A Brief Overview of Diversity-Preservation Methodologies in Evolutionary Optimization

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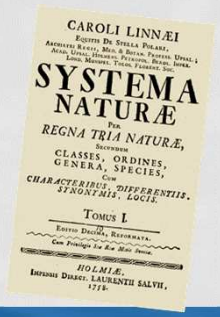
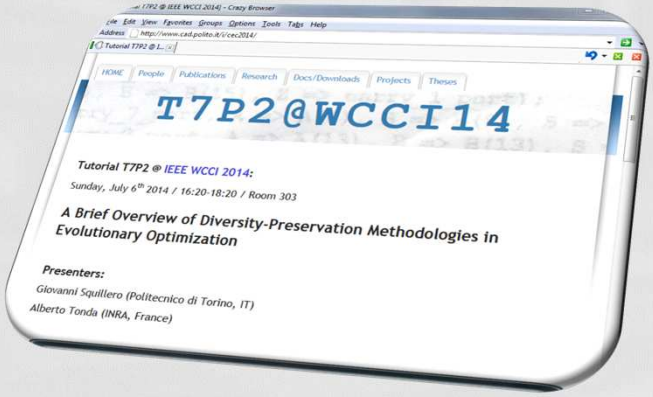
Why yet another taxonomy?

- Offer a unifying view to the many research lines
- Re-orders and re-interprets the different approaches into a single framework
- Unlink the techniques from the paradigm they were developed in (as far as possible)
- Allow comparisons



Material & bibliography

http://www.cad.polito.it/i/cec2014/



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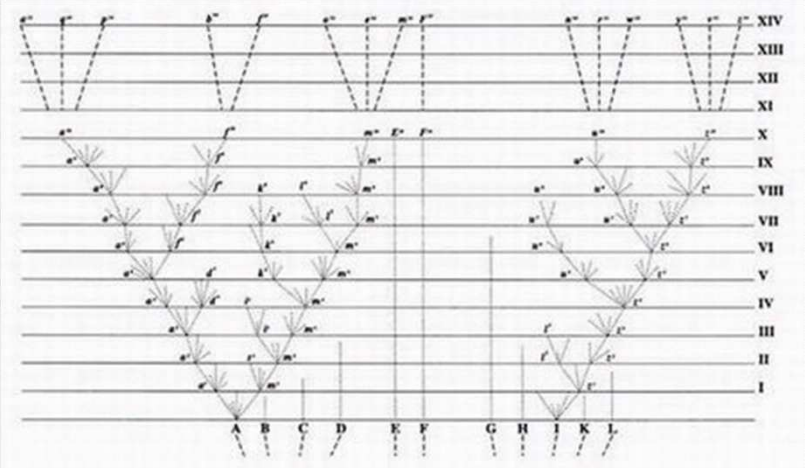
Darwin's tree of life



The only illustration in *On the Origin of Species by Natural Selection* (1859)

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Evolutionary algorithms

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divergence of character

vs.

premature convergence

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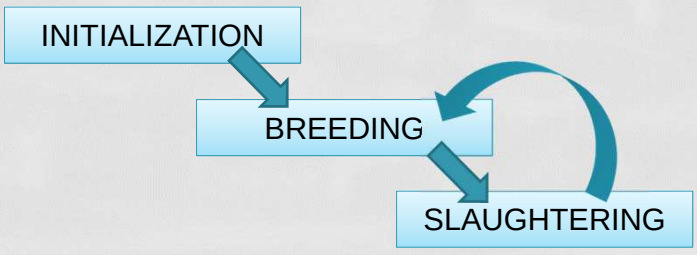
Outline

- Instructions and warnings
- Divergence of character in natural and artificial evolution
- Background (diversity and similarity, …)
- Mechanisms for promoting diversity
  - Proposed taxonomy
  - Well-known techniques
- Conclusion

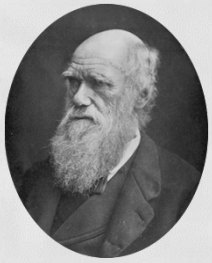
Instructions and warnings

- A rough idea about “what” an evolutionary algorithm is



- Optimization, not artificial life!

