DARPA/TASK Project

Evolution of UAV Surveillance Strategies and Additional Significant Results of Multi-Type, Self-Adaptive Genetic Programming

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

Outline

- Project highlights
- Evolution of UAV surveillance strategies
- Coevolution of team strategies in a complex, dynamic 3D game (Quidditch)
- Human-competitive results in automatic quantum computer programming
- Available technologies

Project Highlights (1)

- Development of the Push programming language for evolutionary computation.
- Development of the PushGP multi-type, self-adaptive genetic programming system.
- Development of the Pushpop autoconstructive evolution system.
- Development of the Breve simulation environment for complex agent-based systems.
- Integration of Push/PushGP with Breve.
- Integration of PushGP/Pushpop with MIT/BBN-derived transport network agent simulator.
- Integration of Elementary Adaptive Modules into a framework for the evolution of multi-agent systems.
- Demonstration of the use of servos in evolved agent architectures.

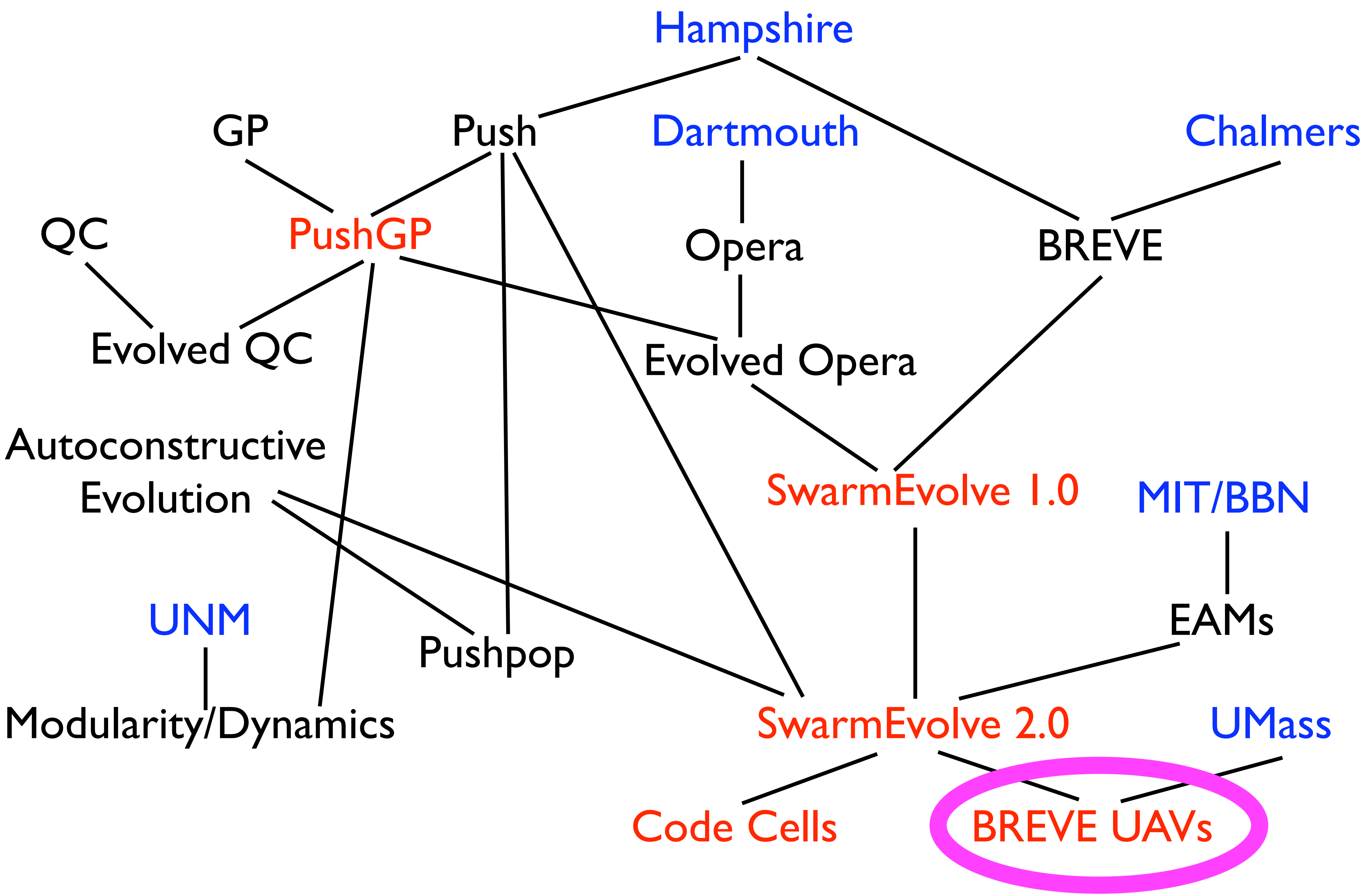
Project Highlights (2)

- Demonstration of the utility of a genetic algorithm in conjunction with the Dartmouth 3D Opera problem simulator.
- Evolution of transport network control agents.
- Demonstration of the evolution of modularization in PushGP.
- Demonstration of the efficacy of size-fair genetic operators in PushGP.
- Development of diversity metrics in PushGP and Pushpop.
- Demonstration and extension of the "Van Belle/Ackley effect" (UNM).
- Demonstration of reliable auto-diversification in the Pushpop autoconstructive evolution system.
- Discovery of new quantum algorithms using the PushGP genetic programming system.

