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THE ANALYSIS OF SOME DIFFICULT PROBLEMS OF NATURAL LANGUAGE PROCESSING IN THE LIGHT OF THE NEUROLOGY RESULTS

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The paper analyzes the difficult problems of natural language processing with artificial intelligence tools and, starting from the results in neurolinguistics tries to sketch a state of the art and, meanwhile, to draft a glimpse of the causes of the current theoretical limitations of computational linguistics. Major difficulties that were identified and that are discussed in the paper are metaphor understanding, discourse processing, and empathy.

INTRODUCTION

The study of natural language was a leading research subject in the 20th century, not only in linguistics but also in mathematics (for example, formal languages), philosophy (in its main two directions: hermeneutics and analytic philosophy), logic (the neo-positivism of the school of Vienna vs. the language games of Wittgenstein), and computer science (Natural Language Processing but also the theory of programming languages). Not at least, in the last years of twentieth century and the beginning of the new one, due to the technology advances, language investigation in connection to neurology (neurolinguistics) got a boost.

In recent years remarkable results were obtained in the research and technology on Artificial Intelligence (AI) and in one of its most important and difficult domains: Natural Language Processing (NLP). Probably all readers know and use Google Translate. Many probably also entered in dialog with virtual assistants (conversational bots) such as Siri from Apple, Cortana from Microsoft, Google Assistant or Alexa from Amazon. However, probably any people that used them experienced some totally wrong translations or weird replies of the conversational bots to their queries.

These problems reveal some important drawbacks of the state of the art in the NLP domain, which may be even fundamental and undefeatable. Natural language is known to be ambiguous (Jurafsky & Martin, 2009), its understanding needs empathy, common sense knowledge, and the experience of space and time, which humans naturally get during their life (Winograd, 1987). Even the well-known Turing test (Turing, 1950), which is a dialog test, is now replaced by the Winograd schemas, which emphasize the difficulty of NLP to handle simple questions related to space and life experience that humans can answer without problems, such as "The trophy doesn't fit in the brown suitcase because it's too big. What is too big?" and "Joan made sure to thank Susan for all the help she had given. Who had given the help?" (Levesque, Davis & Morgenstern, 2012).

For decades, the research in NLP focused on constructing grammars and efficient parsers but they were not able to cope, with an acceptable efficiency, with natural language ambiguity, flexibility (that means that you may say the same thing in many similar ways), and the other above-mentioned problems. In recent years, due also to the huge amount of textual data on internet and other high capacity electronic storage devices, the ambition to obtain deep natural language understanding was replaced by the less demanding aim of text mining, that means to extract useful data from texts instead of 'understanding' them. This simpler task is from the beginning not supposed to be perfect and it implies only shallow parsing and even considers acceptable to do not take into account the structuring of words in text (the so-called "bag of words" approach).

The achievements in NLP mentioned above, based on the text mining approach, use mainly the so-called "machine learning" techniques: naïve Bayes, hidden Markov models, support vector machines, and, not the least, neural networks (NNs). Nowadays, NNs have been used with important successes in improving the performances of AI applications, including NLP. Special types of NNs, such as LSTM (Long Short Term Memory), recursive, and convolutional neural networks try to consider words' contexts in text, in order to have better performances than the "bag of words" approaches.

It is obvious that the AI research centered on artificial NNs, simulated in software or even in hardware starts from the results obtained in the study of the human brain, one driving idea being that mind may be explained only by the functioning of the brain's neural networks. Therefore, neurology should be a valuable source of knowledge for NLP developers. However, even if many results were obtained in the neurolinguistics, major neurologists recognize that still there are important unknowns: "The brain itself is a very complex system, and the description of the relation between language functions and the brain remains a big challenge [...] The brain's functioning however, is not yet completely understood. This holds for all different neural levels, from the single neurons and the communication between them up to the level of local circuits and the level of macrocircuits at which neuronal ensembles or even entire brain regions communicate" (Friederici, 2017).

