The University of Texas at Austin
Aerospace Engineering and Engineering Mechanics
Cockrell School of Engineering

April 2022

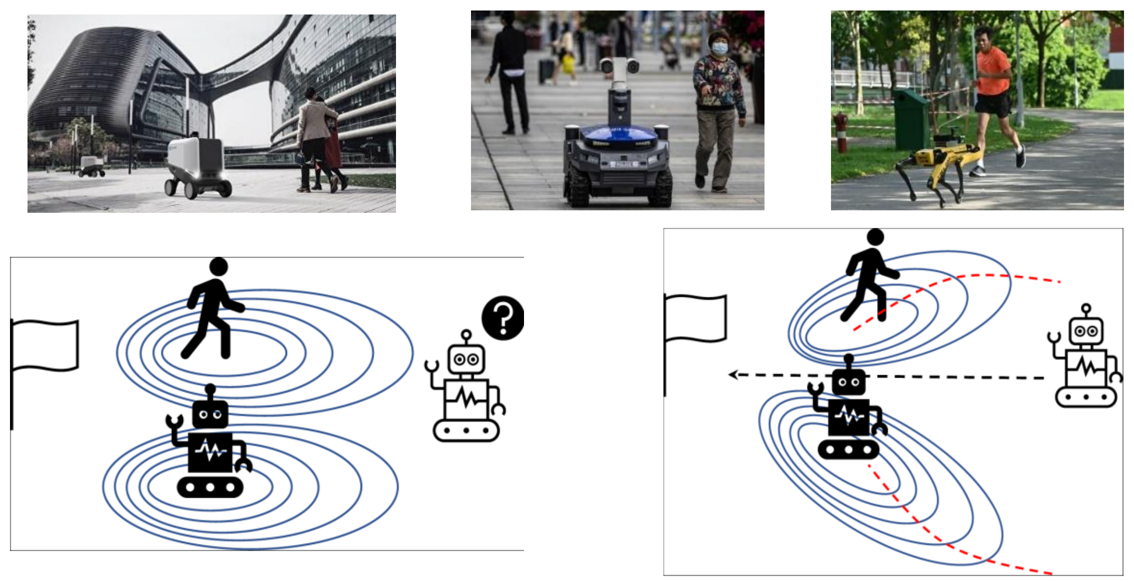
2022 NRI-FRR PI MEETING SHORT TALK FOR AWARD #1924790

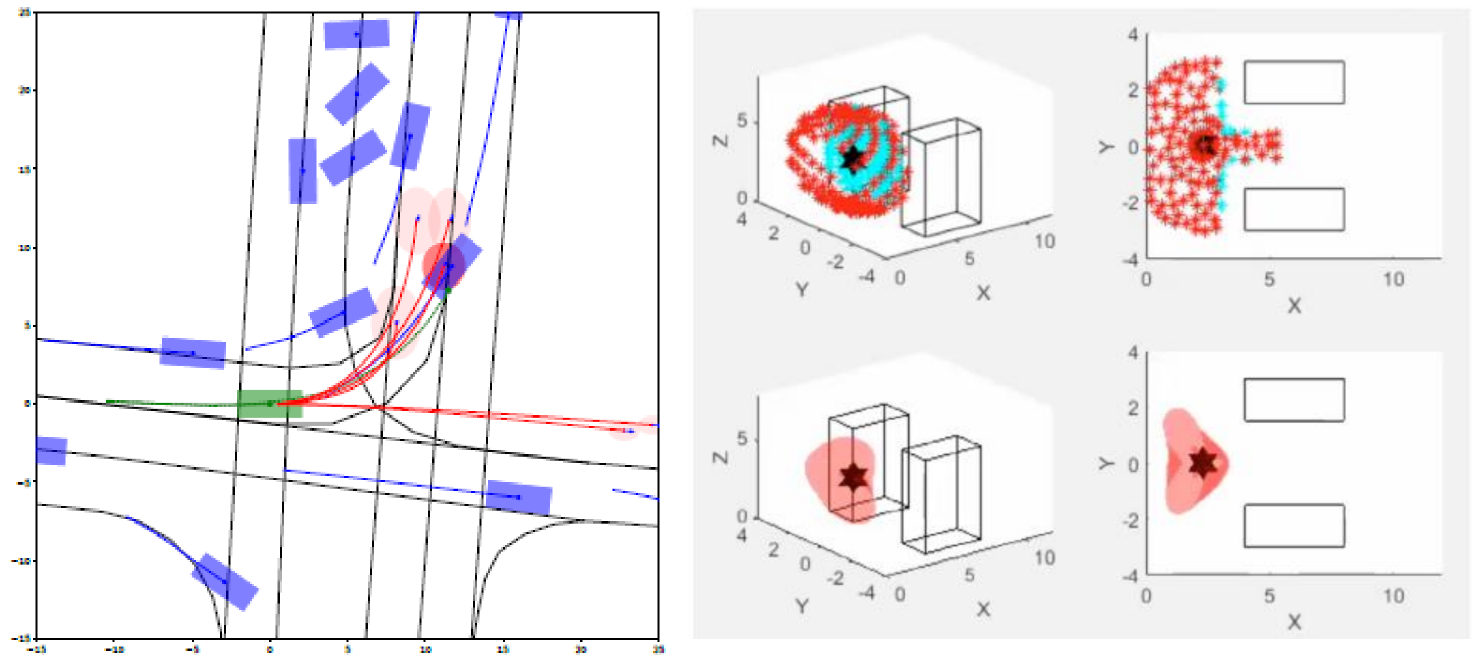
Efstathios (Stathis) Bakolas
Associate Professor
ASE/EM Department, The University of Texas at Austin

