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Institute of Computer Science
Chair of Cognitive Modeling

Cognitive Modeling

11. Rational Speech Act Theory

Further Information:

Frank, M. C., & Goodman, N. D. (2012). *Predicting pragmatic reasoning in language games*. Science, 336 (6084), 998. doi:10.1126/science.1218633

Goodman, N. D., & Frank, M. C. (2016). Pragmatic language interpretation as probabilistic inference. *Trends in Cognitive Sciences, 20* (11), 818–829. doi: 10.1016/j.tics.2016.08.005

Martin V. Butz & Johannes Lohmann

Communication

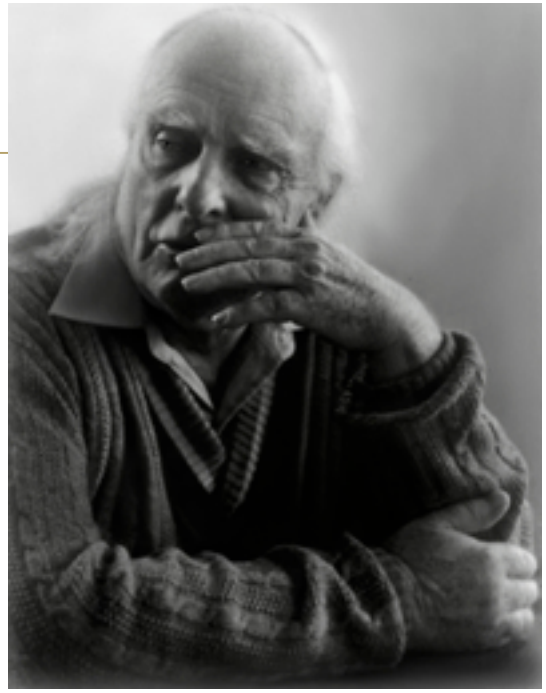
- Rationality
- Bayesian Inference
- Reasoning

- Semantics
- Pragmatics

- Conversation
  - Speakers
  - Listeners

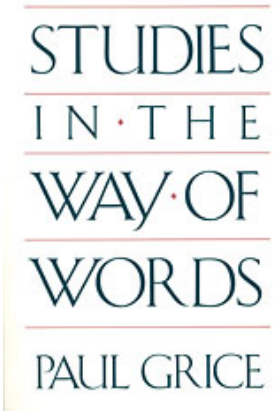
- Conveying meaning / intentions / facts / knowledge…

“One of my avowed aims is to see talking as a special case or variety of purposive, indeed rational, behavior […]”



Herbert Paul Grice
(March 13, 1913 – August 28, 1988)
Picture from:
https://www.goodreads.com/author/show/1961539.Paul_Grice

Studies in the Way of Words
Paul Grice, 1989, p. 28,
Harvard University Press



The Cooperative Principle of Conversation (Grice, 1989, quoted from page 27)

Four categories with specific maxims and submaxims.

1. Quantity:
   - Make your information as informative as required.
   - Do not make your contribution more informative than is required.

2. Quality (Try to make your contribution one that is true.):
   - Do not say what you believe to be false.
   - Do not say that for which you lack adequate evidence.

3. Relation
   - Be relevant!

4. Manner (be perspicuous / comprehensible / clear)
   - Avoid obscurity of expression.
   - Avoid ambiguity.
   - Be brief.
   - Be orderly.

Relation to Everyday, Cooperative Behavior (Grice, 1989, quoted from page 28)

- “Quantity:
  - If you are assisting me to mend a car, I expect your contribution to be neither more nor less than is required.
    - If, for example, at a particular stage I need four screws, I expect you to hand me four, rather than two or six.
- Quality:
  - I expect your contribution to be genuine and not spurious.
    - If I need sugar as an ingredient for a cake you are assisting me to make, I do not expect you to hand me salt;
    - if I need a spoon, I do not expect a trick spoon made of rubber.
- Relation:
  - I expect a partner’s contribution to be appropriate to the immediate needs at each stage of the transaction.
    - If I am mixing ingredients for a cake, I do not expect to be handed a good book, or even an oven cloth […].
- Manner:
  - I expect a partner to make it clear what contribution he is making and to execute his performance with reasonable dispatch.”

