Introduction to Artificial Intelligence

Week 7

Evolutionary Algorithms Part I

Evolutionary Algorithms

- Use the concepts of the Neo-Darwinian Synthesis or Lamarckian Evolution
  - Natural Selection
  - Inheritable Traits
  - Fitness Biased Reproduction
  - Fitness is generated based on the
  - Generational/Time Series
- Four major overarching techniques discovered about 1980
  - Genetic Algorithms - Holland
  - Genetic Programming - Koza
  - Evolutionary Programming - Fogel
  - Evolutionary Strategies – Rechenbreg/Schwefel
- Large arguments about priority of technique leads to a compromise on the title of Evolutionary Algorithms – schisms still fighting for dominance – beware ye who enter here

EA System

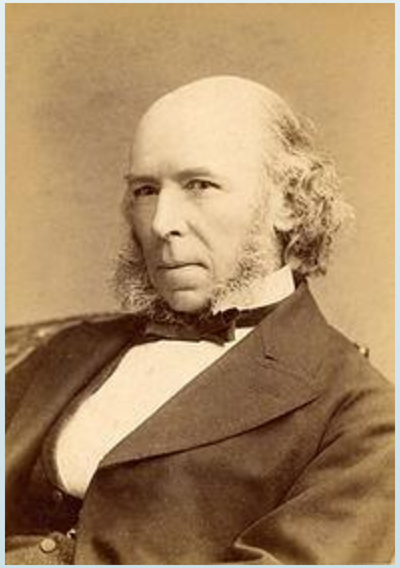
- Create a randomized **population** made up of **chromosomes**, data structures which encode a potential solution
- Until <Done>, based on a **stopping criteria**
  - Find an **objective/fitness score** for each member of the population
  - **Select members** to act upon using some **variation operators**
    - Apply operations on the members
      - **Crossover**
      - **Mutations**
  - Replace some members of the population with these children from the variation operators
  - Keep some members from the previous population in the new population, i.e. **elitism/inheritance**

Selection

- Cartoon of the ideas of Natural Selection by Darwin
- Provides a fitness biased method of keeping good structures
  - Note Biased not based
  - We can still accept 'worst' choices
- Structures which have a higher fitness on the objective score are more likely to continue on in the population

Survival of the Fittest

- Major misconceptions in the application of this phase
- Darwin didn’t coin it – nor was it used until the 5th edition of Origins
- Used by Herbert Spencer in Principles of Biology
  - "This survival of the fittest, which I have here sought to express in mechanical terms, is that which Mr. Darwin has called 'natural selection', or the preservation of favoured races in the struggle for life.“
- Darwin’s use was based on the fitness of a creature to survive in a local environment

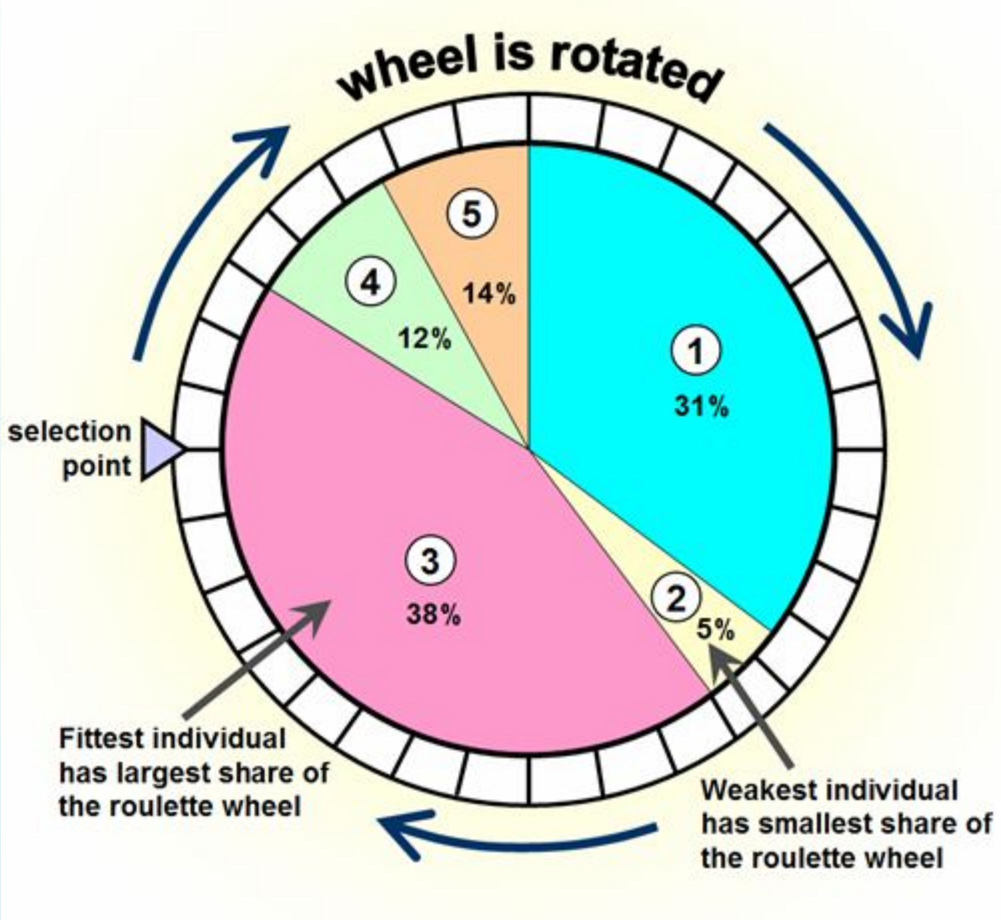


Biological Fitness

- The phrase seams to imply that there is an innate idea of what is FIT/UNFIT
- Post Hoc Ergo Proctor Hoc Fallacy
  - The creature survived as it was fit
  - The creature is fit because it has survived
- Biological Fitness is defined as the number of offspring which reach sexual maturity and are able to pass along their genes
- Evolutionary Algorithms fall under this misconception – we apply fitness as a post hoc

Fitness Proportional

- Each member is given a section of the wheel in relation to their fitness score
- Usually Fit(Member)/ Sum of Fit(All Member)
- Wheel is spun for a number of times
- Winners Breed Together



