



Planning

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Decision-making vs. Planning

Decision-making is at a higher level than planning and includes determining the goals of the agent. It might also imply the use of a cognitive model, psychological and physiological state, and more. In my mind planning begins with a goal or set of goals and is the processing of putting together actions to achieve these goals. Decision-making is more about determining what the goals are.

Generally the PAR system works with actions, not goals. The PAR system lacks decision-making capabilities and currently has very limited planning. Actions can be assigned to agents by the user or an algorithm for choosing actions can be hard coded into the agents. We are working on encoding entire procedures or tasks as PARs. These tasks can then be selected by the user and assigned to agents. Previously we also enabled users to give the agents standing orders which rules of behavior for the agents. It would be very possible to connect a cognitive model or other decision-making system to the PAR agents to create more sophisticated, intelligent, autonomous agents.

Levels of Planning

Most planning begins with a goal or set of goals, a state of the world, a pool of available actions, a pool of available agents, rules about how the world works (encoded in the actions), and possibly some constraints (normally encoded in the goals or the planner but possibly in the actions). Planning can occur at many levels from a very high level with few details (e.g. *leave the room*) to a very low level with many details (e.g. *joint0 = 90, joint1 = 120, ...*). Building planners that focus on a certain level of detail narrows their scope making their process cleaner. High level planners take a state of the world as a goal and string together a series of actions that will achieve that state from the current state. The details of the execution of the actions may be left out. These details may be filled in by subsequent planners. Hierarchical plans may also be constructed. Low level planners are concerned less with the overall context of the action and more with the action's interaction with the environment. Also as one moves from higher level planners and plans to lower level ones, there should be less and less ambiguity in the plans. For example, a high level plan may contain an action *Leave the room*. In a lower level plan, this could become a *walk* action from one location to another and in a still lower level plan might be the specification of particular path points or foot steps (path planner) ultimately grounding in the joint angles required to place the figure in those poses and locations (motion planner).

There are no absolutes. Planning is really a continuum in levels of detail of the action specifications and levels of detail in the resulting states of the world. The primitive planning built into PAR lays somewhere in the middle, but the PAR representation could be used in planning any where in the continuum. So the question is if lines must be drawn, where should they be? If one were to assign the task of creating planners for the PAR system, what planners should be built and what would their scope be? I would roughly split it in thirds; a high level planner or decision-maker (perhaps the user), a mid-level planner with some sophistication to manipulate the PARs efficiently, and low-level motion and path planners used in the execution of the actions on a virtual human. Where one level stops and the other begins is difficult to say. Certainly if a choice is at the joint angle level, a low-level planner should be used. If the choice is between two courses of action based on their utilities, a high-level planner should be used. I would view PAR or middle-level planning to be more about efficiency in the plan and planning time. It isn't about

what is best for the virtual human. It is about what is the best way to achieve some state(s). I would think of the middle level as action selection.

Planning and Constraints

Constraints are goals that must be maintained through time. They may be constraints on a certain plan, during a certain time, for a certain agent, or universal. They can come at any level of planning. *Do no harm. Never run. Avoid collisions.* They may be passed along the levels of planning as conditions of the PAR actions or may be built into the planners (e.g. collision detection in the motion planning of reach). If passed as conditions, the lower level planners must have enough sophistication to understand the conditions and incorporate them into new plans. For example, a constraint might be *Keep Agent1 out of Room101*. This might be translated by a planner into a locomotion action for Agent0 with during condition *!location(Agent1, Room101)*, meaning that during the locomotion action, Agent1 must not be in Room101. The motion generator for Agent0's locomotion would need to be rather sophisticated to plan paths and trajectories that would prevent Agent1 from entering Room101.

The viability of constraints in the PAR system depends on the type of constraints and the sophistication of the planners. Constraints on action choice. Constraints on world states. Constraints on resources. PAR can represent these constraints and planners could be constructed that deal with them elementarily provided there are no conflicts and solutions can be found. Constraints on actions simply limit the number of actions to choose from. Provided that PARs are probably created with during and post conditions, constraints on world states are just one step removed from limiting action choice. Constraints on resources involve creating a resource manager.

Other Issues with Planning

Sophistication of the planning algorithms

Reactions

Re-planning

Prevention

Resources

Uncertainty

Dynamic environments

Efficiency

Failure recovery

Action transitions

Teams and competition

Epistemic planning

Scope

Logics

Appendix: Terminology

PAR agents

Embodied agents

Digital humans

Virtual humans

Avatars

Autonomous agents