Project Overview

Project Title: NRI: FND: Efficient algorithms for safety guiding mobile robots through spaces populated by humans and mobile intelligent machines and robots
Funding Organization: National Science Foundation; Award # 1924790, Poster number: 17 (Session 3)
Team personnel and institution: E. Bakolas (PI); A. Tsolovikos, S. Patrick, A. James, M. Braquet; University of Texas at Austin

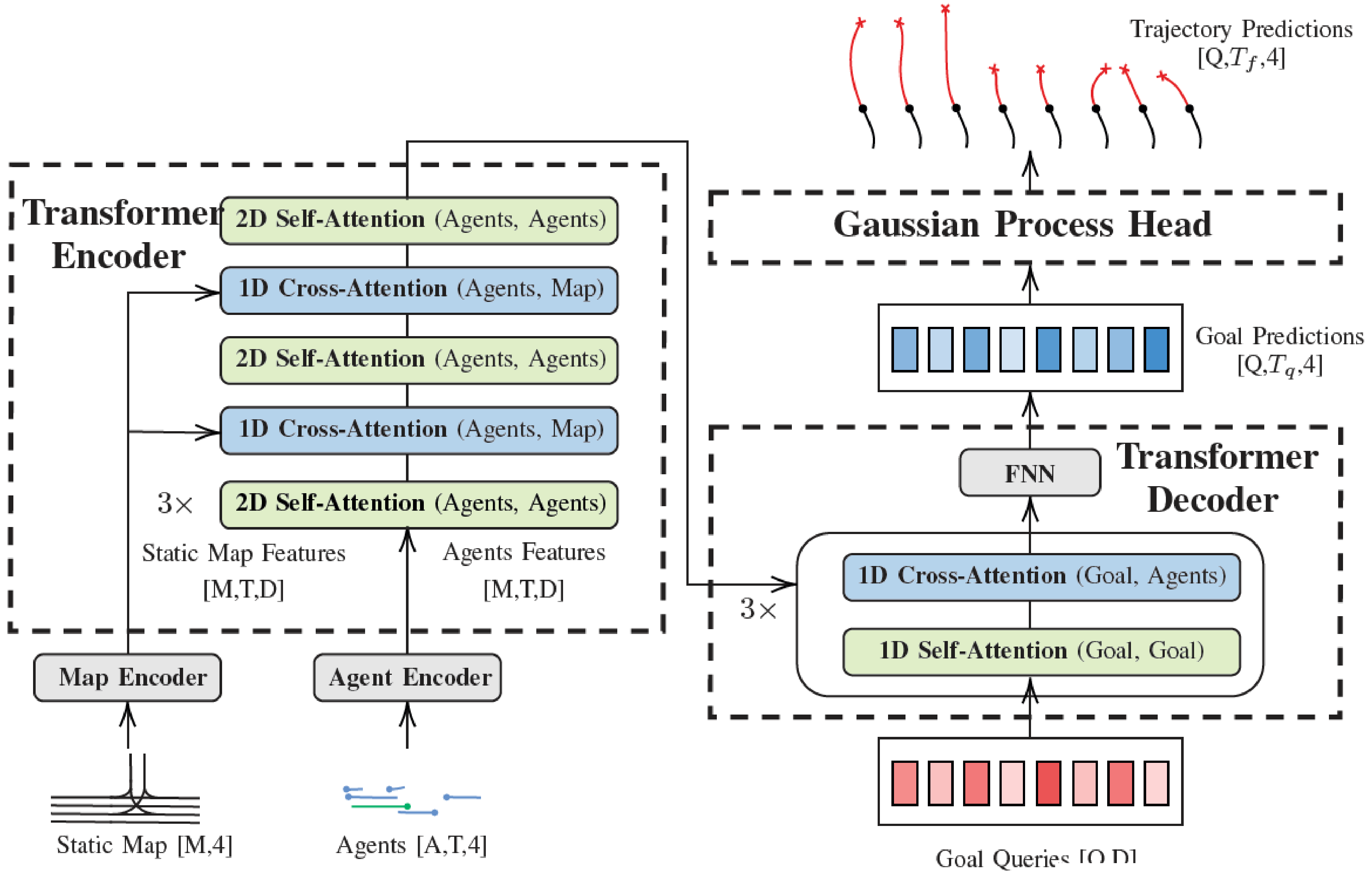
- **Motivation:** Local motion planners that account for the intentions and future trajectories of nearby agents can find solutions to problems where worst-case / robust path planners may fail
- **Goal:** Create intent-aware and real-time executable local motion planning algorithms that can safely guide a robot in dynamic workspaces populated by multiple agents (such as humans, robots, autonomous vehicles etc.)
- **Impact:** Promote integration of intelligent machines in different aspects of our everyday life (e.g., Amazon fulfillment centers, busy crossroads on campus)
- **Technical Approach:** Combined motion prediction and local motion planning
  1. **Intent-aware motion prediction problem**: compute real-time predictions of the intent and future trajectories of nearby mobile agents/obstacles near the ego-agent and quantify uncertainty
  2. **Local motion planning problem:** Compute safe trajectories that keep mobile robots away from both static and moving obstacles (dynamic / uncertain environment)

