# Technical Status Report and Project Summary July, 2003

DARPA Agent Based Computing (ABC) Program, Taskable Agent Software Kit (TASK)

PI: Lee Spector, Hampshire College

Project: Multi-type, Self-Adaptive Genetic Programming for Complex Applications

## Project URL: http://hampshire.edu/lspector/darpa-selfadapt.html

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## General

Please see the project web page (URL: http://hampshire.edu/lspector/darpa-selfadapt.html) for a description of the project and a list of publications and related materials. Note that several of the publications related to this project have dedicated web pages, several including movies of developed systems, source code, etc. For one recent example (which includes movies), see:

http://hampshire.edu/lspector/gecco2003-collective.html

## Personnel

• Hired Jon Klein (author of the BREVE simulation environment) as research assistant for the 2003-2004 school year. In the previous year Jon worked part time on the project and part time as an Instructor in the Hampshire College School of Cognitive Science.

• The PI (Spector) received the highest honor bestowed by the National Science Foundation for excellence in both teaching and research, the NSF *Director's Award for Distinguished Teaching Scholars*. A press release is avaliable at http://www.hampshire.edu/cms/index.php?id=2249. Research on the DARPA TASK effort was featured (and credited to DARPA) in the application for this award and in related presentations at NSF.

## Specific Accomplishments Since July, 2002

The following items are listed in roughly reverse chronological order.

• Developed an integrated development/analysis plan for smart (evolved) UAV simulation with the University of Massachusetts TASK group, oriented toward a TASK-wide demo in the summer of 2004. Hampshire College will provide and enhance the BREVE simulation environment as necessary. The University of Massachusetts will build the UAV simulation within BREVE to correspond to the OEF scenario as specified by the TASK group as a whole (principally by the Metron and Alphatech groups). Hampshire College will enhance the functionality of the UAVs via genetic programming technologies developed as part of this effort. The University of Massachusetts will analyze the resulting system behavior using their Proximity relational knowledge discovery system.

• Began work on revising and further standardizing the specification for the Push programming language for evolutionary computation, which underlies much of the work in this effort. There now exist at least five distinct versions of Push, implemented by different people in three base languages (Lisp, C++, and Java), and standardization is necessary to ensure the coherence of the overall effort. Chris Perry (on the Hampshire College faculty and author of the C++ version, which has also been incorporated into the BREVE simulation environment) is helping with this effort.

• Demonstrated the emergence of collective behavior in two versions of the SwarmEvolve system. In particular we demonstrated the emergence of a form of multicellular organization in evolving populations of agents based on a traditional flocking algorithm (in SwarmEvolve 1.0), and the emergence of altruistic feeding behavior in a system that is considerably less constrained (as the agents are controlled by evolved computer programs). This latter system (SwarmEvolve 2.0) provides significant new avenues of study by allowing for agents of arbitrary complexity to evolve within complex, dynamic worlds (see below). A paper on this work will be published/presented at the Genetic and Evolutionary Computation Conference (GECCO) in Summer, 2003. Paper title: “Emergence of Collective Behavior in Evolving Populations of Flying Agents”; authors: Lee Spector and Jon Klein. URL: http://hampshire.edu/lspector/gecco2003-collective.html

• Participated in the 8th International Conference on the Simulation and Synthesis of Living Systems (ALife 8). Spector presented three papers and Klein presented one:

> Spector, L. 2002. Adaptive populations of endogenously diversifying Pushpop organisms are reliably diverse. In R. K. Standish, M. A. Bedau, and H. A. Abbass (eds.), Proceedings of Artificial Life VIII, the 8th International Conference on the Simulation and Synthesis of Living Systems , pp. 142-145. Cambridge, MA: The MIT Press. http://hampshire.edu/lspector/pubs/spector-alife8.pdf

Klein, J. 2002. breve: a 3D simulation environment for the simulation of decentralized systems and artificial life. Proceedings of Artificial Life VIII, the 8th International Conference on the Simulation and Synthesis of Living Systems. Cambridge, MA: The MIT Press. http://www.spiderland.org/breve/breve-klein-alife2002.pdf

Spector, L., and J. Klein. 2002. Evolutionary Dynamics Discovered via Visualization in the BREVE Simulation Environment. In Bilotta et al. (eds), Workshop Proceedings of the 8th International Conference on the Simulation and Synthesis of Living Systems , pp. 163-170. Sydney, Australia: University of New South Wales. http://hampshire.edu/lspector/alife8-visualization.html (web page includes full text and also graphics/animations)

Spector, L., and J. Klein. 2002. Complex Adaptive Music Systems in the BREVE Simulation Environment. In Bilotta et al. (eds), Workshop Proceedings of the 8th International Conference on the Simulation and Synthesis of Living Systems , pp. 17-23. Sydney, Australia: University of New South Wales. http://hampshire.edu/lspector/alife8-music.html (web page includes full text and also graphics/sound)

• Participated in the Sixth International Conference on Quantum Communication, Measurement, and Computing (QCMC). Our contribution includes discoveries made by our genetic programming system, about the communication capacities of quantum gates. Publication:

Spector, L., and H.J. Bernstein. 2002. Communication Capacities of Some Quantum Gates, Discovered in Part through Genetic Programming. To appear in Proceedings of the Sixth International Conference on Quantum Communication, Measurement, and Computing (QCMC), to be published by Rinton Press. (prepress version with additional figures: http://hampshire.edu/lspector/pubs/spector-QCMC-prepress.pdf )

• Significantly advanced the integration of the Push programming language for evolutionary computation into the BREVE 3D simulation environment:

- C-language Push interpreter plugin (original was Lisp, Java versions by others).
- Push interpreter per BREVE agent.
- BREVE agents can perform/evolve arbitrary computations.
- Push/BREVE callbacks implement sensors/effectors.
- XML specification for Push standardization.

