Evolutionary Computation

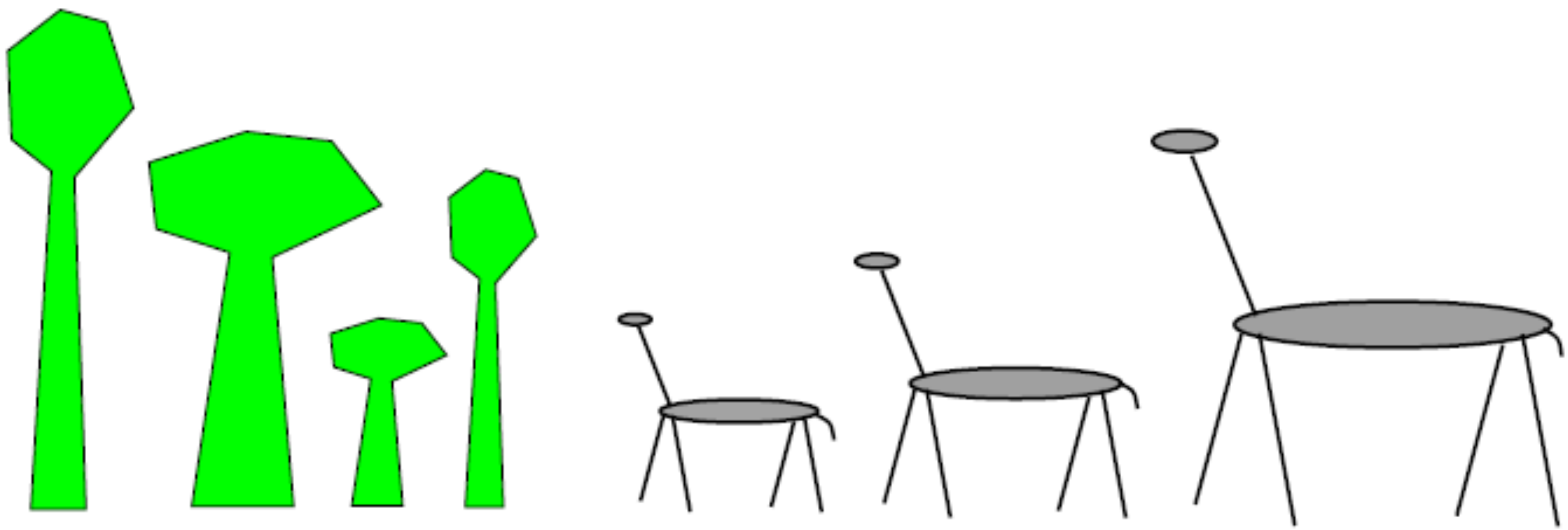
Khaled Rasheed
Computer Science Dept.
University of Georgia
http://www.cs.uga.edu/~khaled

Presentation outline

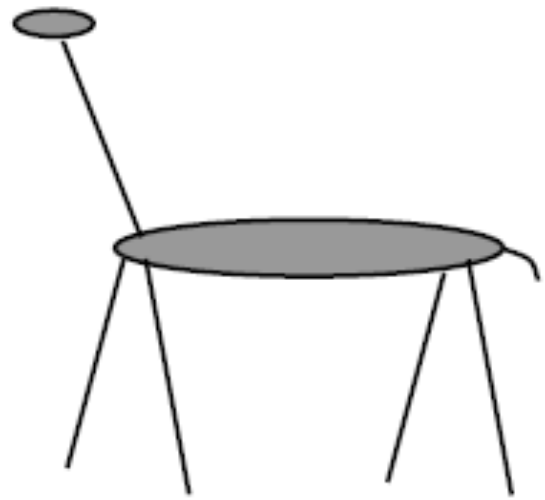
- Genetic algorithms
  - Parallel genetic algorithms
- Genetic programming
- Evolution strategies
- Classifier systems
- Evolution programming
- Related topics
- Conclusion

In the forest

- Fitness = Height
- Survival of the fittest



Reproduction



Genome: ATTGCGCCATGAT ATTAAACCATAGT

Crossover:

ATTG	CGCCATGAT
ATTA	AACCATAGT
ATTG	AACCATAGT

Mutation:

