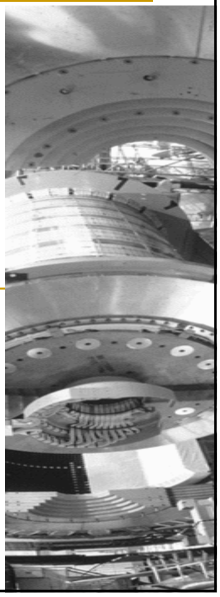
# Parallel Genetic Programming

***Francisco Fernández de Vega***
***Grupo de Evolución Artificial***
***University of Extremadura (Spain)***



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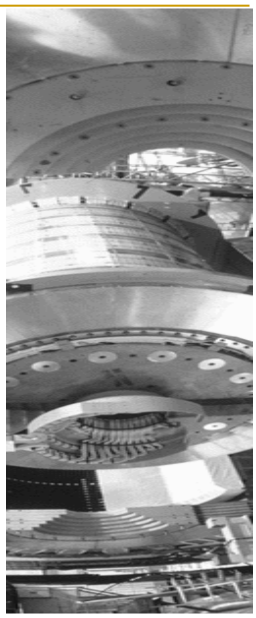
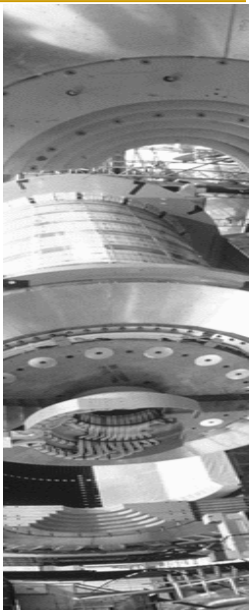
# Summary:



- Introduction.
- History.
- Parallel GP.
- The Island Model.
- Successful Applications.
- Future.

## Summary:



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## Some considerations

- Genetic Programming can be considered a Machine Learning system:
  - “[machine learning] is the study of computer algorithms that improve automatically through experience [Mitchell, 1996].
- The emphasis is on *learning* (instead of on *knowledge).*
- The dream of computers that program themselves [Samuel, 1963] could be reached soon.

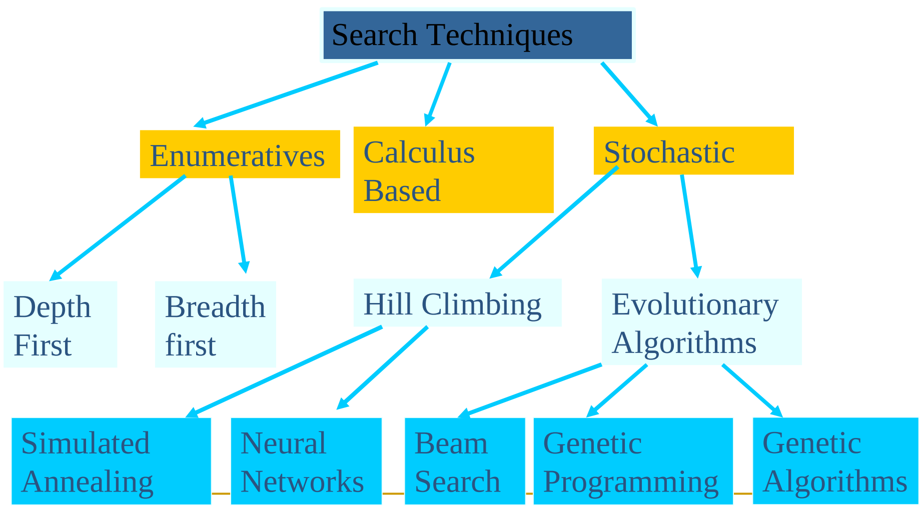
## What's Genetic Programming?

- According to Banzhaf et al*, GP is a system that induce computer programs by evolutionary means.
- GP (Koza, 1992) is a kind of Evolutionary Algorithm (EA). (Genetic Alorithms, Genetic Programming, Evolutinary Strategies, Evolutionary Programming).
- EAs can be seen as search techniques (stochastic search technique).

*Banzhaf, W., Nordin, P., Keller, R.E., Francone, F.D. Genetic Programming, an Introduction. Morgan Kaufmann 1998.



## Different Search Techniques



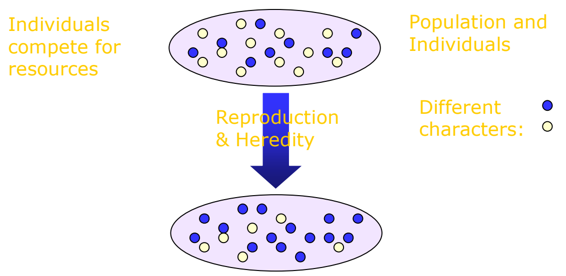

As classified by Banzhaf et al

## How does an EA work

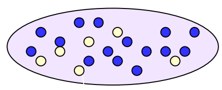
- A summary:
  - T=0;
  - Initialize and evaluate [P(t)]
  - While not stop_condition do
    - P´(t)=variation [P(t)]
    - Evaluate P´(t)
    - P(t+1)=select [P´(t),P(t)]
    - T=t+1
  - end while

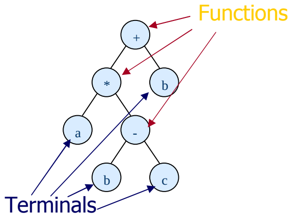


## How does GP work?



# How does GP work?






GP Individual

Genetic Operators:

- Crossover.
- Mutation.
- Selection.
- Reproduction.

