|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **GA** | **ES** | **EP** | **GP** | **DE** | **PSO** |
| Representation | Bit-strings | Real-valued vectors | Real-valued vectors | Tree structures | Real-valued vectors | Real-valued vectors |
| Recombination | 1-Point crossover | Discrete or intermediary | None | Exchange of subtrees | Uniform crossover | None |
| Mutation | Bit flip | Gaussian perturbation | Gaussian perturbation | Random change in trees | Differential mutation | Adding velocity vector |
| Parent selection | Fitness proportional – implemented by Roulette Wheel | Uniform random | Deterministic (each parent one offspring) | Fitness proportional | Given individual deterministically + Uniform random selection of the 3 necessary other vectors | Deterministic (each parent creates one offspring via mutation) |
| Survivor selection | Generational | (μ,λ) or (μ+λ) | Probabilistic (μ+μ) | Generational replacement | Deterministic elitist replacement (parent vs. child) | Generational (offspring replaces parents) |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Representation | Binary | Integer | Real-valued vector | Permutation | Tree |
| Mutation | Bit-flip | Random setting | Uniform mutation | Swap mutation | Replace 1 subtree |
|  |  | Creep mutation | Nonuniform mutation | Insert mutation |  |
|  |  |  | Self-adaptive mutation\* | Scramble mutation |  |
|  |  |  |  | Inversion mutation |  |
| Recombination | 1-point crossover | 1-point crossover | Simple arithmetic crossover | Order 1 crossover | Exchange 2 subtrees |
|  | n-point crossover | n-point crossover | Single arithmetic crossover | Partially mapped crossover |  |
|  | Uniform crossover | Uniform crossover | Whole arithmetic crossover | Cycle crossover |  |
|  |  |  | Blend crossover | Edge recombination |  |

Nonuniform mutation: x’i = xi + N(0,σ)

Self-adaptive mutation: 〈 x1,…,xn, σ 〉

Uncorrelated mutation with one σ

σ’ = σ • exp(τ • N(0,1))

x’i = xi + σ’ • Ni(0,1)

learning rate τ ∝ 1/ n½

σ’ < ε0 ⇒ σ’ = ε0

Uncorrelated mutation with n σ’s

σ’i = σi • exp(τ’ • N(0,1) + τ • Ni (0,1))

x’i = xi + σ’i • Ni (0,1)

τ’: overall learning rate

τ: coordinate wise learning rate

τ’ ∝ 1/(2 n)½  and τ ∝ 1/(2 n½) ½

σi’ < ε0 ⇒ σi’ = ε0

Correlated mutations

**Covariance Matrix Adaptation Evolution Strategy** **(CMA-ES)**

〈 x1,…,xn, σ1,…, σn ,α1,…, αk 〉

k = n • (n-1)/2

Covariance matrix:

cii = σi2

cij = 0 if i and j are not correlated

cij = ½•(σi2 - σj2 ) •tan(2 αij) if i and j are correlated

σ’i = σi • exp(τ’ • N(0,1) + τ • Ni (0,1))

α’j = αj + β • N (0,1)

*x* ’ = *x* + *N*(*0,C’*)

**x:** the vector 〈 x1,…,xn 〉

**C’**: the covariance matrix **C** after mutation of the α values

τ ∝ 1/(2 n)½  and τ ∝ 1/(2 n½) ½ and β ≈ 5°

σi’ < ε0 ⇒ σi’ = ε0 and

| α’j | > π ⇒ α’j =α’j - 2 π sign(α’j)

Partially Mapped Crossover

Cycle Crossover

Edge recombination

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Population Management | Selection |  | sampling algorithms | Parent selection | survivor selection | Diversity |  |  |  |
| Generational model | FPS | - | Roulette wheel alg. | uniform | Elitism | Explicit | Fitness sharing |  |  |
|  |  | windowing | Stochastic universal sampling alg. |  | Delete worst |  | Crowding |  |  |
|  |  | sigma scaling |  |  | Round-robin | Implicit | Automatic speication |  |  |
| Steady-state model | Rank-based selection | Linear ranking |  |  |  |  | Island model parallel EAs |  |  |
|  |  | Exponential Ranking |  |  |  |  | Cellular EAs |  |  |
|  | Tournament  selection |  |  |  |  |  |  |  |  |
|  | uniform |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |

Population management models

μ/λ=1 Generational EA

μ/λ=1 Steady state EA

Parent selection

global

Fitness-Proportionate Selection (FPS)



Scaling

windowing

sigma scaling

Rank-based selection

Linear ranking

Exponential ranking

local

Tournament selection

Parent Selection

Uniform

Survivor Selection

Selection pressure