Real Time Crowd Navigation From First Principles of Probability Theory

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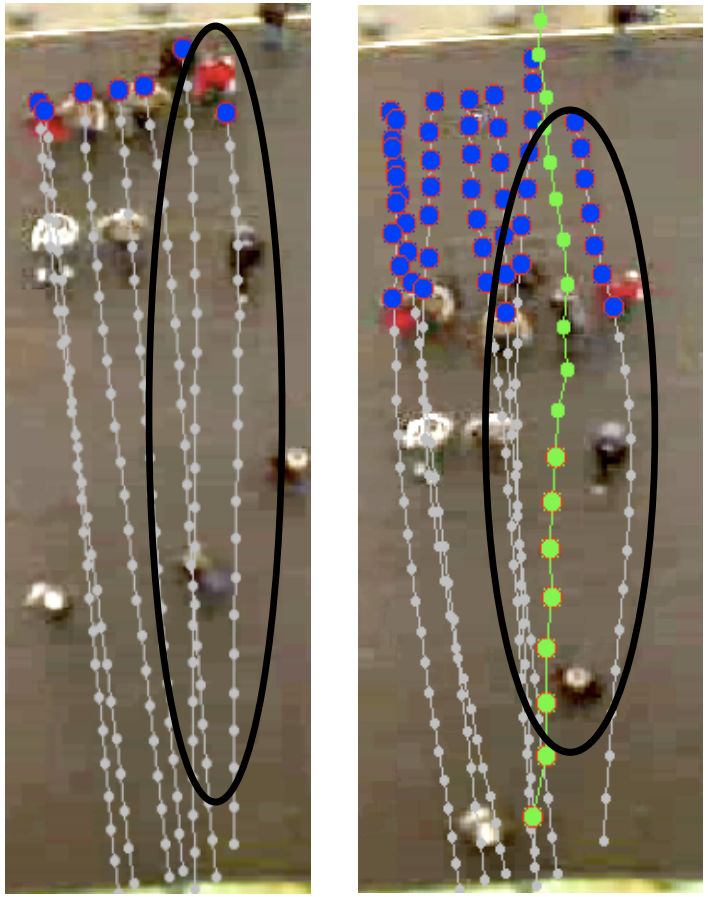
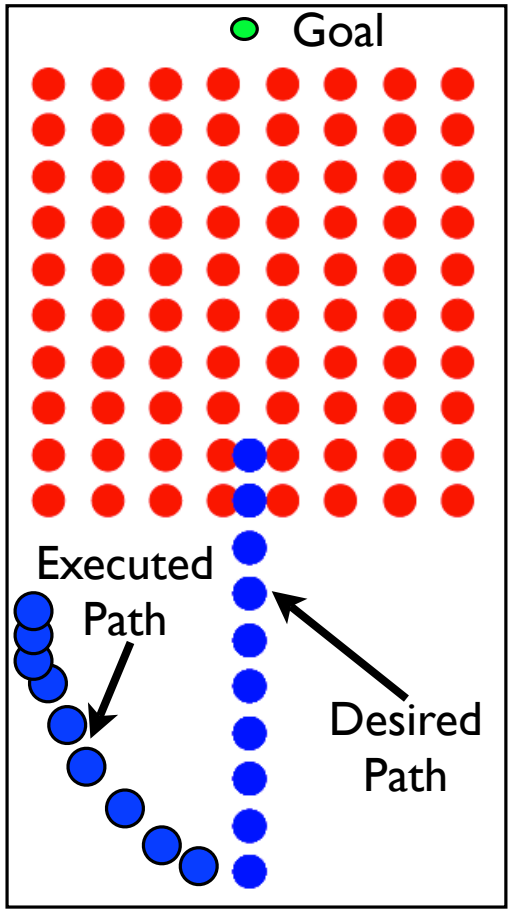
What is Crowd Navigation?