Project Highlights (3)

- Evolution of goal-directed 3D swarms driven by parameterized flocking equations (in SwarmEvolve 1.0).
- Evolution of goal-directed 3D swarms driven by open-ended programs in a Turing complete representation (in SwarmEvolve 2.0).
- Demonstration of the emergence of collective behavior and multicellular organization in 3D swarms (in SwarmEvolve 1.0 and 2.0).
- Analysis of the relations be environmental stability, genetic stability, and adaptation (in SwarmEvolve 2.0).
- Co-evolution of teams players for a complex, dynamic, 3D game.
- Production of course materials using multi-agent simulations (WUB World, Capture the Flag).
- Evolution of high-performance surveillance strategies for UAVs.

Research/Demo Graph



UMass Slide

(HC notes)

UAV Collaboration

PROXIMITY	Behavior Analysis	UMass
Push/Evolution	Adaptive UAV Behaviors	Hampshire College
OEF	UAV Simulation & Core UAV Behaviors	UMass
	Breve	Hampshire College

Technologies

- Iterative evolution/design development methodology.
- breve: scriptable 3d simulation environment.
- Push: evolvable, embeddable multi-type programming language.
- PushGP: self-adaptive genetic programming for automatic generation of Push programs.
- UAEvolve: a breve simulation that evolves Push programs for UAV control, developed jointly by UMass and Hampshire College.

Evolved Surveillance Strategy

- Push code:

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-12.1904 ) ( 0.0243,0.4125,-0.0652 FLOAT.RAND CLOSESTTARGET SETTIMEMARK ( 1 )  )  )
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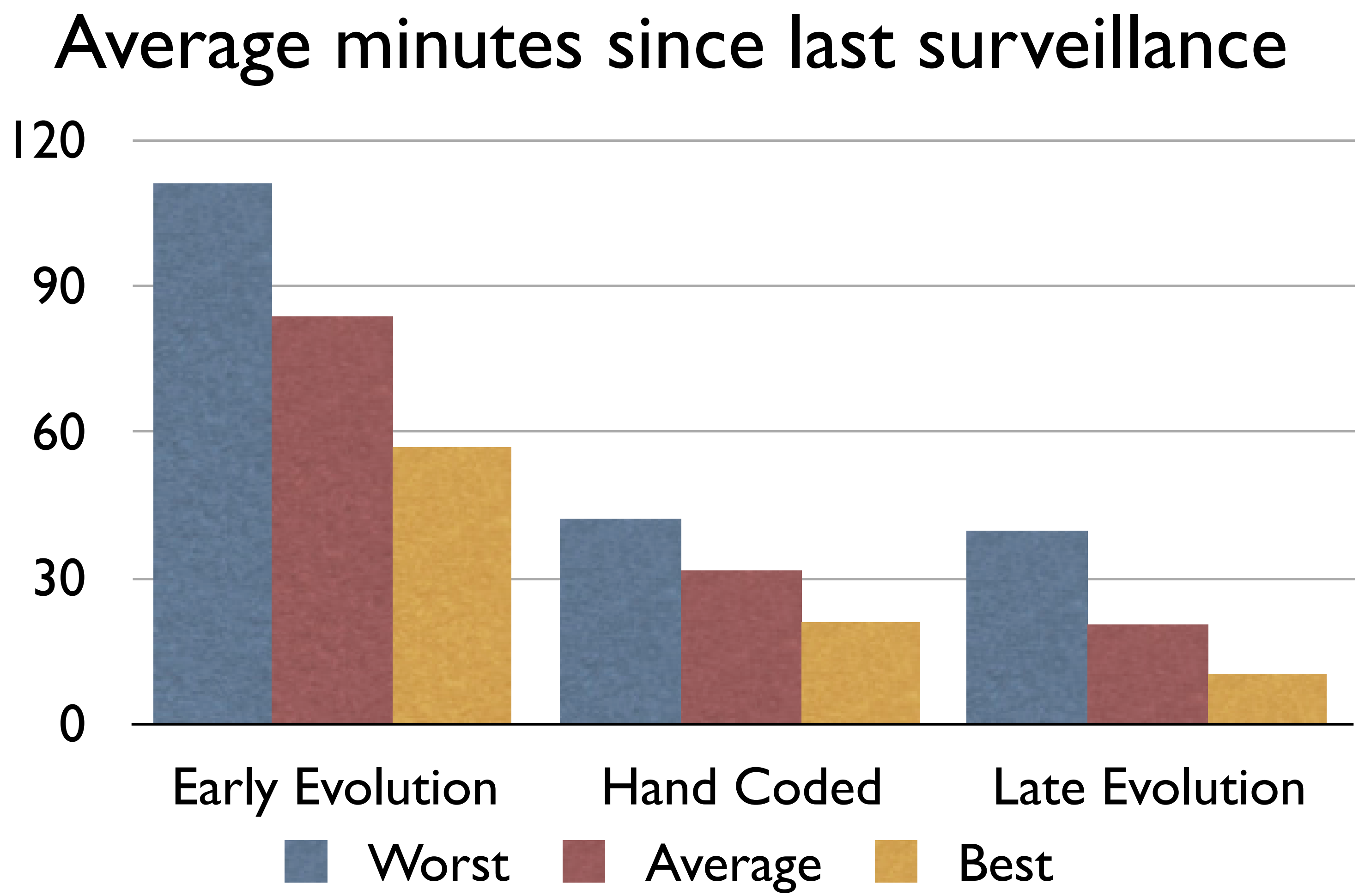
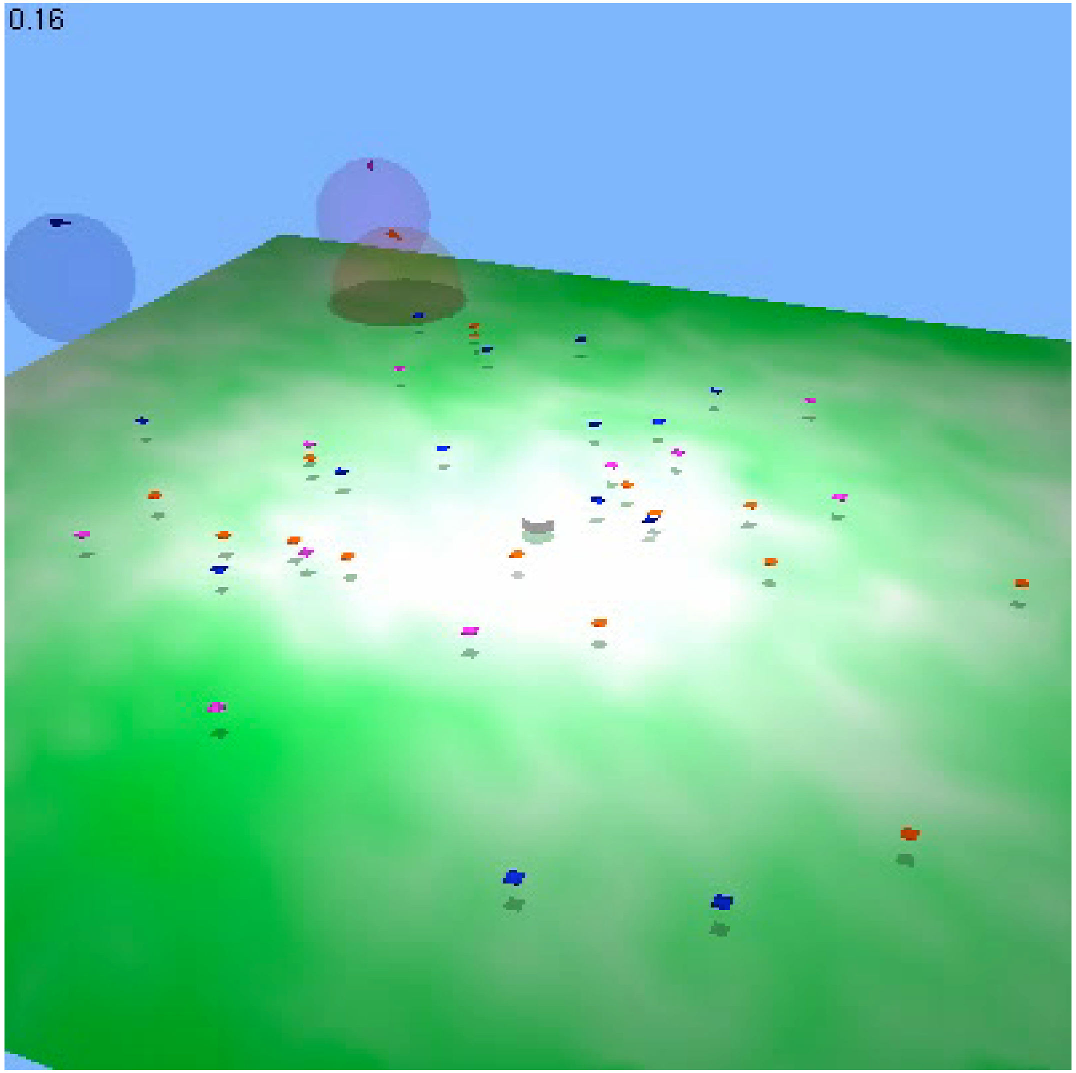
- Filters out lost targets and those deemed inaccessible due to a threat area.
- Ignores recently seen targets.
- Goes to the closest remaining target.
- Behavior appears disorganized at first, but after a short time, an “emergent” tour is established.
- Robust in the face of unexpected target behaviors and threat areas.