Rational Speech Act Theory (RSA)

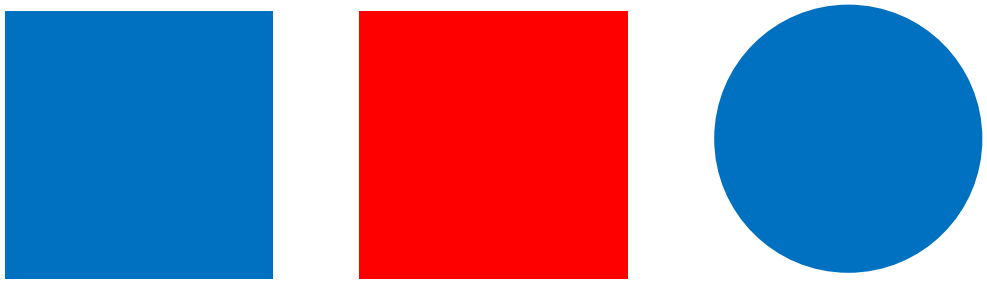
Premise:

- Speakers and listeners reason about each other's reasoning about the literal interpretation of utterances….

[This move — reasoning about likely interpretations — provides ready explanations for complex phenomena ranging from metaphor (Kao et al., 2014) and hyperbole (Kao et al., 2014) to the specification of thresholds in degree semantics (Lassiter and Goodman, 2013).]

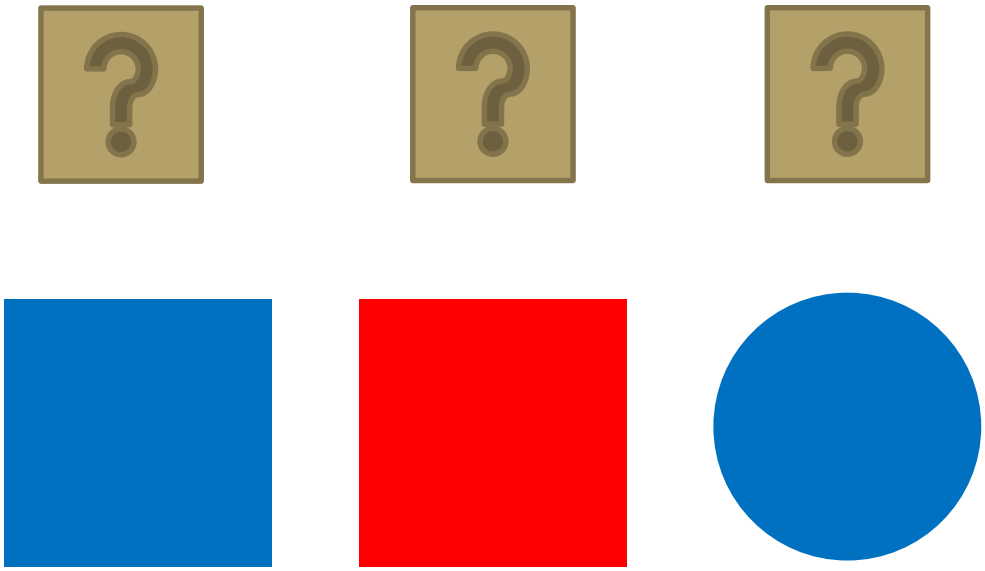
RSA Example 1

How to verbally identify one of the objects,
when being allowed to only utter one feature property
(i.e. “blue”, “red”, “circle”, or “square”)?



RSA Example 2

- Which one is it?
  - When stating: *blue/red/circle/square*

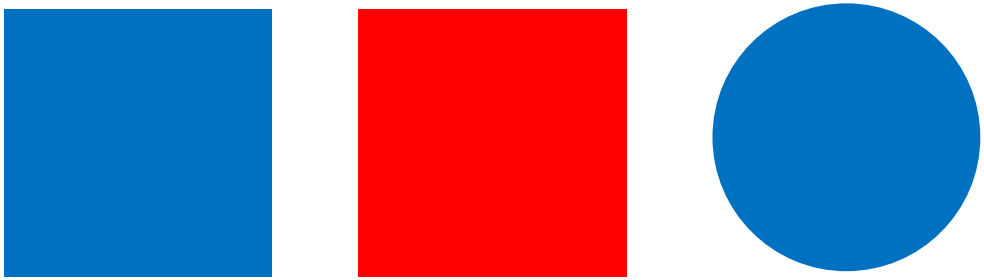


Reasoning about Pragmatic Utterances

- Literal Listener L_0
  - Interprets utterances “literally” (without deeper reasoning).
- Pragmatic Speaker S_1
  - Chooses an utterance “pragmatically” (amongst those utterances that are available).
- Pragmatic Listener L_1
  - Interprets utterances “pragmatically”, taking into account (reasoning about) the options (considerations) of the speaker.

