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Cellular Genetic Algorithms

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- Introduction to cGAs
- Typical Scenarios
- Adjusting the ratio
- Asynchronous cGAs
- Current Research
- Dynamic Problems
- Multiobjective cGAs
- Other cGAs
- Applications
- Resources

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One Conference – Many Mini-Conferences

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Optimization Algorithms

- **Exact**
  - **Calculus**
    - **Direct**
    - **Indirect**
      - **Newton**
      - **Greedy**
  - **Enumerative**
    - **DP**
    - **B&B**
- **Ad-hoc heur.**
- **Metaheuristic**
  - **Trajectory**
    - **SA**
    - **VNS**
    - **TS**
  - **Population**
    - **EA**
    - **ACO**

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✓ Panmictic (centralized)
✓ Structured (decentralized)

EVOLUTIONARY ALGORITHM

$t := 0;$

initialize: $P(0) := \{\vec{a}_1(0), \ldots, \vec{a}_\mu(0)\} \in G^\mu;$

evaluate: $P(0) : \{\Phi(\vec{a}_1(0)), \ldots, \Phi(\vec{a}_\mu(0))\};$

while no $\iota(P(t))$ **do**

selection: $P'(t) := s_{\Theta_s}(P(t));$

variation ops.: $P''(t) := \otimes_{\Theta_v}(P'(t));$

evaluate: $P''(t) : \{\Phi(\vec{a}''_1(0)), \ldots, \Phi(\vec{a}''_\lambda(0))\};$

replacement: $P(t+1) := r_{\Theta_r}(P''(t) \cup Q);$

$t := t + 1;$

end while

✓ Generational (genGA)
✓ Steady State (ssGA)

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GOAL

- Decentralize selection and replacement operations

MOTIVATION

- Nature uses separate populations to evolve
- Premature convergence can be managed properly
- Natural way of inducing niches to find different solutions
- Avoiding the recombination of very different solutions is easy
- Physical parallelism can be directly used (larger efficiency)
- The total effort can be reduced in many cases
- The structured cooperation with other techniques is fostered

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Panmixia versus Decentralization

- **Advantages of Decentralized EA's**
  - ❶ **Larger efficiency: numerical and physical**
  - ❷ **Algorithmic improvements in diversity, convergence, multisolution, dynamic environments, ...**
  - ❸ **More complex problems can be addressed**
  - ❹ **New models naturally arise**
- **Drawbacks of Decentralized EA's**
  - ❶ **New theoretical background is needed**
  - ❷ **Decentralizing is NOT always better (!)**
  - ❸ **Larger complexity of implement. and analysis**

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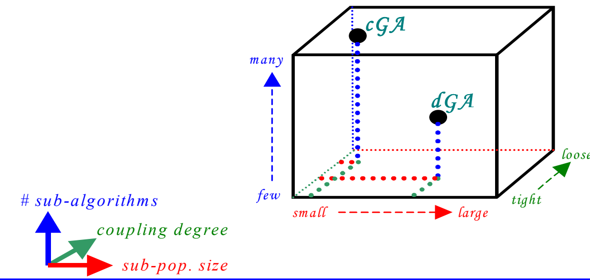
Decentralized Unified Cube

Node-grain of a decentralized EA

```
① Generate initial population
② Evaluate present population
③ While not termination do:
      ③① Select partners
      ③② Apply variation operators
      ③③ Communication with neighbors
      ③④ Replace old solution with new ones
      ③⑤ Compute working measurements
```



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Cellular Genetic Algorithms (I)

SYNCHRONOUS CELLULAR GENETIC ALGORITHM

```
Initialize(P);
Evaluate(P);
while not EndCondition(P) do
   for x=1 to POP_X do
      for y = 1 to POP_Y do
         N        = Neighborhood(P[x][y]);
         Parents  = Selection(N);
         Offspr   = Recombination(Parents);
         Offspr   = Mutation(Offspr);
         Offspr   = Local_Search(Offspr);
         P_aux [x][y]= Insert_Better(P[x][y], Evaluate(Offspr));
      end for
   end for
   P = Replace(P, P_aux);
end while
```


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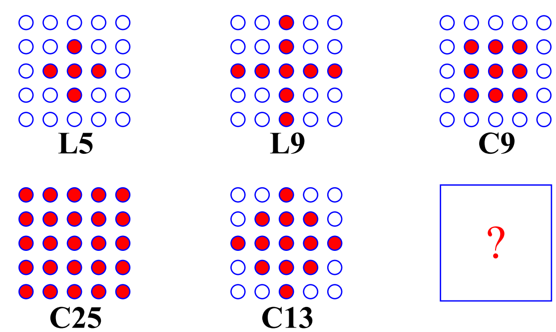
Cellular Genetic Algorithms (II)

FEATURES

- **The population is spatially structured (2-D)**
- **The reproductive cycle affects just to small neighborhoods**
- **Neighborhoods are overlapped**
- **Isolation by the distance**
- **Exploitation intra-N and exploration inter-N**



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Cellular Genetic Algorithms (III)

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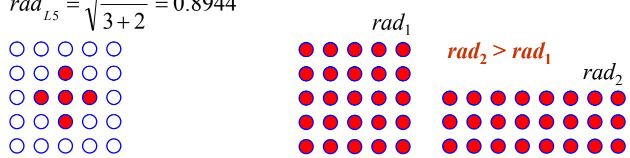
CHARATERIZING THE 2-D SHAPE

- Numerical definition of a concept called **RADIUS**
- Radius can be defined on the **grid** and on the **neighborhood**
- The relationship (***ratio***) neighborhood/grid describes Sel. Pr.

