Domain Engineering to Represent Human Behavior Using Multi-Agent Planning and Inductive Methodologies

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Abstract
This research combines multi-agent planning, the psycholinguistics of question-asking, procedural grounded theory, and hierarchical task networks to represent domains for automated planning.

Introduction
For my PhD research, I explore knowledge representation, coupled with machine learning and causal modeling, to infer the latent mental models of collaborating human problem solvers. Not only do I focus on model development, I actively research how assumptions inform knowledge engineering and data collection, which then influence model selection.

I designed an urban search and rescue (SAR) domain to model human planning during collaborative problem solving, which includes an explicit theory of mind model. We initially assumed teams of human players prioritized high-valued victims and navigation strategies to score more points. However, player behavior deviated from these hypotheses, so I proposed a new domain engineering strategy that accounts for all observed actions from each player, independent of any assumed strategy or inferred goal.

The methodology I developed combines four interdisciplinary research techniques:
1. **Multi-agent planning social protocols** (Baldoni et al. 2019) to represent player/agent coordination and commitment. Both the experiment design and this social protocol assume rational and normative agent behavior.
2. Event annotations, limited to question-asking behaviors. In this current phase of research, I focus on questions because they provide rich, asymmetrical information about collaborator belief and goals (Hawkins and Goodman 2017).
3. Inductive coding schema known as **Procedural Grounded Theory**, (GT), (Meireles et al. 2021) to annotate SAR videos.
4. Annotated events are represented as **Hierarchical Task Networks**, implemented in the Hierarchical Domain Definition Language (HDDL), then mapped to primitive actions and abstract tasks.

To my knowledge, this combination of methods is not found in current planning literature.

Background
A sufficiently complete domain hinges on clear problem definition, the skill and insight of domain engineers, and in specifying enough information about actions and tasks to account for all possible and relevant solutions (Bercher 2022; Gragera et al. 2023).

Domains are problematic when insufficient coverage of possible actions, goals, or solutions do not accurately model human planning behaviors. Such behaviors include: redundancy (repeated actions that add no obvious value), nuance (similar actions that have pragmatic significance), or inefficiency (adds to domain solution complexity).

Many modern planning models abstract away nuance, redundancy, and inefficiency, favoring technical approaches, empirical evaluations, and computational efficiency. However, these approaches are less accurate at capturing subtle and relevant human behavior (Barberis Canonico, McNeese, and Duncan 2018). They could introduce bias, especially when models are not informed by theories of human behavior (Kang 2023; Pereira, Pereira, and Meneguzzi 2021; Sreedharan et al. 2020; Weber and Bryce 2011) that use nuance or redundancy as input. Representing inefficient human behavior with technically efficient approaches could also introduce an ethical risk when output from less-interpretable models are implemented in real-world scenarios like SAR, impacting real people.

Current Research
To emulate human planning behavior within our domains, we can use mixed methodologies such as "human in the loop" (Barberis Canonico, McNeese, and Duncan 2018), mitigating ethical risk. **What key domain engineering features might we overlook when we disregard nuance in human behavior?** For example, humans can request help, allowing the response to be either a 'yes' or 'no', or they ask for help, expecting the answer to be 'yes' because a 'no' would be impolite. This kind of subtlety relies upon the important role of pragmatics in human communication.
**Data and Methods**

To represent human nuance and pragmatics in planning domains, I used Procedural Grounded Theory (GT) and Baldoni’s social protocol framework for multi-agent coordination as the conceptual framework of our label development. Three fully-autonomous annotators, all from our plan recognition team, annotated 12 SAR videos, clarifying labels and analyzing question-asking behaviors with their inferred goals. GT is known to be an initially expensive coding process for the first few observations, yet this cost monotonically decreases with each new observation. This mixed method took 13:30 man hours, combined, for three annotators and twelve observations. I then rigorously analyzed the labels, using axial and selective GT to discern the data-driven patterns and emergent theories of team planning behavior.

**Results and Conclusions**

We achieved an unweighted Cohen’s Kappa score of 0.892 for evaluations, demonstrating reliability and reproducibility. Using this method for observing and representing human planning behavior, I found that:

1. Teams who ask more questions at a consistent rate scored higher than teams who sporadically asked the same number of questions. 2. Compared to all forms of natural language communication, teams who asked more questions scored more points. 3. All teams demonstrated redundancy, nuance, and inefficiency. However, teams who asked questions to clarify an idea, compared to teams who instructed each other, showed increased collaboration, rescued more victims, and scored higher points. 4. Teams who coordinated on tasks that did not require collaboration, compared to teams who collaborated only when required, scored more points and exhibited increased question-asking behaviors.

These results provided the framework design of the HTN structures for primitive actions and abstract tasks, which I then implemented in HDDL. These HTNs account for planning strategies that include high score prioritization and navigation strategies, as well as unexpected actions like repeating questions, team plan deviation, and inefficient team work.

HTN structures and domains crafted with this method are replicable, domain-agnostic, and explainable, ensuring their intelligibility across academic disciplines and practical real-world applications.

**Contributions and Future Work**

While complex models may reduce computational complexity, they may not authentically reflect inefficient human behaviors. My mixed method for domain design generates information that naturally guides the construction of HTNs to represent human planning behavior, which is easily implemented in HDDL. This work is currently developing a unique dataset that relates actions, abstract tasks, goals, and natural language. The next phase of this research would include model comparisons and empirical evaluation metrics.

My dissertation research combines this method, formal semantics, and text extraction of causal and counterfactual language. After completing my PhD, I will continue to promote interdisciplinary research effort between artificial intelligence, social history research, and causal modeling.

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**References**