Tournament

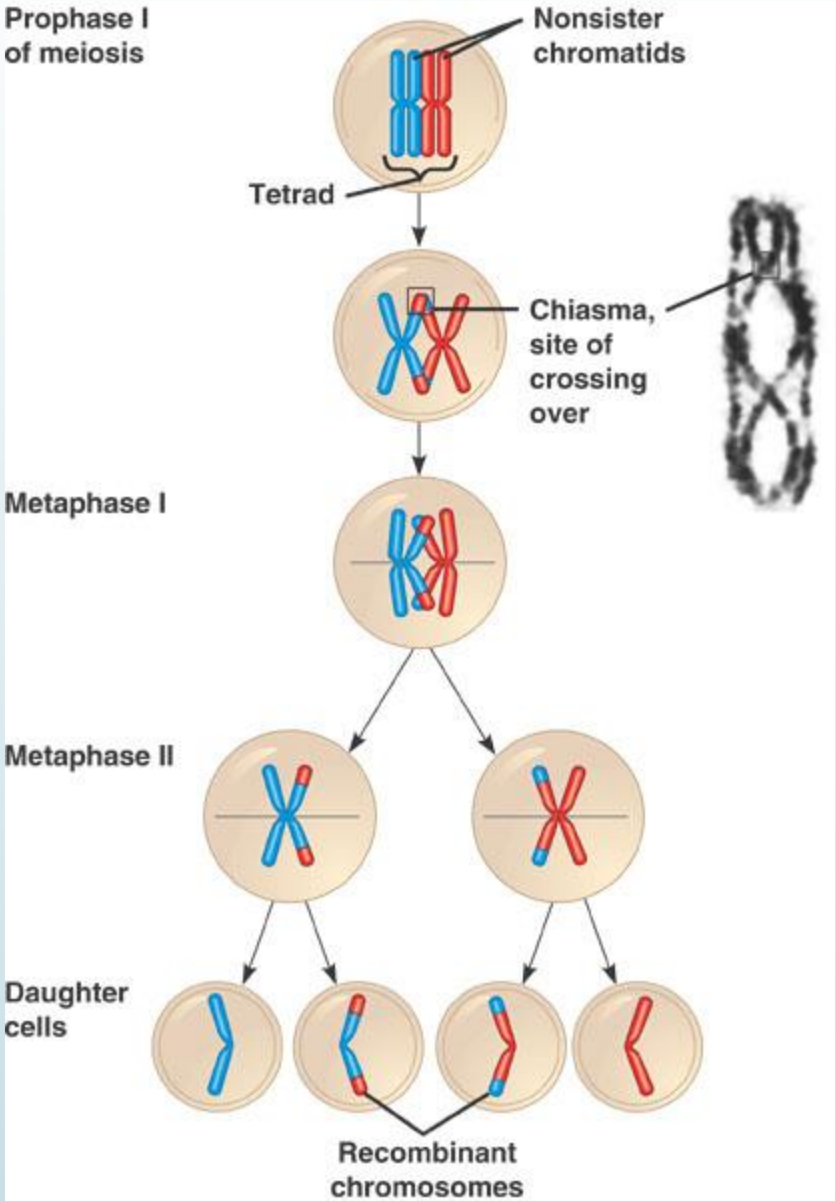
- A number of different manners are held for the construction of the challengers
  - At Random
  - Groups of N
- Each of the structures in a tournament is compared and the most fit continues on to breed
- Fighting solutions
- Selection Pressure (the likelihood of only selecting from the higher fitness cohorts is a controllable feature)
  - Small Tournaments
  - Larger Tournaments

Genetic Algorithms

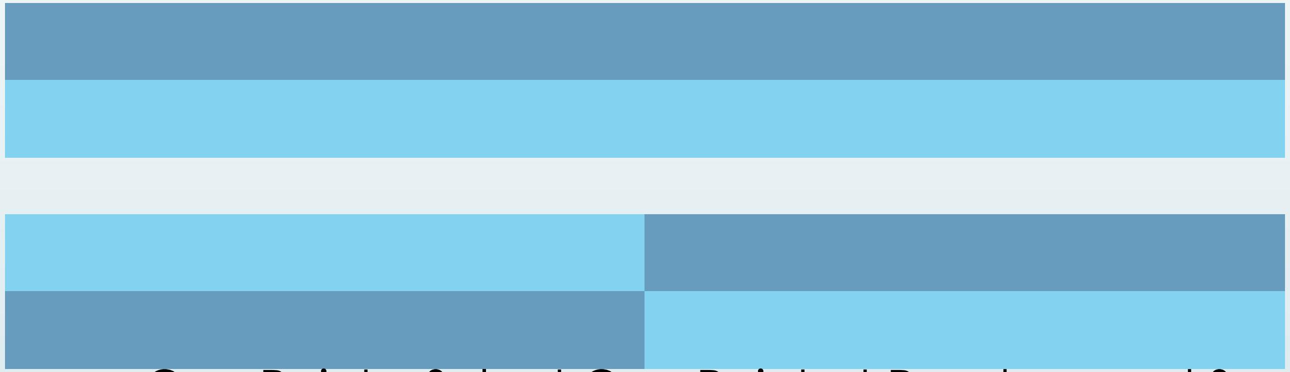
- Representation: Data Structure (commonly a discrete string)
- Selection: Roulette(aka Fitness Proportional) or Tournament
- Crossover: Yes. Data Structure Dependent
- Mutation: Yes. Data Structure Dependent, commonly a small change to a percentage of symbols in the string

Crossover in Biology

- Process of Meiosis
- Creation of **gamete** cells
  - Sex cells
  - from the Greek for wife
- Haploid creatures have chromosome pairs
- Is not a representation of the actions which happen in

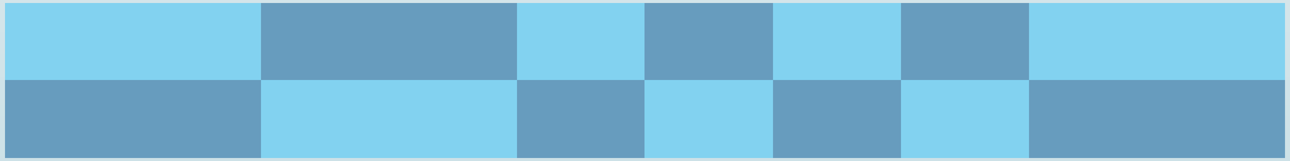


Crossover in a GA on Strings



One Point – Select One Point at Random and Swap

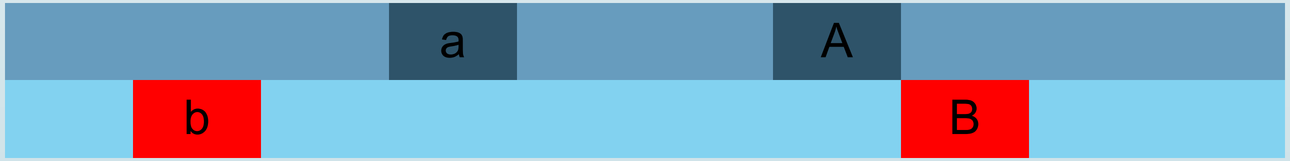
Two Point – Select Two Point at Random and Swap



