Pragmatic Models for Generating and Following Grounded Instructions

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Grounded Instructions

“Add the tomatoes and mix”

“Take me to the shop on the corner”
Semantics vs. Pragmatics

Semantic Grounding
What things in the world does language refer to?

Pragmatic Reasoning
How does context influence interpretation and action?

“Go to the chair”

“Go to that piece of furniture”
Pragmatic Reasoning

Listener

Speaker

chair

furniture

Listener

Listener

furniture

Reasoning Listener

Listener
Planning and Predictive Power

RSA: Pragmatic behavior emerges from reasoning about simple agents

Games and MDPs: (simple) predictors are strengthened by adding search layers

[e.g. Goodman and Frank 2016]

[e.g. Silver et al. 2017]
Semantic Models for Instructions

Pragmatic Reasoning

Grounding in the Real World
To Start: Virtual Environments

SAIL [MacMahon et al., 2006; Chen and Mooney, 2011]
Interpretation Task

Input instruction: go forward to the grey hallway

Output actions:
Input instruction: go forward to the grey hallway
Input instruction: *go forward to the grey hallway*

Output actions:
Input instruction: go forward to the grey hallway

Output actions:
Interpretation Task

Input instruction: 

go forward to the grey hallway

Output actions:
Output Instruction: go forward to the grey hallway
Models of Listeners and Speakers

Inputs

Instruction, $i$

Actions, $a$

go forward to the grey hallway

Listener

$P_L(a | i)$

Outputs

Actions, $a$

go forward to the grey hallway

Instruction, $i$

Speaker

$P_S(i | a)$
Base Models

Base Listener

\[ P_L(a \mid i) = \prod_{t} P_L(a_t \mid a_{1:t-1}, i) \]

LSTM Encoder

LSTM Decoder

Based on Mei et al. [2016]
Base Models

\[ P_S(i \mid a) = \prod_t P_S(i_t \mid i_{1:t-1}, a) \]
Training Models on Human Instructions

**Base Speaker**
Fit Model:
$$\text{argmax}_\theta P_S(i \mid a; \theta)$$

**Base Listener**
Fit Model:
$$\text{argmax}_\phi P_L(a \mid i; \phi)$$

Actions, $a$

Human annotators

Instruction, $i$

go forward to the grey hallway
Listener Tasks

SAIL navigation [MacMahon et al., 2006; Chen and Mooney, 2011]

*go forward to the grey hallway*

Sequential Context-dependent Execution (SCONE) [Long et al. 2016]
Alchemy task

1. remove all the purple chemical from the beaker on the far left
2. do the same with one unit of green chemical
**Listener Tasks**

**SCONE, Tangrams task**

1. remove first figure
2. add it back into middle spot

**SCONE, Scene task**

1. a red guy appears on the far left
2. then to orange’s other side
### Strong Base Listeners

#### Accuracy at following human instructions

<table>
<thead>
<tr>
<th>Task</th>
<th>State-of-the-art</th>
<th>Base listener</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAIL</td>
<td>65.3</td>
<td>59.6</td>
</tr>
<tr>
<td>Alchemy</td>
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<tr>
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<td>70.9</td>
</tr>
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<td>62.4</td>
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State-of-the-art: [Artzi and Zettlemoyer ’13, Suhr and Artzi ’18]

[Artzi and Zettlemoyer ’13, Suhr and Artzi ’18]
A Failure Mode: Ambiguity

**Instruction**

walk along the blue carpet and you pass two objects

<table>
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<th>Base Listener</th>
<th>Correct</th>
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<tbody>
<tr>
<td><img src="image" alt="Base Listener" /></td>
<td><img src="image" alt="Correct" /></td>
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</table>

- **Base Listener**
- **Correct**
Speaker Task and Evaluation

Speaker produces an instruction

Humans try to interpret it

walk along the wood path to the chair
Generation is Hard to Imitate!

