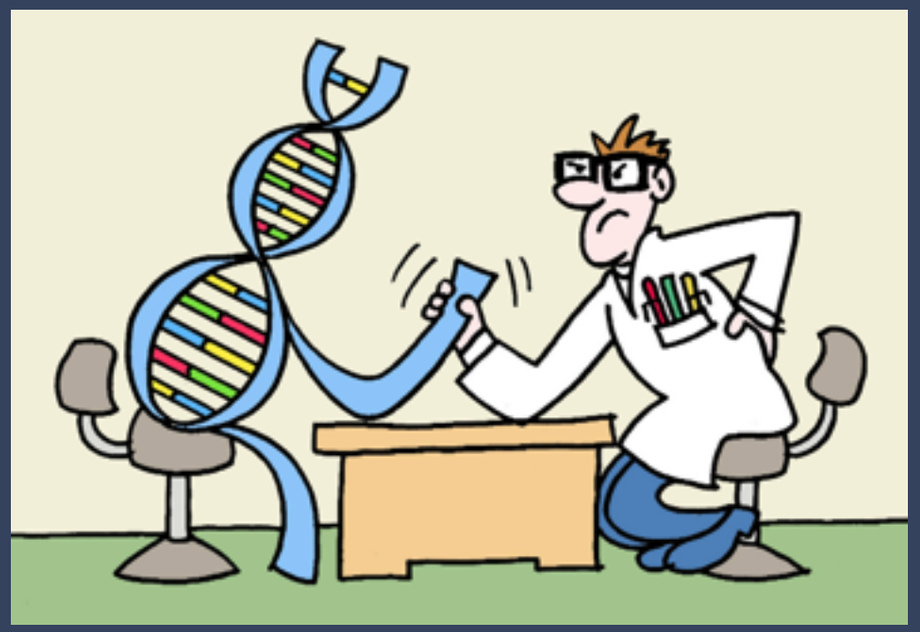
Analyzing a decade of Human-competitive ("HUMIE") winners - what can we learn ?



http://www.genetic-programming.org/hc2005/hclogomf.jpg

Karthik Kannappan, Lee Spector, Moshe Sipper, Thomas Helmuth, William LaCava, Jake Wisdom, Omri Bernstein

What the “HUMIES” are…

Alex Fukunaga and John Koza at the HUMIE awards (2004)

…In a nutshell, “awards for human-competitive results produced by genetic and evolutionary computation”

Human-Competitive

Category	Brief Description
A	Patented invention
B	Equal to accepted scientific results.
C	Could be put in archive of results
D	Publishable as a new scientific result
E	Best incremental solution
F	Achievement in field at time of discovery
G	Indisputable difficulty
H	Actual competition with humans

Analyzing the HUMIES…

Table 1: The 42 HUMIE winners of the past decade. Alg indicates the algorithm used, N stands for Noisy, Pl. stands for Placement

Entry	Author	Alg	N.	Settings	Application Area	Technique	Pl.	A	B	C	D	E	F	G	H
Antanae	Lohn	GP	X	Government	electrical engineering, antennas	developmental GP	1				X	X		X	
Quantum	Spector	GP		Academia	quantum	stack-based, developmental	1		X		X				
2D photonic crystals	Preble	GP		Academia	photonics	tree and bitmap representations	1		X		X	X			
quantum attosecond dynamics	Bartels	ES	X	Academia	quantum	standard ES	1				X	X	X		
sinusoidal oscillators	Aggarwal	GA		Academia	electronics	GA	1		X		X	X	X		
polymer optical fibres	Manos	GA		Academia	polymers	developmental GA	1	X	X		X	X			
finite algebras	Spector	GP		Academia	mathematics	stack-based, developmental	1		X		X	X	X	X	
software patches	Forrest	GP		Academia	software engineering	AST with weighted program path	1							X	
Protein structure prediction	Krasnogor	GP	X	Academia	biology	standard	1					X	X	X	
Free-Cell	Elyasaf	GA		Academia	games	standard GA	1	X		X		X	X	X	
Game Design	Browne	GP		Academia	games	evolving rule trees	1		X	X		X			
Free-Cell	Sipper	GP		Academia	games	policy-based GP	1	X		X		X	X	X	
Jupiter moon search	Izzo	DE		Government	mechanical engineering	self-adaptation differential evolution algorithm, asynchronous island model	1		X	X		X		X	
SAT GP heuristics	Fukunaga	GP		Academia	optimization	strongly typed GP	2				X				
Kinematic Machine Straight Line	Lipson	GP		Academia	mechanical engineering	developmental GP	2					X			
Organization Design Optimization	Khosraviani	GP		Academia	operations research	standard GP	2				X		X	X	

