
P
L
A
ASU

There is Planning and there is *Planning*

"Acting?"

Acting is what planning researchers
do when they grow too old and weary of IPC ;-)

On The Many Interacting Flavors of Planning for Robotics

Challenges and Opportunities

Kartik Talamadupula
Subbarao Kambhampati

Arizona State University

Gordon Briggs
Matthias Scheutz

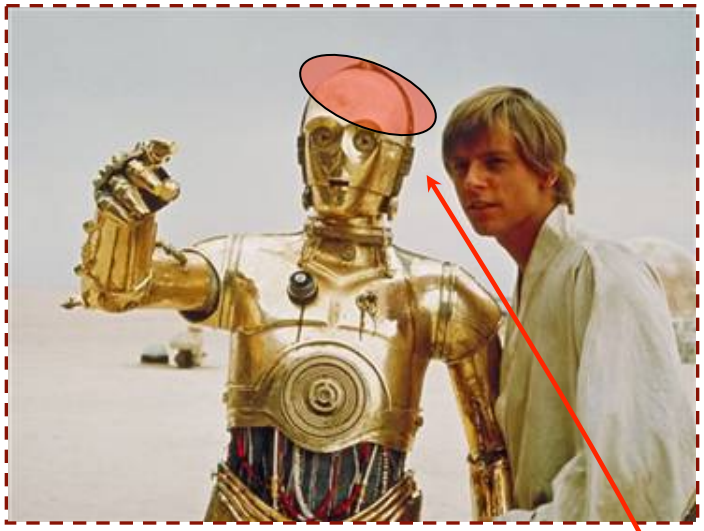
Tufts University

[Funding from ONR, ARO]

Planning for Robots
(in Teaming Scenarios)

- **Already work on bridging task/motion**
  - High-level and Low-level
  - Task and Motion
  - Symbolic and Continuous
- … but **presence of human** in the loop
  - Human-Robot Interaction issues
  - Different *kinds* of planning needed, not just *levels*
- **Planner** must **facilitate** Human-Robot Teaming
  - Based on the scenario: Application, Type of Human, Type of Robot

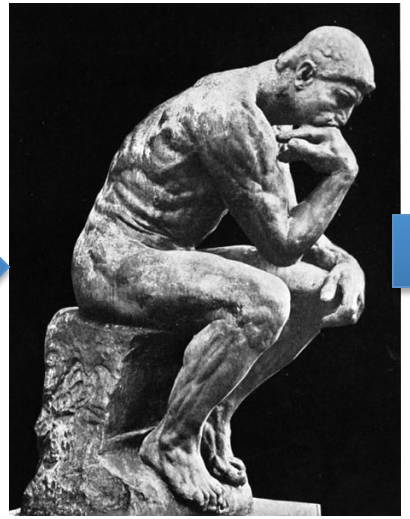
Motivation for Human-Robot Teaming

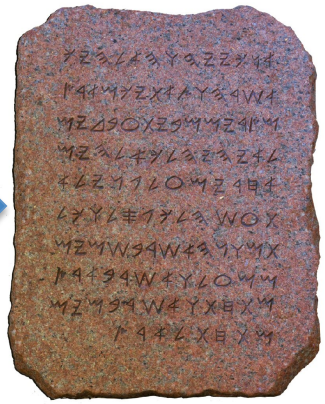


- Early problem in AI
  - Autonomous control for robotic agents
- Plenty of applications
  - Household Assistance
  - Search and Rescue
  - Military Drones and Mules
- All scenarios involve humans giving orders
- Planning must co-opt this area

Planning: Traditional View

A fully specified problem
- --Initial state
- --Goals
  (each non-negotiable)
- --Complete Action Model





The Plan

Need for Acting can Spoil a Perfect Plan ☹

- Search and report (rescue)
- Goals incoming on the go
- World is evolving
- Model is changing

- Infer instructions from Natural Language
- Determine goal formulation through clarifications and questions

Planning: Traditional View

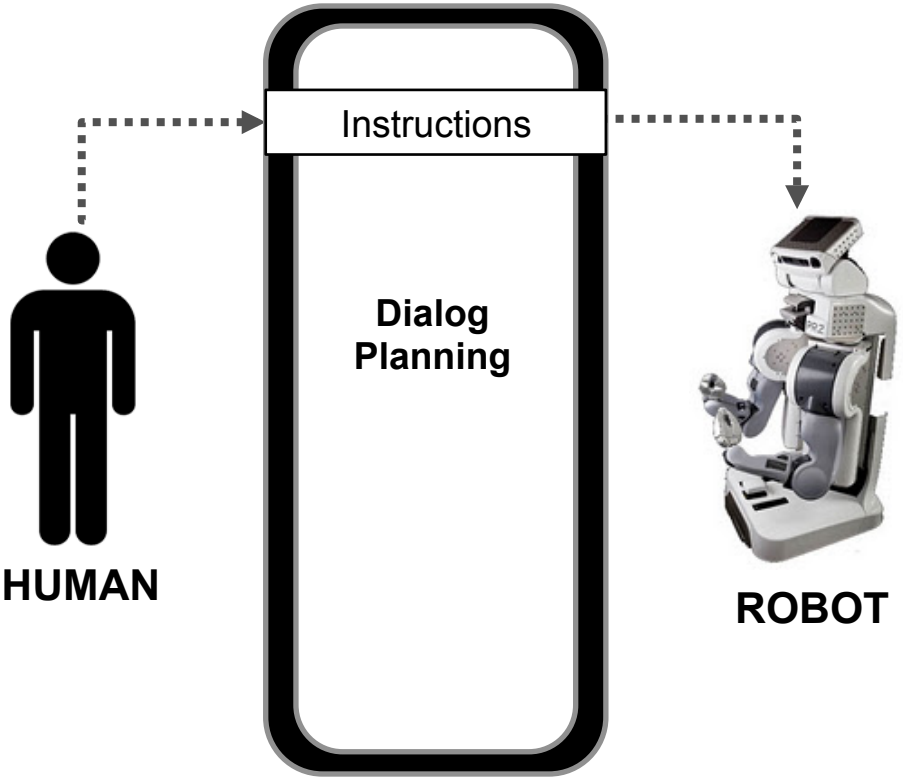
A fully specified problem
--Initial state
--Goals
(each non-ne e)
--Complete Actio l

The Plan

Planning for Human-Robot Teaming

- Planner is an intermediary
  - between Human and Robot
- Two main tasks
  - **Process Information**
    - Changes to the world / state: Replanning
    - Changes to the goals: Open World Quantified Goals
    - Changes to the model: Run-time Model Updates
  - **Elicit Information**
    - Ask for advice / clarification
    - Explain plans and make excuses / hypotheticals