Fitness Function



## Genetic Programming

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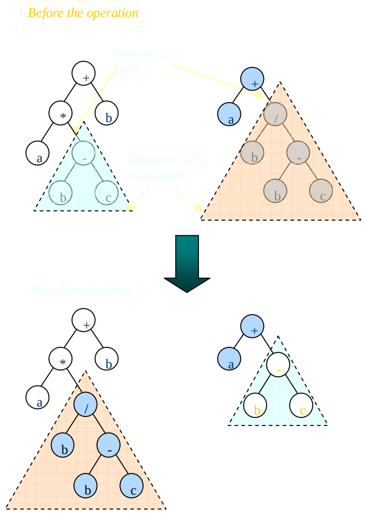
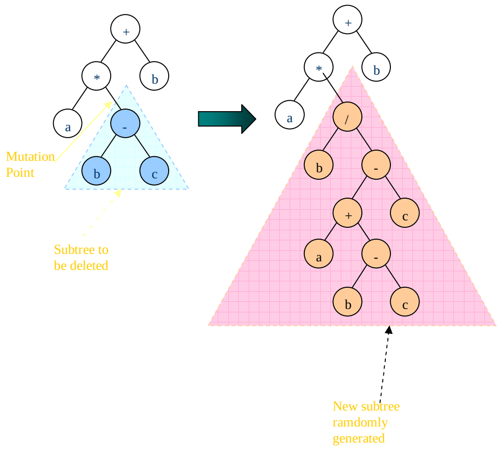



Relies on the Building block hyp

## Genetic Programming

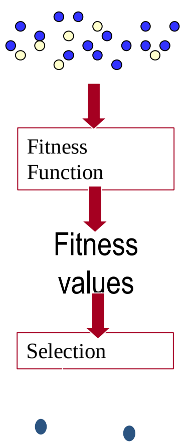
M U T A T I O N





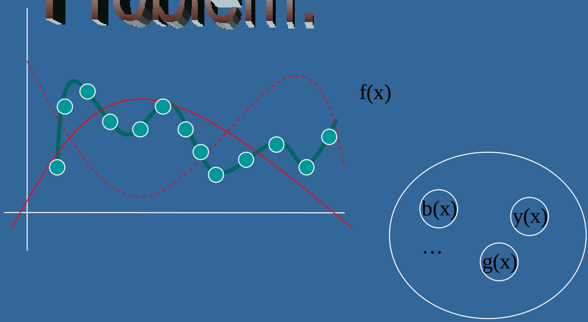

## Genetic Programming

S E L E C T I O



Genetic Programming

# Problem:






## Summary:

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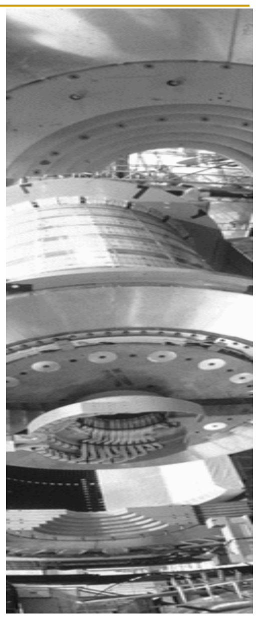


## History

- There are two main ideas behind Parallel Eas:
  - Increase performances:
    - in principle, by adding processors, memory and interconnection networks and putting them to work together on a given problem.
  - Modifying the underlying algorithm can also help in the finding of solutions.



## History

- Ideas involving both EAs and Parallel Computing can be traced back to Holland, 1976.
- But the field had to wait until early 1980s when parallel implementations appear.
- Grefenstete, 1981, was one of the first in examaining some issues concerning parallel implementations of Gas.

## History

- Other researchers began more systematic studies: Gross, Cohoon, Tanese, Pettey, Georges-Schleter, Mühlenbein, and Manderick*.
- They studied Hypercubes parallel architecture, distributed models, theoretic models, island models, and cellular model.

*See "Parallelism and Evolutionary Algorithms", E. Alba & M. Tomassini, IEEE Transactions on Evolutionary Computation, Vol. 6, NO. 5, Oct 2002, 443-462 for a review summary.



## Parallelism & EAs

- Flynn model is still widely accepted for classifying computer architectures.
- The taxonmy is based on the notion of instruction and data stream:
  - SISD: Single instruction, Single Data stream.
  - SIMD: Single Instruction, Multiple Data stream (the preferred model).
  - MISD: Multiple instruction, single data stream.
  - MIMD: Multiple instruction, multiple data stream.
- Shared or Distributed Memory.

## Taxonomy

- Parallel EAs can be classyfied attending to different features.
- M Nowostawski and R. Poli 1999:
  - Master/Worker: A single population and the fitness evaluation of multiple individuals in parallel.
  - Static subpopulations with migration.
  - Static overlapping subpopulations without migration.
  - Massively Parallel genetic algorithms.
  - Dynamic demes.
  - Parallel Steady-state Ga
  - Parallel Messy Ga
  - Hybrid methods.



