NRI-FND-Probabilistic Hypothesis Driven, Adapting Human-Robot Teams

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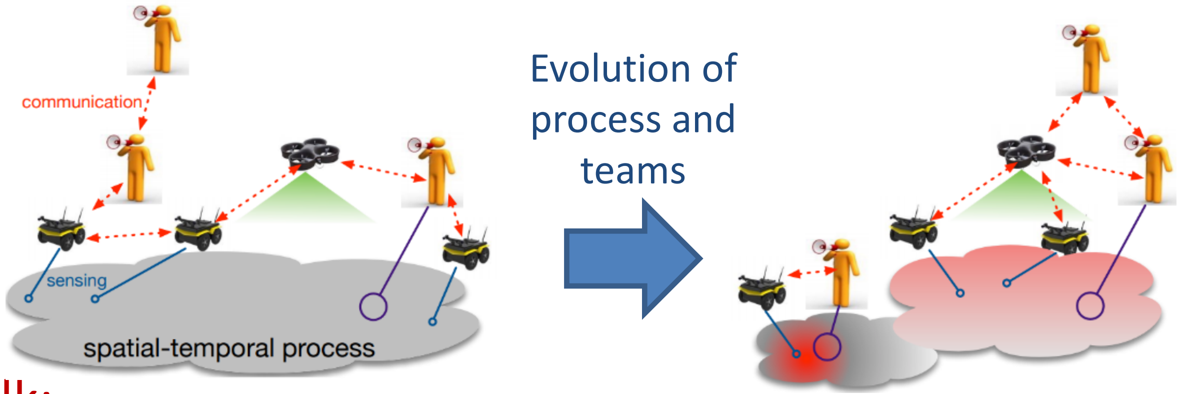
NRI-FND-Probabilistic Hypothesis Driven, Adapting Human-Robot Teams

Challenge

- Cooperation for human-robot teams operating in complex environments evolving over time



Novel Solutions and this Talk:

1) Interaction based on natural language
2) Optimization for multiagent teaming
3) Integration: SaR mission, Firefighter input, Danger level inference, heterogenous planning with probabilistic constraints → three RA-L papers

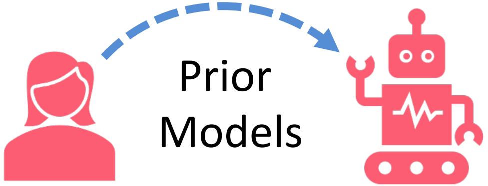
Broader Impact

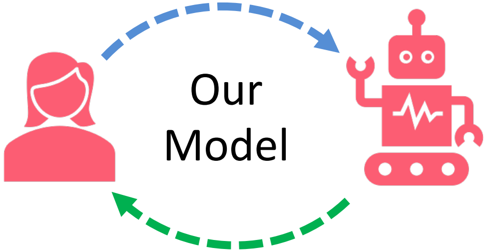
- Applications: SaR, homeland security, disaster response, …
- Outreach activities w/ high schools

Scene Perception enabled by Interactive Natural Language

Interactive Human-Robot Communication

- Prior NLP models
  - Primary focus is on one-way comm/simple models
  - Fail in real-world situation when info is inadequate
- Our Approach: Interactive Communication
  - Leverage models for language-based Re-ID
  - Enable robot to anticipate if current info is adequate
    - if not, robot can ask human for *valuable* information
- Key benefits
  - ***Interactions*** focus on ***essential***, task-related info
  - High rate of task accomplishment





V Shree, WL Chao and M Campbell. "Interactive Natural Language-based Person Search," in RA-L, 2020

Interactive Human-Robot Communication

Task: ID people in crowd based on NL descriptions

Challenges:

