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Boris M. Velichkovsky
Pavel M. Balaban
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Preface

Cognitive Science in Northeastern Europe

Today's cognitive science is the latest version of the century-long quest for a better understanding of the human mind and brain. Various disciplines have brought together empirical methods and theoretical models from their respective fields to further these interdisciplinary efforts. Amongst major of them, one has to mention contemporary informatics with artificial intelligence and robotics, mind philosophy, psychology, linguistics, biology at large, and, of course, neurophysiology. What are scientific sources and organizational history of cognitive and neurophysiological studies in the northeast of Europe?

In this part of the world that is in the former USSR and the contemporary Russian Federation cognitive endeavor has the same root as elsewhere—the romantic tradition of European science. Hermann von Helmholtz was the central figure here in the nineteenth century. He graduated from the Prussian Medical-Military School in Berlin, where his education was paid for by the state. Therefore, he should work as military chirurgic in troops for the rest of life. It was Alexander von Humboldt—nature -philosopher, world traveler, and foreign member of St. Petersburg Academy of Sciences—who as high-ranking Prussian official together with his brother, the great linguist Wilhelm von Humboldt, freed him up from the duties of military service. This opened Helmholtz way to scientific carrier. In the following decades, he contributed a lot not only to his favorite physics but to physiology, mind philosophy, and psychology as well. The founder of this later discipline was his research assistant at Heidelberg University, Wilhelm Wundt. Ladies doctor by education, Wundt was also convinced that newborn "mental chemistry", as science could only be one of interdisciplinary and experimental kind.

The known Russian scholars, Ivan Sechenov and a bit later Vladimir Bechterev, made their studies with Helmholtz, Wundt, and the founder of electrophysiology Emil Duibois Reymond. They studied the same problems but sometimes with radically different accents. For example, when Duibois Reymond declared that consciousness and volition were and would be in the future outside of natural sciences competencies—*ignorabis et ignorabimus*—Sechenov indirectly replied that conscious thought can be understood objectively, that is, by methods of natural

sciences, as inhibited reflex. This approach demonstrated a remarkable productivity in research on the role of prefrontal inhibition in cognitive control and working memory some 100 years later [1]. In the focus of Bekhterev's interests were brain anatomy, mental diseases, psychology, and sociology. In 1885, he founded the laboratory of objective psychology at Kazan University in Volga. This happened only few years after Wundt opened the first psychological institute in the world in Saxonian Leipzig. Linguistics already flourished in Kazan at those times in the work of Jan Baudouin de Courtenay and his students, one of which, Nikolay Trubetskoy, later became international celebrity in phonology. The major international acclaim in the 19th Century the Kazan University had for the work of its liberal rector, mathematician Nikolay Lobachevsky, author of non-Euclidian geometry

In the twentieth century, the idea of integrating different branches of mind-and-brain studies received further impetus from the rocketing development of informatics. In fact, the von Neuman architecture of conventional computer was the first metaphor of modern cognitive psychology [2]. Swiss biologist Jean Piaget even gave psychology a central place among the sciences and technologies, because, in his view, only this discipline studies the conscious mind that makes science and critical thinking possible [3]. However, he always insisted that he studied "epistemic" and not psychological issues. In a similar vein, some of researchers in artificial intelligence, neurophysiology, and psychology would say today that they belong to an interdisciplinary cognitive community whereby adjective "cognitive" replaces here what Piaget called "epistemic" half a century ago. Frankly, other researchers would rather emphasize higher nervous activity and behavior in this context as, for instance, founders and members of Physiological Society named after Ivan Pavlov. An important pioneer of cognitive neuroscience was neuropsychologist Alexandre Luria who became widely known for his research of cognitive development, neurolinguistics, and the functions of brain's frontal lobes [4]. At the end of his life, Luria worked in Moscow but he graduated from Kazan University.

On these historical reasons, the First International Conference of Cognitive Science in the former USSR took place in Kazan in 2004. The 2nd to 8th biannual conferences followed in St. Petersburg, Moscow, Tomsk, and different places of Baltic region. They were organized by the Interregional Association of Cognitive Studies (IACS). Many distinguished international speakers and guests were among hundreds of participants. In particular, one has to name a number of Nobel Prix winners visiting these and related scientific events at different times, such as Daniel Kahneman, Gerald Edelman, James Watson, and Roger Penrose.