ATTGAACCATAGT

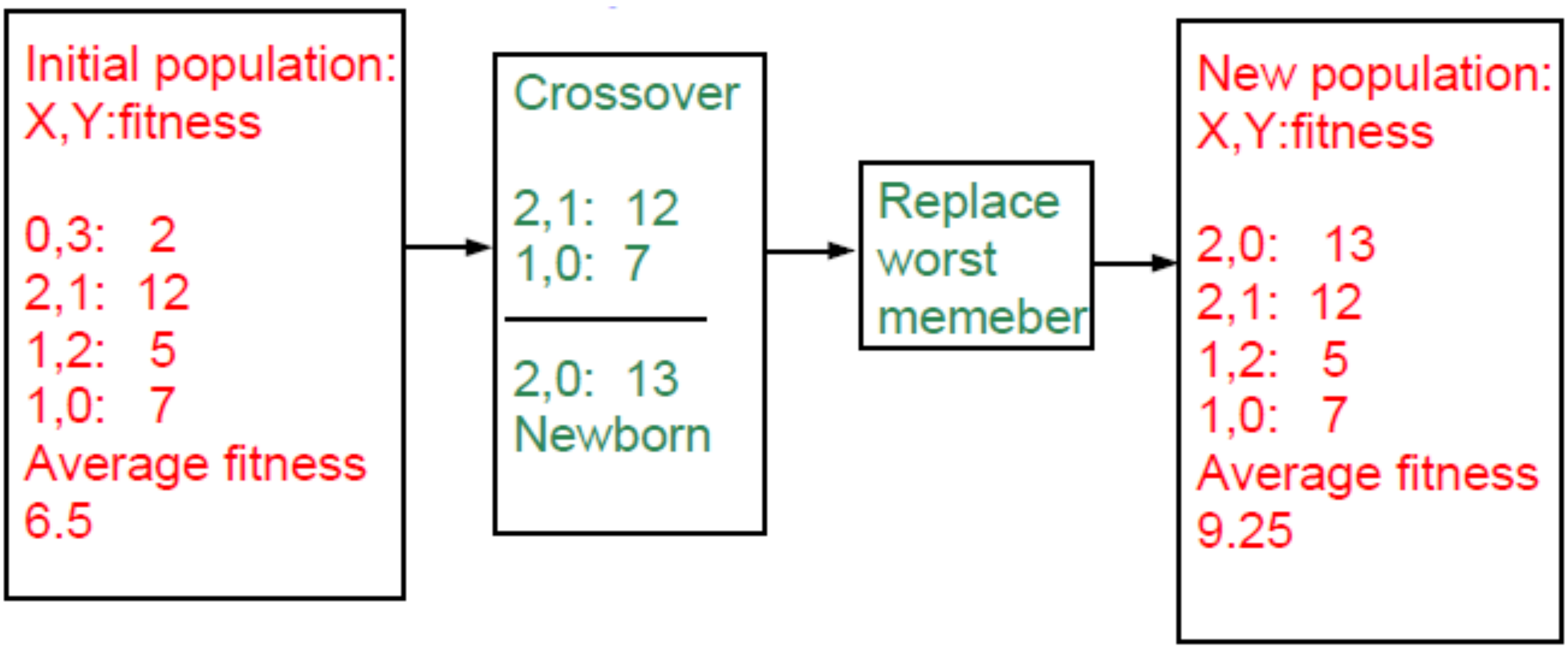
ATTGAAGCATAGT

Genetic Algorithms

- **Maintain a population of potential solutions**
- **New solutions are generated by selecting, combining and modifying existing solutions**
  - Crossover
  - Mutation
- **Objective function = Fitness function**
  - Better solutions favored for parenthood
  - Worse solutions favored for replacement