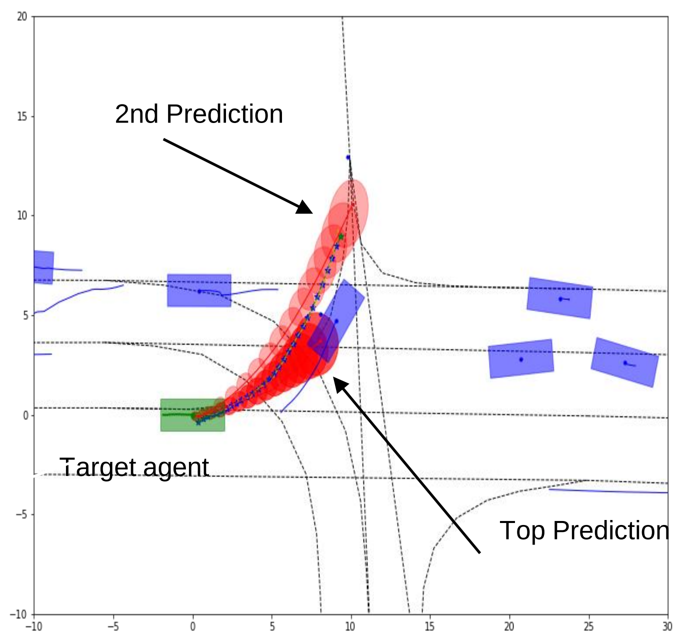


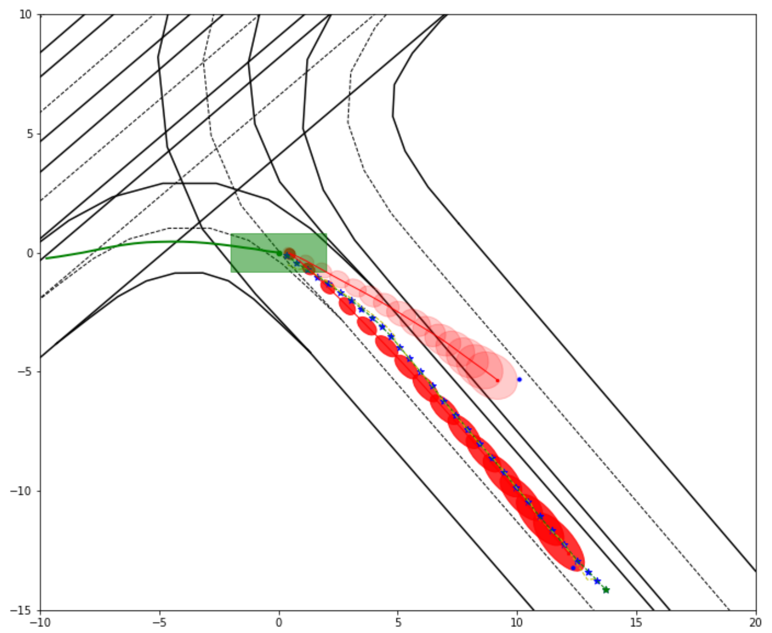


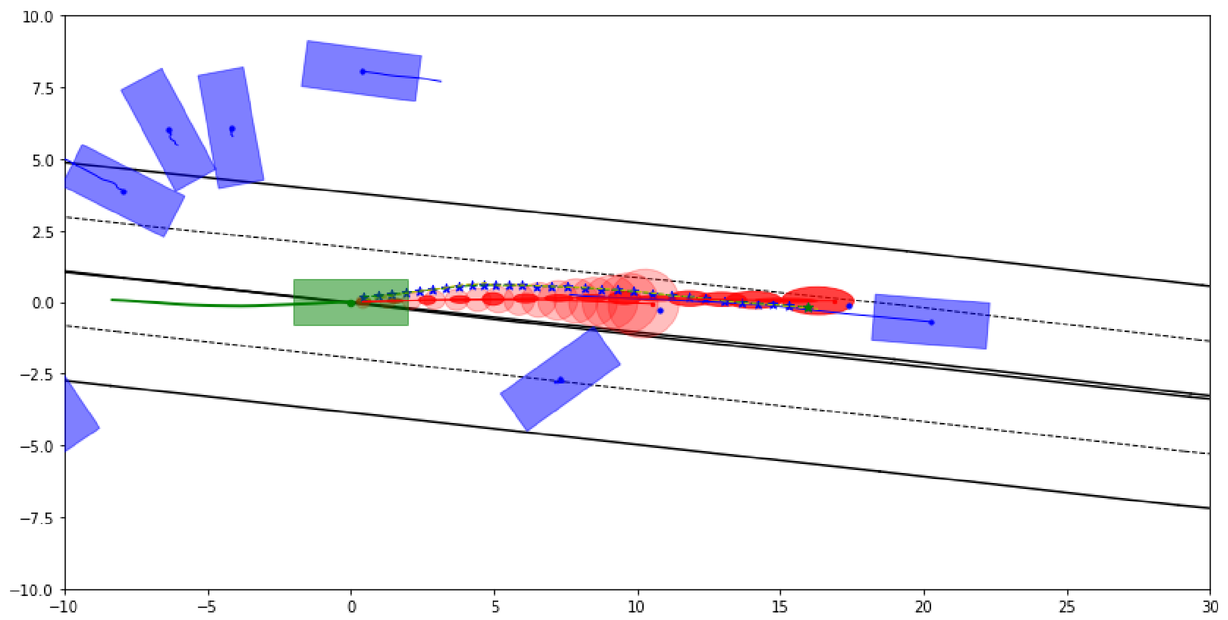
Main idea of proposed approach for motion prediction problem: Use a transformer neural network (Goal Transformer) to infer the motion intent (possible goal positions and velocities) of agents near the ego-agent and Gaussian Process regression tools to predict their corresponding trajectories using past observations and context information

