MODELING DECISION MAKING IN COGNITIVE ARCHITECTURES

Bora Göral | 5337666

2024-2025 Q4
CSE3000 Research Project
Responsible Professor: Bernd Dudzik
Supervisor: Chenxu Hao
23.06.2025

INTRODUCTION

Cognitive architectures have been used to simulate everything from air traffic control decisions to playing chess, mimicking human thought so precisely that they can even model the time it takes for a person to respond to a traffic light. The aim of this study is to answer the research question

"How do heuristic-based, utility-based, and hybrid decision making strategies modeled in implementations that utilize cognitive architectures affect the capabilities of decision making models?" This research question entails the subquestions as follows:

- How do heuristic-based and utility-based decision making strategies improve the capabilities of decision making models?
- How does the hybridization of the strategy improve the capabilities of decision making models?

BACKGROUND

Decision making is a very important part in the implementations using cognitive architectures, acting as the mechanism by which systems select actions. These strategies entail different categories of approaches to decision making systems, which can be described as following:

Utility-based models calculate the expected value of different actions to support adaptive and goal-directed responses, but entails longer computation times.

Heuristic-based strategies offer fast, experience-based judgments, often at the expense of optimality, In situations where exhaustive analysis of the current situation is not feasible, implementations of these approaches can pay off in terms of successful decisions.

Hybrid strategies are also adopted, utilizing trade-offs between utility-based strategies and heuristic-based strategies. These approaches use both utility-based and heuristic based decision making modeling, in order to create models that excel in decision making problems in their domain.

METHODOLOGY

The methodology used for this study is systematic literature review. To ensure the transparency and reproducibility, PRISMA framework is used in collecting resources which entails Identification, Filtering (Inclusion/Exclusion) and Analysis of the relevant literature works studied. Figure 1 illustrates the workflow

