MetaMind: Modeling Human Social Thoughts with Metacognitive Multi-Agent Systems

"What is meant often goes far beyond what is said, and that is what makes conversation possible." - H.P. Grice

Xuanming Zhang, Yuxuan Chen, Samuel Yeh, Sharon Li

THE UNIVERSITY of WISCONSIN MADISON

TSINGHUA UNIVERSITY 1911

NEURAL INFORMATION PROCESSING SYSTEMS

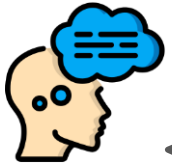
Spotlight

xzhang2846@wisc.edu

Does AI truly understand people?

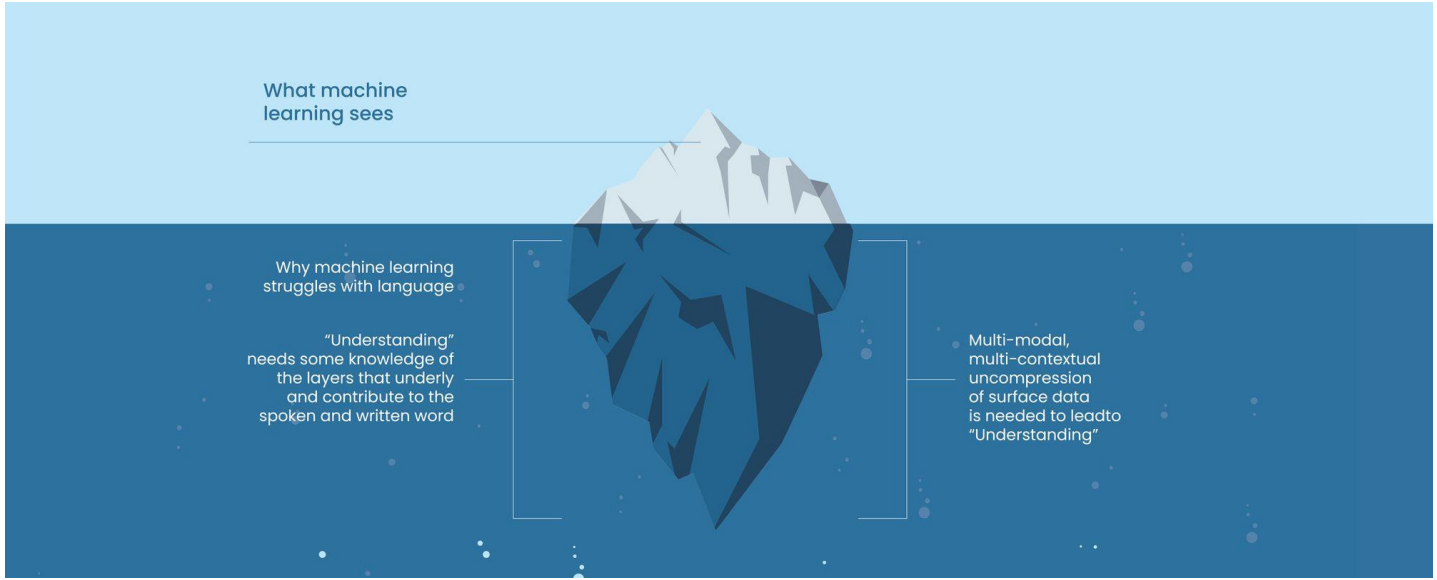
Show thinking

It sounds like it's cold where you are. What were you thinking?