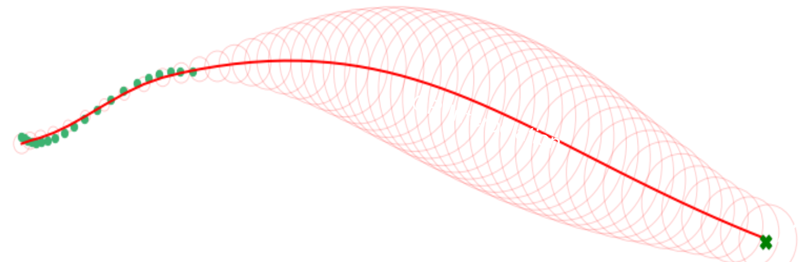
- Transformer: predicts multiple possible goal locations and velocities
- Encoder inputs: Static Map and Agents
- Self-attention: alternates between agents and time
- Cross-attention: agents (Q) attend to centerlines (K,V)
- Decoder queries: possible futures
- Gaussian Process Head: Goal interpolation using a physics-informed cubic spline kernel that accounts for ego-agent's dynamics
- Output: Gaussian mixture of possible future locations and velocities



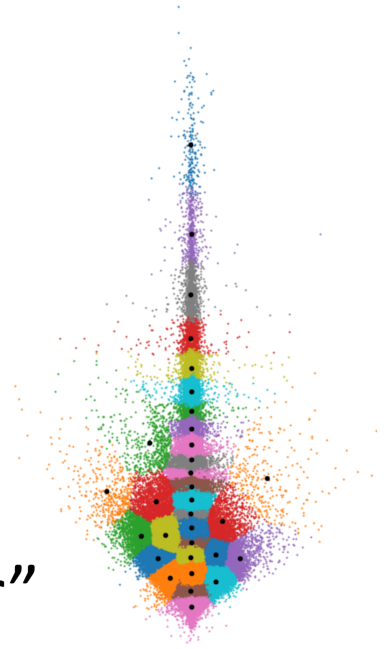






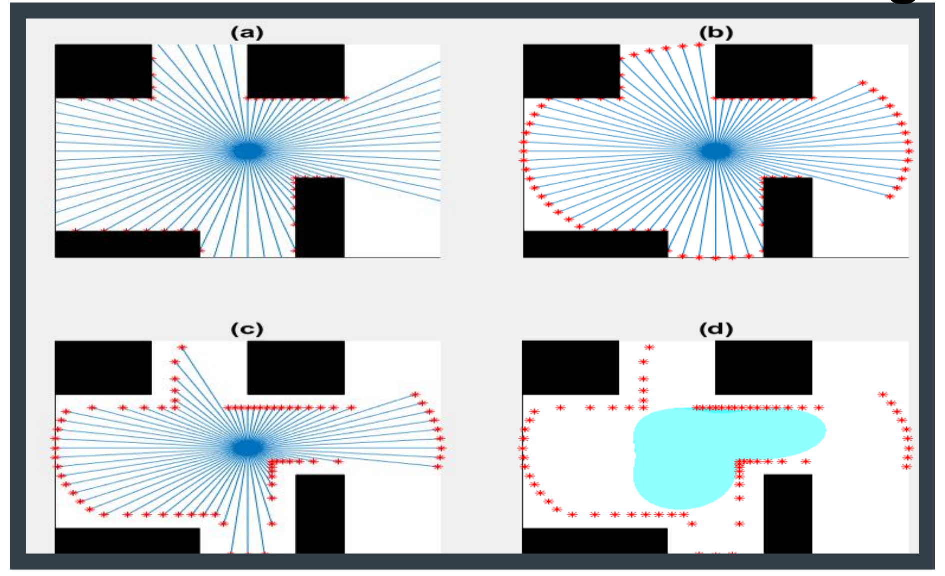


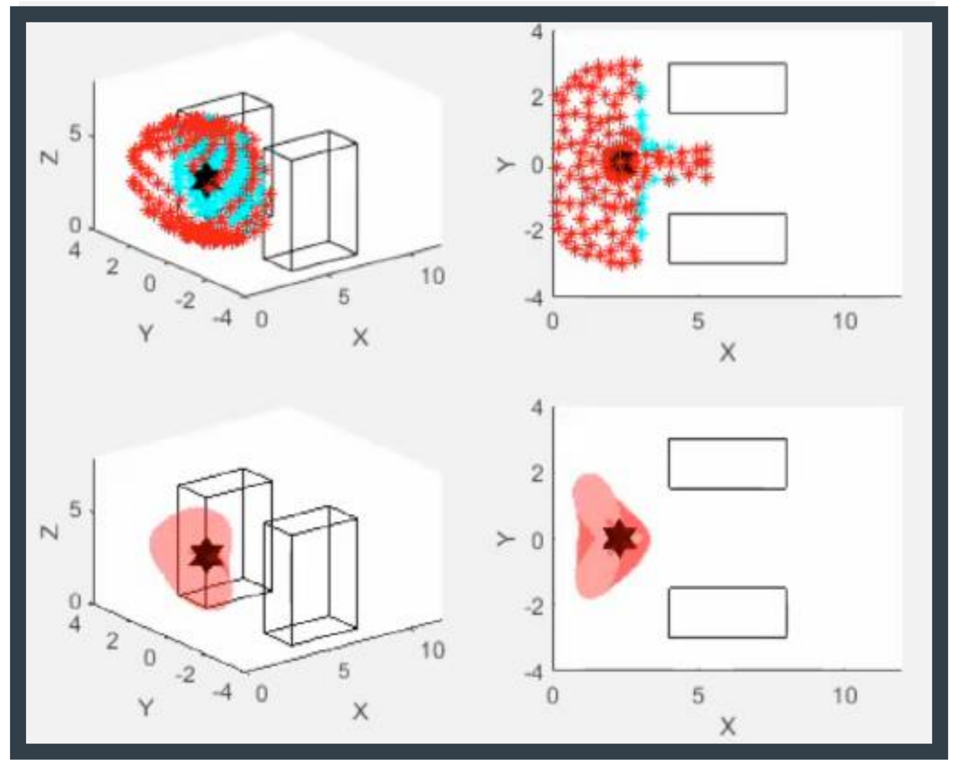
- Each query is trained on a "cluster" of positions and velocities



- **Main idea of proposed approach for local motion planning problem:** Characterize a safe (collision-free) area near the ego-agent and subsequently compute feasible trajectories in a receding horizon way by solving tractable optimizations problem in real time.
- Convert 3D point cloud (LIDAR or RGBD Image) to a collision-free space approximation using Spherical Harmonics
- The collision free space is used as a collision constraint in a trajectory optimization routine.
- To account for dynamic obstacles and uncertainty, we propagate the point cloud for each step of planning horizon using an Extended Kalman Filter.