Divergence of character



- *"Great diversity of forms in nature"*
- *"The principle, which I have designated by this term, is of high importance, and explains, as I believe, several important facts"*
  - *"The principle of divergence causes differences, at first barely appreciable, to steadily to increase, and the breeds to diverge in character, both from each other and from their common parent"*
  - *"The varying descendants of each species try to occupy as many and as different places as possible in the economy of nature"*

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Premature convergence

- I.e., the tendency of an algorithm to converge towards a point where it was not supposed to converge to in the first place
- Probably an oxymoron
- Holland's "Lack of speciation"
- EAs general inability to exploit environmental niches

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Environment vs. Fitness function

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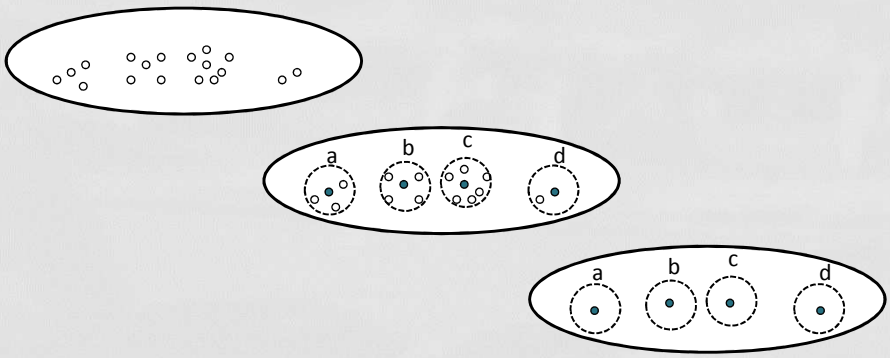
Niches

- Niche: subspace in the environment with a finite amount of physical resources that can support different types of life



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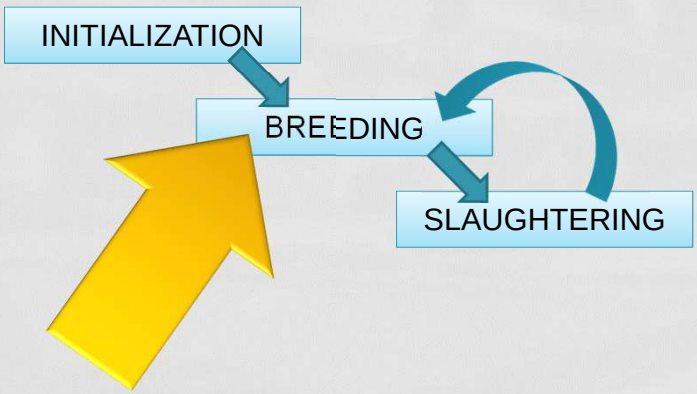
Niches

- Niches favor the divergence of character
- Niches and speciation
- How to create “niches” in EAs since the environment is missing?

Premature convergence

- The problem is endemic



Exploration vs. Exploitation

- Recombination
  - mixes together two or more solutions to create the offspring
  - associated with the idea of *exploration*
- Mutation
  - performs a (usually small) change in an individual
  - associated with the idea of *exploitation*

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Exploration vs. Exploitation

- When all parents are very similar, the effectiveness of recombination is limited
- The ability to explore remote parts of the search space is impaired
- "Conventional wisdom suggests that increasing diversity should be generally beneficial"

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Exploration vs. Exploitation

- When all parents are very similar, the effectiveness of recombination is limited
- what is the definition of "similar"? ts of the search space is impaired
- "Conventional wisdom suggests that increasing diversity should be generally beneficial"

and the definition of "diversity"?

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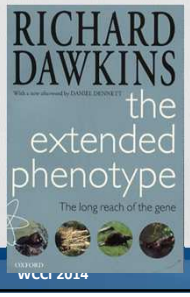
Levels in biology

- **Genotype**: the genetic constitution of an organism
- **Phenotype**: the composite of the organism's observable characteristics or traits
- **Fitness**: individual's ability to propagate its genes (almost)



Richard Dawkins
The Extended Phenotype: The Long Reach of the Gene
Oxford University Press, 1982 (revised ed. 1999)