Some Notations of State and Utterances

- Set of all possible utterances
  - $U = \{square, circle, cloud, blue, red, green, solid, striped, dotted\}$
- Currently available utterances
  - $U_i = \{square, circle, blue, red, solid\}$
- State of meaning (which object is actually meant)
  - $S_i = \{blue\ square, red\ square, blue\ circle\}$



Literal Listener L_0

- L_0: $P_{L_0}(s|u) \propto [\![u]\!](s) * P(s)$

- Utterance interpreted directly $[\![u]\!]: S \rightarrow \{0,1\}$
  - Simple truth function
    - Example $[\![blue]\!]: \{blue\ square, red\ square, blue\ circle\} \rightarrow (1,0,1)$

- Prior over objects (usually uniform) $P(s): S \rightarrow \Delta^S$ (prob. dist. over S)
    - P$(blue\ square, red\ square, blue\ circle) \rightarrow (\frac{1}{3}, \frac{1}{3}, \frac{1}{3})$

- Actual function:
  - $P_{L_0}: U \rightarrow \Delta^S$
    - Example $P_{L_0}(blue) = (.5,0.,5)$

Pragmatic Speaker S_1

- Speech acts as a form of action (choosing and generating an utterance).
- Action choice depends on its expected utility.
  - Goal is to maximize expected utility.
  - Use a softmax function (scaled exponential) to approximate rational choice:
  - S_1: $P_{S_1}(u|s) \propto \exp\left(\alpha U_{S_1}(u;s)\right) P(u)$
  - That is: $P_{S_1}(u_i|s) = \frac{\exp\left(\alpha U_{S_1}(u_i;s)\right)P(u_i)}{\sum_j \exp\left(\alpha U_{S_1}(u_j;s)\right)P(u_j)}$
- Speaker wants to maximize the log likelihood that the listener infers the correct state given the utterance, i.e.,
  - $P_{S_1}(u|s) \propto \exp\left(\alpha(\log L_0(s|u) - C(u))\right) P(u)$
    - Additionally, taking into account the cost of an utterance $C(u)$ (e.g. length of word etc.)

Pragmatic Listener L_1

- L_1: $P_{L_1}(s|u) \propto P_{S_1}(u|s) * P(s)$
  - Pragmatic listener uses Bayesian inference to choose the most likely state referred to by a given utterance u.
  - Essentially reasons about what the pragmatic speaker is likely to do given he/she wants to communicate a certain state.

- As a result, “square” refers more likely to the “blue square”, because, was $s = red\ square$ the speaker would have said red.
  - $P_{S_1}(red|red\ square) > P_{S_1}(square|red\ square)$
  - $P_{S_1}(blue|\ blue\ square) \approx P_{S_1}(square|\ blue\ square)$

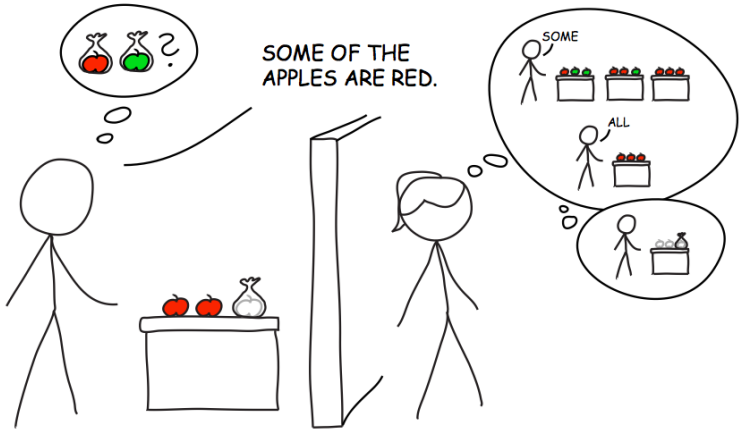
Interacting Bayesian Inference

- Literal Listener L_0
  - Interprets speaker utterances “literally”.
  - L_0: $P_{L_0}(s|u) \propto [\![u]\!](s) * P(s)$
    - Utterance interpreted directly $[\![u]\!](s) \approx P(u|s)$
    - Prior over objects (usually uniform)

- Pragmatic Speaker S_1
  - Chooses an utterance “pragmatically”.
  - S_1: $P_{S_1}(u|s) \propto \exp(\alpha U_{S_1}(u;s))$
    - Speaker chooses the best utterance pragmatically given the state s he/she wants to convey.