Uniform Order – Swap all with Probability of .5

Mutation in a GA on Strings

Point Mutation – Change the Symbol at a Loci to Some Other Symbol



Swap Mutation – Swap Two Loci in the String

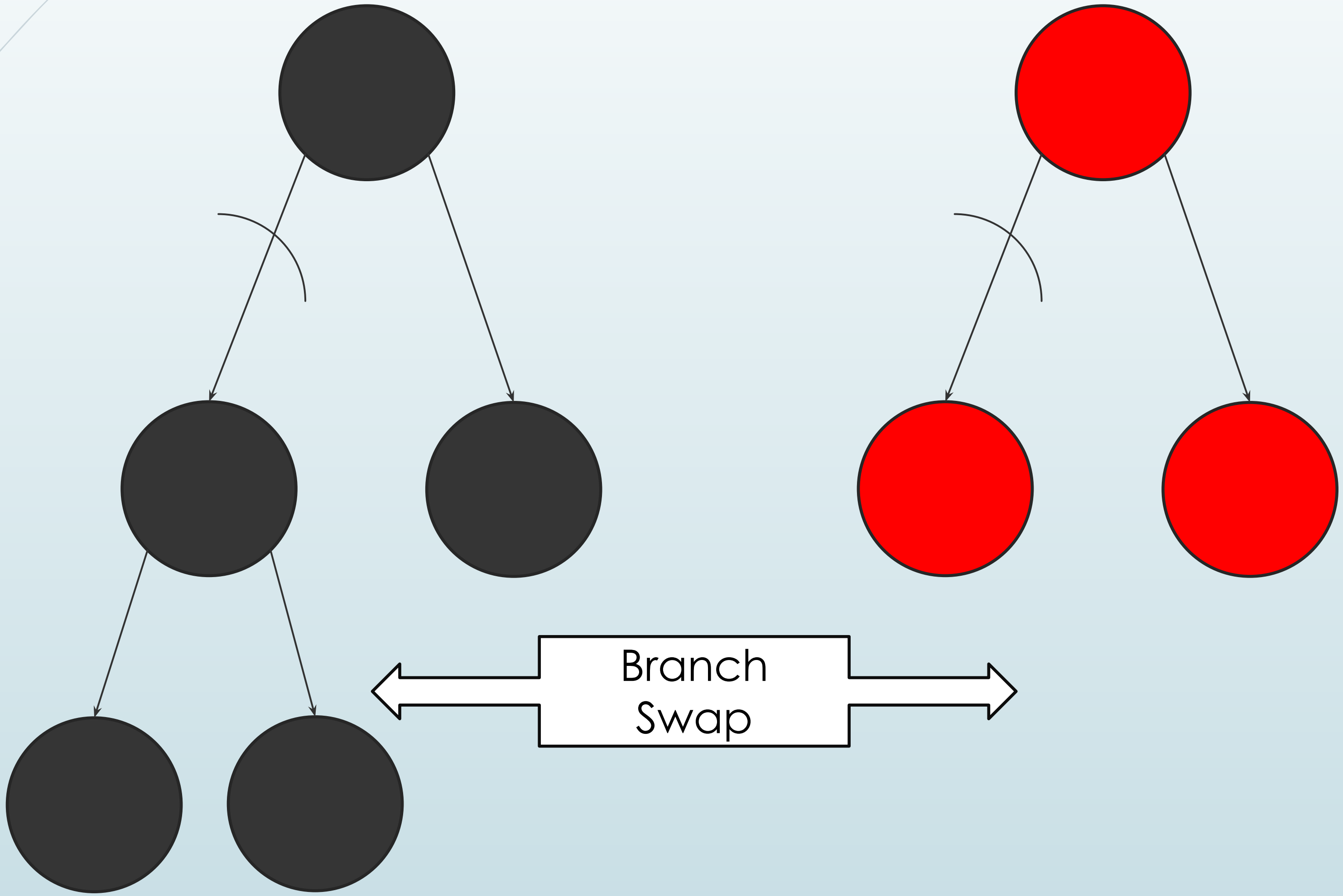
Genetic Programming

- Representation: Tree Based
- Selection: Roulette or Tournament
- Crossover: Yes. Branches of the Trees are Exchanged.
- Mutation: Yes. Leaf value/Symbol Change or Operator Change
- Special Operations: Yes. Removal of Extra Symbols called bloat. Functions may be defined as shorter symbols (ADF)

