From Competence to Efficiency: A Tale of GA Progress

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INTRODUCTION

Genetic algorithms (GAs) - search procedures based on the mechanics of natural selection and genetics - have grown in popularity for the solution of difficult optimization problems. Concomitant with this growth has been a rising cacaphony of complaint asserting that too much time must be spent by the GA practitioner diddling with codes, operators, and GA parameters; and even then these GA cassandras continue, and the user is still unsure that the effort will meet with success. At the same time, there has been a rising interest in GA theory by a growing community - a theorocracy - of mathematicians and theoretical computer scientists, and these individuals have turned their efforts increasingly toward elegant abstract theorems and proofs that seem to the practitioner to offer little in the way of answers for GA design or practice.

What both groups seem to have missed is the largely unheralded 1993 assembly of integrated, *applicable* theory and its experimental confirmation. This theory has done two key things. First, it has predicted that simple GAs are severely limited in the difficulty of problems they can solve, and these limitations have been confirmed experimentally. Second, it has shown the path to circumventing these limitations in nontraditional GA designs such as the fast messy GA.

This talk surveys the history, methodology, and accomplishment of the 1993 applicable theory revolution. After arguing that these accomplishments open the door to universal GA *competence*, the paper shifts the discussion to the possibility of universal GA efficiency in the utilization of time and real estate through effective parallelization, temporal decomposition, hybridization, and relaxed function evaluation. The presentation concludes by suggesting that these research directions are quickly taking us to a golden age of adaptation.

- Complaint: GAs are too heuristic, too hit and miss.

- Practitioners diddle with codes, ops, and parameters.

- Theoreticians diddle with theorems, proofs, and Markov chains.

- Have GAs to solve hard problems quickly and reliably.

- Have applicable theory to answer questions of practice.

- Need to solve mega-problems with mega-machines.

- A brief history lesson.

- A brief lesson of methodology.

- How the West was won.

- How efficiency will be won.

- A genetic algorithm is a search procedure based on the mechanics of natural selection and natural genetics.

- To be a GA in sense of Holland (1975), two things are required:

    1) selection

    2) recombination

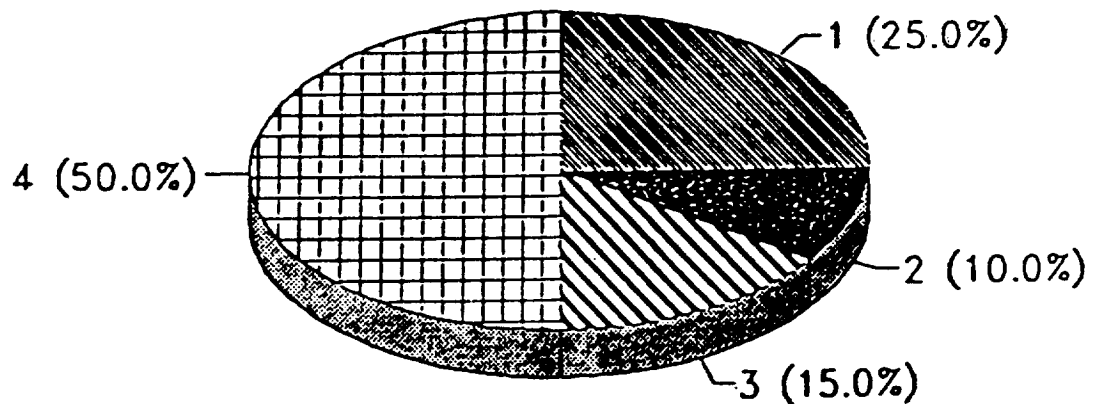- Make more copies of better guys.

- Lots of ways to do: roulette wheel, ranking, tournaments, etc.

- With niching or without.

- Redistribute population according to f.

- $p_i = \dfrac{f_i}{\Sigma f_i}$

- Like spinning a weighted roulette wheel.

- Other ways: tournaments, ranking, expected number.

- Combine bits and pieces of solutions to form new, possibly better, solutions.

- Lots of ways to do: string-wise, tree-wise, single or multiple points.