- Unstructured: no flow rules or static obstacles
- Collect time stamped x,y data (trajectories)

Decoupling leads to Freezing Robot Problem



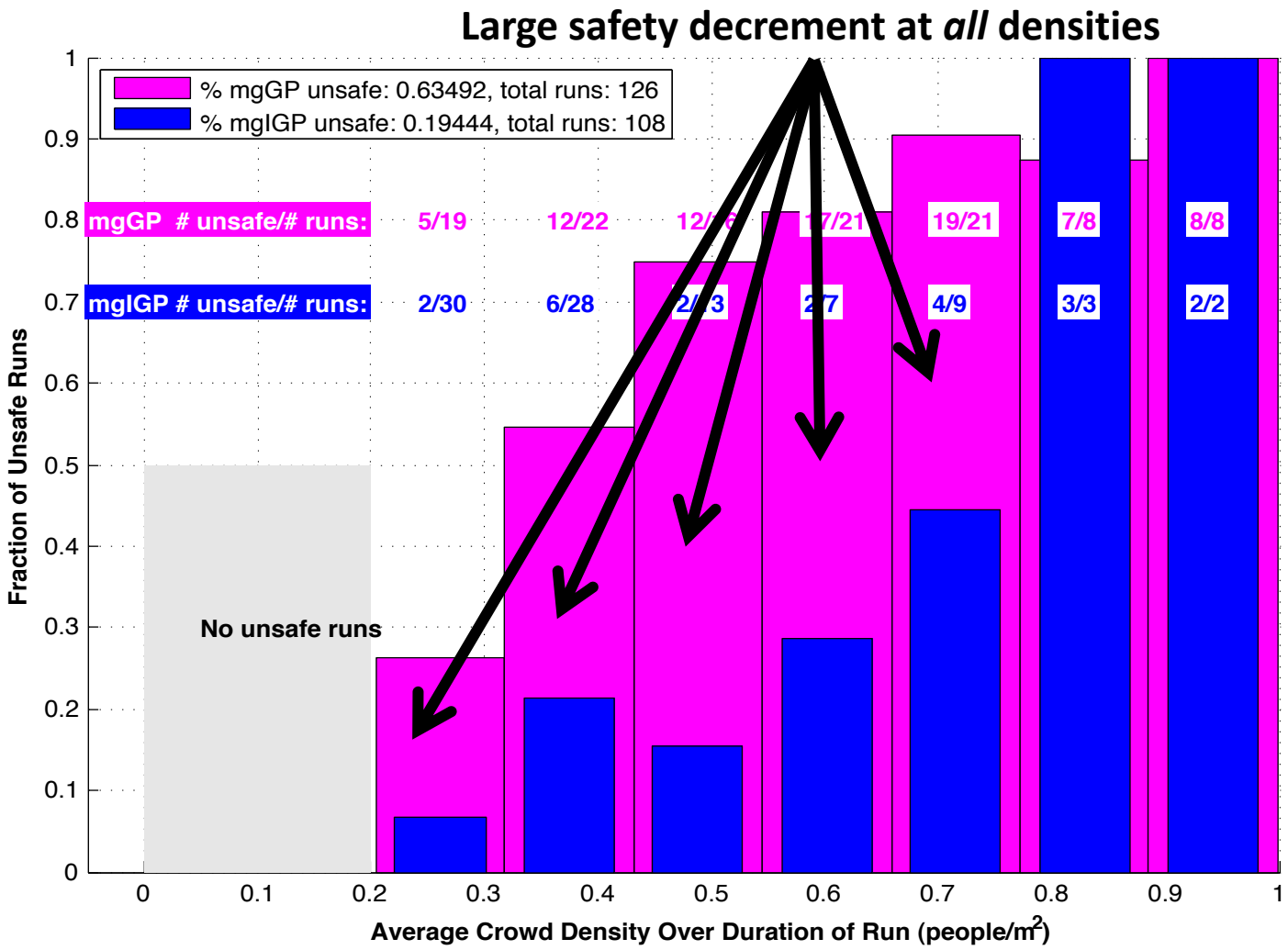
True Pedestrian Movement:
Humans ***leverage*** cooperation



Even with *perfect* future knowledge, "decoupling" prediction and navigation fails

