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CHAPTER 8

The Possible Role of Entropy in Processing Argument Dependencies in Hungarian

Csaba Pléh, István Fekete, and Dániel Varga

It has been commonplace in the research of sentence processing for at least 40 years now, since the beginning of the use of Thematic Roles and different versions of Frame Theories in processing studies, to find facilitative effects between verbs and their arguments (Tanenhaus et al, 1995, Kintsch, 1998). The basic idea was proposed in a rather simple manner by early frame and schema based theories of understanding (Schank, 1972, Kintsch, 1994). Understanding a sentence involves two basic stages:

1. Activating the representation of predicates from a long-term store, together with their argument frames, expected and likely arguments.
2. Filling the arguments with actual phrases from the string.

This kind of approach has been supported many times both theoretically and experimentally by postulating and proving priming relations from processing the predicate towards processing the arguments. Thus reading the verb CUT would facilitate the reading of instrumental arguments (Kinsch, 1998, Kintsch & Mangalath, 2011). There were many discussons over the four decades about the relative impact of general expectations (CUT INSTR) and specific lexical expectations (CUT knife).

These early cognitive theories—which are still continued by the group of Kintsch—were not interested in what grammatical markers are used by the system to assign argument roles to certain noun phrases. This was changed by a more detailed linguistic shift towards the argument relations, with the idea that Thematic Roles are keys to the syntax-semantic interface in understanding (Carlson and Tanenhaus, 1988, Tanenhaus, Carlson, and Trueswell, 1989). Several studies have shown that arguments are processed faster than adjuncts (Kennison, 2002), as adjuncts are optional as opposed to arguments, and that assignment ambiguities slow down processing, such as the structural ambiguity in (1), which is more difficult to process than (2) because either John or the policeman could have the *binoculars*, whereas in (2) it can only be the policeman that carries the *gun*.

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(1) *John saw the policeman with the binoculars.*
(2) *John saw the policeman with the gun.*

The step of Thematic Role assignment has started to play a central role in syntax based parsing theories (Frazier and Fodor, 1978, Ferreira and Clifton, 1986), with much discussion on the automaticity and modularity issues. These considerations have introduced the issue of the possible role of morphology in these expectation-based processes.

Bornkessel and Schlesewsky (2006, Bornkessel-Schlesewsky et al., 2011) have run many behavioral, evoked potential, and imaging studies on sentence understanding in languages using different types of cues to argument roles (order, animacy, case marking). Independently of the cues used, Broca's area always played a crucial role in assigning Thematic Roles. On the basis of these processing data, Bornkessel & Schlesewsky (2006) developed a fully-fledged cross-linguistic theory of the temporal activation of the verbal argument frames and the insertion of noun phrases into the slots as a second step based on neuronal processing evidence.

In our work we concentrate on oblique arguments of Hungarian verbs exploiting the fact that argument relations are coded by case markers in Hungarian (Kiefer, 1987, 2003). Argument processing and Thematic Role assignment in such a language is closely tied with morphological processing. In particular, most arguments with abstract relations are coded by concrete/spatial case markers that originally denoted locational relationships in the physical world. For example, the abstract relation in the Hungarian sentence *János fél a kutyától* ('John is afraid of the dog') is expressed by the ablative suffix *-tól/-től* ('from'). The suffix has two realizations (*-tól*/*-től*), determined by the phonological environment of the noun stem to which it is attached (on Hungarian vowel harmony, see Siptár and Törkenczy, 2000). This alternation of physical/concrete and abstract argument use results several times in ambiguities to decide whether a given NP is an abstract argument or a concrete adjunct. The alternation between spatial and abstract argument interpretation often results in ambiguities.

There has been much discussion on how to differentiate arguments from adjuncts in Hungarian (Komlósy, 1994, Alberti et al, 2014). Table 8.1 illustrates some of these intricacies.

There are, of course, ambiguous argument frames in English too. The sentence *John decided on the boat* can be interpreted either as John chose the boat or that he made his decision while on the boat (Hornstein and Weinberg, 1981). However, in English these cases result from structural ambiguity based on attachment height of the prepositional phrase (PP; in

