Social Robot Navigation with Braids

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Social Robot Navigation
Related Work

Social conventions
- Pacchierotti et al., ’06
- Sisbot et al., ’07
- Lam et al., ’11
- Guzzi et al., ‘13
- Shiomi et al., ‘14

Collision Avoidance
- Kirby, ’10
- Knepper, Rus, ’12
- Chen et al., ’17

- Bennewitz et al. ’05
- Ziebart et al., ’09
- Kruse et al., ’12
- Bandyopadhyay et al. ’12
- Luber et al., ’12
- Park and Kuipers, ’12
- Ferguson et al., ’15
- Trautman et al., ‘15
- Kretzschmar et al., ‘16
- Kim, Pineau, ’16
- Truong et al., ’17
Related Work

- Social conventions
- Collision Avoidance
  - Multi-Agent Dynamics
  - Implicit Communication

This work
This Work

Imitating humans
Reproducing social conventions
Engaging with humans
Body Posture, eye gaze, gestures, explicit indicators
Foundations
Human Navigation is Cooperative

- People must behave like competent pedestrians.
- People must trust co-present others to behave like competent pedestrians.

Wolfinger, ’95

Knepper, Rus, ’12
“Humans show a strong and early inclination to interpret observed behaviours of others as goal-directed actions”.

Csibra, Gergely, ‘07

Dragan, Srinivasa, ’13
What is a Goal?

- Multi-agent dynamics
- Decision making is coupled
- Observers are also actors
- Not crucial to know destinations or trajectories
- *Consensus is the goal!*
Planning Legible Navigation Strategies
Legibility as Entropy minimization

\[ \alpha^* \]
What about $n$ agents?
Insight: The maypole dance

https://www.flickr.com/photos/peteashton/174913998/in/set-72157594176644454/
https://creativecommons.org/licenses/by-nc/2.0/
Insight Encouragement

The maypole braid group

Posted by DAVE RICHESON on MAY 4, 2009

https://divisbyzero.com/2009/05/04/the-maypole-braid-group/
What about $n$ agents?
The Braid Group $B_n$

Relations

$\sigma_j \sigma_k = \sigma_k \sigma_j, |j - k| > 1$
$\sigma_j \sigma_k \sigma_j = \sigma_k \sigma_j \sigma_k, |j - k| = 1$

Composition

Inverse

[Birman, '75]
Reasoning about Joint Navigation Strategies

$P(\tau|\Xi, \alpha)$
SCN: Socially Competent Navigation

\[ a^* = \arg\min_{a \in \mathcal{A}} \lambda D(a) + (1 - \lambda)H(a) \]
Learning a Topology Prediction Model

- Multi-agent scenarios (2, 3, 4 agents)
- *Social Force* (SF) [Helbing, Molnár, ’95]
The Social Force Model

[Helbing, Molnár, '95]
Learning a Topology Prediction Model

- Multi-agent scenarios (2, 3, 4 agents)
- Social Force (SF) [Helbing, Molnár, ’95]
- Rectangular/circular workspace

\[
\langle \mathbb{E}_t, \alpha_t \rangle
\]
Topology Inference Accelerates Consensus

Low is better

Average Entropy (bits)

Time Steps

50 trials

1SCNv3SF

4SF

50 trials
Summary

• A symbolic representation for multi-agent navigation
• Legibility as entropy minimization
• Topology inference sufficient for effective coordination

• Computationally intense
• Projection results in loss of information
• Captures phenomena that are not necessarily useful
• Different numbers of agents, different models