Premature Convergence

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Panmictic Model

- All individuals are part of a single population.
- Any individual may mate with any other, often leading to faster convergence.
- However, this increases the risk of premature convergence and loss of diversity

Premature Convergence

- It's a common problem in optimization algorithms
- Happens when the algorithm gets stuck in a local optimum
- In GAs, this happens when there is a loss of *diversity*
- The individuals that are close to the local optimum dominate the population
- Exploration stops before finding the optimum

Premature Convergence

- If individuals are quite similar, then crossover does not help exploration.

Parents

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Offspring

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Consequences

- reduced search efficiency
- algorithm stops finding promising solutions
- poor generalization
- difficulty escaping local minima

Causes of Premature Convergence

Loss of diversity population becomes genetically uniform, leading to stagnation.

Selection pressure high pressure amplifies fitter individuals quickly, spreading limited genes.

Small or panmictic populations unrestricted mating causes uniformity and rapid domination of early winners.

Self-adaptive mutations unless controlled carefully, they can overspecialize populations.

Inadequate mutation/crossover parameters imbalance between exploitation and exploration contributes to stagnation

Detection of Premature Convergence

- Rapid decrease in population diversity metrics.
- Fitness stagnation across generations.
- Premature plateauing of performance curves.
- Visualization tools for convergence monitoring are needed.

Some Diversity Measures

Hamming Distance Calculates the number of positions at which two chromosomes (sequences) differ.

Shannon Entropy Uses information theory to measure diversity based on the frequencies of different alleles.

Variance/Standard Deviation Can be used as a diversity measure, particularly for populations with real-valued genes, by measuring the spread of the population around its mean.

How to solve premature convergence

- Adaptive mutation rates
- Fitness sharing
- Populaton structures
- Mass extinction models

Adaptive mutation rates

- The mutation rate depends on diversity
- It is small if there is a high diversity
- It gets higher when diversity decreases

Fitness sharing

- Also called *speciation*
- Similar individuals share their fitness
- They share a niche
- The average fitness of the individuals in each niche is calculated
- Each individual in the niche is assigned that average fitness divided by the number of individuals in the niche

Fitness sharing and niching

Fitness sharing reduces the fitness in densely populated areas
it divides the fitness by the number of individuals that share the same fitness

Crowding a percentage of the individuals reproduce
they substitute the most similar individual of a random subset of the population

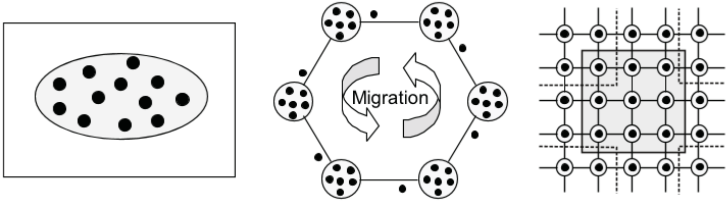
Deterministic crowding introduces competition between children and parents of identical niches
each child replaces the nearest parent if it has a higher fitness

Restricted Tournament Selection two individuals are chosen to reproduce
a random sample of individuals is chosen
each offspring competes with the closest individual
the winner is inserted in the new population

Clearing close individuals are assigned to the same clearing
only the k best individuals survive, the fitness of the others is reset

Population structures

There are three kinds of population structures: - No structure (e.g., the panmictic model) - Large granularty (e.g, the island model) - Course granularity (e.g., the cellular model) - Graph based structures

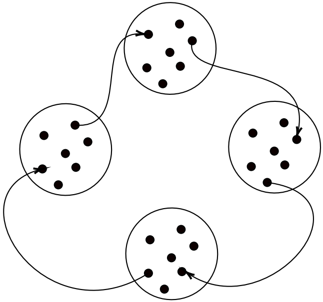


(a) (b) (c)

Image taken from Design Issues in a Multiobjective Cellular Genetic Algorithm

Island model

- There are several subpopulations evolving in parallel
- There are some sporadic migrations of individuals among islands
- There is a distribution of the computational effort
- The diversity is higher



Parameters concerning the island model

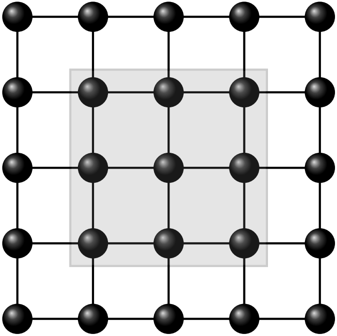
- When should migrations occur?
- What individuals should migrate?
- How many individuals should migrate?
- Where should they go?

Advantages of using Island Models

- Easy to parallelize
- Decreases spread of information
- Increases diversity
- Each island can explore a different region of the search space
- Migration rate controls information spread between sub-populations
- Islands' structure can be a graph

Cellular model

- The population lives in a rectangular grid
- Each individual lives in a cell
- Each individual can only interact with its neighbors
  - Choose which neighbor he should reproduce with
  - Create offspring by applying the genetic operators
  - Evaluate them
  - Decide if the offspring will replace us



Cellular Models

- Localized evolutionary preassure
- Can be parallelized
- Information diffusion and selective pressure
- Effects of neighborhood size on convergence
- Trade-offs between exploration and exploitation
- Visualization of population evolution in space

Graph based approaches

- Each individual is a vertex
- Each individual may only see its neighbors
- Graph measures like average degree and graph distance are important for information spread

Some usual graphs

- Von Neumann
- 1-D Ring
- 2-D Torus
- Overlapping neighborhoods
- Mating and replacement occur only within local neighborhoods, not globally.
- Genetic information diffuses slowly, promoting local adaptation and niche formation.

Mass Extinction models

- If the diversity is too low, there is a mass extinction event
- If this happens, a part of the populaton is reinitialized
- The bigger the proportion of the population is reinitialized, more diversity is introduced
- Instead of using a diversity measure, one could use the number of iterations since the last improvement
- Each time the population doesn't increase, the probability of mass extinction increases

Mass Extinction models

Self-Organized Criticality

- Use a Cellular model
- Each time an individual does not improve, increase its criticality
- Once the criticality of an individual increases a given threshold:
  - Re-initialize it
  - Recursively increase the criticality of its neighbors

Characteristics

- Population is usually stable
- Usually, only a few individuals are re-initialized
- There are occasionally mass extinction events
- This model can be used in many algorithms
- It can be applied to other algorithms that do not use cellular models

Mechanisms of Extinction Events

Extinction as a genetic operator

- Wiping out a portion of the population
- Extinction rate
- Population proportion
- Reseeding intensity

Strategies for triggering extinction

- Randomly at fixed intervals
- Based on stagnation in progress
- Condition-dependent (e.g., no fitness improvement)

Replacement strategies

- random new individuals vs. structured reseeding

Effects on Evolutionary Performance

- Increased evolvability and diversity after extinction
- Improved capacity to escape local optima and find new global solutions

Elitism based approaches

- Elitism is when the best solution is never lost
- There are several kinds of elitism:
  - Order based selection (e.g., Evolution Strategies)
  - Individuals are only updated upon improvement (e.g., Particle Swarm Optimization, Differential Evolution)
  - Best individual preservation (only the best individual is ensured to have a copy in the new population)