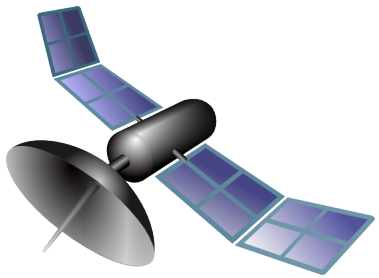
HRT System Schematic



Dimensions

Scenario / Environment

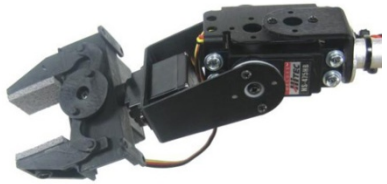
- Inspired by the real world
- Large amounts of domain knowledge from
  - Humans with experience
  - Technical documents and manuals
- New knowledge may arrive during execution
  - Planner must handle such contingencies
- Planner and Robot Features
  - Determined by the needs of the scenario
  - E.g.: NASA needs temporal planning



Dimensions

Robotic Agent

- Central Actor
  - Execute actions
  - Gather sensory feedback
- Different types of robots
  - Various capabilities



Gripper

Humanoid

Mobile

Combined

Dimensions

Human User

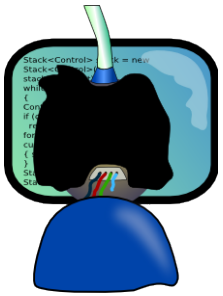
- Specifies and updates:
  - Scenario goals
  - Model (in some cases)
- Must be in communication with robot/system