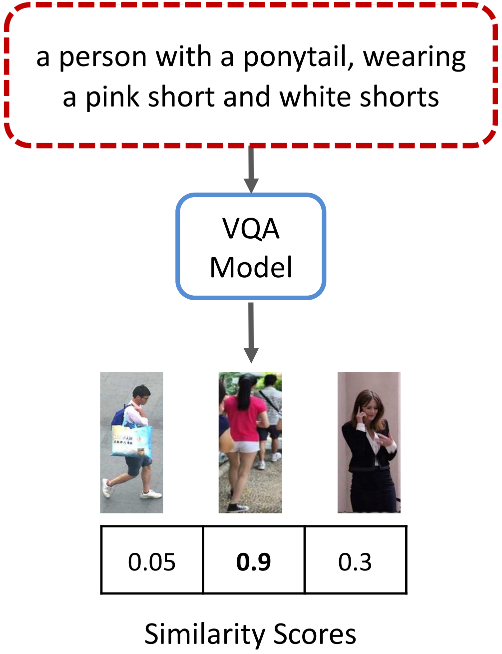
1. Multi-modality of data (language and image)
2. Anticipate robot's need for information

1) SOTA VQA model to assess text-image similarity

- Outputs matching score for gallery images

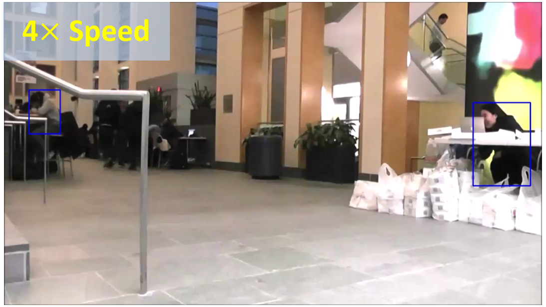
2) Entropy of NL-image match drives next questions

- $E = -\sum_{i=1}^{n} \hat{a}_i \, log \, \hat{a}_i$
- **High Entropy → Low confidence → Ask human for additional information**

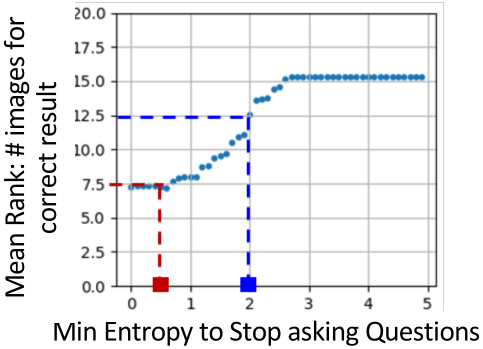


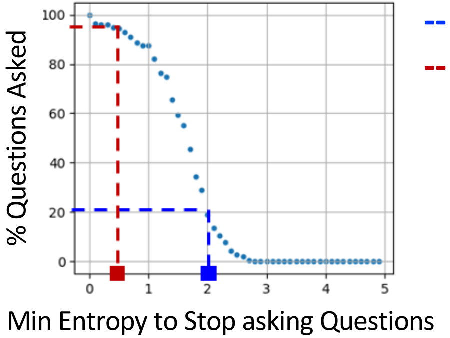
Interactive Human-Robot Communications

- Robot to human: Prepare prior list of questions
    1. Describe appearance of clothes
    2. Describe accessories wearing or carrying
- Optimize ordering of questions via entropy
- Experiments with Jackal (average results shown):



Person detections





-- High Uncertainty
-- Low Uncertainty

Camera-mounted Jackal

Multi-Robot Search Planning for Scenes with Uncertainty

Multi-Robot Planning for Search Missions

Goals:

- Reason **over higher level: like humans do**
- Solutions become layers of larger systems

