What Can Evolutionary Computation Do For You?

Xin Yao (http://www.cs.bham.ac.uk/~xin)

CERCIA, School of Computer Science, University of Birmingham, UK

http://www.cercia.ac.uk

THE UNIVERSITY OF BIRMINGHAM

the centre of excellence cercia for research in computational intelligence and applications

Advantage West Midlands

Er …

- Nothing (if you are not in this field)?
- A lot (if you are in this field)?
- Sometimes it can be very useful (for most people).
- But what "times"?
- Maybe we should look at a broader picture …

THE UNIVERSITY
OF BIRMINGHAM

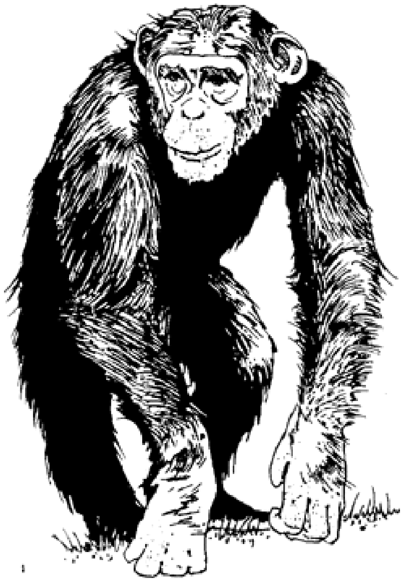
What Existing Computers Still Can't Do Well

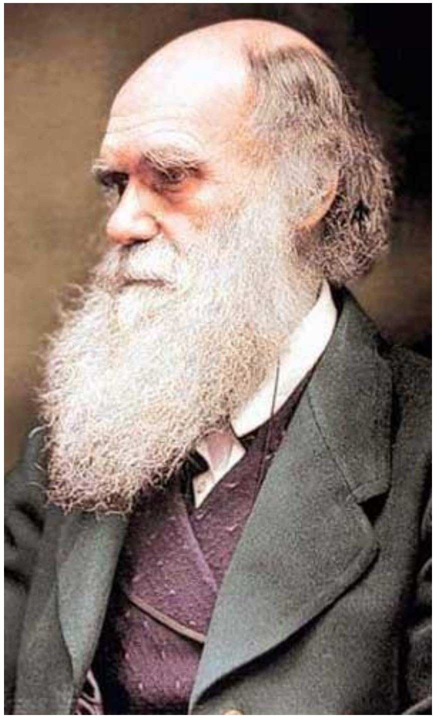
- Brittle
- Doesn't learn
- Hopeless in dealing with noisy and inaccurate information
- Never grow up
- Unable to adapt
- Turning us into slaves
- but also give us jobs …

the centre of excellence
cercia
for research in computational intelligence and applications

Advantage
West Midlands

Inspiration: Mother Nature





What Is Evolutionary Computation

- It is the study of computational systems which use ideas and get inspirations from natural evolution.
- Evolutionary computation (EC) techniques can be used in optimisation, learning and creative design.
- EC techniques do not require rich domain knowledge to use. However, domain knowledge can be incorporated into EC techniques.

THE UNIVERSITY OF BIRMINGHAM
cercia the centre of excellence for research in computational intelligence and applications

THE UNIVERSITY OF BIRMINGHAM

Outline of This Talk

- **Adaptive Optimisation**
- **Data Mining and Machine Learning**

the centre of excellence cercia for research in computational intelligence and applications

Advantage West Midlands

THE UNIVERSITY OF BIRMINGHAM

Case Study I:

Modelling: Both Structures and Parameters

the centre of excellence cercia for research in computational intelligence and applications

Advantage West Midlands

THE UNIVERSITY OF BIRMINGHAM

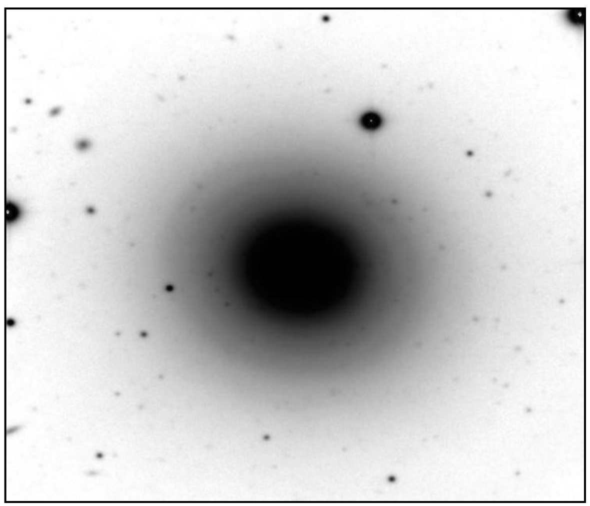
Discovering `New' Physical Laws in Astrophysics --- Modelling Radial Brightness Distributions in Elliptical Galaxies