TABLE 8.1 *Varieties of the morphology of some argument frames in Hungarian*

Type	Example	Gloss
Unambigouous	Emlékszik a fiú**ra** Haragszik a tanító**ra.** Készül a verseny**re.** Találkozott a lán**nyal.** Csókolózott a rendő**rrel.**	remembers the boy-ON angers the teacher-ON Prepares the race-ON Met the girls-INST Kissed the cop-INST
ambiguous in marking	Gondol a lány**ra.** Gondol valami**t.**	thinks girl-ON thinks something-ACC
ambiguous argument / adjunct	Gondolkodik a lány**on.** Gondolkodik a haj**ón.**	thinks girl-ON thinks boat-ON

the cited example the PP is 'on the boat'). In Hungarian, however, they are related to the case suffixes of nouns. Earlier studies on the processing of argument structures in Hungarian have shown that these assumed interactions between morphology and sentence processing do indeed hold. Gervain and Pléh (2004) showed that prenominal, sentence initial verbs facilitate the processing of constructions like 'Anna thought of the boat,' and postverbal nouns that are ambiguous between a locational and an abstract-argument reading are read slower than unambiguous arguments. Compare 'Anna RUMINATED on the boat' versus 'Anna RUMINATED on the problem,' where in the latter case the locative meaning is excluded. Gervain and Pléh interpreted their data as supporting priming, facilitative effects from the verb to morphological endings coding for arguments. Figure 8.1 shows one of the examples for the concrete/physical meaning being slower, as it activates the abstract meaning too.

Thus, the data implies a processing model where a verb based expectation arrow would metaphorically 'point' towards the argument. That is why the argument noun would be read faster compared to the adjunct/argument Ambiguity between locative and argument reading slows down reading the NP.

Instrumentals are interesting structures regarding both the possible arguments frames of the main verbs, warrying between comitative, and 'real instrumental' readings. They also alternate between argument and adjunct readings. (3) to (5) show some of the interesting structures we worked with.

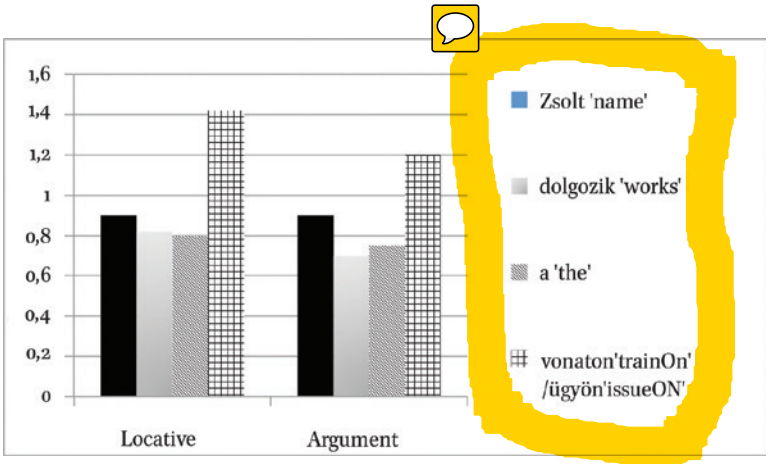

FIGURE 8.1 *Spatial case endings are ambiguous, thus they are read slower than arguments with the same case ending* 'John works on the train/ on the case.'

(4) *A katona a kert-ben **sétált** a lánny-*[1]*al.* **adjunct**
'The soldier the garden-IN walked the girl-INST'

(4) *A katona a kertben **játszott** a lánnyal.* **ambiguous**
'The soldier the garden-IN played the girl-INST'

(5) *A katona a kertben **találkozott** a lánnyal.* **argument**
'The soldier the garden-IN met the girl-INST'

Fekete and Pléh (2011) compared unidirectional (6), and bidirectional (7) comitative constructions, and the singular or plural anaphoric continuations in a word-by-word self paced reading paradigm.

(6) *A fiú gúnyolódott a lánnyal, aztán leült/leültek.*
'The boy mocked the girl-INST, and then sat down/and then they sat down.'

(7) *A fiú játszott a lánnyal, aztán leült/leültek.*
'The boy played the girl-INST, and then sat down/and then they sat down.'

By unidirectional comitative construction we mean an event with an agent and a patient, while a bidirectional construction involves an agent and a co-agent. Crucially, unidirectional constructions are semantically irreversible, while bidirectional constructions are reversible. Hungarian, as being a PRO-DROP

1 Notice that there is fusional allomorphy here. Instrumental case *-val/-vel* is fused with stem ending consonats. Thus *lány-val* is realized as *lánnyal*. See Kiefer (2003).