Performance



- "Hand Coded" strategy produced by UMass team: tour-based, go to nearest accessible target not yet seen in the current tour, local search for missing targets.
- "Early Evolution" strategy: closest target vector + random vector.
- 10 trials/method, 50 simulated minutes/trial, data collected at ends of trials.
- Unseen targets: 150 minute penalty.

Evolved Strategy



- Small domes = sensor horizons.
- Large dome = threat area.

Coevolution of Team Strategies in a Complex, Dynamic 3D Game

Goal: Explore evolution of control and adaptation in dynamic, heterogeneous environments.

"Quidditch," invented by J.K. Rowling in her series of Harry Potter books.

Like a mixture of basketball and soccer, but: flying broomsticks, four player types, three ball types (two of which are enchanted and semi-intelligent)

Quidditch as an AI challenge problem was proposed by Spector, Moore and Robinson at GECCO 2001 (LBP). Work presented here presented by Crawford-Marks, Spector, and Klein at GECCO 2004 (LBP).

Quidditch Features

- Richly heterogeneous—player roles, balls themselves are active/intelligent.
- Richly 3-dimensional—flying game, full use of the third dimension.
- Extensible—rules not uniquely determined by the Rowling books; physics based on magic spells so the sky is the limit!
- Beyond human experience—unlike soccer, few intuitions about strategy to bias methods.

Balls

- Quaffle: large red ball, not enchanted. Goals are scored by throwing the Quaffle through one of three hoops at either end of the pitch. A goal is worth 10 points.
- Bludgers: two iron balls, enchanted to indiscriminately attack players.
- Golden Snitch: walnut-sized ball with translucent wings. Fast and agile, tries to avoid the Seekers. Catching the Snitch rewards the team with 150 points and ends the game.