- **Empirical laws are widely used in astrophysics.**
- **However, as the observational data increase, some of these laws do not seem to describe the data very well.**
- **Can we discover new empirical laws that describe the data better?**

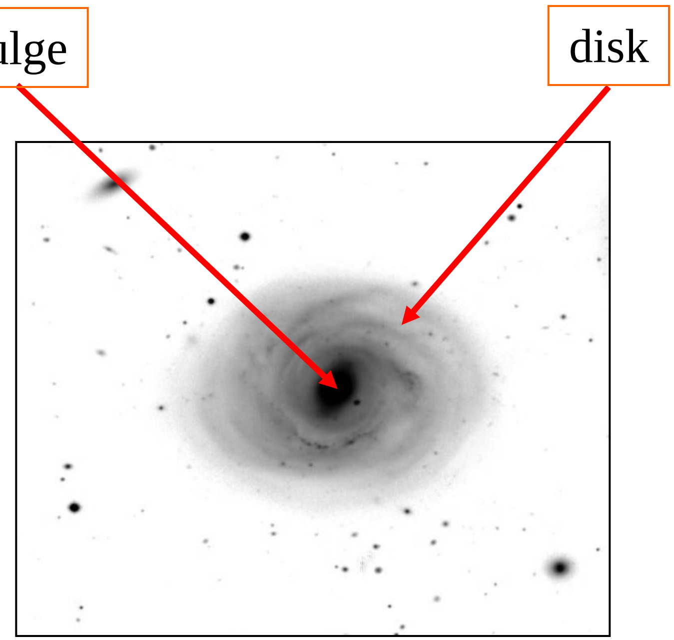
the centre of excellence cercia for research in computational intelligence and applications

Advantage West Midlands

Monochromatic (Negative) Images of Galaxies



A typical elliptical galaxy



A typical spiral galaxy

Current Approach

- **Select a functional form in advance**

  Drawbacks: ad hoc, difficult to determine and may only suit a smaller number of profiles

- **Apply fitting algorithms to find suitable parameters for the function. Usually adopt the non-linear reduced c2 minimization**

$$\chi^2 = \frac{1}{\upsilon}\sum_i \frac{[I_{model}(i) - I_{obs}(i)]^2}{\delta^2}$$

where $I_{obs}(i)$ is the individual observed profile value, $I_{model}(i)$ is the value calculated from the fitting function, υ is the number of degrees of freedom, and δ is the standard deviation of the data.

Drawbacks: difficult to set initial values and easily trapped in local minima

THE UNIVERSITY OF BIRMINGHAM

Our Evolutionary Approach

(1) Find functional forms using GP (Genetic Programming) :

- **A data-driven process without assuming a functional form in advance**
- **A bottom up process which suits modelling a large number of galaxy profiles without any prior knowledge of them**

(2) Fit parameters in the form found using FEP (Fast Evolutionary Programming):

- **Not sensitive to initial setting values**
- **More likely to find global minima**

J. Li, X. Yao, C. Frayn, H. G. Khosroshahi, S. Raychaudhury, ``An Evolutionary Approach to Modeling Radial Brightness Distributions in Elliptical Galaxies,'' *Proc. of the 8th International Conference on Parallel Problem Solving from Nature (PPSN VIII)*, Lecture Notes in Computer Science, Vol. 3242, pp.591-601, Springer, September 2004.

cercia — the centre of excellence for research in computational intelligence and applications

Advantage West Midlands

THE UNIVERSITY OF BIRMINGHAM

Case Study II:

Material Modelling

the centre of excellence cercia for research in computational intelligence and applications

Advantage West Midlands

Determining Unified Creep Damage Constitutive Equations in Aluminium Alloy Modelling

- Creep behaviours of different materials are often described by physically based unified creep damage constitutive equations.
- Such equations are extremely complex.
- They often contain undecided constants (parameters).
- Traditional approaches are unable to find good near optima for these parameters.
- Evolutionary algorithms (EAs) have been shown to be very effective.

