Lang2LTL-2: Grounding Spatiotemporal Navigation Commands Using Large Language and Vision-Language Models Supplementary Material

Jason Xinyu Liu[1], Ankit Shah[1], George Konidaris[1], Stefanie Tellex[1], and David Paulius[1]
[1]Brown University

I. SPATIAL RELATIONS

We define the following spatial relations and rules for the spatial referring expression recognition (SRER) and the spatial predicate grounding (SPG) module. $\vec{v}_f$ and $\vec{v}_g$ represent the figure (from the ground landmark to the figure landmark) and the ground vector (from the ground landmark to the robot), respectively.

TABLE I: Spatial Relations and Corresponding Rules.

Relation	Rule
left	$\vec{v}_f \in [\vec{v}_g - \pi, \vec{v}_g]$
right	$\vec{v}_f \in [\vec{v}_g, \vec{v}_g + \pi]$
in front of	$\vec{v}_f \in [\vec{v}_g - \pi/2, \vec{v}_g + \pi/2]$
opposite to	$\vec{v}_f \in [\vec{v}_g - \pi/2, \vec{v}_g + \pi/2]$
behind	$\vec{v}_f \in [\vec{v}_g - 3\pi/2, \vec{v}_g - \pi/2]$
near	$\vec{v}_f \in [\vec{v}_g - \pi, \vec{v}_g + \pi]$
next to	$\vec{v}_f \in [\vec{v}_g - \pi, \vec{v}_g + \pi]$
adjacent to	$\vec{v}_f \in [\vec{v}_g - \pi, \vec{v}_g + \pi]$
close to	$\vec{v}_f \in [\vec{v}_g - \pi, \vec{v}_g + \pi]$
by	$\vec{v}_f \in [\vec{v}_g - \pi, \vec{v}_g + \pi]$
north of	$\vec{v}_f \in [0, \pi]$
south of	$\vec{v}_f \in [\pi, 2\pi]$
east of	$\vec{v}_f \in [-\pi/2, \pi/2]$
west of	$\vec{v}_f \in [\pi/2, 3\pi/2]$
northeast of	$\vec{v}_f \in [0, \pi/2]$
northwest of	$\vec{v}_f \in [\pi/2, \pi]$
southeast of	$\vec{v}_f \in [\pi, 3\pi/2]$
southwest of	$\vec{v}_f \in [3\pi/2, 2\pi]$

The rule for the spatial relation between is that the figure landmark must lie between the two parallel lines perpendicular to the vector connecting and passing through the two grounding landmarks.

II. DETAILS ABOUT SPATIAL REFERRING EXPRESSION RECOGNITION (SRER)

The prompt for the spatial referring expression recognition (SRER) module is as follows,

Referring Expression Generation Prompt

```
Your task is to repeat exact strings from the
given utterance which possibly refer to certain
propositions.

Utterance: move to red room
Propositions: red room
```

```
Utterance: visit Cutler Majestic Theater
Propositions: Cutler Majestic Theater

Utterance: robot c move to big red room and
then move to green area
Propositions: big red room | green area

Utterance: you have to visit Panera Bread on
Beacon Street, four or more than four times
Propositions: Panera Bread on Beacon Street

Utterance: go to Cutler Majestic Theater at
Emerson College on Tremont Street, exactly three
times
Propositions: Cutler Majestic Theater at Emerson
College on Tremont Street

...

Utterance: make sure you never visit St. James
Church, a Christian place of worship on Harrison
Avenue, Dunkin' Donuts, Thai restaurant Montien,
New Saigon Sandwich, or Stuart St @ Tremont St
Propositions: St. James Church, a Christian
place of worship on Harrison Avenue | Dunkin'
Donuts | Thai restaurant Montien | New Saigon
Sandwich | Stuart St @ Tremont St

Utterance: move the robot through yellow region
or small red room and then to large green room
Propositions: yellow region | small red room |
large green room

Utterance:
```