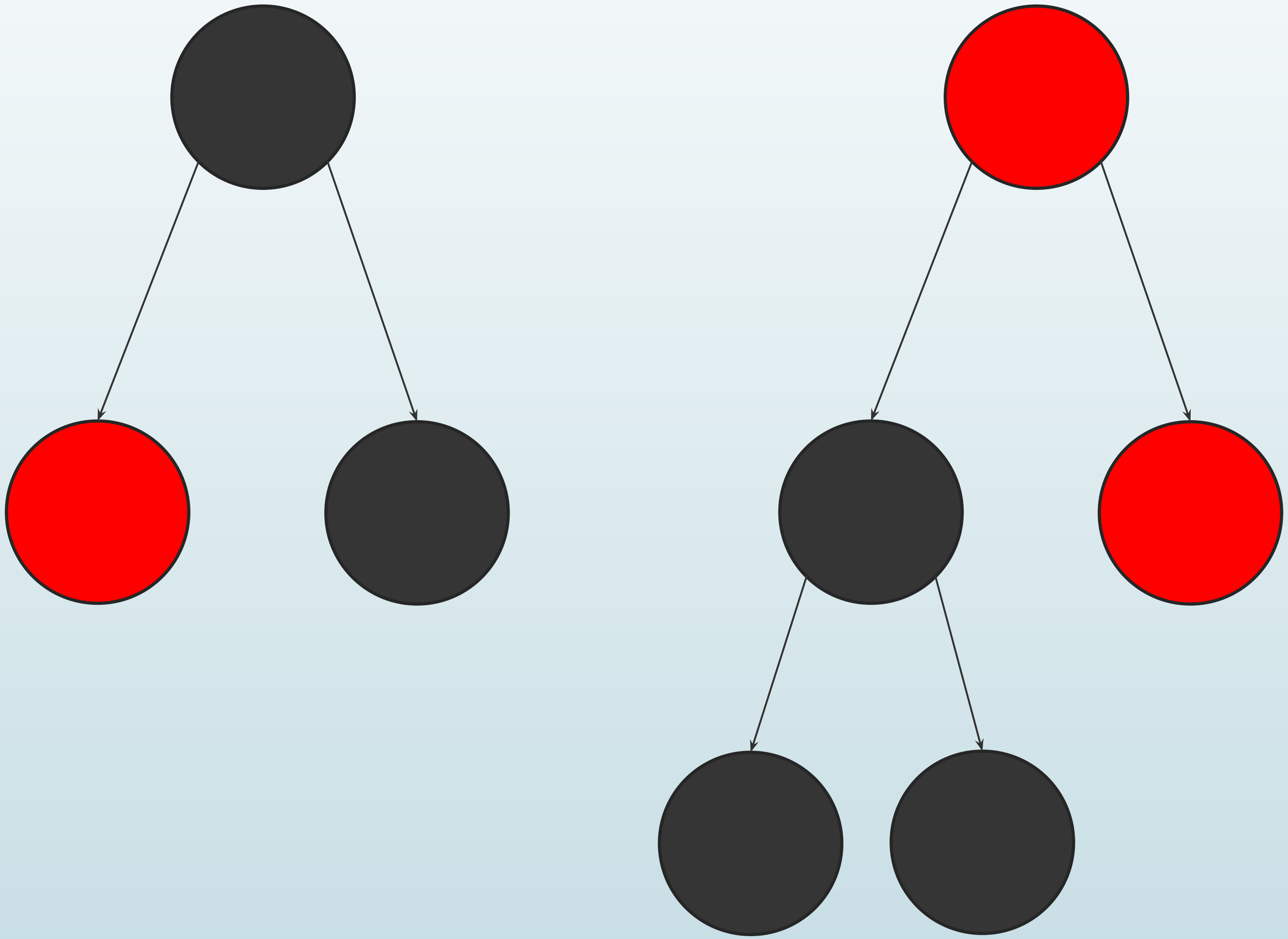
GP Parse Trees and LISP

- The idea comes from the programming language of LISP
- (function, arg1, arg2, …, argN)
- Arguments are functions or terminals
- Terminals are literals (1, `x`) or variables (x, count)
- LISP allows for programs which manipulate code and run that code
- Other languages need to create a simulator
- Prefix notation e.g. (+ 1 (* 7 X)) is 7x+1
- No need for order of operations – all operations are explicitly ordered by brackets