## Taxonomy

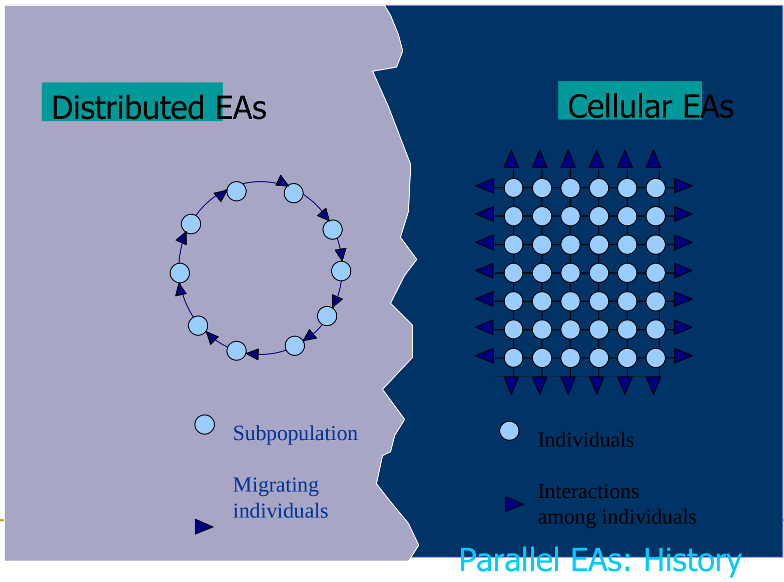
- M. Tomassini, 1999:
  - Global parallel evolutionary algorithm (parallelization at the fitness level) also called by the author master/worker model (coarse-grained model).
  - Island distributed evolutionary algorithms (population based approach).
  - Cellular evolutionary algorithm (fine-grained model).

## Structured EAs

- Structured populations has been used for improving EAs.
- Two main types of algorithms:
  - Distributed EAs.
  - Cellular EAs.
- On the oposite side, panmictic EA is the classic model.
- None of the models require a parallel implementation.



## Structured EAs

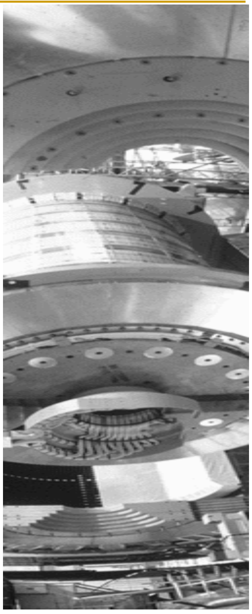


## Nonstandard Structured EAs

- We could use different parameters/representations in different subpopulations (Tanese, Lin & Punch & Goodman, Herrera & Lozano & Moraga).
- These algorithms are sometimes called heterogenous.



## Summary:



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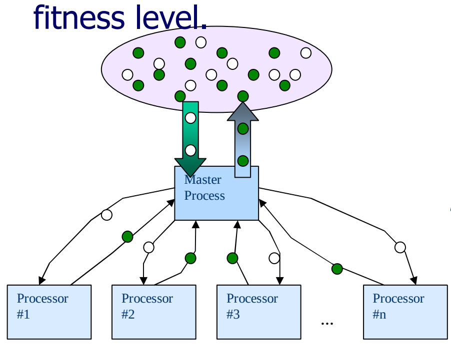
## Parallel Models

Parallelising at the fitness level.




This model is also called "global model".

Why should we use a parallel model?

- We want to increase performances.

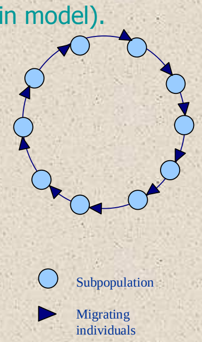
How could we parallelise?

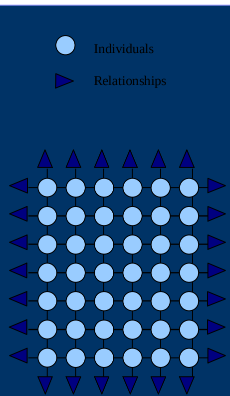
- At the individual level.
- At the population level.
- At the fitness evaluation level



## Parallel Models

Parallelising at the population level (also called island model or coarse-grain model).




Fine-grained model (also called Grid or Cellular model)

## Parallel GP: A review

- Juillé and Pollack 1995 presented one of the first attempts to parallelize GP.
- They implemented a global model, although also presented some result using sub-populations.
- The proposal was somehow specific for the SIMD model they were using.
- One of their aims was to reduce interprocessor communication.



## Parallel GP : A review

- P. Tuffs, 1995, presented the same year another master/worker parallel version of GP.
- He approached a classification problem by means of GP. -the development of a system to do data mining on a fairly large (multi-gigabyte) database of credit-card transactions. The task was to classify customers and predict their future behavior-
- Probably it was the first attempt to parallelize GP (the book correspond to year 1993, although was published on 1995).

## Parallel GP : A review

- Andre and Koza 1996 presented another Parallel GP Implementation using a network of 66 transputers (VLSI device containing 32 bit on-chip processor, memory and links)
- They employed the island-model.
- An appropriate migration rate showed improvement in the computational effort required for the Boolean 5-parity function.(64 demes, SubPop_size=500, Migration_rate=5%)
- The main conclusion was that Parallel GP could achieve super-linear speedups.



## Parallel GP : A review

- K. Stoffel and L. Spector 1996, implemented a parallel version of GP using linear programs evaluated by means of a stack.
- Several processors generate independently its own segment of the next generation.
- They implemented crossover in parallel: Individuals from different processors may undergo crossover.

## Parallel GP : A review

- Oussaidène et al 1997, presented a parallel implementation of GP for trading model induction.
- They employed the global model architecture (parallelization at the fitness level), employing a master/worker model, where each node from the network is in charge of evaluating individuals comming from a master node.
- The master node is in charge of the main GP algorithm.
- The model may undergo a load imbalance problem.



## Parallel GP: A review

- Results offered by Koza were questioned later by W. F. Punch 1998. His experiments on the Royal Tree problem were not so optimistics. His main conclusions were that multiple-solution problems would be more amenable to multiple populations than single-solution problems.
- On the other hand, non-deceptive problems would be more amenable to multiple populations than deceptive problems.
- He only tried a set of parameters for the parallel model.