Novice

Uses the robot merely as an assistant

Domain Expert

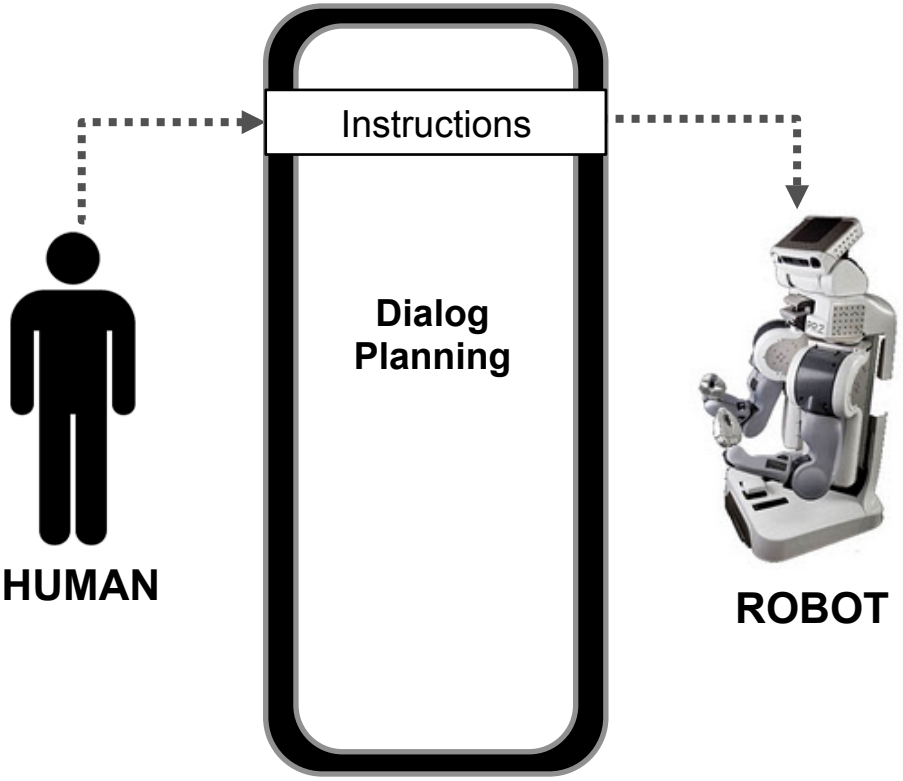
Authority on the execution environment



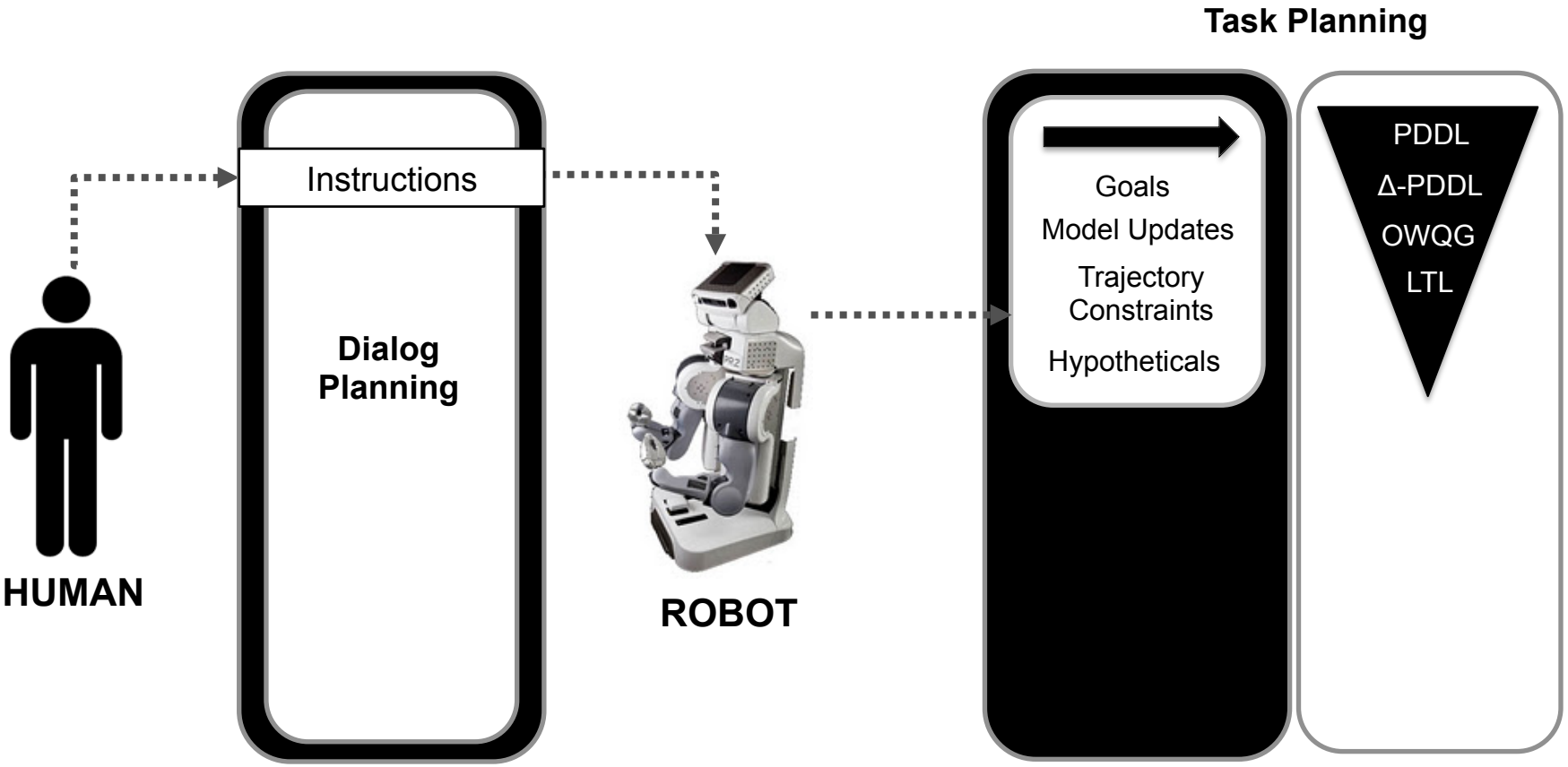
System Expert

Authority on the integrated AI system

HRT System Schematic



HRT System Schematic



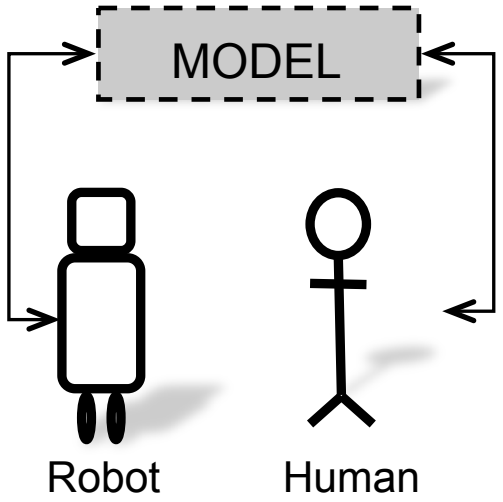
Planning

Goal Management

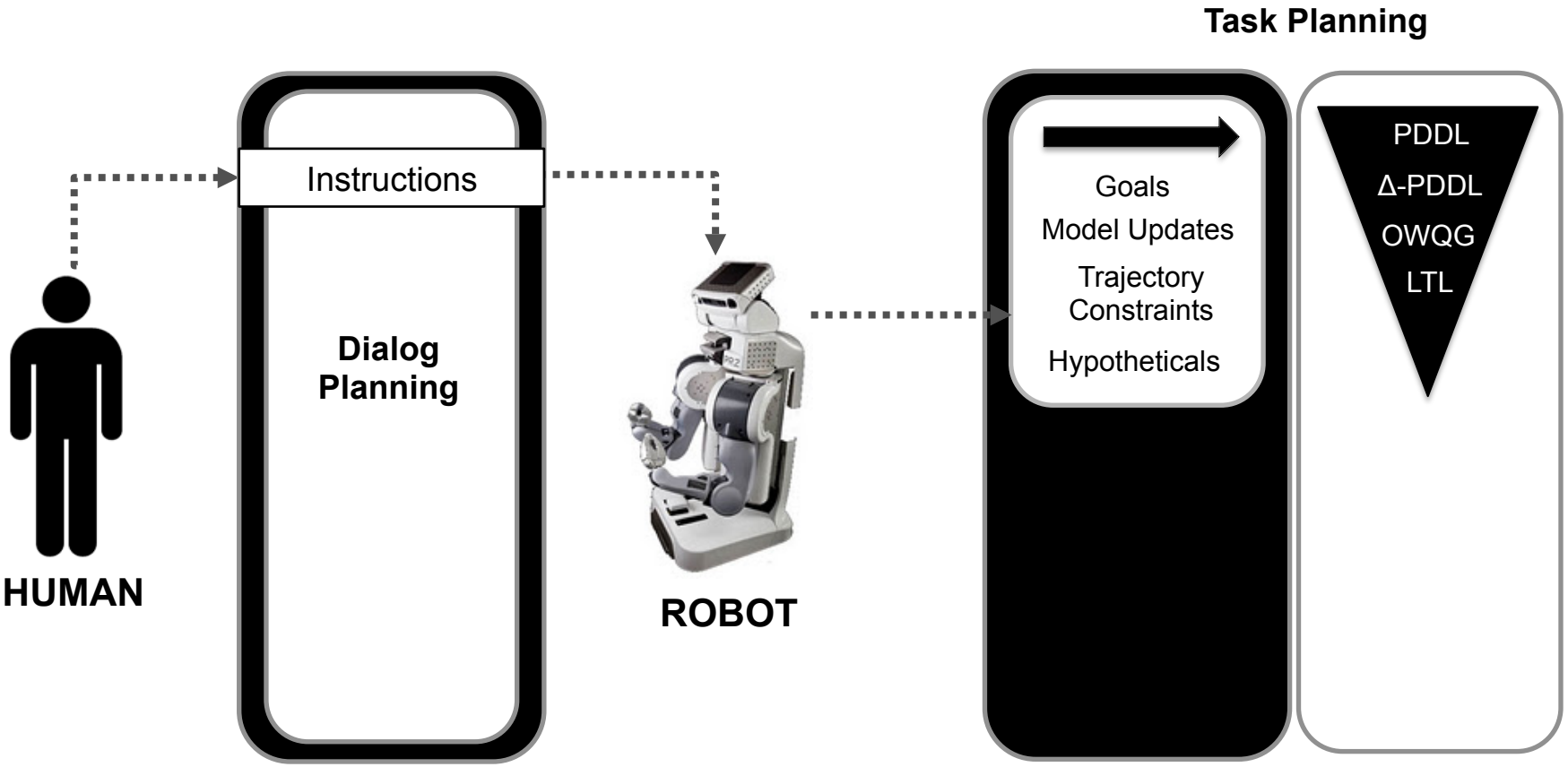
- Human-Robot Teaming
  - Utility stems from delegation of goals
- Support different types of goals
  - Temporal Goals: Deadlines
  - Priorities: Rewards and Penalties
    - Bonus Goals: Partial Satisfaction
  - Trajectory Goals
  - Conditional Goals
- Changes to goals on the fly
  - Open World Quantified Goals
    [Talamadupula et al., AAAI 2010]