- Example, single-point crossover:

$$1\ 1\ 1\ 1\ 1 \quad \rightarrow \quad 1\ 1\ 0\ 0\ 0$$
$$0\ 0\ 0\ 0\ 0 \quad \quad\quad 0\ 0\ 1\ 1\ 1$$

- Intuitive version.

- GA Power = Reproduction + Recombination.

- It is something like human innovation.

- Combining *notions* to form *ideas*.

- Can we make this more rigorous?

- The *zeitgeist* of cybernetics.

- Holland's swashbuckling vision.

- 1975: A very good year.

- 1993: The hits just keep on coming.

- The 1950s and 1960s were exciting times.

- Digital computation comes alive.

- ENIAC (1945).

- Perceptrons and other neural nets.

- Various dreams of digital evolution.

- Iterative circuit computers (1958, 1959).

- Pathbuilding addressing scheme.

- Problem: What to do with these computers?

- Create bands of roving programs.

- Fighting, mating, loving, dying, and competing for real estate and time.

- Emphasis on exchange.

- Rechenberg: Hardware *evolutionsstrategie.*

- Schwefel: Software *evolutionstrategie.*

- Fogel, Owens and Walsh: Dueling FSMs.

- Emphasis on genetic hill climbing: selection + mutation.

- *Adaptation in Natural and Artificial Systems*, 1975.

- Building blocks are the key.

- Bits and pieces of solutions recombined to speculate on better solutions.

- Facet wise mathematical theory.

- How the theory applies to economics, optimization, machine learning and other complex systems.

- Completion of GA design decomposition (Goldberg, 1991)

- Mixing results (Goldberg, Deb and Thierens, 1993; Thierens and Goldberg, 1993): Simple GAs mixing limited.

- fm GA results (Goldberg, Deb, Kargupta and Harik, 1993): Nontraditional GAs can solve hard problems quickly and reliably.

- The Era of Visions (1950-something to 1975)

- The Era of Knowledge (1975 to 1985)

- The Era of Competence (1985 to 1993)

- The Era of Efficiency (1993 to ???)

- The Golden Age of Automated Innovation (20xx to ???).

- Invention and engineering, not science.

- Require economy of modeling, not grand unifying theories.

- Example: The Wright Brothers

- O'Hare story.

- Why change the ground rules - material to conceptual.

- Design is design is design.

- Philosophy of engineering as antidote to philosophy of science.

- Economy of modeling critical.

- Effective design decomposition of your problem.

- Facet wise, economic models of subproblem facets.

- Bounding empirical study and calibration.

- Scaling laws (dimensional analysis) important.

- Design decomposition.

- Scaling laws of time and space.

- Results:

  1) limits of sGAs

  2) efficiency of linkage-friendly GAs.

- Know what GA processes: building blocks (BBs).

- Ensure BB supply.

- Ensure BB growth and speed.

- Ensure good BB decisions.

- Ensure good BB mixing (exchange).

- Know BB challengers.

- Similarities among strings.

- Schemata are similarity subsets.

- Schemata described by similarity templates.

- Example: *1*** = {strings with 1 in second position}.

- Population contains schemata.

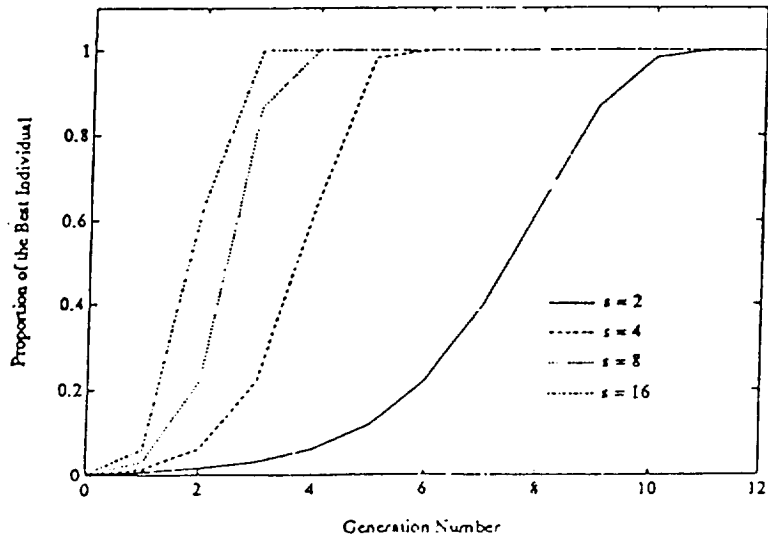| String	Fitness
10111	10
01000	5
11010	3
00011	20

- Analysis of selection time alone.

