Planning for Human-Robot Teaming
Challenges & Opportunities

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Thanks Matthias Scheutz@Tufts HRI Lab

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[None (yet?) from NSF ☹]


planning
Search
Learning
Heuristics
based
Temporal
Web
Graph
Plan
Heuristic
Partial
Databases
search
Integration
Refinement
Reachability
plans
Data
Probabilistic
Dependencies
Incomplete
Plans
Planner
Based
order
Coverage
Information
information
Integrating
Relevance
partial
Statistics
State
Query
Queries
Domain
Autonomous
Plan
Programming
Explanation-based
Classical
mining
Models
analysis
CSP
planners
approach
Satisfaction
Answering
Hybrid
reuse
Using
Space
ASU
Graphplan
Over-subscription
framework
Imprecise
Approaches
Challenges
Mining
graph
Artificial
Improving
Optimizing
Gathering
Exploiting
Constraint
Solving
Task
AI
Causal
Effective
Utility
heuristic
retrieval
Brief
Synthesis
state-space
unifying
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Model-lite
Handling
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Architecture
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Explanation
Scheduling
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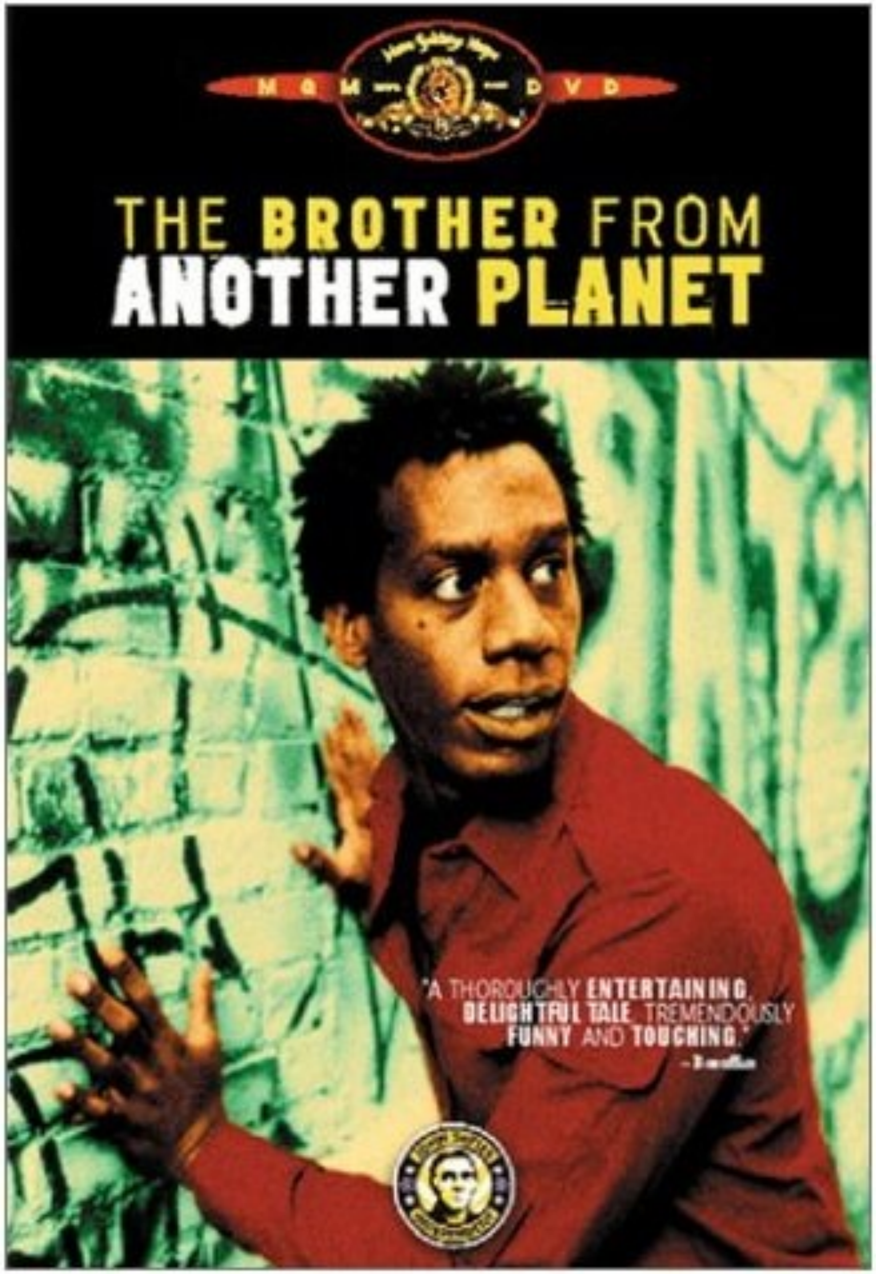
Replanning
Study
Menkes
propositional
Framework
Intelligence
specifications
Belief
Reuse
Process
Satisficing
Generating
planner
performance
transform
Trust
via
Effectively
role
Vossen
vs
web
utility
Kambhampati

Two Great Societies Separated by a Single Problem

IEEE Robotics & Automation Society

Planning

icaps

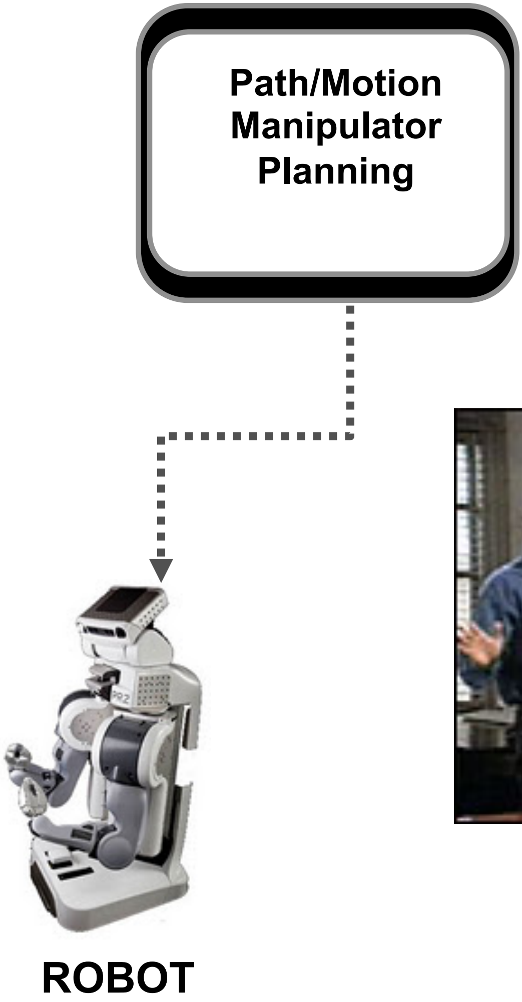

MGM DVD
THE BROTHER FROM ANOTHER PLANET
"A THOROUGHLY ENTERTAINING, DELIGHTFUL TALE, TREMENDOUSLY FUNNY AND TOUCHING."

Motivation

Robots as Remote Sensors/ Effectors

- Most applications of Robots view them as glorified remote sensors/effectors
- The role of planning here is mostly limited to path and manipulator planning

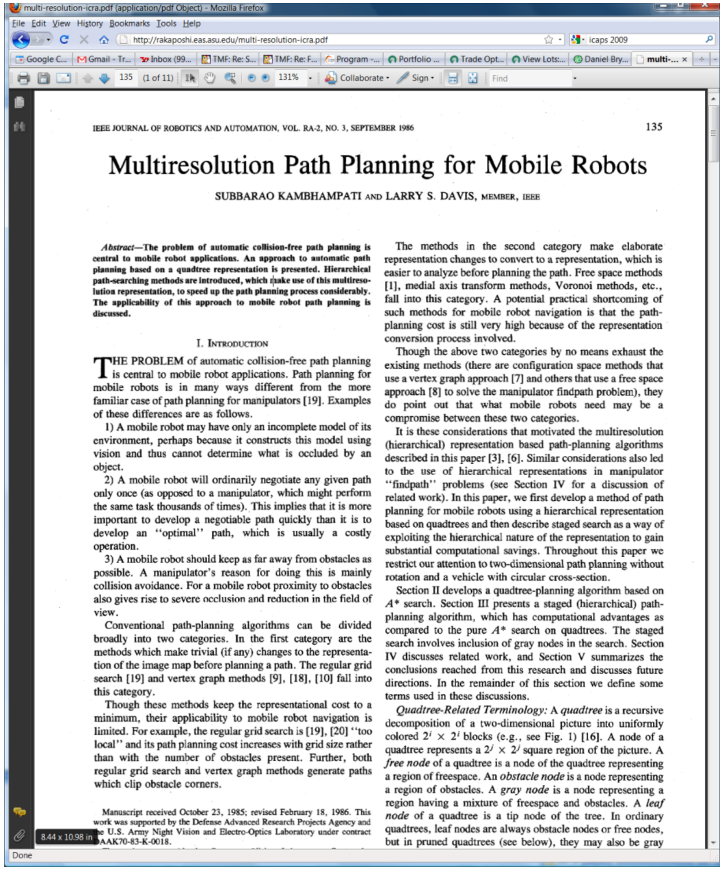
Not that
there is
Anything
wrong
With that..