• Building on the enhanced Push/BREVE integration, produced a major upgrade to the SwarmEvolve system (now version 2.0):

- Behavior (including reproduction) controlled by evolved Push programs.
- No hard-coded species. Color, color-based agent discrimination controlled by agents.
- Energy conservation.
- Facilities for communication, energy sharing.
- Enhanced user feedback (e.g. diversity metrics, agent energy determines size).

• Implemented and experimented with alternative models for target dynamics as discussed in the OEF working groups. In particular, added "random walk" dynamics and clarified existing "linear drift" dynamics. Additional dynamics models can be rapidly integrated.

• Formalized measures of agent diversity, using the formula:

$$diversity(P) = \frac{\sum_{i \in P} \frac{|\{j \in P : \Delta(i,j) > \delta\}|}{|P|-1}}{|P|}$$

This is the average, over all agents, of proportion of remaining population considered "other" by some distance metric (big delta) and some threshold (little delta). Considered genotypic instances (based for example on code, code size), phenotypic instances (based for example on color, behavior, signals), and reproductive/developmental instances. Discussed relations to "entropy" based measures with Jim Crutchfield of the SFI TASK group.

• Corresponded with the University of Massachusetts TASK group on the development of a BREVE-based UAV simulator, for use in conjunction with their Proximity data mining system. The UMass group has now completed construction of a first version BREVE UAV simulator and we are planning further collaboration.

• Completed first integration of an "Elementary Adaptive Module" (EAM), as developed by the MIT/BBN TASK group, into the SwarmEvolve system:

- Now: single EAM per agent.
  Potentially: any number, any architecture.
- Now: servo EAM only.
  Potentially: all EAM types.
- New Push instructions: setServoSetpoint, setServoGain, servo.
- Initial indications: high utility.

• Prepared presentation for Miami TASK PI meeting. URLs for presentation slides:

- Keynote (Apple) format: http://hampshire.edu/lspector/TASK-Feb-2003.key.sit
- PDF format: http://hampshire.edu/lspector/TASK-Feb-2003.pdf
- Powerpoint format: http://hampshire.edu/lspector/TASK-Feb-2003.ppt

• Enhanced SwarmEvolve system for real-time evolution of goal-directed swarms of agents in several ways, including:

- Food consumption/growth
- Birth near mothers
- Corpses
- Food (target) sensor, inverse square signal strength
- GUI controls and metrics
- Feeders (targets) redesigned, increased in number

These enhancements, which increase both the complexity of the system and its correspondence to the OEF challenge problem, constitute "SwarmEvolve 1.5."

• Conducted preliminary investigation of SwarmEvolve food supply (a metric related to surveillance coverage in the OEF challenge problem) as a function of environmental stability and mutation rate. Preliminary data can be summarized as follows:

| | | MUTATION | | |
|---|---|---|---|---|
| | | low | med | high |
| STABILITY | low | 54% | 17% | 18% |
| | med | 43% | 12% | 10% |
| | high | 55% | 14% | 12% |

Lower numbers here indicate better evolved coverage. These data confirm some expectations (e.g. that adaptation suffers if stability or mutation rates are too low) but also points to some interesting areas for further study (e.g. the observation that too *much* stability impairs long-term adaptation because the system to an inflexible strategy that appears good in the short term. Investigation of this phenomenon is ongoing.

• Presented several of the items above to TASK workshop attendees (Santa Fe Institute, October 9-11) and other visitors (some from the co-located MICA meeting).
URLs for presentation slides:

PDF format: http://hampshire.edu/lspector/TASK-Oct2002-Spector.pdf
Powerpoint format: http://hampshire.edu/lspector/TASK-Oct2002-Spector.ppt

• Continued discussions with University of New Mexico TASK group, including an October 9 visit to the Albuquerque campus (in part to participate in the thesis defense of TASK participant Terry Van Belle).

• Produced first version of a C-language Push interpreter integrated into the BREVE simulation environment, a critical step in the eventual integration of the work on multi-type, self-adaptive genetic programming (Push, PushGP, and Pushpop) with the work on real-time evolution of goal-directed swarms of agents (in the BREVE simulation environment).

• Completed a book review related to quantum computing aspects of the project. (The search for quantum algorithms provides objectively hard problems for testing the developed genetic programming techniques.):

> Spector, L. 2003. Book Review: The Quest for the Quantum Computer, by J. Brown. To appear in Genetic Programming and Evolvable Machines (Kluwer Academic Publishers).

## Current Plans

• Continue collaboration with University of Massachusetts TASK group on UAV simulation in BREVE, working toward the TASK-wide demo in the summer of 2004. Use genetic programming techniques to enhance the performance of the U. Mass UAVs.

• Continue investigation of the emergence of collective behavior and of MIT/BBN Elementary Adaptive Modules in SwarmEvolve. Enhance support for Elementary Adaptive Modules and evaluate their impact on evolvability and adaptation.

• Investigate the addition of morphology evolution in SwarmEvolve or a successor system. Upgrade existing experimental framework to use full physical simulation with evolved physical controllers.

• Develop software and protocols for distributed simulation/evolution runs on high-performance computer clusters.

• Use the experimental framework already developed (SwarmEvolve) to characterize conditions under which coordinated behavior is adaptive.

• Disseminate research results at conferences and in publications.