Section 11.4  Hierarchical Planning

It treats the HLA’s multiple outcomes exactly as if the HLA were a **nondeterministic** action, as in Section 4.3. For our case, the agent itself will choose the implementation.

The programming languages community has coined the term **demonic nondeterminism** for the case where an adversary makes the choices, contrasting this with **angelic nondeterminism**, where the agent itself makes the choices. We borrow this term to define **angelic semantics** for HLA descriptions. The basic concept required for understanding angelic semantics is the **reachable set** of an HLA: given a state $s$, the reachable set for an HLA $h$, written as $\text{Reach}(s, h)$, is the set of states reachable by any of the HLA’s implementations.

The key idea is that the agent can choose which element of the reachable set it ends up in when it executes the HLA; thus, an HLA with multiple refinements is more “powerful” than the same HLA with fewer refinements. We can also define the reachable set of a sequence of HLAs. For example, the reachable set of a sequence $[h_1, h_2]$ is the union of all the reachable sets obtained by applying $h_2$ in each state in the reachable set of $h_1$:

$$\text{Reach}(s, [h_1, h_2]) = \bigcup_{s' \in \text{Reach}(s, h_1)} \text{Reach}(s', h_2).$$

Given these definitions, a high-level plan—a sequence of HLAs—achieves the goal if its reachable set **intersects** the set of goal states. (Compare this to the much stronger condition for demonic semantics, where every member of the reachable set has to be a goal state.) Conversely, if the reachable set doesn’t intersect the goal, then the plan definitely doesn’t work. Figure 11.9 illustrates these ideas.

The notion of reachable sets yields a straightforward algorithm: search among high-level plans, looking for one whose reachable set intersects the goal; once that happens, the algorithm can **commit** to that abstract plan, knowing that it works, and focus on refining the plan further. We will return to the algorithmic issues later; for now consider how the effects of

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**Figure 11.9** Schematic examples of reachable sets. The set of goal states is shaded in purple. Black and red arrows indicate possible implementations of $h_1$ and $h_2$, respectively. (a) The reachable set of an HLA $h_1$ in a state $s$. (b) The reachable set for the sequence $[h_1, h_2]$. Because this intersects the goal set, the sequence achieves the goal.