Anticipatory Models for Effective Communication in Multi-Agent Teams

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Vision

Autonomous agents collaborating in nondeterministic world need to
- Communicate new information effectively,
- React to changing environment.

Hand-crafted protocols are **time consuming** and **not flexible** to environmental changes.

We envision autonomous agents being able to reason about **anticipatory behaviors** to improve team efficiency in collaborative environments.

Intuition

Learning from efficient human teams: Proactive information delivery (sharing relevant information without being asked) is a key characteristic of effective human teams.

Implicit Communication

The ability to anticipate information needs and communicate without being explicitly requested.

Ex) Your friend is traveling to Boston for a conference tomorrow. You find out that the T will be closed. You inform your friend so he has time to re-plan.

Extension: **Implicit action** is the ability to take *actions* that does not advance toward the agent's own goal but benefit the overall performance of a team, without being explicitly asked.

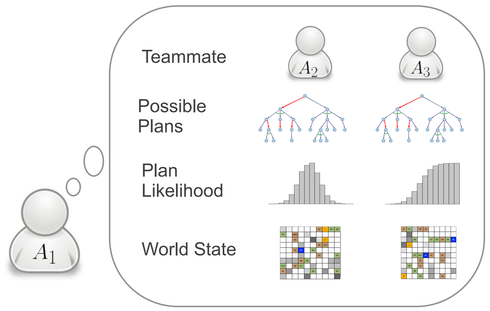
Technical Objectives

1. Design and implement a framework that enables implicit communication.
2. Validate that agents who act and communicate proactively are more effective team members.

Approach

Theory of Mind

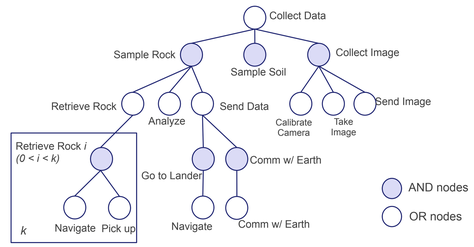
The mechanism that allow humans to infer and reason about another human's state of mind, such as beliefs, desires, and intentions.



Hierarchical Task Planning

Leveraging domain specific hierarchical structure to reduce search space in planning and reasoning of other agents plans.

Represent possible plans in terms of decompositions of compound tasks using AND/OR tree. Example:



Reasoning About Communication

For each new observation, agent simulates the result of communicating versus not using its belief of teammate's world and act to minimize the expected cost of the overall team.

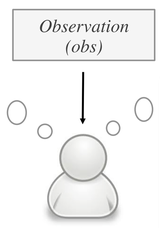
If communicate *obs,* simulate re-planning for teammate: A_j

$\mathbb{D}(p)$ + *Re-plan* = $\mathbb{D}'(p)$

S + *obs* = S'

$$Comm(obs_{A_i \to A_j}) = CoC + \mathbb{E}_{p \sim \mathbb{P}'}[Cost(p|S')]$$

Observation (obs)



If omit *obs*, evaluate original plan relative to A_i's world:

$$Omit(obs_{A_i \to A_j}) = \mathbb{E}_{p \sim \mathbb{P}}[Cost(p|S_{Ai})]$$

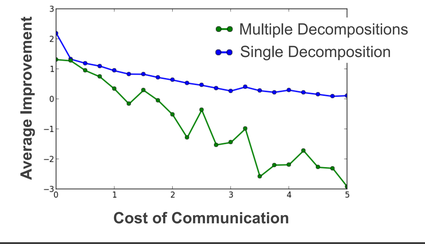
In case of failure, include the expected cost of re-planning.

Imperfect Mental Models

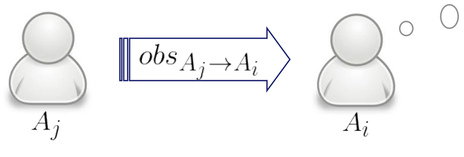
The effectiveness of our communication model relies on having an accurate mental model of other team members.

But our mental models may diverge due to
- Omitted messages
- Multiple possible task decompositions
- Accumulated error over time for lengthy tasks

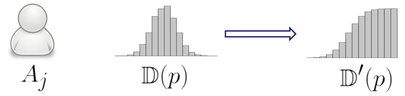
Diverging Mental Models due to Multiple Task Decompositions



Bayesian plan recognition for maintaining synced mental models:



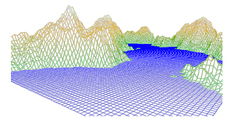
Update mental model of sender:



$$\mathbb{D}'(p) = \mathbb{P}(p|obs, \mathbb{D}) \propto \mathbb{D}(p) \cdot \mathbb{P}(obs|p)$$

Real World Application and Simulation Environment

UAV Terrain Surveying Mission



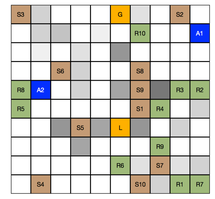
- Varying capabilities
- Common goal
- Unpredictable environment
- Communication is expensive
- Domain with hierarchical structure

Want Autonomous Agents to communicate **useful** information and prune out irrelevant observations.

Mars Rover Planning Domain

Objects: Lander (**G**), Agents (**A**), Rocks (**R**), Soils (**S**)

Tasks: Sample Rocks, Soils, Take Images, Navigate, etc..

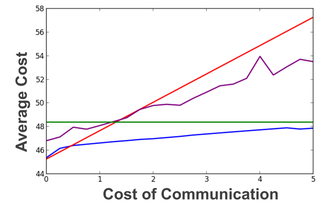


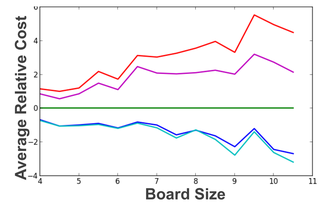
Models

---- **No Comm**: Agent omits all messages
---- ***Smart Comm***: Our proposed communication model
---- **Rand Comm**: Agent communicates with probability 0.5
---- **Full Comm**: Agent communicates all new observations

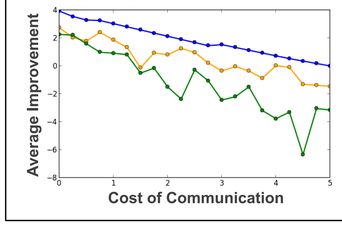
Results

Average costs compared with baseline with deterministic planner:





Towards synced mental models:



Single Decomposition
Multiple Decomposition
BPR-Comm for Multiple Decomp.

BPR-Comm: SmartComm + Bayesian plan Recognition for received messages.

Future Work

1. Provide agents the ability to **detect diverging mental models**.
2. Given **multiple observations**, identifying the subset that is useful to a teammate efficiently.