$$rad = \sqrt{\frac{\sum(x_i - \bar{x})^2 + \sum(y_i - \bar{y})^2}{n^*}} \quad \bar{x} = \frac{\sum_{i=1}^{n^*} x_i}{n^*} \quad \bar{y} = \frac{\sum_{i=1}^{n^*} y_i}{n^*}$$

$$ratio_{cGA} = \frac{rad_{neighborhood}}{rad_{grid-topology}}$$

$$rad_{L5} = \sqrt{\frac{2+2}{3+2}} = 0.8944$$



L5

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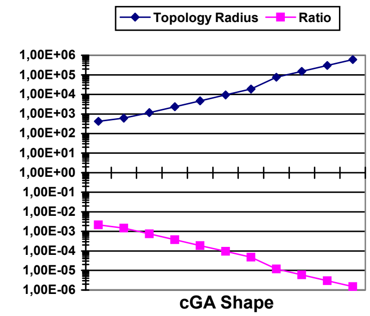
#	Topology	Radius	Ratio using NEWS
a	1024 × 1024	4.180460501E+2	0.002139477217369000
b	2048 × 512	6.094017558E+2	0.001467668892463000
c	4096 × 256	1.184720431E+3	0.000754946041780600
d	8192 × 128	2.365115325E+3	0.000378163377720300
e	16384 × 64	4.729689472E+3	0.000189103323864000
f	32768 × 32	9.459311312E+3	0.000094552337955660
g	65536 × 16	1.891861418E+4	0.000047276190078740
h	131072 × 8	7.567445452E+4	0.000011819047863290
i	262144 × 4	1.513489090E+5	0.000005909523933205
j	524288 × 2	3.026978179E+5	0.000002954761967579
k	1048576 × 1	6.053956359E+5	0.000001477380983545



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Typical Scenarios: Diversity (I)

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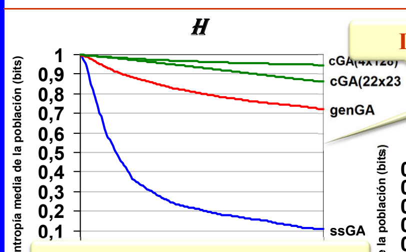

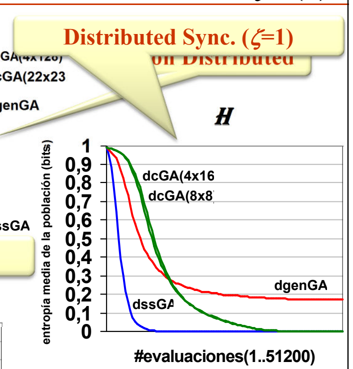

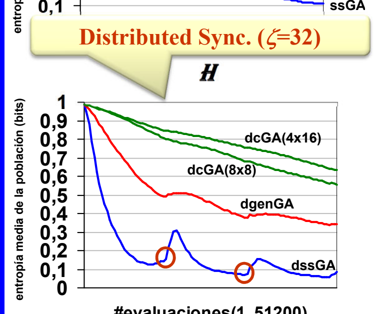

SPH16-32
512 individuals (8×64)
DPX1(p_c=1.0)
MUT(p_m=1/l)

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Typical Scenarios: Diversity (II)

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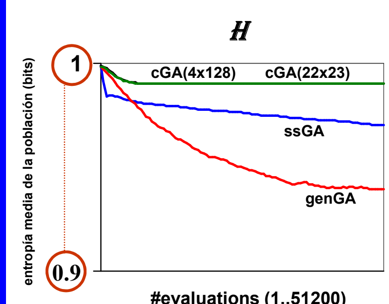

SSS128
512 individuals (8×64)
DPX1(p_c=1.0)
MUT(p_m=1/l)

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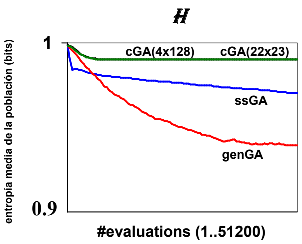
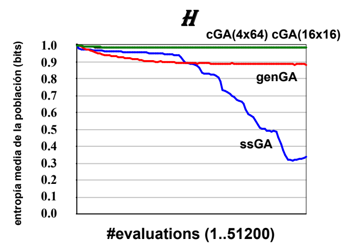
SSS128
from 512 i (8×64)
to 256 i (8×32)

Typical Scenarios: Diversity (III)





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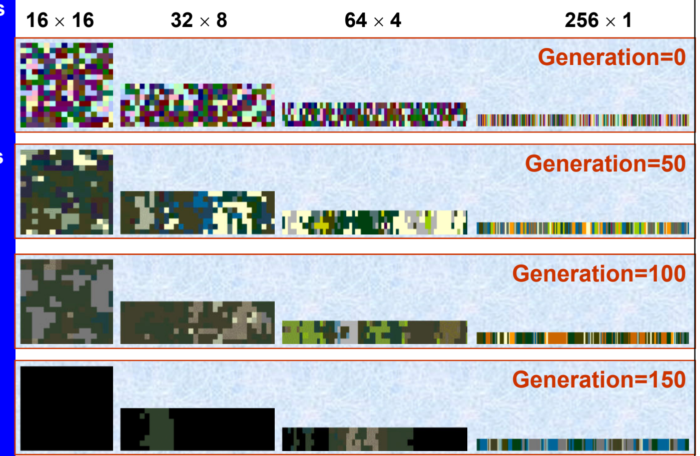
MMDP15
256 individuals
DPX1(p_c=1.0)
MUT(p_m=0.1)

Typical Scenarios: Diversity (IV)

Influence of the grid shape on the diversity



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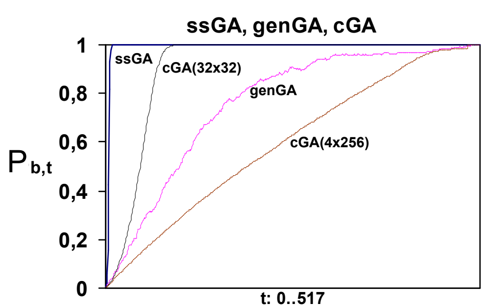
BEST CLASS
1024 individuals
Random fitness in [0..255]

Typical Scenarios: Selection Pressure (I)

Centralized versus cGA Models



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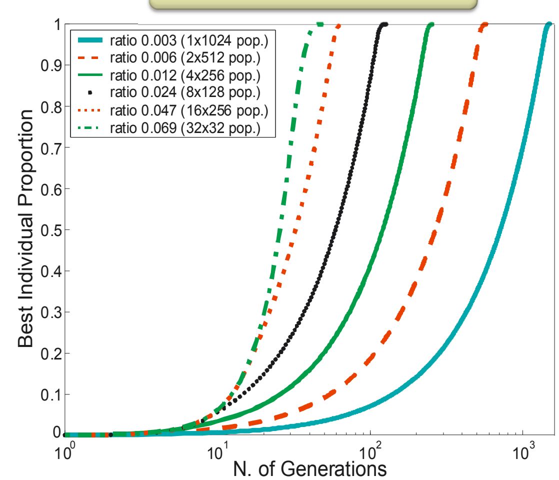
BEST CLASS
1024 individuals
Random fitness in [0..255]

