Research Statement
Evolutionary, Hybrid, PDE-ODE Planners

by
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Utility and meaning in the behavior of an agent are highly contingent on the agent's ability to semantically embed its actions in the context of its environment. Such an ability is cloned into an agent using a class of intelligent motion controllers that are called motion planners. The applications of motion planning are numerous. They include, among other things, autonomous mobile robots, animation, computer game design, intelligent manufacturing and holonic systems, scheduling, automated reconnaissances, operations research, network switching, and self-guided systems in general. The design of abstract motion planning paradigms that can be configured to work in a multitude of situations is the center piece of research activities in artificial intelligence (AI), and automation. To the best of my knowledge, for the past four years, more than 40% of the papers published in the IEEE International Conference on Robotics and Automation (ICRA), the flagship of the IEEE Robotics and Automation Society, are in planning.

Planning has been traditionally dominated by classical AI, geometric-based, search techniques. The fact that the search for a solution for the general planning problem was proven to be PSPACE-COMPLETE, suggesting an exponential lower bound on complexity, widely opened the door for evolutionary AI techniques to be used in this area. A multitude of evolutionary AI tools have been applied for the design of planning systems. Among such tools: reinforcement learning, genetic algorithms, neural nets, fuzzy logic, Bayesian belief networks, and hybrids of these techniques. The operational requirements modern systems impose on planners can be quite stringent. For example, a planner may be required to:

1- successfully operate in the face of incomplete information,
2- take into account the aging of information in deriving successful plans,
3- tackle, in a decentralized manner, large scale systems,
4- integrate the continuous-time nature of control, with the discrete time nature of on-line information acquisition and command.
Such demands kept the search for new planning paradigms highly active.

My research explores the use of a new area in evolutionary AI called artificial life (AL). The AL approach is a self-organizing, bottom-up approach to behavior synthesis. It's a major departure from the traditional approach to behavior synthesis which sequentially uses the steps: represent, reason, generate action for behavior synthesis (figure-1) . Instead, a planner with an AL-based behavior selection mechanism starts from a "seed" belief about its environment. This belief is coupled to an experiential stage that requires the sensors to continuously engage the environment. A feedback is then applied to condition belief by experience. The control action is the outcome of this process (figure-2).

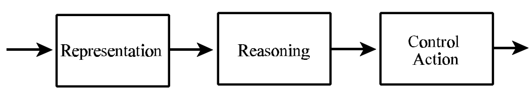

Figure-1

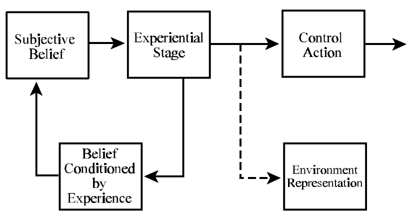

Figure-2

In an AL system, the members of the group of basic planning agents, who through synergetic interaction generate the desired planning action, are equipped with elementary, *a priori* known planning capabilities called the Geno-type of behavior (G-type). On the other hand, the overall plan that can be used for governing the behavior of the whole group evolves in space and time as a result of the interpretation of the G-type in the context of a particular environment. The whole control action is called the Pheno-type (P-type) of behavior.

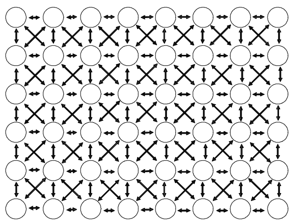

Figure-3

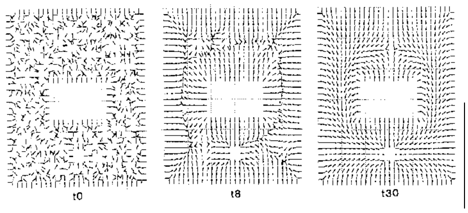

Figure-4

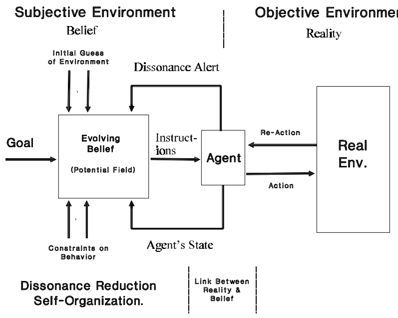

Figure-5

Figure-3 shows a collective of micro-agents who through synergetic interaction generate the plan in figure-4. The plan acquires its final form by evolving in space and time to guide an agent to a target zone while avoiding obstacles. Based on the AL approach, a new class of intelligent controller called evolutionary, hybrid, pde-ode controllers (EHPC) was developed (figure-5). An EHPC system consists of two parts:

1- a discrete time-continuous time system to couple the discrete-in-nature data acquisition process to the continuous-in-nature action release process,
2- a hybrid, PDE-ODE controller to convert the acquired data into in-formation that is encoded in the structure of the differential control action group.

EHPC systems have been applied to challenging problems in autonomous mobile agents, traffic management, and combinatorial optimization. They were used to bypass the classical, and somehow problematic, high-level, low-level control arrangement to plan motion for a robot manipulator. Instead, an EHPC-based single module is suggested to interface the data from the environment, constraints on behavior, and target information to the motion actuators of the robot. EHPCs were also applied to the challenging problem of finding a constrained trajectory linking a starting point to a terminal one for an agent of arbitrary, unknown shape, working in an environment with arbitrary unknown clutter. Although very little information is available to the planner, it can successfully lay a path to the target from the first attempt (first attempt completeness). Subsequent attempts only enhances the quality of the path. The approach was also applied to the problem of decentralized planning for large scale traffic systems. A provably-correct, non-blocking controller, with a complexity that is linear in the number of agents planner was developed. Recently EHPCs were used in developing a planner that can integrate both spatial and directional constraints in action generation. The planner was found to have numerous applications in areas like traffic management, operations research, etc. A derivative of the planner was also used to suggest an algorithm for the important problem of finding an optimum path on a directed graph. The algorithm has linear complexity in the number of vertices of the graph.

I strongly believe that the results obtained till now barely scratch the surface of what the EHPC planning paradigm is capable of. Near future results are expected to be in the area of planning with aging information.