Integrating Surprisal and Dependency Locality Theory: A Broad Coverage Model

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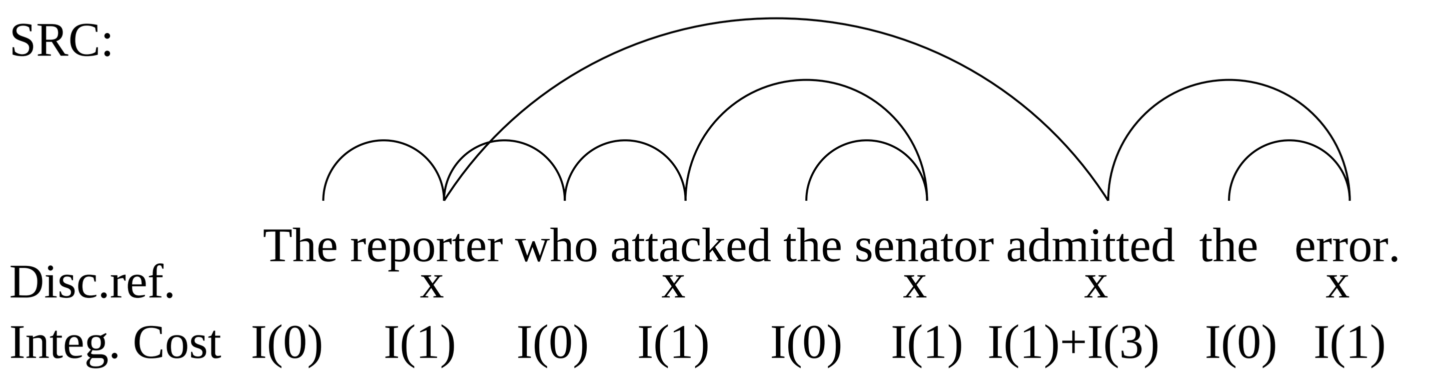
Introduction

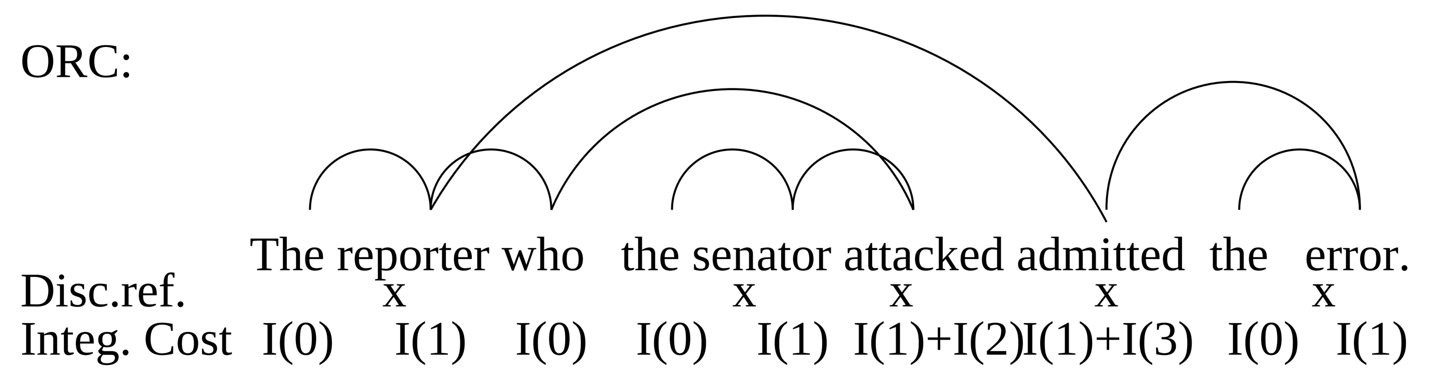
- **Dependency Locality Theory** (DLT; Gibson, 1998) predicts processing difficulty based on integration cost (IC), the effort required when integrating a head with its dependents.
- Alternative: **Surprisal** (Hale, 2001) relates processing difficulty to the amount of information processed at each word in the sentence.
- Demberg and Keller (2007) tested both IC and Surprisal on an eyetracking corpus, and found that Surprisal, but not IC, predicts reading times in a broad-coverage setting.
- Here we propose a variant of DLT capable of making **broad coverage predictions** by redefining integration cost in terms of surprisal.

Integration Cost

- Integration cost occurs at heads of phrases when dependents are integrated; the number of discourse referents crossed determines cost.
- We used Minipar to compute dependency structures, determine discourse referents, and compute the integration cost for every word.

