Expecting the Unexpected: Detecting and Reacting to Unplanned-for World States

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Developing autonomous systems is challenging because complete and correct models do not exist for complex domains such as aircraft flight. Realistic systems bound the state set expanded during planning and compensate for unexpected situations with reactive mechanisms. This abstract describes a method by which a system can determine if it is unprepared for the current world state and a means to successfully respond to such an unhandled state.

We first identify subclasses of unhandled states, then investigate how system performance improves when detecting them. The Cooperative Intelligent Real-time Control Architecture (CIRCA) (Musliner, Durfee, & Shin 1995) combines a planner, scheduler, and real-time plan executor to provide guaranteed performance for controlling complex systems. Domain knowledge includes action (ac) and temporal transitions (tt) that model how the world state changes over time. We have implemented and tested algorithms to detect and respond to unhandled states in CIRCA.

Figure 1 shows the relationship between subclasses of possible world states. Modeled states have distinguishing features/values represented in the planner knowledge base; we have not considered methods (e.g., discovery) to handle unmodeled states. The planned-for set are states from which failure is avoided. Handled states are on a path to a goal, while deadend are not. The planner can model other states, including those that are reachable but "removed" due to resource limitations, and "imminent-failure" that are not considered reachable but, if reached, are modeled as leading to failure. As shown in Figure 1, states actually reached may include any subclass.

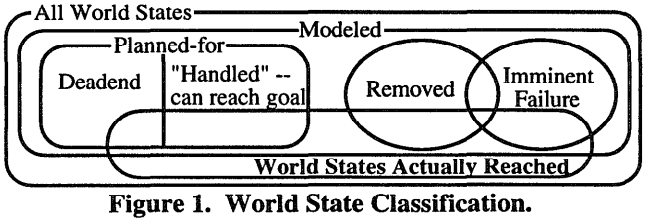

Figure 1. World State Classification.

Because they are either more probable or more critical, we have targeted deadend (D), removed (R), and imminent-failure (IF) states for detection. Figure 2a shows a deadend state. The planner expands states until finding a goal path, but state D remains either because no action can reach the goal (G) or because the planner minimized resources by not selecting such actions. After completing a plan, CIRCA builds a deadend state list then uses ID3 (Quinlan 1986), with deadend states as positive examples and all other reachable states as negative examples, to build a minimal test condition set for detecting deadend states.

CIRCA's planner backtracks when a proposed plan cannot be scheduled for guaranteed real-time execution. We have modified CIRCA's planner to remove improbable states after backtracking, but detect such states using ID3 as described above. Figure 2b illustrates this concept -- a low probability tt leads from state I to a state (R) removed after backtracking. Without R, downstream actions to avoid failure (F) are not required so scheduling becomes easier. The shaded region encloses the removed state set.

Figure 2c shows an imminent-failure state (IF). The planner considers IF unreachable because no modeled transition set connects I to IF, thus it plans no action to avoid F. However, if IF is reached, the system will fail unless it reacts. We modified CIRCA to list all unreachable states that lead via a single temporal transition to failure (ttf), then use ID3 to build tests for detecting these IF states.

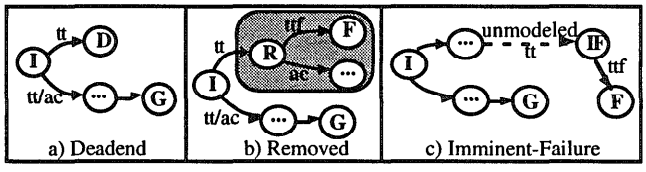

Figure 2. Unhandled State Illustrations.

Upon detecting an unhandled state (D, R, or IF), CIRCA reacts by replanning based on the current state. We have performed tests using an aircraft simulator. After CIRCA successfully flew normal "flight around an airport pattern", we modeled an unhandled "gear fails on final approach to landing" emergency. By differing CIRCA's aircraft gear model, we produced each type of unhandled state. CIRCA was able to detect and respond (e.g., execute "go-around" and "gear-down" action) to each D, R, or IF state, whereas without detecting that unhandled state it would consistently fail (i.e., plane would crash). We continue tests with more complex flight examples, and are studying associated research issues such as imposing time bounds on CIRCA's planner to guarantee timely responses to unhandled states.

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References

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Quinlan, J. R. 1986. Induction of Decision Trees. *Machine Learning* 1:81-106.