Externalizing Internal State

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Current autonomous robots that are highly reactive are not significantly intelligent and the robots that are significantly intelligent are not sufficiently reactive. The previous research has concentrated on modifications to internal computational structures of robots, ignoring the modifications to external environments (which can preserve both intelligence and reactivity). This work is the first to formalize the modification of an environment that externalizes the internal states. Since some reactive robots exhibited problems like deadlocks and myopic functionality, hybrid architectures with modules like planners began to be explored. In this transition, the potential of reactivity went largely unexamined. Making a robot more reactive essentially means transforming its internal state into an external state that can be extracted through perception. Some internal states have to be updated whenever external world changes and externalizing these states eliminates such updates, since the most recent information is available in the world itself. Hence there are reasons for robots to be more reactive.

Externalization of state is common in pragmatic life. For example, in a buffet restaurant where customers themselves serve food, but drinks are served by waiters, all the customers who have glasses on their tables can be considered as having been served. In the mobile robot competitions of the American Association of Artificial Intelligence, the rocks in the event of finding life on Mars were painted black to aid in visual recognition. Black paper indicating the danger zones was spread out on a part of the floor. The doors of the lander were painted blue and orange. The life forms consisted of balls and cubes of bright colors. However this kind of environmental modification has not been formally incorporated into the architectures of autonomous robots. As a result, it has been viewed more as a low level fix rather than as a paradigm that deserves a separate investigation. Our work bridges this gap.

The states are externalized through environment modifiers called "markers". These markers are semantically equivalent to the internal states that they externalize, e.g. a blue strip of paper (a marker) on the door of a refrigerator can be used to recognize the refrigerator and thus the presence of the blue strip is equivalent to the presence of the refrigerator (when these strips are put only on the refrigerators). An introduction of markers requires a modification to the behaviors' stimuli, so that the markers can play an active role in the functionality of a robot. Markers can be kept only on certain objects that meet a criterion (local externalization) or on all objects that meet the criterion (global externalization). Markers can also be used to specialize stimuli of behaviors (to avoid triggering of the behaviors on unwanted occasions). In [1], we have handled these technical challenges in formalizing the state externalization and defined various metrics to capture properties of the markers. The "strength" of a marker captures the extent to which one can exploit the marker in externalizing state. The time required to recognize a marker is a measure of its "efficiency". The relationships between logical formulae describing the markers can be used to test the "redundancy" of a set of markers.

We have also addressed [1] the problem of automated synthesis of markers. It may be desirable for certain chains of behaviors to execute after certain other chains of behaviors, since this fulfills some goals of interest to a user. Since there is no explicit representation of goals in a purely reactive robot, such an ordering of behaviors is hard to guarantee. The chains of behaviors may not execute in the desired order, either because the relevant stimuli are absent or are not strong enough to be detected. Given two chains of behaviors, what marker should be introduced in the environment to join these chains? We have proposed a procedure to compute markers that concatenate the chains of behaviors *through the external world*, rather than generating them through internal reasoning, as in the classical planners. This illustrates the utility of markers in the composition of more complex reactive behavior. One may be concerned that a frequent change in the tasks of a user will require a significant user intervention for a frequent introduction and removal of markers or a change in the definitions of the robot's behaviors. To prevent this, we have shown how the markers can be automatically introduced and removed, with the help of a marker management module.

[1] **Mali A. D.**, Externalizing Internal State, Technical Report TR-98-016, Dept. of Computer Science, Arizona state university.