Question 1

a) According to John Koza there are five stages when planning to solve a problem using a genetic program. What are they? Give a short description of each.

(15)

(b) How could you cope with division by zero in a program being evolved by a genetic programming approach?

(3)

(c) What do you understand by code bloat in a genetic program? Suggest a way that code bloat could be reduced.

(7)

Question 2

With regards to Genetic Algorithms :-

a) Describe a parent selection technique and show the algorithm.

(8)

b) Describe how one-point crossover works.

(8)

c) One-Point Crossover is not suitable for The Travelling Salesman Problem (TSP).
Why is this?
Give a description of a crossover operator that is suitable for the TSP.

(9)

Question 3

(a) Describe the motivation behind the simulated annealing algorithm.

(5)

(b) The following table shows six evaluations of a simulated annealing algorithm. For each evaluation give the probability of the next state being accepted (to 4 dp). Assume the objective function is being maximised.

Current Evaluation	Neighbourhood Evaluation	Current Temperature
75	65	25
75	55	25
75	65	50
75	55	50
65	75	25
65	75	50

Ensure you show the formula you use and describe the terms.

(5)

(c) One aspect of a simulated annealing cooling schedule is the temperature. Discuss the following

i) What is the effect of having the starting temperature too high or too low?

(4)

ii) How do you decide on a suitable starting temperature?

(6)

iii) How do we decide on a final temperature?

(5)

Question 4

a) Describe the approaches used by Chellapilla/Fogel and Jonathan Schaeffer to create a world class checkers player.

(15)

b) Discuss the two approaches and give your views as to which, if any, could be described as artificially intelligent. Justify your reasoning.

(10)

Question 5

a) Describe what you understand by the artificial intelligence technique, *evolutionary strategies*? Ensure you describe the mutation operator and the importance it plays.

(7)

b) Given the following two evolutionary strategy schemes

$(\mu + \lambda)$
(μ , λ)

describe the difference between the two schemes

(6)

What scheme did Schwefel originally use?

(2)

c) With regards to evolutionary strategies, describe the Rechenberg "1/5 success rule", discuss why it is used and possible parameters.

(10)

Question 6

a) Describe how ants are able to find the shortest path to a food source in nature.

(4)

b) Using the travelling salesman problem as an example, describe the following terms in relation to ant algorithms

Visibility
Evaporation
Transition Probability

(6)

(c) Suggest a suitable problem, other than the travelling salesman problem, that an ant algorithm could be used to solve.
Discuss how the problem would be represented, the heuristic value that could be used and how you would decide how much pheromone to deposit.

(15)

Model Answers

Question 1 – Model Answer

Parts a and b are bookwork. Part c was not covered in the lectures and would require “reading around the subject.”

a) According to John Koza there are five stages when planning to solve a problem using a genetic program. What are they? Give a short description of each

1) Identify the terminal set. That is the “symbols” that can appear at the leaves of the parse tree. For example X, Y, Z (i.e. variables).

1 mark for stating, 2 marks for example

2) Identify the function set. That is the “symbols” that can appear at the inner nodes of the parse tree. For example +, /, *, -, cos, sin, etc..

1 mark for stating, 2 marks for example

3) Identify the fitness measure that is used to evaluate a given evolved program.
For example, how well does the evolved program fit a given function. Given, say, X^3 in the range (-10..+10) how far is each point in the evolved program away from the same point in X^3? The sum of these errors is the evaluation of the program, with the aim being to minimise that error.

1 mark for stating, 2 marks for example

4) What are the control parameters of the algorithm? For example, what is the population size and how many iterations will be carried out?

1 mark for stating, 2 marks for example

5) What is the terminating condition and what designates the result? For example, do we run for a given number of iterations or do we run for a certain amount of time. For the result designation, do we take the best program found in all the runs or do we take the best program from the final population?

1 mark for stating, 2 marks for example

(b) How could you cope with division by zero in a program being evolved by a genetic programming approach?

It is usual to use a protected division by zero which returns 1 if a division by zero is attempted.

3 marks

(c) What do you understand by code bloat in a genetic program? Suggest a way that code bloat could be reduced.

Code bloat is the phenomena whereby the size of the program is disproportionate to the function it performs. For example, a program might represent X^2 but take a parse tree of depth 10, with a total number of nodes exceeding 1000.

4 marks

There are some mechanisms to control code bloat. For example,
Include a term in the evaluation function that penalises larger programs.
Limit the depth of the search tree so that no program can exceed a certain depth.