We intend to emphasize in this paper some neurology results that clarifies some language phenomena, but also some still unexplained totally facts. The paper continues with a section that introduces the most important difficult problems of AI natural language processing and a section that discusses neurology findings about how the brain processes language. The fourth section makes an overview of the event-related potentials in the brain that provide data about language processing. The last section before conclusions discusses three difficult NLP problems from the neural corelated perspective.

DIFFICULT NLP PROBLEMS

We may classify the difficult NLP problems in those specific to several of the classical chapters of linguistics and in those general to all chapters. According to the first classification, very difficult problems of NLP are especially related to semantics (metaphors and metonymies, coping with space and time), pragmatics (co-reference resolution, context awareness, illocutionary force, conversational implicatures, etc.), and discourse (coherence, inter-animation, polyphony, narration, etc.). However, even syntax, for which a lot of research has been done and grammars were proposed even thousands of years ago (the Sanskrit grammar of Panini), implies complex problems, not solved completely, the best example being that there is not a grammatical theory and formalism absolutely accepted by the linguistics community.

A general problem of NLP, which appears in all chapters of linguistics, is ambiguity. This is in general much better handled by humans than computers, due to their ability to cope with the other, above mentioned problems: coherence, metaphors, co-reference resolution, etc. Unfortunately, AI techniques were not until now able to perform in a similar degree with humans for these problems, and there are informed opinions that raise questions if they will never do (Trausan-Matu, 2006b, 2017a; Winograd, 1987). In fact, we may say that it seems that ambiguity is even many times desired by human speakers and writers, examples being humor, metaphors, illocutionary speech acts, political and diplomatic discourse, etc. Another phenomena, which may be somehow related to this idea is poetry, musicality, multivocality, and polyphony (Trausan-Matu, 2013, 2017b).

Theoretically, a fundamental problem is that we still do not know everything about how humans deal with natural language, even if many facts about human language processing are now known, especially due to the neurology, psychology, and sociology advances. It is now recognized, for example, that embodiment, empathy, and, related to these two, the experience of living in space and time have a fundamental influence in human language understanding (Winograd, 1987; Trausan-Matu, 2017a); there are results in neurolinguistics in the analysis of metaphors, for example, but, in addition to Winograd's schema mentioned above, phenomena such as polyphony, musicality, poetry, creativity are still not clearly explained.

From another point of view, it is known that no other beings can communicate in natural language as humans do. As in many other cases, the differences between humans and other living beings are said to be due to natural evolution. In this idea, for example, researches tried to teach monkeys or dolphins (considered as "superior" mammals) to "speak" but these researches failed. As Friederici shows, "chimpanzees (our next relative) are unable to learn to combine words to construct larger utterances" (Friederici, 2017). It seems that humans' brain has from birth a capability to process the complex language that we use for communication. However, the mastering of natural language needs also the participation in a community, implying learning, fact proven by little children lost and raised by animals. Without contact to humans until 7 to 12 years old, they lose capacity of managing natural language (Friederici, 2017). This debate on the innate vs. acquired characteristics of language (Chomsky and Piaget, 1988) is reflected also in the technological approaches used in NLP: knowledge-based systems built by human experts versus neural networks or other machine learning techniques.

NEUROLOGY FINDINGS ABOUT LANGUAGE PROCESSING IN THE BRAIN

Between neurology and artificial intelligence are relations in both directions: the research findings from neurology are analyzed and modeled for developing computer programs that mimic human behavior and reasoning. On the opposite direction, AI models and implementations may be used for verifying theories about the functioning of the brain.

However, even if a lot of progress has been achieved in neurology and artificial intelligence, there still are many disputed facts about human language and its relation to our brain and body. The role of embodiment, for example, is discussed not only in the case of language, but also in artificial intelligence, in general.

