tua*" (plural feminine object) and so on. Thus, the changes must be reflected in the main training files to refer to possible scenarios considered in the validation phase. Furthermore, a necessary modification is performing separate training for female and male persons, as the interrogative pronoun "*which*" varies according to gender in the Albanian language (*"cili, cila"*). As a result, the validation was changed accordingly.

```
? a ka motra jote nje cader
.cx
 -> po
 ...  -> ajo
 ...  -> ka
po ajo ka
```

```
? does your sister have an umbrella
.cx
 -> yes
 ...  -> she
 ...  -> does
yes she does
```

```
? a ka mami yt nje vella
.cx
```

```
? does your mother have a brother
.cx
 -> ,
 ...  -> -s
 ...  -> do not have a brother
.
, -s do not have a brother
```

```
? a ka babi yt nje makine
.cx
```

```
? does your father have a car
.cx
 -> no
 ...  -> she
 ...  -> does not have a car
.
no she does not have a car
```

```
? a ka motra jote nje biciklete
.cx
 -> jo
 ...  -> ajo
 ...  -> nuk ka nje biciklete
.
jo ajo nuk ka nje biciklete
```

```
? does your sister have a bike
.cx
 -> no
 ...  -> she
 ...  -> does not have a bike
.
no she does not have a bike
```

```
? a ka shoqja jote nje videoloje
.cx
 -> jo
 ...  -> ajo
 ...  -> nuk ka nje videoloje
.
jo ajo nuk ka nje videoloje
```

```
? does your friend have a videogame
.cx
 -> no
 ...  -> she
 ...  -> does not have a videogame
.
no she does not have a videogame
```

```
? sa vjec eshte motra jote
.cx
 -> ajo
 ...  -> eshte shtate vjec
.
ajo eshte shtate vjec
```

```
? how old is your sister
.cx
 -> she
 ...  -> is seven year -s old
.
she is seven year -s old
```

```
? sa vjec eshte babi yt
.cx
Exploitation number of updates >= 4000
```

```
? how old is your father
.cx
 -> he
 ...  -> is forty_two year -s old
.
he is forty_two year -s old
```

Figure 3. The change of possessive pronouns with the gender of both the subject and the object in the Albanian sentence (remark 3). The training is modified accordingly with correct results (Albanian – left) in most cases.

From the results provided in Figure 3 and Figure 4, it can be safely concluded that for the proposed modifications a correct response is outputted, unless when grey-highlighted, introducing some errors in both cases.

```
? sa vjec eshte gjyshe -ja jote       ? how old is your Grandma
.cx                                   .cx
 -> ? cila                             -> ? which
 ...  -> gjyshe                        ...  -> Grandma
.                                     .
? cila gjyshe                         ? which Grandma

? sa vjec eshte gjysh -i yt           ? how old is your Grandpa
.cx                                   .cx
 -> ai                                 -> ? which
 ...  -> eshte nje burre               ...  -> Grandpa
.                                     .
ai eshte nje burre                    ? which Grandpa

? sa vjec eshte daje -a yt            ? how old is your uncle
.cx                                   .cx
 -> ? cili                             -> ? which
 ...  -> daje                          ...  -> uncle
.                                     .
? cili daje                           ? which uncle
```

Figure 4. Validation results from performing separate training of the interrogative pronoun "*which*" for female and male persons, varying according to gender in the Albanian language (*"cili, cila"*) (remark 3). Correctness is achieved most often.

4. Adjectives in Albanian also change with gender and plurals. In the example conversations, only gender is considered. Thus, the main files are adjusted according to the meaning when necessary. For example, "*old -er , young -er*" and "*young -er , old -er*" are equivalented to "*me e madhe , me e vogel*" (feminine), "*me i madh , me i vogel*" (masculine) and "*me e vogel , me e madhe*" (feminine), "*me i vogel , me i madh*" (masculine), respectively. The system is able to properly detect the gender in all cases, except with the questions *"? is Oliver young -er than you"*, *"? is Oliver old -er than you"* to which no answer is given.
5. In Albanian, nouns change pattern in several circumstances. Let be the word "mother" an example. Some phrases with mother and their corresponding in Albanian are given below:

my mother -----------------------> mami im (root word)
with my mother -----------------> me mami**n** tim
my mother's ---------------------> **e/i** mami**t** tim (unmeaningful with no articles "i, e")
because of my mother ---------> prej mami**t** tim
to my mother -------------------> mami**t** tim