A sample of the data from the paper…

Entry	Author	Alg	N.	Settings	Application Area	Technique	Pl.	A	B	C	D	E	F	G	H
Optical Lens Systems	Koza	GP		Industry	optics	developmental GP	2	X				X	X	X	
Quantum Fourier Transform Algorithm	Massey	GP		Academia	quantum	developmental GP	2		X				X	X	
Assembly Programs	Edgar	GP		Academia	software engineering	micro GP	2			X					X
Space Systems Design	Terrile	GA		Government	mechanical engineering		2					X	X	X	
Photochemistry	Sastry	GA		Academia	chemistry	multi-objective GA	2		X	X	X	X			
Mate-In-N Chess Problem	Sipper	GP		Academia	games	Koza-style GP	2		X		X		X	X	X
RTL Benchmark Circuits	Pecenka	GA		Industry, Academia	electronics	non-binary GA	2				X			X	
User Identification on Smart Phones	Shahzad	GA		Academia	security	GA with partical swarm optimization	2	X				X	X	X	
Domain-Independent Satisficing Planning	Pierre	Metaheuristic		Academia	planning		2		X		X	X		X	
Verficiation algorithm for evolvable hardware	Lukas	GP		Academia	electronics	Cartesian GP	2				X	X		X	
Automated probe microscopy	Woolley	GA		Academia	mechanical engineering	Cellular GA	2	X			X	X	X	X	X
Solid state NMR pulse sequences	Bechmann	GA		Academia	physics	standard GA	3	X	X	X	X	X	X	X	
Automated Program Repair	Dewey-Vogt	GP		Academia	software engineering	GP over AST edit operations	3				X			X	
Optimal Broad-band Stokes/Mueller Polarimeter	Letnes	GA		Academia	optics	standard GA	3	X	X	X	X	X	X	X	

More data from the paper…

Entry	Author	Alg	N.	Settings	Application Area	Technique	Pl.	A	B	C	D	E	F	G	H
Solving Iterated Functions using GP	Schmidt	GP		Academia	mathematics	symbolic regression algorithm	3					X	X	X	
Mixed-Integer Evolution Stategies-Medical Images	Thomas	ES	X	Academia	image processing, medicine	Mixed-Integer Evolution Strategies	3					X	X	X	
GP-Rush - Rush Hour Puzzle	Hauptman	GP		Academia	games	policy-based GP	3		X		X		X	X	X
Descriptor Operators	Perez	GP		Government	computer vision	standard GP	3	X	X	X	X	X	X	X	
Evolving automatic defect	Glazer	GA		Academia	electronics	standard GA	3	X			X	X	X	X	
Diagnosing Prostate Cancer	Llor	GBML	X	Academia	medicine		3		X		X	X			
Automated Alphabet Reduction Method	Bacardit	GA		Academia	biology	Extended Compact Genetic Algorithm (EDA)	3		X		X	X		X	
Circuit Design	Stoica	GA	X	Government	electronics	Mixtrinsic evolution (SW & HW)	3	X			X				
Game Playing	Sipper	GP		Academia	games	standard GP	3								X
Image Compression	Grasemann	GA		Academia	image processing	Coevolutionary	3		X			X	X	X	
Ellipse Detection	Yao	GA	X	Academia	image processing	Multi-population	3	X	X			X			
Interest Point Detection	Olague	GP	X	Government	computer vision	standard GP	3		X	X	X	X	X	X	

Even more data from the paper…

Algorithm

- Genetic Programming (GP)
- Genetic Algorithms (GA)
- Evolutionary Strategies (ES)
- Differential Evolution (DE)
- Genetics Based Machine Learning (GBML)
- Metaheuristics

Setting

- Academia
- Government
- Industry

“Noisy data”

- A metric on whether the input data to the program that was evolved was potentially “noisy”
- For example, a physical measurement is considered “noisy” since there’s always an error in measuring, etc.
- However, input in case of say, a well defined symbolic regression problem trying to fit a mathematically known curve is not noisy.