In neurology, research in how the brain is involved in coping with natural language started from several classes of evidence. Historically the first was the analysis of the incapacities (various types of aphasia) that appeared after injuries and damages on the brain due to car accidents, war wounds, and strokes. Other points of departure for investigations were genetic uncommon features which drove to some language disorders (Pinker, 1999). Due to electroencephalography (EEG) and, in recent years, to technological advances like fMRI, many details about how various phenomena are involved in natural language processing have correlates in the brain activity were discovered.

First, it seems that language processing in the brain may be divided in two: dictionary, lexical processing and grammar, syntactic processing (Pinker, 1999).

Broca 's and Wernicke's regions are known from long time ago as brain areas involved in language processing (Amunts, 2008). The premotor cortex was discovered using functional imagining techniques to be involved in language processing (Wilson et al., 2004; Skipper et al., 2005). Other implied areas are dorsolateral prefrontal cortex, frontal operculum and the insula, subcortical nuclei, the basal ganglia, and the thalamus (Friederici, 2006). Speech implies breathing and the related muscles, the tongue, lips, the vocal cords, etc. all these being controlled by the cortical motor, the somatosensory areas, and the cerebellum (Amunts, 2008).

Subcortical brain structures. limbic and right hemisphere networks can be associated to meaning comprehension of sentences and to "more fundamental cognitive, motivational, and emotional processes" (Tucker, Frishkoff, and Luu, 2008).

Computation of coarse semantic representation seems to involve the middle and superior temporal cortex with a right hemisphere network (Mason and Just, 2006; Macwhinney and Li, 2008). Semantic memory seems to involve the left anterior temporal lobe (LATL) (Westerlund and Pylkkänen, 2014).

EVENT-RELATED POTENTIALS IN THE BRAIN THAT PROVIDE DATA ABOUT LANGUAGE PROCESSING

Important information about neural corelates to natural language processing are provided by measuring several physiological data: event-related potentials (ERP) in the brain (Steinhauer and Connolly, 2008) detected from electrical potentials, and changes in blood flow, visualized by EEG or magnetoencephalography (positron emission tomography – PET, functional magnetic resonance imaging – fMRI, and blood oxygen level dependent – BOLD) (Friederici, 2017).

For example, closure positive shift (CPS) – is related to prosodic boundaries and, together with an N400/P600 pattern also to syntactic errors (Steinhauer and Connolly, 2008). N400 is a negative-going waveform with a peak about 400 ms after a word with problems: "Words that were physically aberrant (larger than normal) elicited a late positive series of potentials, whereas semantically inappropriate words elicited a late negative wave (N400). The N400 wave may be an electrophysiological sign of the 'reprocessing' of semantically anomalous information." (Kutas and Hillyard, 1980).

Other phenomenon, the P600 peak in an EEG was associated with grammatical errors or syntactical complex constructions that need revision ('garden-path') both on reading or hearing (Coulson, King, and Kutas, 2010; Friederici, 2002).

Another event-related potential is the mismatch negativity (MMN), which was related to categorical phoneme perception, being probed the audio–visual McGurk–MacDonald effect (Massaro, 1998): "the subject sees the speaker articulate /ka/ but hears /pa/ – this combination results in the perception of /ta/" (Steinhauer and Connolly, 2008).

Early left anterior negativity (ELAN) is an indicator of natural language syntax neural corelates (Friederici, 2002). However, as in other cases in neurolinguistics, these data are disputed (Steinhauer and Drury, 2012).

NEUROLOGY CORELATES TO DIFFICULT PROBLEMS OF NATURAL LANGUAGE PROCESSING

As we already mentioned, there are several difficult problems of NLP. We will consider here only three of them: metaphors, discourse processing, and empathy.