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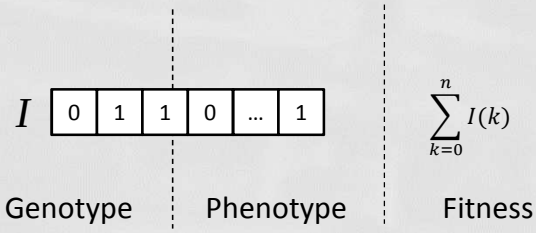
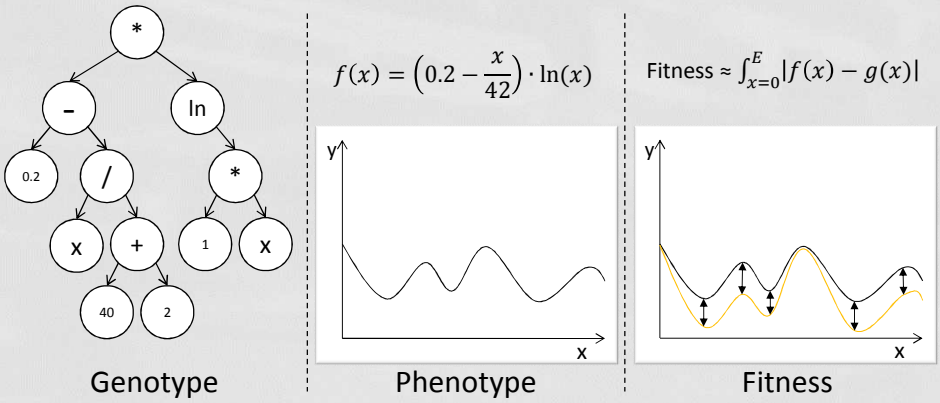
Levels in EC (proposal)

- **Fitness**: how well the candidate solution is able to solve the target problem
- **Genotype**: the internal representation of the individual, i.e., what is directly manipulated by genetic operators
- **Phenotype**: the candidate solution that is encoded in the genotype
  - the intermediate form in which the genotype needs to be transformed into for evaluating fitness
  - if genotype can be directly evaluated: genotype and phenotype coincide

Levels in EC (GA)

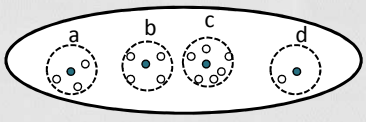


Levels in EC (GP & LGP)



Niches in EA

- Niching: grouping similar individual
  - similar spatial positions (i.e., islands)
  - similar genotypes (i.e., niching)
  - similar phenotypes
- Several approaches are based on niching



Detecting clones

- Detecting whether two individuals are clones, i.e., identical, is often an easy task at any level

Measuring diversity

- Diversity $\Rightarrow$ distance metric: *how far* the individual is
  - from (a subset of) the whole population
  - from a single individual
- Diversity $\Rightarrow$ property of the population
- But, at what level?
  - Phenotype
  - Genotype
  - Fitness

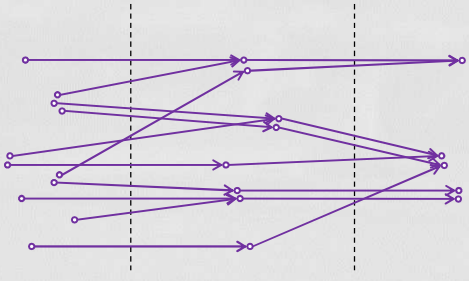
Measuring diversity

- Different fitness values imply different phenotypes, different phenotypes imply different genotypes

$$F_x \neq F_y \Rightarrow P_x \neq P_y \Rightarrow G_x \neq G_y$$

Measuring diversity

- What about "diversity"?
- Locality principle
- Rechenberg's *strong causality*



Measuring diversity

- Phenotype
  - Usually ad-hoc
- Genotype
  - Different genotypes in the population
  - GP subtree frequency
  - Edit distance (a.k.a., Levenshtein distance)
  - Entropy and free energy
- Fitness
  - Usually trivial

Outline

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- Mechanisms for promoting diversity
  - Proposed taxonomy
  - Well-known techniques
- Conclusion?

What has been proposed to alleviate it?