P. Trautman and A. Krause. Unfreezing the robot: Navigation in dense interacting crowds. In *IROS*, 2010.

Decoupling: Suboptimal at any Density



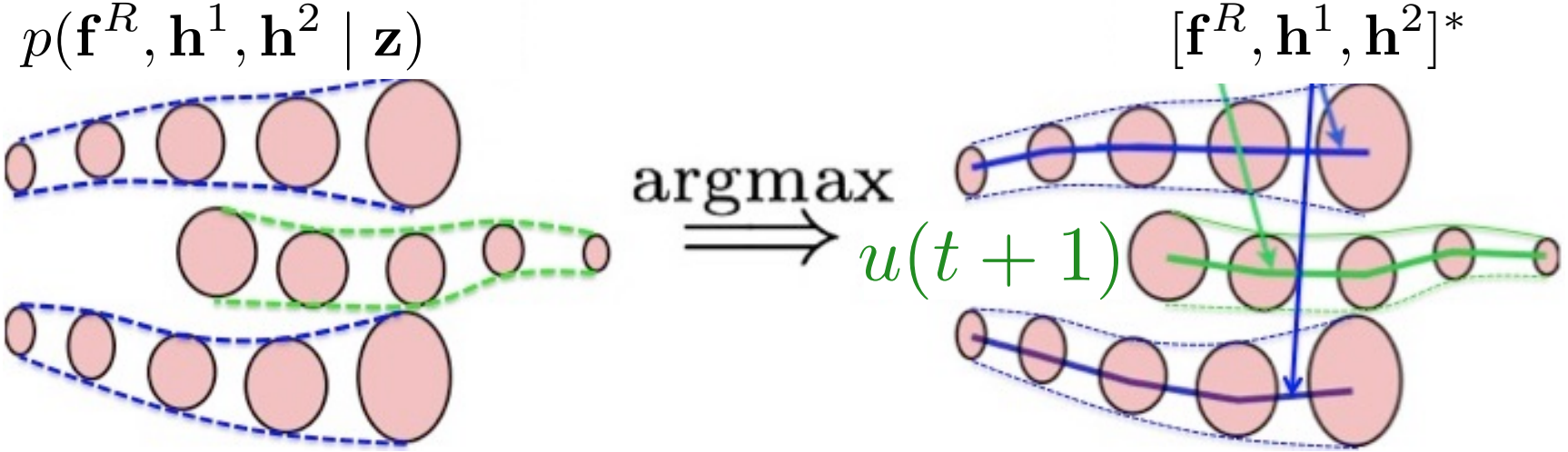
Trautman, P.; Ma, J.; Krause, A.; and Murray, R. M. 2013. Robot navigation in dense crowds: the case for cooperation. In *ICRA*.

Necessity of Coupled Models

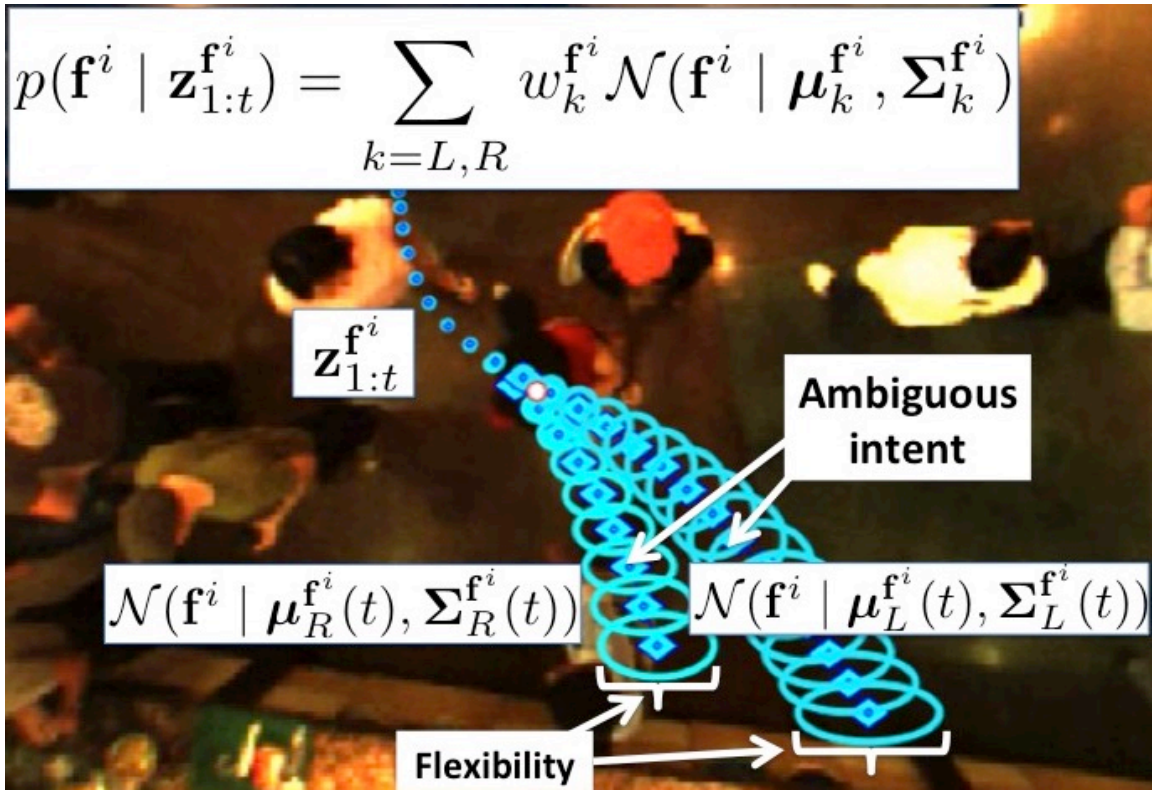
$$[\mathbf{f}^R, \mathbf{h}]^* = \arg\max_{\mathbf{f}^R, \mathbf{h}} p(\mathbf{h}, \mathbf{f}^R \mid \mathbf{z}_\mathbf{T}^h, \mathbf{z}_\mathbf{T}^R)$$