The actual book is the postproceeding volume of the 9th International Conference of Cognitive Science, which took place in Moscow from October 10 to 16, 2020 (**Intercognsci–2020**). The Russian Academy of Sciences (RAS) participated in the organization of this conference, and it was partially supported by the Russian Foundation of Basic Research and a number of universities and institutions including the National Research Center "Kurchatov Institute."

In the particular circumstances of this year due to the coronavirus pandemic, only a few colleagues from other parts of Europe and the world were able to participate physically. On the contrary, the interdisciplinary character of reports and virtual discussions at this year conference was very strong. Contributions spanned from artificial intelligence and robotics, to consciousness and voluntary actions, and eye–brain–computer interfaces. For the first time, they also reported on the activities of the Physiological Pavlov Society, besides those of the IACS. We are glad to present a selection of peer-reviewed papers written by members of both these learned societies to our readership around the world.

This publication was made possible thanks to the expertise and generous help of Springer Nature. Special thanks go to Dr. Leontina Di Cecco and Arumugam Deivasigamani from the editorial and production departments of this publishing house, respectively. We are also thankful to Dr. Anna A. Zinina, who intelligently managed the work of communicating with authors during the preparation of their articles. As mentioned above, the work on the volume was supported by the National Research Center "Kurchatov Institute" (decisions 1055 and 1057 from July 2, 2020) and the Russian Foundation of Basic Research (project 18-00-00569/18-00-00940).

January 2021

Boris M. Velichkovsky
Pavel Balaban

References

1. Posner, M. I. (ed.): Cognitive neuroscience of attention. The Guilford Press, NY (2004)
2. Neisser, U.: The limits of cognition. In: P. M. Jusczyk & R. M. Klein (eds.). On the nature of thought. Essays in honor of D.O. Hebb. Erlbaum, Hillsdale (1980)
3. Piaget, J.: Psychology and epistemology: Towards a theory of knowledge. Penguin, Harmondsworth (1972)
4. Luria, A. R.: Basic problems in neurolinguistics. Mouton, The Hague (1976)

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Animal Cognition and Molecular Mechanisms

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Language, Cognitive Systems, and the Methodology of Observation

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Abstract. Language and speech constitute one of the major manifestations of the covert cognitive systems. Each representative of Homo sapiens constantly and massively produces material that can be used as a source of data for the reconstruction of cognitive processes. At the present time linguistic corpora exist that represent linguistic behavior, both spoken and written. This observational resource remains underestimated. Linguists are usually interested in narrow linguistic issues, while specialists in cognitive science only infrequently consult observational data. I discuss a number of linguistic phenomena that manifest general cognitive systems. These linguistic phenomena include discourse structure, disfluencies, a range of reference-related processes, agreement, and multichannel communication. I demonstrate that corpus-based studies of these phenomena shed light on cognitive systems and processes, such as goal-oriented behavior, decision making, non-deterministic choice, working memory, attention, consciousness, theory of mind and so forth. Linguistic resources thus provide a window into general cognition. The methodology of observation may be very useful to this end, especially if used in conjunction with experimentation and modeling methods.

Keywords: Language · Cognitive systems · Observational evidence · Linguistic resources · Discourse structure · Reference · Multimodality

1 Introduction

In this paper I argue for the following two interrelated points:

- Cognitive science may gain from linguistic evidence much more than it currently does;
- Observation is a valuable and informative scientific methodology, along with the other widely recognized methodologies.

Language and speech are among the major **manifestations** of the covert cognitive systems. Each representative of Homo sapiens constantly and massively produces material that can be used as the source of knowledge on how cognitive systems operate. This source of knowledge is strongly underestimated in general cognitive studies, being

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usually delegated to specialized fields such as psycholinguistics or cognitive linguistics. In this paper I discuss a number of linguistic phenomena that manifest various cognitive systems or cognitive processes, such as dynamic structure of behavior, decision making, attention, working memory, consciousness, predictive planning, theory of mind, embodiment, etc. Such notions are *italicized* in the discussion below for a reader's convenience.

Nowadays, linguistic evidence is available in the form of various **resources**, or corpora, representing linguistic behavior, both spoken and written. Observation of the evidence contained in those resources complements the knowledge obtained via the methodologies of experimentation and modeling.