Typical Scenarios: Selection Pressure (II)

Influence of the ratio



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Typical Scenarios: Response to Selection in a cGA

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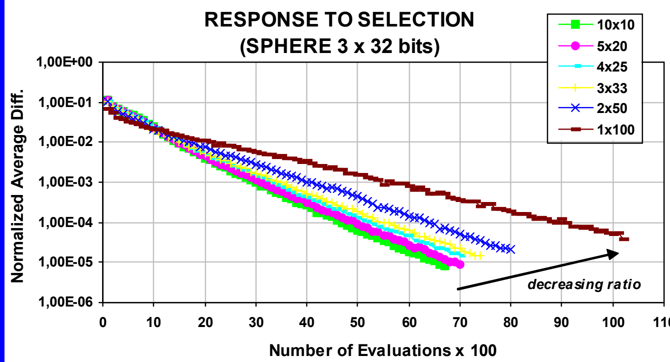

RtS in a cGA : $R(t+1)=S(t+1)-S(t)$
100 individuals
Decceleration of search

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Typical Scenarios: Replacement Policy in a cGA

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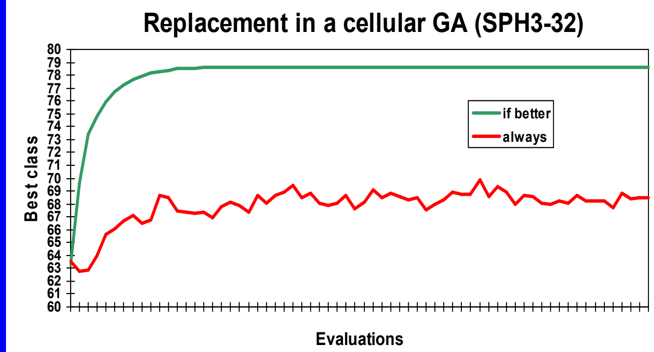

Replacement in a cGA
SPH3-32 (grid 2×64)

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Typical Scenarios: Importance of the grid in a cGA (I)

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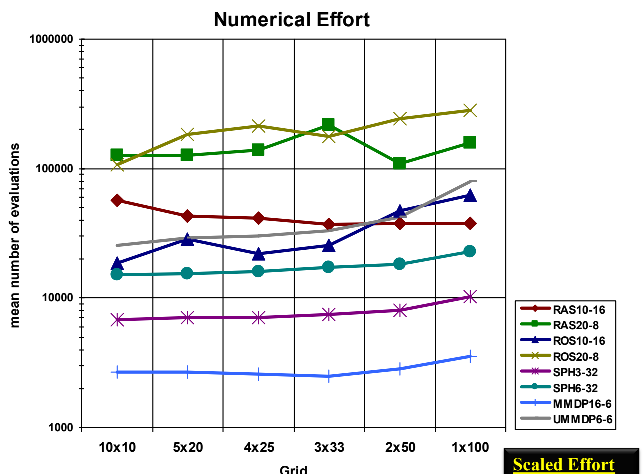

Scaled Effort
100 individuals
8 problems

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Typical Scenarios: Importance of the grid in a cGA (II)

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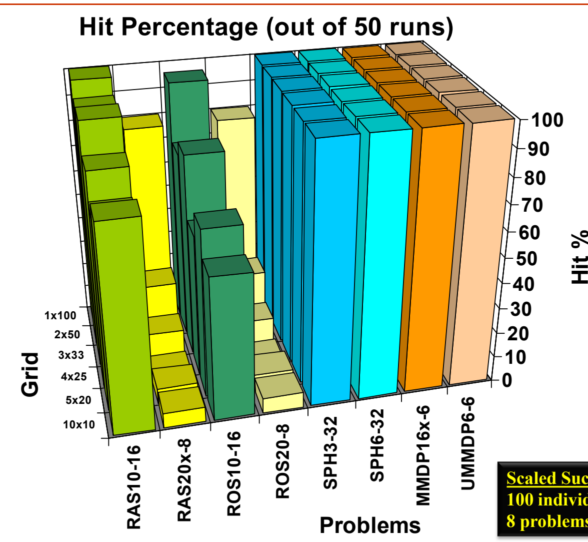

Scaled Success
100 individuals
8 problems

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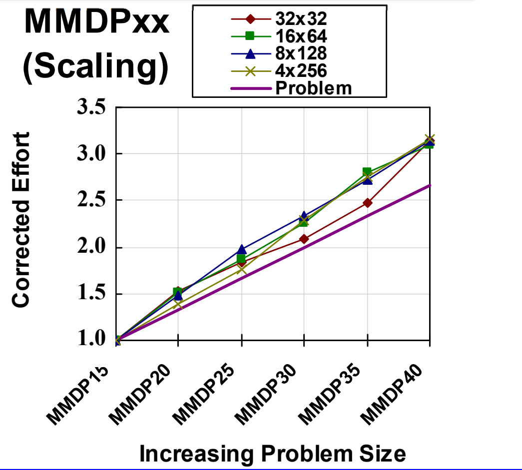
Typical Scenarios: Scaling the cGA

Constant Population Shape (1024 individuals)
Proportional Selection, DPX1(p_c=1.0), MUT(p_m=1/l)



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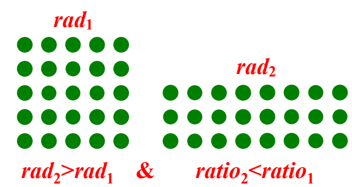
Adjusting the Ratio (I)

- The ratio between the grid shape and the neighborhood defines the intensification/diversification ratio



↑RATIO ⇨ ↑exploitation

↓RATIO ⇨ ↓ exploration

TUNABLE TRADEOFF!