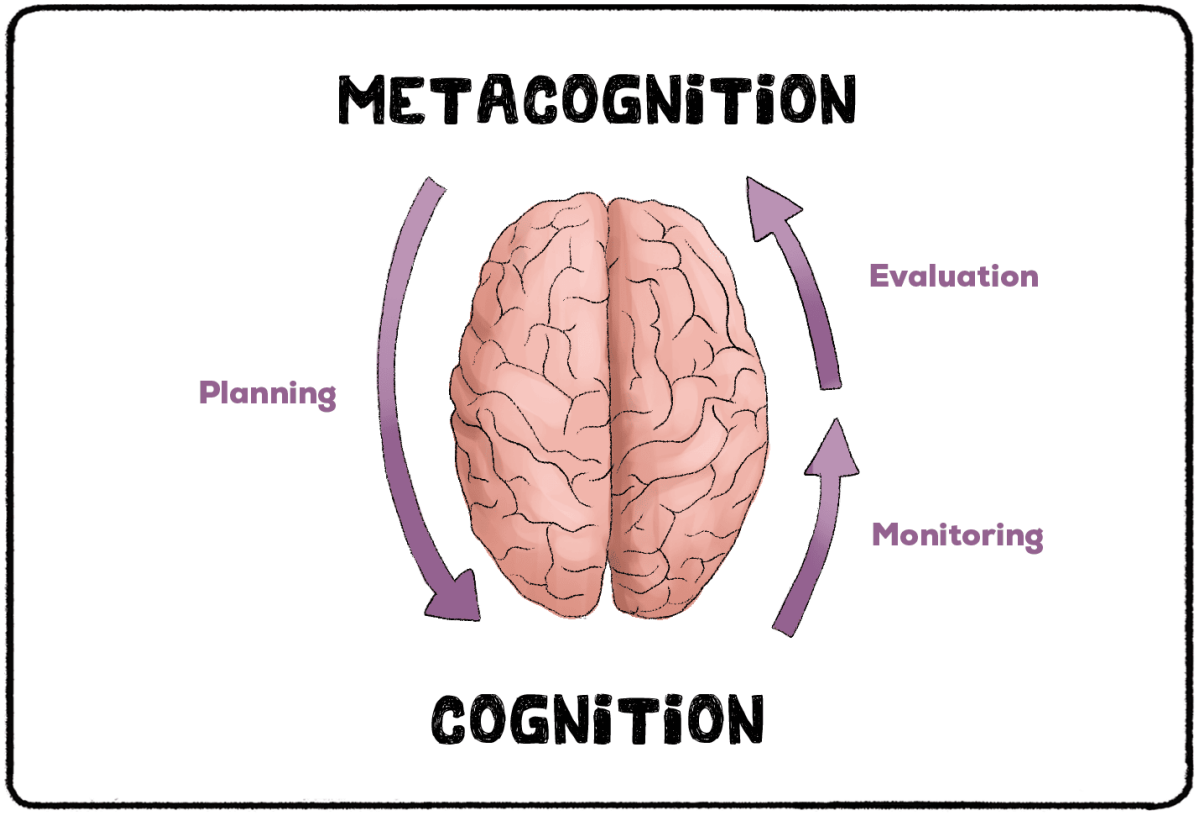
How about coming over to my place for a drink?