## Parallel GP : A review

- Fernandez et al 1999, presented experimental results on an island-model implementation of GP.
- Although results were preliminar, this is the first time some important parameters of the island-model are tested (communication topology).



## Parallel GP : A review

- Folino et al, 2000, presented a new implementation of GP using the cellular model.
- Fernández et al, 2000, studied more deeply the relationship among several important parameters for the island-model (subpop size, number of subpop, communication topology).

## Parallel GP : A review

- The latest results on both the island and cellular GP models have been presented very recently:
  - F. Fernández et al., 2003, described latest results with the island-model, while G. Folino et al, 2003, presented a Cellular Scalable implementation for GP. Their results are compared with previously described results using parallel GP.



## Parallel GP tools

- Many GP tools allow the use of “demes” but simmulated in a sequential fashion.
- There have been several parallel implementations during the last few years.
- Several languages (C, java, C++) and communication frameworks (sockets, java rpc, pvm, mpi …) have been employed.

## Communication Tools

- PVM: Parallel Virtual Machine (V.S. Sunderam, "PVM: A framework for parallel distributed computing, " J. Concurr. Practice and Experience, vol.2, no.4, pp. 315-339, 1990")
- MPI: Message Passing Interface.(Message Passing Interface Forum, "MPI: A message-passing interface standard," Int. J. Supercomput, Applic., vol.8, no.3-4, pp.165-414, 1994)
- GLOBUS.
- Others (Sockets, Java-RMI…)



## Parallel GP tools

- Chong, 1998, presented DGP, a java based distributed approach to genetic programming on the Internet.
- F. Fernández et al, 1999, developed a parallel GP tool implementing the island-model, and communicating subpopulations by means of PVM. This tool was later improved by means of MPI (Fernández et al, 2000).
- Spezzano et al, 2001, presented CAGE: A tool for parallel genetic programming applications. They implemented the cellular model.
- Classic LilGP software (Punch) also has a couple of parallel version implemented using PVM and MPI (see Fernández parallelilgp)

## Parallel GP tools

- DREAM project: It is aimed at providing a framework for evolutionary computation.
- It allows distributed computing.
- Any Evolutionary Algorithm could be used, by adjusting some parameters, within DREAM.
- Founded by European Union.
- See: http://www.dcs.napier.ac.uk/~benp/dream/dream.htm



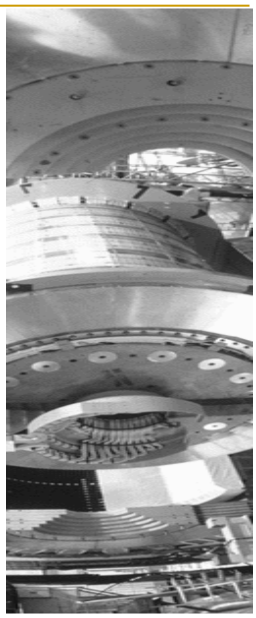
## Parallel GP tools

- Paradiseo: Parallel and Distributed Evolving Objects.
- It is based on EO (Evolutionary Computation Framework).
- Includes tools for:
  - Population Based Metaheuristics.
  - Single Solution Based Metaheuristics.
  - Multi-Objective Metaheuristics.
  - Parallel and Distributed…

## Parallel GP tools

- ECJ: A Java-based Evolutionary Computation Research System.
- Includes asynchronous Island Model over TCP/IP.
- Multiobjective Optimization.,

## Summary:



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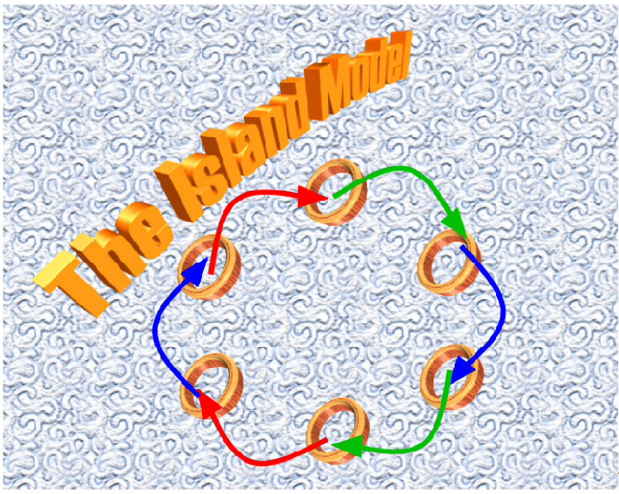
# Island Model




Important Parameters:

Size of Subpop.

Topology.

Communication rate.

Granularity.

Synchronization.

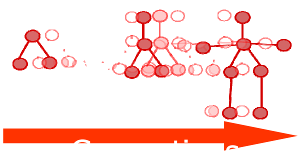
Important concern:

Comparing results.



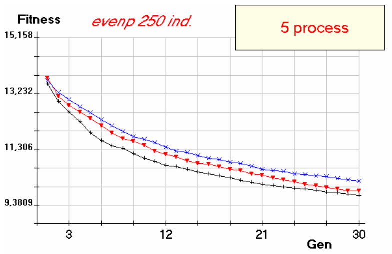
# Island Model – Comparing results

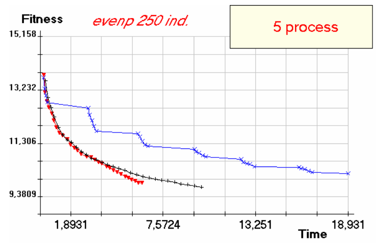
- Traditionally experimental results are shown comparing Fitness/Generation.
- Two reasons for avoiding this kind of comparisons:
  - The Bloat phenomenon in GP.