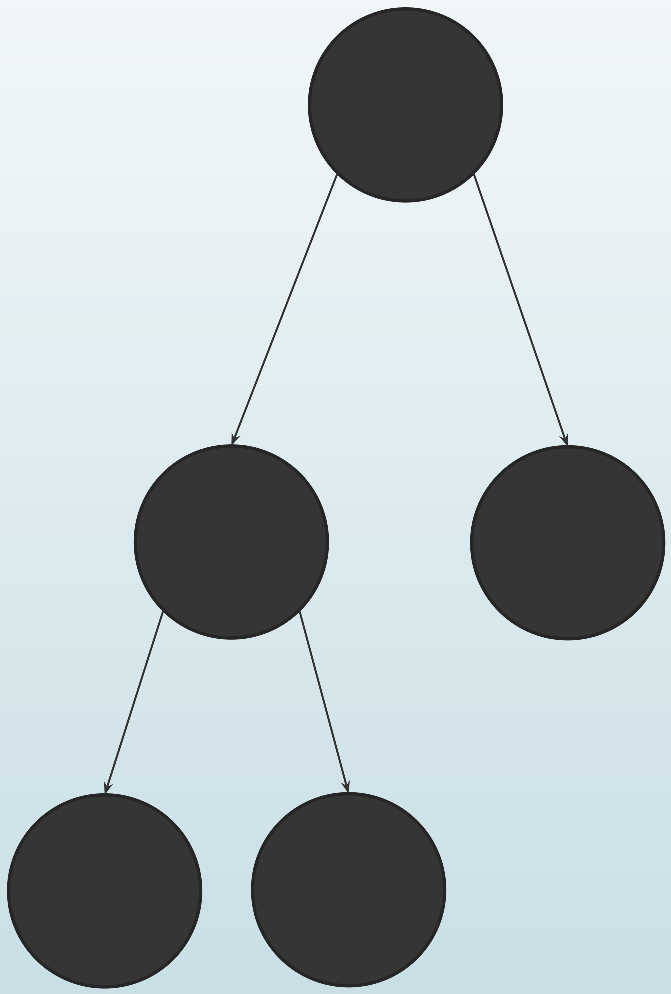
Crossover in a GP Tree



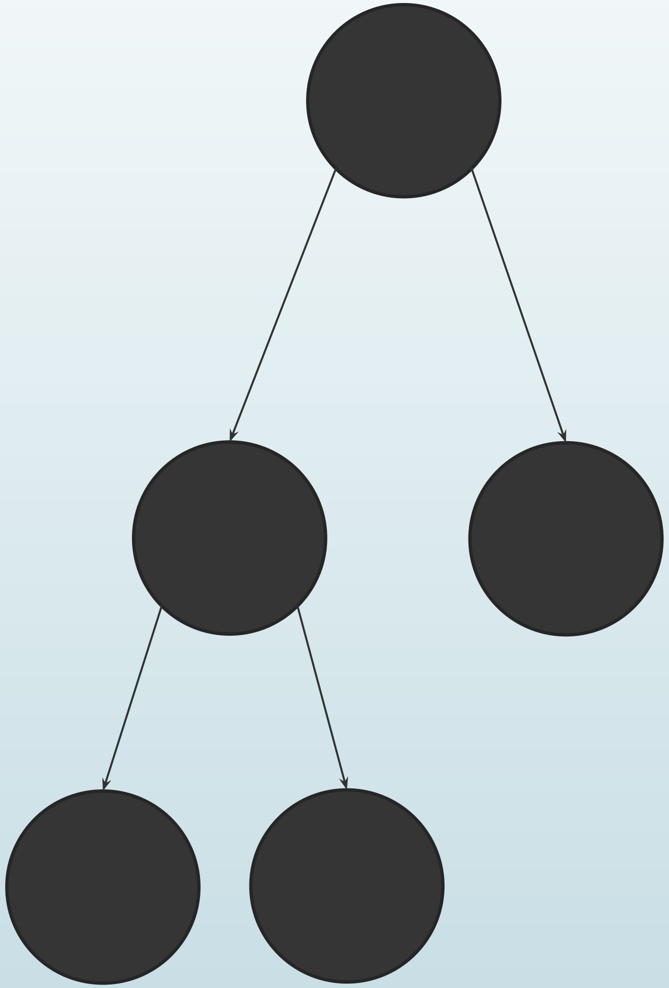
Crossover in a GP Tree



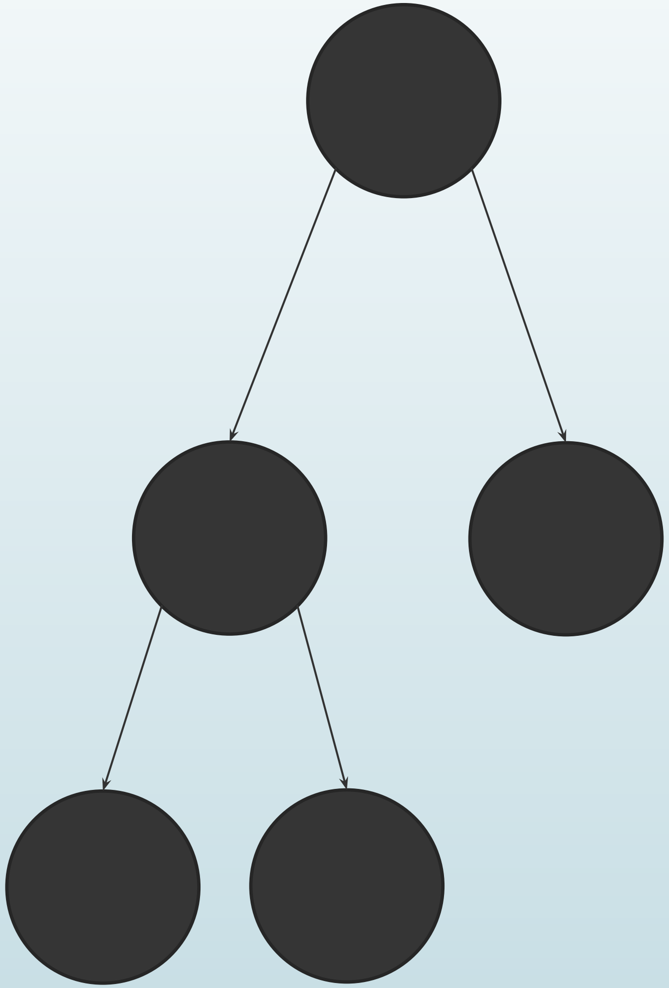
Mutation of a Terminal in a GP Tree



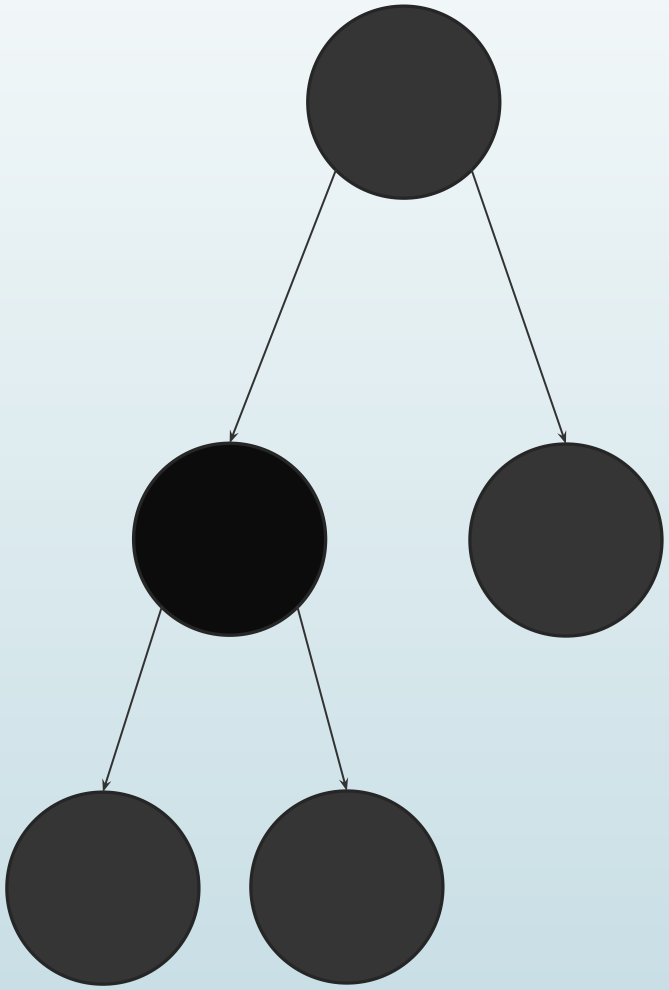
Mutation of a Operation in a GP Tree



Growing Operation in a GP Tree

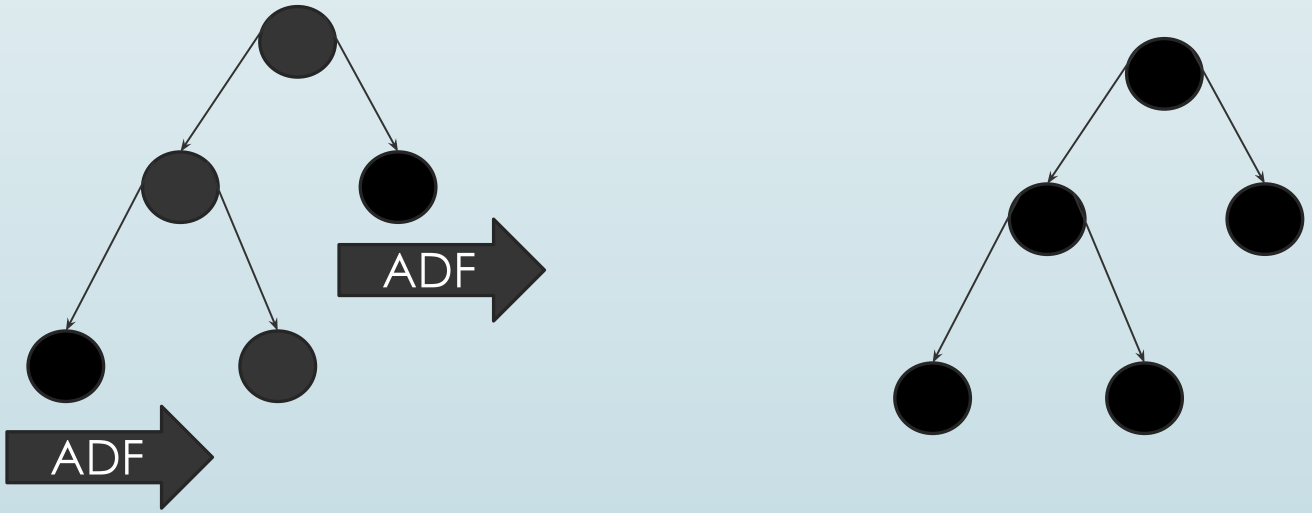


Cut Operation in a GP Tree



ADF Trees

- ADF – Automatically Defined Functions
- Many Times we have a tree computed again and again – repetition is costly
- Allow for the construction of GPs with smaller GP trees – construct a hierarchy



Rules on Functions in Trees

- All trees should produce `legal` programs
- Operations which produce common errors – such as divide by zero – should have a protected version that explicitly maps those errors to a legal input value – such as 0

Bloat

- A number of operations provide no change in the result
  - Anything multiplied by 1
  - Anything added to 0
- A number of operations cancel out parts of the tree
  - Anything multiplied by 0
  - An operation followed by its inverse
- Leads to trees which are equally as fit but are larger

Why does Bloat exist

- Imagine two trees which both add 5 to 6 the one has 3 nodes in the tree, the other has 10 nodes which add a value multiplied by 0
- You require a minimum number of 3 nodes to implement (+ 5 6)
  - One for each of the arguments
  - One for the operand
- 7 nodes in the second tree are bloat
- What is the probability that a mutation operation (change operand/argument) will affect the solution to the problem?

