CZECH TECHNICAL UNIVERSITY IN PRAGUE

Faculty of Electrical Engineering
Department of Cybernetics

Parallel Evolutionary Algorithms.
Coevolution.

Petr Pošík

Parallel Evolutionary Algorithms

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- Which of the above can be parallelized easilly???

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But first:

- The difference between parallel model and parallel implementation.

Parallel Implementation vs. Parallel Model

Sequential implementation:

- The algorithm is able to run on a single machine in a single process, often in a single thread only.

Parallel implementation:

- The algorithm is able to take advantage of multiple CPU cores or multiple machines.

The effect of parallelization:

- Reduction in the solution time by *increasing computational power*.
- The speed-up should be proportional to the number of parallel machines.

Global model:

- The population is not divided in any way, the selection operator can consider all individuals.

Parallel model:

- The population is somehow divided into subpopulations, which limits mainly the selection operator.

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Possible combinations:

- Sequential implementation of the global model (usual case, simple GA)
- Parallel implementation of the global model (master-slave, brute-force speed-up)
- Sequential implementation of a parallel model (modified behavior)
- Parallel implementation of a parallel model (modified behavior, brute-force speed-up)

Parallelization of the Global Model

Master-slave model

Master

- runs the evolutionary algorithm, and
- controls the slaves, distributes the work.

Slaves

- take batches of individuals from the master,
- evaluate them, and
- send their fitness back to the master.

Other possibilities:

- Sometimes we can parallelize also initialization, mutation, and (with a bit of care) crossover.
- The hardest parts to parallelize are selection and replacement.
- When does the parallelization actually pay off???

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Master-slave implementation does not change the behavior of the global model.

- Hints on implementation (locking, synchronizing) can be found in [Luk09, chap. 5].

[Luk09] Sean Luke. *Essentials of Metaheuristics*. 2009. available at http://cs.gmu.edu/∼sean/book/metaheuristics/.

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DEMO: Island model of PGA applied on TSP

`http://labe.felk.cvut.cz/~posik/pga`

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  - diversity → convergence; population convergence vs. convergence in time

Migration (cont.)

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- term *epoch* in the context of PGAs describes the part of evolution betweem 2 migration events

Other Parallel Models

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Also called *fine-grained PGA*:

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- Easy parallelization via multithreading.
- Very efficient model for *vector processors*, often found on GPUs:
  - many identical operations can be performed in parallel in the same time

Model Combinations

Hierarchical model:

- various combinations of the above mentioned models, e.g.
- island model where each deme uses master-slave fitness evaluation,
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  - Can each deme use a *different fitness function*???

Injection Model

Heterogenous island model where

- each deme uses a different fitness function!!!
- Usable when many quality criteria must be assessed; each deme
  - concentrates on one criterion and
  - submits partial solutions to other demes to be reworked using another criterion.
- Each deme preserves solutions of high quality when only its particular criterion is applied.

Summary: PGAs

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- Parallel models change the behavior of the EA:
  - they can reduce the danger of premature convergence and speed-up the algorithm in the same time.
- There are many possibilities on parallelization:
  - the optimal decision depends on the (parallel) computer architecture and on the task being solved
  - all possibilities introduce their own set of tunable parameters :-(

Learning outcomes

After this lecture, a student shall be able to

- explain the main motivation for parallelization;
- explain the difference between parallel *implementation* and parallel *model* of EA;
- describe the features of individual combinations of sequential/parallel implementation and global/parallel model;
- know which parts of individual EAs (fitness evaluation, selection, replacement, mutation, crossover, model building, etc.) can be implemented in parallel easilly, and explain why;
- explain the principle and features of the master-slave parallelization;
- implement island model and explain its features, describe the characteristics of migration operator (type, topology, degree of connectivity, trigger, selection/replacement strategy, count);
- describe spatially embedded model, heterogeneous model, injection model, and their use cases.

Coevolution

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Coevolution in EAs:

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- It is closer to the biological evolution than ordinary EAs are.

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Coevolution can help in

- dealing with increasing difficulty of the problem,
- providing diversity in the system,
- producing not just high-quality, but also robust solutions,
- solving complex or high-dimensional problems by breaking them into nearly decomposable parts.

Types of coevolution

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By relation type:

- cooperative (synergic, compositional)
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By the entities playing role in the relation:

- 1-population
  - intra-population
  - individuals from the same population cooperate or compete
- N-population
  - inter-population
  - individuals from distinct populations cooperate or compete

1-population competitve coevolution

Example: The goal is to evolve a game playing strategy

- successful against diverse opponents!!!

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Solution: Intra-population competitive coevolution

- by playing several games against other strategies in the population.
- All individuals of the same type.
- In the beginning, all are probably quite bad, but some of them are a bit better.
- The fitness (the number of games won) may not rise as expected since your opponents improve with you.

