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Define, Evaluate, and Improve Task-Oriented Cognitive Capabilities for Instruction Generation Models

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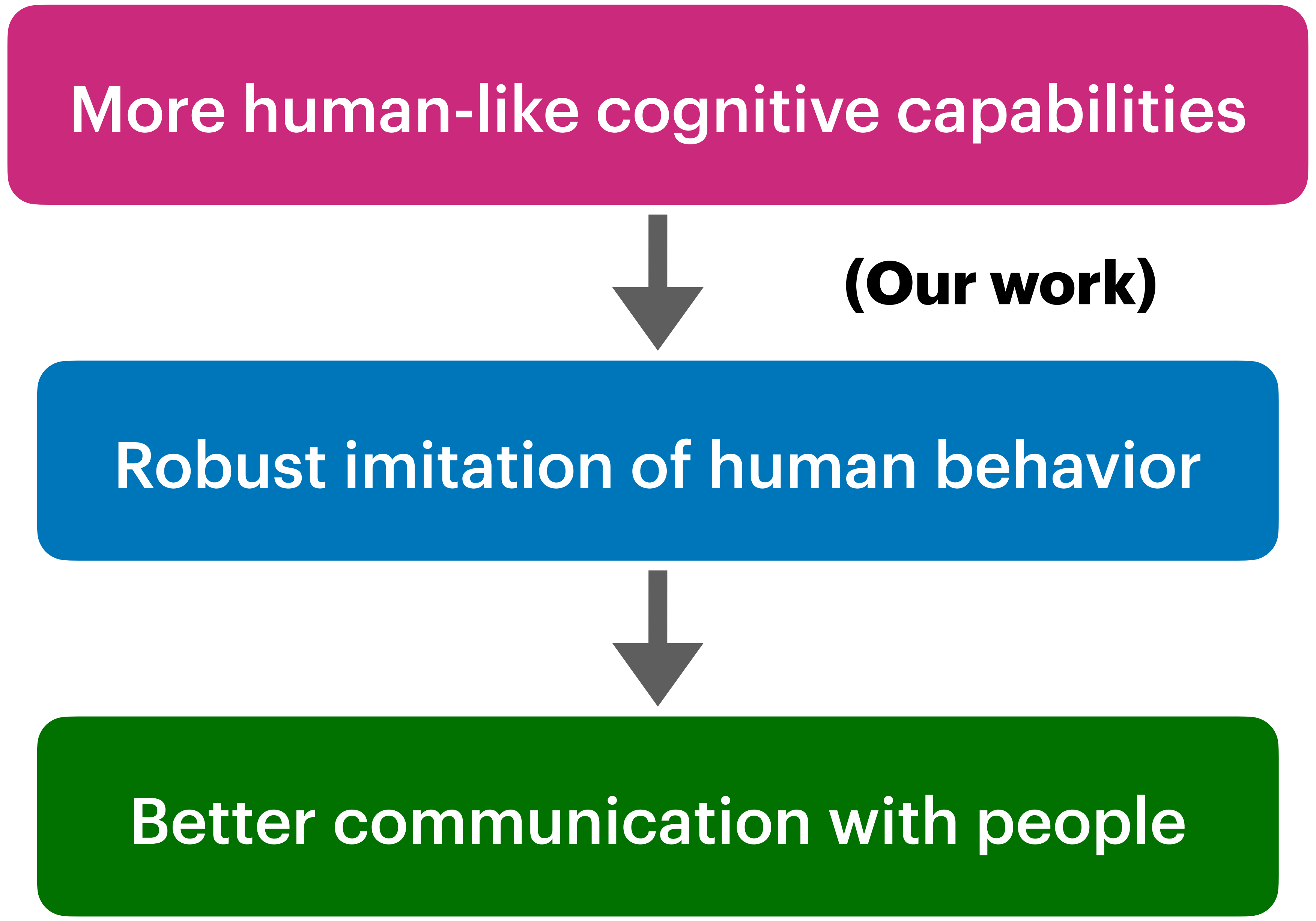
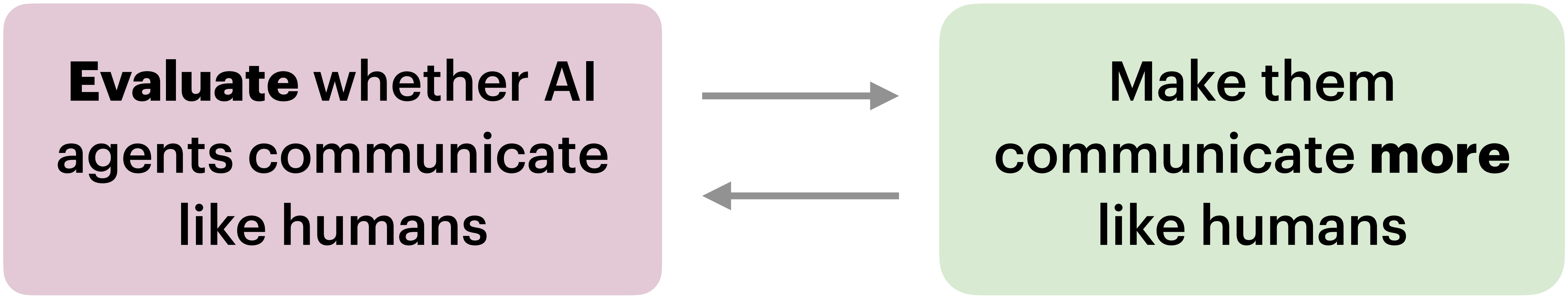
Motivation: More human-like cognition leads to better communication