If no rule is applied, the system is unable to respond properly. To address this issue, the training is performed following the structure of English plurals (-s), adding the particle (highlighted in bold) at the end of the word with a dash. The special case word group “*my mother’s – i/e mamit tim*” remains unresolved in this stage because of the appearance of the gender-dependent article before the noun.

6. Referring to the adjectives explained in remark 4 above, another issue arises with concern to the capabilities of the system in processing large input sentences. The comparatives “*older, younger*” become “*me e madhe, me e vogel*”, changing from a number of one to three words in Albanian. As a result, the question *“? is <person> old -er or young -er than you”* (9 words) which is equivalent to *“? eshte <personi> me e madhe apo me e vogel se ti” (“? eshte <personi> me i madh apo me i vogel se ti”)* (11 words) cannot be used for training, being the system unable to read the word *“ti”* (you – necessary to perform the age comparison), extending out of the range of acceptable input words. A solution is proposed, to considering the noun and their article as a single word, resulting in changes: *e vogel -> e_vogel; e madhe -> e_madhe; i vogel -> i_vogel; i madh -> i_madh* reflected at the training files and, thus, reducing the number from 11 to 9 words. With this modification being made, it is obtained a correct validation and with proper gender recognition as given in the results below. It is concluded the issue not being related to language recognition, however such limitation should be targeted for future use of the system in more complex languages than English.

? eshte Letizia me e_vogel apo me e_madhe se ti
.cx
-> ajo
... -> eshte
... -> me e_madhe
ajo eshte me e_madhe

? eshte Oliver me i_vogel apo me i_madh se ti
.cx
-> ai
... -> eshte
... -> me i_madh
ai eshte me i_madh

7. For word groups of more than one word an under dash is added in-between to make them appear as a single word (as in the example photo_albums). The validation is successful for some cases, however being limited for long words of too many letters. For example: *albume_fotografike (photo_album -s), filma_vizatimore (cartoon -s), kafshe_shtepiake (pet -s)*, or for age numbers, such as *gjashtedhjete_e_shtate (67 – sixty_seven), pesedhjete_e_nente (59 – fifty-nine)* and so on. These words are either mistaken (for example *albume_fotografike* becomes *albume_fotograf**police***, *filma_vizatimore* becomes *filma_vizatimor**kater***) or some part of it is left out *(gjashtedhjete_e_nente -> gjashtedhjete_e or kafshe_shtepiake -> kafshe_shtepiak*), etc.

5. Results and Discussion

The output sentences in both languages are extracted from 28 conversation test examples, within the datasets, for each language. In some cases, the Albanian sentences change their usual pattern, in particular when possessive pronouns force an article to be added between the noun and the pronoun, arising some issues during the training.

A set of declarative sentences from the corresponding dataset in each language is presented to the system through the interface, in the form of verbal descriptions. Afterwards, the system is trained using basic questions on the information acquired from the given declarative sentences and guided to produce the correct answers. At the final test stage, evaluation of the system generalization capabilities is performed by asking a set of question similar in structure and meaning to the questions used for training. The ability of the system in processing the memorized information to reproduce correct answers in the context in the exact same way it was taught to during the training but involving different nouns, verbs or adjectives, is validated. The system output sentences are only considered valid if they are syntactically and semantically correct and appropriate for the conversation [13].

For the Albanian language, the validation is made using 28 conversation test examples, which included 128 questions. The system answered correctly to 110 of those questions, while 12 answers were incorrect and 6 voids (the system's output is void - no answer). As a result, the percentage of correct output sentences over the total number is **85.94%**, for the *people_albanian* dataset considered. For the corresponding conversation in the English language, out of the same total number of 128 questions, 115 answers were correct, 13 were incorrect and 0 unanswered (void). As a result, the percentage of the correct output sentences over the total requested is **89.84%**. The results have shown that, in most cases, the same question is mistaken in both languages, with a few others one language being more efficient than the other. Interestingly, the system never misses an answer in the English language, being it either correct or not. While for the Albanian language, it remains void in some cases, claiming an issue to be considered. Table 2 and Table 3 summarize the system's performance for each language.