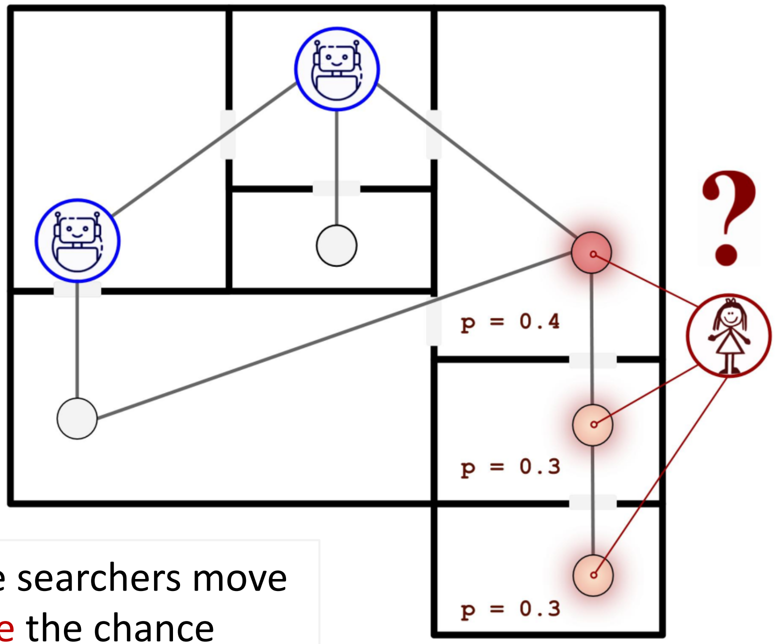
Common abstractions:

- Low-level details: local planning, nav, control
- Represent environment as a graph
- Discrete time: each step = multiple actions
- General, combinatorial optimization problem

Multi-Robot Efficient Search Path Planning (MESPP[1])

→

How should the searchers move to maximize the chance of finding the target?



Simple search scenario. Probabilities p represent belief of target location

[1] Hollinger et al, 2009. Efficient multi-robot search for a moving target. The Intl Journal of Robotics Research 28.2: 201-219.

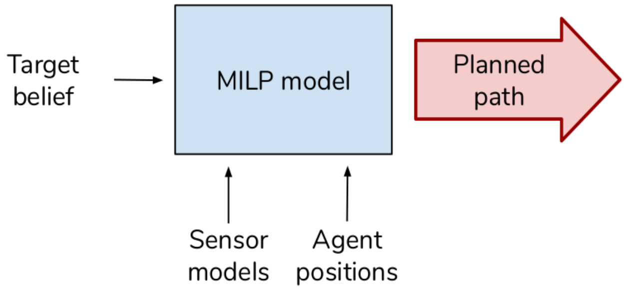
Multi-Robot Efficient Search Path Planning (MESPP)

We proved MESPP is NP-hard[2] even for...

- grid graphs
- one searcher
- stationary target
- perfect sensing

simplest MESPP problem is *at least as hard* as well-known intractable problems

...and noticed it could be formulated via linear constraints



First set of Mixed-Integer Linear Programming (MILP) models for tackling the MESPP problem

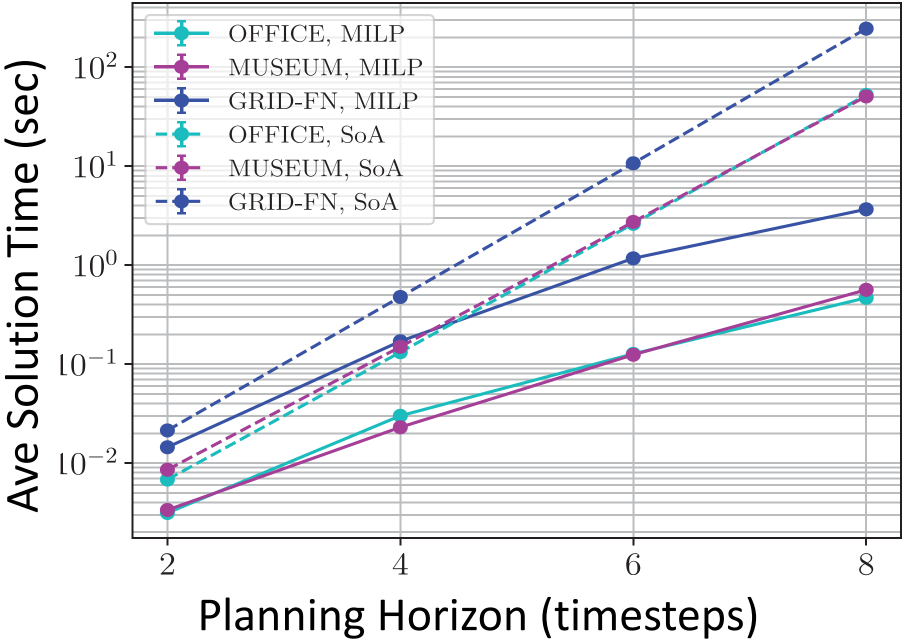
[2] Asfora, BA, Banfi, J and Campbell, M, Mixed-Integer Linear Programming Models for Multi-Robot Non-Adversarial Search. IEEE RA-Letters, 2020