End goal vs. Means goal

- The *end goal* in optimization is reaching better solutions in less time
- Promoting diversity has often been seen as the key factor to improve performances
- Promoting diversity is a mere *means goal* (yet a quite important one)
- No distinction is made here whether the means goal is
  - preserve existing diversity
  - increase diversity

How diversity is promoted (theory)

- A methodology for promoting diversity alters the selection probability of individuals

$$\bar{p}_{x|\Psi} = p_{x|\Psi} \cdot \xi(x, \Psi)$$

- **Mere definition**: we do not imply that a mechanism operates *explicitly* on the selection operators
- **But** the *effects* on selection probabilities are assessed to classify it

How diversity is promoted (theory)

individual

set of individuals (may be empty)

$$\bar{p}_{x|\Psi} = p_x \cdot \xi(x, \Psi)$$

corrective factor

selection probability of individual x given that all individuals in set Ψ are also chosen

selection probability of individual x

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How diversity is promoted (practice)

- Fitness scaling
- Fitness holes
- Tweaking selection mechanism
- Adding selection mechanism
- Multiple populations
- Population topologies

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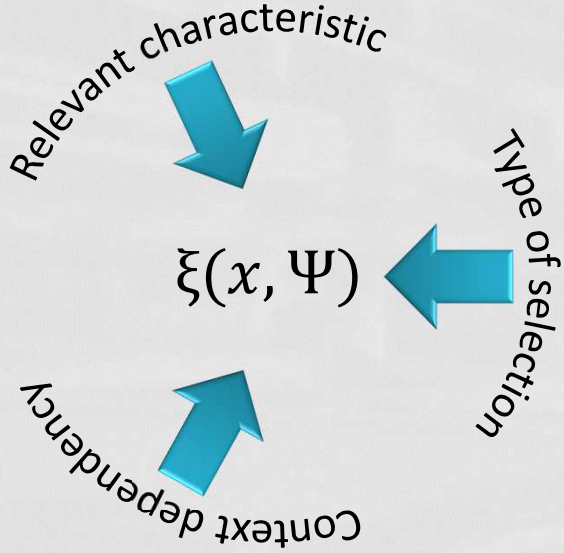
Taxonomy



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Relevant characteristic

- Lineage (**LIN**)
- Phenotype (**PHE**)
- Genotype (**GEN**)
- ~~Fitness~~ (used as a proxy for either phenotype or genotype)

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Lineage-based methodologies

- The value of ξ does not depend on individual structure nor behavior, but it can be determined considering circumstances of its birth (e.g., time, position)
- LBMs can be applied to any kind of problem, even in addition to other diversity preservation methods

Genotype-based methodologies

- Particularly effective when it is possible to define a sensible **distance** between genotypes
- Often used to
  - avoid overexploitation of peaks in the fitness landscape
  - promote the generation of new solutions very far from the most successful ones
  - preserve variability in the gene pool

Phenotype-based methodologies

- Usually impractical
- Sometimes fitness distance can be used as a proxy for phenotype distance (multi objective EAs, or many objective EAs)
- **Spam: tutorial authors are actively studying genotypic distances that can be used to predict phenotypic distances**

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Type of selection

- Parent selection (α or ~~α~~)
  - Usually non-deterministic
- Survival selection (ω or ~~ω~~)
  - Usually deterministic

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Context dependency

- Context independent (**CI**)

$$\forall x, \Psi: \xi(x, \Psi) = \xi(x, \emptyset) = \xi(x)$$

- Context dependent (**CD**)