Bloat Saves Solutions

- In the first tree the changing of an operation or argument will completely change the result, 100% of the time it will change the outcome
- In the bloated tree, 3 nodes are part of our solution, one to add, and two to multiply by 0. Changing these nodes will lead to a different answer.
- Yet 4 nodes are inconsequential to the answer – 40% of the time there will be no change in fitness based on a mutation
- Heritability – A solution with more of these null mutations is likely to have its children survive as they have the same fitness

Bloat in Biology

- Repetition of genes
- Repetition of genes
- Duplication of genes
- Transposon Elements
- Repetition of genes
- Transposon Elements
- Not to be confused with redundant systems – Example Weight Loss Pill Trials

Fat Blocking Pill

- Idea – We want to create a diet pill
- Block the regulatory system in the human body which makes you gain weight
- Step 1 – find system
- Step 2 – create blocking drug
- Step 3 – Clinical Trials on Mice

Mice Got Fatter

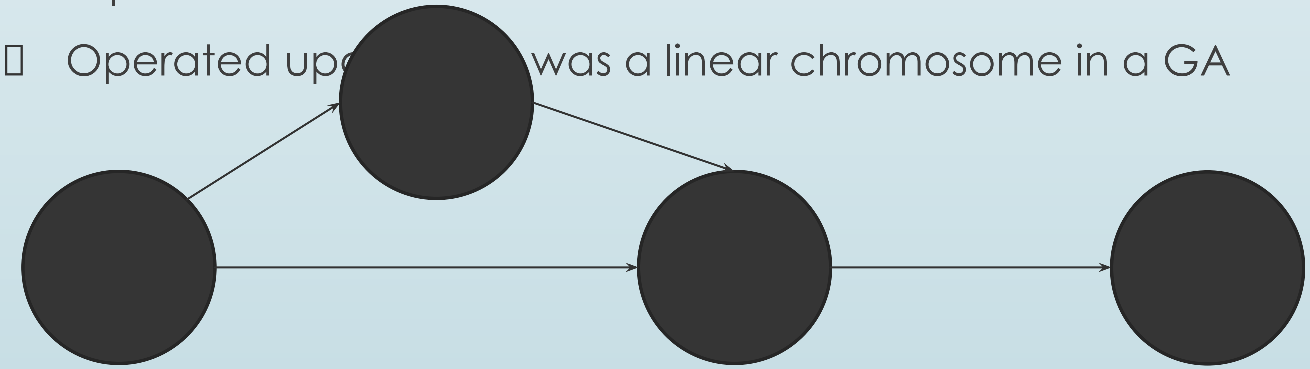
- The clinical trial showed the mice not only gained weight – they gained more weight than the control on the same diet!
- But we Blocked the Signals
- Ah – but did you block all the signals
- Mammals have a secondary fat producing system which will come into effect when our primary system is compromised
- Issue – this secondary system is not as refined

Parsimony

- We like things simple in design of solutions
  - *Il semble que la perfection soit atteinte non quand il n'y a plus rien à ajouter, mais quand il n'y a plus rien à retrancher.* (*Terre des Hommes*, 1939).
  - It seams that a perfect design is not one which one looks for things to add, but is one where there is nothing left to remove
- Let the trees grow but trim them at the result
- Penalize Larger Trees!
  - Reduction in fitness score
  - Less chance to Breed
- Find a method which does not use a tree based model for the representation

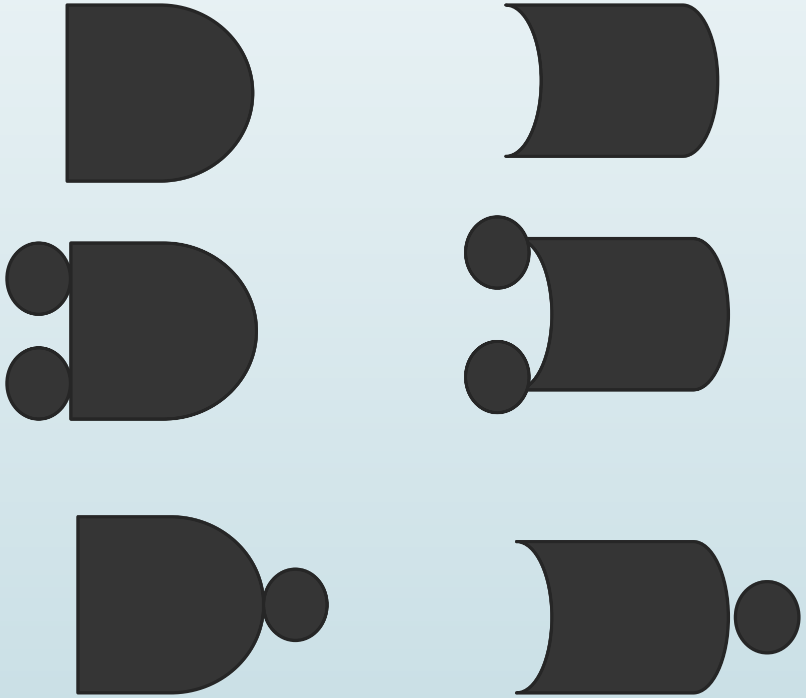
Other Representations

- Directed Acyclic Graphs (DAG)
  - Cartesian Genetic Programming
  - Function Stacks
- Instead of Evolving Trees – Representation is graph
- Repeated input branches are passed down the DAG representation
  - Removes the need to recompute
  - Expansion and Bloat is limited – fixed size data structure
  - Operated up was a linear chromosome in a GA