THE UNIVERSITY OF BIRMINGHAM

Example Equations

$$\frac{d\varepsilon}{dt} = \frac{A}{(1-\omega_2)^n} \sinh\left(\frac{B\sigma(1-H)}{1-\phi}\right),$$

$$\frac{dH}{dt} = \frac{h}{\sigma}\frac{d\varepsilon}{dt}\left(1-\frac{H}{H^*}\right),$$

$$\frac{d\phi}{dt} = \frac{K_c}{3}(1-\phi)^4,$$

$$\frac{d\omega_2}{dt} = \frac{DA}{(1-\omega_2)^n} \sinh\left(\frac{B\sigma(1-H)}{1-\phi}\right),$$

where A, B, h, H^*, K_c and D are material constants, and n is given by

$$n = \frac{B\sigma(1-H)}{1-\phi} \coth\left(\frac{B\sigma(1-H)}{1-\phi}\right).$$

the centre of excellence cercia for research in computational intelligence and applications

THE UNIVERSITY OF BIRMINGHAM

Evolutionary Parameter Calibration and Optimisation

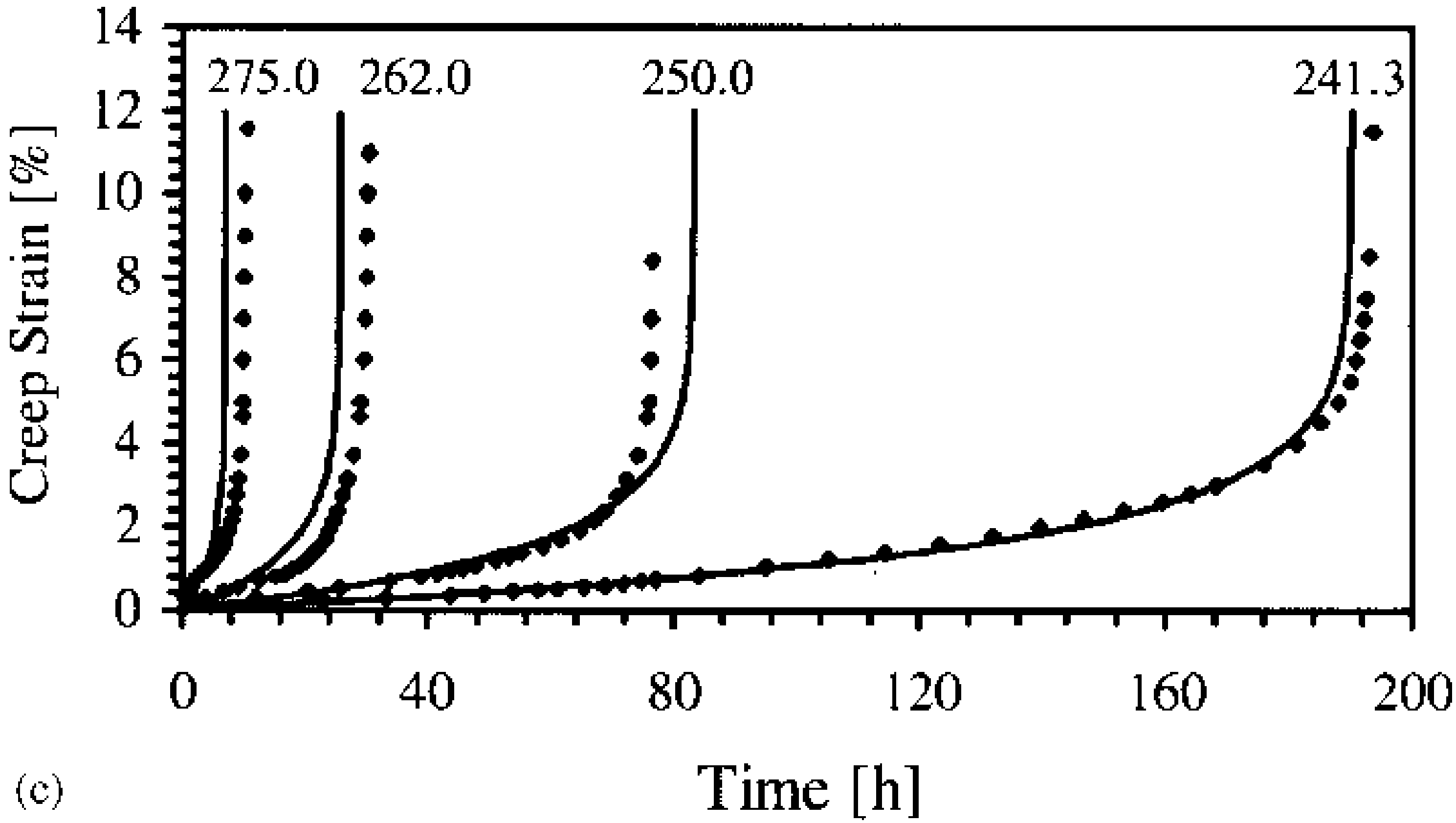
- **Classical evolutionary programming (CEP), fast EP (FEP) and improved fast EP (IFEP) can be used to find parameters in a complex and non-differentiable space.**

