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## The Design-to-Criteria Scheduler: A Component for Complex Agent Control

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### Introduction

Complex autonomous agents operating in open, dynamic environments must be able to address deadlines and resource limitations in their problem solving. This is partly due to characteristics of the environment, and partly due to the complexity of the applications typically handled by software agents in our research. In open environments, requests for service can arrive at the local agent at any time, thus making it difficult to fully plan or predict the agent's future workload. In dynamic environments, assumptions made when planning may change, or unpredicted failures may occur<sup>1</sup>. In most real applications, deadlines or other time constraints are present on the agent's problem solving [5, 4]. For example, in an anti-submarine warfare information gathering application [2], there is a deadline by which the mission planners require the information. Resource limitations may also stem from agents having multiple different tasks to perform and having bounded resources in which to perform them. Temporal constraints may also originate with agent interactions – in general, in order for agent  $\beta$  to coordinate with agent  $\alpha$ , the agents require mutual temporal information so that they can plan downstream from the interaction.

For agents to adapt rationally to their changing problem solving context, which includes changes in the environment<sup>2</sup> and changes to the set of duties for the agent to perform, they must be able to:

1. Represent or model the time and resource constraints of the situation and how such constraints impact their problem solving. We believe this must be done in a

<sup>1</sup>This differs from states that are explicitly recognized and *planned for* [1] as software agents may be required to perform a different set of tasks, as well as having to react to changes in the environment.

<sup>2</sup>Including resources uncontrollably becoming more or less constrained. For example, network latency increasing due to some activity other than the agent's problem solving.

quantified fashion as different constraints have different degrees of effect on problem solving.

2. Plan explicitly to address the resource limitations. In our work, this may imply performing a different set of tasks, using alternate solution methods, or trading-off different resources (or quality), depending on what is available.
3. Perform this planning online – in the general case, this implies coping with exponential combinatorics online in soft real time.

While the first two requirements obviously follow from the domain, the third requirement is less obvious. Agents must be able to perform real time control problem solving online because of the dynamics of the environment. If it is difficult to predict the future and there is a possibility of failure, or new tasks arriving, agents will, by necessity, have to react to new information and replan online.

The Design-to-Criteria (DTC) [10, 7, 11, 9, 8] agent scheduler and the TÆMS task modeling framework [3] are our tools for addressing these requirements and achieving resource-bounded agent control. TÆMS provides agents with the framework to represent and reason about their problem solving process from a quantified perspective, including modeling of interactions between tasks and resource consumption properties. Design-to-Criteria performs analysis of the processes (modeled in TÆMS) and decides on an appropriate course of action for the agent given its temporal and resource constraints. Design-to-Criteria both produces resource-aware schedules for the agent, and, does this reasoning process online in a resource bounded fashion.

When DTC and TÆMS are used in an agent, typically, a domain-specific problem solver or planner translates its problem solving options into TÆMS, possibly at some level of abstraction, and then passes the TÆMS models on to the scheduler for analysis. It is also possible to use a TÆMS task structure library or pre-defined task structures in lieu of the domain expert – the scheduler will still custom tailor a course of action for the

agent that is appropriate for the current context.

Key features of the DTC scheduler / TÆMS dual:

- Quantified view of agent activities – all activities are characterized via discrete probability distributions in three dimensions: quality, cost and, duration. Uncertainty is inherent in the representation.
- Explicit representation of alternative different ways to perform tasks.
- Representation and quantification of interactions between activities.
- Representation of temporal and resource constraints, e.g., deadlines on tasks or components of task structures.
- Analysis of the different alternative courses of action for the agent in light of its goal criteria. For example, finding a fast and cheap solution when both time and money are constrained, or, finding a fast and expensive (but higher quality) solution when money is less constrained.
- Scheduling agent activities to meet deadlines and keep commitments or agreements made with other agents.
- Reasoning about the interactions between tasks and performing trade-off analysis of the costs/benefits of avoiding negative interactions or leveraging positive interactions.
- Evaluation of schedule uncertainty and planning to reduce uncertainty when desired. (For situations in which a mid-stream schedule failure leads to catastrophic system-wide failure, we have developed an offline variant of DTC that uses contingency analysis [6, 12] to explore and evaluate recovery options.)

We are currently working on a research-use release of the new real-time Design-to-Criteria scheduler. The scheduler can be used in any agent that can represent its activities via TÆMS and can enable the agent to evaluate its different options and meet temporal constraints, deadlines, resource limitations, or simply provide a means to customize agent control depending on the context. The release version will both operate in real-time and produce schedules that enable the agent to meet real-time deadlines. Information on the release is at:

<http://www.umcs.maine.edu/~wagner/dtc>

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