- By aligning AI agents with humans: how to perceive and describe the world



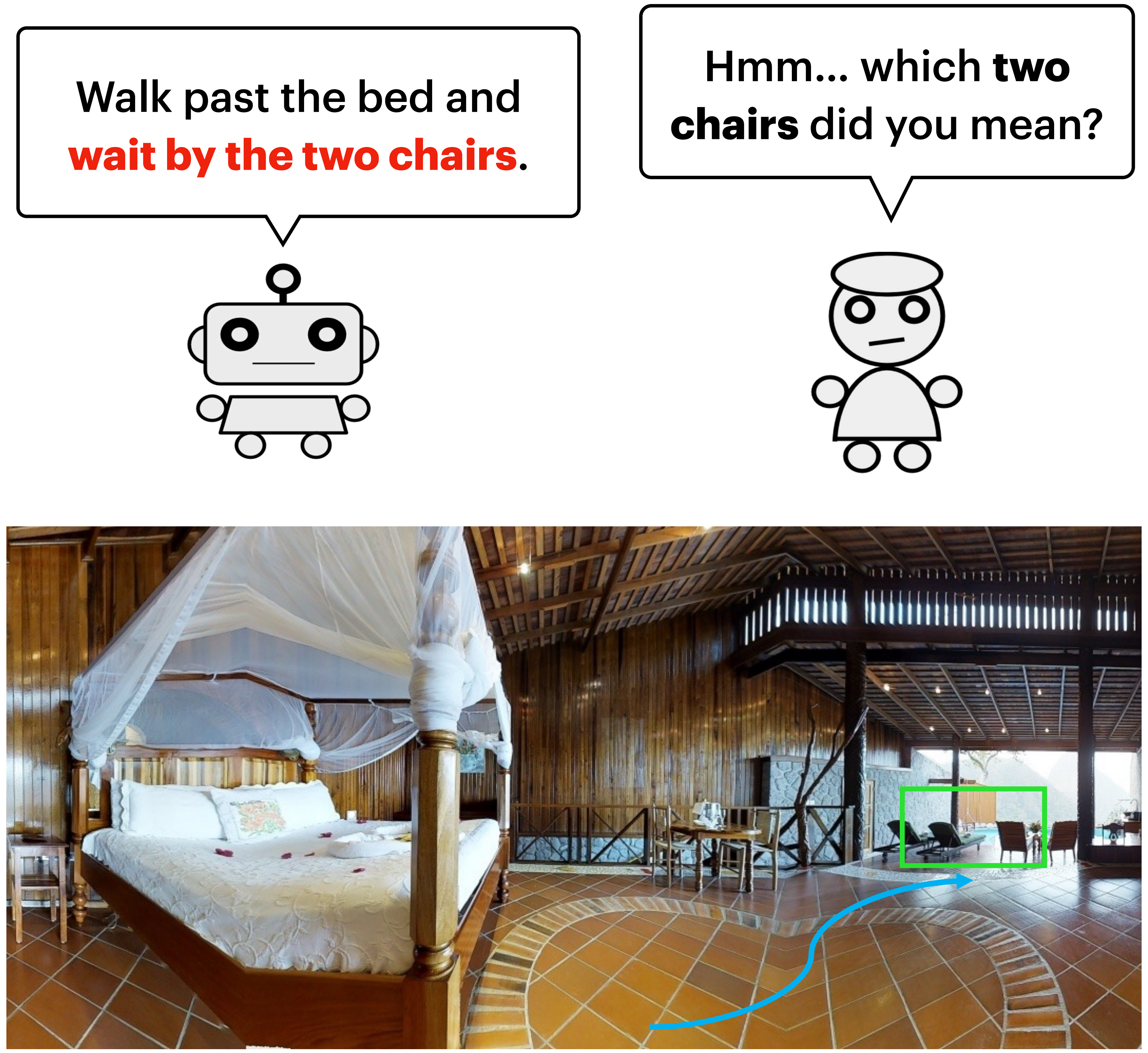
Mechanism



The evaluation step is difficult for black-box models

Problem: How to generate navigation instructions for people to follow

- Instructions generated by vanilla instruction generation (*speaker*) models fail to communicate well with humans
- How to generate better instructions by **reasoning pragmatically**?
- How to **evaluate cognitive capabilities** of speaker models?



Contributions

- A new scheme for evaluating task-oriented cognitive capabilities in instruction generation models
- An 11% success rate improvement in guiding real humans in photorealistic environment, by equipping vanilla speakers with theory-of-mind capabilities
- A call to construct better theory-of-mind models for improving the instruction generation models