$$\exists x, \Psi_1, \Psi_2: \xi(x, \Psi_1) \neq \xi(x, \Psi_2)$$

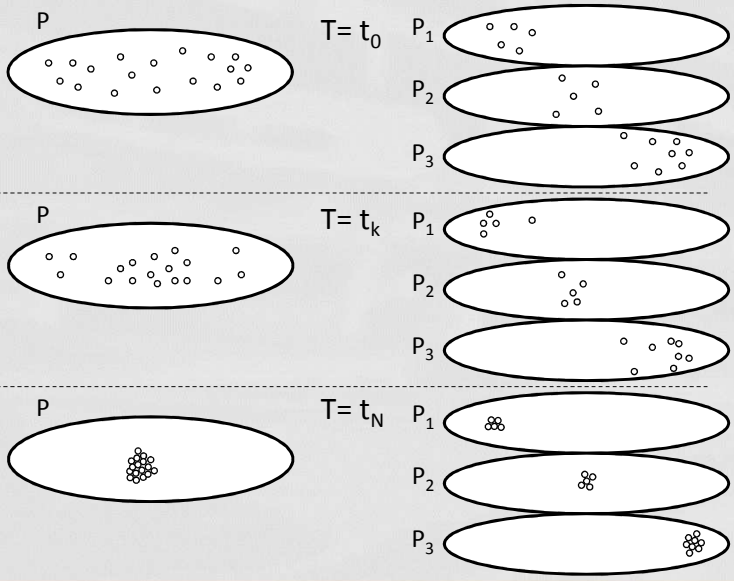
Proposed taxonomy

Methodology	Element	Selection: Parent	Selection: Survival	Context dep.
Allopatric Selection [TLS12]	Lineage	no	yes	n.a.
Cellular EAs [Rob87]	Lineage	yes	yes	yes
Deterministic Crowding [Mah95]	Lineage	no	yes	n.a.
Gender [All92]	Lineage	yes	no	yes
Island Models [WRH99]	Lineage	yes	yes	yes
Segregation [Aff01]	Lineage	yes	yes	yes
Clearing [Pét96]	Genotype	yes	yes	no
Delta (pseudo) entropy [ST08, SSS11]	Genotype	yes	no	no
Diversifiers [KB95]	Genotype	yes	yes	no
Fitness Sharing [DG89]	Genotype	yes	yes	no
FOCUS [DJWP01]	Genotype	no	yes	no
Gender[1] [All92]	Genotype	yes	no	yes
GDEM [TB03]	Genotype	no	yes	no
Reference points partitioning [DJeda, DJedb]	Genotype	no	yes	no
Restricted Tournament Selection [Har95]	Genotype	no	yes	no
Sequential Niching [BBM93]	Genotype	no	yes	no
Standard Crowding [DJ75]	Genotype	no	yes	no
Tarpeian Method [Pol03]	Genotype	yes	yes	no
Two-level Diversity Selection [BB02]	Genotype	yes	no	yes
Crowded-Comparison Operator [DPAM02]	Phenotype	yes	no	no
Extinction [GFC99]	Phenotype	no	yes	no
Hierarchical Fair Competition [HGS+05]	Phenotype	yes	yes	yes
Random Immigrants [Gre92]	Phenotype	yes	yes	no
Strength Pareto [ZT99]	Phenotype	yes	no	no
VEGA [Sch85] [HL92]	Phenotype	yes	no	yes

Island model

- Recipe [**LIN αω CD**]
  - The population is partitioned into sub-populations
  - Only local interactions are allowed
  - Periodically, individuals are moved between sub-populations (migrations)
- Rationale
  - Since EAs are stochastic in nature, different populations will tend to explore different parts of the search space
  - … but global interactions can be useful

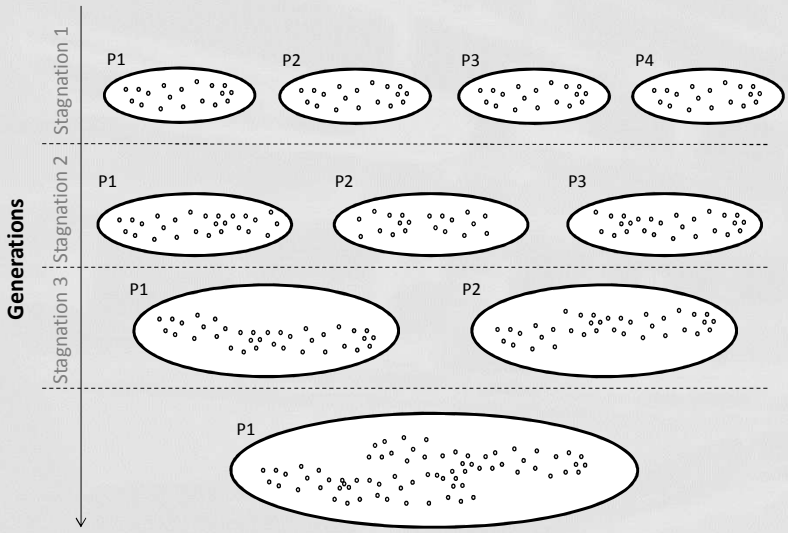
Island model



Segregation

- Recipe [LIN αω CD]
  - The population is partitioned into *N* sub-populations
  - Only local interactions are allowed
  - Upon stagnation, the *N* sub-populations are merged into *N*-1 sub-populations
- Rationale
  - same as island models
  - the selective pressure decreases during evolution