3 marks (for one good example)

<u>Question 2 – Model Answer</u>

a) Parent Selection Technique
The technique described in the lectures was roulette wheel selection.
The idea behind the roulette wheel selection technique is that each individual is given a chance to become a parent in proportion to its fitness. It is called roulette wheel selection as the chances of selecting a parent can be seen as spinning a roulette wheel with the size of the slot for each parent being proportional to its fitness. Obviously those with the largest fitness (slot sizes) have more chance of being chosen.
Roulette wheel selection can be implemented as follows

1. Sum the fitnesses of all the population members. Call this TF (total fitness).
2. Generate a random number n, between 0 and TF.
3. Return the first population member whose fitness added to the preceding population members is greater than or equal to n.

In marking this question I will be looking for the following points.

- Why it is called "roulette wheel" selection.
- The algorithm, in outline, has been presented.
- The fact that parents are picked in proportion to their fitness.
- An example may be useful in describing the technique.

8 marks, pro rata

b) One Point Crossover

One-point crossover takes two parents and breeds two children. It works as follows

Parent 1	1	0	1	1	1	0	1
Parent 2	1	1	0	0	1	1	0

Child 1	1	0	0	0	1	1	0
Child 2	1	1	1	1	1	0	1

- Two parents are selected.
- A ***crossover point*** is chosen at random (shown above by the dotted line).
- Child 1 is built by taking genes from parent 1 from the left of the crossover point and genes from parent 2 from the right of crossover point.
- Child 2 is built in the same way but it takes genes from the left of the crossover point of parent 2 and genes from the right of the crossover point of parent 1.

8 marks, pro rata

c) Crossover Operators for the TSP
The problem with one-point crossover is that it can lead to illegal solutions for some problems.
Take, for example, the travelling salesman problem (TSP). A chromosome will be coded as a list of towns. If we allow the one-point crossover operator we can (and almost definitely will) produce an illegal solution by duplicating some cities and deleting others.

We can deal with this by developing crossover operators that do not produce illegal solutions. ***Order-based crossover*** is one such crossover operator.

It works as follows (assume the coding scheme represent cities)

Parent 1	A	B	C	D	E	F	G
Parent 2	E	B	D	C	F	G	A
Template	0	1	1	0	0	1	0

Child 1	E	B	C	D	G	F	A
Child 2	A	B	D	C	E	G	F

- Select two parents
- A template is created which consists of random bits
- Fill in some of the bits for child 1 by taking the genes from parent 1 where there is a one on the template (at this point we have child 1 partially filled, but it has some "gaps").
- Make a list of the genes in parent 1 that have a zero in the template
- Sort these genes so that they appear in the same order as in parent 2
- Fill in the gaps in child 1 using this sorted list.
- Create child 2 using a similar process

Question 3 – Model Answer

(a) Describe the motivation behind the simulated annealing algorithm

I am looking for an answer that says that simulated annealing (SA) allows escape from local optima. The student could describe a hill climbing algorithm and describe how this can get stuck and then describe an SA algorithm, saying that it will accept worse moves with some probability. That probability depends on the change in the evaluation function and the temperature of the system.
The larger the change, the less likely it is to be accepted. The lower the temperature, the less likely the potential solution is to be accepted.

A description of "hills" and "valleys" would be acceptable as an example of the way SA searches the landscape.

The student could also say that the only difference between hill climbing and simulated annealing is the "accept" function. Both algorithms ALWAYS accept better solutions. SA sometimes accepts worse solution (hill climbing never does).

I am not looking for a description of the physical annealing process.

5 marks, pro-rata

(b) Calculate the probabilities for simulated annealing

Current Evaluation	Neighbourhood Evaluation	Current Temperature	Acceptance Probability
75	65	25	0.6703
75	55	25	0.4493
75	65	50	0.8187
75	55	50	0.6703
65	75	25	1.4918
65	75	50	1.2214

Half mark for each correct answer (3 marks)

These are calculated by the formula exp(-*c*/*t*), where *c* is the change in the evaluation function and *t* is the temperature.

2 marks

c, i)What is the effect of having the starting temperature too high or too low?

The starting temperature must be hot enough to allow a move to almost any neighbourhood state. If this is not done then the ending solution will be the same (or very close) to the starting solution. Alternatively, we will simply emulate a hill climbing algorithm.

