NRI: FND: Spatial Patterns of Behavior in HRI Under Environmental Spatial Constraints

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This project has advanced autonomous reasoning about spatial patterns of behavior during human-robot interactions. It provided empirical knowledge and methods to incorporate spatial constraints into the way robots reason about spatial formations.

The Challenge

Prior work has shown that methods that reason about human spatial behavior are promising for automatic conversational group detection. However, these methods tend to be brittle because they build on simple mathematical models of spatial formations (e.g., side-by-side or circular arrangements). These models do not consider that the configuration of the space where the interactions happen and the presence of other nearby people can affect human spatial patterns of behavior.

Scientific Impact

As robots enter consumer marketplaces, it is essential for them to be able to cope with the complexity of group interactions. Spatial reasoning is a foundational ability to facilitate group HRI in domains like service robotics, education and healthcare.

This project has studied: How can robots detect spatial group formations under spatial constraints? How do humans perceive these formations in HRI as a function of robot embodiment? How can robots autonomously generate appropriate spatial behavior to sustain conversations in constrained environments?

Broader Impacts

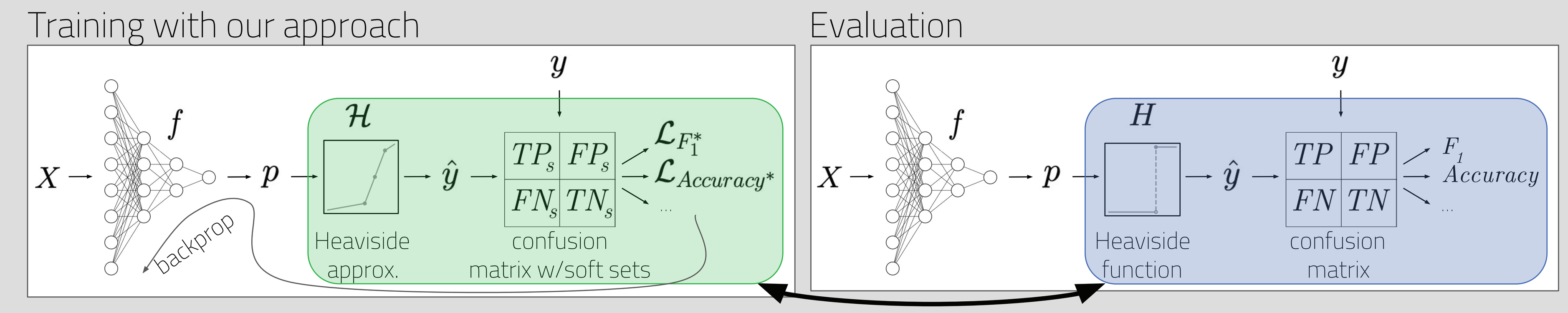
The methods and insights gained from this project are relevant to robotics applications in a wide range of critical, socially relevant domains. For all publications, we have open-sourced our code, lowering barriers of entry to this line of research.

Thus far, this project has provided training for 4 PhD students and 14 undergrads (including 5 female students and 2 Hispanic students). Research findings have been incorporated in class lectures (e.g., AI, HCI) and used to engage more than 200 middle school and high school students with our research (e.g., through presentations at the Yale Young Global Scholars Program and CodeHaven).

Contributions

1. We proposed **data-driven approaches to detect conversational groups** [1,2]. These approaches combine graph abstractions, neural networks, and graph clustering to identify interactions. Recently, we have facilitated training of the graph neural networks as follows:

Neural network binary classifiers are often evaluated on metrics such as Accuracy and F1-Score, but they are commonly trained with cross-entropy. How can this training-evaluation gap be addressed? In our NeurIPS 2022 paper [5], we proposed to train neural network binary classifiers using a differentiable approximation of the Heaviside function with a soft-set version of confusion matrix values. This approach allows to more easily train Graph Neural Networks for conversational group detection (as in [2]) using imbalanced datasets.

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Want to try the approach?
$ pip install torch-btg

Then, in your Python code:
from torch_btg.loss import fb_loss
...
criterion = fb_loss(beta=1.0)
```

Fig. 1. Bridging the gap: unifying training and evaluation

2. We proposed methods to **predict appropriate poses for a robot to take part in group formations** subject to the physical layout of the surrounding environment [3], as in Fig. 2. One method was model-based; the other was data-driven. The model-based approach was more successful at avoiding poses generated in nonfree areas of the environment, but the data-driven method was better at capturing the variability of group formations.

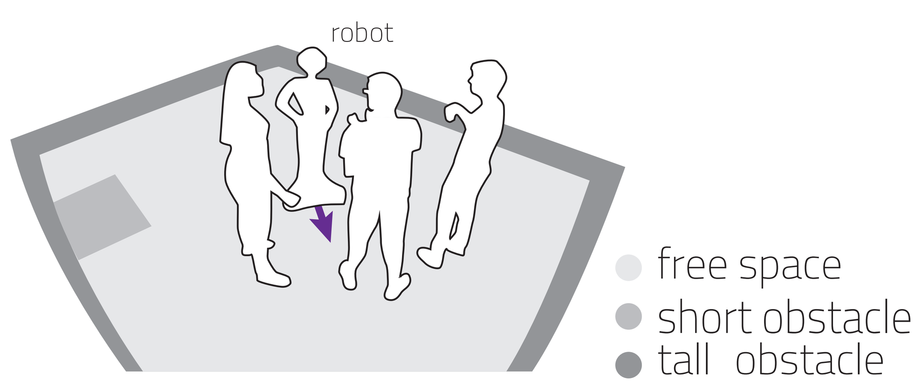

Fig. 2. Pose generation problem: Given the poses of interactants and a map of the environment, predict a pose for a robot in the group.

3. We advanced our **understanding of the effects of robot embodiment on human perception of conversational groups** [4]. Our results suggest that human perception of groups can be significantly affected by whether robot embodiment leads to a discernible robot orientation.

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