The importance of the **observation methodology** was pointed out many times in the history of science. For example, one of the founders of Gestalt psychology Wolfgang Köhler wrote: "There seems to be a single starting point for psychology, exactly as for all the other sciences: the world as we find it, naively and uncritically. The naiveté may be lost as we proceed. Problems may be found which were at first completely hidden from our eyes. < … > This origin is necessary because there is no other basis from which a science can arise." [1, p. 3]. Wallace Chafe, a linguist whose fundamental contribution will be salient in the discussion below, said: "I will be combining observations of natural language with introspective data concerning the meanings and functions of phenomena observable in compilations of naturally occurring corpora. < … > Furthermore, both spoken and written corpora have the decided advantage of providing data that are natural and not manipulated. < … > Certainly corpus-based observations must be supplemented with introspections, constructed sentences, and experiments, which can carry us beyond the accidental limits of a corpus and give us further insights and further verifiability. But introspections, constructions, and experiments without corpora are fatally limiting." [2, p. 19–20].

The **linguistic phenomena** considered below in six subsequent sections include:

- Discourse Structure
- Disfluencies
- Reference and Referential Choice
- Referential Strategies and Referential Conflict
- Agreement
- Multichannel Communication.

This particular selection is not uniquely suited to the goals of the paper. Virtually any linguistic phenomenon would work to demonstrate the point. I concentrate here on the linguistic phenomena I studied over the years. So this paper largely recounts studies done by myself and my coauthors.

My approach is in line with what George Lakoff [3, p. 40] called the **cognitive commitment**: "a commitment to providing a characterization of general principles for language that accords with what is known about the brain and mind from other disciplines, as well as our own." As was pointed out by Dagmar Divjak [4], this commitment is not always taken sufficiently seriously by cognitive linguists. Furthermore, Aleksandr E. Kibrik (1939–2012) proposed the idea of the **reconstruction of cognitive structure**: "At the foundation of the contemporary cognitive approach to language there is an idea

of a focused reconstruction of cognitive structures on the basis of overt linguistic form. Such reconstruction relies on the postulate of cognitive motivation of linguistic form: to the extent that form is motivated it reflects the underlying cognitive structure" [5, p. 53].

In this paper I intentionally avoid numerous references to general cognitive literature; if I tried, for example, to involve vast literature on attention or working memory, my task would become boundless. Relevant references may be found in the specific linguistic studies that I cite here.

2 Discourse Structure

Discourse is a complex phenomenon. Particular discourses, such as a long conversation or a novel, can be very voluminous. The highest level divisions of discourse determine its global structure, such as chapters in a book. At the opposite end, there is **local discourse structure** consisting of minimal units of discourse. It is the local structure that is the subject of this section, and the discussion is limited to spoken discourse. Local discourse structure provides a window into the basic cognitive phenomenon of the *dynamic structure of behavior*.

The local structure of spoken discourse consists of **elementary discourse units** (EDUs), see [6]. Speech is produced not as a monotonous flow, but in a stepwise fashion. A study of local discourse structure done by our group is based on the corpora of Russian and some other languages, see www.spokencorpora.ru. Our approach was significantly influenced by the work of Chafe [2] and by the work of the Russian phonetician Sandro V. Kodzasov who explored various aspects of prosody, that is non-segmental sound, see [7]. Spoken discourse can only be explored via a procedure known as discourse transcription: a systematic graphic representation of the structural and functional phenomena of speech, see [6].

EDUs are identified on the basis of prosodic (behavioral) criteria, including pausing, tonal contours, accentual centers, tempo patterns, and loudness patterns. Consider example (1) from the Russian corpus "Funny Life Stories":

(1)

21.33	15	•••(0.90) Kogda mne budet /dv̲adcat' let, When I am twenty years old,
23.44	16	/–tebe budet ••(0.39) tol'ko \pjatn̲adcat'. you will only be fifteen.

An acoustic representation of example (1) appears in Fig. 1. This example contains two EDUs, #15 and #16. The first of these has an absolute boundary pause at the beginning marked as "A" in Fig. 1. Both EDUs have holistic tonal contours. Each of the EDUs has an accentual center; the corresponding syllables are marked by ellipses in Fig. 1. There is a clear deceleration effect: in EDU #15 the difference between the mean durations of the initial and final syllables is 128 ms to 206 ms, while in EDU #16 it is 118 ms to 176 ms.

