Human communicates with robots
- through language

Robots interact with environments
- perceive visual information
- perform planning, take actions
Vision-and-Language Navigation Task

Unseen environment


Vision-and-Language Navigation: Interpreting visually-grounded navigation instructions in real environments, Peter Anderson et al., CVPR 2018
Vision-and-Language Navigation Task

Unseen environment

Photorealistic images

Vision-and-Language Navigation: Interpreting visually-grounded navigation instructions in real environments, Peter Anderson et al., CVPR 2018
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Incorrect action

Correct action

Deviate from correct path
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Unseen environment

Current navigation architectures

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Current navigation architectures

Unseen environment

Alignment confusion

Observation + decision space

Facing the end of the bed, take an immediate right and exit the bedroom through the open doorway. Walk straight until you see a large red painting. At the painting make a turn towards and go through the doorway on the right of the painting. Enter the bedroom, you will reach your destination.

**Current navigation architectures**

Need to make multi-step decisions, making error correction harder.
Our work: Evolving Graphical Planner

A differentiable graphical planner

Evolving Graphical Structure

Proxy graphs for planning

Graph-augmented supervision

Condensation
Facing the end of the bed, take an immediate right and exit the bedroom through the open doorway. Walk straight until you see a large red painting. At the painting make a turn towards and go through the doorway on the right of the painting. Enter the bedroom, you will reach your destination.
Our work: Evolving Graphical Planner

A differentiable graphical planner: global decision space helps
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Our work: Evolving Graphical Planner

A differentiable graphical planner: Graphical memory – topological connection + raw feat.

Instructions

Facing the end of the bed, take an immediate right and exit the bedroom through the open doorway. Walk straight until you see a large red painting. At the painting make a turn towards and go through the doorway on the right of the painting...

Observations
(visual + angle)

Graphical memory

\[ G_t = (V_t, E_t) \]

\[ v_t^i = (visual_t^i, angle_t^i) \]
Our work: Evolving Graphical Planner

A differentiable graphical planner: Graphical memory

Instructions

Facing the end of the bed, take an immediate right and exit the bedroom through the open doorway. Walk straight until you see a large red painting. At the painting make a turn towards and go through the doorway on the right of the painting...

Observations (visual + angle)

- Grounding: global alignment

Graphical memory

Topological map

Our work: Evolving Graphical Planner

A differentiable graphical planner: Graphical memory

Instructions

Facing the end of the bed, take an immediate right and exit the bedroom through the open doorway. Walk straight until you see a large red painting. At the painting make a turn towards and go through the doorway on the right of the painting...

Observations (visual + angle)

- Follow the memorized path
- Decision made in single step
- Easier error correction
Our work: Evolving Graphical Planner

A differentiable graphical planner: Proxy graphs

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Facing the end of the bed, take an immediate right and exit the bedroom through the open doorway. Walk straight until you see a large red painting. At the painting make a turn towards and go through the doorway on the right of the painting...

Observations
(visual + angle)

Ever expanding graph...
Our work: Evolving Graphical Planner

A differentiable graphical planner: Proxy graphs

Instructions

Facing the end of the bed, take an immediate right and exit the bedroom through the open doorway. Walk straight until you see a large red painting. At the painting make a turn towards and go through the doorway on the right of the painting...

Observations
(visual + angle)

Operate on the full graph: high planning cost

Ever expanding graph...
Our work: Evolving Graphical Planner

A differentiable graphical planner: Proxy graphs

\[ G_t = (V_t, E_t) \]

\[ \tilde{G}_t = (V_t, E_t) \]

Ever expanding graph...

Hierarchical Graph Representation Learning with Differentiable Pooling, Ying et al. NeurIPS’18

Our work: Evolving Graphical Planner

A differentiable graphical planner: Proxy graphs

\[ G_t = (V_t, E_t) \]

Pool

\[ \widetilde{G}_t = (V_t, E_t) \]

Pooling matrix \( A_t \): soft “attention” or aggregation from the original graph

Hierarchical Graph Representation Learning with Differentiable Pooling, Ying et al. NeurIPS'18

Our work: Evolving Graphical Planner

A differentiable graphical planner: Proxy graphs

\[ G_t = (V_t, E_t) \]

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Our work: Evolving Graphical Planner

A differentiable graphical planner: Proxy graphs

\[ G_t = (V_t, E_t) \]

Neural message passing: \textit{GraphNeuralNetworks}(G_t, k = \text{steps})
Our work: Evolving Graphical Planner

A differentiable graphical planner: Proxy graphs

\[ G_t = (V_t, E_t) \]

\[ \tilde{G}_t = (V_t, E_t) \]

Pooling matrix \( A_t \): transpose as the un-pool matrix
Our work: Evolving Graphical Planner

A differentiable graphical planner: Proxy graphs

\[ G_t = (V_t, E_t) \]

Propose next action

Un-pool

\[ \tilde{G}_t = (V_t, E_t) \]
Our work: Evolving Graphical Planner

A differentiable graphical planner: Proxy graphs – multi-channel

Propose next action

Hierarchical Graph Representation Learning with Differentiable Pooling, Ying et al. NeurIPS’18
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A differentiable graphical planner: how to supervise the imitation learner?

Facing the end of the bed, take an immediate right and exit the bedroom through the open doorway. Walk straight until you see a large red painting. At the painting make a turn towards and go through the doorway on the right of the painting...

Expert trajectories are provided

Speaker-Follower Models for Vision-and-Language Navigation, Fried&Hu et al., NeurIPS’18
The Regretful Agent: Heuristic-Aided Navigation through Progress Estimation, Ma et al., ICCV’19
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A differentiable graphical planner: how to supervise the imitation learner?