The Gap

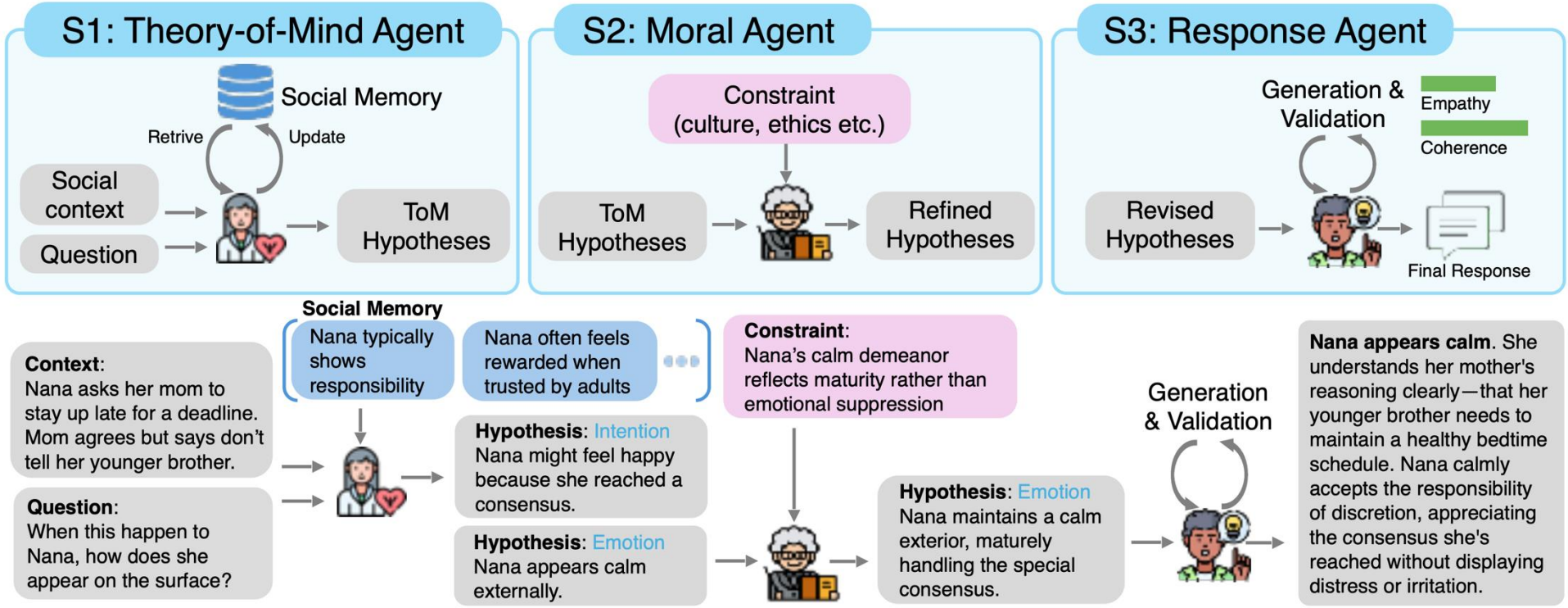


They understand language, but they don't understand *people*.

Human Social Thought



MetaMind: Beyond the Language



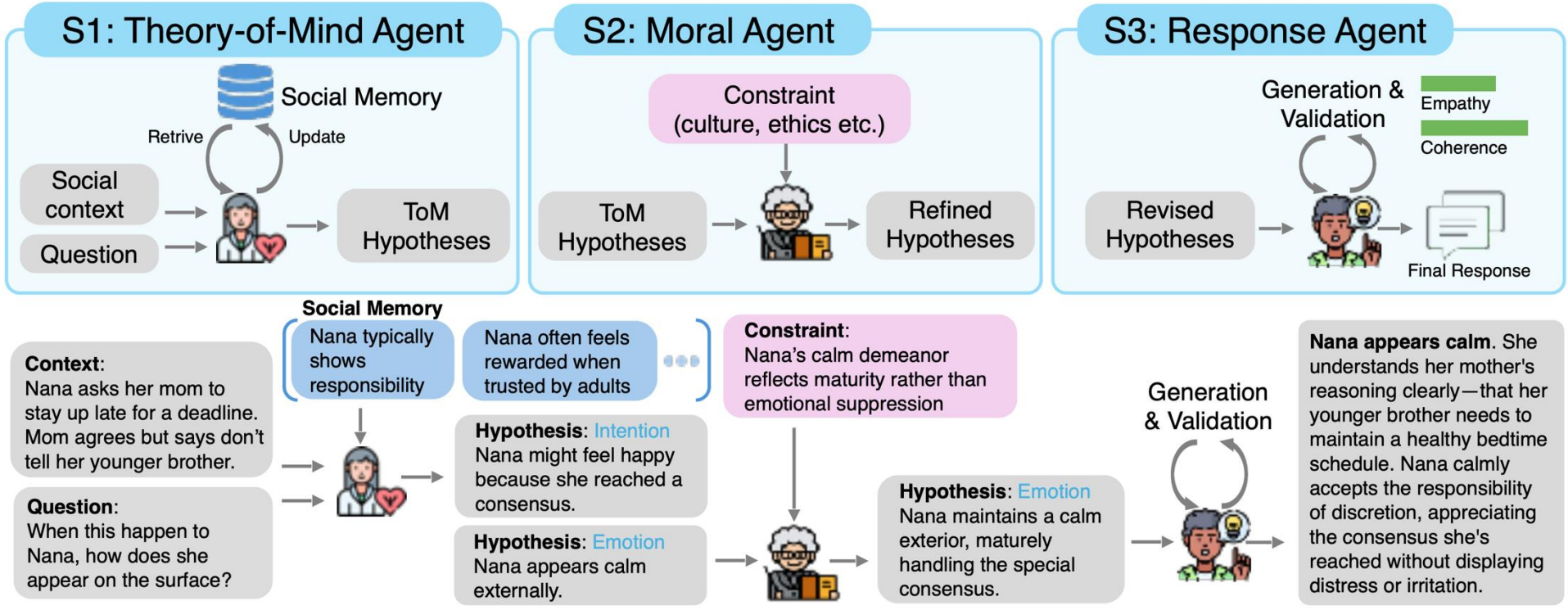
Hypotheses Selection

$$\tilde{h}^* = \arg\max_i \; [\underbrace{\lambda \cdot P(\tilde{h}_i|u_t, C_t, M_t)}_{\text{Contextual plausibility}} + \underbrace{(1-\lambda) \cdot \log \frac{P(\tilde{h}_i|u_t, C_t, M_t)}{P(\tilde{h}_i)}}_{\text{Information Gain}}]$$