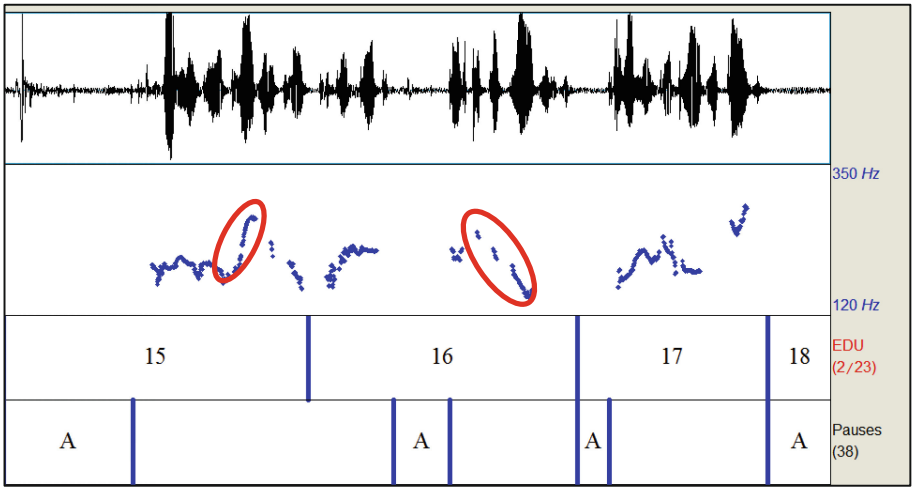

Fig. 1. An acoustic representation of example (1)

The stepwise character of speech and the organization of EDUs have deep evolutionary roots and have much in common with the structure of *goal-oriented behavior* in other species. Chafe [2] suggested that EDUs (intonation units, in his terms) are an overt manifestation of the *foci of consciousness* – a cognitive system that also progresses in a stepwise fashion. Semantically, EDUs typically represent events or states and form a network of connected nodes that can be depicted via hierarchical graphs of Rhetorical Structure Theory [8].

Syntactically, EDUs correlate with clauses. In a number of studies of various languages and various corpora, the level of such correlation was found to vary between 40% and 70%, the latter being more common. There are always residues of subclausal and superclausal EDUs; in a Russian corpus their shares were found to be 26% and 6%, respectively. Overall, clauses are target units via which discourse production progresses. At the same time, clauses are units of experience storage in *long-term memory*. Clause is thus at the intersection of two axes: online dynamic structure of behavior and offline storage. Clause as the fundamental unit of language must have arisen on the basis of the proto-humans' converging abilities to structure their own behavior and the reported experience. In contrast, sentences as groups of EDUs or clauses are much less robust, second-order units that can only be identified in spoken discourse through a fairly sophisticated prosody-informed procedure; see [6] for further details.

To recapitulate this section, spoken discourse is a structured and uniquely explicit manifestation of meaningful behavior. Local discourse structure consists of identifiable behavioral acts – elementary discourse units. EDUs conform to fundamental cognitive constraints, also found in non-linguistic behavior. EDUs correlate with the basic linguistic unit: clause. Human speech is shaped by the coordination of two kinds of segmentation: the quanta of one's own behavior (EDUs) and the quanta of reported experience (clauses).

3 Disfluencies

The delivery of speech is often less than ideal, cf. [9]. Various kinds of **disfluencies** occur. Roughly one can distinguish between two kinds: hesitation (mild disfluency) and self-correction (severe disfluency); see [10] for additional detail. An example of a **hesitation** is found in example (1): it is a pause in the middle of EDU #16, which is not a canonical place to make a pause. In general cognitive literature, this phenomenon is sometimes described as *lingering*; it results from some kind of a temporary *cognitive deficit*: the speaker has hard time finding an appropriate way to phrase his/her thought. This deficit is eventually overcome, and the structure under construction is completed.

Self-correction occurs when a speaker is not able to resolve his/her difficulties and has to cancel and redo some part of the already begun structure. Consider example (2) from the "Funny Life Stories" corpus.