- Must-innovate time.

- Compare to other times.

- $t_s \sim t_x$

- Size s.

- $Q_{i,t+1} = Q_{i,t}^{s}$

- $Q_{i,t} = Q_{i,0}^{s^t}$

- $t^* = \dfrac{1}{\ln s}\left[\ln n + \ln\left(\ln n\right)\right]$

- Population sizing.

- $n_0 = c(\alpha)\,\beta^2 m\chi^2 \rightarrow n_0 = 0(\ell)$

- Good decisions vs. stepwise decisions.
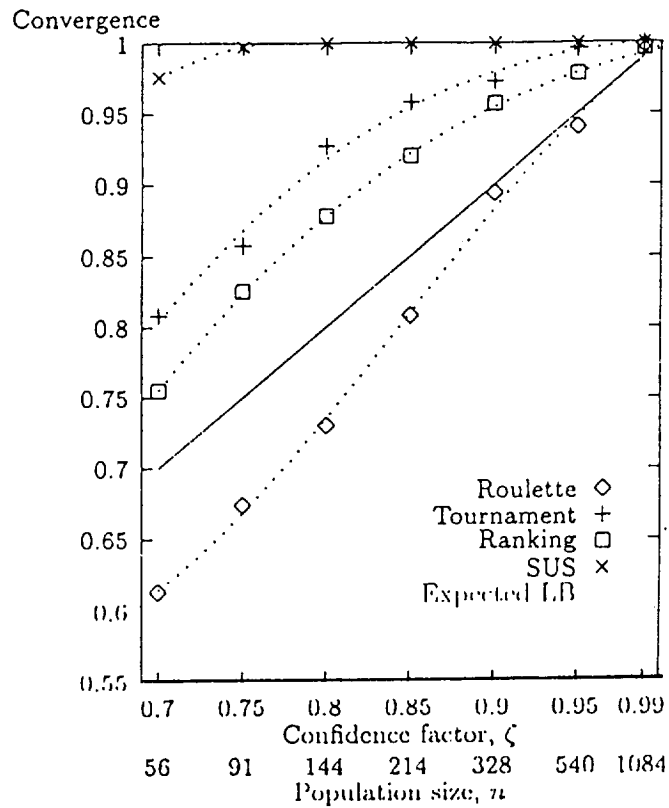
- Innovation vs. hill climbing.

Figure 1 - Simulation results for F1 with ℓ = 200, presented on a graph of convergence as measured by the average number of correct alleles versus confidence (population size). The results are consistent with the ℓ = 20 and ℓ = 50 simulations, and the SUS and ranking results show more pronounced margins above the expected lower bound than the runs at lower ℓ values.