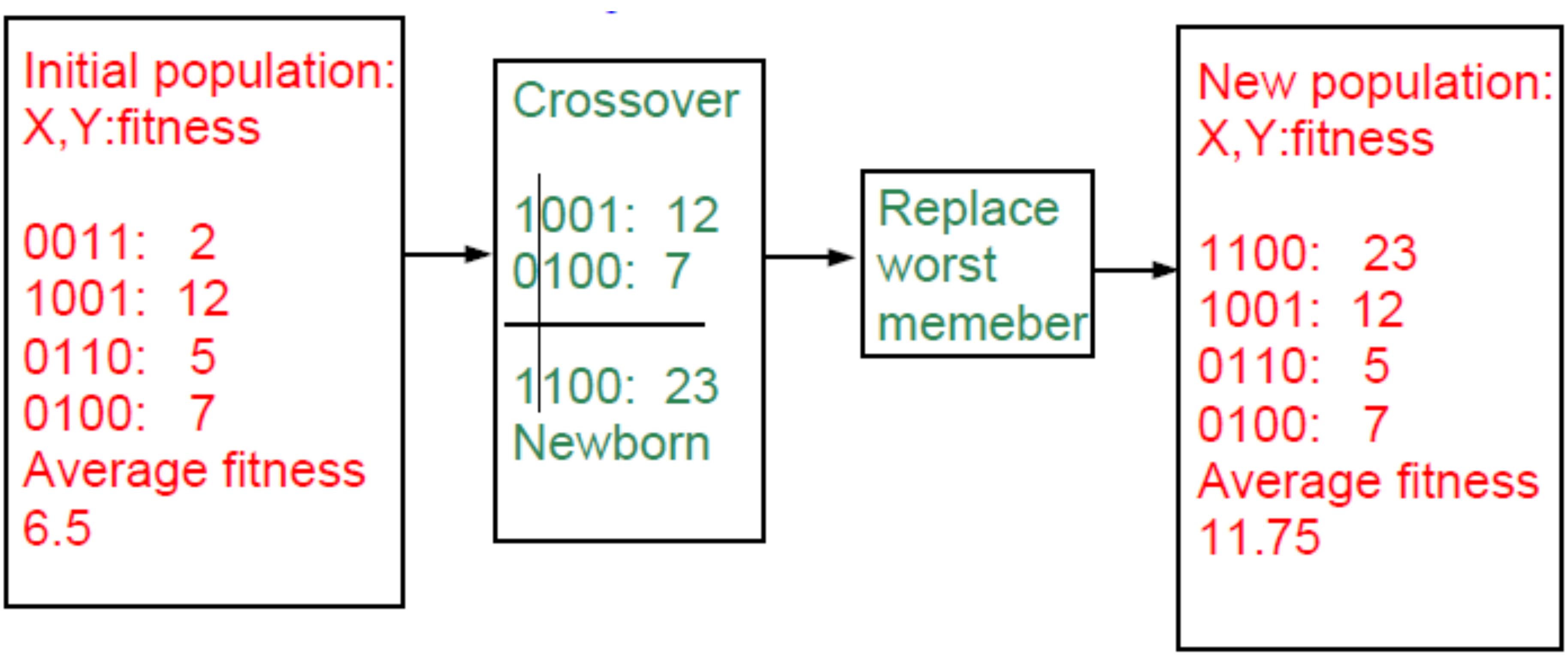
Example: numerical optimization

- **maximize 2X^2-y+5 where X:[0,3],Y:[0,3]**



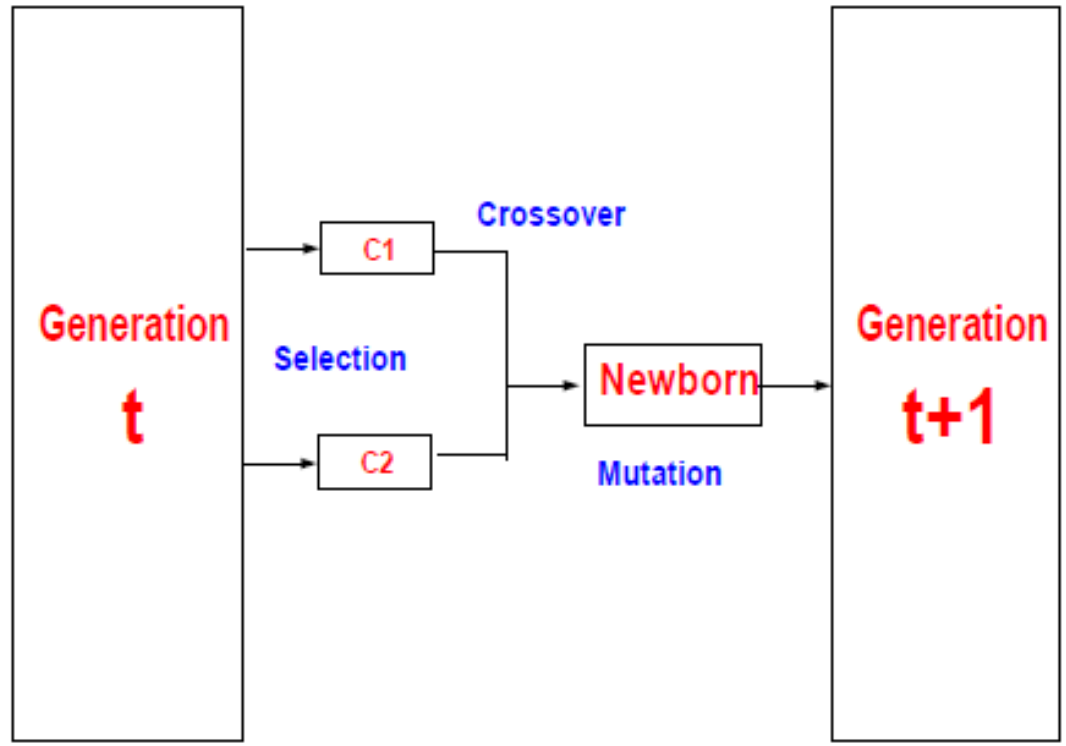
Example with binary representation

- **maximize 2X^2-y+5 where X:[0,3],Y:[0,3]**



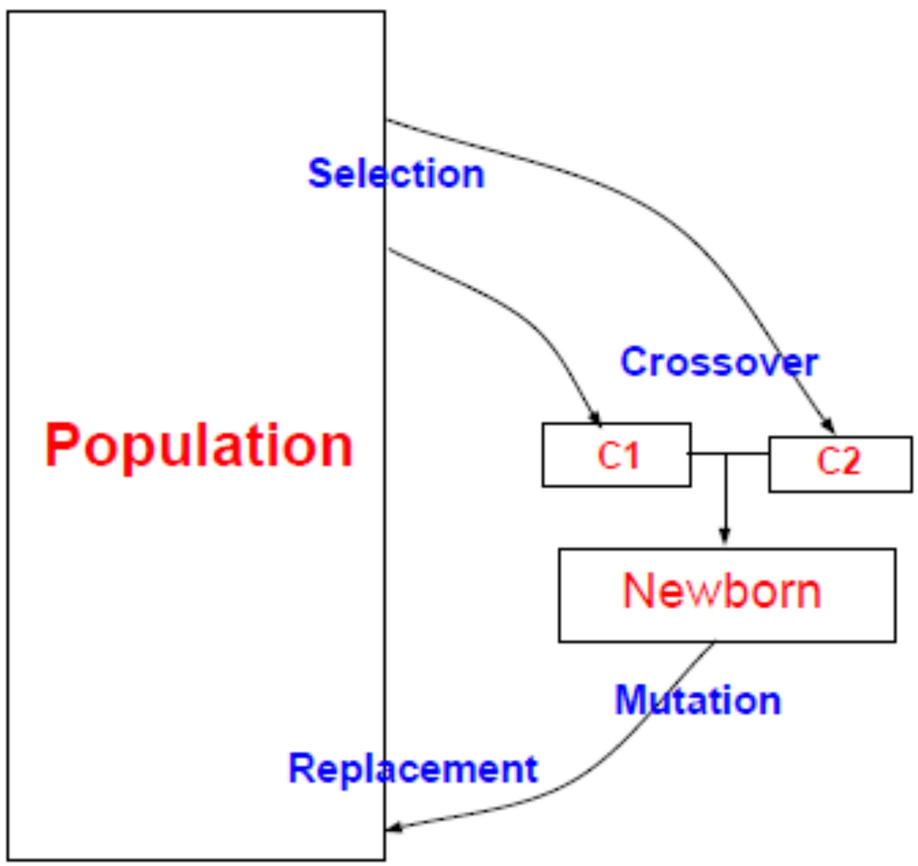
Elements of a generational genetic algorithm

- Representation
- Fitness function
- Initialization strategy
- Selection strategy
- Crossover operators
- Mutation operators



Elements of a steady state genetic algorithm

- Representation
- Fitness function
- Initialization strategy
- Selection strategy
- Crossover operators
- Mutation operators
- Replacement strategy



Selection strategies

- **Proportional selection (roulette wheel)**
  - Selection probability of individual = individual's fitness/sum of fitness
- **Rank based selection**
  - Example: decreasing arithmetic/geometric series
  - Better when fitness range is very large or small
- **Tournament selection**
  - Virtual tournament between randomly selected individuals using fitness

Crossover Operators

- **Point crossover (classical)**
  - Parent1=x1,x2,x3,x4,x5,x6
  - Parent2=y1,y2,y3,y4,y5,y6
  - Child =x1,x2,x3,x4,y5,y6
- **Uniform crossover**
  - Parent1=x1,x2,x3,x4,x5,x6
  - Parent2=y1,y2,y3,y4,y5,y6
  - Child =x1,x2,y3,x4,y5,y6
- **Arithmetic crossover**
  - Parent1=x1,x2,x3
  - Parent2=y1,y2,y3
  - Child =(x1+y1)/2,(x2+y2)/2,(x3+y3)/2

Mutation Operators

- change one or more components
- Let Child=x1,x2,P,x3,x4...
- Gaussian mutation:
  - $P \neg P \pm \Delta p$
  - Δ *p: (small) random normal value*
- Uniform mutation:
  - $P \neg P$ *new*
  - *p new : random uniform value*
- boundary mutation:
  - $P \neg$ *Pmin OR Pmax*
- Binary mutation=bit flip

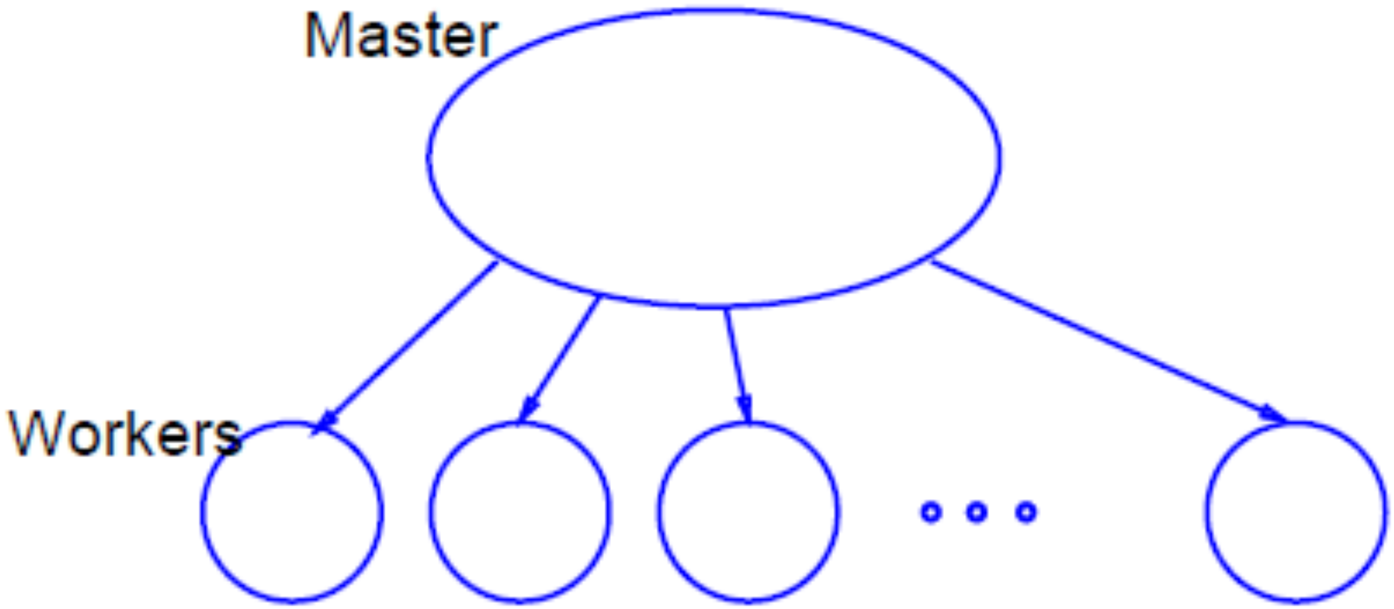
Advantages of Genetic-Algorithm based optimization