Path/Motion
Manipulator
Planning

ROBOT


(From Castle Rock Entrnt.)

My very first planning paper was a Path Planning paper.. ☺



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Multiresolution Path Planning for Mobile Robots

SUBBARAO KAMBHAMPATI AND LARRY S. DAVIS, MEMBER, IEEE

Abstract—**The problem of automatic collision-free path planning is central to mobile robot applications. An approach to automatic path planning based on a quadtree representation is presented. Hierarchical path-searching methods are introduced, which make use of this multiresolution representation, to speed up the path planning process considerably. The applicability of this approach to mobile robot path planning is discussed.**

I. INTRODUCTION

THE PROBLEM of automatic collision-free path planning is central to mobile robot applications. Path planning for mobile robots is in many ways different from the more familiar case of path planning for manipulators [19]. Examples of these differences are as follows.

1) A mobile robot may have only an incomplete model of its environment, perhaps because it constructs this model using vision and thus cannot determine what is occluded by an object.

2) A mobile robot will ordinarily negotiate any given path only once (as opposed to a manipulator, which might perform the same task thousands of times). This implies that it is more important to develop a negotiable path quickly than it is to develop an ''optimal'' path, which is usually a costly operation.

3) A mobile robot should keep as far away from obstacles as possible. A manipulator's reason for doing this is mainly collision avoidance. For a mobile robot proximity to obstacles also gives rise to severe occlusion and reduction in the field of view.

Conventional path-planning algorithms can be divided broadly into two categories. In the first category are the methods which make trivial (if any) changes to the representation of the image map before planning a path. The regular grid search [19] and vertex graph methods [9], [18], [10] fall into this category.

Though these methods keep the representational cost to a minimum, their applicability to mobile robot navigation is limited. For example, the regular grid search is [19], [20] ''too local'' and its path planning cost increases with grid size rather than with the number of obstacles present. Further, both regular grid search and vertex graph methods generate paths which clip obstacle corners.

The methods in the second category make elaborate representation changes to convert to a representation, which is easier to analyze before planning the path. Free space methods [1], medial axis transform methods, Voronoi methods, etc., fall into this category. A potential practical shortcoming of such methods for mobile robot navigation is that the path-planning cost is still very high because of the representation conversion process involved.

Though the above two categories by no means exhaust the existing methods (there are configuration space methods that use a vertex graph approach [7] and others that use a free space approach [8] to solve the manipulator findpath problem), they do point out that what mobile robots need may be a compromise between these two categories.

It is these considerations that motivated the multiresolution (hierarchical) representation based path-planning algorithms described in this paper [3], [6]. Similar considerations also led to the use of hierarchical representations in manipulator ''findpath'' problems (see Section IV for a discussion of related work). In this paper, we first develop a method of path planning for mobile robots using a hierarchical representation based on quadtrees and then describe staged search as a way of exploiting the hierarchical nature of the representation to gain substantial computational savings. Throughout this paper we restrict our attention to two-dimensional path planning without rotation and a vehicle with circular cross-section.

Section II develops a quadtree-planning algorithm based on A^* search. Section III presents a staged (hierarchical) path-planning algorithm, which has computational advantages as compared to the pure A^* search on quadtrees. The staged search involves inclusion of gray nodes in the search. Section IV discusses related work, and Section V summarizes the conclusions reached from this research and discusses future directions. In the remainder of this section we define some terms used in these discussions.

Quadtree-Related Terminology: A *quadtree* is a recursive decomposition of a two-dimensional picture into uniformly colored $2^i \times 2^i$ blocks (e.g., see Fig. 1) [16]. A node of a quadtree represents a $2^j \times 2^j$ square region of the picture. A *free node* of a quadtree is a node of the quadtree representing a region of freespace. An *obstacle node* is a node representing a region of obstacles. A *gray node* is a node representing a region having a mixture of freespace and obstacles. A *leaf node* of a quadtree is a tip node of the tree. In ordinary quadtrees, leaf nodes are always obstacle nodes or free nodes, but in pruned quadtrees (see below), they may also be gray

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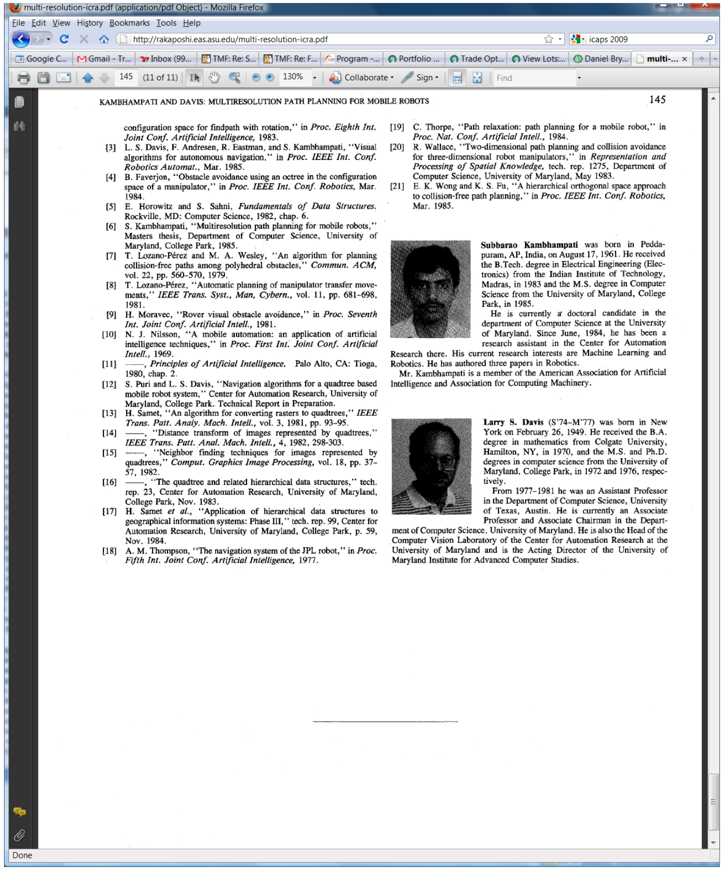

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Subbarao Kambhampati was born in Peddapuram, AP, India, on August 17, 1961. He received the B.Tech. degree in Electrical Engineering (Electronics) from the Indian Institute of Technology, Madras, in 1983 and the M.S. degree in Computer Science from the University of Maryland, College Park, in 1985.

He is currently a doctoral candidate in the department of Computer Science at the University of Maryland. Since June, 1984, he has been a research assistant in the Center for Automation Research there. His current research interests are Machine Learning and Robotics. He has authored three papers in Robotics.

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Larry S. Davis (S'74–M'77) was born in New York on February 26, 1949. He received the B.A. degree in mathematics from Colgate University, Hamilton, NY, in 1970, and the M.S. and Ph.D. degrees in computer science from the University of Maryland, College Park, in 1972 and 1976, respectively.

From 1977–1981 he was an Assistant Professor in the Department of Computer Science, University of Texas, Austin. He is currently an Associate Professor and Associate Chairman in the Department of Computer Science, University of Maryland. He is also the Head of the Computer Vision Laboratory of the Center for Automation Research at the University of Maryland and is the Acting Director of the University of Maryland Institute for Advanced Computer Studies.

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- The role of planning here is mostly limited to path and manipulator planning
  - Not that there is anything wrong with that..