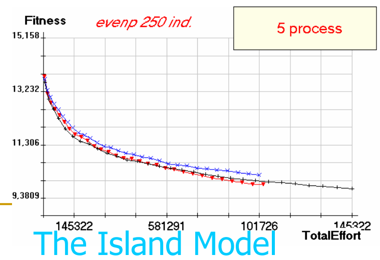


  - Populations with different size require different time to evaluate a generation.

## Island Model – Comparing Results






## Island Model – Measuring Results

- Proposal: Evaluate Fitness/Effort (for convergence) or Fitness/Time (for speedup) (Fernández, Galeano, Gómez).

**Computational effort:**

**The total number of nodes GP has evaluated for a given number of generations.**

$PE_g$=i*p*avg_length$_g$

p:the number of populations

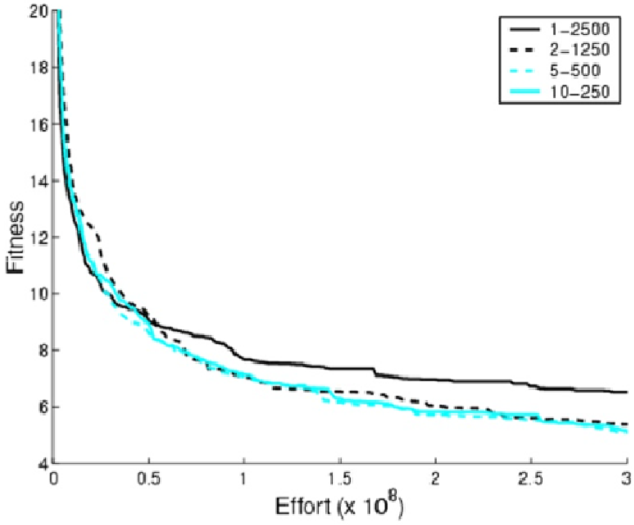
i:the number of individuals per population

avg_length$_g$: the average length of individuals in all the populations in generation g.

The computational effort $E_g$ at a generation g is:

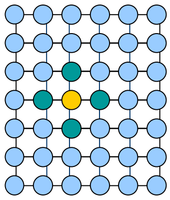
$$E_g = PE_g + PE_{g-1} + \dots + PE_1 + PE_0$$

## Island Model – Comparing Results



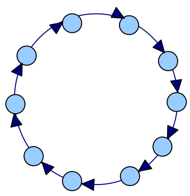

## Island Model - Topology

- Andre and Koza 1996 connected each subpopulations with 4 neighbors in the N, E, W, S directions.



# Island Model - Topology

- Punch, 1998, used a typical Island model with ring topology.



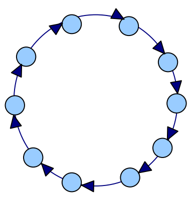
Ring Topology

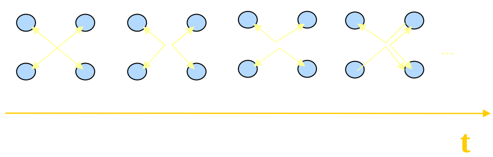
- He employed that topology for his experiments but no comparisons with different topologies were provided in the paper.



# Island Model - Topology

- Fernandez et al 2000 introduces a random topology and compare it with grid and ring topology.

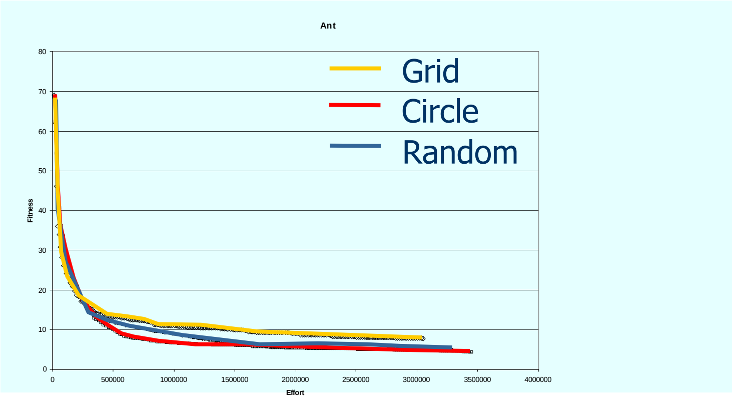





Ring Topology Random Topology: It changes dynamica

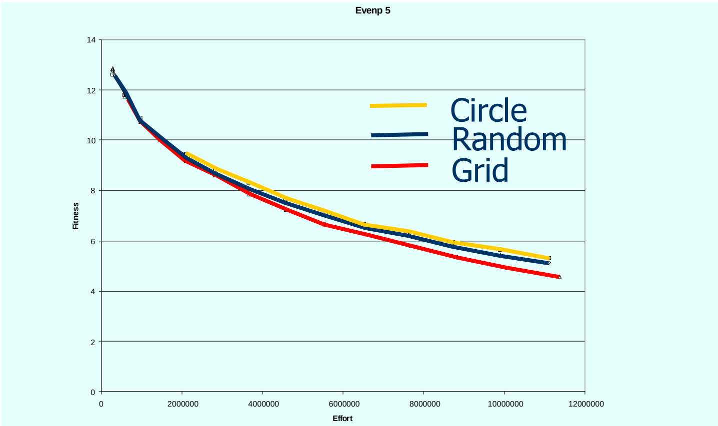
- The main conclusion is that if the remaining parameters stay fix, there are no significant differences when changing topology.