$$u(t+1) = \mathbf{f}^{R*}(t+1)$$

- *What* must $\psi(\mathbf{h}, \mathbf{f}^R, \gamma)$ model?
- *How* can $\psi(\mathbf{h}, \mathbf{f}^R, \gamma)$ model it?



The *How* and *What* of Interaction



Theorem: Crowd navigation cost is statistically valid $\iff$ cost *only* a function of the *full* set of mixture statistics $\iff$

$$C\Big(\underbrace{\boldsymbol{\mu}^R_\ell(t), \boldsymbol{\mu}^{\mathbf{f}^i}_k(t),}_{\text{intents at } t} \quad \underbrace{\boldsymbol{w}(t)}_{\text{preference}} \quad , \quad \underbrace{\boldsymbol{\Sigma}(t)}_{\text{flexibility}} \Big)$$

$\rightarrow$ Provide statistically valid interaction function $\mathbf{P}^{IGP}_{\neg\kappa}$

$\rightarrow$ Provide a real time locally optimal solver

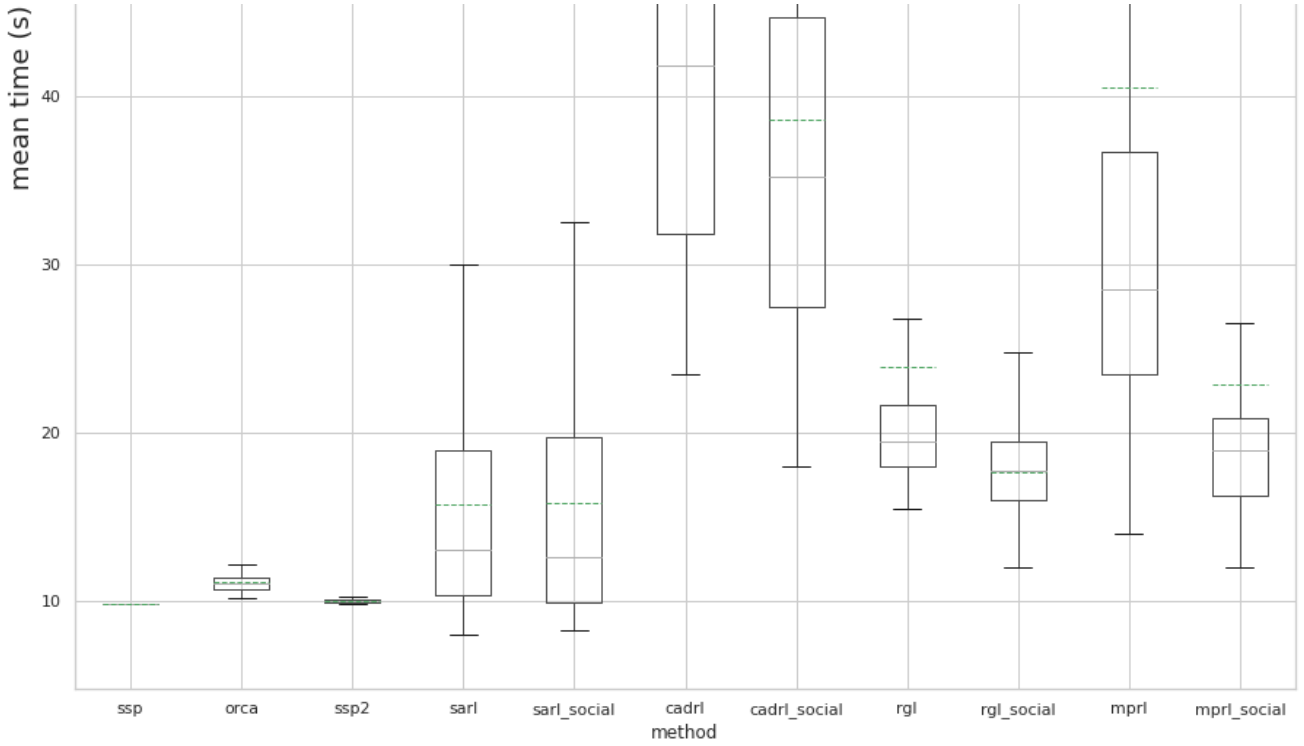
Corollary: Mismodeling flexibility leads to a) overaggressive or b) overcautious (FRP) robot