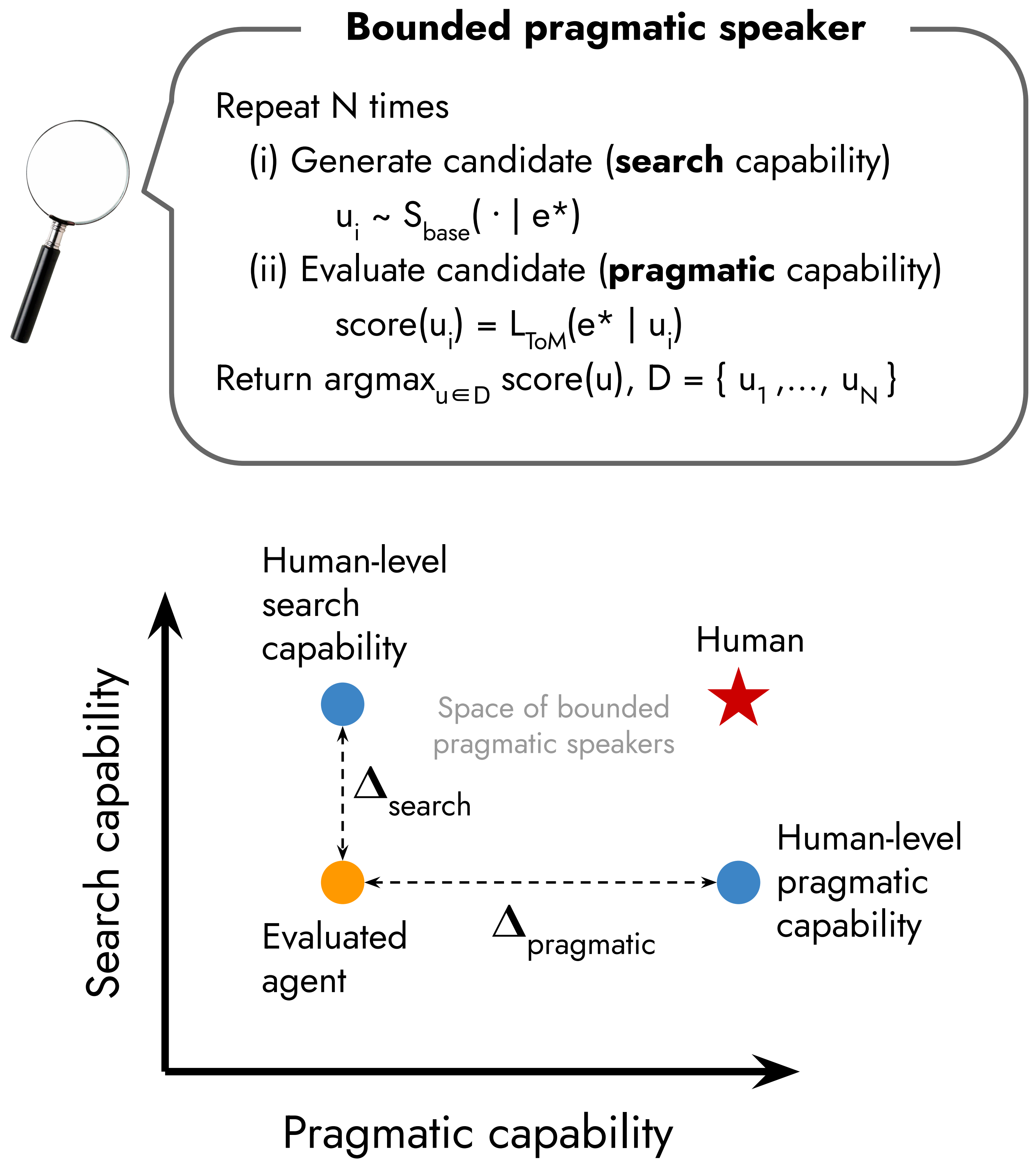
Distinguishing two capabilities: ToM and Search

- Humans are bounded pragmatic speakers (Sanborn and Chater 2016)
- Two **cognitive capabilities:**

  ❋ **Search:** evaluate whether can generate relevant instructions

  ❋ **Theory-of-Mind:** evaluate whether can simulate how human interprets the instructions

(a) (b)