- Finds global optima
- Can handle discrete, continuous and mixed variable spaces
- Easy to use (short programs)
- Robust (less sensitive to noise, ill conditions)

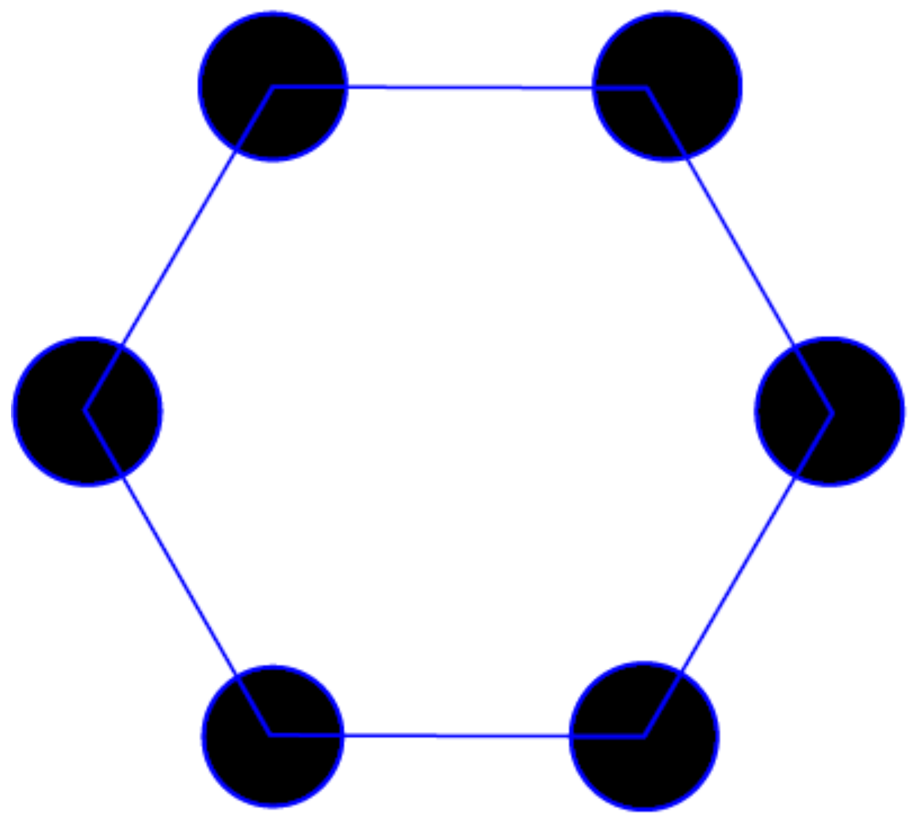
Disadvantages of Genetic-Algorithm based optimization

- Relatively slower than other methods (not suitable for easy problems)
- Theory lags behind applications

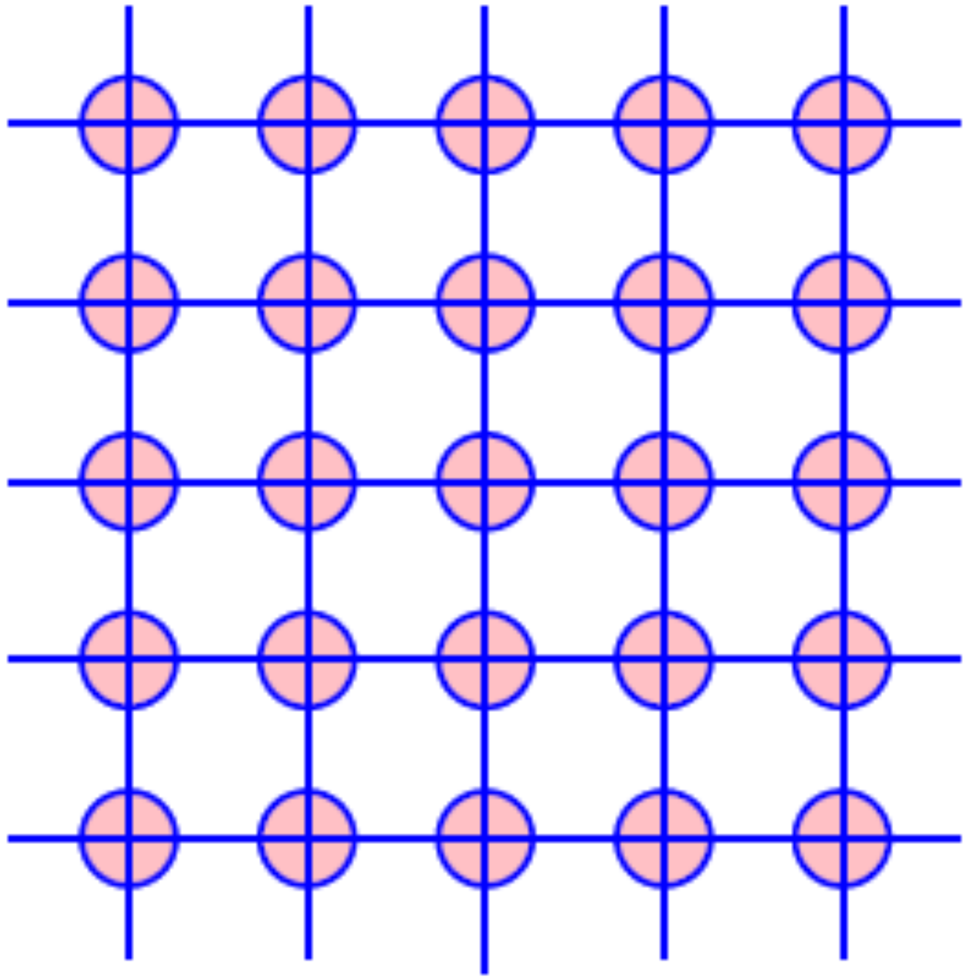
Global parallel GA



Coarse-grained parallel GA (Island model)