MILP Optimization for Planning for MESPP

- Fast and ***scalable*** probabilistic search
- Centralized and ***distributed*** solutions[3]
- First MILP model to encompass:
  - multiple searchers
  - arbitrary capture ranges
  - false negatives

90x faster than SoA

Run time: SoA [1] vs MILP models [2] on distributed approach
Equal: conditions, environments, collected reward



[1] Hollinger et al, 2009. Efficient multi-robot search for a moving target. The Intl Journal of Robotics Research 28.2: 201-219.
[2] Asfora, BA, Banfi, J and Campbell, M, 2020. Mixed-Integer Linear Programming Models for Multi-Robot Non-Adversarial Search. IEEE RA-Letters, 5(4), pp.6805-6812
[3] Code is open source and available at https://github.com/basfora/milp_mespp.git

Firefighter Search & Rescue Mission:
Cmdr NL, Danger Inference, Risk Aware Planning

Scene Understanding via Domain Knowledge

According to Ithaca firefighters[6]

- Decisions are made based on risk vs reward
  - risk a lot to save a lot, risk nothing if you are saving nothing
- Search plan has priority areas
  - goal is to stand between victim and danger
  - experience and current situation dictates path
- First responders need succinct and reliable information
  - who, where, what – not a stream of constant data
- Danger perception is qualitative
  - standard training with combined factors, but no official scale

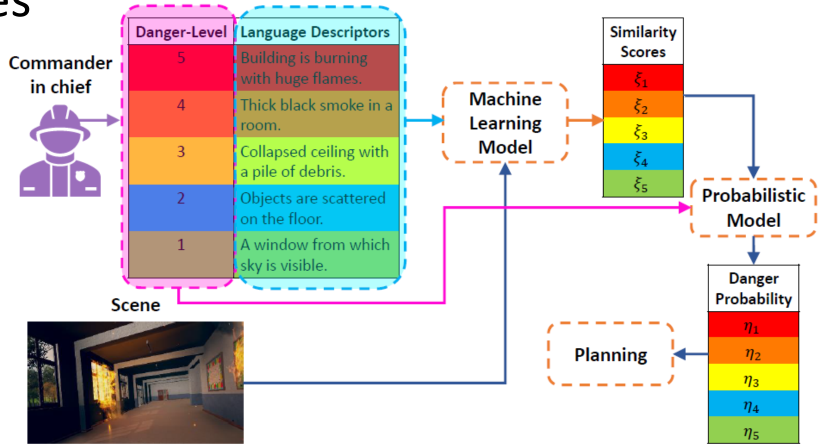
Sources: cityorithaca.org, chfd.info

Led to strategies for using natural language, the language itself, and planning optimization

Big thanks to **Assistant Chief Tom Basher** (City of Ithaca Fire Dept) and **Chief George Tamborelle** (Cayuga Heights Fire Dept)

Scene Perception via Human+Robot Fusion

- **Robots**: Good at detecting low level features
- **Humans:** Good at high-level scene understanding like danger
- **Goal:** unify scene perception by leveraging both, robots' and humans' abilities.
  - *Best of both worlds*
- Scene danger-estimation approach:
  - ***Expert (mission commander)*** provides descriptions and danger-levels
  - ***Scene/Description similarity*** assessment using an ML Model
  - ***Danger inference*** using a probabilistic model combining both



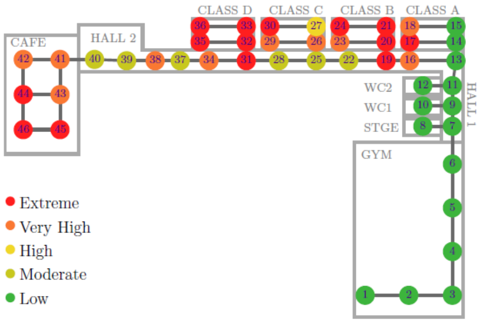
V Shree*, B Asfora*, R Zheng, S Hong, J Banfi, M Campbell. "Exploiting Natural Language for Efficient Risk-Aware Multi-robot SaR Planning," RA-Letters, 2021