TABLE 8.2 *The critical verbs used in the experiments on* COM *and* INST *processing*

Comitative	Instrumental
borozott = drank wine with	csipkelődött = bantered with
találkozott = met with	foglalkozott = dealt with
tegeződött = were on familiar terms with	incselkedett = flirted with
csókolózott = kissed with	gúnyolódott = japed/jested with
sétálgatott = walked ith	orított = shouted with
bulizott = partied with	szimpatizált = liked somebody
mulatozott = racketed with	csúfolódott = mocked
párbajozott = duelled with	együttérzett = sympathized with
verekedett = fought with	kikezdett = made a pass at sb.
énekelt = sang with	törődött = cared for someone

language, uses zero anaphors in the continuation sentences in these constructions (Pléh and Radics, 1978). Table 8.2 shows the verbs used in these studies.

Not surprisingly, after unidirectionals (6), the singular, after bidirectionals (7), the plural continuations were read faster, showing a 'deep anaphora effect' in the sense introduced by Hankamer & Sag (1976). In other words, it is easier to refer to the subject of a unidirectional construction than referring to both the agent and the patient with the plural. However, in the case of a bidirectional construction, the plural reference is more accessible because the two agents are equal in terms of their involvement in the event.

Interestingly, reading times and answering times were both faster after the unidirectional instrumental frames. This is presumably due to the argument versus adjunct status of the verb-NP relations. The reading times are summarized in Figure 8.2. Some of the verbs (4 out of 10) in the bidirectional (comitative) condition can stand alone without any further arguments beside the agent. The reading times are summarized on Figure 8.2. NVN (noun-verb-noun) indicates the word order used in this condition. Crucially, during sentence processing on the region of the verb the second argument is not spelled out, so in the bidirectional (comitative) condition the parser encounters a bifurcation, which causes slowdown in processing (complexity spill-over): the sentence could as well finish as a grammatical sentence without an argument (e.g., the boy sang, partied, walked, etc.), or the verb could select for a second argument, a co-agent, while in the unidirectional (instrumental) condition the verb obligatorily selects for an argument, hence the faster processing times of the second arguments in the instrumental condition.

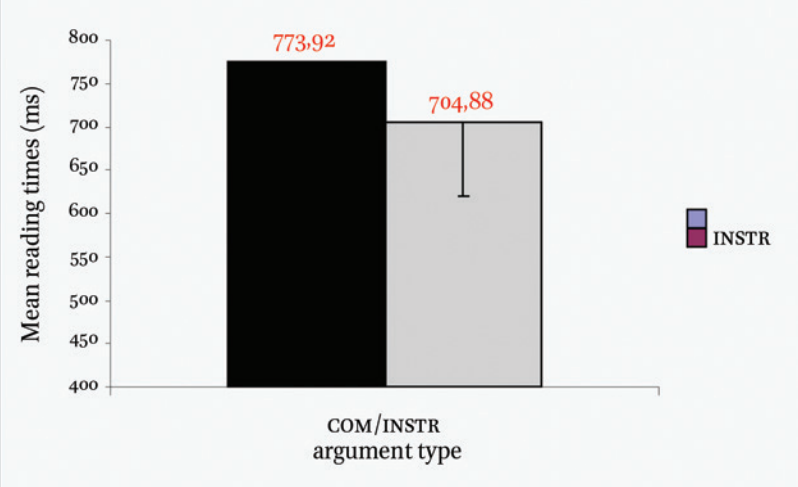

FIGURE 8.2 *Mean reading times of the arguments after the critical verbs (NVN) in the COM-INSTR experiment.*

Reanalysis with the Possible Role of Entropy

Although in the studies mentioned above the frequencies were controlled, and the role of collocations was controlled for by reversing the noun phrases in the different conditions, the issue of the statistical conditional predictability in the argument relations was not raised at all. However, it should be noted that we strived to step around this confound by conducting a separate experiment where the verbs were presented in sentence-final position, which rules out the possibility that verbs project their argument structure, that is, expectations are made about the continuation with a second argument (Fekete and Pléh, 2011). Importantly, Hungarian has a relatively free word order. This way, we can rule out the argument-adjunct effects, which arose in the previous condition where sentences were presented in NVN word order.

In the present paper, a post hoc reanalysis of the reaction time data of Fekete and Pléh (2011) is conducted by using entropy of relations as a possible predictor. Importantly, we are examining reaction time data of our experiment in which verbs presented were between two case marked NPs, thus between possible arguments. Informally, in this situation entropy is the uncertainty of the case ending following a given verb. So, for example, the Hungarian verb *harcol* ('fight') can select for three different oblique case endings (*-ért* 'for,' *-val/-vel* 'with,' *ellen* 'against') with unequal probability. Moreover, the second case ending 'with' is in itself ambiguous. The given actor can either refer to a co-agent who is on the side of the semantic agent or an enemy against whom

the agent is fighting. This creates a rather uncertain situation following this verb. By contrast, the verb *gondol* 'thinks' licenses only one case ending, *-ra/-re* (literally 'on'). Thus there is a clear difference in terms of the uncertainty with regard to the argument structure.