- Serial work, W, is proportional to nt

- $n = 0(\ell)$

- $t = 0(\log n)$

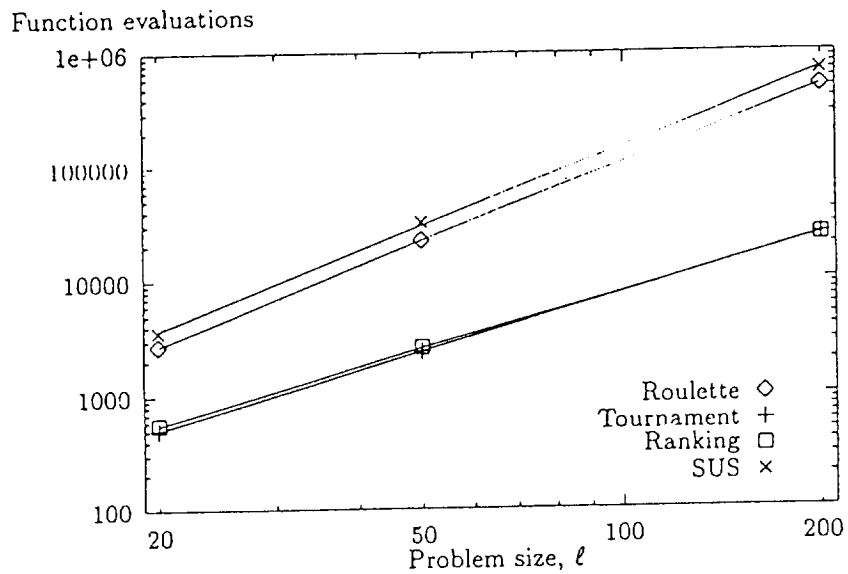- $W = 0(n \log n)$

Function evaluations

Figure 2 - The total number of function evaluations for each selection scheme, graphed versus ℓ value on log-log axes at ζ = 0.9 for function F1. The total number of function evaluations varies approximately as $\ell^{1.7}$ in the pushy (ranking and tournament) selection schemes and $\ell^{2.3}$ in the purely proportionate (SUS and roulette) schemes.
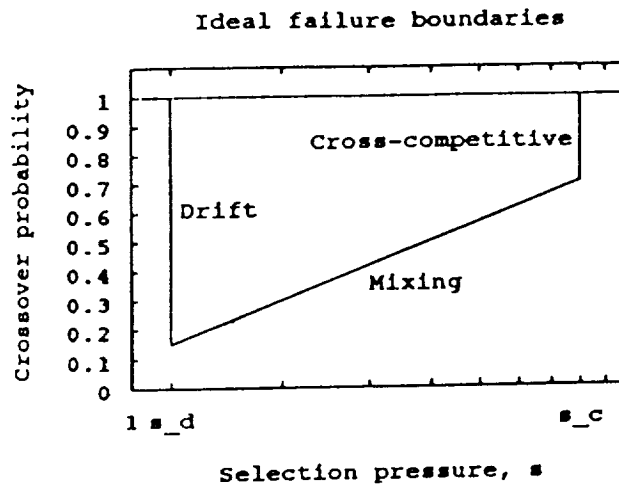
Ideal failure boundaries

