# Ensuring Reasoning Consistency in Hierarchical Architectures

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Ensuring reasoning consistency in agents employing hierarchical task decompositions can be difficult. We have identified two specific problems that result when hierarchical context changes during problem solving. First, the agent can be too responsive, taking an external act or making an internal derivation before higher context is fully elaborated. Second, the agent can fail to respond to a change in the context, leaving a local level "unsituated" with respect to the higher contexts. In both cases, an agent's assertions of knowledge in a local level can be inconsistent with the larger context, leading potentially to irrational behavior.

Previous methods for maintaining "cross-level" consistency have relied upon a combination of both architectural techniques and explicit knowledge. Architectural solutions preserve inexpensive knowledge design while knowledge-based methods compromise that advantage, requiring a knowledge engineer anticipate all situations in which inconsistency could arise. Thus, the goal of our work is to solve consistency problems *architecturally*, guaranteeing appropriate responsiveness within a level of the hierarchy to ensure reasoning consistency. Architectural solutions also solve a number of existing problems in run-time *compilation* (Goel 1991), thus enabling agents to learn execution knowledge that avoids decomposition overhead.

Our solution, hierarchical consistency (HC), consists of two parts which work together to ensure consistency. First, we have extended truth maintenance methods (Doyle 1979) to determine context dependencies for subtask processing. When a dependency is violated, the architecture responds by retracting dependent structure (Wray & Laird 1998). Second, we have synchronized activity among subtasks such that knowledge is asserted locally only when the higher context is stable. Together, these two methods allow locally non-monotonic, persistent and parallel assertions while ensuring that local problem solving is consistent with changes in the hierarchical context.

We have implemented the algorithms comprising HC in the Soar architecture (Laird, Newell, & Rosenbloom 1987) and applied HC to several domains, including a research version of TacAir-Soar (Tambe *et al.* 1995). We compared "HC agents" to previously-developed Soar agents in these domains. We summarize our experimental results as follows: 1) HC agents require less knowledge than the original agents, because no explicit across-level consistency knowledge is necessary; 2) knowledge access time in hierarchical consistency increases slightly, due to additional architecture processing; 3) total knowledge accesses decrease because less knowledge is needed; 4) overall task performance time often improves because fewer knowledge accesses offset the increase in cycle time; and 5) HC agents are more robust in situations unforeseen when they were designed. Additionally, hierarchical consistency solves the non-contemporaneous constraints problem (Wray, Laird, & Jones 1996), thus providing a structure for on-line compilation of dynamic, hierarchical execution knowledge. Based on these results, we believe hierarchical consistency provides efficient, general solutions for maintaining consistency in hierarchical architectures.



## References

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