Table 2: Summary table for the Albanian Language

File category	No. of files	No. of sentences
Training files	3	234
Validation files (train.txt)	28	34
Testing files (test.txt)	28	128
Log files (results)	1	*Total:* 128 *Incorrect:* 12 *Unanswered:* 6 *Efficiency:* **85.94%**

Table 3: Summary table for the English Language

File category	No. of files	No. of sentences
Training files	3	225
Validation files (train.txt)	28	33
Testing files (test.txt)	28	128
Log files (results)	1	*Total:* 128 *Incorrect:* 13 *Unanswered:* 0 *Efficiency:* **89.84%**

5.1. The language-awareness of the system

To prove that the system learns based on examples, without being able to recognize which language it is using, a test example is introduced and can be found in *people_prove.txt* file. In this example, using similar phrases of the dataset *People* or *people_albanian,* the system is told that its mother is in the kitchen and is trained in both languages to answer to the question *"? where is your mother"*. Two cases are considered:

1. Both examples are taught to the system during the training stage and tested along. The system is able to answer in the language it is being asked.

```
? ku eshte mami yt
.cx
 -> ajo
 ...  -> eshte ne kuzhine
ajo eshte ne kuzhine
```

```
? where is your mother
.cx
 -> she
 ...  -> is in the kitchen
she is in the kitchen
```

2. For a question in English the system is taught to answer in Albanian. A translation equivalence is applied between the two languages (*your mother = mami yt*). The training example is written such that mixed sentences in English and Albanian are used as if both part of the same conversation, with no difference in meaning i.e. the training begins in English with the question *"? where is your mother"* and the system is, afterwards, taught the equivalence of the word mother in both languages (*your mother means mami yt*). Having now a bridge between the languages, the system is guided to answer to the question "*? where is your mother*" in Albanian (*ajo eshte ne kuzhine = she is in the kitchen*). At the testing stage, if asked in English, the following output is obtained i.e. to the question in English the system responds in the Albanian language as taught to.

```
? where is your mother
.cx
 -> ajo
 ...  -> eshte ne kuzhine
ajo eshte ne kuzhine
```

In early language learning, words acquire meaning through their connection to actions and perceptions coming from the different sensory systems, a process called language grounding. Indeed, while in adult's second language acquisition the skills related to the new language are mainly built on the already acquired structures related to the mother tongue, in bilingual children [18] the two languages develop on an equal basis primarily through grounding, which in addition to giving meaning to lexicon and grammatical structures allows the child to establish a link between the meanings in the two languages, anchoring them to a common structure, and then to generalize the acquired knowledge from one language to the other. The connection between the words "Mum" and "mami", which in the previous example is built through the sentence "Mum in Albanian is called mami", in bilingual child learning is made through the association of those two words with the perception of maternal presence, which compared to the simple verbal connection has a much higher immediacy and efficacy. In Baddeley's working memory model, the integration of verbal information with information from other sensory systems is made in the so-called episodic buffer. The current version of the ANNABELL model can process only verbal information, therefore it does not include that component.

6. Conclusion

In this paper we have presented the generalisation capability of the cognitive system ANNABELL, able to learn a language completely from scratch, engaging in the parallel learning of the two different languages, English and Albanian. The structure of sentences in the Albanian language is quite different with respect to English, being much complex and requiring few simplifications to be performed, however the main aspects of the languages are considered with correct outcomes in the test. No previous knowledge is provided before and during the training stage about the languages being used, but the information is given as a set of simple example conversations, same in each language. The system learns to answer correctly, with tested accuracy between 86%-90%. The system triggered by a question in one language retrieves an answer in the same language. It could be considered a similar approach to the natural organisation of the information in the brain of a 4 years old child, who stores the acquired information in the same area of the brain, without specific distinction of the language but maintaining the ability to always associate the answer in the correct language.

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