Incremental & predictive pragmatic interpretation: A rational analysis

Probabilisitic pragmatics (Franke and Jäger, 2016; Goodman and Frank, 2016) models pragmatic interpretation as probabilistic inference to the best explanation of a speaker's utterance. This approach has focused so far on holistic, utterance-final reasoning. In contrast, we here explore possibilities of probabilistic pragmatics predict the temporal development of rational interpretation during word-by-word processing. We derive two notions: (i) next-word probability and (ii) accumulated interpretation evidence. We discuss pilot applications of each to data from (i) EEG-studies on scalar implicature processing (Augurzky and Franke, 2016; Augurzky, Franke, and Ulrich, 2017) and (ii) mouse-tracking studies on rapid intonation-sensitive meaning disambiguation (Roettger and Stoeber, 2017; Roettger and Franke, 2017).

Probabilistic pragmatics, holistic reasoning. Pragmatic interpretation is usually captured by a distribution $P_L(t \mid m)$ that assigns a probability to each meaning t given a message m. These are defined by Bayes rule, combining the prior $P(t)$ and the likelihood $P_S(m \mid t)$ with which a speaker would utter m to express meaning t: $P_L(t \mid m) \propto P(t)\, P_S(m \mid t)$. The speaker's likelihood of message choice $P_S(m \mid t)$ is usually defined in such a way that true messages are preferred over false ones (Gricean Quality) and that of any two true messages the likelihood of choosing the semantically stronger is higher (Gricean Quantity). More complex notions, e.g., additional manner considerations, can be added, but none of this is important for present purposes.

Incremental, predictive pragmatic interpretation. The interpretation rule above is holistic: it assigns an interpretation t to a whole utterance m. But we can also define what a rational pragmatic interpreter would believe after observing any initial part of an utterance m. Let utterance $m = w_1, \dots, w_n$ be a sequence of words. Define $m_{\to i} = w_1, \dots w_i$ as the initial subpart of m up to and including word w_i. Write $m_{\to i}, w_{i+1}$ for the continuation of $m_{\to i}$ with word w_{i+1}. Let $M(m_{\to i}) = \left\{ m' \in M \mid m'_{\to i} = m_{\to i} \right\}$ be the set of all messages from superset M (see below) which have the same initial subpart up to word w_i as m. Two interesting aspects of incremental and predictive pragmatic interpretation can be defined for a listener who has observed $m_{\to i}$. These are beliefs about the likely next word w_{i+1} in the speaker's utterance [1] and about the likely eventual speaker-intended pragmatic meaning t [2]:

$$P_L(w_{i+1} \mid m_{\to i}) \propto \sum_t P(t) \sum_{m' \in M(m_{\to i}, w_{i+1})} P_S(m' \mid t) \quad [1]$$

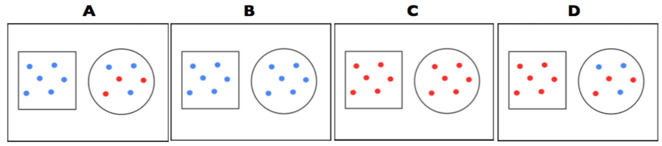
$$P_L(t \mid m_{\to i}) \propto P(t) \sum_{m' \in M(m_{\to i})} P_S(m' \mid t) \quad [2]$$

The quantities in [1] and [2] depend on sets M of potential speaker utterances and T of possible meanings. It is a vexing issue how to handle estimate or determine these in general. But for applications to data from concise experimental designs, we temporarily adopt the **experimental microcosmos assumption (EMA)**: sets M and T are defined by the sentences and relevant meaning distinctions in the experiment.

Case study 1. Augurzky and Franke (2016) recorded ERPs from 25 native German speakers. Participants were saw one of four picture types (see illustration below) and then read one of eight sentence types (1). ERPs were measured at the three positions indicated in (1).

(1) Alle/Einige$_1$ Punkte sind blau/rot$_2$, die im Kreis/Quadrat$_3$ sind
all/some dots are blue/red, that in the circle/square are
All/some of the dots in the circle/square are blue/red

We use contextually determined pragmatic expectations about the likely next word following scheme in [1], and use it as a predictor of the grand average N400 amplitude after onset of the critical positions in (1). We find that the model performs quite well ($r \approx 0.81$, $p < 0.001$). The model also captures differences in ERP responses between two groups of participants (e.g. Spychalska, Kontinen, and Werning, 2016): predominantly semantic and predominantly pragmatic responders are best modelled, respectively, by using a literal or a pragmatic speaker function $P_S(m \mid t)$ in [1]. This suggests that probabilistic pragmatic models may help bridge theoretical pragmatics and quantitative psycholinguistic modeling. Notice that similar measures of next-word probability, e.g., derived from corpus frequencies, predict quantitative patterns in reading times related to syntactic parsing or N400 amplitudes associated with lexical-semantic processing (e.g. Levy, 2008; Frank et al., 2015). Our approach instead quantifies



expectations of *pragmatic adequacy in context* beyond syntax or lexeme associations for sentences of identical syntactic complexity and lexical cohesion.

Under the EMA, alternative sentences co-present during the experiment should matter. To test this, Augurzky, Franke, and Ulrich (2017) also explored a variant of the previous experiment which did not include fillers with the quantifier *all*. In line with the EMA, all traces of scalar implicature calculation in the ERP signals disappeared.

Case study 2. Roettger and Stoeber (2017) looked at mouse-tracking data on early intonation-driven sentence interpretation. While listening to a spoken sentence, participants moved a slowed-down mouse to select one of two pictures that showed potential meanings of the incoming sentence. There were four different conditions, individuated by the kind of question displayed at the beginning of a trial (e.g., "Does the yellow wuggy carry a chicken?"), as well as the wording and intonational contour of the sentence (e.g., "The BLUE wuggy carries a chicken"). Results show that average mouse-trajectories gravitate towards the target picture, even before lexically disambiguating material was encountered by exploiting early intonational information (e.g., already after hearing stressed *blue*). The incremental interpretation scheme in [2] predicts the temporal order among conditions of when average mouse trajectories start gravitating to the target picture, if we assume the EMA and that listeners expect sentences with the natural given/old intonational contour for the presented topic question.

In order to further test the role of the (listener's assumption about) a hypothetical speaker's production behavior $P_S(m \mid t)$ in intonation-based online intention inference, Roettger and Franke (2017) manipulated the reliability of the intonational cue in a between-subjects design. Participants in the reliable group processed utterances with an intonational contour that was natural for the preceding context question. For participants in the unreliable group 33% of critical utterances occurred with an intonational contour that was unnatural for the context. Preliminary data analyses shows that participants in the reliable group were able to exploit intonational cues very rapidly already from the start of the experiment (suggesting that this behavior is not just an experiment-induced rational task strategy). In contrast, participants in the unreliable speaker group seemed to quickly unlearn to exploit intonational cues. We tentatively conclude that participants enter the task expecting a speaker who acts pragmatically adequate, exploit this assumption rationally, but give up on this assumption if it turns out to be unwarranted.

Conclusion. These case studies gesture towards how probabilistic pragmatics could possibly be relevant for making predictions about online pragmatic processing. Much hinges on the specification of M and $P_S(m \mid t)$, as well as on how exactly predictions from [1] or [2] are to be mapped onto empirical data. Consequently, this work is meant only as a first illustration of how empirical applications of a rational analysis of pragmatic processing could possibly look like, thus illustrating with concrete examples what work in the second phase of our XPrag.de entails.

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