Robots as full-fledged Team-members

- Increasing number of applications want the robots to be full-fledged team members
- Teaming significantly broadens the roles for planning
  - Need to take high-level goals from team members and plan for them

Case Study

Urban Search and Rescue

- Human-Robot Team in Urban Setting
  - Find and report location of critical assets
  - Human: Domain expert; removed from the scene

SEARCH AND REPORT

- Deliver medical supplies
- Bonus Goal: Find and report injured humans
- Requirements
  - Updates to knowledge base
  - Goal changes

[Talamadupula et. al., AAAI 2010]

RECONNAISSANCE

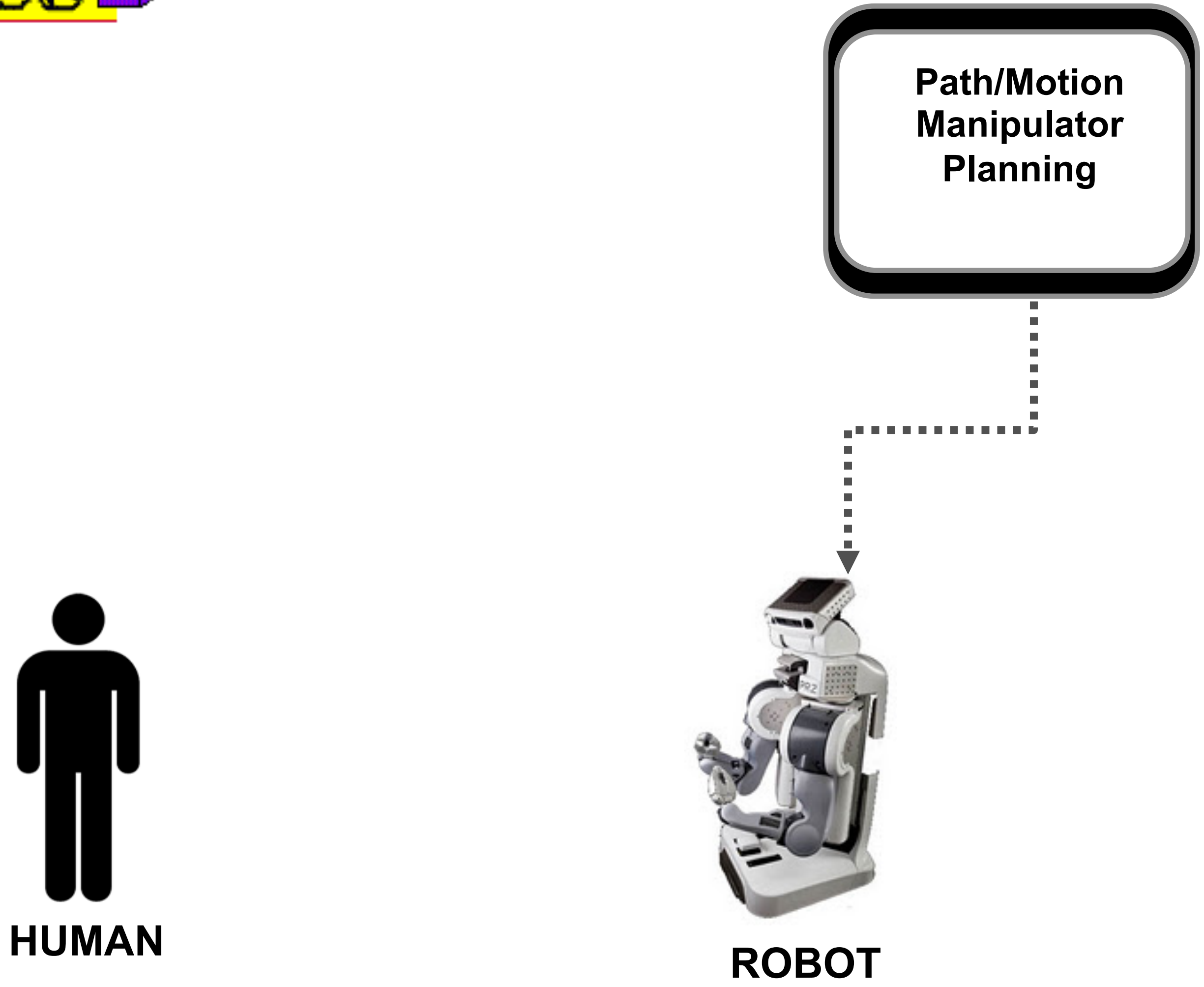
- Gather information
- High risk to humans
  - E.g. Bomb defusal
- Requirements
  - Support model changes
  - New capabilities
    - E.g.: Zoom camera

Human-Robot Teaming Scenarios

➢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

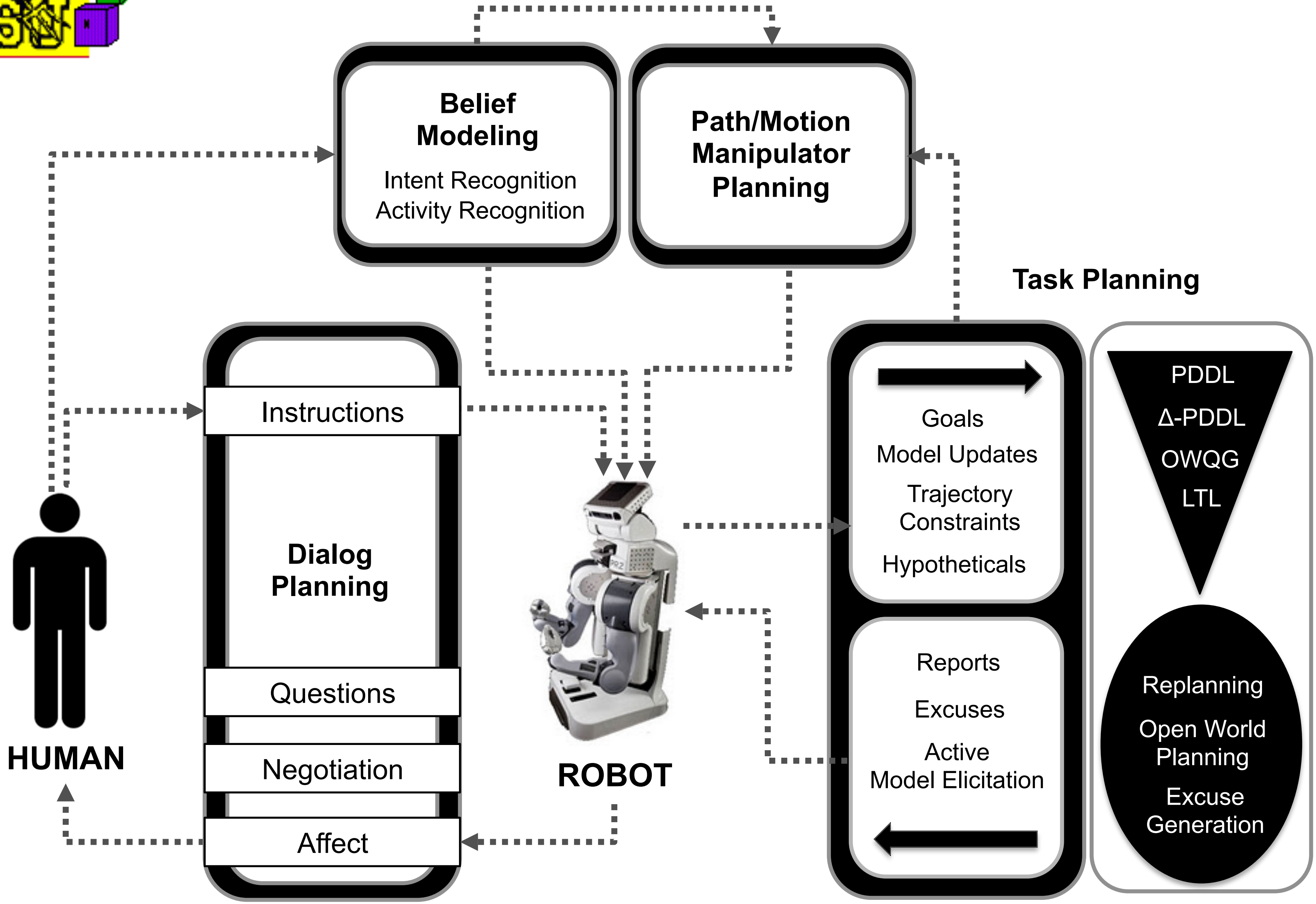
[NIPS 2013; HRI 2012 AAAI 2010…]