2 marks

However, if the temperature starts at too high a value then the search can move to any neighbour and thus transform the search (at least in the early stages) into a random search. Effectively, the search will be random until the temperature is cool enough to start acting as a simulated annealing algorithm.

2 marks

c, ii) How do you decide on a suitable starting temperature?

If we know the maximum distance (cost function difference) between one neighbour and another then we can use this information to calculate a starting temperature.

2 marks

Another method, suggested in (Rayward-Smith, 1996), is to start with a very high temperature and cool it rapidly until about 60% of worst solutions are being accepted. This forms the real starting temperature and it can now be cooled more slowly.

2 marks

A similar idea, suggested in (Dowsland, 1995), is to rapidly heat the system until a certain proportion of worse solutions are accepted and then slow cooling can start. This can be seen to be similar to how physical annealing works in that the material is heated until it is liquid and then cooling begins (i.e. once the material is a liquid it is pointless carrying on heating it).

2 marks

c, iii) How do we decide on a final temperature?

It is usual to let the temperature decrease until it reaches zero. However, this can make the algorithm run for a lot longer, especially when a geometric cooling schedule is being used.
In practise, it is not necessary to let the temperature reach zero because as it approaches zero the chances of accepting a worse move are almost the same as the temperature being equal to zero.
Therefore, the stopping criteria can either be a suitably low temperature or when the system is “frozen” at the current temperature (i.e. no better or worse moves are being accepted).

5 marks (pro-rata)

Question 4 – Model Answer

This question is based on a case study that was presented to the students (and presented in one lecture). In addition, the students were presented with three papers by Fogel and Chellipilla which they were encouraged to read. These papers were

- Chellapilla K, Fogel D. Anaconda Defeats Hoyle 6-0: A Case Study Competing an Evolved Checkers Program against Commercially Available Software, Congress on Evolutionary Computation 2000 (CEC'02), pp 857-863
- Chellapilla K. and Fogel D. Evolving Neural Networks to Play Checkers without Expert Knowledge,IEEE Trans. Neural Networks, 1999, Vol. 10:6, pp. 1382-1391
- Chellapilla K. and Fogel D. Evolution, Neural Networks, Games, and Intelligence, Proc. IEEE, 1999, Vol. 87:9, Sept., pp. 1471-1496

a) Describe the approaches used by Chellapilla/Fogel and Jonathan Schaeffer to create a world class checkers player.

The approach by Chellapilla/Fogel to evolve a world class checkers player.

The main things I am looking for from the students is

- The structure of the system
  - A neural network that has a board representation as input
  - The output of the neural network representing a heuristic value of the board quality
  - This value being passed into a mini-max search
  - The neural network being evolved by the use of an evolutionary strategy.

3 marks

- There is a process of co-evolution in that there is a population of neural networks which play against each other and then “compete” for survival such that the worse players are killed and the better players survive to the next generation where they undergo mutation to create a (hopefully) better player.

3 marks

- How the system built by Fogel and Chellapilla does not employ any domain knowledge (unlike Chinook (Jonathan Schaeffer) which won the world checkers championship in 1994. It is simply “learning” its own strategies.

2 marks

The approach used by Jonathan Schaeffer

For this answer I am looking for the student to show knowledge of Chinook. In effect this used an approach that used mini-max search, with alpha-beta pruning, parallel processor and with as much domain knowledge as the team could put into it.

For mentioning

Mini-max and alpha-beta pruning

2 marks

Opening and Endgame Database

2 marks

Won the world championship in 1994. The first machine world champion, defeating Marion Tinsley who had held the title for 40 years, only losing 3 games in that time (the 4^{th}, 5^{th}, 6^{th} and 7^{th} losses were against Chinook).

2 marks

Other evidence of having read around this area

1 mark

b) Discuss the two approaches and give your views as to which, if any, could be described as artificially intelligent. Justify your reasoning.

This question gives the student the opportunity to give a philosophical view of AI. I don't really mind what they write here as long as they use logical arguments and justify their remarks.

The type of things I would expect the students say are
- Chinook (Schaeffer) is not really AI as it is really just a massive parallel search.
- Blondie 24 (Fogel) is more AI as it uses a technique (ES's) which is based on Darwin's principle of natural evolution and survival of the fittest.

But I am happy to have the argument put the other way.

10 marks, pro rata

Question 5 – Model Answer

a) Describe what you understand by the artificial intelligence technique, *evolutionary strategies*? Ensure you describe the mutation operator and the importance it plays.