- Pragmatic Listener L_1
  - Interprets an utterance “pragmatically”.
  - L_1: $P_{L_1}(s|u) \propto P_{S_1}(u|s) * P(s)$
    - Pragmatic listener uses Bayesian inference to choosing the most likely state referred to by a given a (pragmatically= chosen utterance:

Some Enhancements



- **Quantifier Interpretations….**
  - "Some, all, none …
    …of the apples are red."

- **Question under Discussion**
  - What is the communicative goal?
  - Exact information versus hyperbolic meaning
    - Examples: 1) the coffee their was 1000$;
      2) it took hours until the ordered food was served;
      3) the backpack weight a least a ton.
  - ➢ Compare likelihoods of interpreting an utterance literally or in a hyperbolic manner.
  - Used also for
    - Irony – example: "What a fantastic day today" (while it is a cold, cloudy, rainy day)
    - Metaphoric speaking – example: "John is like an elephant." (communicating features rather than literal facts).

Several More

- Combining RSAs with compositional semantics
  - "Every apple is not red."
    - Surface scope: For all apples it is true that not red (no apple is red).
    - Inverse scope: It is not the case that all apples are red (but some may be red).
- Fixing free parameters
  - Combining vague values with priors
- Single objects versus sets of objects
- Generic language
    - Example 1: Swans are white.
    - Example 2: Mosquitos carry malaria.
- Modeling semantic inference
    - ➢ Modeling utterance refinements within the listener's interpretation.
- Politeness: social reasoning about social reasoning
    - ➢ Striving for a "happy" state of mind of the listener.

New Enhancement: Using Ambiguities in a Strategic Manner

1. Inferring preferences of the listener by monitoring responses to ambiguous utterances.

2. Utilizing ambiguous utterances in an anticipatory, strategic manner for the purpose of inferring preferences of the listener after registering her/his response.

Note that…

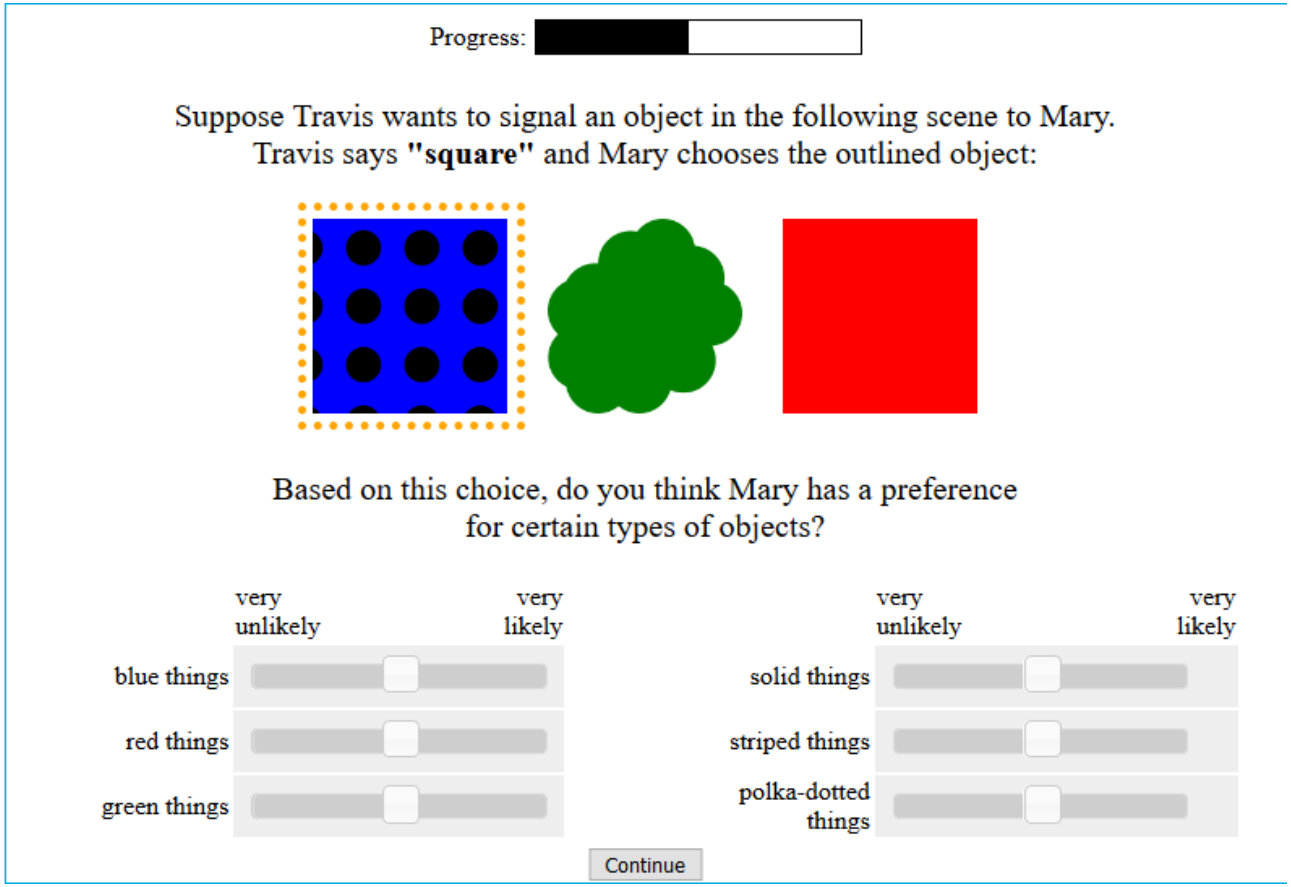
- Sometimes, we
  - Would like to find out about preferences / beliefs / knowledge of others but we
  - Do not want to ask directly
    (due to politeness reasons / because we do not want to reveal our own beliefs / preferences / knowledge / ignorance just yet)….
- Examples ?