Shape	$rad_{topology}$	rad_{NEWS}	ratio
20×20	8.15	0.8944	0.10968 ≈ 0.110
10×40	11.9	0.8944	0.07519 ≈ 0.075
4×100	28.9	0.8944	0.03096 ≈ 0.031

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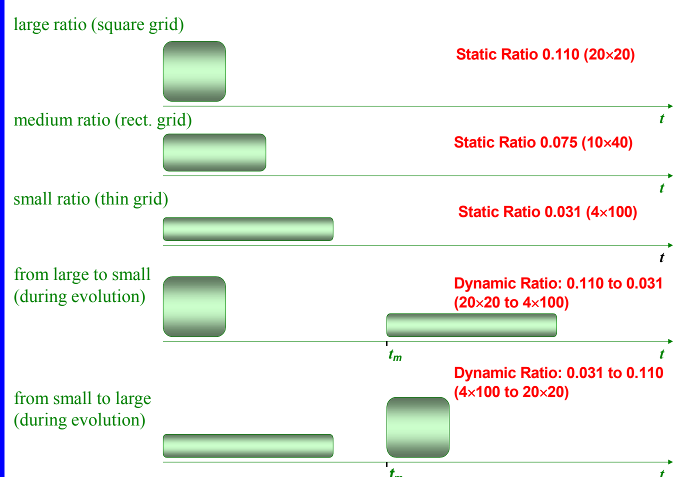
Adjusting the Ratio (II)



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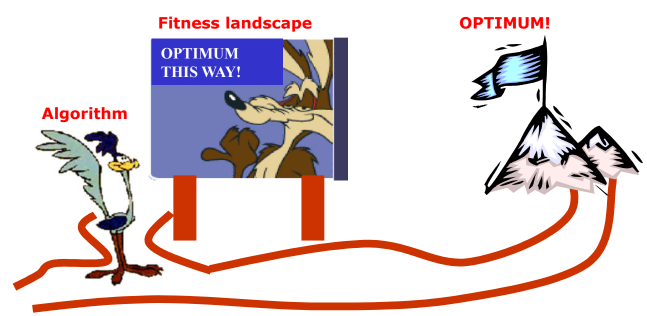
Adjusting the Ratio (III)

- Let us select some different and representative problems:



The MMDP problem (misleading)

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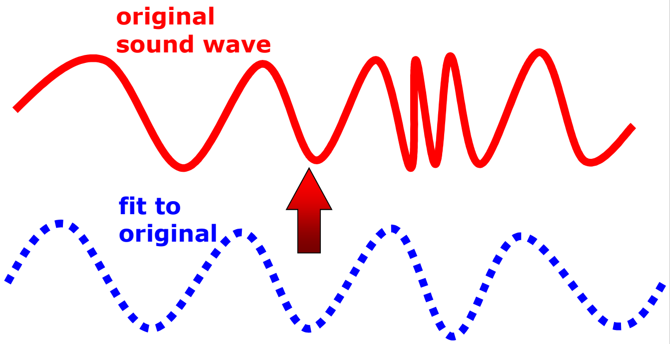
Adjusting the Ratio (IV)

• Let us select some different and representative problems:



The FMS problem (real-world like)

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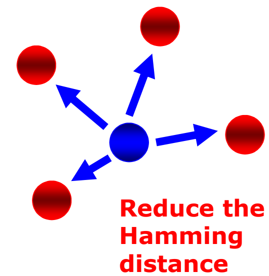
Typical Scenarios: Adjusting the Ratio (V)

• Let us select some different and representative problems:



The P-PEAKS problem (generator)

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Adjusting the Ratio (VI)

• Let us study 5 different ratii over 3 problems:

MMDP: Massively Multimodal Deceptive Problem
⇨ **BEST: SQUARE GRID**

FMS: Frequency Modulation Sounds (multimodal)
⇨ **BEST: DYNAMIC GRID**

P-PEAKS: Problem Generator (highly epistatic)
⇨ **BEST: THIN/DYN. GRID**

	0.110	0.075	0.031	0.110 / 0.031	0.031 / 0.110
MMDP	**170637.9**	237003.4	331719.6	1002900.0	1002900.0
FMS	612112.1	594093.9	593519.1	692205.2	**575353.8**
P-PEAKS	50458.1	50364.6	**48653.6**	57769.7	**48012.1**

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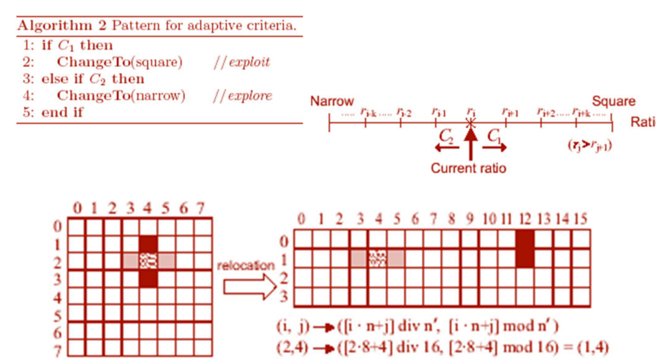
Adjusting the Ratio… Automatically! (I)

Define a model that **self-modifies** the grid shape during the search as a function of the convergence speed, trying to maintain the diversity and to refine the global optimum faster at execution time



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Adjusting the Ratio… Automatically! (II)

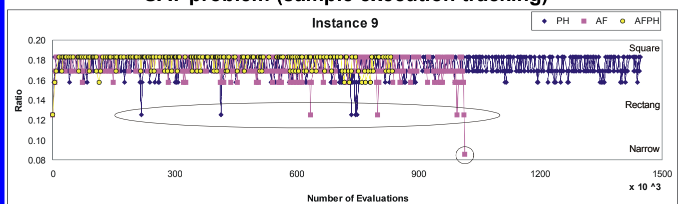
Q. How do we determine if the population is going **too** fast or **too** slow?