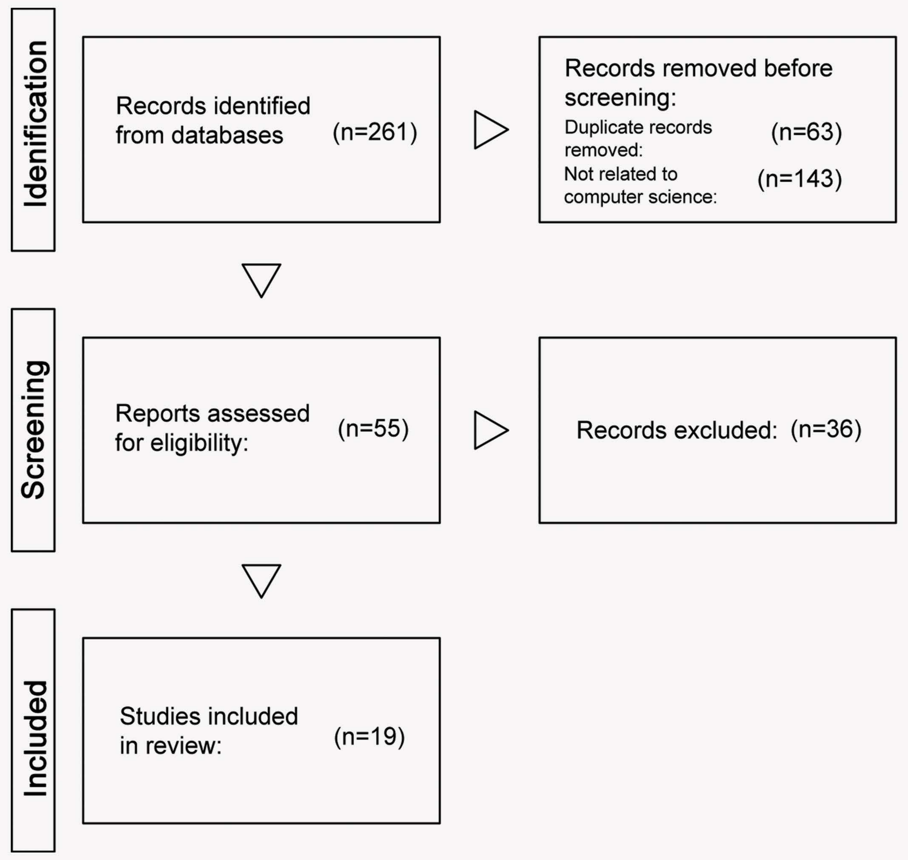

Figure 1: The PRISMA workflow used in the systematic literature review

UTILITY BASED APPROACHES

Zhou et al. (2025) examines a utility driven approach by offering hybrid lane changing strategy for autonomous vehicles, integrating the SOAR cognitive architecture with deep reinforcement learning (DRL). [1] The utility driven approach can be seen in Figure 2, where the computation-based model is introduced alongside the cognitive architecture to optimize decision making. Article claims that employing DRL **enhances the model's adaptability and making decision efficiency** in dynamic environments since it improves training by taking into account the importance of data samples and states.

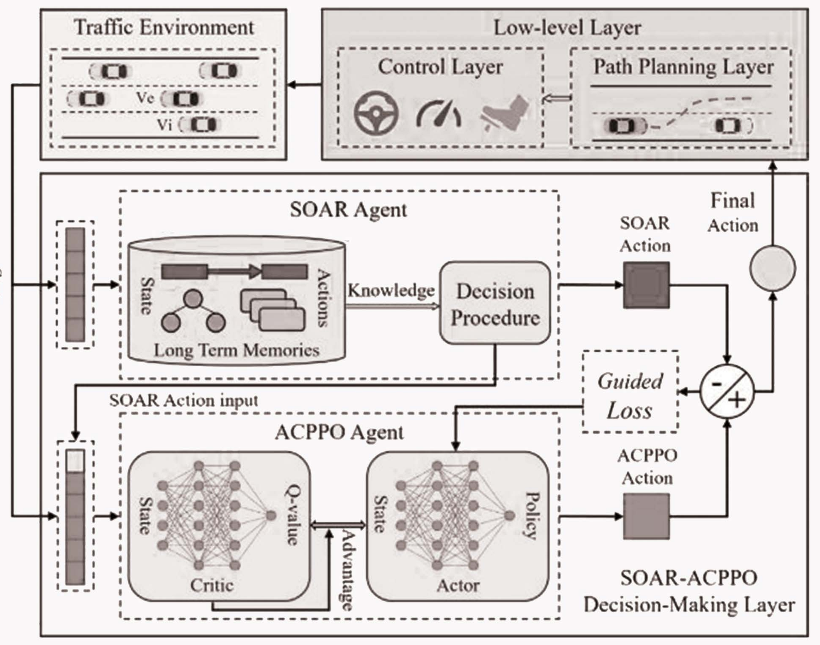

Figure 2: The architecture used in the implementation, introducing ACPPO Agent that is utility-driven alongside the SOAR architecture. [1]

HEURISTICS BASED APPROACHES

Heuristic techniques have taken center stage in the development of cognitive architectures in applications where quick, human-like decision making is crucial. Instead of using utility-based optimization strategies, these systems primarily rely on intuitive, rule based procedures.

Luo et al. (2022) use heuristic techniques with the SOAR-based cognitive architecture for mobile robot space exploration.[2] Figure 2 illustrates how the SOAR cognitive architecture is used with a heuristics-based decision making strategy, making the decision making faster based on the input from the surroundings.