An individual in an ES is represented as a pair of real vectors, $\boldsymbol{v} = (\boldsymbol{x}, \boldsymbol{\sigma})$.

1 mark

The first vector, $\boldsymbol{x}$, represents a point in the search space and consists of a number of real valued variables. The second vector, $\boldsymbol{\sigma}$, represents a vector of standard deviations.

1 mark

Mutation is performed by replacing $\boldsymbol{x}$ by

$$\boldsymbol{x}^{t+1} = \boldsymbol{x}^{t} + N(0, \boldsymbol{\sigma})$$

where $N(0, \boldsymbol{\sigma})$ is a random Gaussian number with a mean of zero and standard deviations of $\boldsymbol{\sigma}$. This mimics the evolutionary process that small changes occur more often than larger ones.

3 marks, pro rata

The remaining 2 marks will be awarded for showing evidence of reading around the subject.

b) Describe the difference between the two evolutionary strategy schemes

In evolutionary computation there are two variations as to how we create the new generation. The first, termed $(\mu + \lambda)$, uses μ parents and creates λ offspring. Therefore, after mutation, there will be $\mu + \lambda$ members in the population. All these solutions compete for survival, with the μ best selected as parents for the next generation.

3 marks, pro-rata

An alternative scheme, termed (μ, λ), works by the μ parents producing λ offspring (where $\lambda > \mu$). Only the λ compete for survival. Thus, the parents are completely replaced at each new generation. Or, to put it another way, a single solution only has a life span of a single generation.

3 marks, pro-rata

The original work on evolution strategies (Schwefel, 1965) used a (1 + 1) strategy. This took a single parent and produced a single offspring. Both these solutions competed to survive to the next generation.

2 marks, pro-rata

c) With regards to evolutionary strategies, describe the Rechenberg "1/5 success rule", discuss why it is used and possible parameters.

ES's can be proven to find the global optimum with a probability of one but the theorem only holds for a *sufficiently* long search time. The theorem tells us nothing about how long that search time might be.

1 mark

To try and speed up convergence Rechenberg has proposed the "1/5 success rule." It can be stated as follows

> *The ratio, φ, of successful mutations to all mutations should be 1/5. Increase the variance of the mutation operator if φ is greater than 1/5; otherwise, decrease it.*

2 marks

The motivation behind this rule is that if we are finding lots of successful moves then we should try larger steps in order to try and improve the efficiency of the search. If we not finding many successful moves then we should proceed in smaller steps.

1 mark

The 1/5 rule is applied as follows

$$\text{if } \varphi(k) < 1/5 \text{ then } \boldsymbol{\sigma} = \boldsymbol{\sigma} c_d$$
$$\text{if } \varphi(k) > 1/5 \text{ then } \boldsymbol{\sigma} = \boldsymbol{\sigma} c_i$$
$$\text{if } \varphi(k) = 1/5 \text{ then } \boldsymbol{\sigma} = \boldsymbol{\sigma}$$

The variable, k, which is a parameter to the algorithm, dictates how many generations should elapse before the rule is applied. c_d and c_i determine the rate of increase or decrease for $\boldsymbol{\sigma}$. c_i must be greater than one and c_d must be less than one. Schwefel (Schewel, 1981) used $c_d = 0.82$ and $c_i = 1.22$ (=1/0.82).

3 marks

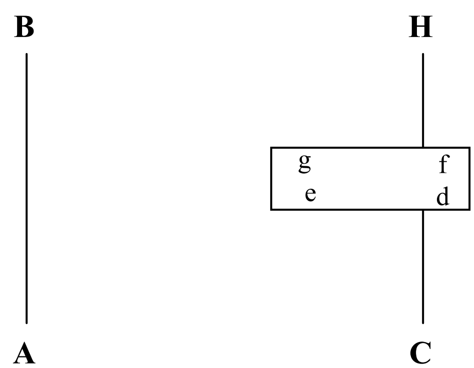
3 marks awarded for evidence of reading the literature

3 marks

Question 6 – Model Answer

a) Describe how ants are able to find the shortest path to a food source in nature.

From the course notes
Consider this diagram.