Crowd Navigation Evaluation Challenges

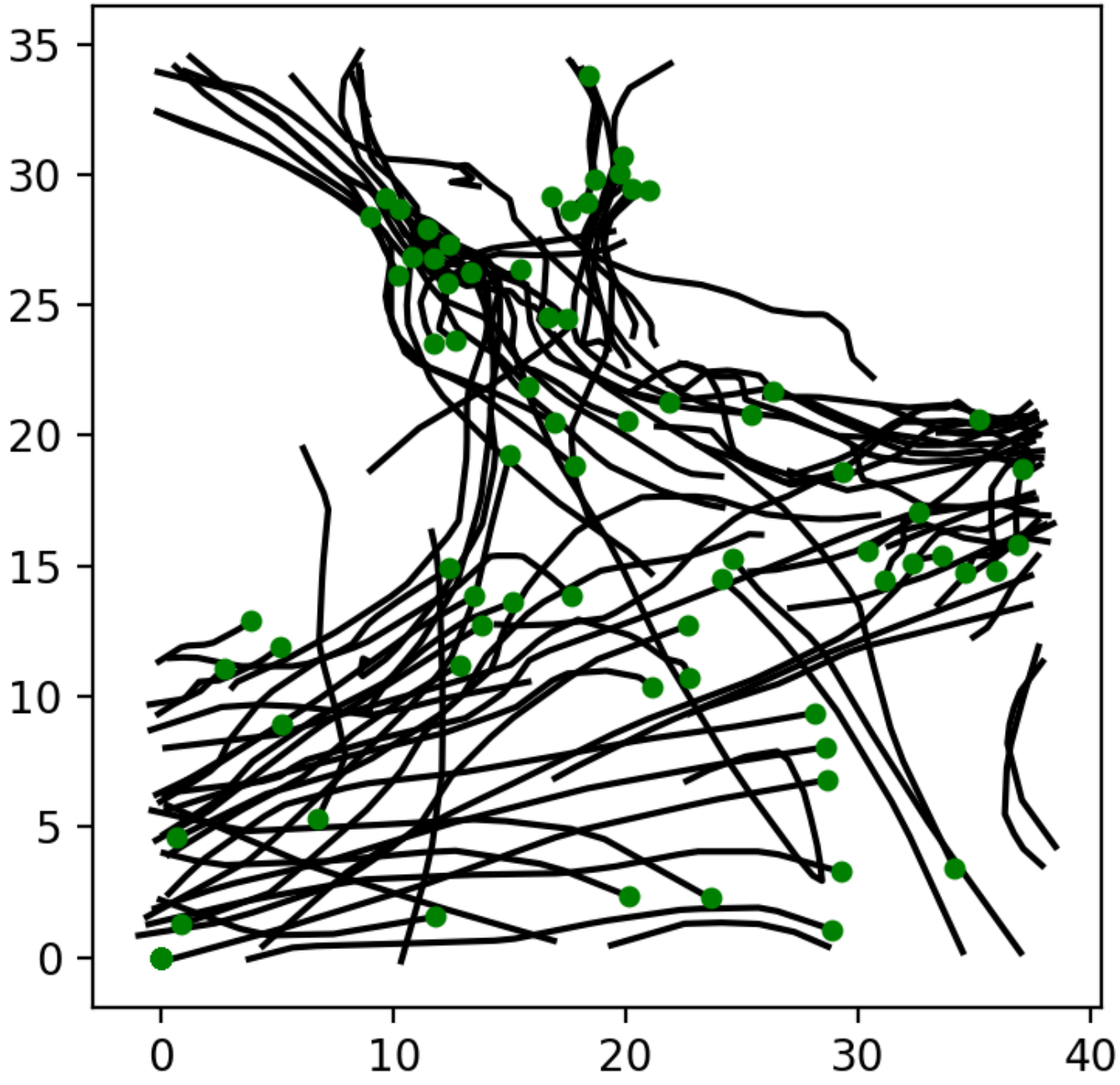
- Real world deployment expensive: 6 months-year to deploy statistically valid study
- ORCA, Social Forces based simulation non-*discriminative*
  - Optimal policy is ”blind, straight line”