(2)

22.99	23	mne \stydno bylo v /školu xodit', I was ashamed to go to school,
24.12	24	••(0.38) a u nas /malčik učilsja, and there was a boy in our class,
25.53	25	•••(0.72) i ètot /malčik menja posto= == and this boy const= ==
26.94	26	(A on naoborot \otraščival /volosy, (While he the other way around was growing his hair,
28.28	27	i u nas s nim polučilos' odnoj \dliny gde-to primerno.) and he and I got the hair of about the same length.)
30.29	28	•••(0.28) i /on menja načal podka = ‖ nu tipa \postojanno /podkalyval, and he started teas = ‖ well he was like constantly teasing me,

In EDU #24 the speaker introduced a new character, and in #25 she starts telling about the boy teasing her but interrupts herself, having realized that the addressee lacks crucial information, necessary for understanding the reported events. This background information is introduced in EDUs #26 and #27 by way of a parenthetical construction, and subsequently the situation of teasing is reported anew in EDU #28. The cognitive basis of this phenomenon of self-repair is twofold. First, it is *self-monitoring*: the speaker not only speaks, but also listens to herself at the same time. Second, it is the permanent process of modeling the other, known as *theory of mind*: the speaker assesses her own discourse from the point of view of the interlocutor's supposed cognitive states and, if such assessment suggests that her contribution was not satisfactory from the other's point of view, she corrects her behavior accordingly.

4 Reference and Referential Choice

What is inside EDUs and clauses? One of the main phenomena found there is instances of **reference**, that is linguistic expressions mentioning referents, or entities. For example,

at a certain point in discourse I may want to mention Peter the Great, as opposed e.g. to Catherine the Great. An elegant demonstration of how important referential expressions are was offered in [11, p. 230–232], where all referential expressions were removed from a piece of text, which operation rendered the text entirely incomprehensible. In contrast, if one removes everything except for referential expressions, a semantic backbone of the text remains partly recoverable. Reference thus constitutes a lion's share of all information conveyed in natural communication.

Reference is among the most basic cognitive operations performed by language users. Cognitively, reference is a linguistic manifestation of *attention*. Just like attention, reference is selective: at any moment one can only attend to a few things and can only mention a few entities. As was demonstrated in the Sect. 2, discourse tends to move forward via clause-size moments. Clauses typically involve one or two participants, much more rarely three participants and very rarely more than three. This linguistic limitation is a specific instantiation of a more general limitation of the attentional system. Furthermore, many languages attribute the privileged status of subject to one of clause participants. This corresponds to the cognitive notion of *focal attention*, cf. [12].

When the decision to mention Peter the Great is in place, the speaker needs to choose a particular referential expression among the available options. This is the process of **referential choice**.

Basic referential choice is the choice between a lexically full and a lexically reduced forms. Lexically full forms are also called full noun phrases (full NPs) and include, primarily, proper names (such as Peter) and descriptions based on common nouns (e.g. the tzar). Reduced mentions include pronouns (such as he) and zero expressions. Basic referential choice is driven by a referent's status in *working memory*, specifically by the degree of its *activation*:

- high activation in working memory => reduced mention
- low activation in working memory => full mention

Reference and referential choice are instances of *decision making*; speakers make decisions of this kind every moment and do that very rapidly. Table 1 summarizes the cognitive underpinnings of the two phenomena. In [13] I discussed the major issues in reference and referential choice, including both theoretical and cross-linguistic ones.

Table 1. Reference, referential choice, and the corresponding cognitive systems

Linguistic phenomenon		Cognitive phenomenon	
Reference	Decision to mention a referent	Attention	Selective processing of certain information to the exclusion of other information
Referential choice	Decision on which referential expression to employ	Working memory	High level of activation, allowing immediate access

Referential choice is based on referent activation in working memory. But where does activation come from? According to one of the suggestions, attention and working memory are two related cognitive systems: "attention can serve as a kind of 'gatekeeper' for working memory" [14, p. 202]. This idea is supported by the observation of linguistic evidence: what is mentioned (and therefore attended) at the discourse moment t_n is mentioned in a reduced way (and thus highly activated) at the discourse moment t_{n+1}. In linguistic terms, mention t_{n+1} is usually called an anaphor and mention t_n its antecedent. All models of referential choice (aka anaphora, coreference, etc.) recognize that proximity to antecedent is among the key factors of reduced reference. The omnipresent connection between a prior mention and the current reduced reference thus sheds crucial light on the issue of the *relationship between* these two central cognitive systems, *attention and working memory*, hotly debated in psychology for decades (see e.g. a recent review in [15]).