How to use expert trajectory supervision?

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Option 1: “teacher forcing”

Expert trajectory dataset: \( D = \{(a_1, a_2, \ldots, a_T)_i\} \)

Speaker-Follower Models for Vision-and-Language Navigation, Fried&Hu et al., NeurIPS’18
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A differentiable graphical planner: how to supervise the imitation learner?

Facing the end of the bed, take an immediate right and exit the bedroom through the open doorway. Walk straight until you see a large red painting. At the painting make a turn towards and go through the doorway on the right of the painting...

Option 1: “teacher forcing”

\[
P(a_1, a_2, \ldots, a_T \mid s) = P(a_1 \mid s) \prod_{t=2}^{T} P(a_t \mid a_1, a_2, \ldots, a_{t-1}, s)
\]
Our work: Evolving Graphical Planner

A differentiable graphical planner: how to supervise the imitation learner?

Facing the end of the bed, take an immediate right and exit the bedroom through the open doorway. Walk straight until you see a large red painting. At the painting make a turn towards and go through the doorway on the right of the painting...

Option 1: “teacher forcing” – drifting issue in unseen data

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Our work: Evolving Graphical Planner

A differentiable graphical planner: how to supervise the imitation learner?

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Option 2: “student forcing”
Our work: Evolving Graphical Planner

A differentiable graphical planner: how to supervise the imitation learner?

Facing the end of the bed, take an immediate right and exit the bedroom through the open doorway. Walk straight until you see a large red painting. At the painting make a turn towards and go through the doorway on the right of the painting...

Option 2: “student forcing” – generate new supervision (shortest path)

\[ D^* = \left\{ (a_1^*, a_2^*, \ldots, a_{T_i}^*) \right\} \]

\[ D \cup D^* \]

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Option 2: “student forcing” – shortest path supervision

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Option 2: “student forcing” – graph augmented supervision

A differentiable graphical planner: how to supervise the imitation learner?
Our work: Evolving Graphical Planner

A differentiable graphical planner: how to supervise the imitation learner?

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Option 2: “student forcing” – graph augmented supervision

- Ground truth always exists
- No mismatch problem
- No need to access the ENV

Speaker-Follower Models for Vision-and-Language Navigation, Fried&Hu et al., NeurIPS’18
The Regretful Agent: Heuristic-Aided Navigation through Progress Estimation, Ma et al., ICCV’19
Our work: Evolving Graphical Planner

A differentiable graphical planner: full training process

- Instructions
- Observations (visual + angle)
Our work: Evolving Graphical Planner

A differentiable graphical planner: test inference matches the training

Instructions

Graphical memory

Multi-channel planner

Action

Observations (visual + angle)
Experiments

- Room-to-Room (R2R): all trajectories are generated through shortest-path, emphasize on goal reaching
Contribution of each component

- Room-to-Room (R2R): all trajectories are generated through shortest-path, emphasize on goal reaching

The global decision space, the planner and the new supervision strategy help on navigation success rate.
Compare to existing backbones

- Room-to-Room (R2R): all trajectories are generated through shortest-path, emphasize on goal reaching

<table>
<thead>
<tr>
<th>Models</th>
<th>Type</th>
<th>Val unseen</th>
<th>Test</th>
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</thead>
<tbody>
<tr>
<td>Seq2Seq [1]</td>
<td>IL</td>
<td>6.01 39 - 53</td>
<td>7.81 22 - 28</td>
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<tr>
<td>Ghost [25]</td>
<td>IL</td>
<td>7.20 35 31 44</td>
<td>7.83 33 30 42</td>
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<td>RCM* [47]</td>
<td>IL+RL</td>
<td>5.88 43 - 52</td>
<td>6.12 43 38 50</td>
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<tr>
<td>Monitor [14]</td>
<td>IL</td>
<td>5.98 44 30 58</td>
<td>- - - -</td>
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<tr>
<td>Monitor* [14]</td>
<td>IL</td>
<td>5.52 45 32 56</td>
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<td>Regretful* [19]</td>
<td>IL</td>
<td>5.32 50 41 59</td>
<td>5.69 48 40 56</td>
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<td>Baseline agent</td>
<td>IL</td>
<td>6.20 43 36 52</td>
<td>- - - -</td>
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<td><strong>EGP (ours)</strong></td>
<td>IL</td>
<td>5.34 52 41 65</td>
<td>- - - -</td>
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<tr>
<td><em><em>EGP</em> (ours)</em>*</td>
<td>IL</td>
<td><strong>4.83</strong> 56 44 64</td>
<td><strong>5.34</strong> 53 42 61</td>
</tr>
</tbody>
</table>

We outperform previous backbone architecture
Room-for-room with pure imitation learning

- Room-for-Room (R4R): measured by Coverage weighted by Length Score (CLS), normalized dynamic time warping (DTW), Success rate weighted normalized Dynamic Time Warping (SDTW), emphasize on path following
Room-for-room with pure imitation learning

- Room-for-Room (R4R): measured by Coverage weighted by Length Score (CLS), normalized dynamic time warping (DTW), Success rate weighted normalized Dynamic Time Warping (SDTW)

We achieve the state-of-the-art using pure imitation learning

<table>
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<th>PL</th>
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<th>CLS↑</th>
<th>nDTW↑</th>
<th>SDTW↑</th>
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<td><strong>EGP (ours)</strong></td>
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Contributions

- A differentiable graphical planner that extends the decision space globally
- A new supervision strategy for training imitation agent in navigation
- Introduce proxy graphs for improving the efficiency of planning

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