Path/Motion Manipulator Planning

HUMAN

ROBOT



Belief Modeling

Intent Recognition
Activity Recognition

Path/Motion Manipulator Planning

Task Planning

HUMAN

Instructions

Dialog Planning

Questions

Negotiation

Affect

ROBOT

Goals
Model Updates
Trajectory Constraints
Hypotheticals

Reports
Excuses
Active Model Elicitation

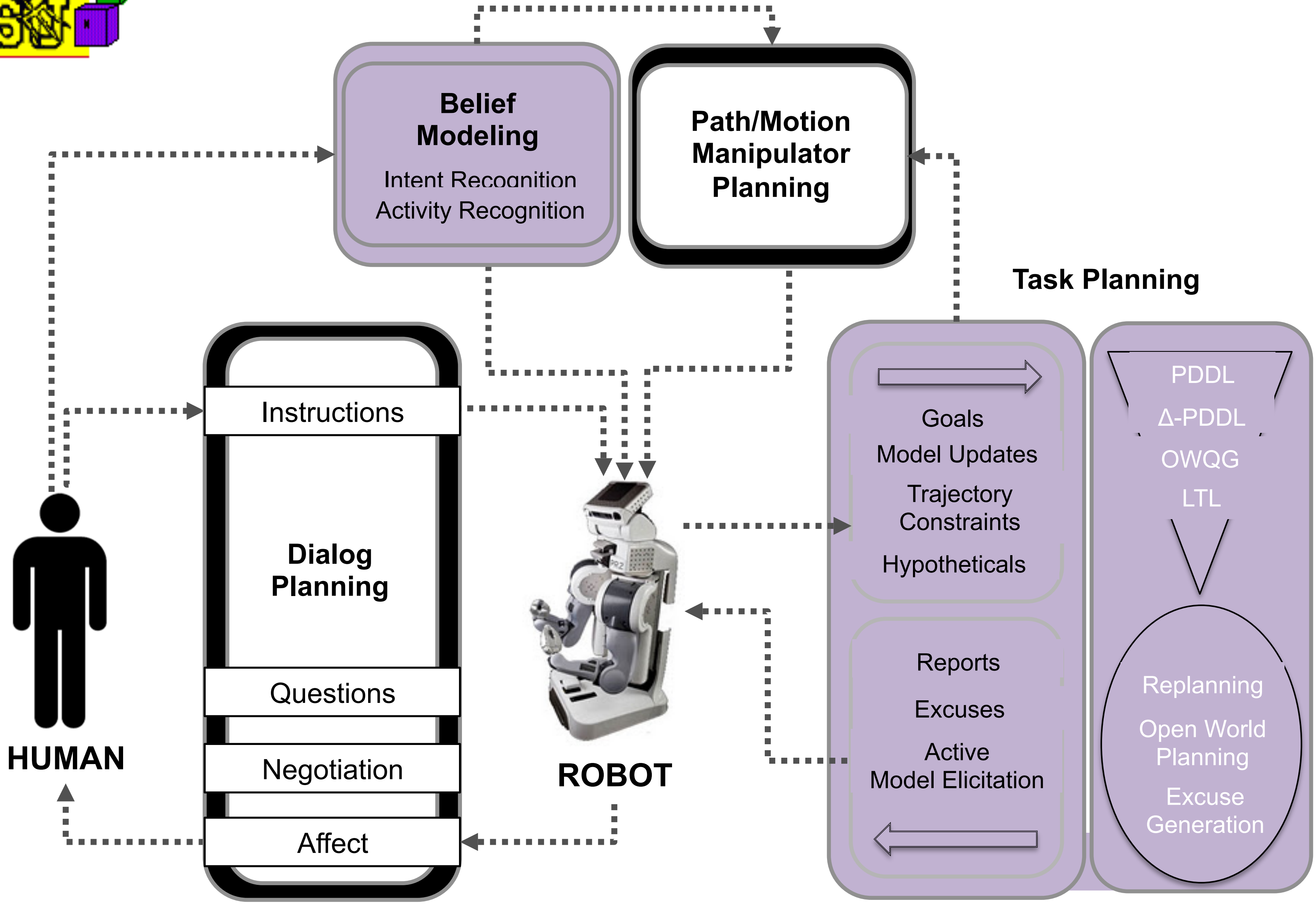
PDDL
Δ-PDDL
OWQG
LTL

Replanning
Open World Planning
Excuse Generation

Position Statement

- Human-Robot teaming scenarios significantly broaden the roles of planning beyond path and motion planning
  - Task Planning
  - Belief Modeling
  - Dialog planning
- We advocate investigating the challenges posed by all these planning roles

Humans?



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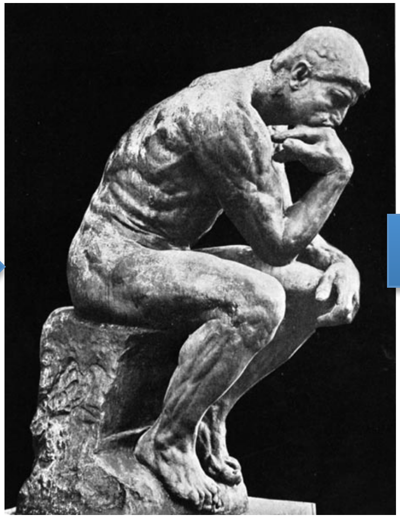
Planning: Traditional View

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



The Plan

Hard problem
→Tremendous progress has been made in taming the combinatorics

Planning: Traditional View

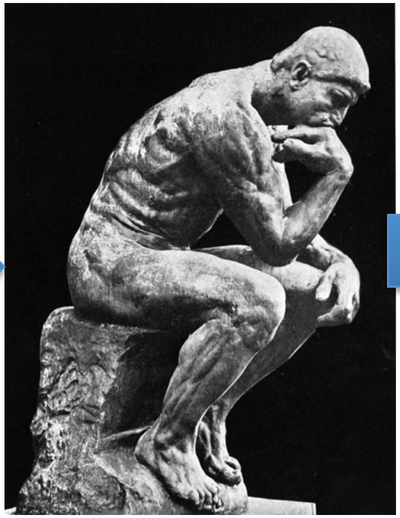
A fully specified problem
--Initial state
--Goals
(each non-ne e)
--Complete Actio l