Human accuracy at following instructions from:

- Other humans
- State-of-the-art
- Base speaker

[Daniele et al. 2017] [Fried, Andreas, Klein 2018]

- SAIL: 70.9 (Other humans), 73.2 (State-of-the-art), 62.8 (Base speaker)
- Alchemy: 29.3
- Scene: 31.3
- Tangrams: 60.0
throw out the purple chemical
Semantic Models for Instructions

Pragmatic Reasoning

Grounding in the Real World

Go forward to the grey hallway
Instruction: *walk along the blue carpet and you pass two objects*
Instruction: *walk along the blue carpet and you pass two objects*
Instruction: *walk along the blue carpet and you pass two objects*
Instruction: walk along the blue carpet and you pass two objects
walk along the blue carpet and you pass two objects
walk along the blue carpet and you pass two objects
Listener: Reasoning About Routes

walk along the blue carpet and you pass two objects

walk along the blue carpet and you pass two objects
Listener: Reasoning About Routes

walk along the blue carpet and you pass two objects
Generated Instruction: go forward four segments to the intersection with the bare concrete hall
go forward four segments to the intersection with the bare concrete hall
Explicit Pragmatic Reasoning

**Interpretation**

> "blue"

Frank and Goodman, 2012; Goodman and Stühlmuller, 2013; Wang et al., 2016

**Generation**

> "The sun is in the sky"

Golland et al., 2010; Monroe and Potts, 2015; Mao et al., 2016; Cohn-Gordon et al. 2018...

**Both**

Monroe et al. 2017, Khani et al. 2018

Large, structured domains

Our work
Building a Pragmatic Listener

walk along the blue carpet and you pass two objects

Base Listener proposes

Base Speaker rescores $P_S(i \mid a)$

walk along the blue carpet and you pass two objects
### Listener Results

#### Accuracy at following human instructions

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- State-of-the-art: [Artzi and Zettlemoyer '13, Suhr and Artzi '18]
- Base listener: [Fried, Andreas, Klein 2018]
Instruction: walk along the blue carpet and you pass two objects

Base Listener

Pragmatic Listener
Instruction

*a red guy appears on the far left then to orange’s other side*
Unified Pragmatic Inference

Pragmatic Listener

walk along the blue carpet ...

Base Listener → ? → Base Speaker → walk along the blue carpet ...

actions

Pragmatic Speaker

walk along the blue carpet ...

Base Speaker → ? → Base Listener → walk along the blue carpet ...

instructions
Building a Pragmatic Speaker

- Base Speaker proposes
- Base Listener rescores $P_L(a \mid i)$
- Walk forward past the stool
- Go forward four segments to the intersection with the bare concrete hall

$P_L(a \mid i)$
Building a Pragmatic Speaker

proposes

walk forward past the stool

0.4

go forward four segments to the intersection with the bare concrete hall

0.8

rescores

\( P_L(a \mid i) \)

0.8
Building a Pragmatic Speaker

Base Speaker proposes

Base Listener rescores $P_L(a | i)$

walk forward past the stool

go forward four segments to the intersection with the bare concrete hall

0.4

0.8
Speaker Results

Human accuracy at following instructions from:

- Other humans
- Base speaker
- Pragmatic speaker

[Fried, Andreas, Klein 2018]

BLEU does not predict followability:
Pragmatics and Communicative Success

Base Speaker

throw out the purple chemical  ✗

Pragmatic Speaker

throw out the first purple chemical  ✔

Human

remove all the purple chemical from the beaker on the far left  ✔

Diagram:

1. Purple
   2. Green
   3. Orange
   4. Purple
   5. Yellow
   6. Purple
   7. Yellow
   8. Purple
   9. Yellow
Instruction Quality: Alchemy

Averaged from 3 or 5 point Likert scales [Daniele et al. 2017]. Differences between base and pragmatic all statistically significant by $\chi^2$ on counts.