## Island Model - Topology






## Island Model - Topology



## Island Model – Migration Rate

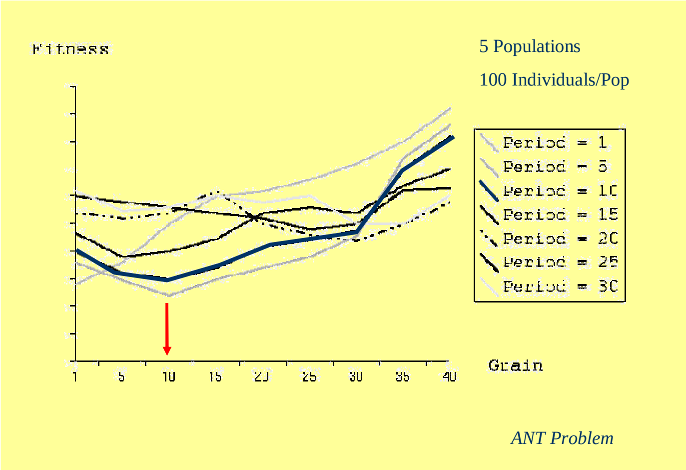
- How many individuals should migrate each migration step?
- Deppending on the number of individuals, results are different.  The limits are:
  - 0 individuals migrating (isolated populations)
  - All the individuals migrating.
- Different migration rates applied in literature:
  - Juillé & Pollack: 1 migrating individual per subpopulation.
  - Andre and Koza: 0%-8% migrating individuals per subpop.
  - Punch 1998: 2 individuals.



## Island Model – Migration Rate

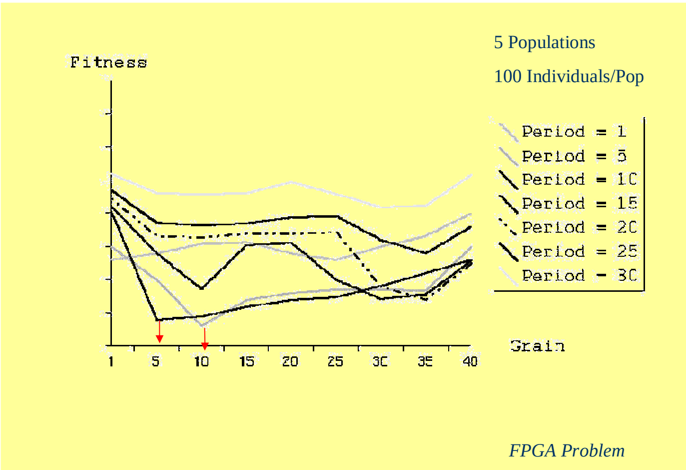
- Fernandez et al 2003: best migration rate is between 5% and 10% in 4 test problems (2 classic  and 2 real-life problems):
  - Even Parity 5.
  - Ant Problem.
  - Routing and Placing circuits on FPGAs.
  - Medical Diagnosing.

## Island Model – Migration Rate






## Island Model – Migration Rate

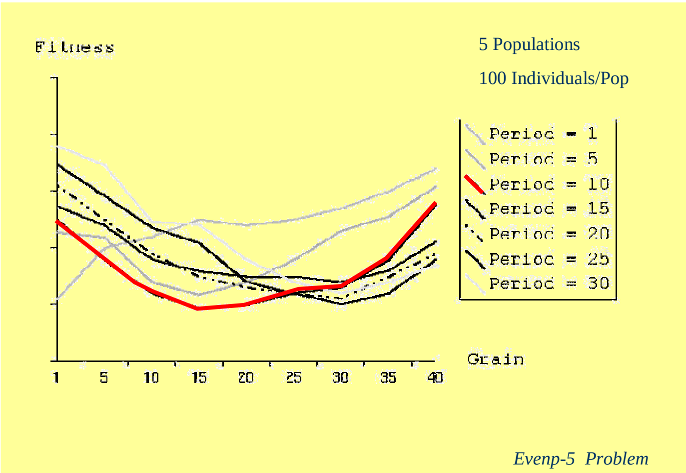


## Island Model – Migration Frequency

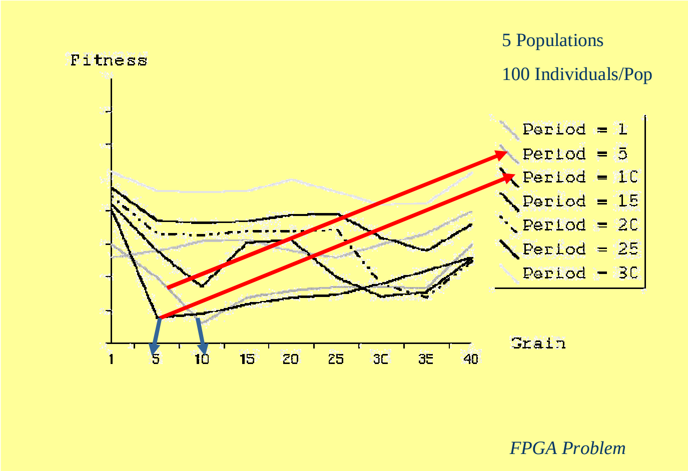
- Both Juillé & Pollack and also Andre and Koza employ migration every generation.
- In Punch 1998, subpop. wait for 10 generations before the migration step.
- In Fernandez et al 2003, a wider study have been carry on, comparing different frequencies.
- Best convergence results appear when about 10% of individuals from each subpopulation are sent every 5-10 generations.