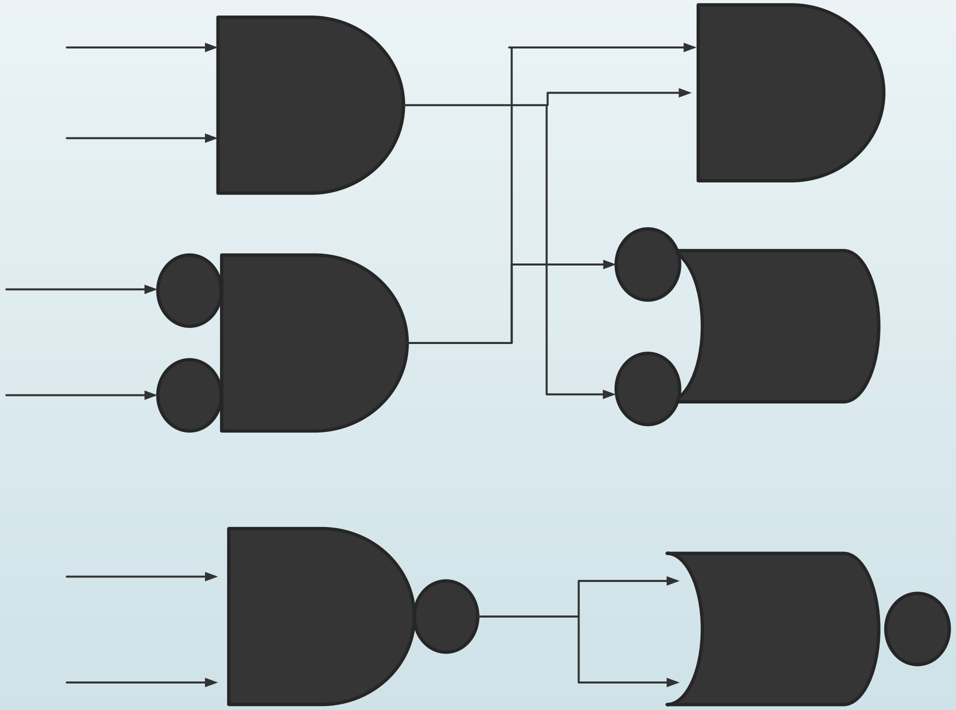


Cartesian Genetic Programming

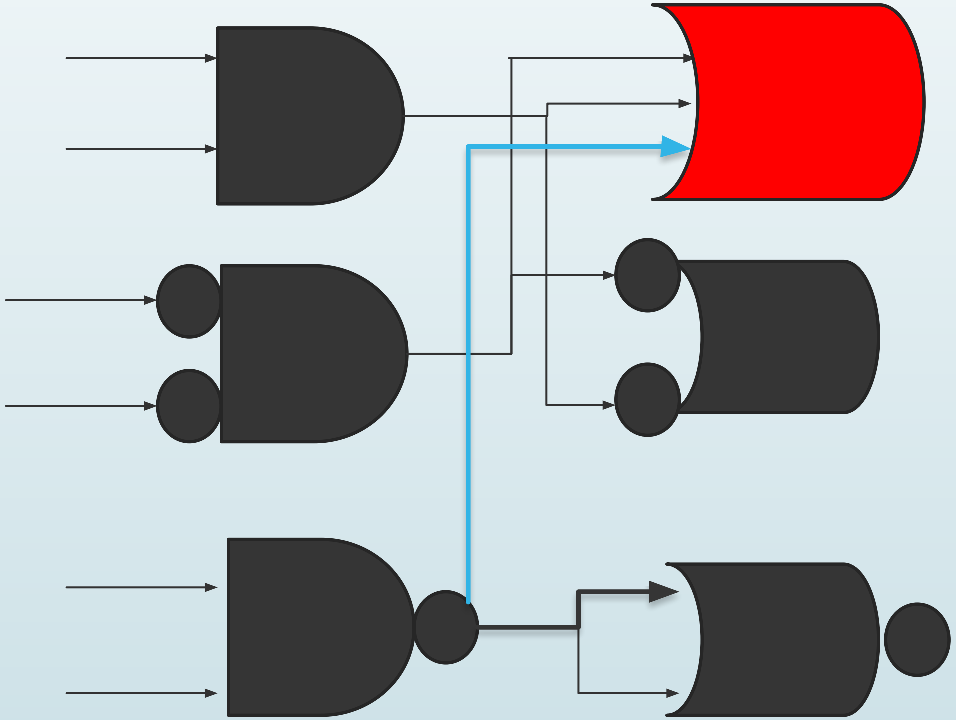
- NxM grid of Operations connected by wires
- Think Printed Circuit Boards



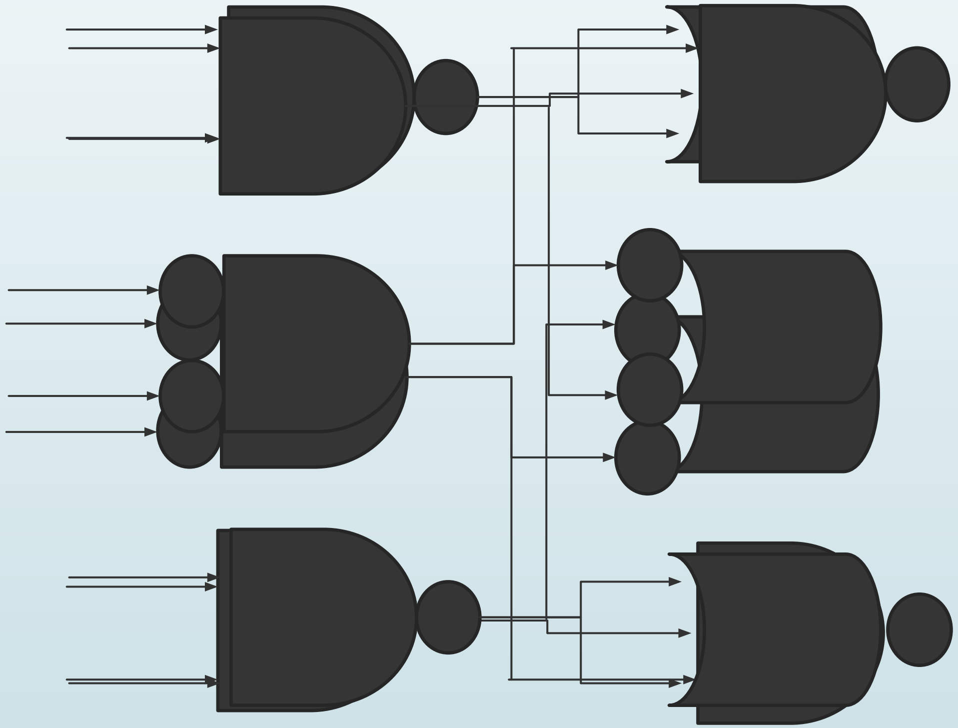
Data Structure



Mutations Can Affect Nodes and Edges



Flip Operations



Function Stack Representation

- Function Stacks have a linear chromosome consisting of nodes
- Node Contains
  - Function of 0..N inputs
  - Inputs – Either Pervious Nodes in Order of the Chromosome or an input value
  - An Ephemeral Constant
- Crossover as per a linear string in a GA
- Mutations change the operation or constants

Evolutionary Programming

- Representation: Finite State Machine
- Selection: Replace with a member of a sample of mutants if better than parent
- Crossover: No.*
- Mutation: Yes. Add or Remove a node, or Change transition, output, or starting node.
- Note: Designed for use in an online setting for controller

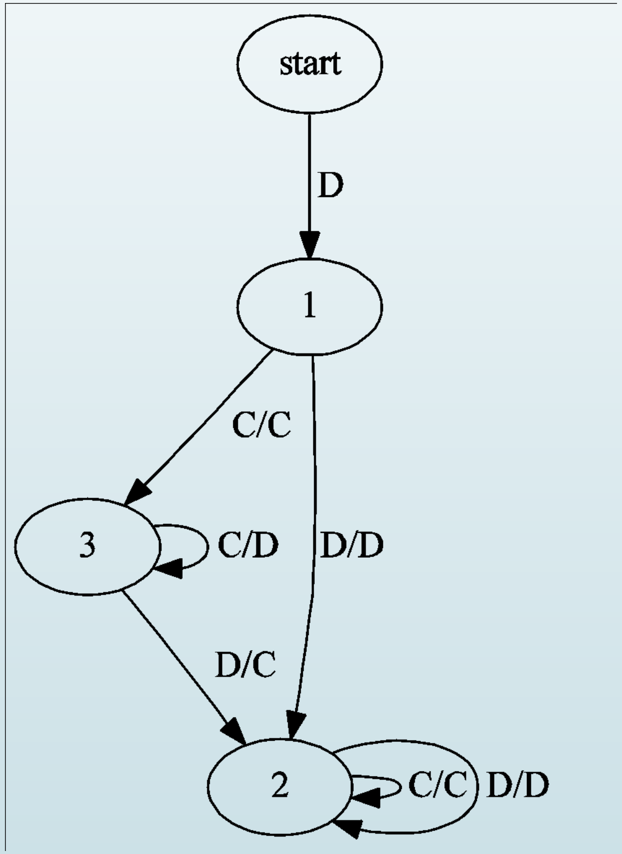
Finite State Machine

- A determinisitic finite state machine is defined by a tuple <Q, I ,Z , O, δ, ω, q> where:
  - Q – finite set of states
  - I – finite set of inputs
  - Z – finite set of outputs
  - δ – transition function δ:IxQ->Q
  - ω – output function ω:IxQ->Z
  - q – initial starting state where q ϵ Q
- You can also define it via a state transition diagram