Model Management

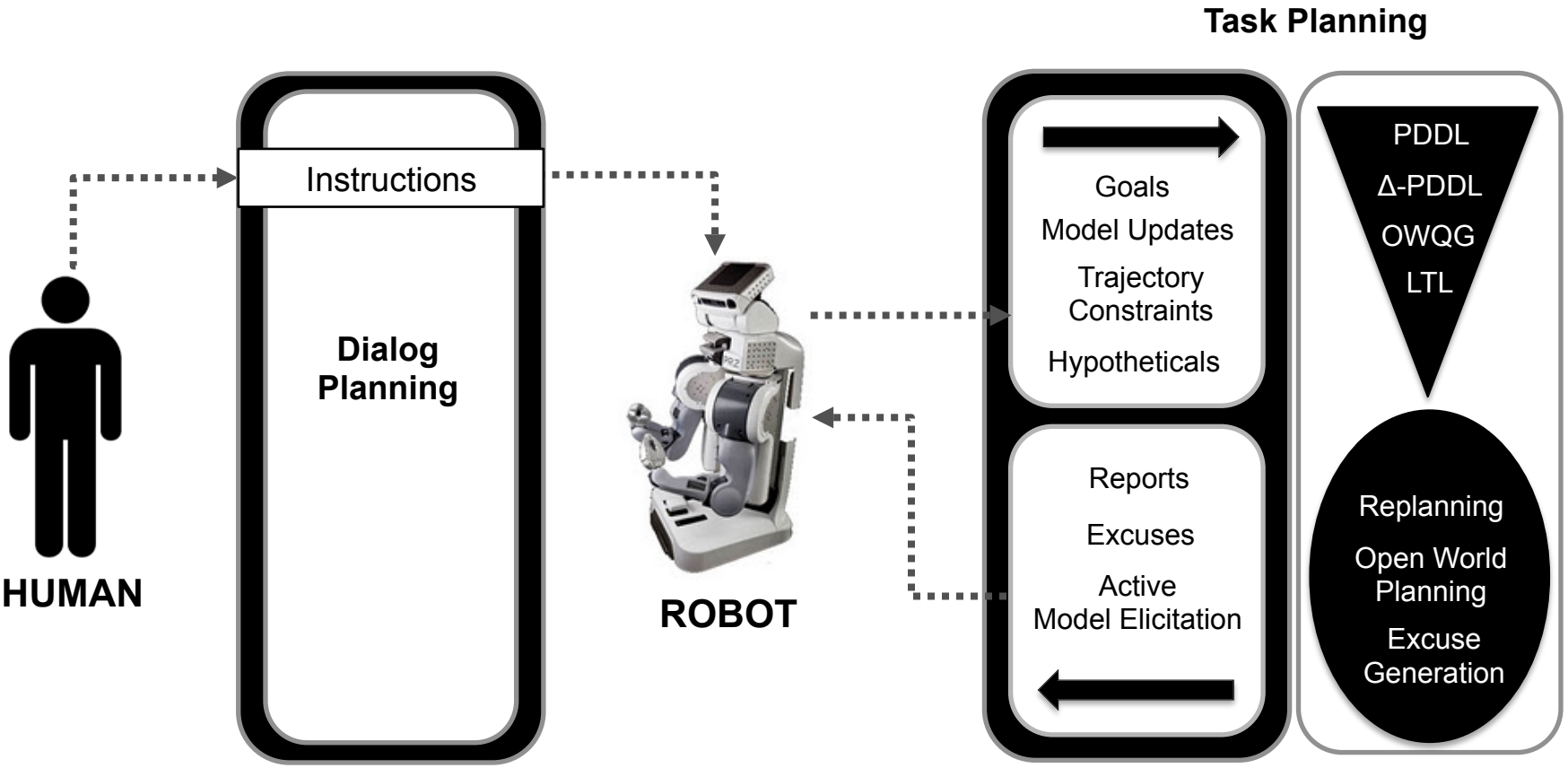
- One true model of the world
  - Robot
    - High + Low Level models
  - Human User
    - Symbolic model + Additional knowledge
  - Planner must take this gap into account
- Model Maintenance v. Model Revision
  - Usability v. Consistency issues
  - Use the human user's deep knowledge
- Distinct Models
  - Using two (or more) models
    - Higher level: Task-oriented model
    - Lower level: Robot's capabilities