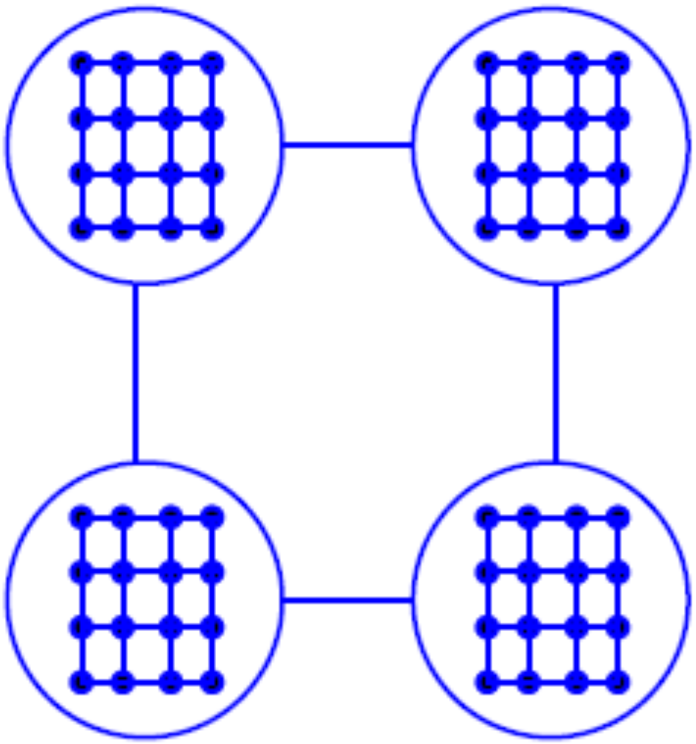


Fine-grained parallel GA



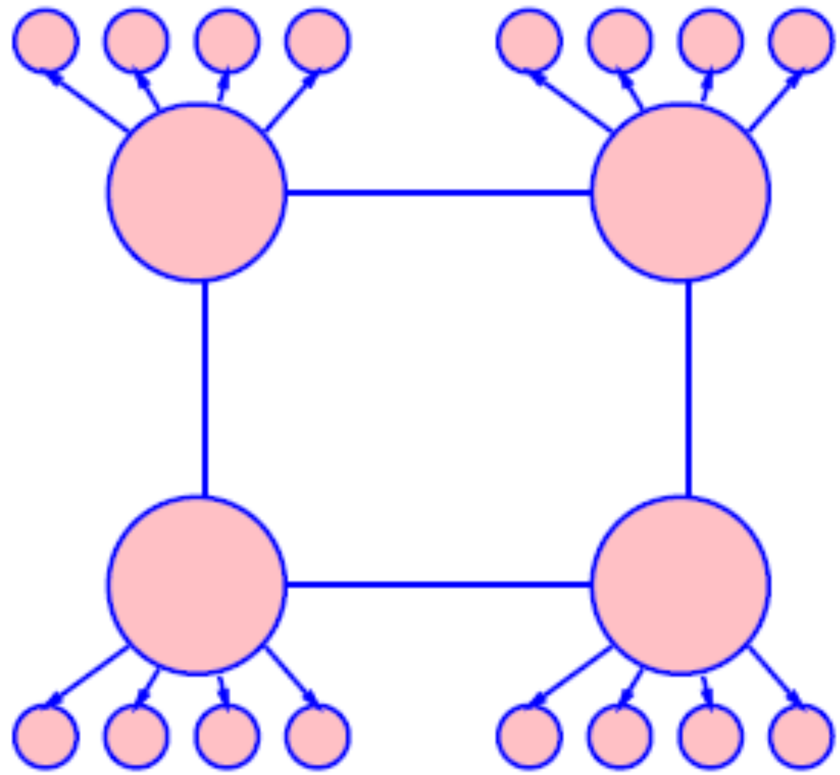
Hybrid parallel GA

- Coarse-grained GA at high level
- Fine-grained GA at low level



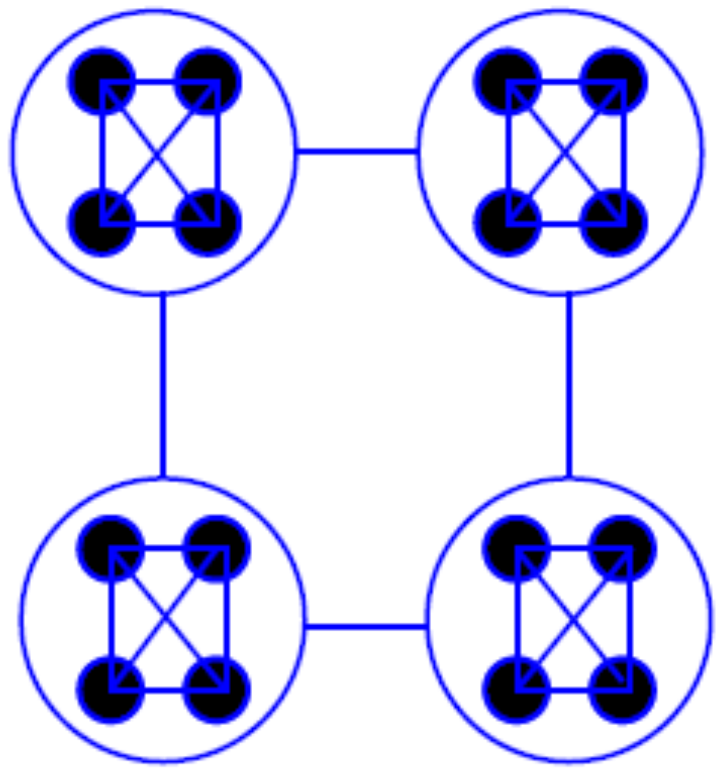
Hybrid parallel GA

- Coarse-grained GA at high level
- Global parallel GA at low level



Hybrid parallel GA

- Coarse-grained GA at high level
- Coarse-grained GA at low level



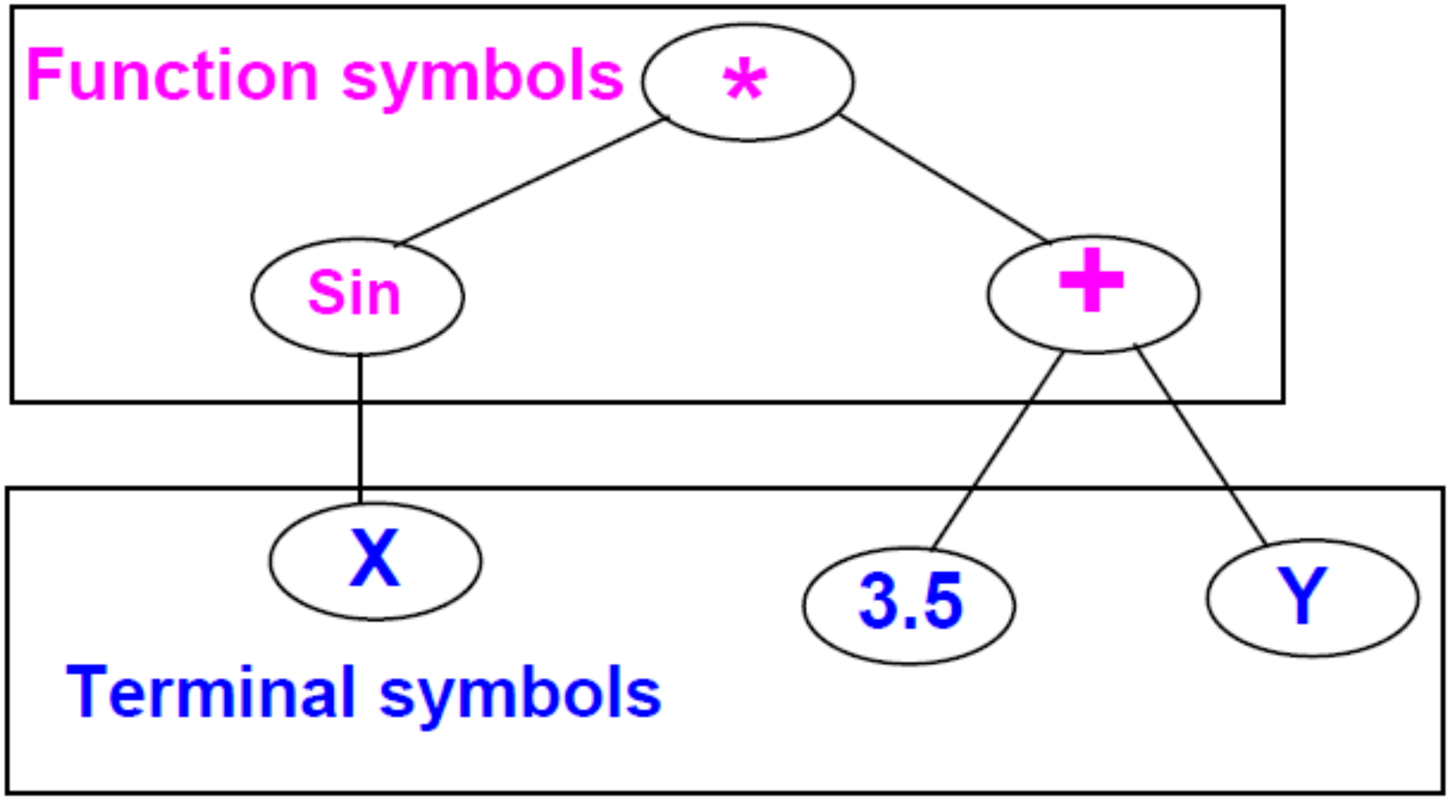
Genetic Programming (GP)

- Introduced (officially) by John Koza in his book (genetic programming, 1992)
- Early attempts date back to the 50s (evolving populations of binary object codes)
- Idea is to evolve computer programs
- Declarative programming languages usually used (Lisp)
