



**Figure 11.10** Goal achievement for high-level plans with approximate descriptions. The set of goal states is shaded in purple. For each plan, the pessimistic (solid lines, light blue) and optimistic (dashed lines, light green) reachable sets are shown. (a) The plan indicated by the black arrow definitely achieves the goal, while the plan indicated by the red arrow definitely doesn't. (b) A plan that *possibly* achieves the goal (the optimistic reachable set intersects the goal) but does not *necessarily* achieve the goal (the pessimistic reachable set does not intersect the goal). The plan would need to be refined further to determine if it really does achieve the goal.

with approximate descriptions, there is a middle ground: if the optimistic set intersects the goal but the pessimistic set doesn't, then we cannot tell if the plan works (Figure 11.10(b)). When this circumstance arises, the uncertainty can be resolved by refining the plan. This is a very common situation in human reasoning. For example, in planning the aforementioned two-week Hawaii vacation, one might propose to spend two days on each of seven islands. Prudence would indicate that this ambitious plan needs to be refined by adding details of inter-island transportation.

An algorithm for hierarchical planning with approximate angelic descriptions is shown in Figure 11.11. For simplicity, we have kept to the same overall scheme used previously in Figure 11.8, that is, a breadth-first search in the space of refinements. As just explained, the algorithm can detect plans that will and won't work by checking the intersections of the optimistic and pessimistic reachable sets with the goal. (The details of how to compute the reachable sets of a plan, given approximate descriptions of each step, are covered in Exercise 11.HLAP.)

When a workable abstract plan is found, the algorithm *decomposes* the original problem into subproblems, one for each step of the plan. The initial state and goal for each subproblem are obtained by regressing a guaranteed-reachable goal state through the action schemas for each step of the plan. (See Section 11.2.2 for a discussion of how regression works.) Figure 11.9(b) illustrates the basic idea: the right-hand circled state is the guaranteed-reachable goal state, and the left-hand circled state is the intermediate goal obtained by regressing the goal through the final action.