Danger Level Inference: NL+Images

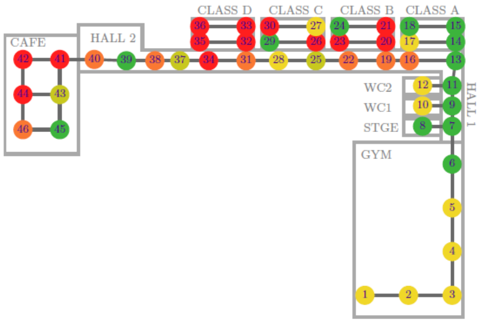
- Data collection to train ML model
  - Use Synthetic disaster images
  - 4000 sentence descriptions from AMT
- Inferred Danger Level
  - Fuse similarity scores across images
  - Results demonstrate estimated danger to be similar to ground truth data
- Key Advantages
  - Can adapt to different emergencies without retraining
  - Danger estimates can be leveraged to plan safer human-robot mission

- A number of houses could be seen along the roadside. The place looks green.
- The houses are lit on fire and looks like a big accident has occurred.

Word-cloud of sentences

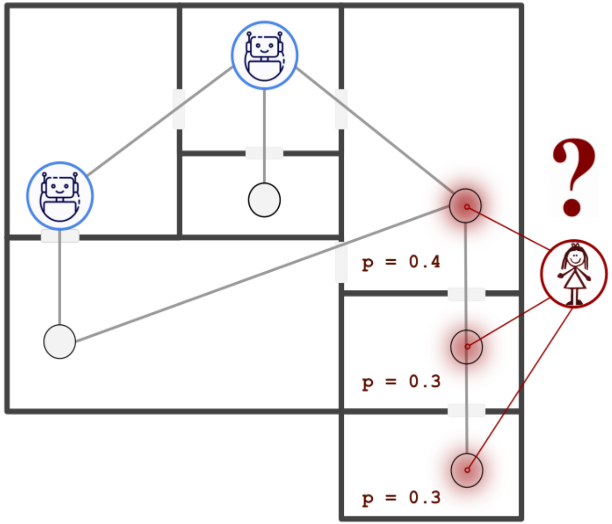


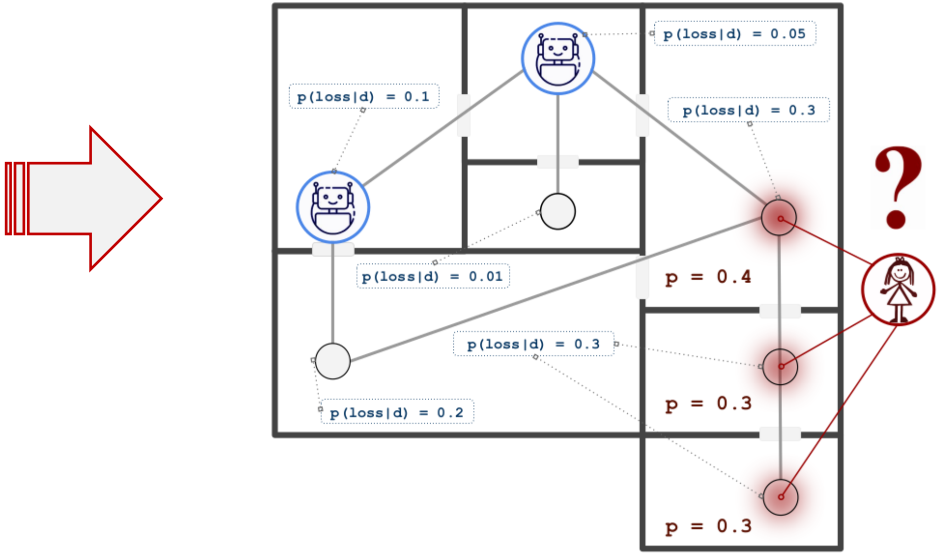
Ground Truth (AMT)