Application area

Many, including:

- Electrical Engineering
- Operations Research
- Games
- Quantum Computing
- Software engineering

Problem “type”

- Classification
- Clustering
- Design
- Optimization
- Planning
- Programming
- Regression

Specific technique

Many, including:

- Stack based GP
- Developmental GP
- Using an abstract syntax tree with weighted program paths
- Mixed integer evolution strategies

“Human competitive” categories

Category	Brief Description
A	Patented invention
B	Equal to accepted scientific results.
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D	Publishable as a new scientific result
E	Best incremental solution
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Place/Position (1/2/3)?

Explicitly ignored in analysis since determining which entries placed first, second or third is a highly subjective process.

Examples...

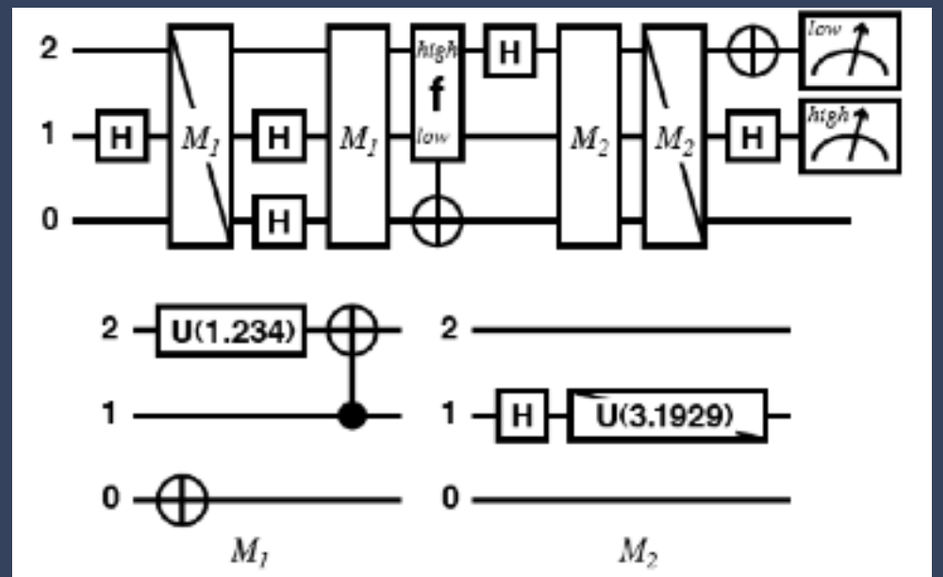

Figure 8.7. A gate array diagram for an evolved version of Grover's database search algorithm for a 4-item database. The full gate array is shown at the top, with M_1 and M_2 standing for the smaller gate arrays shown at the bottom. A diagonal line through a gate symbol indicates that the matrix for the gate is transposed. The "f" gate is the oracle.

Automatic Quantum Computer Programming: A Genetic Programming Approach, Lee Spector et al.

GP/academia/not-noisy/quantum/programming/stack-based +developmental/B+D

Examples…

http://broadcast.oreilly.com/Aian/FreeCell_14.PNG

GA-FreeCell: Evolving Solvers for the Game of FreeCell, Achiya Elyasaf et al.

GA/academia/not-noisy/games/design/standard-GA/B+D+F+G+H

Examples…

Program	Version	LOC	Statements	Program Description	Fault
`gcd`	example	22	10	example from Section 2	infinite loop
`uniq`	ultrix 4.3	1146	81	duplicate text processing	segfault
`look`	ultrix 4.3	1169	90	dictionary lookup	segfault
`look`	svr4.0 1.1	1363	100	dictionary lookup	infinite loop
`units`	svr4.0 1.1	1504	240	metric conversion	segfault
`deroff`	ultrix 4.3	2236	1604	document processing	segfault
`nullhttpd`	0.5.0	5575	1040	webserver	remote heap buffer exploit
`indent`	1.9.1	9906	2022	source code processing	infinite loop
`flex`	2.5.4a	18775	3635	lexical analyzer generator	segfault
`atris`	1.0.6	21553	6470	graphical tetris game	local stack buffer exploit
total		63249	15292		

Figure 4. Benchmark programs used in our experiments, with size in lines of code (LOC). The 'Statements' column gives the number of applicable statements as defined in Section 3.2.