Example:





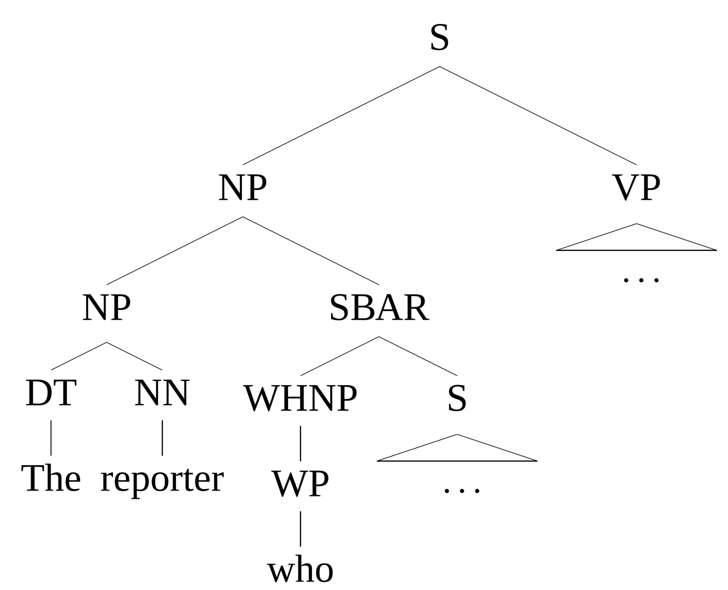
Surprisal

- Processing difficulty is triggered when surprising linguistic material is processed (structures that are unlikely given the current input).
- The Surprisal S_{k+1} at word w_{k+1} is defined as the conditional probability of w_{k+1} given the left context (words w_1 to w_k):

$$\begin{aligned} S_{k+1} &= -\log P(w_{k+1}|w_1 \cdots w_k) \\ &= \log P(w_1 \cdots w_k) - \log P(w_1 \cdots w_{k+1}) \end{aligned} \quad (1)$$

  where $P(w_1 \cdots w_k)$ is the prefix probability of the string $w_1 \cdots w_k$.
- We used Roark's (2001) incremental lexicalized parser to compute prefix probabilities.

Example:



Example	Rule	Rule prob.
The reporter who ...	S → VP NP	$p = 0.6$
The reporter who ...	NP → NP SBAR	$p = 0.004$
The reporter	NP → DT NN	$p = 0.5$
reporter	NN → reporter	$p = 0.0002$
who	WHNP → WP	$p = 0.2$
who	WP → who	$p = 0.8$

Surprisal-based Integration Cost

- Surprisal-based Integration Cost (SIC) combines DLT and Surprisal.
- At a head w_h, the SIC of a syntactic dependent w_d is defined as $S_{d...h}$, the cumulative Surprisal of the words intervening between w_h and w_d.
- The Surprisal of a region of words can be defined as:

$$S_{d...h} = \log P(w_1 \cdots w_h) - \log P(w_1 \cdots w_d) \quad (2)$$

- If d directly follows h, then SIC reduces to standard Surprisal.
- The total SIC at h is defined as the sum of the Surprisal of all its dependents:

$$SIC_h = \sum_d S_{d...h} \quad (3)$$

- SIC is distance-based like IC, but distance is measured as Surprisal of the intervening words, not as number of intervening discourse referents.
- **Hypothesis:** intervening high-Surprisal material makes it more difficult to keep a dependent in memory.

Experiments

Method

- Data: Dundee Corpus (Kennedy & Pynte, 2005); contains eyetracking record of 10 subjects reading 51,000 words of newspaper text.
- Method: hierarchical mixed effects model with reading time as the dependent variable and SIC, standard IC, or Surprisal as target variable.
- The models included nine control variables that are known to influence reading time (e.g., frequency, launch distance).

Results and Discussion

- The results we report are for the **verbs and nouns** in the corpus (the other words don't have any dependents and therefore zero SIC); model $R^2 = 0.166$.
- **Surprisal** not a significant predictor of reading times (unlike on the full Dundee corpus).
- **Standard Integration Cost** significant negative predictor, contrary to theoretical expectation (but consistent with Demberg & Keller, 2007).
- **Surprisal-based Integration Cost** significant positive predictor.
- Correlations: IC and SIC uncorrelated with Surprisal ($r = 0.08$), but IC and SIC significantly correlated ($r = 0.69$). But no colinearity (tested using scaling, VIF): IC and SIC explain separate portions of the variance.

Predictor	(interc)	word length	word freq.	landing pos.	prev. word fixated	bigram prob.	SIC	length : freq.	length : wlpos
Coefficient	126.36	29.71	15.49	-1.48	-18.61	-2.11	0.04	-4.71	-1.20
p-value	***	***	***	**	***	***	**	***	***

Conclusions

- Surprisal-based Integration Cost predicts reading times in natural, contextualized text.
- A realistic model of processing difficulty needs to integrate both locality-based factors (integration cost) and probabilistic measures (Surprisal).

References

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