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### Amount of Information

- **Too Little**
  - Base speaker
  - Pragmatic speaker
  - Human instructions

- **Too Much**

### Difficulty of the Task

- **Very Hard**
  - Base speaker
  - Pragmatic speaker
  - Human instructions

- **Very Easy**

### Confidence in Reaching End State

- **Not Confident**
  - Base speaker
  - Pragmatic speaker
  - Human instructions

- **Confident**

Pragmatics and Communicative Success

- **Base Speaker**
  - remove the last figure
  - add it back
  - x

- **Pragmatic Speaker**
  - remove the last figure
  - add it back in the 3rd position
  - ✓

- **Human**
  - take away the last item
  - undo the last step
  - x
Semantic Models for Instructions

Pragmatic Reasoning

Grounding in the Real World

Go forward to the grey hallway
Room-to-Room Navigation Task

Turn left and take a right at the table. Take a left at the painting and then take your first right. Wait next to the exercise equipment.

[Anderson et al., 2018]
Discrete motion, but real images
Base Follower Model

LSTM Encoder

LSTM Decoder with Attention

go past the couch

[Anderson et al., 2018]
Base Follower Model

LSTM Encoder

LSTM Decoder with Attention

go past the couch...
Base Follower Model

LSTM Encoder

go past the couch

LSTM Decoder with Attention

[Anderson et al., 2018]
Base Follower Model

LSTM Encoder

LSTM Decoder with Attention

go past the couch...
**Base Follower Model**

LSTM Encoder

```
+----+----+----+----+----+
|    |    |    |    |    |
|    |    |    |    |    |
|    |    |    |    |    |
|    |    |    |    |    |
|    |    |    |    |    |
```

```
... ... ... ...
```

```
go past the couch ...
```

LSTM Decoder with Attention

```
+----+----+----+----+----+
|    |    |    |    |    |
|    |    |    |    |    |
|    |    |    |    |    |
|    |    |    |    |    |
|    |    |    |    |    |
```

```
... ... ...
```

[Anderson et al., 2018]
Generalization to New Environments

Two test sets

**Seen**
(Old environments, but new routes)

**Unseen**
(New environments and new routes)
Pragmatic Inference

go down the stairs ...

Base Listener \(\rightarrow\) ? \(\rightarrow\) Base Speaker

route

go down the stairs ...
Pragmatic Inference

Base Listener proposes

Base Speaker rescores

A → B → stop

0.1

A → B → C → stop

0.2

go past the couch...

A → B → stop

go past the couch...
Pragmatic Inference

Navigation Accuracy

- Seen environments:
  - Base listener: 53.1%
  - Pragmatic listener: 62.8%

- Unseen environments:
  - Base listener: 39.7%
  - Pragmatic listener: 50.0%

[Fried, Hu, Cirik et al. 2018]
Walk past hall table. Walk into bedroom. Make left at table clock. Wait at bathroom door threshold.
Walk past hall table. Walk into bedroom. Make left at table clock. Wait at bathroom door threshold.
Pragmatic Speaker:
walk past the dining room table and chairs and take a right into the living room. stop once you are on the rug.

Human Description:
walk through the kitchen. go right into the living room and stop by the rug.

Base Speaker:
walk past the dining room table and chairs and wait there.
Pragmatic Speakers in Other Domains

Generation from Meaning Representations

Input:
Name[Fitzbillies],
EatType[Coffee Shop],
PriceRange[Cheap],
CustomerRating[5 out of 5],
Area[Riverside],
FamilyFriendly[Yes]

Base Speaker:
Fitzbillies is a family friendly coffee shop located near the river.

Pragmatic Speaker:
Fitzbillies is a family friendly coffee shop that serves English food. It is located in riverside area. It has a customer rating of 5 out of 5 and is cheap.

Abstractive Summarization

Input:
The 1-0 scoreline that took Barcelona through to the Champions League quarterfinals made their clash with Manchester City all seem rather academic.

Base Speaker:
Barcelona beat Barcelona 1-0 in the Champions League quarterfinals.

Pragmatic Speaker:
Barcelona beat Manchester City 1-0 in the Champions League.
Unified procedure for sequential interpretation and generation

Reasoning counterfactually, and about likely interpretations

Pragmatics helps for complex tasks in real-world domains
Thank you!

https://github.com/dpfried/pragmatic-instructions
https://github.com/ronghanghu/speaker_follower