HRT System Schematic



HRT System Schematic



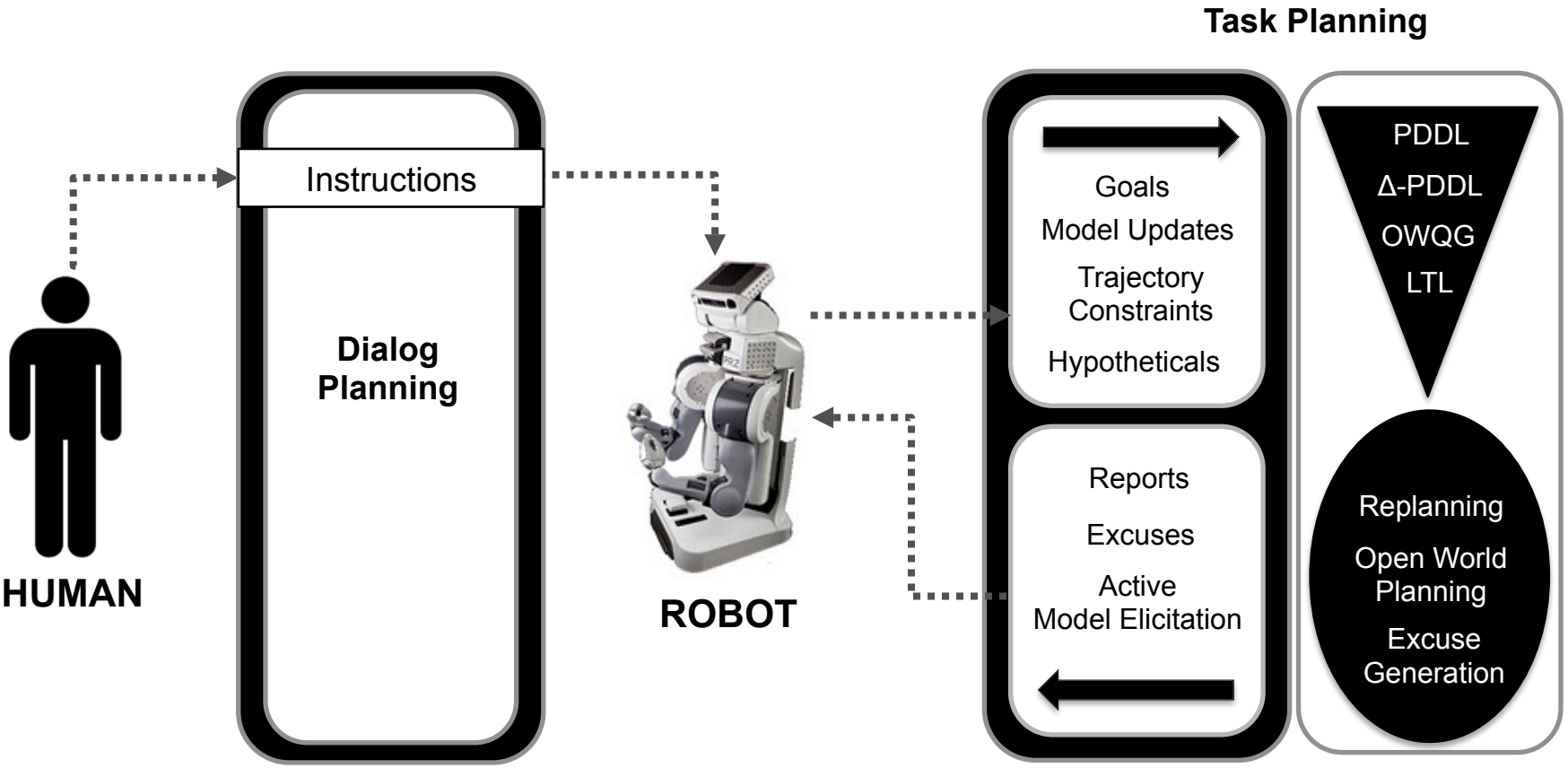
Excuses & Hypotheticals

- **Excuse Generation**
  - Make "excuses" if task unsolvable
  - Changes to planning task
    - Initial State [Goebelbecker et al. 2010]
    - Goal Specification
    - Planning Operators [Cantrell, Talamadupula et al. 2011]
- **Hypotheticals**
  - Goal "opportunities"
  - Conditional Goals [Talamadupula, Benton et al. 2010]

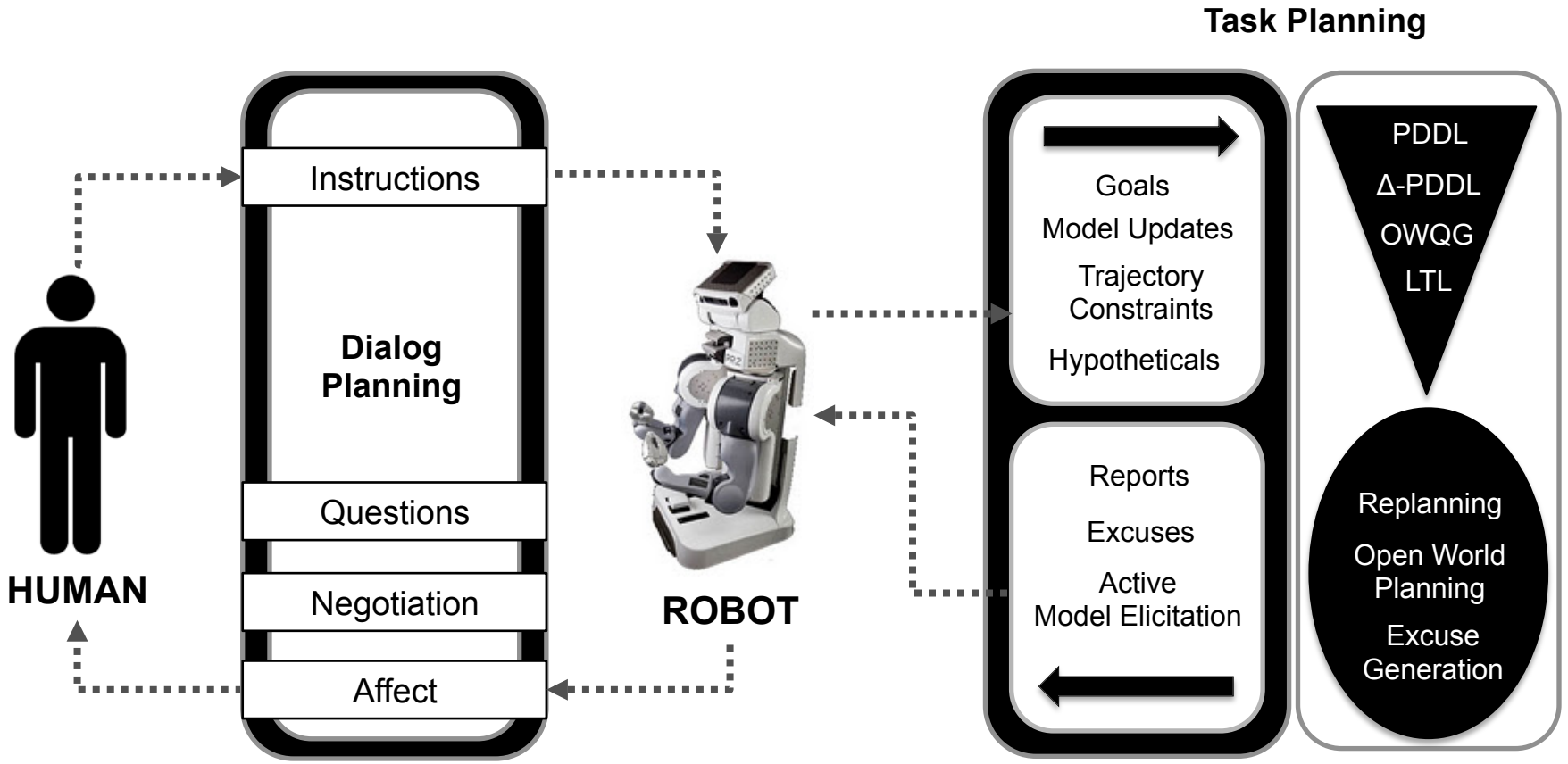
Explanations

- **Asking for help**
  - Proactively request humans for help
  - Take navigation paths into account [Rosenthal et al. 2012]
- **Explanations**
  - Returning a plan is not enough
  - Human must be informed "why" the robot is doing something
    - May result in more elaboration /information