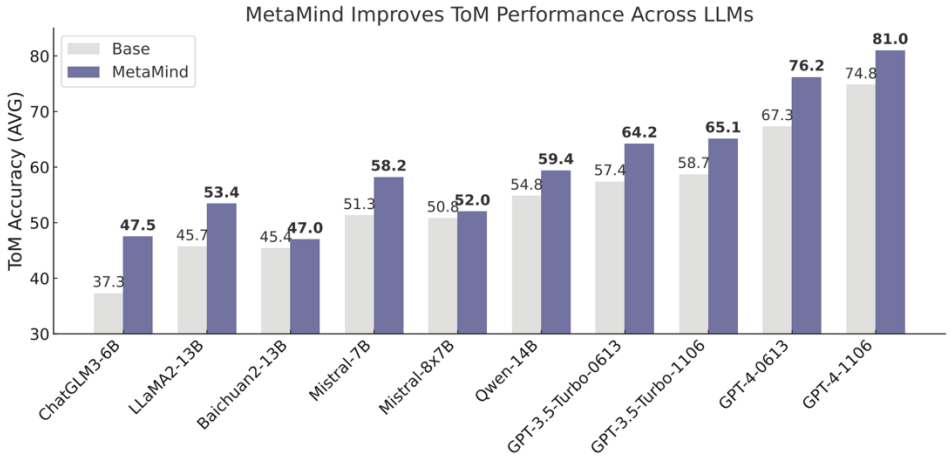
Where the first term denotes the contextual plausibility of the revised hypothesis, and the second term reflects the implicit information gain of the revised hypothesis when considering the context. The weight λ balances contextual plausibility and social appropriateness with how much the hypothesis is informed by the context versus being generic.

MetaMind: Learning from Experience

$$U(o_t) = \underbrace{\beta \cdot \text{Empathy}(o_t, u_t, M_t)}_{\text{Emotional alignment}} + \underbrace{(1-\beta) \cdot \text{Coherence}(o_t, C_t, \tilde{h}^*)}_{\text{Contextual coherence}}$$



Experimental Result



★ Theory-of-Mind Reasoning

	Emotion	Desire	Intention	Knowledge	Belief	NL Comm.	AVG.
Base (GPT-4)	75.7	69.7	**84.7**	52.1	82.8	84.0	74.8
w. CoT [31]	73.2	63.3	77.9	60.4	83.6	83.0	73.6
w. HM [57]	76.4	71.1	80.2	59.3	84.1	85.0	76.0
w. ToM2C [58]	77.2	70.4	81.5	57.8	85.3	84.6	76.1
w. Generative Agents [28]	74.8	72.0	78.9	55.6	83.2	86.4	75.1
w. SymbolicToM [56]	75.9	70.9	79.6	58.2	84.0	83.7	75.4
w. **MetaMind** (ours)	**78.7**	**76.5**	84.3	**68.2**	**88.6**	**88.5**	**81.0**

★ Social Cognition

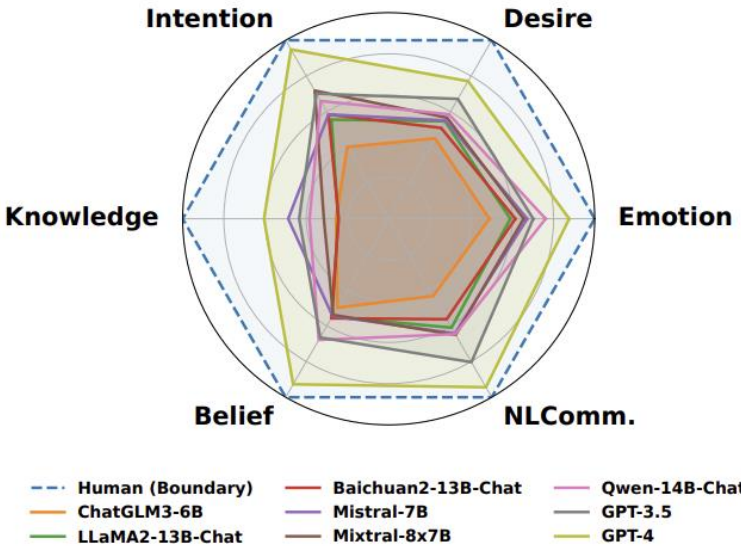
UOT: Unexpected Outcome Test **SIT**: Scalar Implicature Task **PST**: Persuasion Story Task **FBT**: False Belief Task
AST: Ambiguous Story Task **HT**: Hinting Test **SST**: Strange Story Task **FRT**: Faux-pas Recognition Test