Automatically finding (software) patches using genetic programming, Westley Weimer et al.

GP/academia/not-noisy/software-engineering/programming/AST/G

Algorithm	Count
GP	22
GA	15
ES	2
DE	1
GBML	1
Metaheuristic	1

Category	Brief Description	Count
A	Patented invention	10
B	Equal to accepted scientific results.	20
C	Could be put in archive of results	8
D	Publishable as a new scientific result	29
E	Best incremental solution	25
F	Achievement in field at time of discovery	25
G	Indisputable difficulty	26
H	Actual competition with humans	9

Application	Count
Antennas	1
Biology	2
Chemistry	1
Computer Vision	2
Electrical Engineering	1
Electronics	5
Games	6

Application	Count
Image processing	3
Mathematics	2
Mechanical Engineering	4
Medicine	2
Operations Research	1
Optics	2
Optimization	1

Application	Count
Photonics	1
Physics	1
Planning	1
Polymers	1
Quantum computation	3
Security	1
Software Engineering	3

Problem “type”	Count
Classification	5
Clustering	1
Design	20
Optimization	8
Planning	1
Programming	4
Regression	3

Suggestions for HUMIE aspirants (Humieanoids?)

Problem type...

Not already solved by another technique easily

Collaborators from a non-computer science domain

Solving problems that matter

Rethinking A to I ?

Handicapping a GP system by not feeding it what we currently know can lead to high A to I, but might reduce the number of useful results produced by GP systems or increase the time to produce interesting new and interesting results dramatically.

Integrating human (expert) knowledge in a useful way in a GP system is non-trivial.

The “HUMIES” in a broader context …

“Legions of researchers have chased after the best iris or mushroom classifier. Yet this flurry of effort does not seem to have had any impact on the fields of botany or mycology”, Kiri L. Wagstaff, California Institute of Technology

“

The “HUMIES” in a broader context …

The HUMIES only look at human competitive results produced by ***evolutionary computation***

Viewing the results in the context of other results produced by other computational techniques

Questions?

Thank you!

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- Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the National Science Foundation.

The HUMIE winners… 2004…

An Evolved Antenna for Deployment on NASA's Space Technology 5 Mission, Jason D. Lohn et al.

Automatic Quantum Computer Programming: A Genetic Programming Approach, Lee Spector

Evolving Local Search Heuristics for SAT Using Genetic Programming, Alex Fukunaga

How to Draw a Straight Line Using a GP: Benchmarking Evolutionary Design Against 19th Century Kinematic Synthesis, Hod Lipson

Organization Design Optimization Using Genetic Programming, Bijan KHosraviani et al.

Taking evolutionary circuit design from experimentation to implementation: some useful techniques and a silicon demonstration, Adrian Stoica et al.

The HUMIE winners … 2005 …

Two-dimensional photonic crystals designed by evolutionary algorithms, Stefan Preble et al.

Learning from Learning Algorithms: Applications to attosecond dynamics of high-harmonic generation, Randy Bartels et al.

Shaped-pulse optimization of coherent soft-x-rays, Randy Bartels et al.

Automated Re-Invention of Six Patented Optical Lens Systems using Genetic Programming, John Koza et al.

Evolution of a Human-Competitive Quantum Fourier Transform Algorithm Using Genetic Programming, Paul Massey et al.

The HUMIE winners… 2005…

Evolving Assembly Programs: How Games Help Microprocessor Validation, Fulvio Corno Edgar et al.

Evolutionary Computation Technologies for the Automatic Design of Space Systems, Richard J. Terrile et al.

Evolutionary Computation applied to the Tuning of MEMS gyroscopes, Didier Keymeulen et al.

Multi-Objective Evolutionary Algorithms for Low-Thrust Orbit Transfer Optimization, Seungwon Lee et al.

The HUMIE winners… 2005…

Attaining Human-Competitive Game Playing with Genetic Programming, Moshe Sipper et al.

GP-Gammon: Genetically Programming Backgammon Players, Yaniv Azaria et al.

GP-Robocode: Using Genetic Programming to Evolve Robocode Players, Yehonatan Shichel et al.

GP-EndChess: Using Genetic Programming to Evolve Chess Endgame Players, Ami Hauptman et al.

Effective Image Compression using Evolved Wavelets, Uli Grasemann et al.