HRT System Schematic



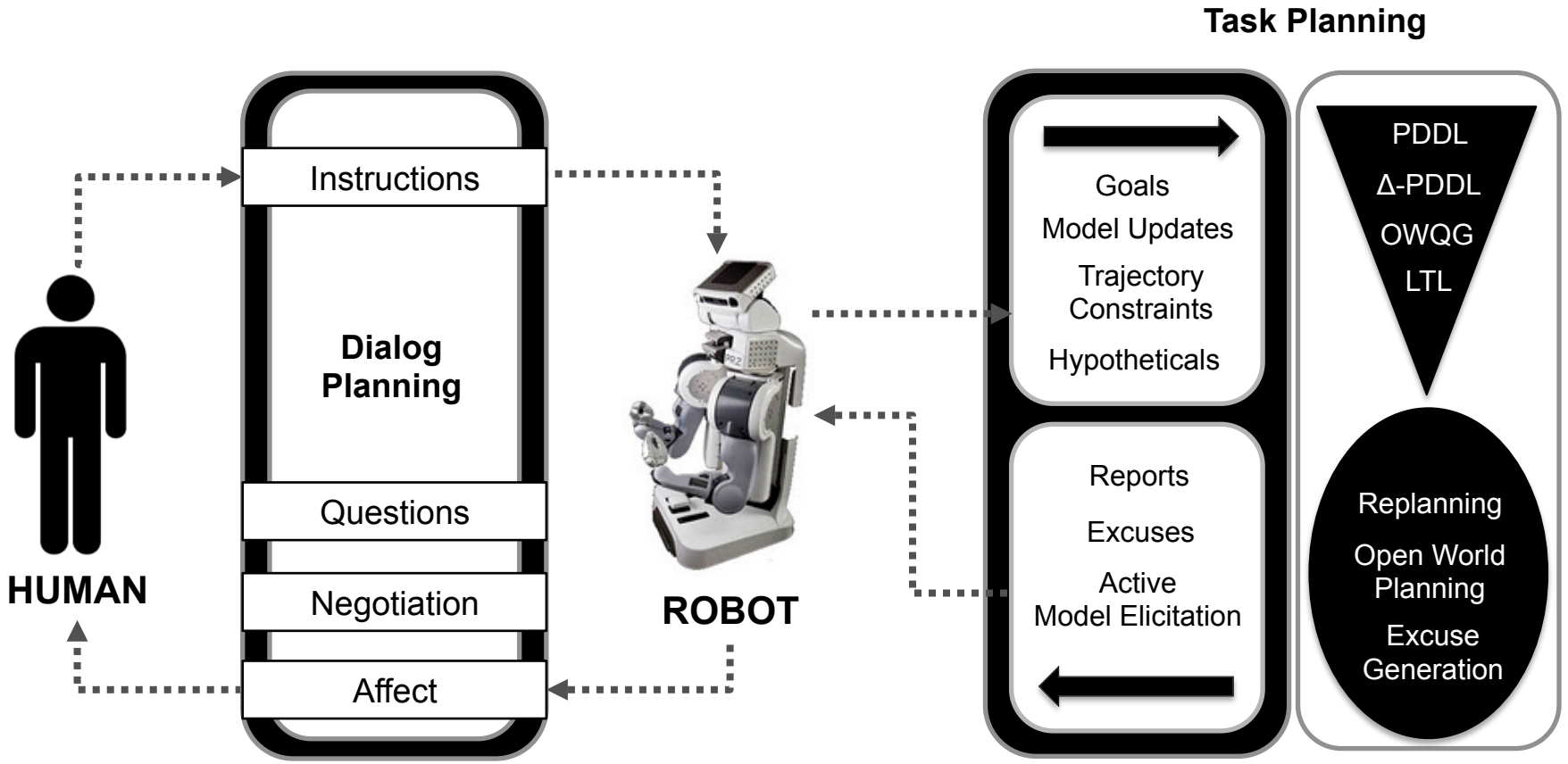
HRT System Schematic



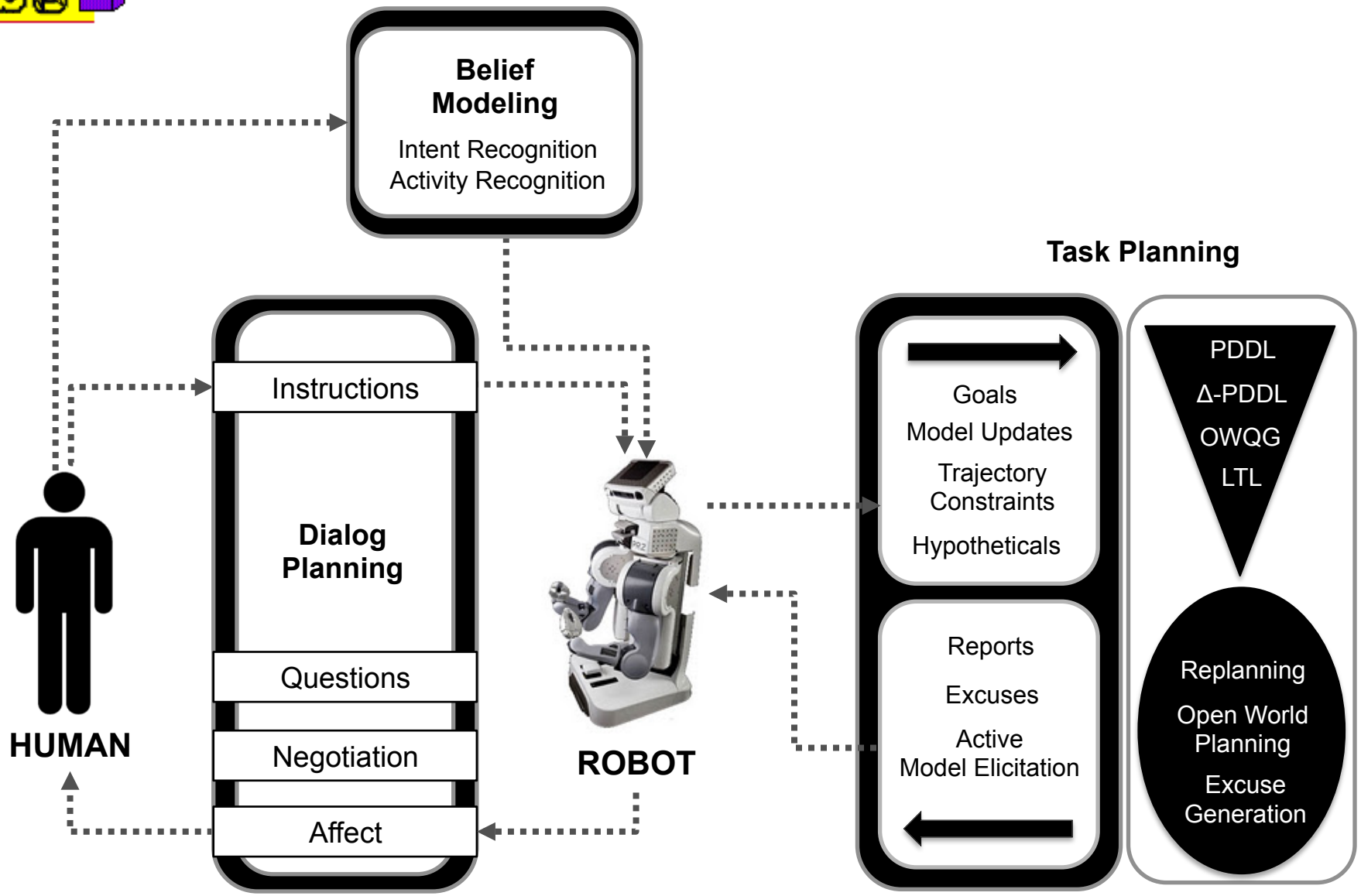
Dialog Planning

- Most natural form of communication between Human and Robot: NL Dialog
- Human-to-Robot
  - Instructions: Model updates [Cantrell et al. 2011]
  - Objectives: Goal changes
- Robot-to-Human
  - Questions
  - Negotiation
  - Affect