- Programs are represented as trees

GP individuals

- A population of trees representing programs
- The programs are composed of elements from the FUNCTION SET and the TERMINAL SET
- These sets are usually fixed sets of symbols
- The function set forms "non-leaf" nodes. (e.g. +,-,*,sin,cos)
- The terminal set forms leaf nodes. (e.g. x,3.7, random())

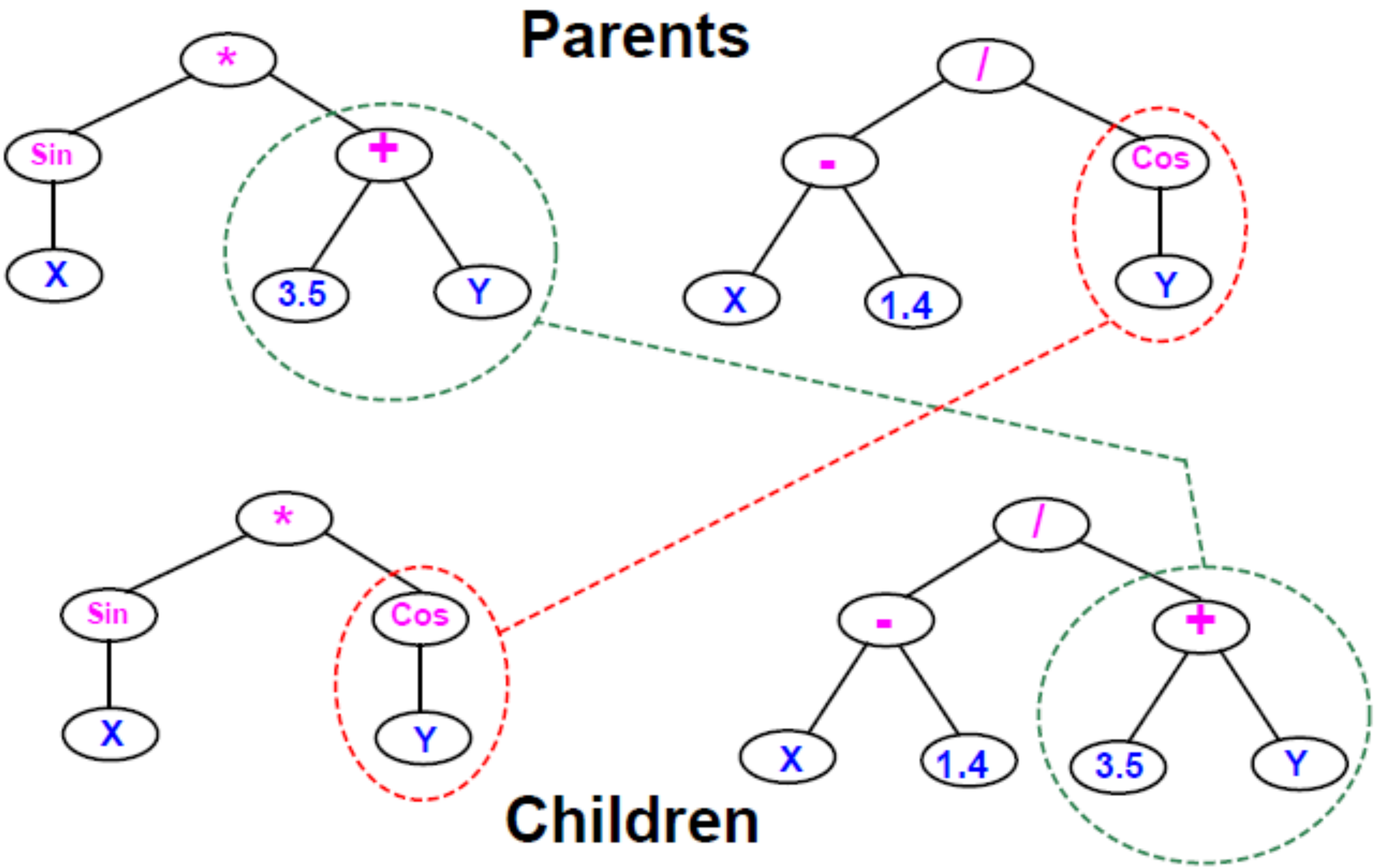
Example: GP individual



GP operation

- Fitness is usually based on I/O traces
- Crossover is implemented by randomly swapping subtrees between individuals
- GP usually does not extensively rely on mutation (random nodes or subtrees)
- GPs are usually generational (sometimes with a generation gap)
- GP usually uses huge populations (1M individuals)