A. We propose three different criteria for measuring the search speed:

- ✓ the average fitness → criterion **AF**
- ✓ the population entropy → criterion **PH**
- ✓ a combination of both of them → criterion **AFPH**

Since these criteria check simple conditions over the average fitness and the population entropy it is clear that they are inexpensive to measure, while they are indicative of the search states at the same time too

SAT problem (sample execution tracking)



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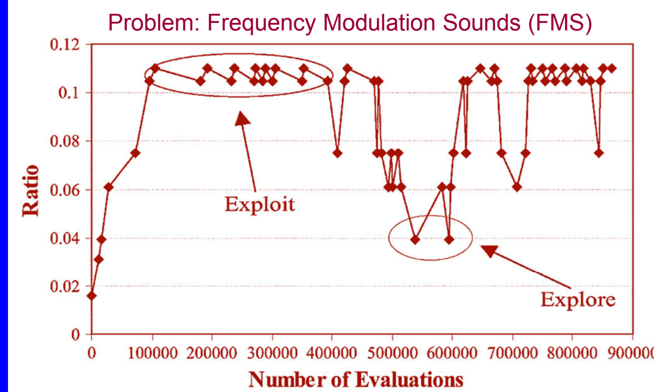
Adjusting the Ratio… Automatically! (III)

- Our studies conclude that cGAs with dynamic ratio effectively self-adapt to difficult optimization problems



- Higher numerical performance at negligible cost

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Asynchronous cGAs: Update Policy

- Updating in cEA's is an influent issue (like in CA's):

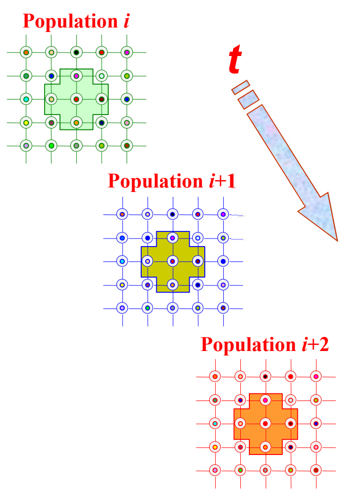
ASYNCHRONOUS UPDATING

Fixed Line Sweep updates contiguous individuals from first to last

Fixed Random Sweep makes a random cell permutation and always uses it

New Random Sweep makes a new random permutation each time step

Uniform Choice selects the next individual for updating randomly with replacement



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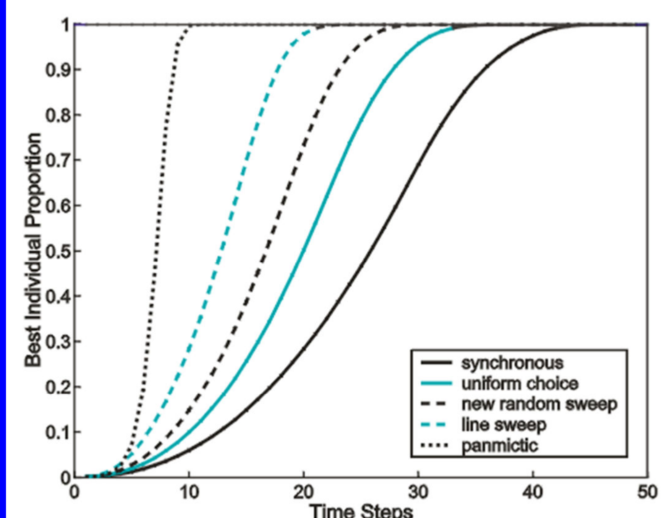
Asynchronous cGAs: Selection Pressure



Asynchronous cGAs: Some Results

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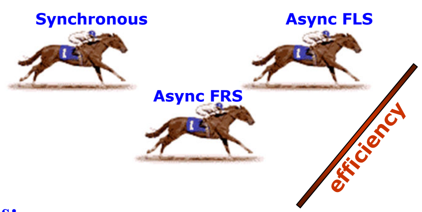
RESULTS

	Synchro	Line Sweep	Fixed Random	New Random	Uniform Choice
MMDP	277950	**201887**	216300	217850	238850
FMS	560760	543928	**427291**	480500	534772
P-PEAKS	243300	**189550**	191700	201400	203350



Conclusions:
- Sync is always the worst policy
- Fixed Line Sweep (FLS) is simple and efficient
- For FMS, FRS is more efficient but FLS improves the hit %

Current Research (I): cGAs on GPUs

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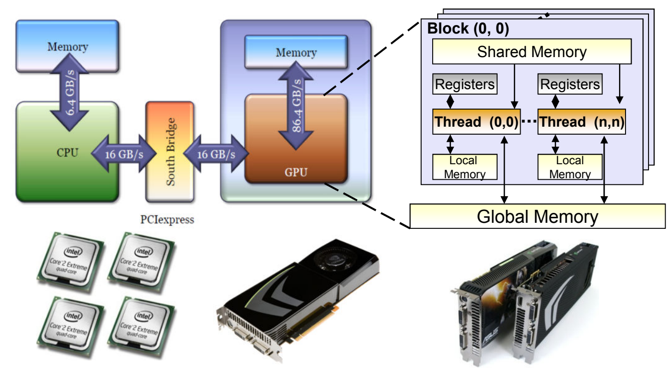
- Graphics Processing Units (GPUs) are low cost, ubiquitous hardware that allow parallel execution of computational demading algorithms



- Our goal is to exploit the benefits of GPUs to improve the real time efficiency of Cellular Genetic Algorithms

Current Research (II): cGAs on GPUs

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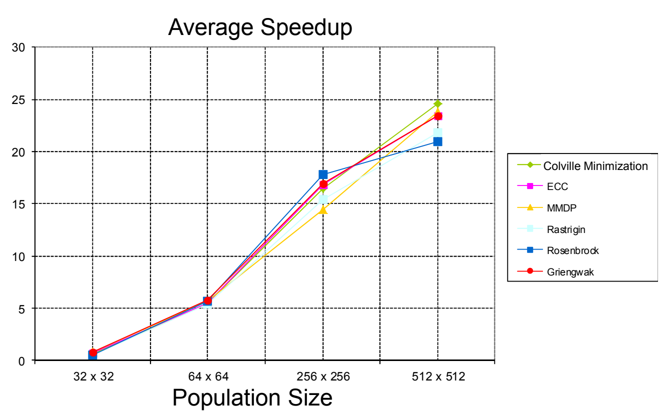
- Our results show that GPUs obtain almost linear speedup when the execution time of cGAs is compared to those in CPUs