III. DETAILS ABOUT LIFTED TRANSLATION (LT)

The prompt to GPT-4 for translating the lift command "navigate to a at most twice" using retrieval augmented generation (RAG) with 10 in-context examples is as follows,

Referring Expression Generation Prompt

```
Command: navigate to a exactly twice
LTL formula: M & a F & ! a F a | ! a G | a G | ! a
G | a G ! a

Command: navigate to a exactly three times
LTL formula: M & a F & ! a F & a F & ! a F a | !
a G | a G | ! a G | a G | ! a G | a G ! a

Command: navigate to a exactly once
LTL formula: M a | ! a G | a G ! a

Command: visit a at most twice
LTL formula: ! F & a U a & ! a U ! a F & a U a &
! a U ! a F a
```

```
Command: go to a at most twice
LTL formula: ! F & a U a & ! a U ! a F & a U a &
! a U ! a F a

Command: navigate to a exactly five times
LTL formula: M & a F & ! a F & a F & ! a F & a F
& ! a F & a F & ! a F a | ! a G | a G | ! a G | a
G | ! a G | a G | ! a G | a G | ! a G | a G ! a

Command: navigate to a exactly four times
LTL formula: M & a F & ! a F & a F & ! a F & a F
& ! a F a | ! a G | a G | ! a G | a G | ! a G | a G
| ! a G | a G ! a

Command: you can go to a at most twice
LTL formula: ! F & a U a & ! a U ! a F & a U a &
! a U ! a F a

Command: you can visit a at most twice
LTL formula: ! F & a U a & ! a U ! a F & a U a &
! a U ! a F a

Command: you can visit a at most twice
LTL formula: ! F & a U a & ! a U ! a F & a U a &
! a U ! a F a

Command:
```

IV. Language Commands for Robot Demonstration

Table II and III contain language commands and language grounding results for robot demonstrations in indoor and outdoor environments, respectively.

TABLE II: Commands for Robot Demonstration in Indoor Environment

Navigational Command	Lang2LTL-2 Result
1.	success
2. go to the couch in front of the TV, the couch to the left of the kitchen counter, the kitchen counter between the couch and the refrigerator, the table next to the door, and the chair on the left of the bookshelf in any order	success
3. move to the couch in front of the TV, then the couch to the left of the kitchen counter, then the refrigerator right of the kitchen counter, then the table to the left of the bookshelf, then the table next to the door	success
4. walk to the chair in front of the bookshelf but only after the kitchen counter	success
5. move from the red couch near the TV to the blue couch left of the kitchen counter and only visit each landmark one time	success
6. go to the kitchen counter on the left side of the fridge exactly once and do not visit the kitchen counter on the left side of the fridge before the couch left of the TV	success
7. patrol the fridge right of kitchen counter at least five times	success
8. go to the kitchen counter between the blue couch and the fridge at most three times	success
9. visit the couch left of the counter, in addition never go to the TV in front of the couch	success
10. visit the blue couch near the kitchen counter then go to the fridge near the counter, in addition never visit the couch in front of the TV	success
11. visit the blue couch near the kitchen counter then go to the fridge near the counter, in addition never visit the couch in front of the TV or the kitchen counter	success
12. go to the refrigerator right of the kitchen counter, and only then go to the the couch left of counter, in addition always avoid the couch in front of the TV	success
13. go to the refrigerator near the kitchen counter then the couch left of the kitchen counter then the couch in front of the TV, in addition after going to the refrigerator near the kitchen counter, you must avoid the kitchen counter	success
14. go to the blue couch near the kitchen counter then the red couch in front of the TV, in addition go to the red couch in front of the TV only after visiting the refrigerator	success
15. go to the table near the door then the blue couch next to the kitchen counter then the red couch in front of the TV, in addition go to the table near the door only after visiting the bookshelf	success
16. go to the kitchen counter between the couch and fridge only after visiting the couch next to the counter, in addition go to the couch next to the counter only after visiting the refrigerator	success
17. go to the kitchen counter between the couch and the refrigerator exactly two times, in addition always avoid the TV in front of the couch	success
18. go to the bookshelf exactly two times, in addition always avoid the TV in front of the couch and the chair near the bookshelf	success
19. visit the couch next to the kitchen counter exactly two times, in addition do not go to the couch next to the kitchen counter before the couch near the TV	success
20. visit the couch in front of the TV at least two times, in addition do not go to the couch in front of the TV before the kitchen counter between the blue couch and the fridge	success
21. go to the refrigerator near the kitchen counter then the couch in front of the TV, in addition you must go to the couch left of the kitchen counter exactly twice	success
22. go to the blue couch next to the kitchen counter but never go to the blue couch next to the kitchen counter	unsatisfiable. abort correctly
23. go to the kitchen counter between the refrigerator and the blue couch at least twice, in addition go to the kitchen counter between the refrigerator and the blue couch exactly once	unsatisfiable. abort correctly
24. do not go to the desk near the door until the bookshelf, and do not go to the bookshelf until the desk near the door	unsatisfiable. abort correctly
25. find the kitchen counter between the refrigerator and the blue couch, in addition always avoid the red couch and the TV	unsatisfiable. abort correctly