Figure 3 - A control map of a GA shows the drift, mixing, and cross-competitive limits of GA success. Within those boundaries, a GA should be expected to work well.
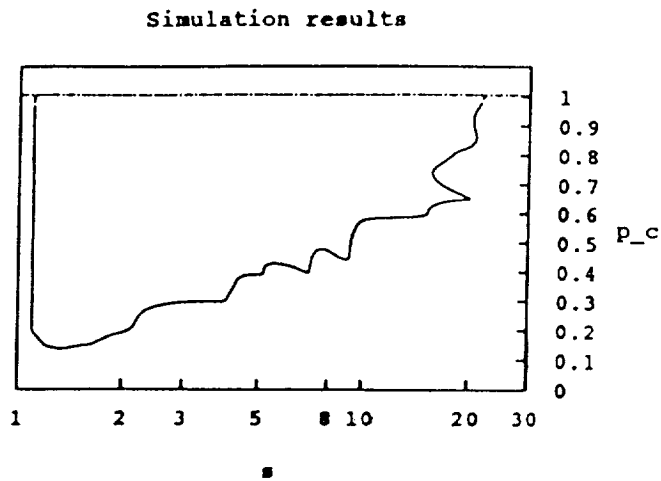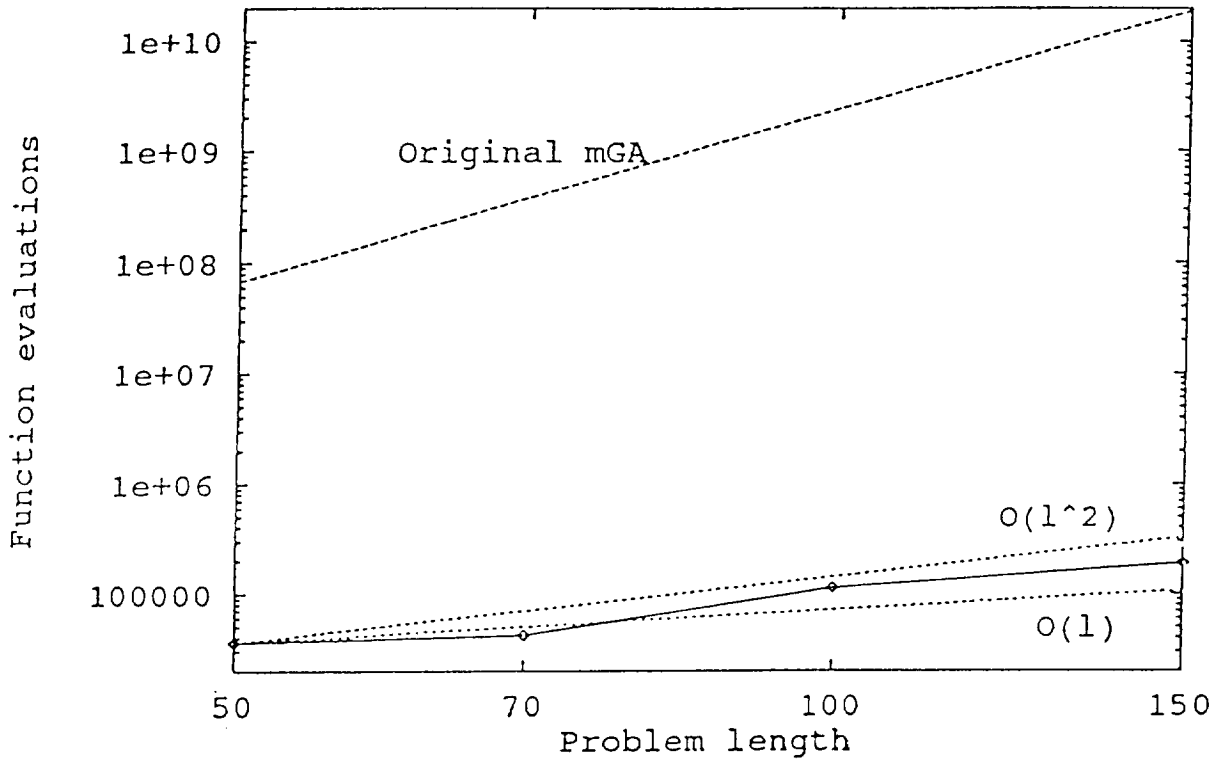
Simulation results

Figure 4 - Simulation results of simple GAs. An average of 50 runs is plotted. Points for s values smaller than 1.2 are obtained with a population size 21 (70% confidence) and other points are obtained with a population size 160 (99% confidence).

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Messy GA Complexity

- Real estate

- Time

- Sampling

- Hybrids and evaluation efficiencies

- Studies hung up on topology or migration rate.

- Sizing in primary issue (Goldberg, Kargupta, Horn and Cantu, 1995)

- Two models: complete isolation and perfect mixing.

- Two constraints: fixed reliability and fixed computation.

- BBs converge reliably in favorable signal-to-noise.

- Can we sustain diversity or inject lost BBs at right time?

- Mutation-like ops, dominance and diploidy, and niching.

- Value of mutation here.

- Discrete event simulation: Accurate-costly evaluation vs quick-dirty.

- How to trade off?

- Past studies: quick and dirty wins.

- Miller and Goldberg 1995. Theoretical investigation quantifies.

- All real applications are hybrids.

- How do we combine different techniques efficiently?

- Need economic balance of work.

- Likewise need efficient parallelization of evaluation.

SUMMARY

- History, methodology, competence and efficiency.

- Fast, reliable GAs are here.

- Applicable theory is here.

- Guidelines for efficiency are on the way.

CONCLUSIONS

- Practitioners must become aware of these results

- Or face a life of diddling.

- Theoreticians must understand this methodology

- Or be doomed to staring at Markov chains.

- Embrace will take us to a golden age of automated innovation.