Example: GP crossover



Advantages of GP over GAs

- More flexible representation
- Greater application spectrum
- If tractable, evolving a way to make "things" is more useful than evolving the "things".
- Example: evolving a learning rule for neural networks (Amr Radi, GP98) vs. evolving the weights of a particular NN.

Disadvantages of Genetic Programming

- Extremely slow
- Very poor handling of numbers
- Very large populations needed

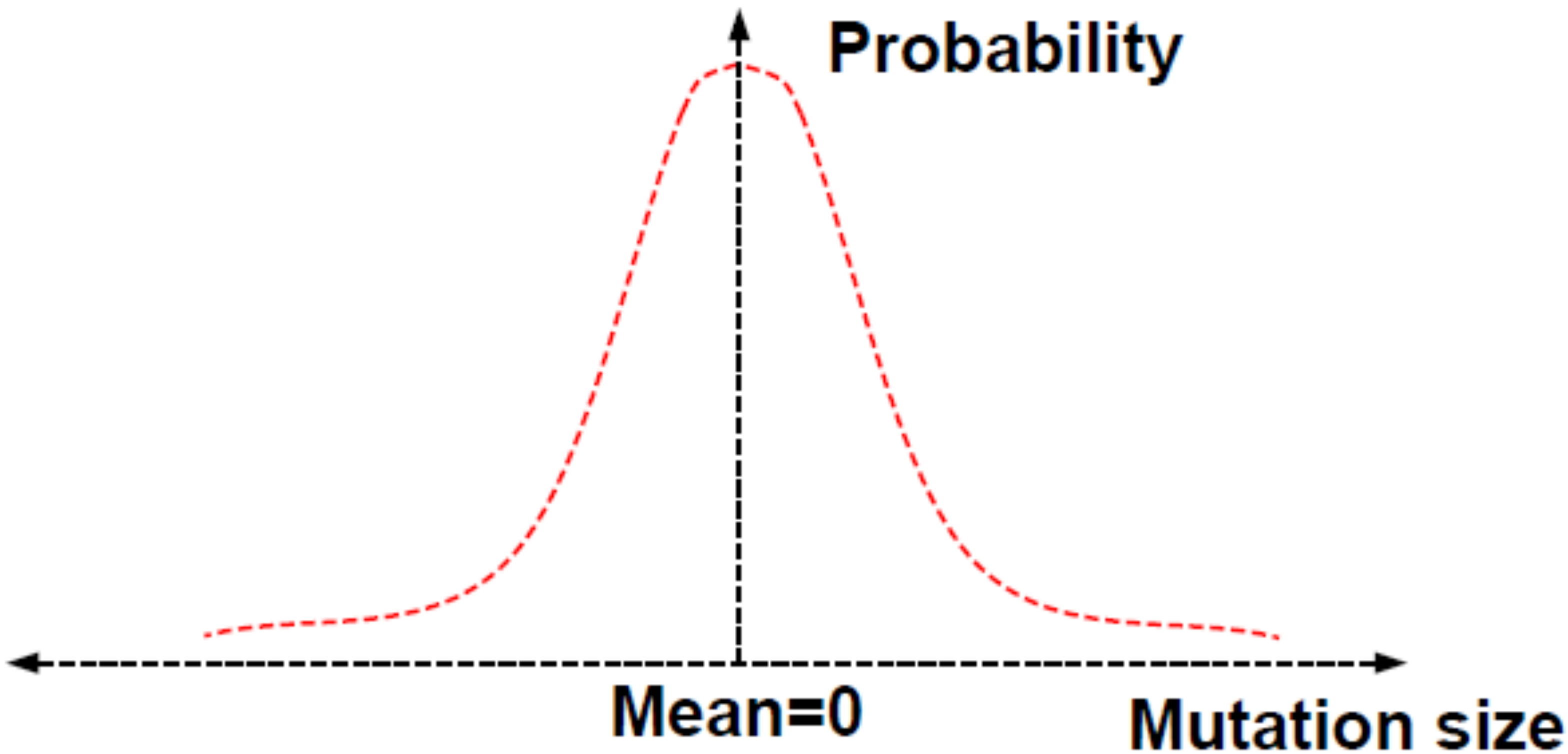
Modern Trends

- **Genetic programming with linear genomes (Wolfgang Banzaf)**
  - Kind of going back to the evolution of binary program codes
- **Hybrids of GP and other methods that better handle numbers:**
  - Least squares methods
  - Gradient based optimizers
  - Genetic algorithms, other evolutionary computation methods
- **Evolving things other than programs**
  - Example: electric circuits represented as trees (Koza, AI in design 1996)

Evolution Strategies (ES)

- **Were invented to solve numerical optimization problems**
- **Originated in Europe in the 1960s**
- **Initially: two-member or (1+1) ES:**
  - one PARENT generates one OFFSPRING per GENERATION
  - by applying normally distributed (Gaussian) mutations
  - until offspring is better and replaces parent
  - This simple structure allowed theoretical results to be obtained (speed of convergence, mutation size)
- **Later: enhanced to a (μ+1) strategy which incorporated crossover**

Normal (Gaussian) mutation



Modern evolution strategies

- Schwefel introduced the multi-membered ESs now denoted by $(\mu + \lambda)$ and (μ, λ)
- (μ, λ) ES: The parent generation is disjoint from the child generation
- $(\mu + \lambda)$ ES: Some of the parents may be selected to "propagate" to the child generation

ES individuals

- **Real valued vectors consisting of two parts:**
  - Object variable: just like real-valued GA individual
  - Strategy variable: a set of standard deviations for the Gaussian mutation
- **This structure allows for "Self-adaptation“ of the mutation size**
  - Excellent feature for dynamically changing fitness landscape

Machine learning and evolutionary computation

- In machine learning we seek a good hypothesis
- The hypothesis may be a rule, a neural network, a program … etc.
- GAs and other EC methods can evolve rules, NNs, programs …etc.
- Classifier systems (CFS) are the most explicit GA based machine learning tool.