Metaphors

Metaphors are definitory for our life (Lakoff and Johnson, 1980); they are often used to give insight in what a concept means. For example, "Stocks are very sensitive creatures", identified from a discourse in the New York Stock Exchange web page http://www.nyse.com/), gives a lot of insight on what stocks are, which cannot be obtained only from reading a dictionary definition or from a formal ontology. To understand this metaphor, you must be a human being that had experienced the sensitivity of life creatures, you would need also empathy. Metaphor recognition in texts is one of the most difficult problems of NLP and only some attempts were performed to implement recognition systems (Naranayan, 1999; Trausan-Matu, 2000, 2006a).

A metaphor has a descriptive role, it is creating a link, a transfer of properties (as in "stocks are very sensitive creatures") or contexts ("the exchange rate is increasing") between two concepts, two phenomena or two situations, one well understood and one less known.

In neurology, a lot of research has been done in recent years and important results have been obtained in analyzing processes involved in metaphors. In particular, auditory (comparisons with sonorous events or contexts) and motion metaphors were investigated. Schmidt-Snoek et al. detected associated, different scalp distributions to these metaphors (Schmidt-Snoek et al., 2015), by analyzing the ERP associated to motion (for example, "The partnership was a financial tail spin") and auditory (for example, "His emails were an insistent knock") unfamiliar metaphors. Other researchers also found such connections between the usage of the above mentioned classes of metaphors, for example: "the past is heavy" (Slepian and Ambady, 2014), "anger is heat" (Wilkowski et al., 2009), "love is a journey" (Gibbs, 2013).

Even the metaphorical usage of not sensory-motor words has been proven that it activates sensory motor regions (e.g., Cacciari et al., 2011; Lacey et al., 2012; Desai et al., 2013).

Discourse processing

Discourse is one of the most complex dimensions of human language. Neurologists tried to find associated brain areas to discourse processing. Consequently, from the analysis using fMRI several neural networks were identified in association with functions implied in discourse processing (Mason and Just, 2006; Macwhinney and Li, 2008):

1. Conceptual coherence seems to be obtained with a bilateral network from the dorsolateral prefrontal cortex (DLPFC).

2. Text integration implies the inferior frontal gyrus (IFG) and the LATL through a left hemisphere network. LATL is "one of the regions typically involved in the comprehension of structured sentences as compared to unstructured sentences or word lists […]. The LATL is also recruited during the composition of basic adjective–noun phrases" (Westerlund and Pylkkänen, 2014).

Empathy

Empathy was emphasized by Winograd as being essential to natural language understanding (Winograd, 1987). In psychology, empathy is defined as "a phenomenon in which one person can experience states, thoughts and actions of another person, by psychological transposition of the self in an objective human behavior model, allowing the understanding of the way the other interprets the world" (Marcus, 1997).

In neurology, empathy began to be investigated and explained after the discovery of the mirror neurons by an Italian research group that included Giacomo Rizzolatti and Vittorio Gallese (Praszkier, 2016). As mentioned by Ramachandran "The mirror neurons, it would seem, dissolve the barrier between self and others. I call them 'empathy neurons'" (Ramachandran, 2006). The lack of mirror neurons was discovered at autistic children (Praszkier, 2016; Ramachandran, 2006), which display symptoms such as lack of empathy, theory of other minds, language skills, and imitation (Ramachandran, 2006).

However, other researchers consider that mirror neurons might be only one part of the mechanism that generates empathy. For example, it was found that the oxytocin hormone can generate empathy (Krznaric, 2014). Rhythm also was associated with empathy (Krznaric, 2014; Takahashi et al. 2014).

CONCLUSIONS

The advanced technology used now in neurological investigations started to provide explanations to brain processes involved in natural language understanding, including complex phenomena such as empathy, discourse processing, and metaphors. They provided also, in addition to other evidence, from patients with brain injuries, new data about lexical, syntactical, and semantics processing. However, if even artificial intelligence tools for natural language processing evolved considerably in recent years (and the artificial neural networks are now in the front of the NLP AI technology), they still are not performing similarly to humans. Some new results have shown that not only neurons can explain all the phenomena, for example, empathy seems to be explained also by the oxytocin hormone (Krznaric, 2014).

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