HRT System Schematic



HRT System Schematic

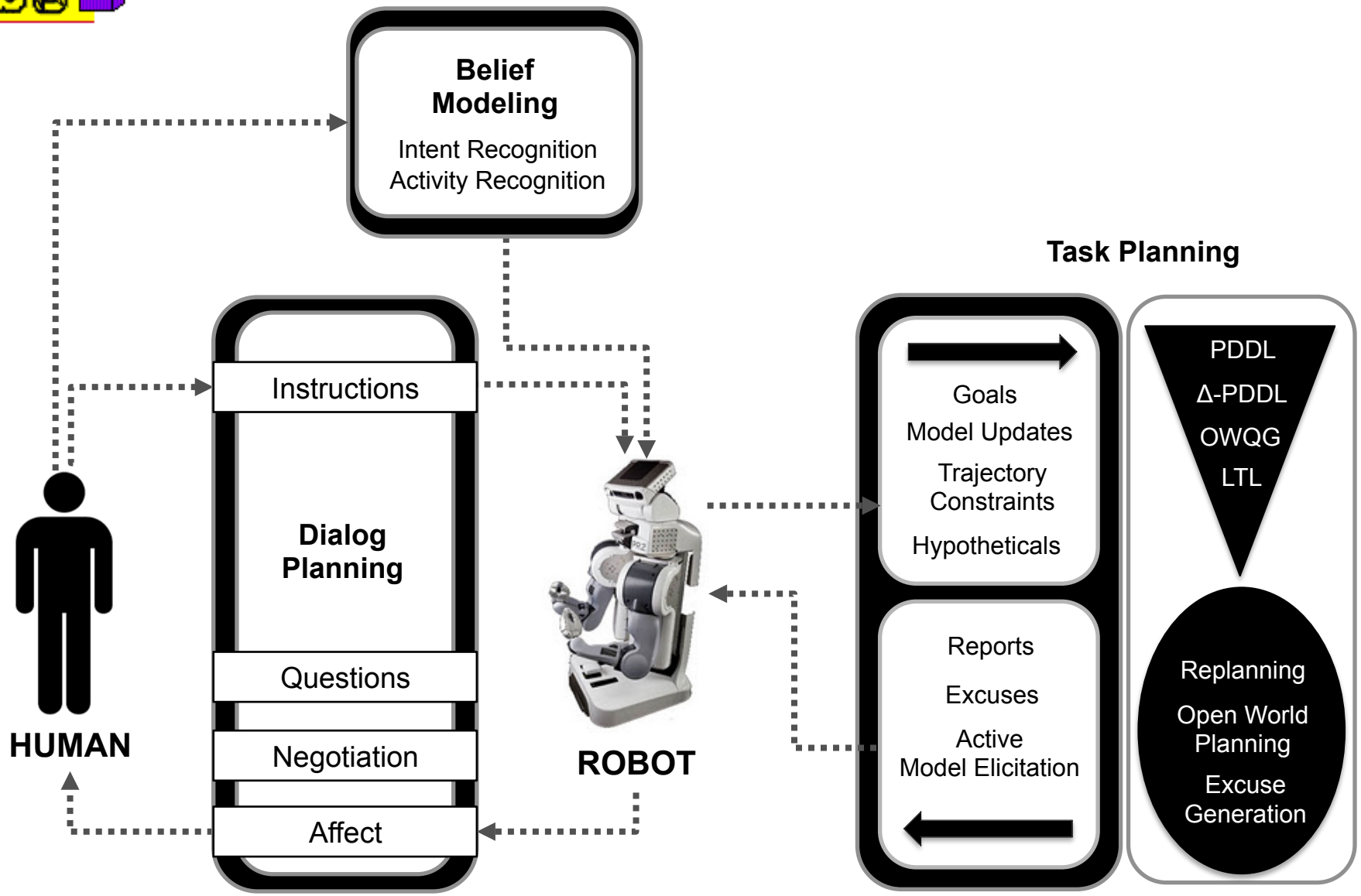


Belief Modeling

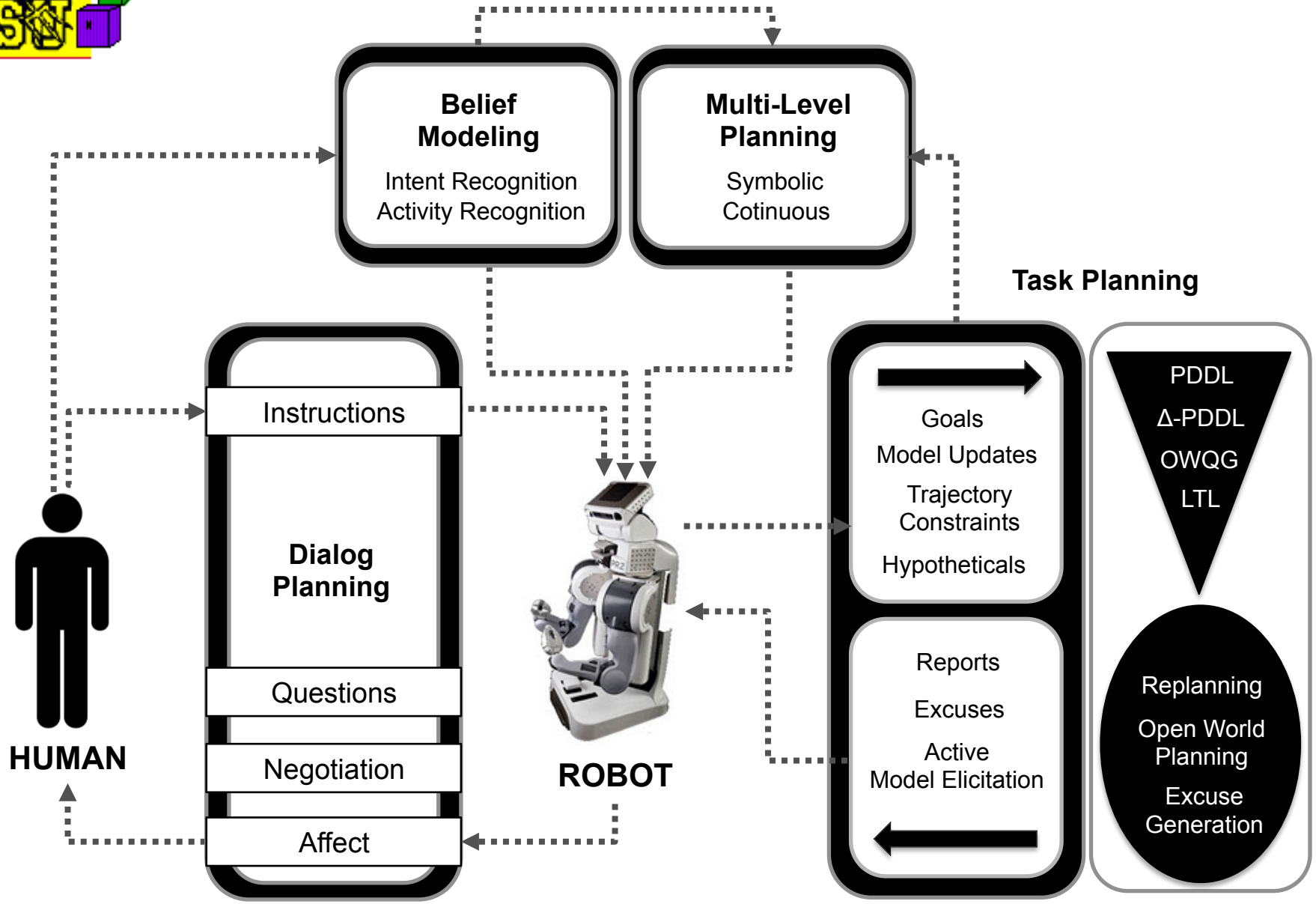
- **Humans communicate via task-based dialog**
  - For team situations, model team members
  - Expect robots to do the same
- **Example:**
  - When Commander Y interrupts Cindy the robot with a directive for later, Cindy must model Commander Y's mental state in order to define that goal
- **Belief Updates**
  - Take utterances from humans and update