Current Research (III): cGAs on Multicores

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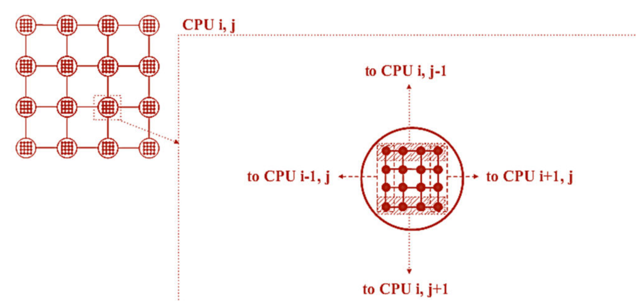
- Advanced techniques are needed to cope with the high computational requeriments of the current real-world problems
- We have added parallel asynchronicity to canonical cGAs achieving a new highly efficient algorithm



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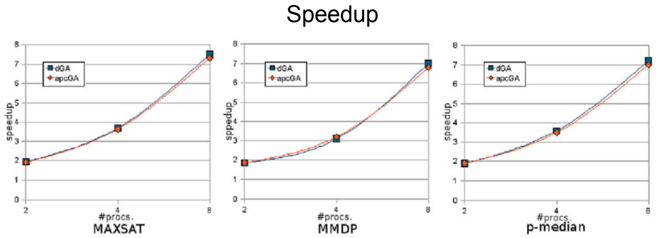
Current Research (IV): cGAs on Multicores

- Our new cGA has been successfully evaluated in NP-hard and well-known problems



- Benefits:
  - Numerical behaviour is maintained or even **improved**
  - Execution time is drastically **reduced**

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Current Research (VI): Active Components on cGAs

- Idea: identify «**active components**» from other metaheuristics and include these components inside a classical (now hybrid) cGA

ACO: Ant Colony Optimization

PSO: Particle Swarm Optimization

- Goal: easily **improve** the efficiency and accuracy of cGAs

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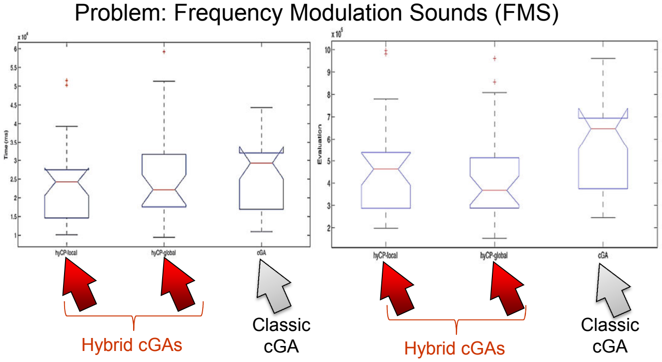
Current Research (VII): Active Components on cGAs

- We have evaluated a cGA hybridized with a PSO in well-known combinatorial optimization problems. See one example:

Problem: Frequency Modulation Sounds (FMS)



- Our hybrid algorithm outperforms a classical cGA in terms of execution time and numbers of evals. to reach the optimum

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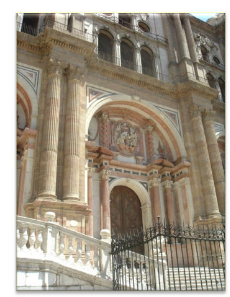
Dynamic Optimization with cGAs (I)

Many Non-Stationary Optimization Problems Exist in Real-Word !

Traffic Light Controllers

Video Image Color Segmentation



Gas Engine Control

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Dynamic Optimization with cGAs (II)

Many New Algorithms

Diploid\Dominance
BIPOP
Micro GA
Multinational GA
Parallel EA Variants
Stochastic GA
Variable
Triggered Hypermutation
Immune System
Local Search
Random Immigrant
Self-adaptive Mutation
Self-Organizing Scouts
Cultural GA
Multiploid
Thermodynamical GA
Shifting Balance GA
Aging EA
Self-adaptive Mutation with update rule

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Dynamic Optimization with cGAs (III)

- In General:

$$f(x,t) = \begin{cases} f_1(x) & \text{si } t \in U_1 \subset T \\ f_2(x) & \text{si } t \in U_2 \subset T \\ \vdots & \vdots \\ f_n(x) & \text{si } t \in U_n \subset T \end{cases} \quad \text{con } \bigcap_{i=1}^{n} U_i = \phi$$

- In most cases:
  - n is 2 or 3
  - U_i is a set of intervals with the same length for all i *(period of change)*

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Dynamic Optimization with cGAs (IV)

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Dynamic Optimization with cGAs (V)

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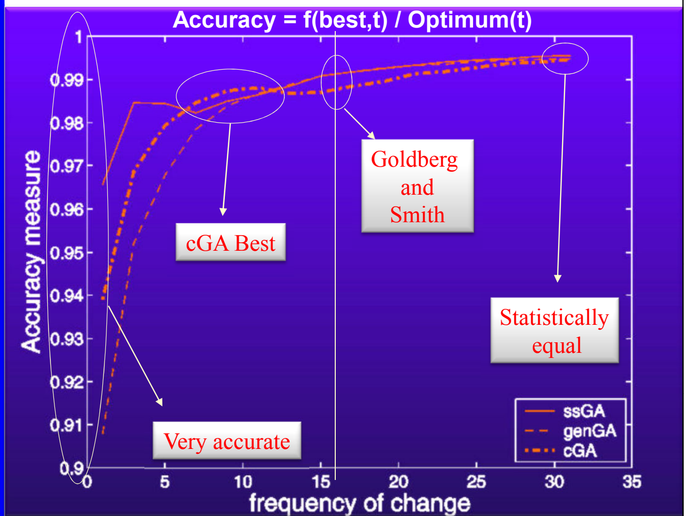
Dynamic Optimization with cGAs (VI)



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Multiobjective cGAs (I)

Multiobjective Optimization

- Most optimization problems in the **real world** involve the minimization and/or maximization of **more than one** function → **Multiobjective Optimization Problems** (MOPs)
- **Multiobjective optimization** involves finding a set of non-dominated solutions called **Pareto Optimal Set**
- The **image** in the objective space of the Pareto optimal set is known as the **Pareto Front**
- Obtaining the Pareto front of a given MOP is the **main goal of multiobjective optimization**

Metaheuristics for Multiobjective Optimization

- **Search space** in MOPs
  - Usually very **large**
  - **Function evaluation** demands high **computational resources**
    - Exact techniques **difficult** to apply → **metaheuristics**
- **Evolutionary Algorithms** (GAs in particular) are very **popular** techniques for multiobjective problems: NSGA-II, SPEA2, etc.