Approach

- Strategically use ambiguous utterances!
- Then observe the reactions / responses of the listener.
- Thus, learn about the preferences / beliefs / knowledge the listener has…
  - by observing how the listener disambiguates your ambiguous utterances!

Novel Experiment

https://www.langsci.uci.edu/scontras/experiments/prior_inference/4-pilot-training/prior-inference.html



Enhancing the RSA Model

- Take into consideration, that the listener may choose a non-instructed object (with low probability; e.g. because he/she has a preference for that object).

- Listener uses prior preferences to disambiguate ambiguous utterances.
  - Should choose the object he/she prefers if the speaker allows a choice.

- Deep pragmatic speaker observes listener's choice and interprets it in the light of the present situation.
  - Needs prior over effects of preferences.
  - Needs to compute a posterior over preferences.

Enhanced Literal Listener L_0

- L_0: $P_{L_0}(s|u) \propto [[u]](s) * P(s)$

- Utterance with soft interpretation parameter β:
  $[[u]]: S \rightarrow \Delta^S$
  - Example 1:
    $[[blue]]\ with\ \beta = 1: \{blue\ square, red\ square, blue\ circle\} \rightarrow (.4, .2, .4)$
  - Example 2:
    $[[red]]\ with\ \beta = 2: \{blue\ square, red\ square, blue\ circle\} \rightarrow (\frac{2}{7}, \frac{3}{7}, \frac{2}{7})$

- Prior over objects dependent on feature preference $P(s): S \rightarrow \Delta^S$ (prob. dist. over S) soft preference parameter γ:
  - Example 1:
    Preference for blue things with $\gamma = 2$:
    P$(blue\ square, red\ square, blue\ circle) \rightarrow (.375, .25, .375)$
  - Example 2:
    Preference for red things with $\gamma = 1$:
    P$(blue\ square, red\ square, blue\ circle) \rightarrow (.25, .5, .25)$

