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Avoiding Failure via Pre-planned Responses and Time-Bounded Planning

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Complex plans are required to safely operate an autonomous system in a dynamic environment. An ideal planner would build all reactions offline so it could deliberate as long as necessary to develop its response set. However, it may be impossible to build and store all plans offline, so online planning is required whenever previously unplanned-for situations arise. In a dynamic system, online planning must be terminated within time bounds imposed by the environment, with potentially adverse affects on plan quality. We propose that the *primary* goal of any system is to avoid failure (e.g., system destruction), and a *secondary* consideration is to achieve other goals.

In this abstract, we propose a method to balance offline vs. online planning in terms of failure avoidance. We combine pre-planned responses with time-bounded online planning in CIRCA, the Cooperative Intelligent Real-time Control Architecture (Musliner, Durfee, and Shin 1993), shown in Figure 1. CIRCA combines a planner, scheduler, and real-time plan execution subsystem (RTS) to allow guaranteed performance for critical responses. We have augmented CIRCA to allow contingency plan storage via a Plan Dispatcher module and a small but quickly-accessed cache within the RTS.

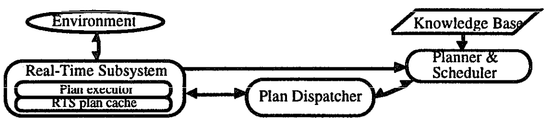

Figure 1. CIRCA.

Figure 2 illustrates different scenarios possible during plan execution. If the executing plan handles the current state, CIRCA has ensured failure avoidance. However, if the system leaves this "planned-for" state set, then the current plan may not maintain safety, and CIRCA must respond with sufficient speed to avoid failure. Each Figure 2 oval represents a set of states, with "planned-for" ovals representing states for which the planner has built offline plans, while blank ovals represent unhandled state sets. As shown in the figure, CIRCA must be able to detect unhandled states in each set (the shaded regions in the figure) and quickly determine the minimum time before a temporal transition to failure (TTF) may occur, using algorithms from (Atkins, Durfee, and Shin 1996). When it detects an unplanned-for state with a quick TTF, CIRCA switches in *guaranteed real-time* to a plan stored in the RTS cache. If a TTF occurs slowly, so the plan dispatcher has time to download the plan but the planner may not have time to build a new plan, CIRCA downloads then executes a plan stored in the Dispatcher. If either no TTF exists or the TTF is "very slow", CIRCA allows online replanning, with a planning time bound corresponding to the time before a TTF may occur and imposed using a strategy based on the anytime approach (Dean et al. 1993).

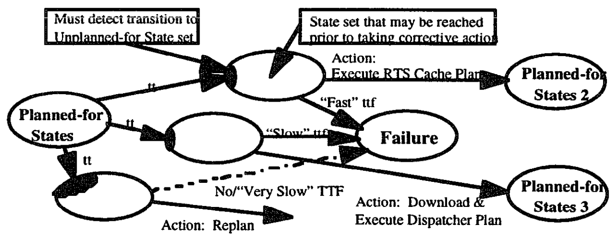

Figure 2. Possible Plan Space Transitions.

The combination of offline and time-bounded online planning directly address weaknesses present when each is used alone. Time-bounded planning approaches are only effective if sufficient time exists to create a minimally acceptable plan. Our approach requires replanning only in situations with "very slow" or no TTFs, leaving substantial time for building each plan. Conversely, if no online planning were available, the cached plans must contain an exhaustive response set regardless of available deliberation time. In this work, we have focused our attention on one important quantity: time remaining before failure can occur. We are performing tests using a fully-automated aircraft simulator, in which each TTF is defined by the minimum time before the aircraft may crash.

Acknowledgement

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