B. Li, J. Lin and X. Yao, "A novel evolutionary algorithm for determining unified creep damage constitutive equations," *International Journal of Mechanical Sciences*, 44 (2002): 987–1002.

cercia the centre of excellence for research in computational intelligence and applications

Advantage West Midlands

Model with Evolved Parameters by IFEP



THE UNIVERSITY OF BIRMINGHAM

Real World Impact

- **Used by Corus / Tata Corus.**

the centre of excellence
cercia
for research in computational intelligence and applications

Advantage West Midlands

THE UNIVERSITY
OF BIRMINGHAM

Case Study III:

Constraint Handling

the centre of excellence
cercia
for research in computational intelligence and applications

Advantage West Midlands

Constraint Handling

- Real-world problem has ***many constraints,*** e.g., linear, nonlinear, equality, inequality, …

Evolutionary Constraint Handling

It works better than other methods because

- More effective;
- Good at dealing with non-differentiable and nonlinear problems;
- Avoid unnecessary and unrealistic assumptions.

Stochastic Ranking

- It is a simple yet effective constraint handling method.
- It exploits the characteristics of evolutionary algorithms.

- T. P. Runarsson and X. Yao, "Stochastic Ranking for Constrained Evolutionary Optimization," *IEEE Transactions on Evolutionary Computation*, 4(3):284-294, September 2000.
- T. Runarsson and X. Yao, "Search Bias in Constrained Evolutionary Optimization," *IEEE Transactions on Systems, Man, and Cybernetics, Part C*, 35(2):233-243, May 2005.

Impact Outside Evolutionary Computation

THE UNIVERSITY OF BIRMINGHAM

- **It's used so often that people made it a C library so that everyone can use it easily:**
  - **Xinglai Ji [1] and Ying Xu [2], "libSRES: a C library for stochastic ranking evolution strategy for parameter estimation" *Bioinformatics*, 22(1):124-126, 2006.**
    - [1]Computational Biology Institute, Oak Ridge National Laboratory Oak Ridge, TN 37831, USA
      [2]Department of Biochemistry and Molecular Biology and Institute of Bioinformatics, University of Georgia Athens, GA 30602-7229, USA
- **Also in civil, mechanical, electrical and electronic engineering.**

the centre of excellence cercia for research in computational intelligence and applications

Advantage West Midlands

Real World Is Dynamic

- **Real world is complex and changes all the time.**
  - **E.g., customers make new orders or cancel existing orders all the time. How can I optimise my objectives?**

THE UNIVERSITY OF BIRMINGHAM

Case Study IV:
Dynamic Optimisation

the centre of excellence cercia for research in computational intelligence and applications