ORCA sim collision rate, 0.05-0.25 people/m^2

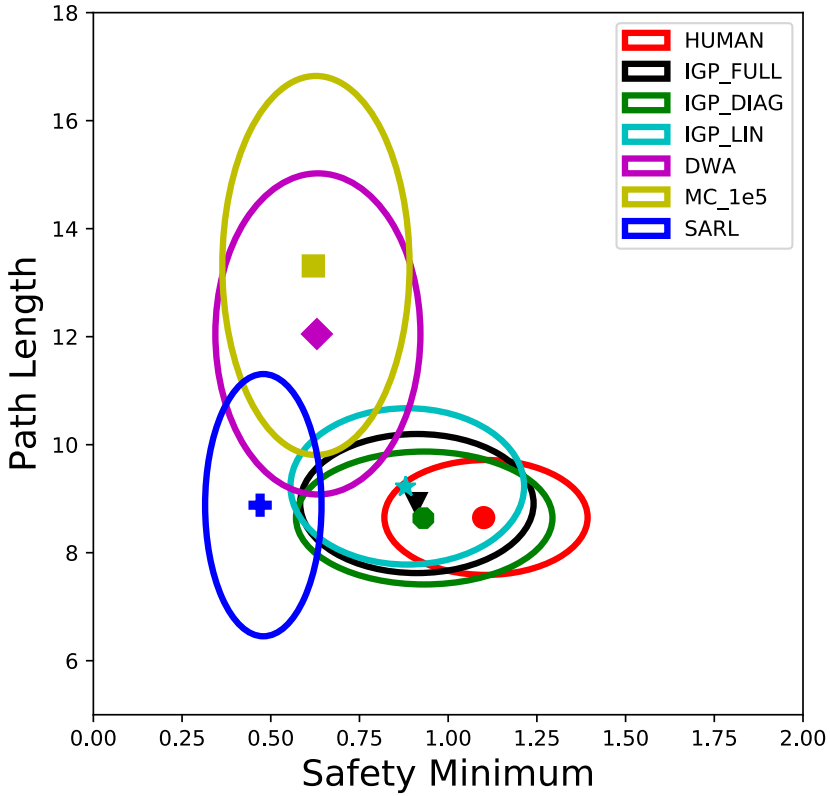
5	7	14	21	28	method
0	0	0	0	0	ssp
0	0	0	0	0	ssp2
0	0	0	0	0	ORCA
2	8	25	56	74	Sarl
6	5	28	59	74	Sarl_social
12	9	28	36	48	Cadrl
10	20	28	40	59	Cadrl_social
0	0	10	27	33	Rgl
3	2	8	8	23	Rgl_social
2	3	13	18	23	Mprl
8	11	19	27	37	Mprl_social