The Plan

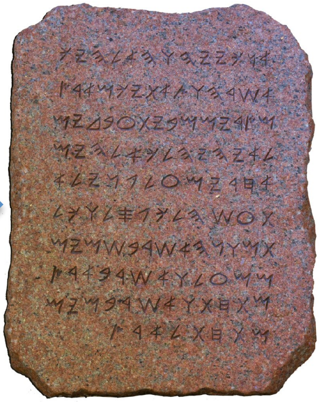
Planning: Traditional View

Partial models and partial specfications

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



Changing goals
Open goals
Replanning



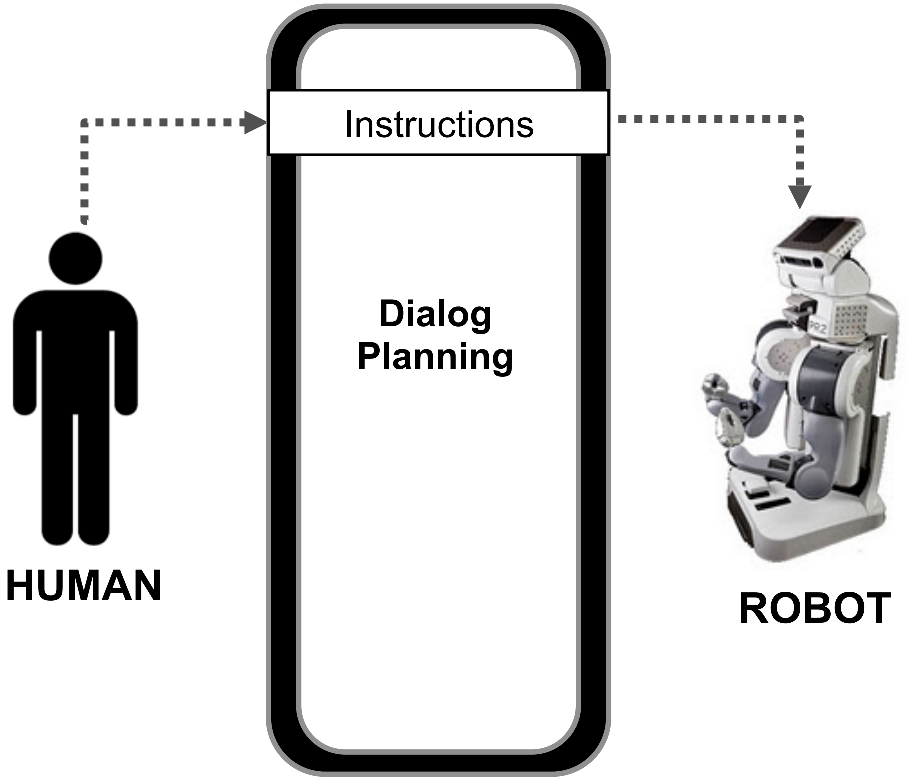
The Plan

Explanation of Planning Failures

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



Instructions

Dialog Planning

HUMAN

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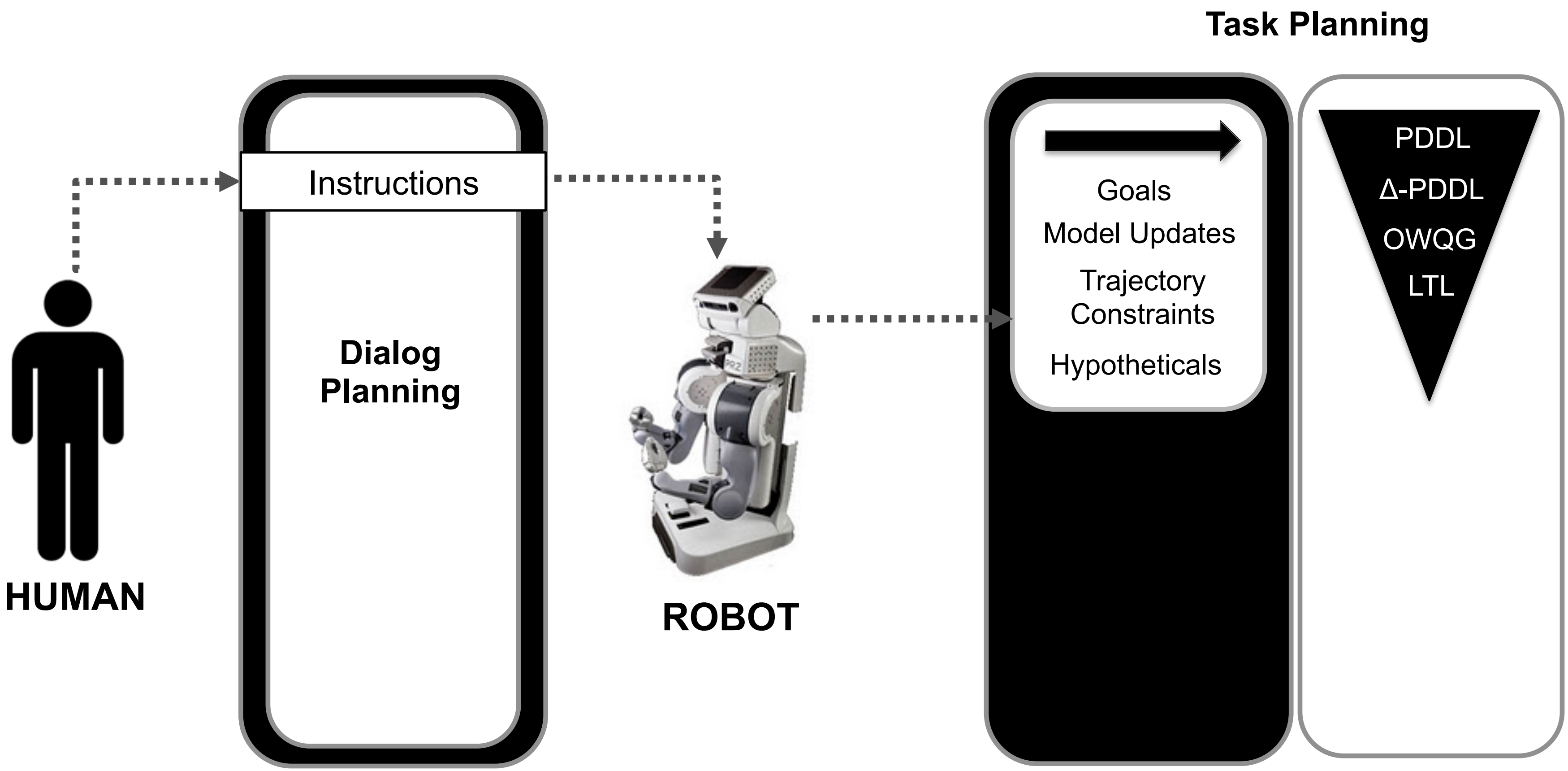
HRT System Schematic



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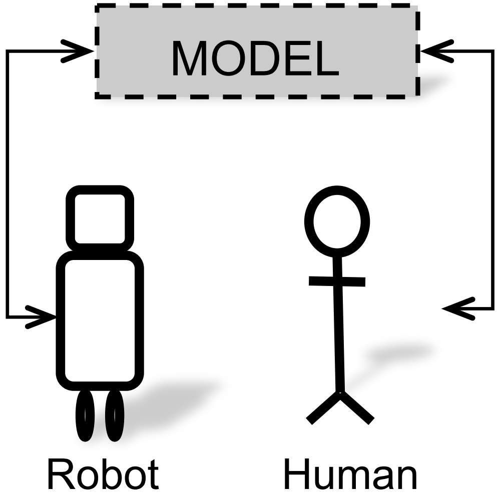
Planning
Goal Management

- 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]