TABLE III: Commands for Robot Demonstration in Outdoor Environment

Navigational Command	Lang2LTL-2 Result
1. go to the stairs between the apartment building and the silver car	success
2. go to the stairs in front of the apartment building, the car to the right of the apartment and the car to the left of the apartment in any order	success
3. go to the white car to the right of the apartment, then visit the silver car near the stairs	success
4. move to the car east of the apartment, then the car west of the apartment, then dumpster north of the apartment, then red brick building north of the apartment	success
5. walk to the stairs between the apartment and the silver car, then the white car near the dumpster, then the dumpster	success
6. navigate to the dumpster north of the white car but do not visit the dumpster north of the white car before the stairs near the apartment	success
7. visit the the white car on the right side of the apartment but do not visit the white car on the right side of the apartment before the silver car on the east side of the apartment	success
8. only visit the apartment once, and do not visit the apartment until you visit the white car west of the apartment first	success
9. walk to the stairs in front of the apartment at least five times	success
10. visit the stairs between the apartment and the silver car at most three times	success
11. visit the silver car on the left side of the apartment exactly twice	success
12. go to the dumpster near the white car, in addition avoid the red brick building north of the apartment	success
13. go to the stairs between the silver car and the apartment then the apartment, in addition do not visit the dumpster north of the apartment	success
14. go to the white car left to the apartment and the silver car right to the apartment, in addition avoid the red brick building north of the apartment	success
15. move to the white car near the apartment at most twice, in addition avoid the dumpster near the white car	success
16. go to the white car near the dumpster exactly three times, in addition avoid stairs in front of the apartment	success
17. visit the dumpster near the white car, in addition you are not permitted to visit the apartment and the stairs between the apartment and silver car	success
18. navigate to the apartment at least two different occasions, in addition you are only permitted to visit the white car near the apartment at most once	success
19. walk to the white car close to the dumpster exactly once, in addition visit the stairs in front of the apartment on at least 2 separate occasions	success
20. visit the silver car east of the apartment exactly twice, in addition visit the red brick building in front of the apartment on at least 3 separate occasions	success
21. move to the stairs in front of the apartment then the apartment, in addition visit the white car near the dumpster exactly once	unsatisfiable. abort correctly
22. Visit the white car, then go to the red brick wall and then go to the silver car near the apartment, in addition you can never go to the apartment once you've seen the white car	unsatisfiable. abort correctly
23. go to the dumpster on the north side of the apartment, but always avoid the dumpster on the north side of the apartment	unsatisfiable. abort correctly
24. do not go to the white car west of the apartment until the red brick wall, and do not go to the red brick wall until the white car west of the apartment	unsatisfiable. abort correctly
25. find the dumpster near the white car, in addition avoid visiting the apartment and the red brick wall	unsatisfiable. abort correctly