## Island Model – Migration frecuency

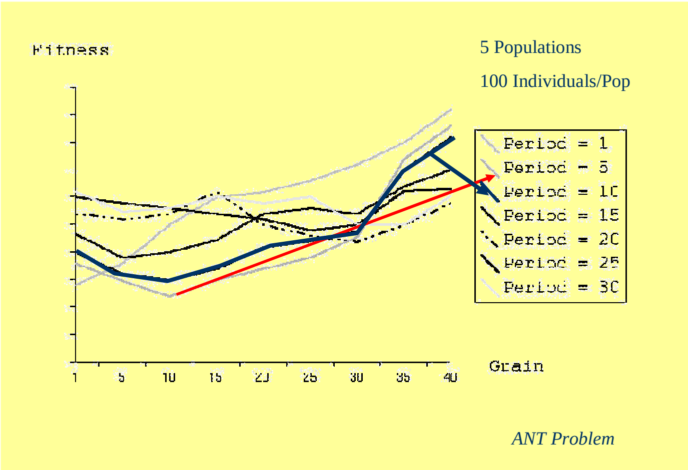


# Island Model – Migration summary






# Island Model – Migration Rate



## Island Model – Migration Summary

- For large values of the grain, exchange individuals less frequently.
- For low values of the grain, exchange more frequently.
- Recommendation: Exchange 10% of the population every 10 generations.



## Island Model – Subpop. Size

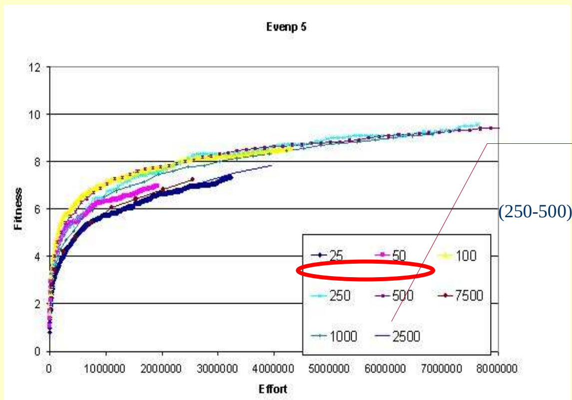
- Experiments presented by Andre & Koza, make use of the large computational capability of the network they employed.
- 32000 individuals are distributed among 64 demes, each with 500 individuals.
- Punch 1998, employed 5 populations, 200 individuals each, and also 7 populations, 700 individuals each.

## Island Model – Subpop. Size

- F. Fernández et al., 2003, presents a set of trials.
- Conclusions:
  - There is a number of individuals with which best results are obtained (regardless of the number of subpops).
  - We must carefully select the number of subpops, not any number of populations obtain the same results.



## Island Model – Subpop. Size

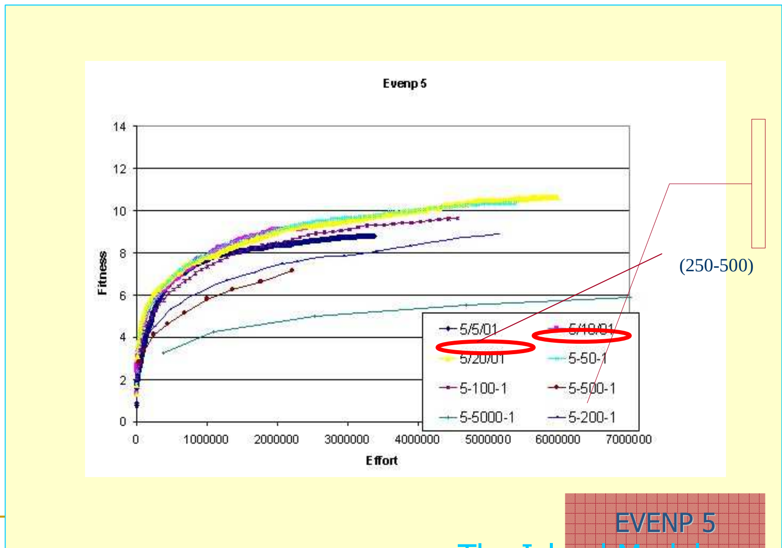



(250-500)

EVENP 5

T
64

## Island Model – Subpop. Size






## Island Model – Synchronisation

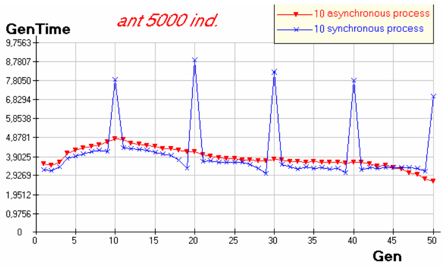
- Synchronism is an important issue when using Parallel GP: different individuals may require different processing time for their evaluation.
- Two models:
  - Synchronous: Exchange step takes place at a given generation.
  - Asynchronous: Populations send individuals when they are ready, and check every generation if new incoming individuals are awaiting.

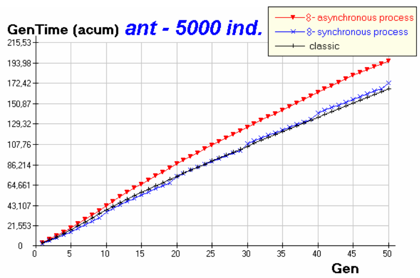
# Island Model – Synchronisation

- Andre and Koza worked with an asynchronous model:  each generation is typically working on different generations after a few ones.
- Dracopoulos and Kent, employed the synchronous model in both the global and island models.
- Fernández et al, 2002, presented a study comparing synchronous and asynchronous models in monoprocesor systems.