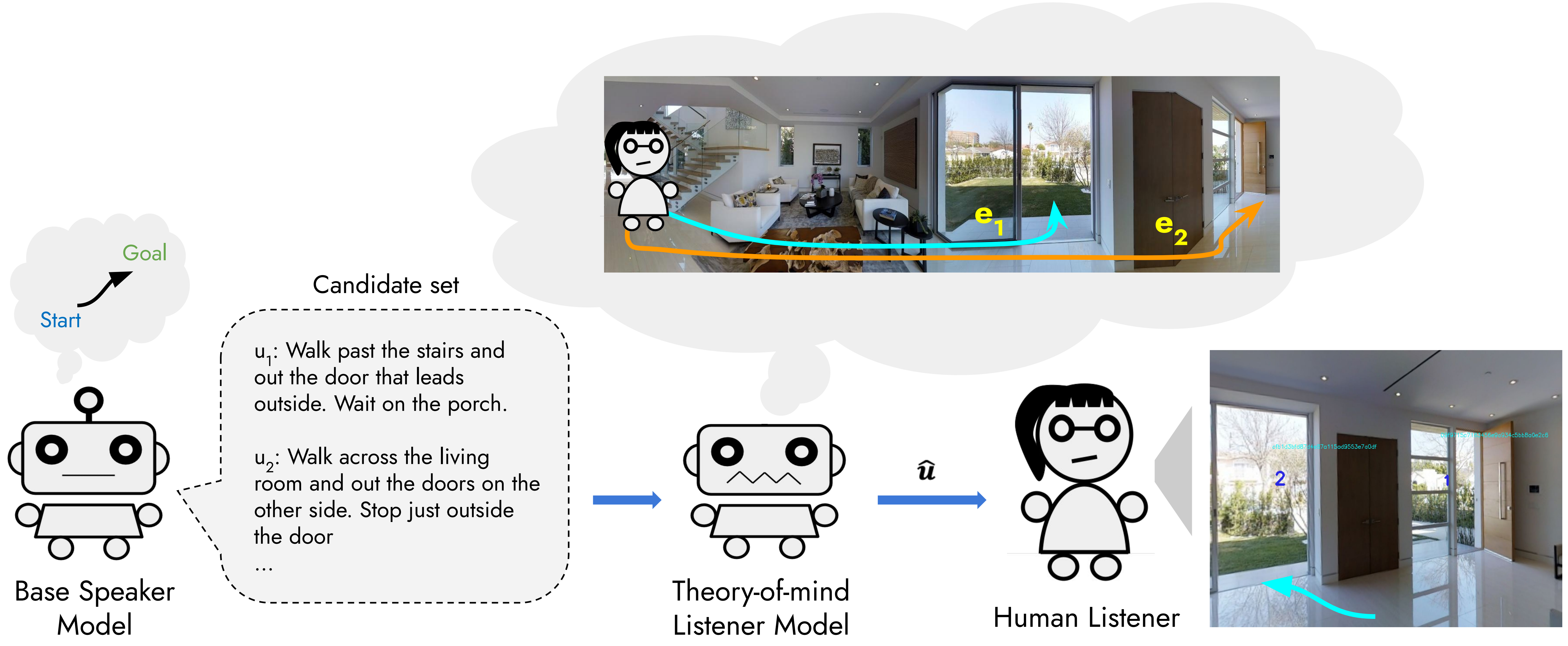


(c) **Recommendation:**

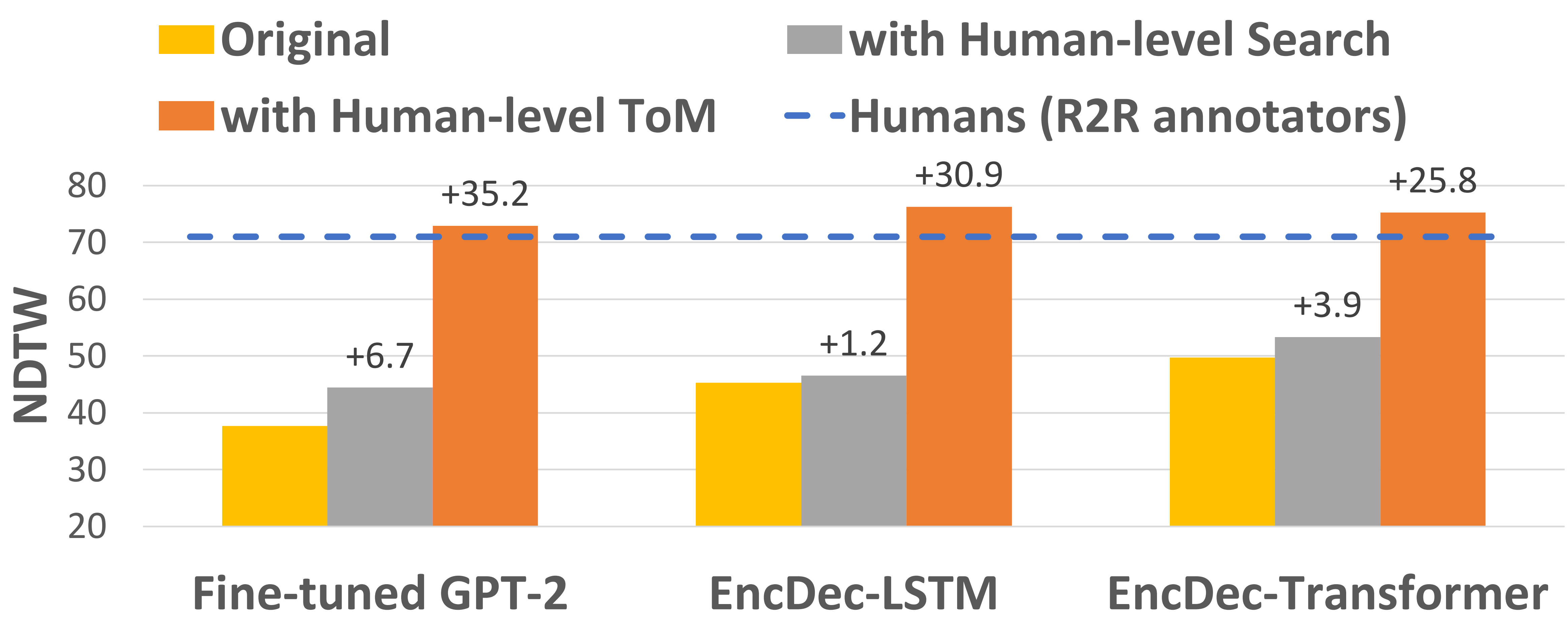
- Large Δ_{search} , small $\Delta_{pragmatic}$ ⇒ improve inference algorithm
- Large $\Delta_{pragmatic}$, small Δ_{search} ⇒ enhance model of listener