[Briggs and Scheutz 2012]

HRT System Schematic

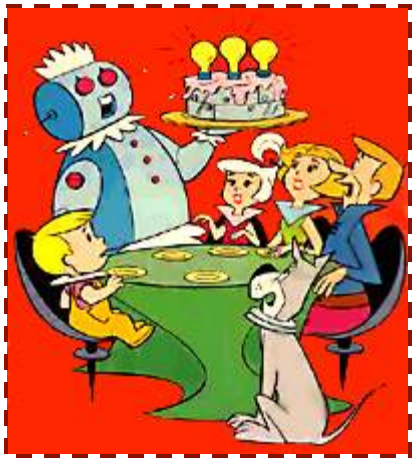


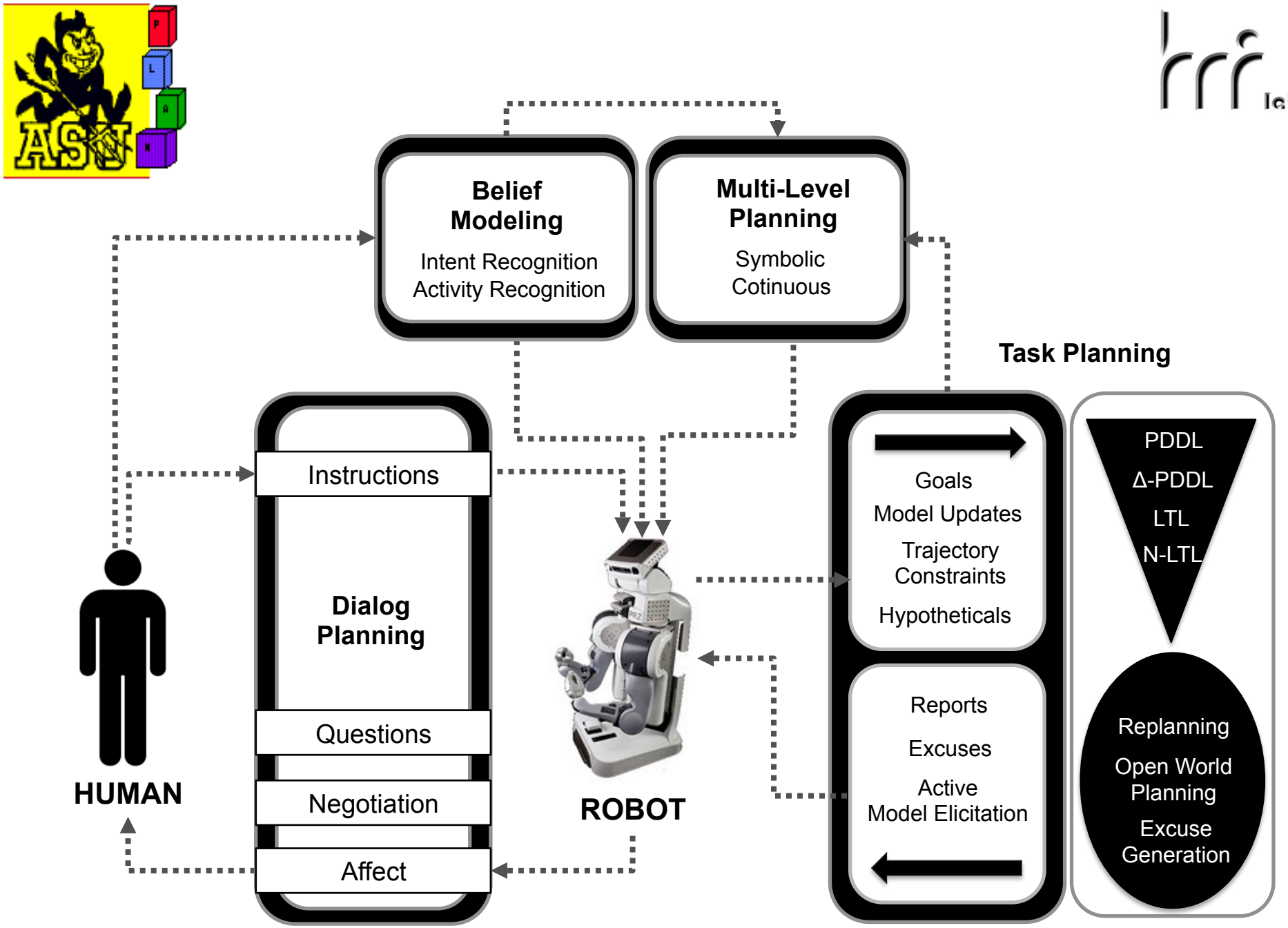
HRT System Schematic



Conclusion

- Combining **different *levels*** of planning
  - Currently: BTAMP, Spark, PlanRob
- **Human-Robot Teaming**: Emerging Problem
  - Presence of human in the loop requires …
- … combining **different *kinds*** of planning
  - Task, Dialog, Trajectory, Belief …
- Need to look at the **overall picture**
  - **Scenario**: Application specific
  - **Human**: Expert, Novice
  - **Robot**: Mobile, Manipulator, Humanoid




Belief Modeling
Intent Recognition
Activity Recognition
Multi-Level Planning
Symbolic
Cotinuous
Task Planning
Instructions
Dialog Planning
Questions
Negotiation
Affect
HUMAN
ROBOT
Goals
Model Updates
Trajectory Constraints
Hypotheticals
Reports
Excuses
Active Model Elicitation
PDDL
Δ-PDDL
LTL
N-LTL
Replanning
Open World Planning
Excuse Generation