Planning

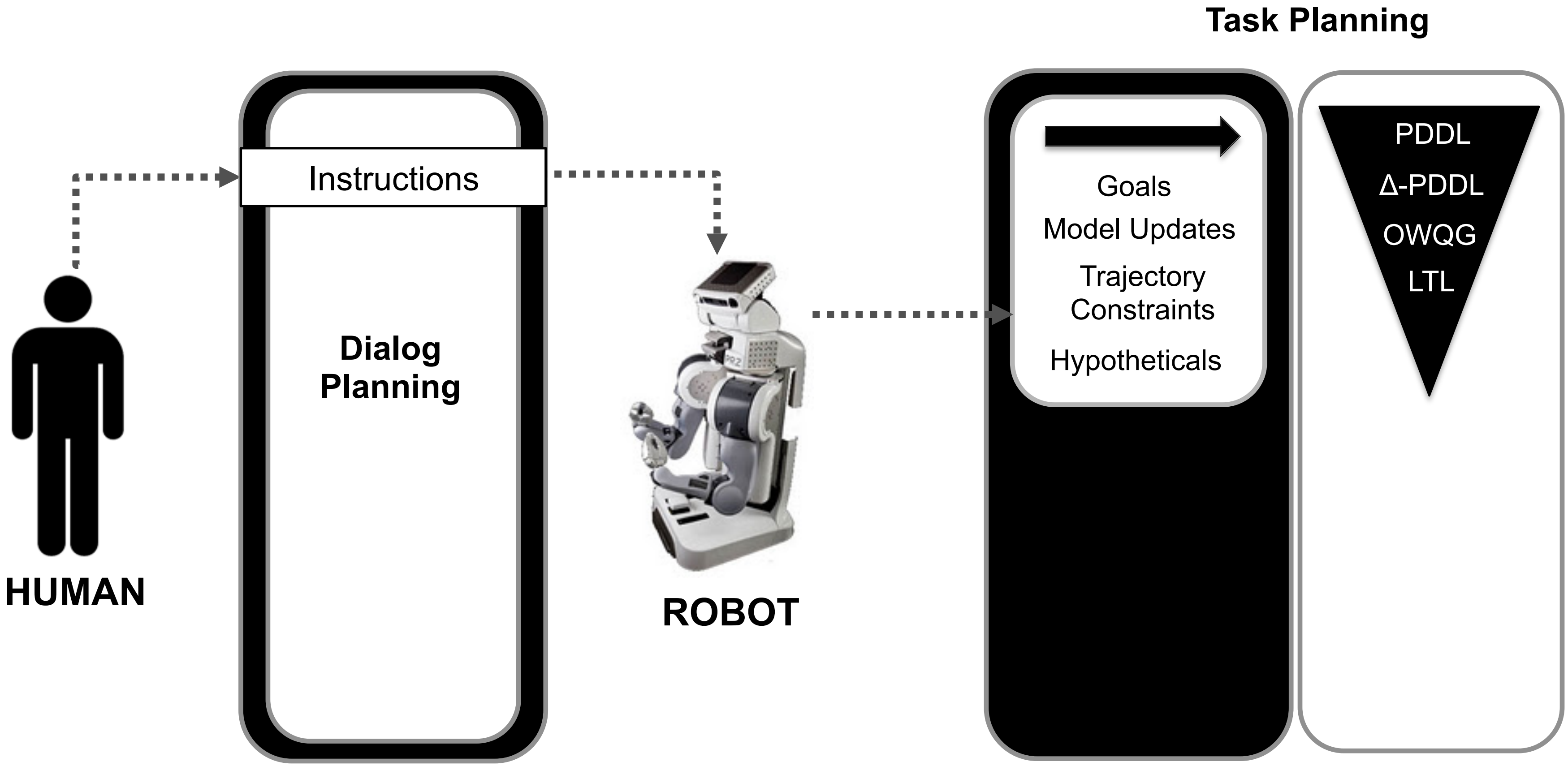
Model Management

- **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



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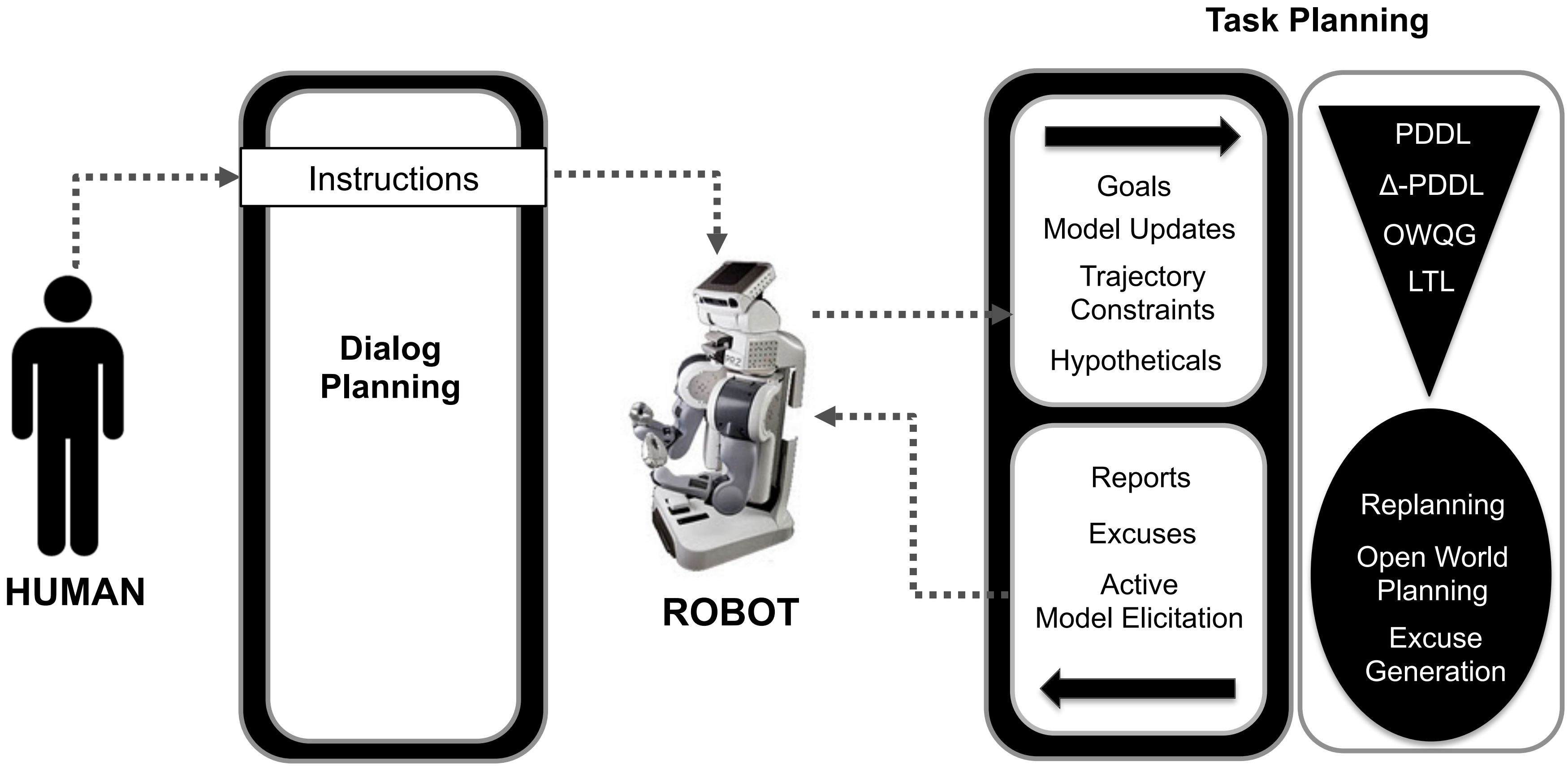

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Excuse Generation

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
- **Explanations**
  - – Returning a plan is not enough
  - – Human must be informed "why" the robot is doing something
    - May result in more elaboration /information

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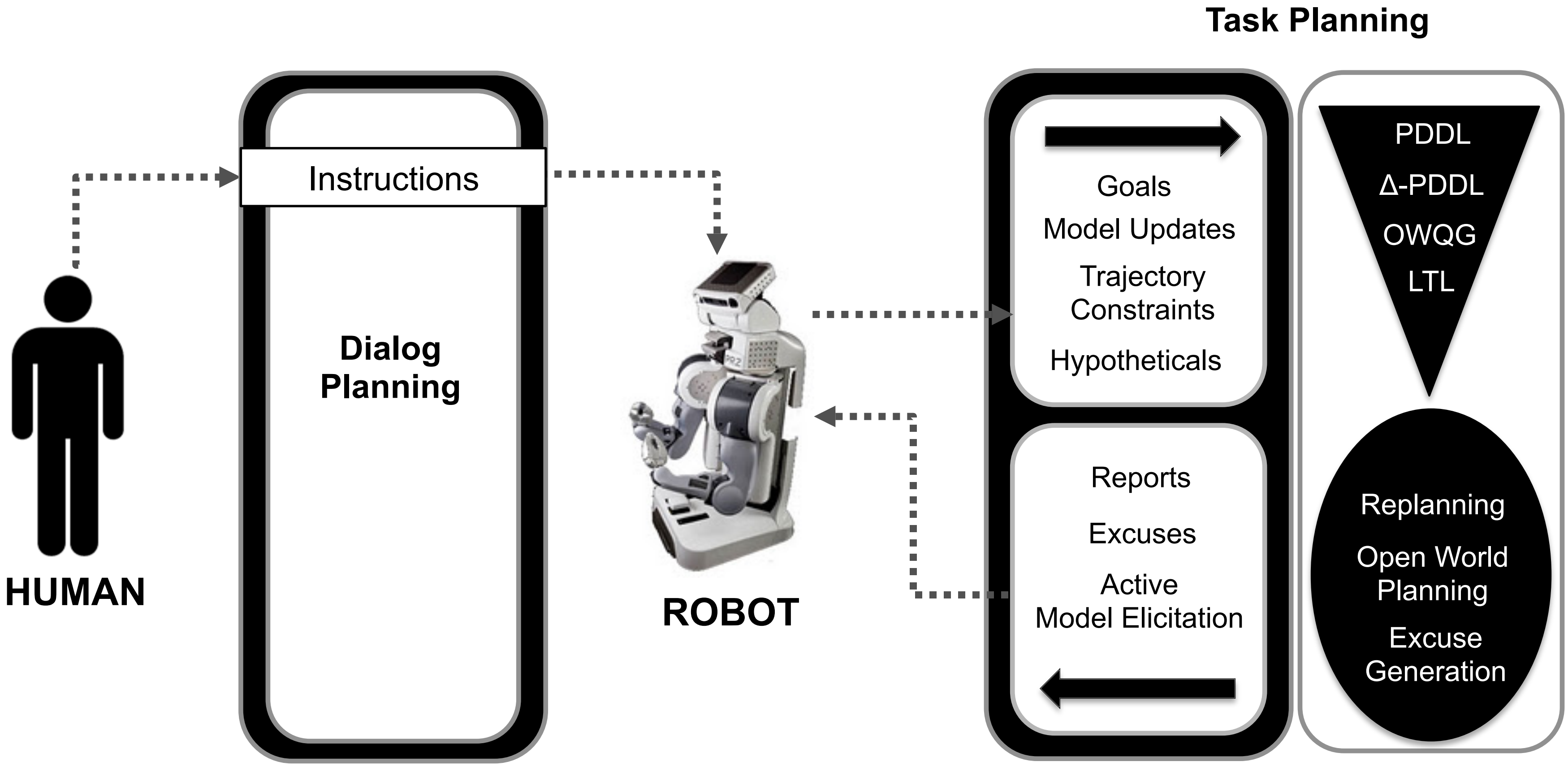