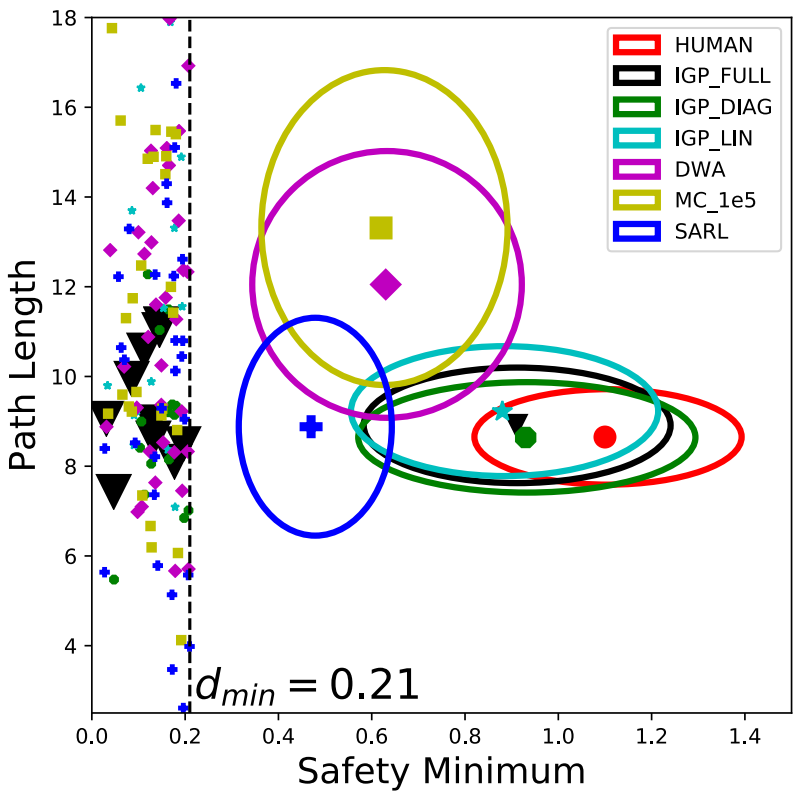


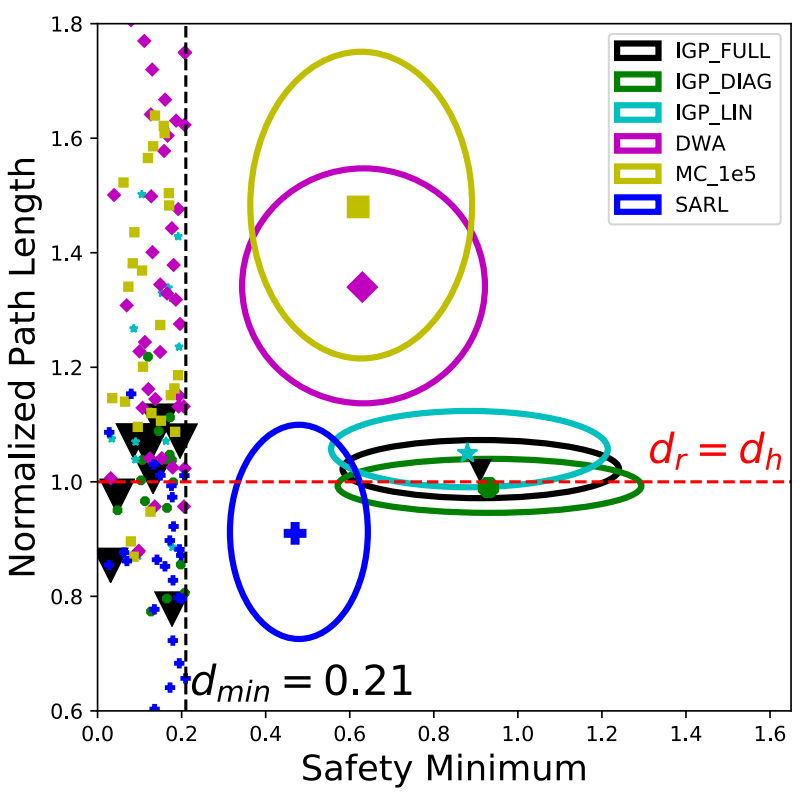
ETH: 241 runs
“Leave one out” evaluation:
-Remove 1 human
-Start and goal
-Compare safety/efficiency of robot and human



Evaluation: Partial Runs







Conclusion

- Provided constraints on permissible interaction functions (for GP mixtures)
- Flexibility key to mitigating freezing robot problem
- Provided a *discriminative* evaluation scenario

Next steps:

- Deploy in real world