Representations of a FSM

Initial 1,D

IF	C	D
1	3,C	2,D
2	2,C	2,D
3	3,D	2,C



Mutations in EP FSM

- Mutations are insertions, deletions, changes to a transition, changes to a output, change starting node
- Insertions – add a node and its connectors, find some set of random transitions to place into it (do not want it isolated)
- Deletions – select a random node, all incoming transitions sent to other nodes at random
- Change transition, change output, change initial, are self explanatory

Evolutionary Strategies

- Representation: Vector of Real Values
- Selection: Replace with a member of a sample of mutations if better than parent
- Crossover: No.*
- Mutation: Yes. Add small normally distributed parameter to a value.

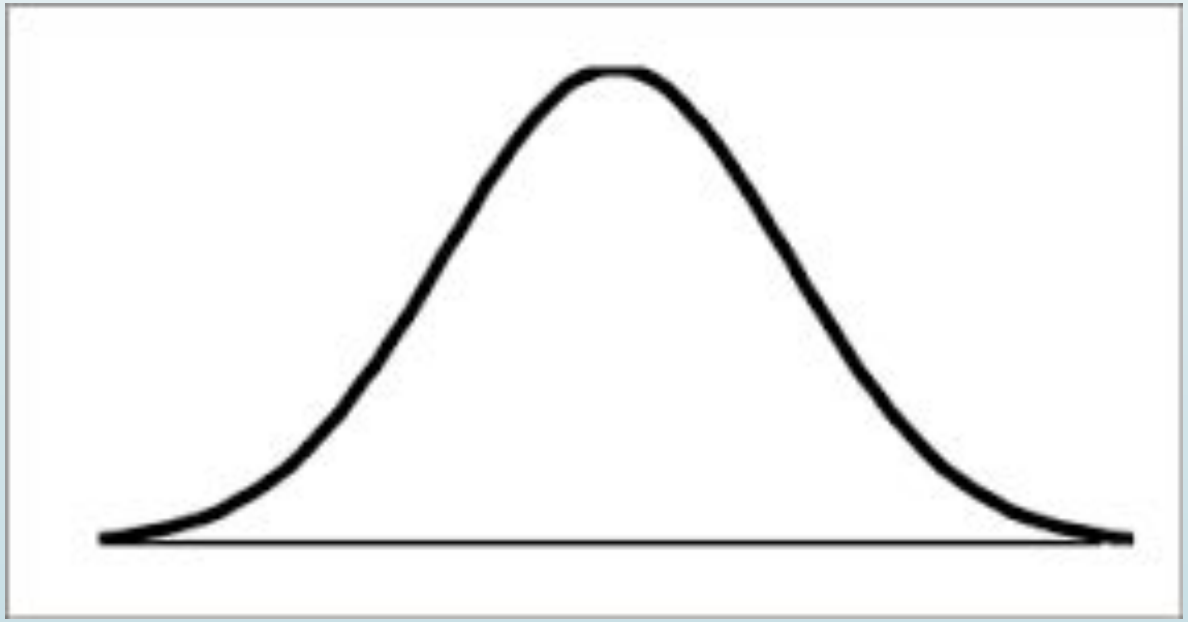
*Has been added in some variants

ES Bracketed Notation

- Normally Distributed Function of mutation is applied to the string of real numbers – some use log normal
- (1+1)-ES – a mutant is tested against its parent and the fittest is retained
- (1+λ)-ES - λ mutants are tested against their parent with the fittest remaining, the parent retained if the best
- (1,λ)-ES - λ mutants are tested against their parent, the parent is never retained, only one of mutants will continue on
- (μ/ρ+, λ)-ES – A population is used where a group of mutants is made for each and compete with the set of parents, this may also have a crossover operation

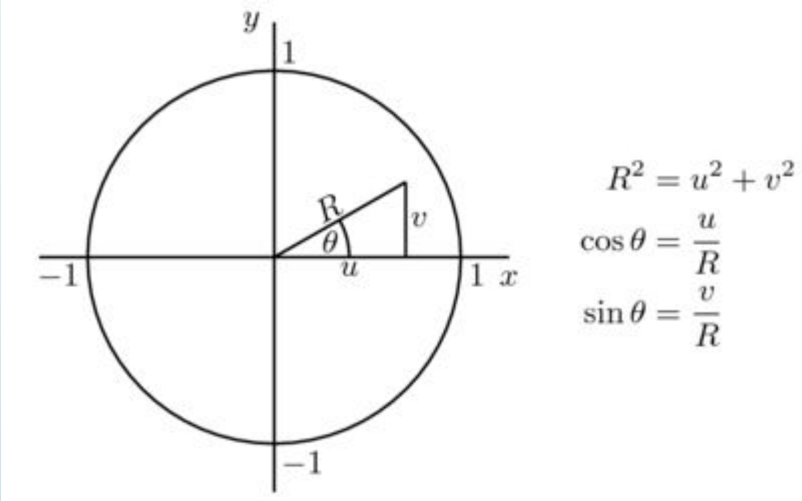
Small Mutations

- Pull from the Gaussian/Normal Distribution
- Many Mutations will make small changes in parameters, few will make large changes



Generating a Normal Random Variation

- Assume we have a Uniform RNG [0,1]
- Add N (larger the better) RNGs subtract N/2
  - Gives an approximation to the normal between +/-N/2
- Box-Muller Transform
  - Take two RNG numbers, u and v
  - Treat u and v as polar coordinates
  - $r^2 = u^2 + v^2$
  - $z_u = u \cdot \sqrt{\frac{-2 \ln r^2}{r^2}}; \; z_v = v \cdot \sqrt{\frac{-2 \ln r^2}{r^2}}$



Which Should I use?

- No Free Lunches Here
- Note the similarities between Genetic Algorithms and Programming – Key Difference is the type of representation
- Similarly Evolutionary Programming and Strategies differ based on representation
- How you can represent your problem has a big effect on which of these methods is available (more on this next time in the representation lecture)
- Offline or Online?
  - Speed of evaluation becomes a factor
  - Crossover is more expensive
  - Fitness evaluation is ALWAYS more expensive