Advantage West Midlands

Route Optimisation for Gritting Trucks

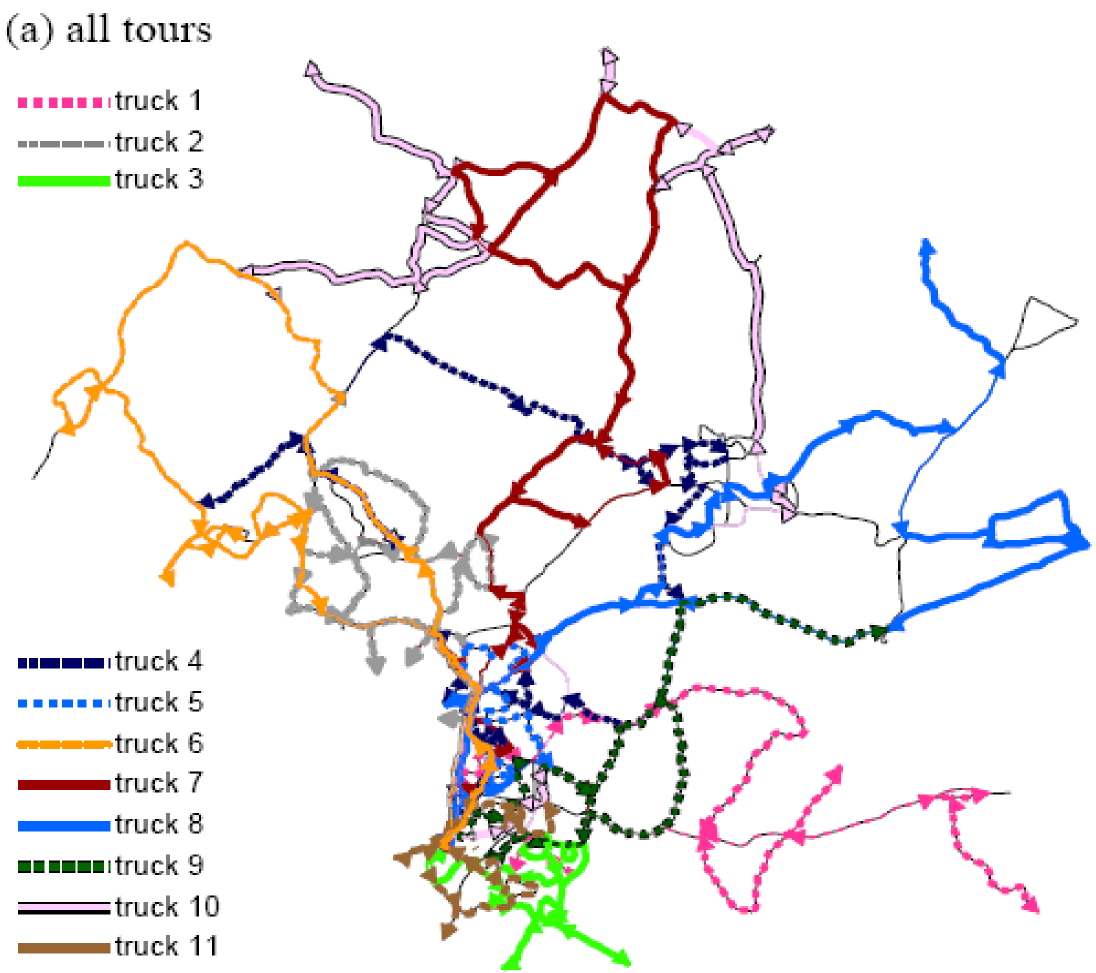
THE UNIVERSITY OF BIRMINGHAM

- Optimisation Problem:
  - Multiple trucks with different capacities
  - Multiple depots
  - Complex routing constraints
  - Dynamic
- Evolutionary algorithms outperformed all other existing algorithms

the centre of excellence cercia for research in computational intelligence and applications

Advantage West Midlands

Real-World Applications



Further Information

THE UNIVERSITY OF BIRMINGHAM

- **Application:**
  - H. Handa, L. Chapman and Xin Yao, ``Robust route optimisation for gritting/salting trucks: A CERCIA experience," *IEEE Computational Intelligence Magazine*, 1(1):6-9, February 2006.
- **Theory:**
  - P. Rohlfshagen, P. K. Lehre and X. Yao, "Dynamic evolutionary optimisation: An analysis of frequency and magnitude of change," In *Proceedings of the 2009 Genetic and Evolutionary Computation Conference*, pages 1713-1720, 2009. (best paper award)

the centre of excellence cercia for research in computational intelligence and applications

Advantage West Midlands

THE UNIVERSITY
OF BIRMINGHAM

Case Study V:

Multi-objective Optimisation

Ubiquity of Multi-objective Problem Solving: in Hardware

- A practical example:
  - X. Yao and T. Schnier, “HARDWARE DESIGN USING EVOLUTION ALGORITHMS,” *European Patent EP1388123*. Held by Ericsson (formerly Marconi).
- Underpinning research:
  - T. Schnier, X. Yao and P. Liu, ``Digital filter design using multiple pareto fronts,'' *Soft Computing*, 8(5):332-343, April 2004.