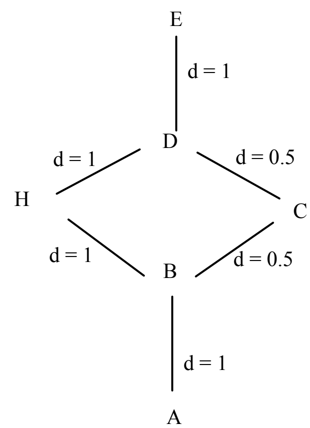
If you are an ant trying to get from A to B then there is no problem. You simply head in a straight line and away you go. And all your friends do likewise.
But, now consider if you want to get from C to H. You head out in a straight line but you hit an obstacle. The decision you have to make is, do you turn right or left?
The first ant to arrive at the obstacle has a fifty, fifty chance of which way it will turn. That is whether it will go C,d,f,H or C, e, g, H.
Also assume that ants are travelling in the other direction (H to C). When they reach the obstacle they will have the same decision to make. Again, the first ant to arrive will have a fifty, fifty chance or turning right or left.

But, the important fact about ants is that as they move they leave a trail of pheromone and ants that come along later have more chance of taking a trail that has a higher amount of pheromone on it.
So, by the time the second, and subsequent, ants arrive the ants that took the shorter trail will have laid their pheromone whilst the ants taking the longer route will still be in the process of laying their trails.
Over a period of time the shorter routes will get higher and higher amounts of pheromone on them so that more and more ants will take those routes.
If we follow this through to its logical conclusions, eventually all the ants will follow the shorter route.

4 marks (pro-rata) for the students answer.

The students might give a slightly more formal answer (below), which is fine

We have described above how ants act in the real world. We can formalise it a little as follows



The above diagram represents the map that the ants have to traverse.
At each time unit, t, each ant moves a distance, d, of 1.
All ants are assumed to move at the same time. At the end of each time step the ants lay down a pheromone trail of intensity 1 on the edge (route) they have just travelled along.
At t=0 there is no pheromone on any edges of the graph (we can represent this map as a graph).
Assume that sixteen ants are moving from E to A and another sixteen ants are moving from A to E.
At t=1 there will be sixteen ants at B and sixteen ants at D. At this point they have a 0.5 probability as to which way they will turn. We assume that half go one way and half go the other way.
At t=*2* there will be eight ants at D (who have travelled from B, via C) and eight ants at B (who have traveled from D, via C). There will be sixteen ants at H (eight from D and eight from B). The intensities on the edges will be as follows.

ED = 16, AB = 16, BH = 8, HD = 8, BC = 16 and CD = 16

If we now introduce another 32 ants into the system (16 from each direction) more ants are likely to follow the BCD rather than BHD as the pheromone trail is more intense on the BCD route.

b) Using the travelling salesman problem as an example, define the following terms with relation to ant algorithms

Visibility
Evaporation
Transition Probability

Below are the notes from the course handouts. The relevant points are re-produced in bold.

Visibility
When an ant decides which town to move to next, it does so with a probability that is based on the distance to that city and the amount of trail intensity on the connecting edge. The distance to the next town, is known as the *visibility*, n_{ij}, and is defined as $1/d_{ij}$, where, d, is the distance between cities i and j.

2 marks (pro-rata) for describing visibility.

Evaporation
At each time unit *evaporation* takes place. This (which also models the real world) is to stop the intensity trails building up unbounded. The amount of evaporation, *p*, is a value between 0 and 1.

1 mark for describing evaporation.

Transition Probability

3 marks (pro-rata) for describing the transition probability

The important points to bring out are that the transition probability determines the likelihood of an ant choosing a particular edge to next travel along. The transition probability is a function of the pheromone already on that edge (the more, indicating that many ants have used it, so it is probably a good route), the visibility (how close is this vertex to the one under consideration) and the fact that the ant must *not* have visited that city before (in keeping with the TSP).

Note, if the student produce the formulae that model these, no extra marks should be awarded but the fact that the student has shown them can be taken into account for the next part of the question.

(c) Suggest a suitable problem, other than the travelling salesman problem, that an ant algorithm could be used to solve.
Discuss how the problem would be represented, the heuristic value that could be used and how you would decide how much pheromone to deposit.

This is the students chance to show they have read the literature (and, to be honest, they would only need to visit Marco Dorigo's web site).
I am looking for

The problem description (e.g. Quadratic Assignment Problem, Vehicle Routing Problem etc.)
4 marks

The heuristic value they would use (the equivalent of the distance between cites in the TSP)
3 marks

How they would deposit pheromone (the equivalent of depositing pheromone in proportion to the tour length in the TSP).
3 marks

I will give **5 marks** for other information given. For example, the formulae that are used within an ant algorithm.