Inferred Danger

Evolution of MILP Planner to Risk Aware MESPP





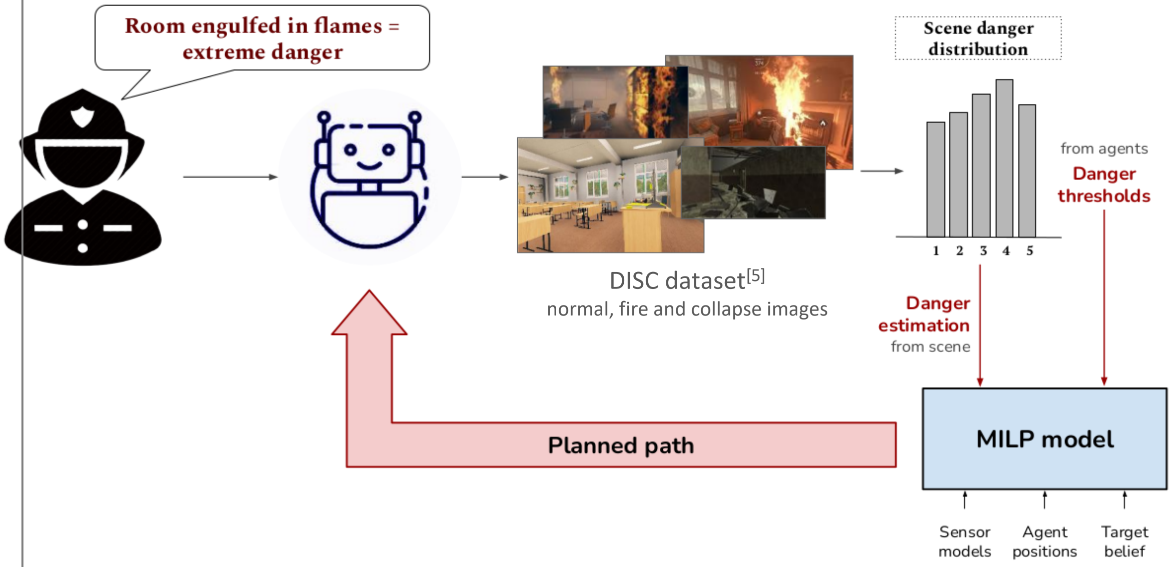
Prior Work:
- nodes: prob of target location
- Focuses on team performance

Risk-Aware MILP Planner:
- nodes: added prob of agent loss given danger
- Includes both performance and safety
- Conditional planning based on online info

Risk-award MILP for Semi-Autonomous Search Missions
Shared Perception, Autonomous Planning

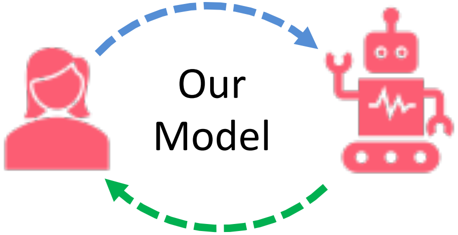
Risk-aware planner is safer, similar performance to baseline[4]

- Reduces agent loss overall
- Customized Danger Thresholds allow protection of valuable agents (e.g. humans)
- Similar search timing
- Slight decrease in success rate
- Slight increase in mission time



[4] V Shree*, B Asfora*, R Zheng, S Hong, J Banfi, M Campbell. "Exploiting Natural Language for Efficient Risk-Aware Multi-robot SaR Planning," RA-Letters, 2021
[5] Jeon, 2019. DISC: A Large-scale Virtual Dataset for Simulating Disaster Scenarios. In IROS (pp. 187-194)

Summary and Conclusions



- Our project develops methods to enable cooperating human-robot teams
  – Interactive Natural Language
  – Scalable, multi-robot planning

- Particularly suited for complex environments evolving in space and time
- Current Risk-Aware planner leverages natural language and optimization to balance performance and safety across the team