# Synchronous - Asynchronous




Results obtained using 1 proc

Synchronous model better for monoprocessor system.
Asynchronous model better for parallel systems.

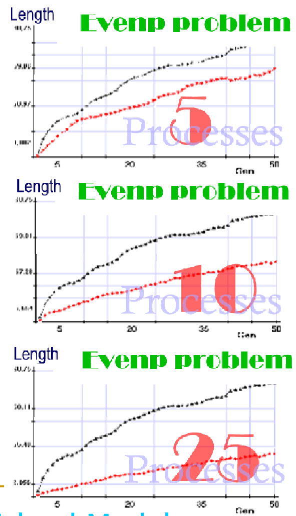
## Synchronous - Asynchronous

- Tongchim and Chongstitvatana, presented a comparison among models using a restricted migration policy.
- Their results only focus on a problem, and shows better performance with the asynchronous model.

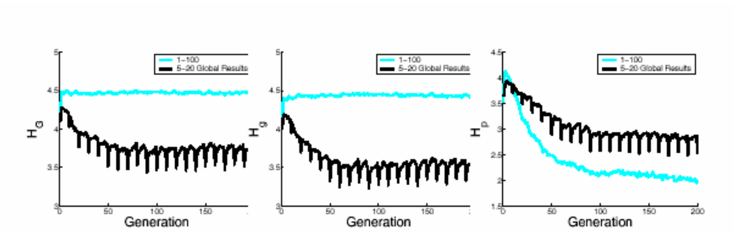


## Island Model - Bloat

- The Island Model seems to prevent the bloat phenomenon.



## Some comments on diversity




Genotypic diversity decreases.
Phenotypic diversity improves.

## What about fault tolerance?

- Fault tolerance is an important issue.
- Different techniques have been employed:
  - Check pointing.
  - Redundancy.
  - Others…
- Is GP Fault tolerant?

# What about fault tolerance?

Figure 2. Even parity 5 problem, with a population length of 2000 and 10% volatility rate

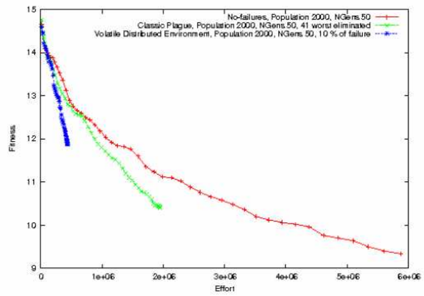
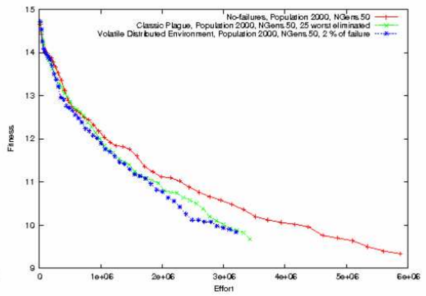



Figure 3. Even parity 5 problem, with a population length of 2000 and 2% volatility rate

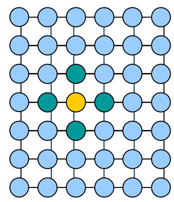



# The Cellular Model

- Folino et al, 2003, have presented a comparison with panmitic and island model approach.
- The method provides results of similar quality than the island model (an small error in the comparisons seems to favor the cellular model in the paper, but a detailed revision shows that results are similar).
- They apply the model to induce decision trees.

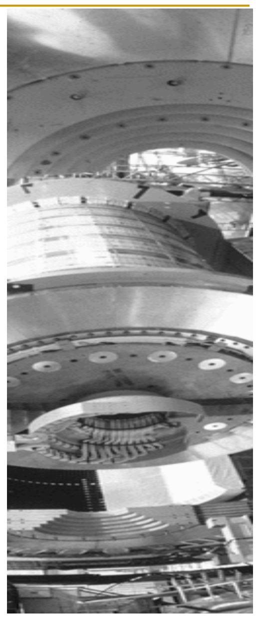
## The Cellular Model

- Each individual is located in a grid position.
- Individuals interact only with their neighboring ones.





## Summary:



- Introduction.
- History.
- Parallel GP.
- The Island Model.
- Successful Applications.
- Future.

## Some Applications

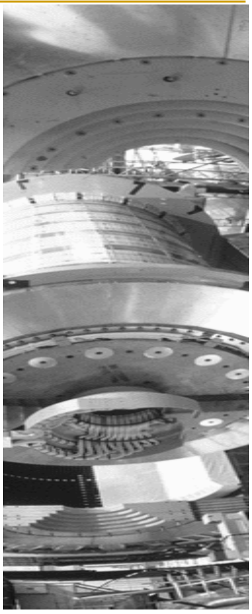
- C. Miccio et al, 1995, described an implementation on a T3D computer for inducing binary decision diagrams.
- M. Oussaidène et al, presented an application to trading model induction.
- F. Fernández, 2001, described a proposal for solving the problem of Placement and Routing of circuits on FPGAs.
- Folino apply the cellular model to generate decision trees.



## Some Applications

- Koza et al 2000, presents a list of "Human-Competitive results obtained by Means of Genetic Programming", including:
  - Synthesis of Analog Circuits.
  - Synthesis of PID controllers.
  - Applications to biomedicine (protein detection).
  - Previously patented inventions, reinvented.
  - Some patented invention.

## Summary:



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## Future

- Some topics for future research:
  - Theoretical models.
  - Heterogeneous models.
  - Improvements by means of better scheduling policies.
  - Bloat phenomenon.

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