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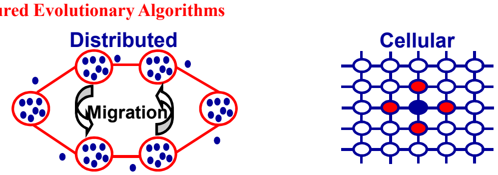
Multiobjective cGAs (II)

Structured Evolutionary Algorithms



Cellular Genetic Algorithms (cGAs)

- **Spatially structured population** (usually **2-D**)
- **Overlapped neighborhoods** (smooth diffusion)
- **Reproductive cycle** applied to small **neighborhoods**
- **Low attention** to solve MOPs

Innovations

- **Adaptation** of a **canonical cGA** to the multiobjective domain → **MoCell**
  - **External archive**
  - **Feedback** of **individuals**
- **Evaluation** with a set of both **unconstrained** and **constrained MOPs**
- **Comparison** against **state-of-the-art** algorithms **NSGA-II** and **SPEA2**
  - **Original implementations**
- Second **goal**: how to **profit** from **well-known operators** in other algorithms
  → SBX, polynomial mutation, ranking and crowding from NSGA-II

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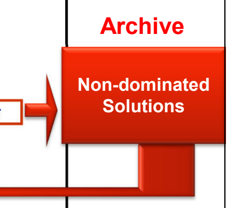
Multiobjective cGAs: MoCell

External archive → storing nondominated solutions

- **Newly** created individuals are inserted into:
  - **Auxiliary population**: if it is not dominated by the current one
  - **Pareto front**: using the crowding procedure (**NSGA-II**)
- **Feedback** of solutions at the **end** of **each iteration**

```
Initialize(P);
Evaluate(P);
Pareto_front = Create_Front();
while not EndCondition(P) do
  for x=1 to POP_X do
    for y = 1 to POP_Y do
      N          = Neighborhood(P[x][y]);
      Parents    = Selection(N);
      Offspr     = Recombination(Parents);
      Offspr     = Mutation(Offspr);
      Offspr     = Evaluate(Offspr);
      P_aux[x][y] = Insert(P[x][y], Offspr);
      Pareto_front = Insert_Pareto_Front(Offspr);
    end for
  end for
  P = Replace(P, P_aux);
  Feedback(P,Pareto_front);
end while
```



Multiobjective cGAs: Metrics

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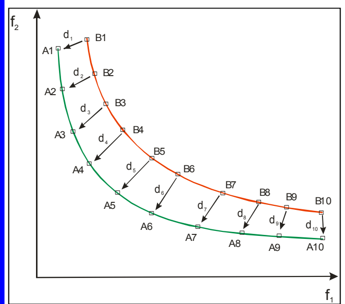
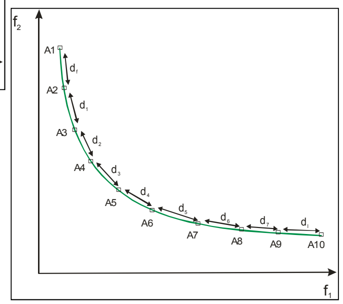


Generational Distance (convergence)



Diversity (spread)

Multiobjective cGAs: MoCell is the State of the Art (!)

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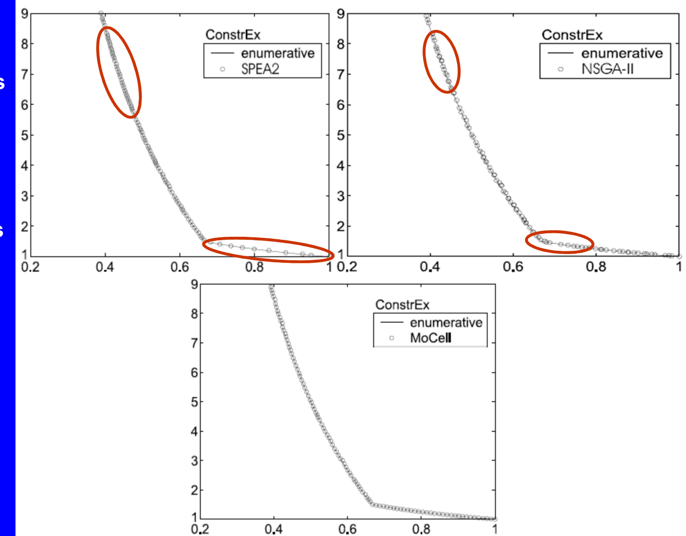

Other cGAs: Real Coded cGAs

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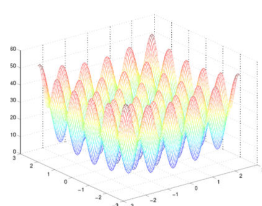
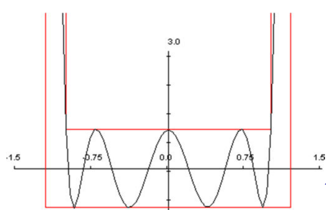
- **Real coded cGAs**
  1. **Easy application of float operations**
  2. **Easy incorporation of local search**
  3. **Rest of advantages of standard cGAs**





$$\begin{pmatrix} a_{11} & \cdots & a_{1j} \\ \vdots & \ddots & \vdots \\ a_{i1} & \cdots & a_{ij} \end{pmatrix} \cdot \begin{pmatrix} x_1 \\ \vdots \\ x_j \end{pmatrix} = \begin{pmatrix} b_1 \\ \vdots \\ b_i \end{pmatrix}$$

Other cGAs: Hierarchical cGAs

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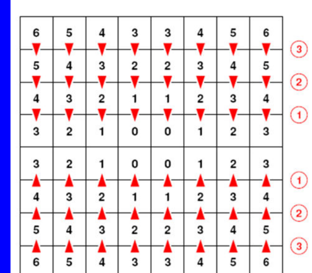
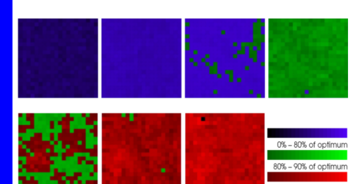
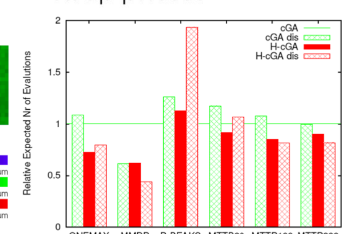