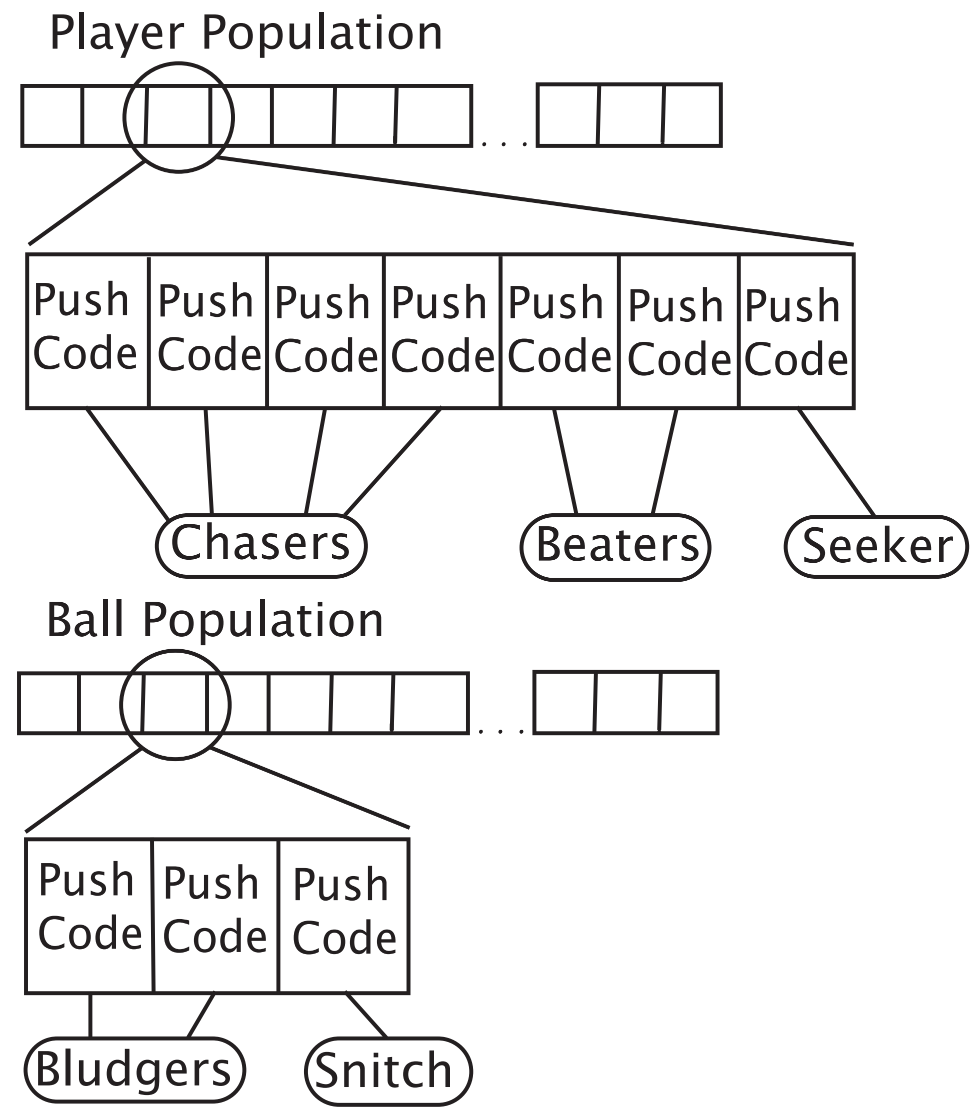
Players

- Chasers: analogous to soccer forwards. Can catch and throw the Quaffle.
- Beaters: defend teammates from Bludgers by whacking them with bats.
- Seekers: one per team. Only objective is to catch the Golden Snitch.
- Keepers*: analogous to soccer goalies. Same abilities as Chasers.

Technologies

- breve: scriptable 3d physical simulation environment.
  http://www.spiderland.org/breve
- Push: evolvable, embeddable multi-type programming language.
  http://hampshire.edu/lspector/push.html
- Coevolutionary genetic programming.

Representations



Fitness

Players:

