ICLR

Enhancing Human-AI Collaboration Through Logic-Guided Reasoning

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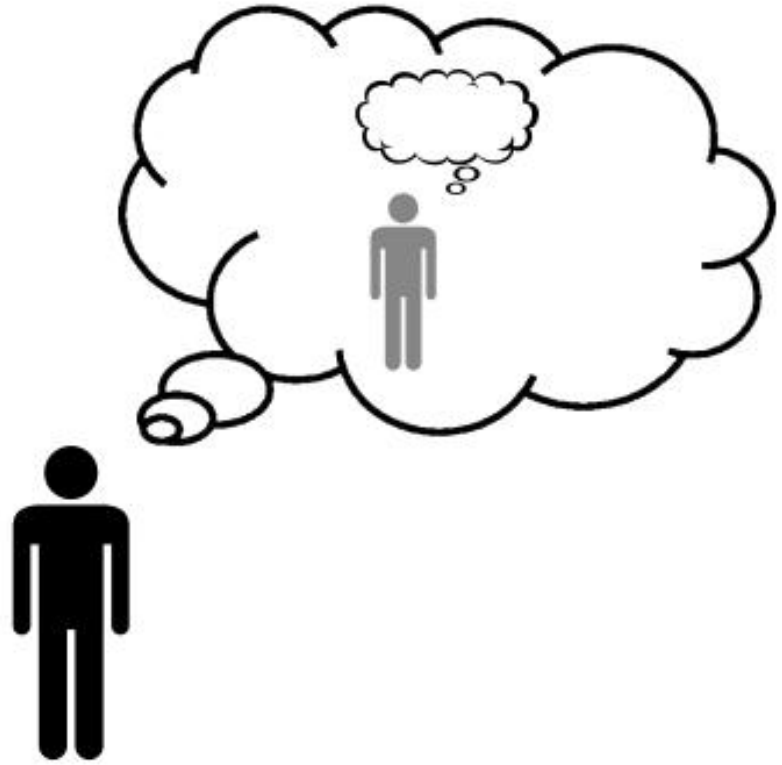
Introduction

Theory of Mind

The ability to understand others' mental states and act upon them



Introduction

Main agent: setup a table

Helper agent: help on the **inferred** goal

Introduction

Spatial-Temporal Predicate In our paper, we extend the above static predicates to spatial-temporal predicates, which include spatial-temporal *property* predicates and spatial-temporal *relation* predicates.

Specifically, the spatial-temporal *property* predicates are defined as

$$X(v) : \mathcal{C} \times \cdots \times \mathcal{C} \times \mathcal{T} \times \mathcal{S} \mapsto \{0, 1\}.$$

We will consider spatial-temporal logic rules where the body part contain spatial-temporal predicates as relation constraints. For example, a sensible rule will look like

$$\begin{aligned} f : & Y_{\text{TurnAround}}(c, t, s) \leftarrow X_{\text{PickUpKey}}(c, t, s) \bigwedge \\ & R_{\text{InFront}}((c', t, s'), (c, t, s)) \bigwedge R_{\text{Behind}}((c'', t, s''), (c, t, s)) \end{aligned}$$

where $c \in \mathcal{C}_{\text{person}}$, $c' \in \mathcal{C}_{\text{block}}$, and $c'' \in \mathcal{C}_{\text{key}}$. In general, the *spatial-temporal logic rule* in our paper is defined as a logical connectives of predicates, including property predicates and spatial-temporal relation predicates,

$$f : Y(v) \leftarrow \bigwedge_{X_{\text{property}} \in \mathcal{X}_f} X_{\text{property}}(v') \bigwedge_{R_{\text{spatial-temporal}} \in \mathcal{R}_f} R_{\text{spatial-temporal}}(v'', v) \quad (1)$$

where $Y(v)$ is the *head predicate* evaluated at the entity-time-location triplet v, $\mathcal{X}_f$ is the set of property predicates defined in rule f, and $\mathcal{R}_f$ denotes the set of spatial-temporal relation predicates defined in rule f.