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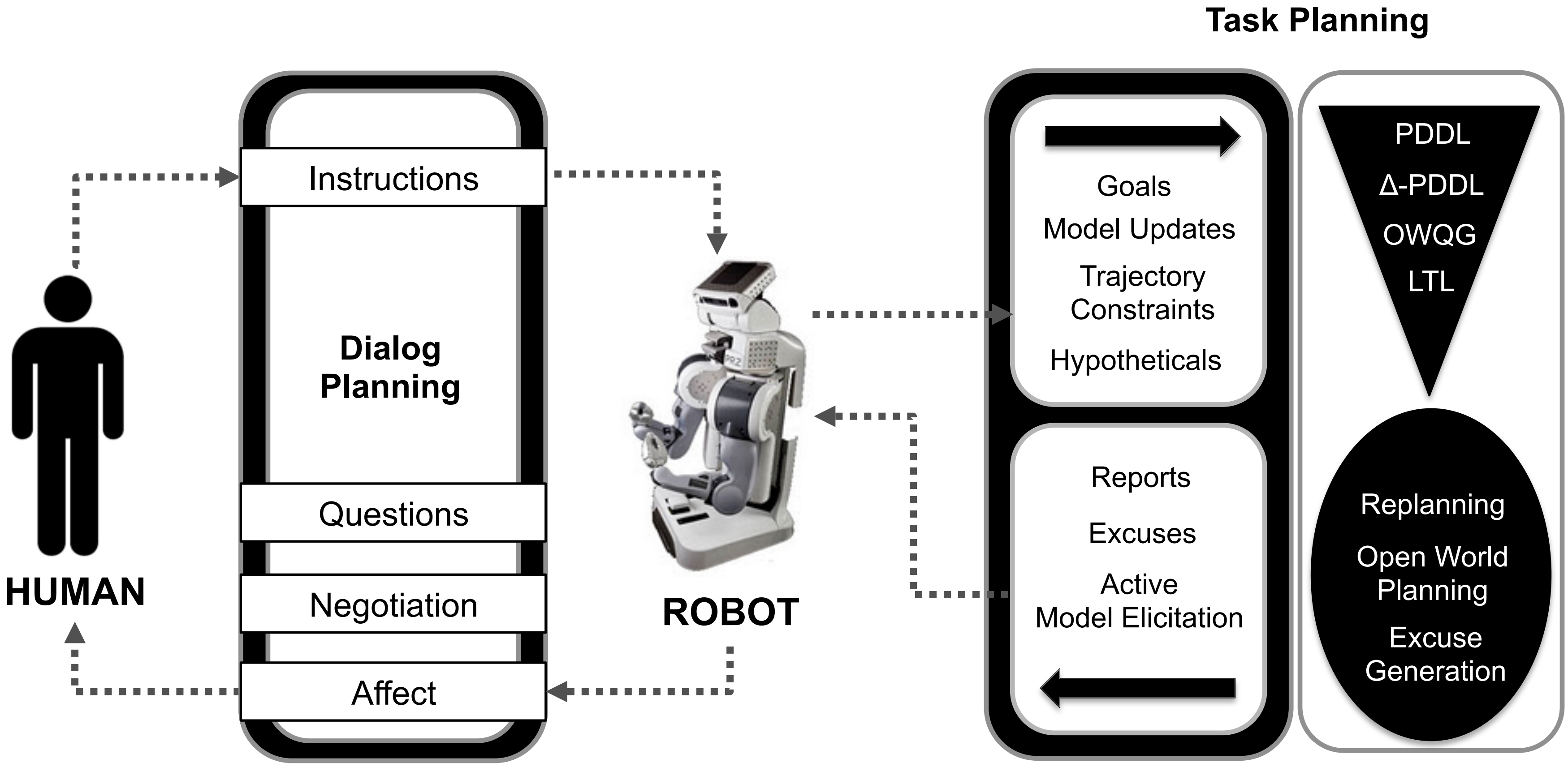

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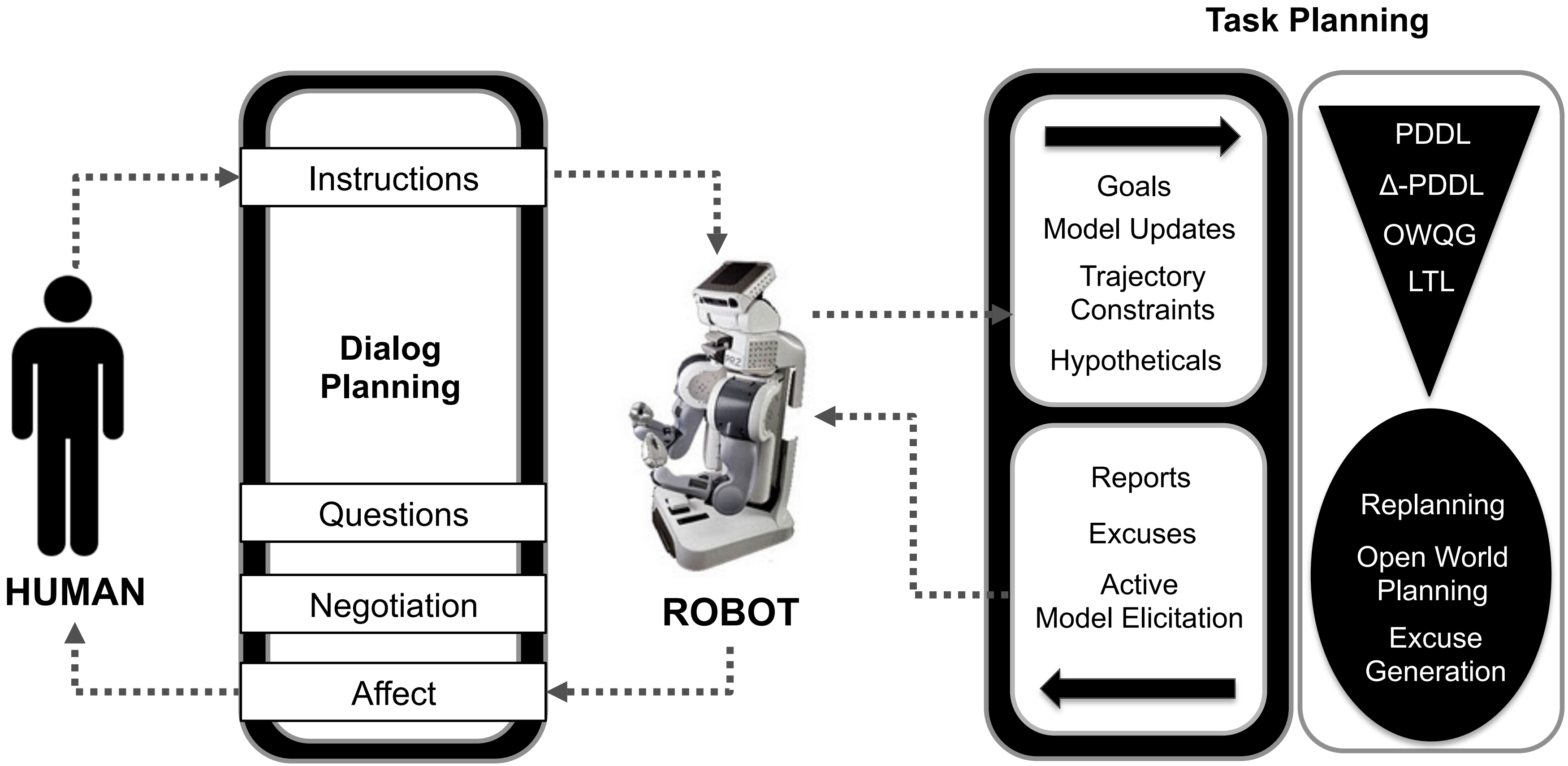
Dialog Planning

- 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



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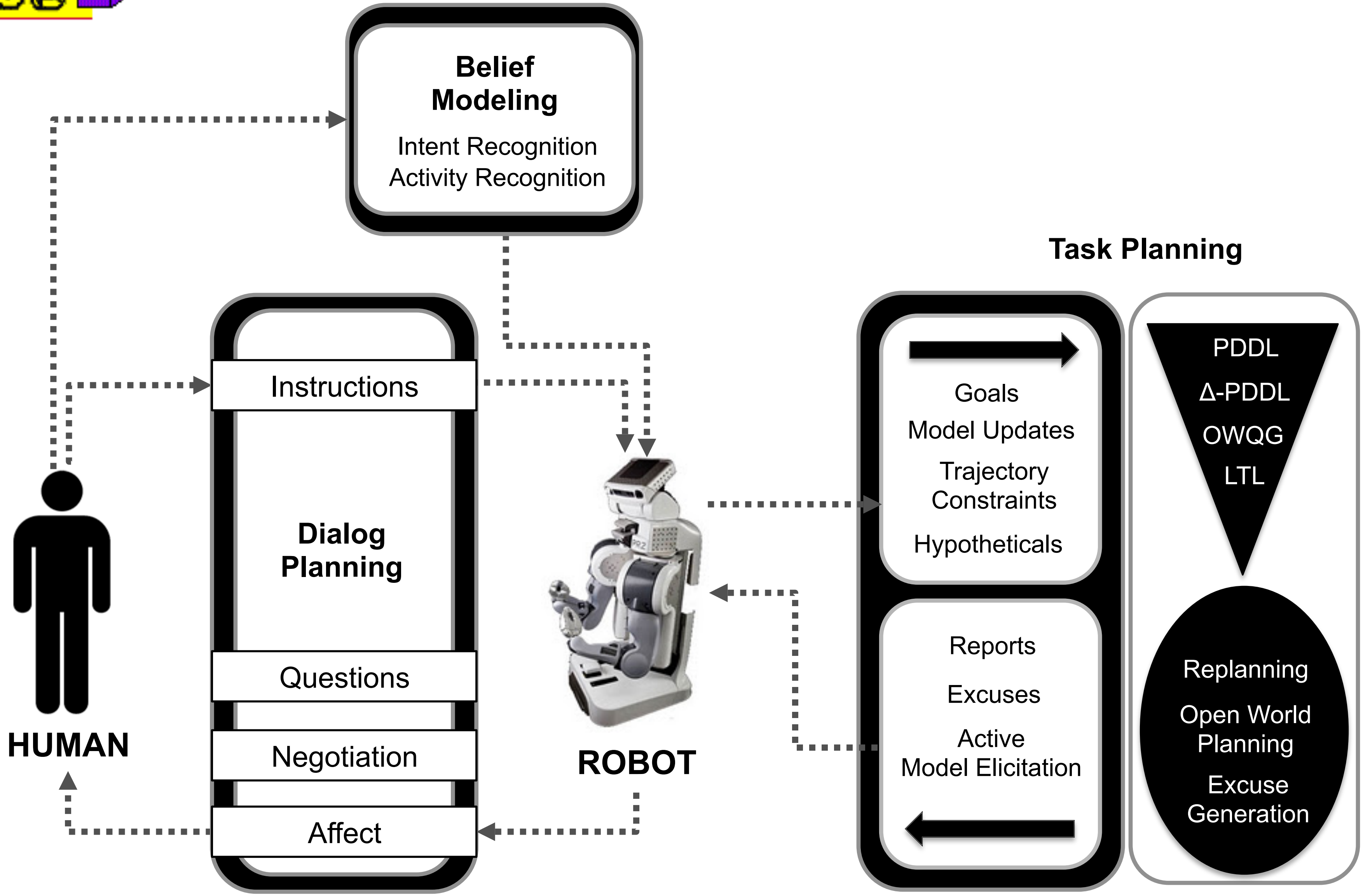