Elements of a classifier system

- **Rule and message system**
  - if <condition> then <action>
- **Apportionment of credit system**
  - Based on a set of training examples
  - Credit (fitness) given to rules that match the example
  - Example: Bucket brigade (auctions for examples, winner takes all, existence taxes)
- **Genetic algorithm**
  - evolves a population of rules or a population of entire rule systems

The Michigan approach: population of rules

- **Evolves a population of rules, the final population is used as the rule and message system**
- **Diversity maintenance among rules is hard**
- **If done well converges faster**
- **Need to specify how to use the rules to classify**
  - what if multiple rules match example?
  - exact matching only or inexact matching allowed?

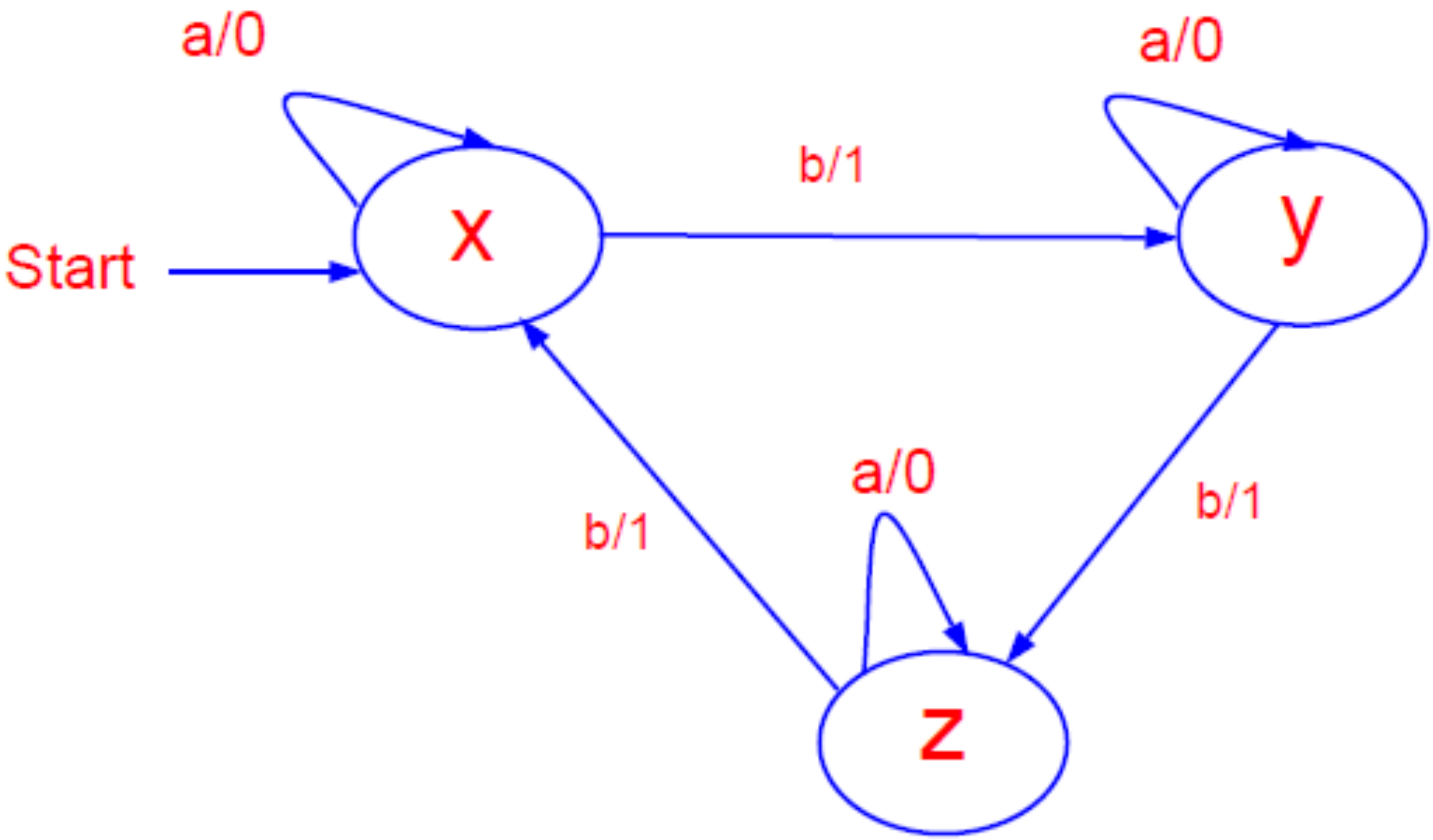
The Pittsburgh approach

- Each individual is a complete set of rules or complete solution
- Avoids the hard credit assignment problem
- Slow because of complexity of space

Evolution programming (EP)

- Classical EP evolves finite state machines (or similar structures)
- Relies on mutation (no crossover)
- Fitness based on training sequence(s)
- Good for sequence problems (DNA) and prediction in time series

EP individual



EP mutation operators

- Add a state (with random transitions)
- Delete a state (reassign state transitions)
- Change an output symbol
- Change a state transition
- Change the start state

Modern EP

- No specific representation
- Similar to Evolution Strategies
  - Most work in continuous optimization
  - Self adaptation common
- No crossover ever used!

Other evolutionary computation "ways"

- **Variable complexity linear representations**
- **Representations based on description of transformations**
  - instead of enumerating the parameters of the individual, describe how to change another (nominal) individual to be it.
  - Good for dimension reduction, at the expense of optimality
- **Surrogate assisted evolution methods**
  - Good when objective function is very expensive
  - fit an approximation to the objective function and uses it to speed up the evolution
- **Differential Evolution**

Related Topics

- **Artificial life**
  - An individual's fitness depends on genes + lifetime experience
  - An individual can pass the experience to offspring
- **Co-evolution**
  - Several populations of different types of individuals co-evolve
  - Interaction between populations changes fitness measures

Other Nature Inspired Heuristics

- **Ant Colony Optimization**
  - Inspired by the social behavior of ants
  - Useful in problems that need to find paths to goals
- **Particle Swarm optimization**
  - Inspired by social behavior of bird flocking or fish schooling
  - The potential solutions, called particles, fly through the problem space by following the current optimum particles

The bigger picture

- All evolutionary computation models are getting closer to each other
- The choice of method is important for success
- EC provides a very flexible architecture
  - easy to combine with other paradigms
  - easy to inject domain knowledge

EC journals

- Evolutionary Computation
- IEEE transactions on evolutionary computation
- Genetic programming and evolvable machines
- other: AIEDAM, AIENG ...

EC conferences

- Genetic and evolutionary computation conference (GECCO)
- Congress on evolutionary computation (CEC)
- Parallel problem solving from nature (PPSN)
- other: AI in design, IJCAI, AAAI ...