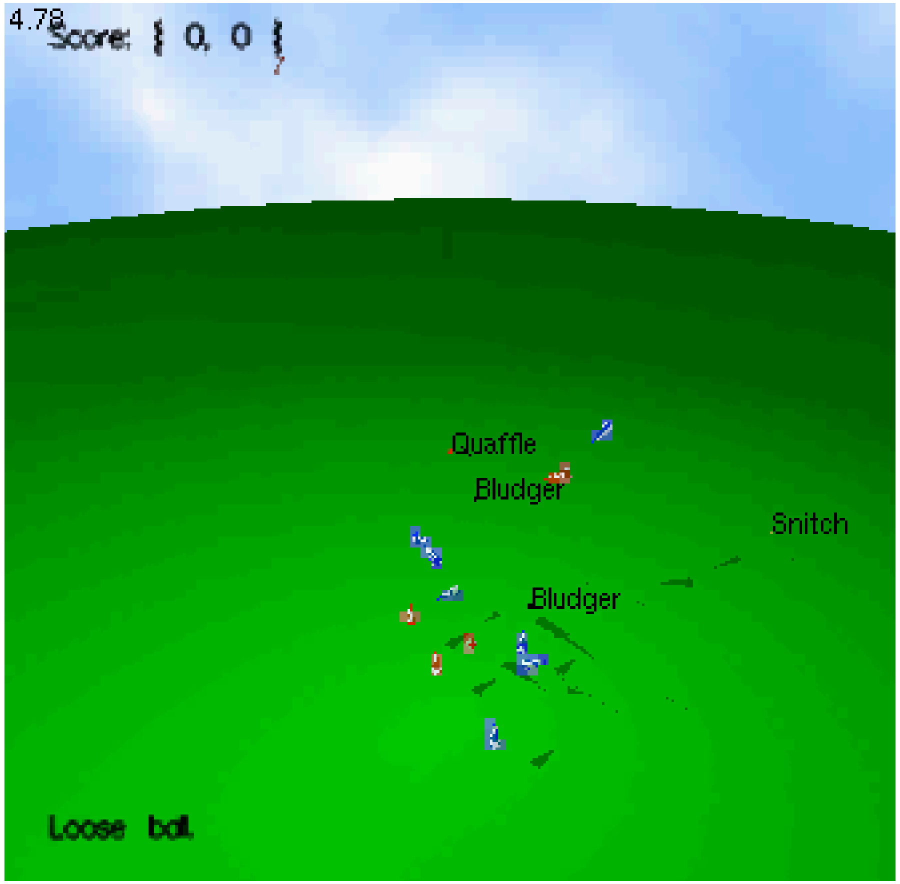
- Small bonuses for moving, catching/throwing the quaffle, possession time, beating bludgers.
- Large bonus based on final score (goals plus Snitch bonus) and score difference.

Balls:

- Large penalty for Snitch being caught.
- Small bonuses for each Bludger collision with a non-Beater player.

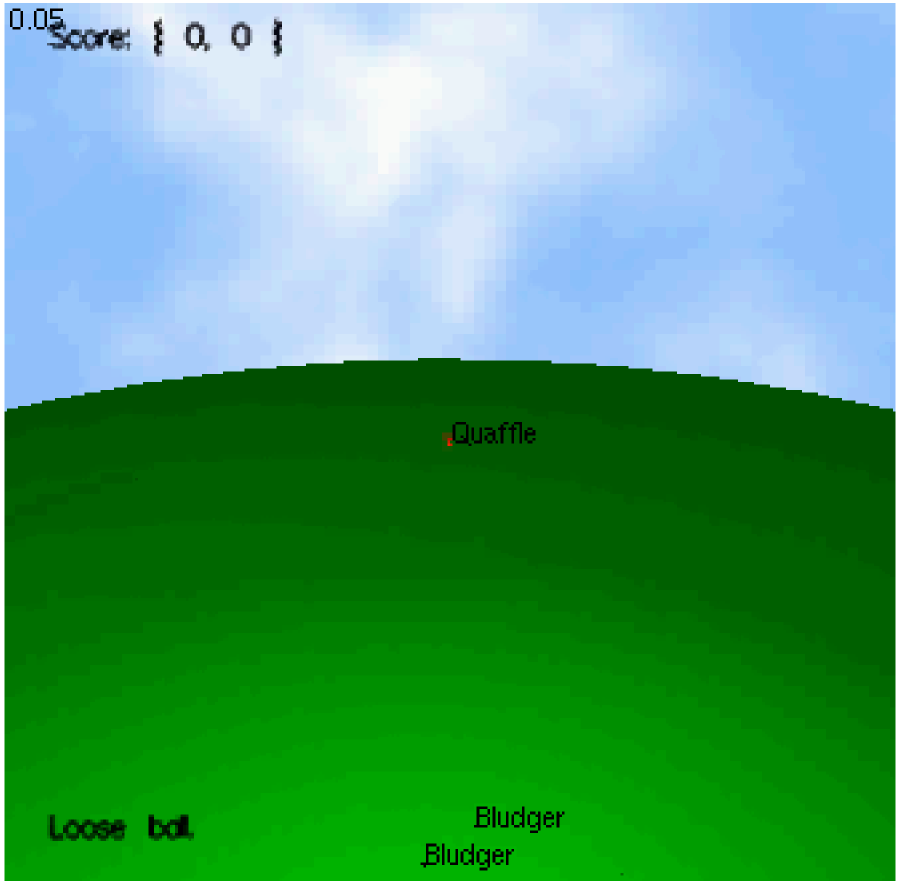
Results

- Initial teams were dumb
- Best of Generation 0 usually had a Seeker that would chase the Snitch