Ubiquity of Multi-objective Problem Solving: in Software

- **K. Praditwong, M. Harman and X. Yao, "Software Module Clustering as a Multi-Objective Search Problem," *IEEE Transactions on Software Engineering*, 37(2):264-282, March/April 2011.**
- **Z. Wang, K. Tang and X. Yao, "Multi-objective Approaches to Optimal Testing Resource Allocation in Modular Software Systems," *IEEE Transactions on Reliability*, 59(3):563-575, September 2010.**

THE UNIVERSITY OF BIRMINGHAM

Outline

- Adaptive Optimisation
- Data Mining and Machine Learning

cercia — the centre of excellence for research in computational intelligence and applications

Advantage West Midlands

Evolutionary Computation Helps Population-based Thinking

THE UNIVERSITY OF BIRMINGHAM

- **Such a new way of thinking can lead to interesting connections to other research fields, e.g., machine learning.**
- **One example is ensemble learning, i.e., "a population of heads are better than one":**
  - **X. Yao and Y. Liu, "Making use of population information in evolutionary artificial neural networks,"** ***IEEE Trans. on Systems, Man, and Cybernetics, Part B: Cybernetics*****, 28(3):417-425, June 1998.**

THE UNIVERSITY
OF BIRMINGHAM

Case Study VI:
Ensemble Learning

the centre of excellence
cercia
for research in computational
intelligence and applications

Advantage
West Midlands

Negative Correlation Learning

THE UNIVERSITY OF BIRMINGHAM

- Negative Correlation Learning is a very simple ensemble learning algorithm inspired by evolutionary computation.
  - Y. Liu and X. Yao, ``Ensemble learning via negative correlation,'' *Neural Networks*, 12(10):1399-1404, December 1999.
- It has many applications.
  - Xin Yao, Gavin Brown, Bernhard Sendhoff and Heiko Wersing, "Exploiting ensemble diversity for automatic feature extraction," *European Patent EP1378855*. (Held by Honda).

the centre of excellence cercia for research in computational intelligence and applications

Advantage West Midlands

THE UNIVERSITY OF BIRMINGHAM

Multi-objective Ensemble Learning

- Multiple objectives can be easily accommodated in ensemble learning:
  - H. Chen and X. Yao, ``Multiobjective Neural Network Ensembles based on Regularized Negative Correlation Learning,'' *IEEE Transactions on Knowledge and Data Engineering*, 22(12):1738-1751, December 2010.
  - A. Chandra and X. Yao, "Ensemble learning using multi-objective evolutionary algorithms," *Journal of Mathematical Modelling and Algorithms*, 5(4):417-445, December 2006.
- Ensembles + Multi-objective + Cloud = Piero

the centre of excellence cercia for research in computational intelligence and applications

Advantage West Midlands

Many More Applications

- The six case studies presented represent only a tiny set of all applications of EC.
- Applications are interesting, but where are the challenges for the future?

Challenge: Theoretical Foundations

THE UNIVERSITY OF BIRMINGHAM

- Theories of evolutionary computation have lagged behind applications, although recent progresses in computational time complexity analysis have been substantial.
- We need to understand when an EA is expected to perform well on what types of problems.
- What makes a problem hard/easy for an EA?

cercia the centre of excellence for research in computational intelligence and applications

Advantage West Midlands

Challenge: Scalability

- At present, large scale optimisation in EC deals with one or two thousand variables at most. We need efficient EAs that can optimise problems with tens or even hundreds of thousands of variables.

Challenge: Dealing with Dynamics and Uncertainty

- We do not have a static and predictable world. Problems are changing even when they are being solved. Constraints are changing with time too.
- How can we optimise more effectively and efficiently in such a dynamic and uncertain environment?

THE UNIVERSITY OF BIRMINGHAM

Challenge: Learn to Optimise

- Optimisation has been treated mathematically. It has been very rare for any optimisation algorithm to consider its previous experience in solving other, often similar, problems.
- Why not? We, human beings, do learn to solve a problem better by applying previous experiences.

the centre of excellence cercia for research in computational intelligence and applications

Advantage West Midlands

THE UNIVERSITY
OF BIRMINGHAM

Enjoy Some of the Challenges?

- Why not join the Birmingham team?
- Available now:
  - Fully funded PhD in evolutionary computation
  - Two job vacancies (postdoctoral research fellows): 3 and 4 years, respectively. Both in evolutionary computation.
- Also available:
  - MRes in Natural Computation
  - MSc in Multi-disciplinary Optimisation

cercia
the centre of excellence for research in computational intelligence and applications

Advantage West Midlands

THE UNIVERSITY OF BIRMINGHAM

Conclusions

- Evolutionary computation has **both** interesting applications and challenging theories.
- It can do **far more** than one might initially have thought.
- There are **golden opportunities** in the research and applications of evolutionary computation.

the centre of excellence cercia for research in computational intelligence and applications

Advantage West Midlands