To operationalize argument related conditional entropy, one can conceive of it as a measure of uncertainty about the nominal contexts in the presence of a given verb. Due to the free movement of NPs in Hungarian, both subsequent and preceding contexts are considered.

The entropy of a discrete probability distribution W is defined by (8).

$$(8) \quad H(W) = -\sum_{w \in W} p(w) \log_2 p(w)$$

Consider the following simple random process: for a given verb word form, we pick a noun phrase in the corpus within a predetermined window form this verb, and take the case of this noun phrase. We define the conditional entropy of the case frames of a verb as the entropy of the output of this random process. Intuitively, it measures how diverse the possible set of cases accompanying a verb is, giving less weight to rare cases.

We computed entropy measures from two corpora. From the MOKK (2006, Kornai et al, 2006) and the MAZSOLA corpus (Sas, 2008) entropy computations were made for the relations between a given verb and the noun endings in a 'plus/minus two content words' frame. These entropy estimates will be used as predictors in the self-paced word-by-word reading time experiments of Fekete and Pléh for the reading of nouns in sentence contexts. In this we wanted to learn whether the entropy relations between verbs and case endings do have an explanatory power in processing and verb-noun attachments.

Entropy in the Two Corpora

The *Szószablya* corpus does not identify dependents, so we work with nouns following the verb within a fixed (4-token) window. The *Mazsola* corpus does identify dependents, but its size is somewhat smaller. (226M tokens versus 712M tokens.)

In the case of the *Mazsola* corpus, we only required the verb stem to correspond, thus, citation forms were used, while in the case of the *Szószablya* corpus, we required the exact word form of the verb as used in the experiments.

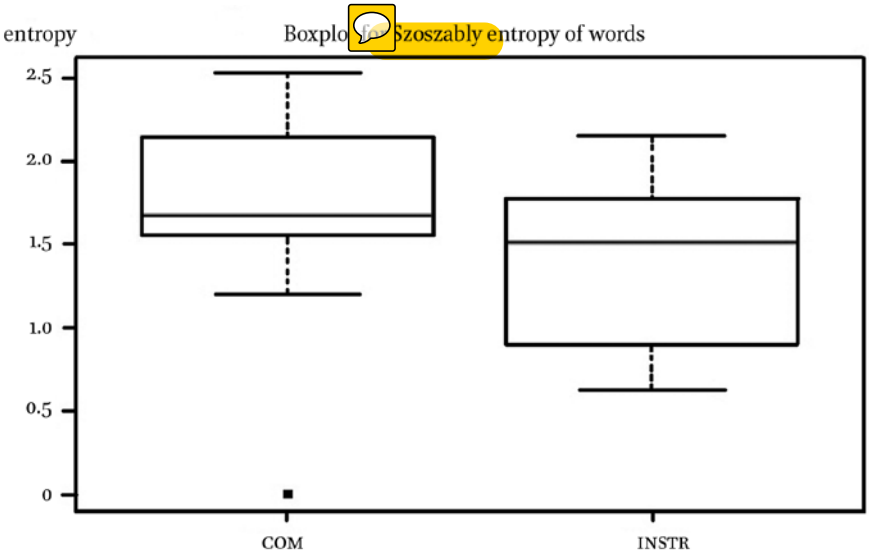

FIGURE 8.3 *Entropy of* COMIT *is higher.*

The correlation between the two entropy measures was extremely high, 0.937, showing that the entropy measure from the two corpora are robustly similar.

The comitative, bidirectional verbs on the whole had a less predictable relation to the nominal case endings in their environment, presumably due to the adjunct status of the oblique NP. As Figure 8.3 shows, their entropy was much higher.

There was a not simple but interesting relationship between the reaction time differences in the verb pairs and entropy, as Figure 8.4. shows

It is important to note that although the reading times above denote the reading times of word 5, this reading time reflects sentence integration processes given that this position is the sentence-final position.