Results

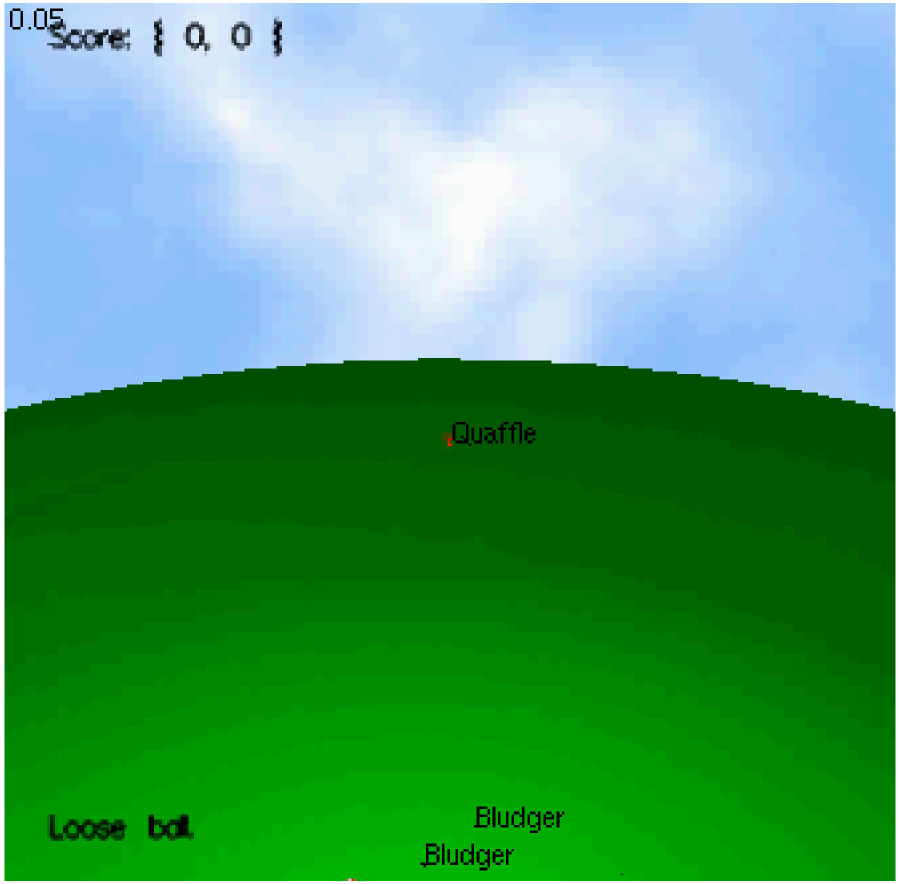
- By Generation 20-30, balls had evolved very good behaviors.
- Bludgers relentlessly attacked nearby players
- Snitches are nearly uncatchable



Results

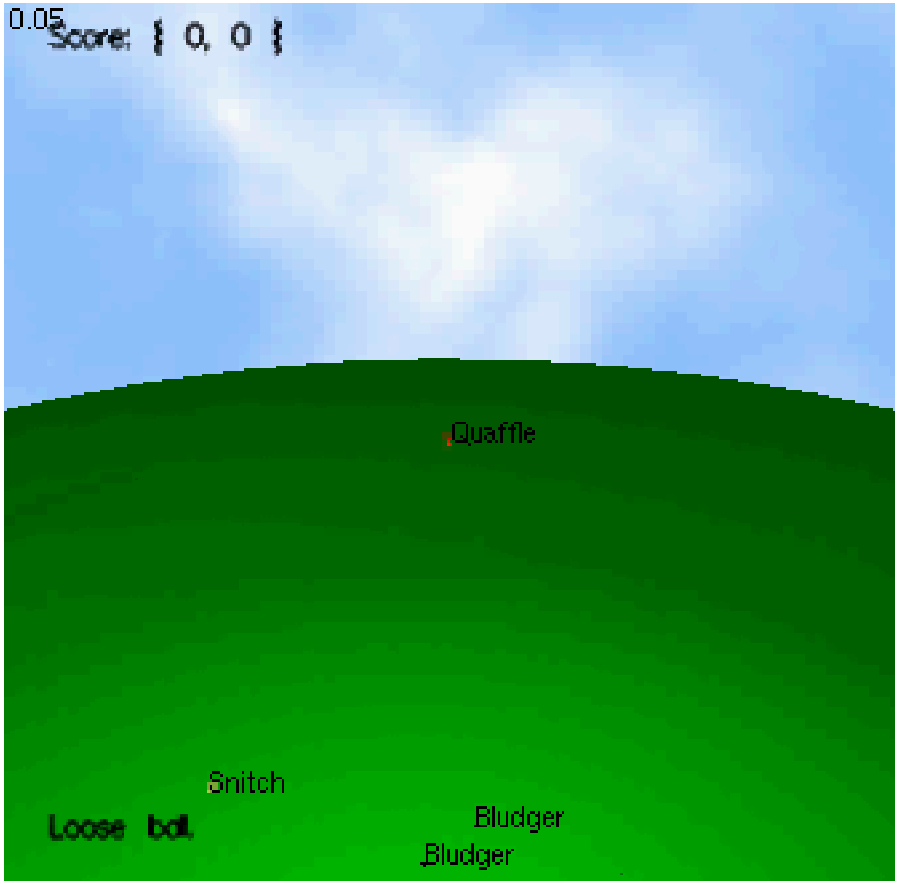
- Because of the difficulty of catching the Snitch, players begin to evolve goal-scoring behavior around generation 20-30

- Chasers employ a very simple chase-and-throw strategy



Results

- By generation 50, the chase-and-throw behavior has propagated to all Chasers, and teams play "kiddie-quidditch"
- Selective pressure on Beaters and Seekers is very small, causing genetic drift