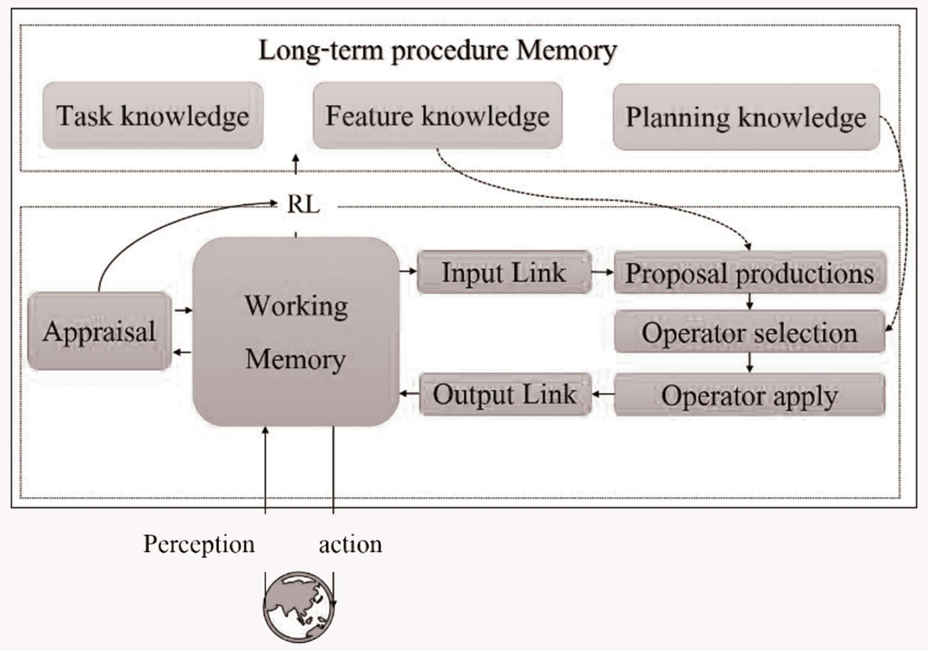

Figure 3: The SOAR based architecture of the decision making model, reactive to the heuristics detected from the environment [2]

HYBRID APPROACHES

Vilchis-Medina et al. (2021) create a hybrid strategy by integrating heuristic based Non-Monotonic Reasoning (NMR) with utility driven planning in autonomous marine robots. [3] Figure 3 briefly illustrates how the heuristic layer works with the utility layer, and how the hybrid strategy works with the functional layer.

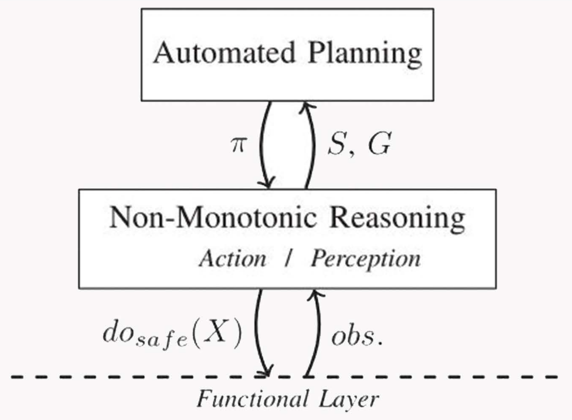

Figure 4: Illustration of the hybrid strategy used by the implementation of Vilchis-Medina et al. [3]

DISCUSSION

The hybridization of the decision making strategy is evident to be successful in the relevant literature works presented. It is also evident that *introducing a heuristic-based strategy on top of a utility-based one*, or vice versa, is beneficial for the optimization of the decision making process. In the light of these insights, it is evident that even though the hybridization of the decision making strategy is clearly increasing the robustness and accuracy of the decision making process, *such an hybridization often requires extreme specialization to niche domains. Consequently, the introduction of a heuristic-based strategy on an already existing utility-based strategy, or vice versa, is evidently increasing robustness for the specified domain.*

CONCLUSION

This systematic literature review was conducted to investigate and explain *how different decision-making strategies are implemented through heuristics-based, utility-based approaches, or how different blends of these approaches can be created to make hybrid models that maximize the performance.* After analyzing the relevant found literature, it was concluded that even though utility-based and heuristic-based approaches have their own strengths, implementations that leverage a hybrid approach are *more capable in decision making, with a trade off of these models being specialized to their niche domains.*

REFERENCES

[1] R. Zhou, H. Cao, J. Huang, X. Song, J. Huang, and Z. Huang. Hybrid lane change strategy of autonomous vehicles based on SOAR cognitive architecture and deep reinforcement learning. Neurocomputing, 611, 2025.
[2] F. Luo, Q. Zhou, J. Fuentes, W. Ding, and C. Gu. A Soar-Based Space Exploration Algorithm for Mobile Robots. Entropy, 24(3), 2022.
[3] Jose-Luis Vilchis-Medina, Karen Godary-Dejean, and Charles Lesire. Autonomous Decision-Making With Incomplete Information and Safety Rules Based on Non Monotonic Reasoning. IEEE Robotics and Automation Letters, 6(4):8357–8362, October 2021.