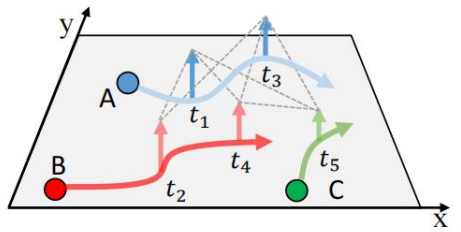
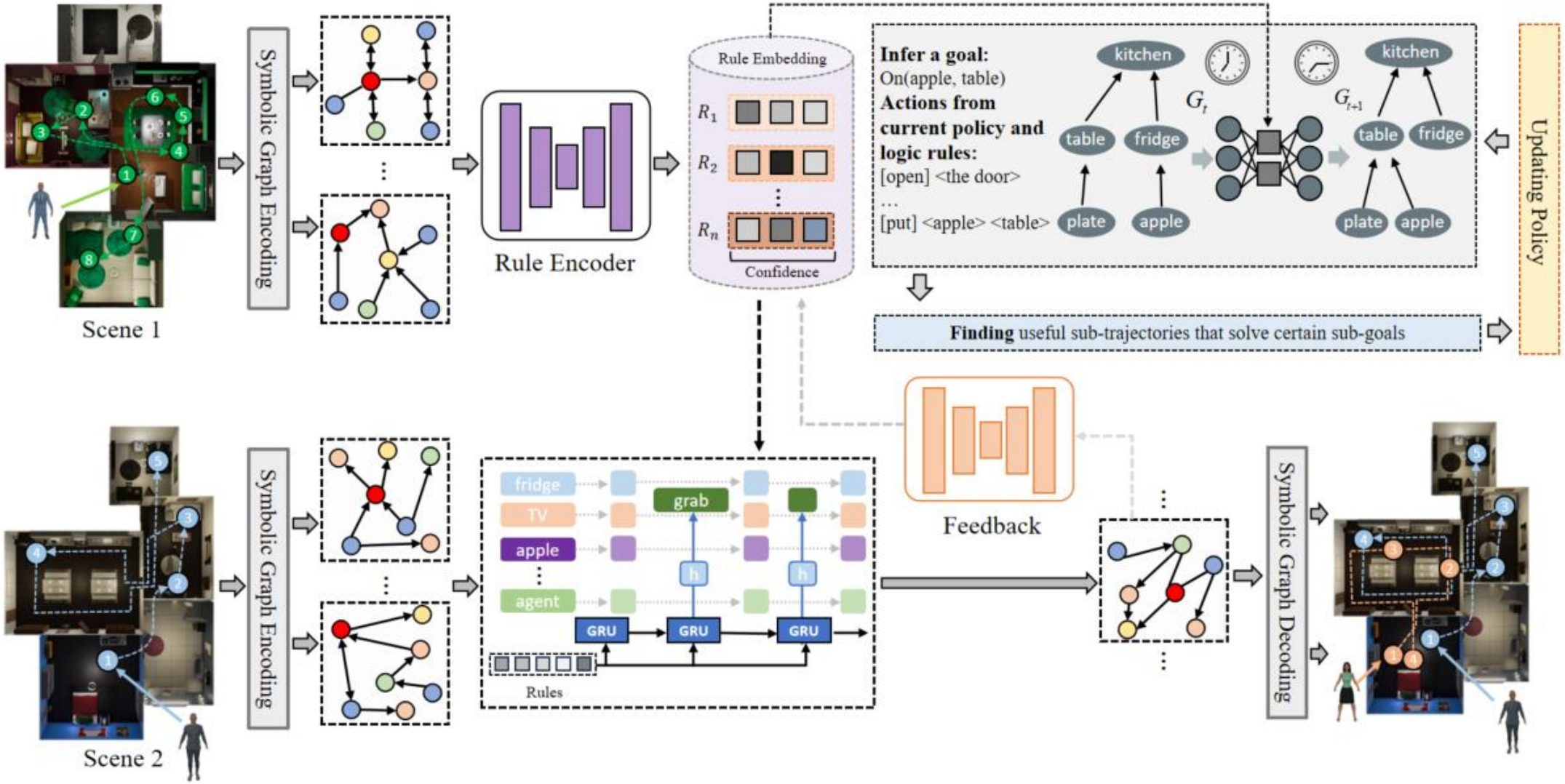


