What do RNN Language Models Learn about Filler-Gap Dependencies?

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Filler-gap dependency

- **filler** is a wh-complementizer such as 'what' or 'who'.
- **gap** is an empty syntactic position licensed by the **filler**.

Examples

- I know what the lion devoured __ at sunrise.
- *I know that the lion devoured __ at sunrise.
Method

Models

- **Google model** - BIG LSTM + CNN Inputs - *Jozefowicz et al. (2016)* - uses the output of a character-level CNN as input to the LSTM, trained on One Billion Word Benchmark, two hidden layers with 8196 units each.

- **Gulordava model** - LSTM *Gulordava et al. (2018)* - trained on 90 million tokens of English Wikipedia, it has two hidden layers of 650 units each.

- **Baseline** - 5-gram model trained on One Billion Word Benchmark.
Method

Suprisal

- **suprisal values**: \( S(x_i) = -\log_2 p(x_i|h_{i-1}) \), where \( x_i \) is the current word or character and \( h_{i-1} \) is the LSTM’s hidden state before consuming \( x_i \), with the probability calculated from the RNN’s soft-max activation.

- The surprisal of a word or a sentence tells us the extend to which the given word or sentence is unexpected under the language model’s probability distribution.

- Wilcox et al. measure surprisal in two places, at the word following the gap and summed over the whole embedded clause following the gap.
Method

Expectations

- **wh-licensor, no gap** - expect higher summed surprisal.
- **no wh-licensor, gap** - expect higher summed surprisal.
- The wh-licensing interaction is calculated by:
  \[ (S(wh-licensor, no gap) - S(no wh-licensor, no gap)) - (S(wh-licensor, gap) - S(no wh-licensor, gap)) \]

Example

- I know that the lion devoured a gazelle at sunrise.
- *I know what the lion devoured a gazelle at sunrise.
- *I know that the lion devoured __ at sunrise.
- I know what the lion devoured __ at sunrise.
Filler-gap dependencies

Flexibility of Wh-licensing:
Do LSTM’s learn filler gap dependencies when the gap appears in subject, object and indirect object?

- I know who __ showed the presentation to the visitors yesterday. (subject)
- I know what the businessman showed __ to the visitors yesterday. (object)
- I know who the businessman showed the presentation to __ yesterday. (indirect object)
Filler-gap dependencies
Robustness of Wh-licensing:
Does the number of words separating filler from gap affect LSTM learning filler-gap dependencies? Small intervention: 3-5 words, medium interventions: 6-8 words, long intervention: 8-12 words.

- I know what your friend gave __ to Sam during the picnic yesterday.

- I know what your new friend from the south of France who only just arrived last week gave __ to Sam during the picnic yesterday. (12 words - long intervention)
Filler-gap dependencies

- **Obj Position, Post-Gap Material**
  - ![Graph showing licensing interaction vs. length of modifier for different datasets]

- **Goal Position, Post-Gap Material**
  - ![Graph showing licensing interaction vs. length of modifier for different datasets]

- **Obj Position, Whole Clause**
  - ![Graph showing licensing interaction vs. length of modifier for different datasets]

- **Goal Position, Whole Clause**
  - ![Graph showing licensing interaction vs. length of modifier for different datasets]
Syntactic Islands

**Wh-Island Constraint:**
Do LSTM’s learn that a gap cannot appear inside double nested clauses headed by wh complementizers?

- I know what Alex said your friend devoured __ at the party. *null-comp*
- I know what Alex said that your friend devoured __ devoured at the party. *that-comp*
- *I know what Alex said whether your friend devoured __ at the party. *wh-comp*
Syntactic Islands

Post-Gap Material

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<thead>
<tr>
<th></th>
<th>google</th>
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Presence of Upstream Gap

Entire Clause

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Wh-Licensing Interaction
Syntactic Islands

Adjunct Island Constraint:
Do LSTM’s learn that a gap cannot be licensed in an adjunct clause?

- I know what the librarian in the dark blue glasses placed ___ on the wrong shelf. *object*
- *I know what the patron got mad after the librarian placed ___ on the wrong shelf. *adjunct-back*
- *I know what, after the librarian placed ___ on the wrong shelf, the patron got mad. *adjunct-front*
Syntactic Islands

Post-Gap Material

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Complex NP and Subject Islands

Complex NP Constraint:

Do LSTM’s learn that a gap cannot be hosted in a sentential clause dominated by a noun phrase with a lexical head noun?

- I know what the family bought ____ last year. (*object*)
- *I know who the family bought the painting that depicted ____ last year. (*that-rc/obj*)
Syntactic Islands

**Post-Gap Material**

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Complex NP and Subject Islands

Subject Constraint:
While CNPC generally doesn’t apply to other NP modifiers, such as PPs, NP occurring in subject position isn’t acceptable none the less.

- I know who the family bought the painting by ___ last year. *(prep/obj)*
- *I know who the painting by ___ fetched a high price at auction. *(prep/subj)*
Syntactic Islands

Obj Position, Whole Clause

Subject Position, Whole Clause