Segregation



Hierarchical fair competition

- Recipe [PHE αω CD]
  - The population is partitioned into sub-populations with similar fitness
  - Only local interactions are allowed
  - The offspring is promoted or demoted according to fitness
  - New random individuals are constantly generated
- Rationale
  - Hard niching with implicit neighborhood
  - Reduce competition between newborns and already optimized individuals (ladder)

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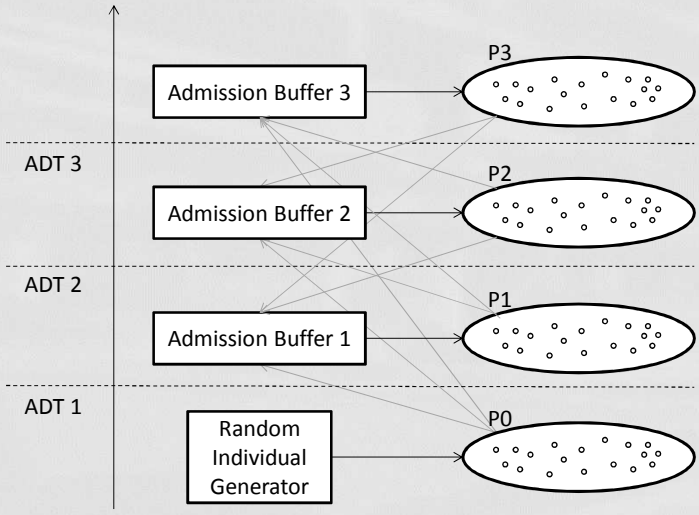
Hierarchical fair competition



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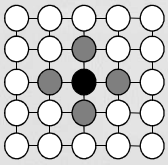
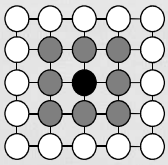
Cellular EA

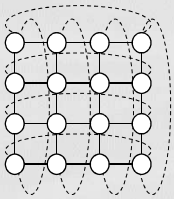
- Recipe [LIN αω CD]
  - Fixed topology (lattice)
  - Only interactions between neighbors are allowed
- Rationale
  - Limiting interaction could defer the takeover of the population by clones of the fittest individual



Linear-5 (L5)



Compact-9 (C9)



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Deterministic crowding

- Recipe [LIN ɛω --]
  - Offspring compete against parents for survival
- Rationale
  - Flexible niching with implicit neighborhood
  - Parents and offspring occupy the same niche
  - No need for evaluating the similarity

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Allopatric selection

- Recipe [LIN αω --]
  - The whole offspring compete for survival
- Rationale
  - Flexible niching with implicit neighborhood
  - No need for evaluating the similarity
  - Genetic operators that create large offspring can be exploited without the risk for the offspring to invade the population

Fitness Sharing

- Recipe [GEN αω CI]
  - Scale down individual fitness

$$\bar{f}(I_k) = \frac{f(I_k)}{\sum_i sh(I_k, I_i)}$$

  - with *sh*(*x*, *y*) depending on the distance between the individuals, and is 0 beyond a fixed radius
- Rationale
  - Flexible niching with explicit neighborhood
  - Reduce attractiveness of densely populated area

Clearing

- Recipe [GEN αω CI]
  - Inside niches of a certain radius, the best *k* individuals retain their fitness while the rest are zeroed
- Rationale
  - Flexible niching with explicit neighborhood
  - Set a hard limit to population density

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Standard crowding

- Recipe [GEN αω CI]
  - New individuals replace the most similar individual in a random niche of size CF
- Rationale
  - Flexible niching with implicit neighborhood
  - Favor novelty (generational approach)

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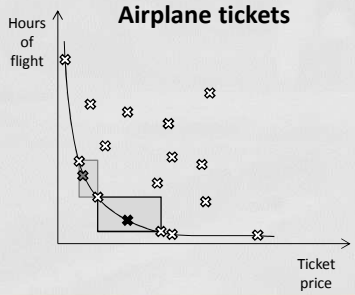
Crowded-comparison operator