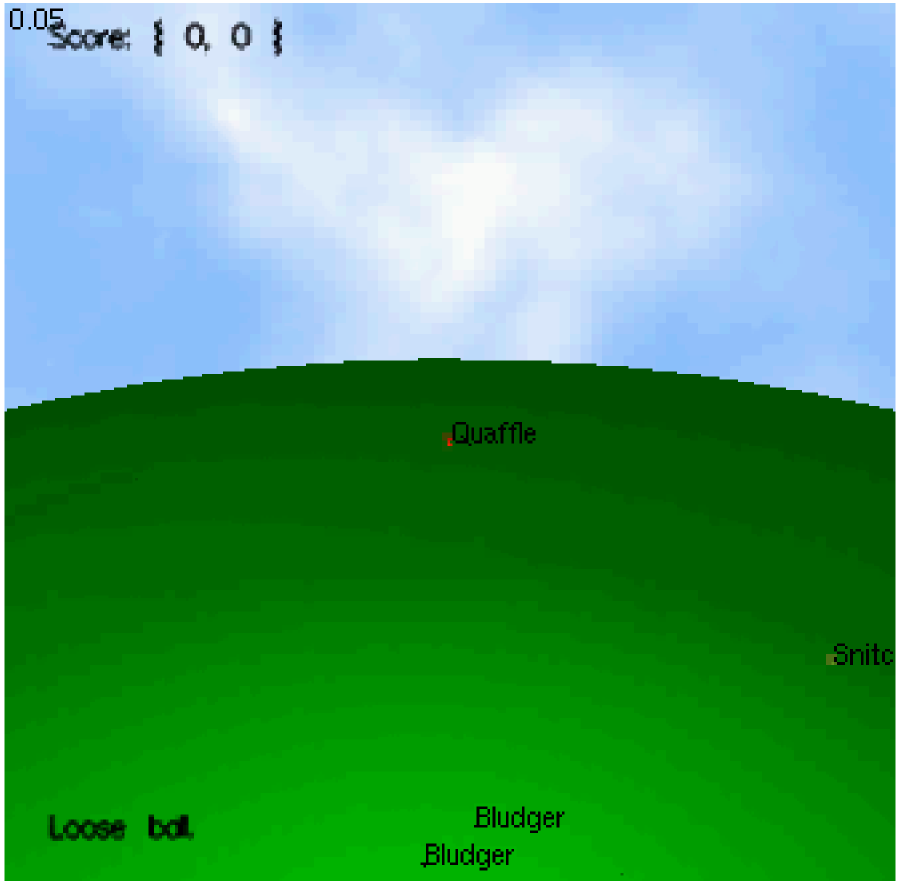
Results

- At the end of latest runs (generation 90+) the beginnings of defensive behavior appear to be emerging.

- See more at:

http://hamp.hampshire.edu/~rpc01/vww.html

http://helios.hampshire.edu/lspector/quidditch-movies/



Human-Competitive Results

in

Automatic Quantum Computer Programming: A Genetic Programming Approach

- Quantum computing may provide awesome computational power; e.g. ~2 minutes rather than 5+ trillion years to factor a 5,000 digit number.
- New quantum algorithms may support new applications and/or help to answer open theoretical questions.
- But discovery of new quantum algorithms is hard!
- Goal: automated discovery of new and useful quantum algorithms.

“Human-Competitive” Criteria

(B) The result is equal to or better than a result that was accepted as a new scientific result at the time when it was published in a peer-reviewed scientific journal.

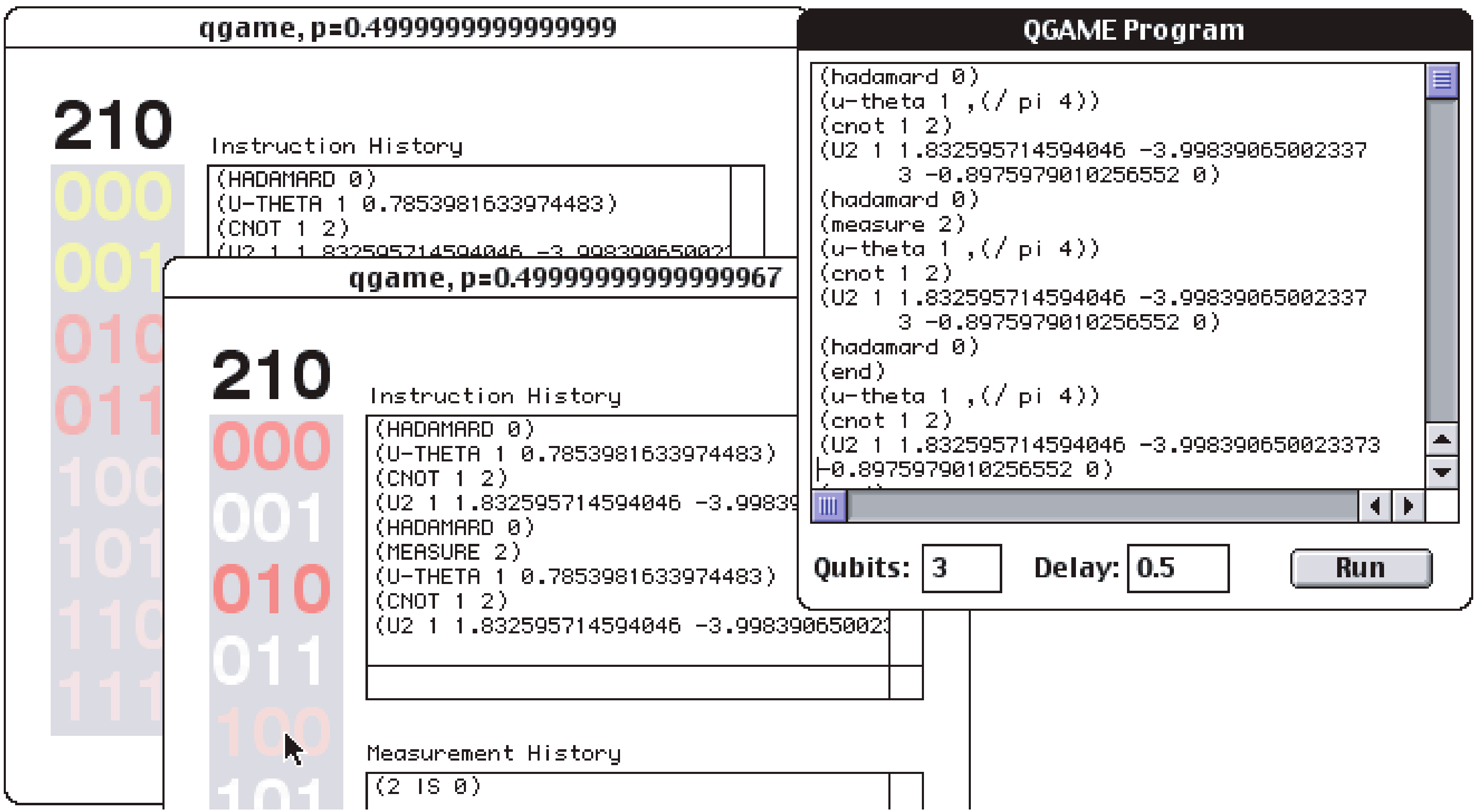
(D) The result is publishable in its own right as a new scientific result independent of the fact that the result was mechanically created.