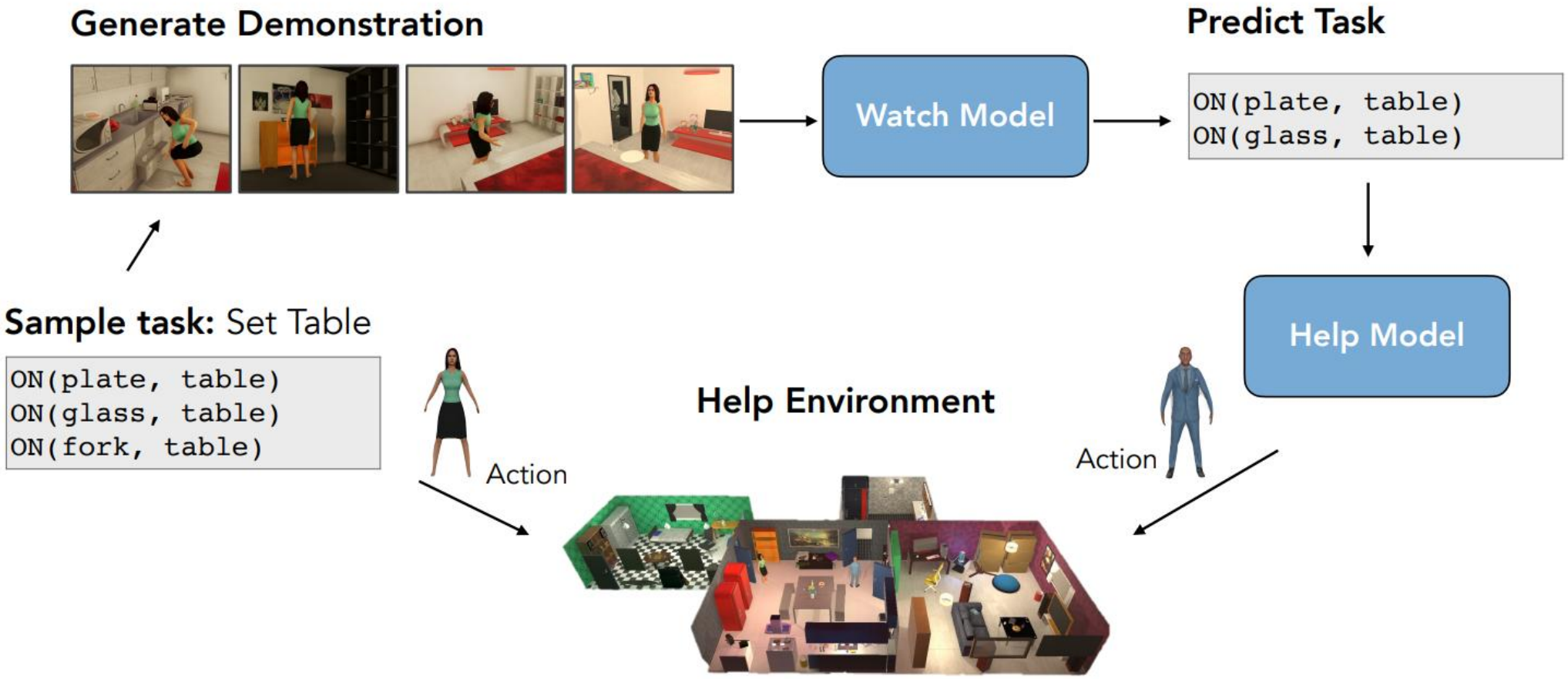
Figure 1: Illustration of feature construction using a simple logic formula with temporal relation predicate ($t_1 < t_2$), $f : Y \leftarrow A \wedge B \wedge C \wedge (A \text{ Before } B)$. The rule defines the template to gather combinations of the body predicate history events. Here predicate A has 2 events and predicate B has 1 event, the temporal relation constraint would lead to valid combinations (also called "paths"). This type of feature construction can be extended to spatial-temporal cases, where we count the valid paths as the feature.

Framework


Scene 1
Symbolic Graph Encoding
Rule Encoder
Rule Embedding
R_1
R_2
R_n
Confidence
Infer a goal:
On(apple, table)
Actions from current policy and logic rules:
[open] <the door>
...
[put] <apple> <table>
kitchen
table
fridge
plate
apple
G_t
G_{t+1}
Updating Policy
Finding useful sub-trajectories that solve certain sub-goals
Feedback
Scene 2
Symbolic Graph Encoding
fridge
TV
apple
agent
grab
h
GRU
Rules
Symbolic Graph Decoding

Experiment

Watch-and-Help Dataset



Result

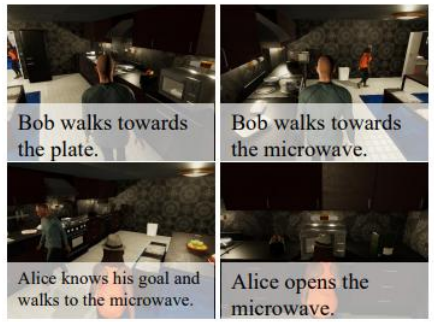
Table 1: Comparative performance of various rule encoder backbones on the Watch-and-Help Dataset: An evaluation across four difficulty tiers using three metrics—Average Number of Moves (AN, lower is better) for successful episodes, Success Rate (SR, higher is better); and Speedup (SU, higher is better).