Distance to antecedent is among the main **activation factors**, contributing to a referent's current activation. There is a number of metrics used in the measurement of referential distance, including linear distance in clauses, distance along the hierarchical discourse structure, distance in paragraphs, etc. Another activation factor is the role played by the antecedent in its clause: it is known that subjects make good antecedents for subsequent reduced mentions. Remember that subjects encode focal attention, which again corroborates the attention-working memory relationship.

The above mentioned factors are grounded in the current discourse context. Another group of activation factors is associated with the referent's more permanent properties, such as the status of the current discourse's protagonist or the inherent property of animacy. In particular, discourse evidence suggests that human referents are *maintained in working memory* better than inanimate ones; a similar conclusion was reached in some experimental studies, e.g. [16]. A flow chart of activation factors, activation level, and referential choice appears in Fig. 2 in the next section.

A number of studies in which activation factors were mathematically assessed and shown to work together in a calculative or a neural network model are reviewed in [13]. One of the results of such modeling is a linguistically based evaluation of the *working memory capacity*. Since the developed calculative model can compute each referent's activation at each discourse moment, summary activation is easily obtained. In that model the value of 1 was the maximal activation of a referent. It was found that summary activation of all referents mostly fluctuates between 2 and 3 and does not exceed 4.

A machine learning study of referential choice in a corpus of English texts is reported in [17]. Several thousand anaphor-antecedent pairs were explored and a number of algorithms were tested. The basic referential choice between full NPs and reduced expressions was predicted with the accuracy of about 90%. Subsequently we inquired into the remaining 10% and found that many of those instances were appropriate to human language users as well. An experimental study demonstrated that the texts containing referential options proposed by the algorithm were comprehended as successfully as those that contained original expressions. This suggests that referential choice is a case of partly *non-deterministic decision making*.

To summarize the discussion in this section, reference and referential choice are decision making processes, related to attention and working memory activation, respectively. In particular, high activation is responsible for reduced reference. There is a set of activation factors, grounded in discourse context and in referent's properties. Discourse evidence suggests that working memory is controlled by attention and has a capacity limit of 4 items. Referential choice is partly non-deterministic.

5 Referential Strategies and Referential Conflict

When making referential choice, a speaker has direct access only to his/her referent activation. But it is also important to model one's addressee's cognitive processes. For example, if I say *he* or *them* without caring about the mental state of my interlocutor, the act of reference will likely be unsuccessful. The human ability of modeling the other's cognitive processes is conventionally called *theory of mind*. The observation of actual practices of referential choice in discourse suggests that there are three different **referential strategies**, related to modeling the other and employed by various speakers:

- Egocentric: assume that others' thoughts are just like mine → referential choice is overly economical;
- Overprotective: no assumptions about others' thoughts → referential choice is overly detailed;
- Optimal: make reasonable assumptions about others' thoughts → referential choice is just about right.

The egocentric strategy is found in young children, sometimes in the elderly, and in certain neurological disorders. The overprotective strategy, for example, is observed in certain computational applications imitating human behavior. Those who generally stick to the optimal strategy may occasionally slip into the egocentric strategy and then mend referential choice immediately after, as in example (3) from the "Night Dream Stories" corpus, similar to what linguists call "antitopic construction".

(3)

13.85	7	I /ja < 2 > ••(0.13) /podo-ošël k nemu, And I approached it,
15.93	8	••(0.34) nu k ètomu /derevu, well this tree,
17.38	9	u kotorogo /sverkalo čego-to, near which something was flashing,

In EDU #7 the speaker uses a third person pronoun, apparently meaning the tree that was activated in his working memory at that time, and then realizes that the referent is not activated in the addressee. He then adds two EDUs that specify the referent by means of a noun phrase with a relative clause.

There is another important domain in which speakers need to utilize their theory of mind: those associated with referential ambiguity, or **referential conflict**. As was pointed out in the previous section, more than one referent may be activated in the participants' working memories at the same time. Consider the following constructed example.

(4) Uncle John was sitting at the table. Suddenly a boy approached him. He yelled at him.