Project: Approach

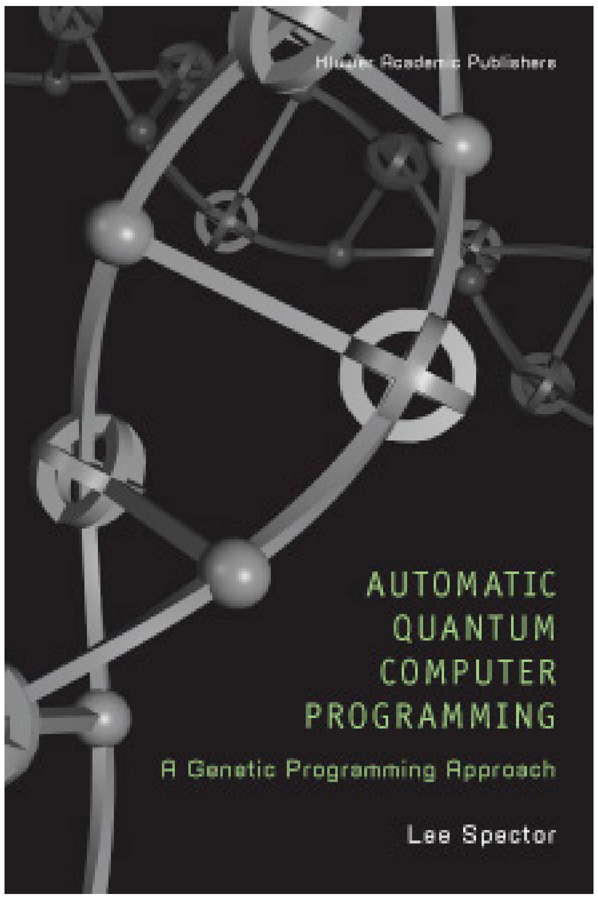
- Use multi-type, self-adaptive genetic programming to discover new quantum algorithms.
- Assess "fitness" via quantum computer simulation.
- Various algorithm/genetic encodings for various problem classes.

QGAME

Quantum Gate And Measurement Emulator
http://hampshire.edu/lspector/qgame.html



Book



Automatic Quantum Computer Programming:
A Genetic Programming Approach
Lee Spector. 2004.
Boston: Kluwer Academic Publishers.
ISBN 1-4020-7894-3.
http://hampshire.edu/lspector/aqcp/

Results

- 1-bit Deutsch-Jozsa (XOR) problem
- 2-bit Grover database search problem
- 1-bit OR problem
- 2-bit AND/OR problem
- Communication and entanglement capacities of “Smolin” and “Bernstein-Spector” gates.
- Re-discovery of quantum dense coding.

Claims

- 1-bit Deutsch-Jozsa (XOR) result: **B**
  EVIDENCE: Original results (by Deutch, Jozsa, and others) were published as new and significant results.

- 2-bit Grover database search result: **B**
  EVIDENCE: Original results (by Grover) were published as new and significant results.

- 1-bit OR result: **B, D**
  EVIDENCE: The first quantum program solving this problem, which was produced by genetic programming, was published by Barnum, Bernstein and Spector in *Journal of Physics A: Mathematical and General*.

- 2-bit AND/OR result: **B, D**
  EVIDENCE: The first quantum program solving this problem, which was produced by genetic programming, was published by Barnum, Bernstein and Spector in *Journal of Physics A: Mathematical and General*.

Claims, continued

- Communication and entanglement capacities of "Smolin" and "Bernstein-Spector" gates: **D**
  EVIDENCE: Publication in the *Proceedings of the Sixth International Conference on Quantum Communication, Measurement, and Computing* (QCMC).

- Re-discovery of quantum dense coding: **B**
  EVIDENCE: Original results were published as new and significant results.

Notes

All of the presented results are better than can be achieved with classical computing (even probabilistic computing). They rely on specifically quantum computational effects.

A subset of these results was awarded a Gold Medal in the Human-Competitive Results competition at the 2004 Genetic and Evolutionary Computation conference (GECCO-2004).

Available Technologies

- Push (now at version 3, in Lisp and C++), PushGP (Lisp and C++), and Pushpop (Lisp): http://hampshire.edu/lspector/push.html.
- Breve (cross platform, version 2 to be released this summer): http://www.spiderland.org/breve.
- QGAME (Lisp and C++): http://hampshire.edu/lspector/qgame.html.
- SwarmEvolve 1.0 and 2.0: http://hampshire.edu/lspector/gecco2003-collective.html.
- Quidditch simulator: http://hamp.hampshire.edu/~rpc01/vww.html
- Multi-agent system course materials (WUB World, Capture the Flag): http://hampshire.edu/lspector/cs263/cs263s04.html