Methods		Partially Observable			
		Level 1	Level 2	Level 3	Level 4
WAH	AN ↓	15.28±0.06	22.24±0.15	28.88±0.15	51.20±0.12
	SR ↑	78.61±0.02	71.02±0.08	60.13±0.11	51.48±0.04
	SU ↑	0.17±0.012	0.14±0.019	0.13±0.016	0.08±0.016
GEM	AN ↓	14.08±0.04	20.40±0.10	28.71±0.05	42.12±0.04
	SR ↑	79.27±0.02	71.32±0.04	60.99±0.07	53.97±0.06
	SU ↑	0.24±0.017	0.22±0.016	0.19±0.012	0.15±0.015
DRRN	AN ↓	13.47±0.13	20.10±0.14	28.68±0.15	38.25±0.01
	SR ↑	80.86±0.09	71.74±0.06	66.27±0.13	57.53±0.18
	SU ↑	0.25±0.015	0.19±0.017	0.17±0.004	0.16±0.009
Seq2Seq	AN ↓	12.76±0.06	19.92±0.06	28.32±0.02	34.16±0.04
	SR ↑	81.12±0.01	72.45±0.18	66.69±0.18	57.86±0.09
	SU ↑	0.38±0.003	0.28±0.008	0.26±0.007	0.21±0.014
ReQueST	AN ↓	12.68±0.03	18.72±0.10	28.12±0.12	32.92±0.18
	SR ↑	81.12±0.05	77.44±0.17	68.52±0.04	55.34±0.07
	SU ↑	0.38±0.019	0.30±0.015	0.25±0.009	0.22±0.011
Ours	AN ↓	11.40±0.04	16.21±0.15	26.16±0.02	31.10±0.05
	SR ↑	82.43±0.17	78.14±0.03	69.84±0.17	58.91±0.16
	SU ↑	0.48±0.015	0.44±0.009	0.36±0.013	0.33±0.017

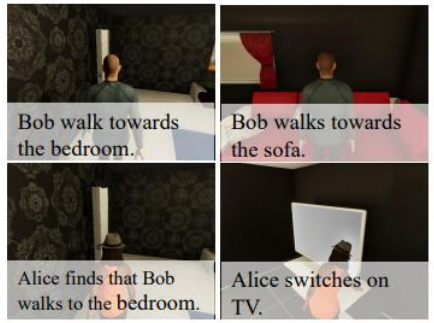
Table 2: Experiment results on HandMeThat dataset. Each model is evaluated on 4 hardness levels with 3 metrics: the Average Score (AS, higher is better), the Success Rate (SR, higher is better), and the Average Number of Moves (AN, lower is better) in successful episodes.

Methods		Partially Observable			
		Level 1	Level 2	Level 3	Level 4
Random	AS ↑	-40.0	-40.0	-40.0	-40.0
	SR ↑	0.0	0.0	0.0	0.0
	AN ↓	N/A	N/A	N/A	N/A
Seq2Seq	AS ↑	-5.1±0.07	-25.3±0.09	-34.5±0.15	-32.0±0.20
	SR ↑	25.50±0.20	10.40±0.14	3.95±0.23	5.30±0.26
	AN ↓	4.21±0.01	4.17±0.04	4.19±0.02	4.12±0.06
GEM	AS ↑	-6.3±0.11	-22.5±0.12	-30.9±0.14	-29.6±0.18
	SR ↑	24.64±0.40	12.47±0.21	5.74±0.15	7.21±0.13
	AN ↓	4.34±0.04	4.36±0.02	4.24±0.00	4.22±0.00
DRRN	AS ↑	-40.0	-40.0	-40.0	-40.0
	SR ↑	0.0	0.0	0.0	0.0
	AN ↓	N/A	N/A	N/A	N/A
Ours	AS ↑	-1.4±0.03	-5.8±0.06	-9.1±0.17	-11.9±0.23
	SR ↑	27.73±0.29	24.81±0.36	20.97±0.12	21.66±0.18
	AN ↓	4.05±0.01	4.09±0.01	4.14±0.03	4.21±0.02

Visualization



Rule: Walk_to(Bob, plate)∧Grab(Bob, plate) ∧ Walk_to(Bob, microwave)∧ Open(Bob, microwave) →Inside(plate,microwave)
Explanation:
- Bob walks towards the plate and grabs it
- Bob walks towards the microwave
- Alice infers his goal as "put the plate into the microwave"
- Alice opens the microwave



Rule: Walk_to(Bob, bedroom)∧Switch_on(Alice, TV)∧ Walk_to(Bob, sofa) →Watch(Bob, TV)
Explanation:
- Bob walks towards the bedroom
- Bob walks towards the sofa
- Alice infers his goal as "watch TV"
- Alice switches on TV

Rule: Walk_to(Bob, sofa)∧Block(Alice,Bob)∧Make_way(Alice,Bob) →Pass_by(Bob,Alice)
Explanation:
- Bob walks towards the sofa
- Alice blocks Bob's way by chance
- Alice makes way for Bob so he can walk quickly
- Bob walks by Alice's side

Figure 4: Visualization and explanation of logic rules in Watch-and-help dataset.

Thanks for Listening!