By the beginning of the last sentence of (4) the system of activation factors brings two referents to a high level of activation, appropriate for the use of third person pronouns. Two pronouns are used in that sentence, but that is infelicitous: a potential addressee would not know who was the agent and who was the patient of the yelling event. A proper speaker, deploying his/her theory of mind, foresees this situation, filters out at least one of the pronouns and uses a full NP in spite of high activation.

It is important to realize that referential conflict is a separate component of referential choice and not one of the activation factors. It is easy to see that: suppose it is not a boy but a girl appearing in the second sentence of (4). Then *He yelled at her* or *She yelled at him* would be perfectly comprehensible. Therefore, the infelicitous character of (4) is certainly due to something different from insufficient activation. We see that gender is a feature of the English language that helps to remove a potential referential conflict. A variety of such devices (referential aids, or deconflicters, see [13]) are employed in each language and cross-linguistically.

We are now ready to consider the full organization of referential choice, shown in a flow chart in Fig. 2.

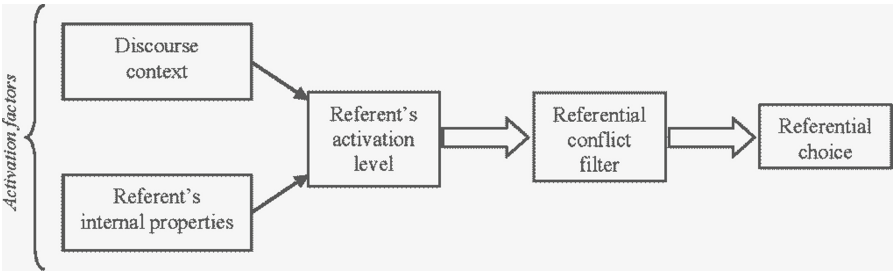

Fig. 2. The cognitive multi-factorial model of referential choice

6 Agreement

According to the linguistic tradition, many morphological facts about languages are explained via the notion of agreement: certain words agree with other words in categories such as person, number, or gender. Agreement is thought to be a purely grammatical asymmetric relationship between verbal units. This view is largely shared by psycholinguists, as well as the general learned public. Consider Russian examples in (5).

(5) a. my bež-im ‘We run’
We run(PRES)-1PL
b. ona beža-l-a ‘She ran’
she run-PAST-FEM.SG

Russian verbs happen to agree with the subject in person and number in the present tense (5a) and in gender and number in the past tense (5b). It seems unquestionable that –im in (5a) appears because the clause subject is the first person plural pronoun, and –a in (5b) because the subject is a feminine singular pronoun. But now consider (6), said by a woman.

(6) ja beža-l-a ‘I ran’
I run-PAST-FEM.SG

What does the verb agree with now? With the first person subject pronoun? Hardly, as that pronoun is not specified for gender. If the verb in (6) agrees with anything, it is the speaker’s own gender. This counterexample is very simple and basic, but it suffices to undermine the traditional grammatical approach. An alternative approach was proposed in [18], the so-called **cognition-to-form mapping**. Apart from instances such as in (6), there are other massive types of evidence that present problems to the grammatical approach. To mention just a few:

- Instances of exophora: in a language such as Russian or Spanish, where adjectives are specified for gender, one can use a sole feminine adjective as applied to a female that is visible to the speaker and the addressee but was never mentioned before verbally.
- Non-local context: agreement features may appear on certain words, while the nearest previous mention in discourse was beyond a reasonable syntactic context, for example in the previous sentence or the previous paragraph.
- Conjunction: conjoined singular nouns typically cooccur with plural forms of verbs, as in *John and Mary are singing*.

The cognition-to-form mapping approach suggests that referents are equipped with certain features in *mental representation*, and these features are mapped on certain sites required by the grammar of the given language. If features of one and the same referent are mapped onto two or several sites, we observe agreement between these sites, as in (5). But it is parallel agreement, resulting from a common external cause, rather than from a formal relationship between linguistic constituents.

The reason why linguists and other scholars still adhere to the problematic notion of form-to-form grammatical agreement is probably associated with the common but narrow view of language as a symbolic system operating on words and governed by formal rules. If language is seen as a cognitively-based and usage-oriented communication process, the picture becomes much more clear and makes better sense.

7 Multichannel Communication

When we communicate naturally, we not only produce chains of words, but also intonate, gesticulate, assume various postures, interact with eye gaze, etc. These processes are