- Recipe [PHE αεω CI]
  - Estimate the *free territory* around solutions and favor solutions less crowded regions
- Rationale
  - Smart implementation of artificial niches
  - Requires a strong correlation between phenotype and fitness
  - NSGA-III introduces ε-domination (adaptive disgretization)



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Reference points partitioning

- Recipe [GEN αεω CI]
  - Population is partitioned using in clusters centered around a set of reference points
  - Reference points are initially chosen by the user, then can be dynamically updated
  - New individuals compete for survival inside their own niche
- Rationale
  - Flexible niching with implicit neighborhood

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Restricted tournament selection

- Recipe [GEN æω CI]
  - New individuals compete with the most similar individual in a random niche of size CF
- Rationale
  - Flexible niching with implicit neighborhood

Sequential niching

- Recipe [GEN αω CI]
  - The most promising points in the search space after each run are altered so to become less interesting in further executions
- Rationale
  - Avoid over exploitation

Vector evaluated genetic algorithm

- Recipe [PHE αtt CD]
  - Divide the mating pool in *N* parts, each one filled with individual selected on their *i*-th component of the fitness
  - Alternative: select on a weighted sum, but use different weight sets for the different parts
- Rationale
  - Increase the push towards specialization
- Caveats
  - Only applicable to MOEAs

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Gender

- Recipe [LIN/GEN αtt CD]
  - Add gender to individual and enforce sexual reproduction
  - More than two sexes are possible, with different mutation probabilities
  - Gender might be part of the genome or not
- Rationale
  - Prevent crossover between clones
  - Limit interactions between related individuals

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Tarpeian method

- Recipe [PHE αω CI]
  - Randomly kill individual who don't adhere to given standards
- Rationale
  - Note: originally used to prevent bloat
  - Creating dynamic and non-deterministic *fitness holes* may have several beneficial effects, including to promote diversity

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Diversifiers

- Recipe [GEN αω CI]
  - Detect less populated areas in the search space and try to generate random inhabitants
- Rationale
  - Increase variability in the gene pool regardless the fitness
  - Require a reliable distance metric

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Random immigrants

- Recipe [PHE αω CI]
  - Periodically insert random individuals in the population
- Rationale
  - Try to introduce novelty
- Caveats
  - Newborns may need to be artificially kept alive when competing against already optimized individuals

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Extinction

- Recipe [PHE αω CI]
  - Upon convergence (or periodically) remove a significant part of the population
  - Then fill up the population with the offspring of the survivors and/or random individuals
- Rationale
  - A gust of fresh air: already optimized individuals are not enough to occupy the whole population and newborns may start exploring new regions
- Caveat
  - Fitness variability used as phenotype variability

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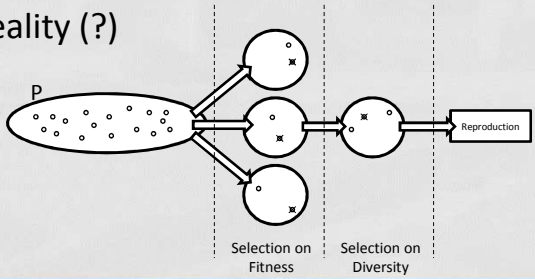
Two-level diversity selection

- Recipe [GEN αω CI]
  - Select three individuals using fitness, then pick the two with maximum distance for reproduction
- Rationale
  - Exploit a reliable distance metric to increase the efficacy of crossover
  - Not so far from reality (?)



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GDEM – Genetic Diversity Evaluation Method

- Recipe [GEN αω CI]
  - Add diversity as an explicit goal and go MO
- Rationale
  - Modify the domination criteria
  - Need a reliable diversity metric
- Historical note
  - See: *Find Only and Complete Undominated Sets* (FOCUS)

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Delta entropy and pseudo entropy

- Recipe [GEN ~~α~~ CI]
  - With a certain probability select individuals on their ability to increase the global entropy of the population instead of fitness
- Rationale
  - Not-so-fit individual with peculiar traits should be preserved
  - Measuring the entropy of the population is easier than defining a distance function

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- Divergence of character in natural and artificial evolution
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  - Well-known techniques
- ~~Conclusion~~