- Cells are labelled with distance to centre
- Compare with inner neighbour, if better swap
- Perform swaps from inside to outside
- Alternate between horizontal and vertical swap phases





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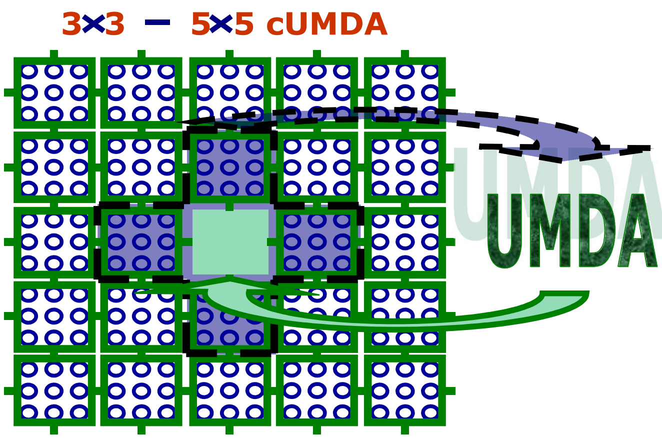
Other cGAs: Cellular EDAs



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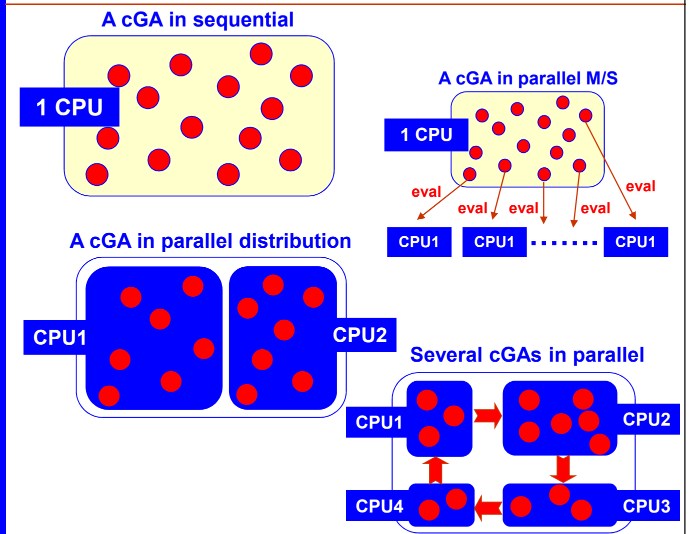
Other cGAs: Parallelism (I)



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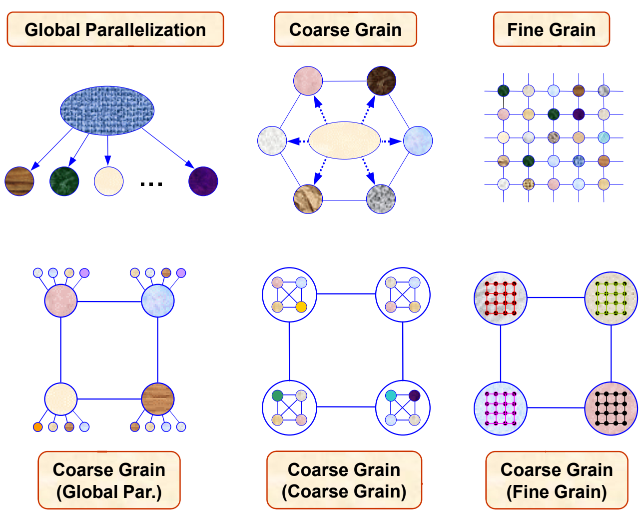

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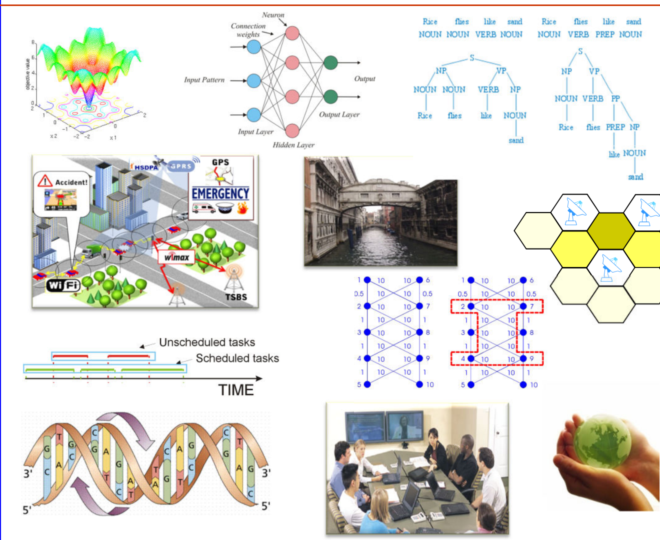
Applications of cGAs



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Interesting Links

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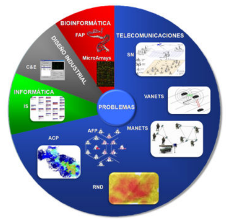
- **NEO-GISUM group at University of Málaga**
  http://neo.lcc.uma.es
- **Enrique Alba's personal web page**
  http://www.lcc.uma.es/~eat/
- **DIRICOM Project**
  http://diricom.lcc.uma.es
- **roadME Project**
  http://roadME.lcc.uma.es
- **MALLBA Library**
  http://neo.lcc.uma.es/mallba/easy-mallba
- **Jcell software for cellular GAs**
  http://neo.lcc.uma.es/JCell



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Alba & Dorronsoro 2008

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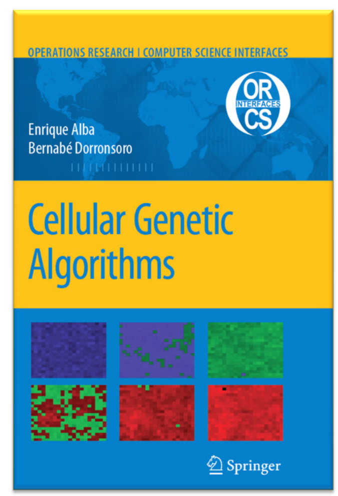

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3 On the Effects of Structuring the Population
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A Definition of the Benchmark Problems

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End of Presentation

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http://neo.lcc.uma.es