Conclusions

– The entropy notion extended to Verb-Argument relations is rather robust
– It is related to argument frame differences such as INSTR COMIT differences
– The entropy of the argument frame has some effects on processing speed

The ambiguity of argument frames that was originally used in these studies can be conceived of as a situation of maximum entropy when all possible

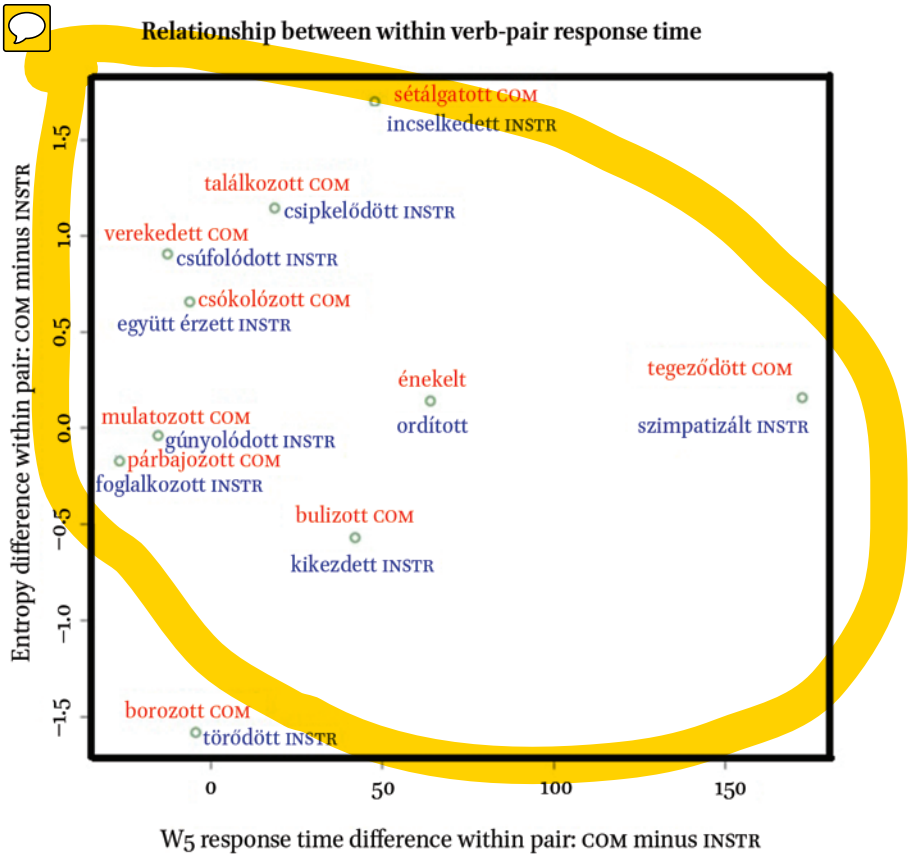

FIGURE 8.4 *Entropy differences correspond to RT differences.*

argument frames are equally likely. Its relation to grammatical effects and semantic priming still has to be clarified. It could be the case that the deep anaphora effect revealed in Fekete and Pléh (2011) is a spillover effect consistent with the difference in entropy between the two case conditions, rather than resulting from a difference in mental representations of the scenarios described by the sentences. In other words, differences in verb-conditioned entropy could in principle explain the resulting pattern more parsimoniously than the putative representational-semantic difference between comitative and instrumental constructions.

Language understanding, which involves both bottom-up and top-down (contextual) processes, is not only inductive but also expectation-driven. We are faster at processing language material which has been anticipated, predicted, or highly probable based on the context or the linguistic environment in a sentence (e.g., Balota, Yap, & Cortese, 2006). One of these expectation-driven

processes is the projection of the argument structure of verbs (the activation of candidate case frames in Hungarian), which is an automatic, very rapid and unconscious process contingent on the entropy of the verb in question. The different psycholinguistic factors such as word frequency, word length, affix type frequency, etc. jointly determine processing time. One of these influencing factors that can predict reading times is the entropy of verb related argument structure.

Our results are in line with findings in the field of inflectional entropy. Moscoso del Prado Martín, Kostic, and Baayen (2004), for example, demonstrated that visual lexical decision latencies of Dutch nouns were positively correlated with inflectional entropy. Similarly to the entropy of argument structure, inflectional entropy indicates the uncertainty as to the probability and the number of inflectional variants the noun has. Specifically, it is higher for nouns that have more inflectional variants as opposed to nouns that have fewer. Crucially, nouns with inflectional variants of equal or similar probabilities also result in an entropy increase. Recently, Pylkkänen et al. (2004) showed that such an effect can be shown at the neuronal level too.

Entropy might provide better explanations for some psycholinguistic phenomena than traditional factors taken into account. Technically this suggests that entropy as a sensitive psycholinguistic variable should be taken into consideration in experimental psycholinguistics by gathering entropy measures from morphosyntactically-annotated corpora or psycholinguistic norms.

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