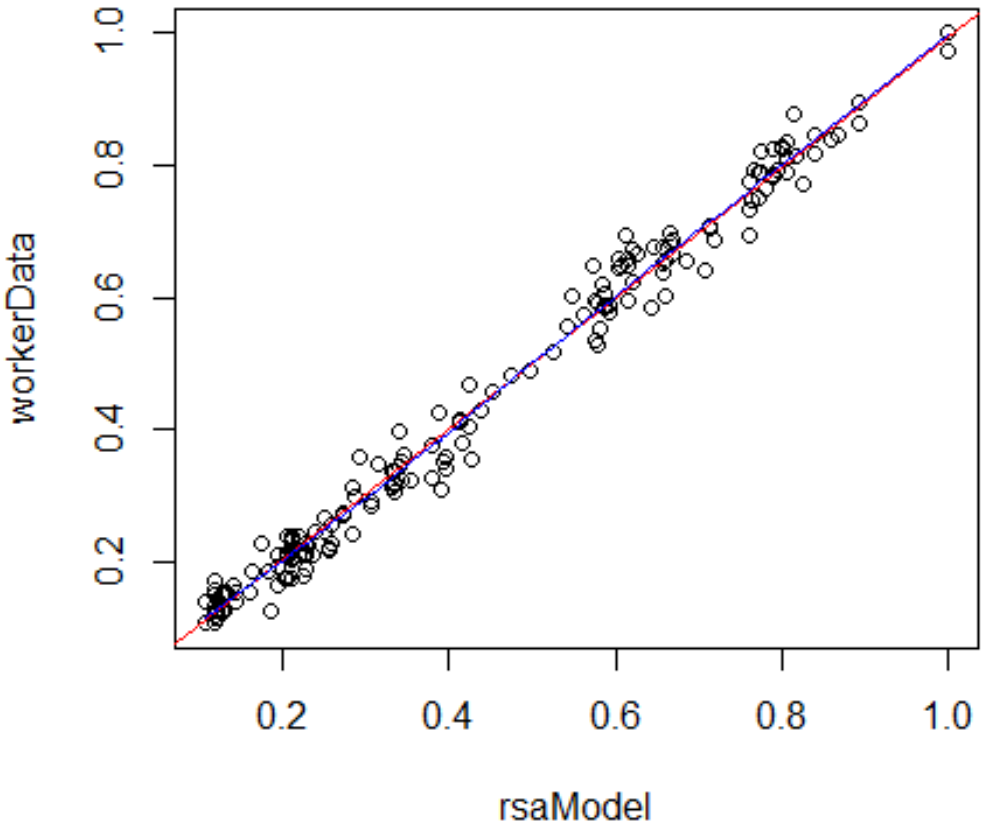
Pragmatic Speaker S_2

- Observes consequence of own speech act by interpreting the listener's consequent object choice o_L.
- Action choice depends on RSA model.
- Pragmatic speaker S_2 considers all possibly derivable feature preferences f_i.
  - That is, preferences for all available features $f_i \epsilon U_t$ for an object constellation at trial t.
- Evaluates likelihoods of the listener's object choice given the chosen utterance and the prior assumption over the listener's feature preferences.
  - $P_{S_2}(f_i|s,u,o_L) \propto P(o_L|f_i,s,u)\,P(f_i)$
- As a result, the posterior over the present feature U_t preferences f can be determined!

Fitting the Data

- Three critical parameters:
  - Parameter α: Preference of most determining utterance by speaker.
  - Parameter β: Obey instruction.
  - Parameter γ: Follow ones preference.
- Optimization criterion:
  - KL divergence between model predictions and normalized slider values
- Standard optimization method of R.
- Fitting individual participants (“worker data”).
- Analysis:
  - Quality of KL divergence (cf. exercise)
  - Meaningfulness of parameters (cf. exercise)
  - Correlation between model predictions and participant estimates for different ambiguity cases.

Current Correlation Plot



- Intercept:
  - 0.005051
    - Confint(model)
      - [2.5 % - 97.5 %]
      - [-.0031 - .0132]
  - p=0.221
- Linear correlation:
  - 0.990438
    - Confint(model)
      - [2.5 % - 97.5 %]
      - [0.9763 - 1.0045]
  - p<2e-16 ***

Conclusion

- RSA is a very powerful model.
- Speech acts are essentially verbal actions.
- RSA models interactive reasoning processes between speaker and listener.
- It is all about Bayesian inference processes over (mostly discrete sets of) world (interpretation) states and utterances.
- Numerous enhancements were published over the last years.
- It appears that the strategic choice of ambiguous utterances can be modeled as well as the resulting interpretation when observing listeners' responses.

- **Next Lectures:**
  - **16.01.2019 Dynamic Multisensory Integration & Body Models**
  - **23.01.2019 The Free Energy Principle, Active Inference, Curiosity, Surprise, & Abstraction**
  - **30.01.2019 A few other Cognitive Models & RECAP**
  - **06.02.2019 Final Exam**

Thank you for the attention ☺

- See tutorial and material at:
- http://probmods.org/
- http://www.problang.org/
- http://webppl.org/