Data Retrieval and Pre-Processing





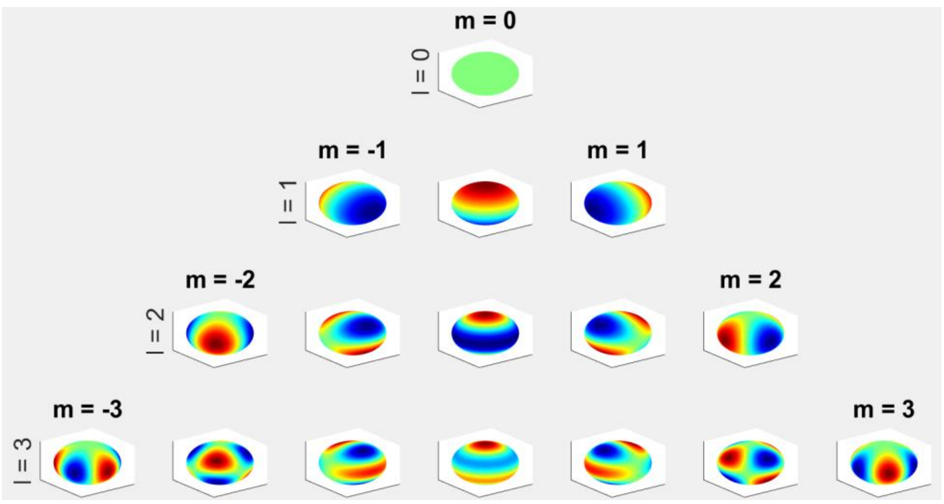
Spherical Harmonics

$$P_l(x) = \frac{1}{2^l l!}\frac{d^l}{dx^l}(x^2-1)^l$$

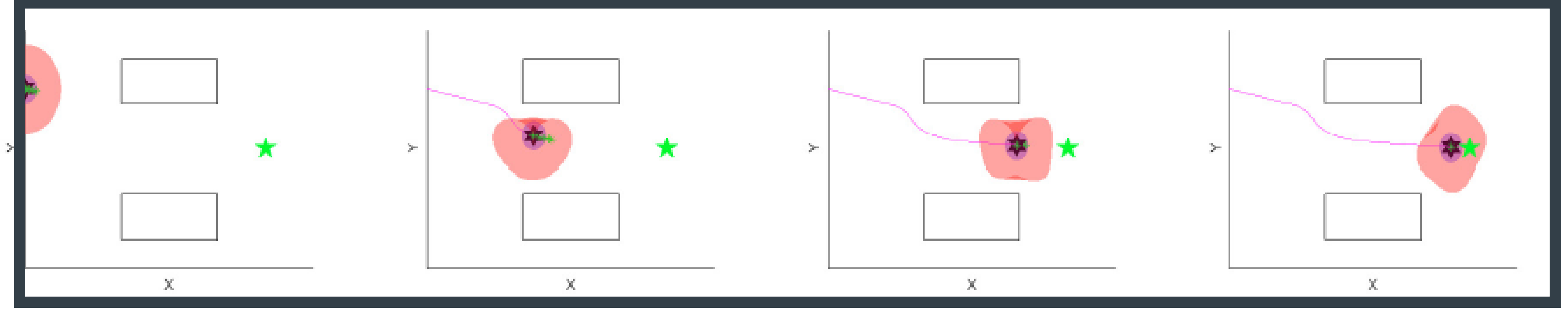
$$P_l^m = (-1)^m(1-x^2)^{m/2}\frac{d^m}{dx^m}(P_l(x))$$

$$S_l^m(\theta,\phi) = \begin{cases} N_l^m P_l^m(\cos(\theta))\sqrt{2}\cos(m\phi), & m>0 \\ N_l^m P_l^m(\cos(\theta)), & m=0 \\ N_l^m P_l^{-m}(\cos(\theta))\sqrt{2}\sin(-m\phi), & m<0 \end{cases}$$

$$f(\theta,\phi) \approx \sum_{l=0}^{L}\sum_{m=-l}^{l} w_l^m S_l^m(\theta,\phi)$$



Trajectory Optimization



Project PI

Efstathios Bakolas (Associate Professor)

Graduate students support by this NSF-NRI award:

Alex Tsolovikos

Steven Patrick

Anegi James

Martin Braquet

Relevant work (published, under review, work in progress)

1. S. Patrick and E. Bakolas, "Collision Avoidance Using Spherical Harmonics," *IFAC MECC 2021*, Austin, TX, USA, 2021A.
2. A. Tsolovikos and E. Bakolas, "Nonlinear Covariance Steering using Variational Gaussian Process Predictive Models," *IFAC MECC 2021*, Austin, TX, USA, 2021.
3. S. Patrick and E. Bakolas, "Using Spherical Harmonics for Navigating in Dynamic and Uncertain Environments (note: submitted for conference publication in 04/2022))
4. A. James and E. Bakolas, "Gaussian Mixture Based Motion Prediction for Clustered Groups of Mobile Agents (note: submitted for conference publication in 04/2022)
5. A. Tsolovikos and E. Bakolas, " Intent and Dynamics-Aware Motion Prediction with Goal Transformer," (note: work in progress)
6. M. Braquet and E. Bakolas, "Vector Field-based Collision Avoidance with Time-Varying Shape Moving Obstacles," (note: work in progress)

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