The HUMIE winners… 2006…

Catalogue of Variable Frequency and Single-Resistance-Controlled Oscillators Employing A Single Differential Difference Complementary Current Conveyor, Varun Aggarwal et al.

Multiobjective Genetic Algorithms for Multiscaling Excited-State Direct Dynamics in Photochemistry, Kumara Sastry et al.

A multi-population genetic algorithm for robust and fast ellipse detection, Jie Yao Nawwaf et al.

Using Evolution to Learn How to Perform Interest Point Detection, Leonardo Trujillo et al.

Synthesis of Interest Point Detectors Through Genetic Programming, Leonardo Trujillo

The HUMIE winners… 2007…

Evolutionary Design of Single-Mode Microstructured Polymer Optical Fibres using an Artificial Embryogeny Representation, Steven Manos et al.

Evolution of an Efficient Search Algorithm for the Mate-In-N Problem in Chess, Ami Hauptman et al.

Towards Better than Human Capability in Diagnosing Prostate Cancer Using Infrared Spectroscopic Imaging, Xavier Llorà et al.

Automated Alphabet Reduction Method with Evolutionary Algorithms for Protein Structure Prediction, Jaume Bacardit et al.

The HUMIE winners… 2008…

Genetic Programming for Finite Algebras, Lee Spector et al.

Evolution of Synthetic RTL Benchmark Circuits with Predefined Testability, Tomas Pecenka et al.

Evolving an automatic defect classification tool, Assaf Glazer et al.

The HUMIE winners… 2009…

Automatically finding patches using genetic programming, Westley Weimer et al.

A Genetic Programming Approach to Automated Software Repair, Stephanie Forrest et al.

A Hybrid GA-PSO Fuzzy System for User Identification on Smart Phones, Muhammad Shahzad et al.

Keystroke-based User Identification on Smart Phones, Saira Zahid et al.

GP-Rush: Using Genetic Programming to Evolve Solvers for the Rush Hour Puzzle, Ami Hauptpman et al.

Learning Invariant Region Descriptor Operators with Genetic Programming and the F-measure, Cynthia B. Perez et al.

Evolutionary Learning of Local Descriptor Operators for Object Recognition, Cynthia B. Perez et al.

The HUMIE winners… 2010…

Evolutionary design of the energy function for protein structure prediction, Paweł Widera et al.

GP challenge: evolving the energy function for protein structure prediction, Paweł Widera et al.

Automated design of energy functions for protein structure prediction by means of genetic programming and improved structure similarity assessment, Paweł Widera et al.

An Evolutionary Metaheuristic Based on State Decomposition for Domain-Independent Satisficing Planning, Jacques Bibai et al.

The HUMIE winners… 2010…

Solving Iterated Functions Using Genetic Programming, Michael Schmidt et al.

Optimizing a Medical Image Analysis System Using Mixed-Integer Evolution Strategies, Rui Li et al.

Mixed-Integer Evolution Strategies for Parameter Optimization and Their Applications to Medical Image Analysis, Rui Li et al.

The HUMIE winners… 2011

GA-FreeCell: Evolving Solvers for the Game of FreeCell, Achiya Elyasaf et al.

A Global Postsynthesis Optimization Method for Combinational Circuits, Z. Vasicek Lukas et al.

Fast and optimal broad-band Stokes/Mueller polarimeter design by the use of a genetic algorithm, Paul Anton Letnes et al.

Genetic Invention of Fast and Optimal Broad-band Stokes/Mueller Polarimeter Designs, Paul Anton Letnes et al.

The HUMIE winners… 2012

Automated probe microscopy via evolutionary optimization at the atomic scale, Richard A.J. Woolley et al.

A systematic study of automated program repair: Fixing 55 out of 105 bugs for $8.00 each, Claire Le Goues et al.

Representations and Operators for Improving Evolutionary Software Repair, Claire Le Goues et al.

Yvalath: Sample Chapter from Evolutionary Game Design (Preface), Cameron Browne

Go without KO on Hexagonal Grids, Cameron Browne

Yvalath: Evolutionary Game Design, Cameron Browne

The HUMIE winners… 2013…

Evolutionary Design of FreeCell Solvers, Moshe Sipper et al.

Search for a grand tour of the Jupiter Galilean moons, Dario Izzo et al.

Genetic algorithms and solid state NMR pulse sequences, Matthias Bechmann et al.