Bounded Pragmatic Speaker: Incorporate bounded Theory-of-mind into instruction generation

- **Base Speaker:** generates a set of relevant candidate instructions for a path
- **Theory-of-mind Listener**:
  - ❋ RL agent(s) simulating how human would follow the instructions
  - ❋ Select the instruction with simulated path most similar to the intended path
- **Human Listener**: follow the selected instruction in the environment



Pragmatic capability (theory-of-mind evaluation) is more deficient than Search capability (candidate generation)



Performance of the base speakers and their human-augmented versions

Experimental Settings

- **Speaker model dataset (reverse Matterport Room2Room dataset):**

  Train:14k, Dev: 4k, Test: 1k

- **Evaluation: measure human's success in following generated instructions**
  - ❋ Give instructions to real humans
  - ❋ Measure similarity between human-generated and intended paths:

    Normalized dynamic time warping (**NDTW** ↑)

- **Models:**
  - ❋ Finetuned GPT-2
  - ❋ EncDec-LSTM
  - ❋ EncDec-Transformer
  - ❋ Pragmatic Speakers

Using ensemble followers as theory-of-mind model can improve base speakers significantly to communicate with humans

ToM listener L_{ToM}	Base speaker S_{base} Fine-tuned GPT-2	EncDec-LSTM	EncDec-Transformer
None	37.7 (▲ 0.0)	45.3 (▲ 0.0)	49.4 (▲ 0.0)
Single VLN-BERT (Majumdar et al., 2020)	38.9 (▲ 1.2)	39.8 (▼ 5.5)	46.2 (▼ 3.2)
Ensemble of 10 EnvDrop-CLIP (Shen et al., 2022)	37.8 (▲ 0.1)	$53.1^{\dagger}$ (▲ 7.8)	$57.3^{\dagger}$ (▲ 7.9)
Ensemble of 10 VLN↻BERT (Hong et al., 2021)	43.4 (▲ 5.7)	$56.4^{\ddagger}$ (▲ 11.1)	54.2 (▲ 4.8)
Humans (skyline)	$72.9^{\ddagger}$ (▲ 35.2)	$76.2^{\ddagger}$ (▲ 30.9)	$75.2^{\ddagger}$ (▲ 25.8)

Performance of the speakers (NDTW) when equipped with different Theory-of-mind listener models

Shrink the gap with humans by 36%!

Takeaways

- Using ensemble followers as theory-of-mind model can **improve** base speakers trained with MLE objective
- Better task-oriented **theory-of-mind model** is needed to bridge the communication gap between AI and humans
- To develop safe and helpful AI requires quantifying the gaps between an AI agent and human