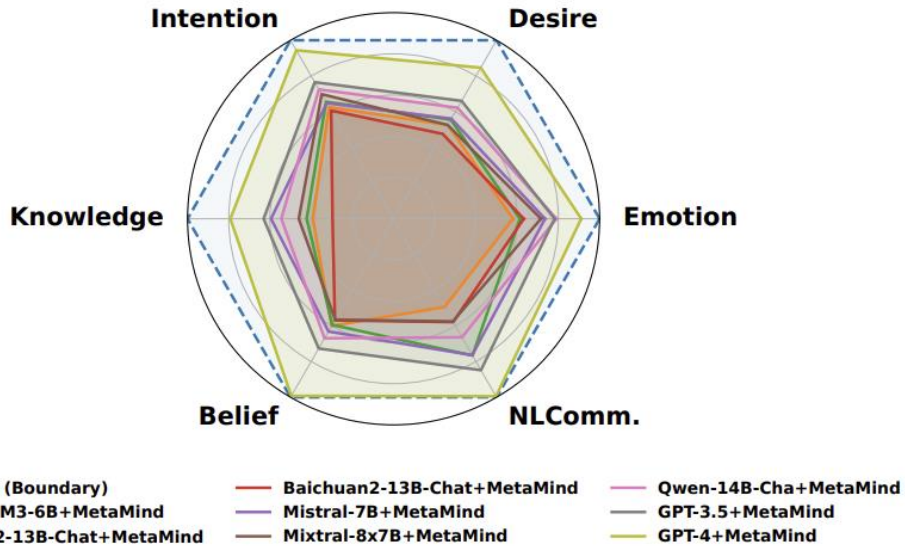
	UOT	SIT	PST	FBT	AST	HT	SST	FRT	AVG.
Base (GPT-4)	71.0	49.0	**65.0**	88.2	77.5	82.5	84.0	73.3	71.5
w. CoT [31]	72.7	55.0	55.0	86.8	81.0	82.5	84.3	75.2	74.1
w. HM [57]	74.0	54.6	59.2	87.6	82.2	83.1	85.0	76.0	75.2
w. ToM2C [58]	75.3	52.9	60.4	88.0	80.1	84.4	83.7	77.8	75.3
w. Generative Agents [28]	73.2	56.8	57.8	87.1	83.6	81.9	85.8	75.9	75.3
w. SymbolicToM [56]	72.4	58.1	58.7	87.9	82.7	82.8	84.2	76.3	75.4
w. MetaMind (ours)	**81.5**	**60.4**	64.8	**90.1**	**88.8**	**86.2**	**88.4**	**83.9**	**80.5**

★ Social Simulation

	Conv.	Pub. Act.	Appo.	Inv. Com.	Online Act.	Help	AVG.
Base (GPT-4)	48.6	59.6	1.2	2.3	63.4	61.5	39.4
w. TDP [20]	72.3	75.9	40.0	20.0	68.6	50.0	54.4
w. HM [57]	68.1	72.4	35.0	22.0	69.2	47.0	52.3
w. ToM2C [58]	70.2	74.1	38.0	18.0	66.5	52.0	53.1
w. Generative Agents [28]	65.4	70.3	42.0	19.0	67.8	55.0	53.3
w. SymbolicToM [56]	60.8	68.1	37.0	21.0	65.4	49.0	50.2
w. MetaMind (ours)	**80.8**	**81.9**	**65.0**	**67.1**	**75.1**	**73.0**	**73.9**

Experimental Result





Conclusion

- Human social intelligence hinges on the nuanced ability to infer unspoken mental states—a capability rooted in ToM that remains a critical gap in modern LLMs.
- To address this, we introduced MetaMind, a multi-agent framework inspired by metacognitive theories, which decomposes social reasoning into three collaborative stages.
- MetaMind enables LLMs to match human performance on key ToM tasks for the first time, bridging the gap between artificial and human social cognition.
- Ablation studies confirm the necessity of all components, underscoring the importance of structured hypothesis generation, ethical constraint enforcement, and iterative validation.

xzhang2846@wisc.edu

https://xmzhangai.github.io/