Belief Modeling

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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

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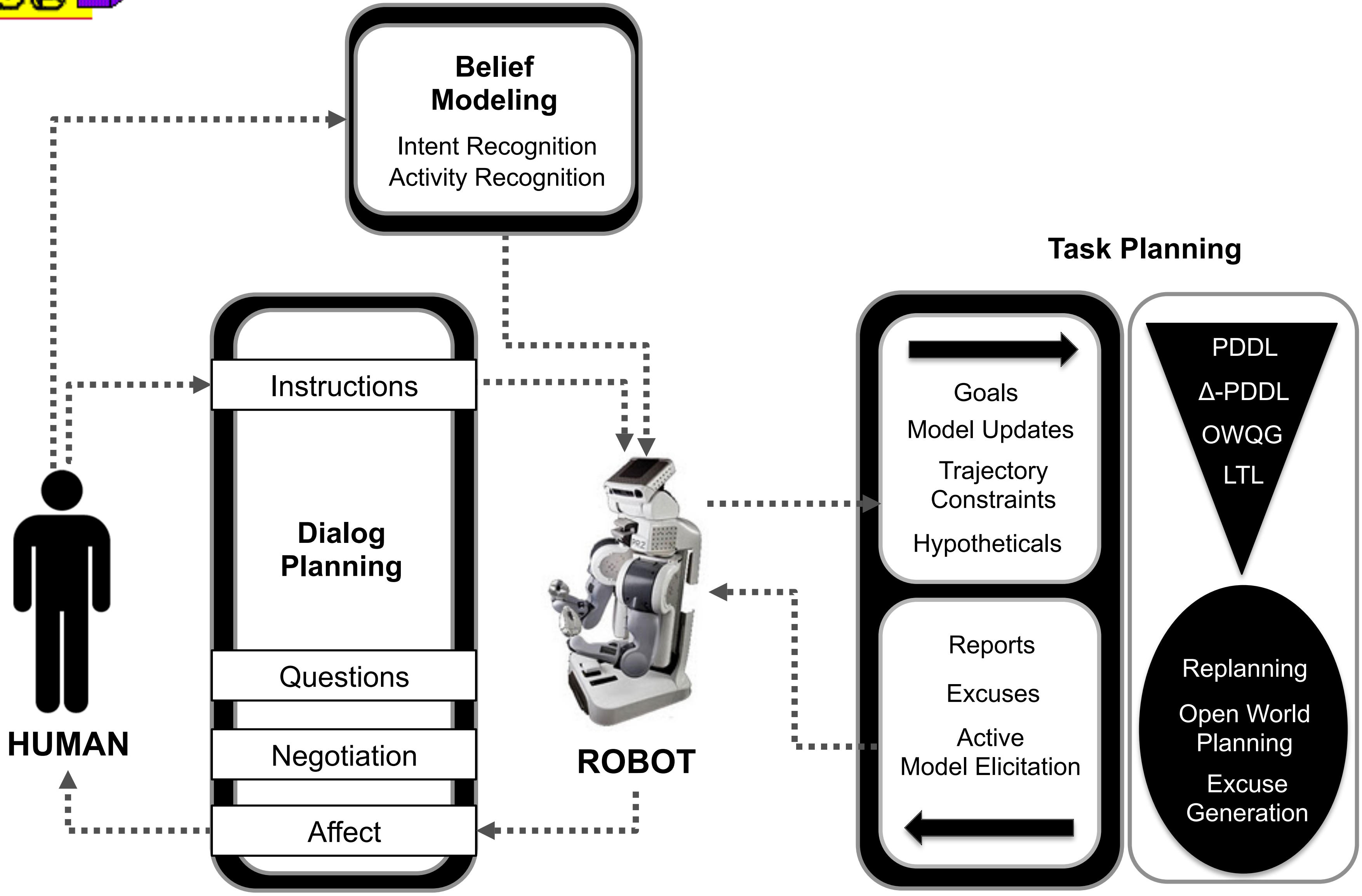

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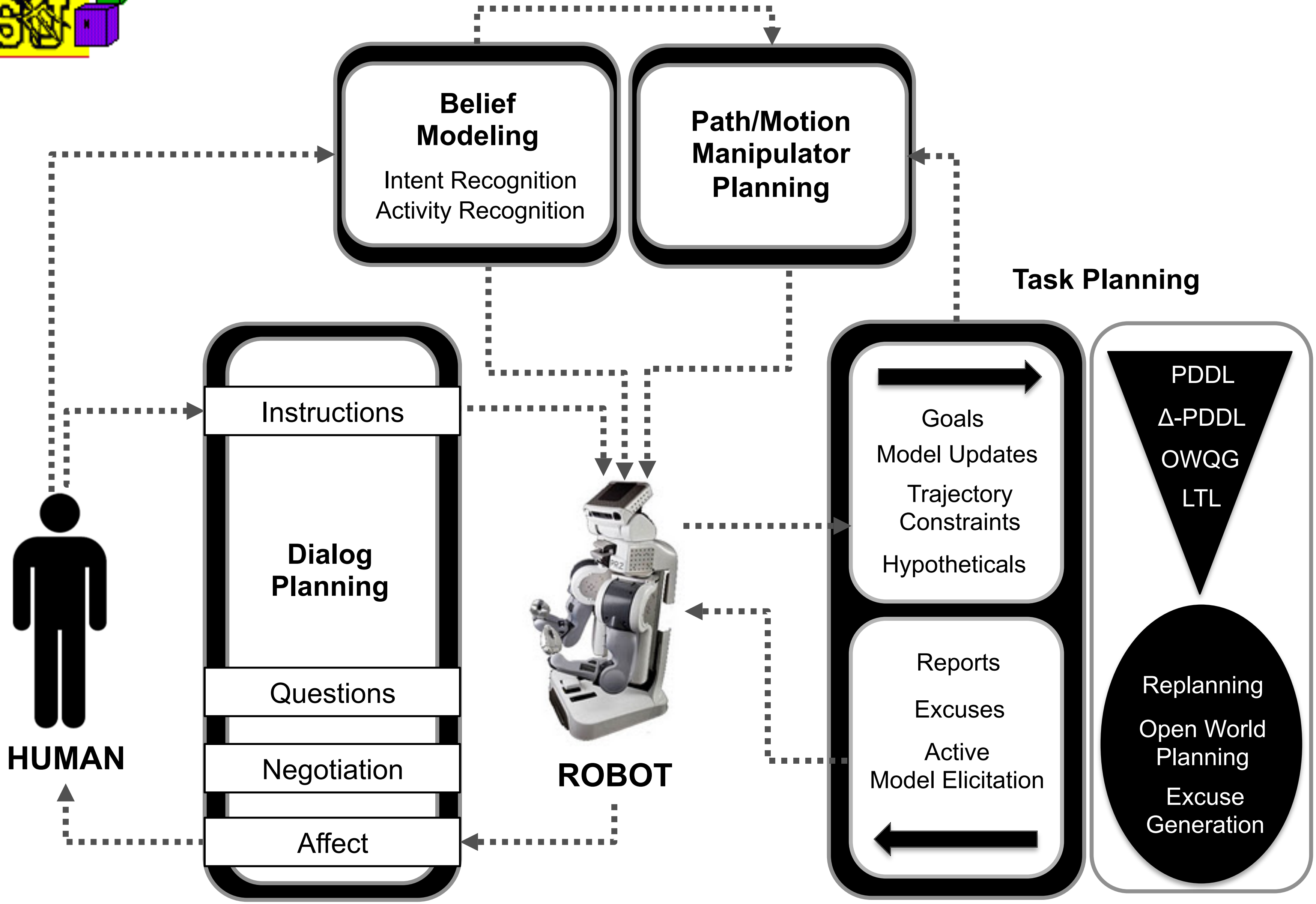

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