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- Fitness evaluation:
  - Algorithm: by its ability to sort. How many sequences is it able to sort correctly? How quickly?
  - Test case: by its difficulty for the current sorting algorithms. How many algorithms did not sort it?
- Predator-prey relationship

N-population cooperative coevolution

Example: The goal is to evolve a team consisting of

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Cooperation:

- symbiotic relationship
- good performance of the team ⇒ high contribution to fitness of all members

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Example: **Niching** methods for

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- maintaining several stable subpopulations in diverse parts of the search space

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Principle:

- better individuals similar to others already in population are thrown away in favour of worse, but diverse individuals
- the selection process is affected by the presence of other individual in the neighborhood

Problems in coevolution

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- by its time-dependence:
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External fitness in coevolution:

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Internal fitness in coevolution:

- **relative**: affected by other individuals
- **dynamic**: affected by evolving individuals (needs re-evaluation)
- **stochastic**: usually evaluated against a smaller number of individuals

“Fitness” in sport

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Football league:

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Football league:

- all teams play against all others
- points awarded for win, draw, and loss
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- tournaments have different prize money to distribute to tournament winners
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The same holds for fitness assessment in coevolution!

Problems with fitness assessment: 1-pop. competitive coevolution

Cycles, etc.

- What if A beats B, B beats C, but C beats A?

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- The quality assessment depends on what we really want:
  - A player that beats the most other players?
  - A player that beats the most other “good” players?
  - A player that wins by the most total points on average?
- Often, additional matches are executed.
- But, do you want to spend your fitness budget
  - on evaluating current individuals more precisely, or
  - on searching further?

2 competitive populations (illustration)

Lotka-Volterra model (Predator-prey population dynamics):

$$\begin{aligned}\frac{dx}{dt} &= \alpha x - \beta xy \\ \frac{dy}{dt} &= -\gamma y + \delta xy\end{aligned}$$

where x is the number of prey (rabbits) and y is the number of predators (wolves).

Assumptions:

1. The prey population has always food enough.
2. The predators eat only the prey.
3. The rate of change of population is proportional to its size.
4. The environment is static.

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Meaning:

- The change of the prey population (dx/dt) is composed of
  - increase due to the newly born individuals (proportional to the population size, αx) and
  - decrese caused by the predation (which is proportional to the rate of predator-prey meetings, βxy).
- The change of the predator population (dy/dt) is composed of
  - decrease due to natural death (proportional to the population size, γy) and
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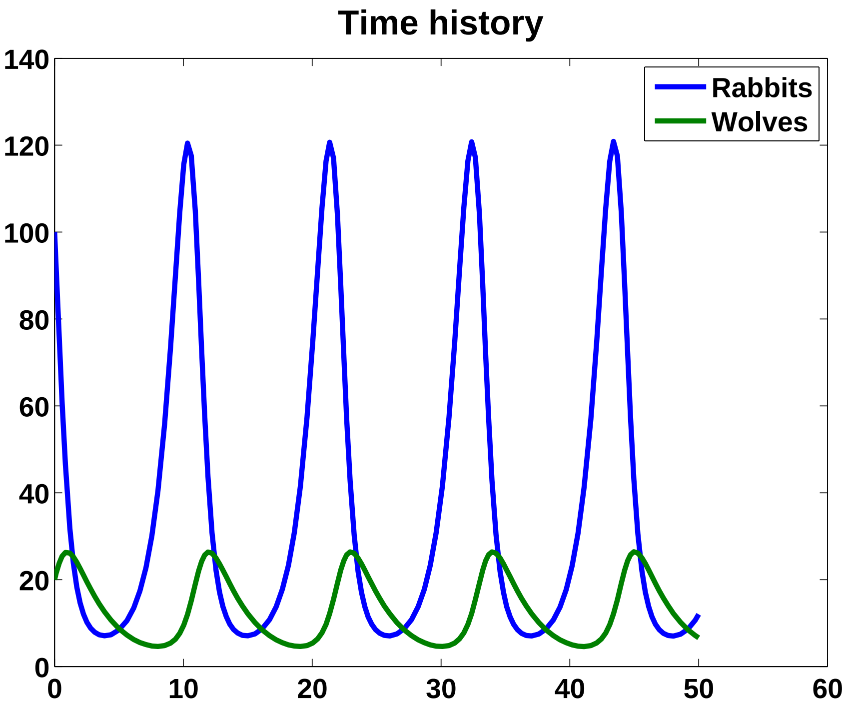

Problems with fitness assessment: 2-pop. competitive coevolution

Arms races

- one population learns a trick and forces the second population to learn a new trick to beat the first one. . .
- one population may evolve faster than the other:

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- Solution:
  - detect such situation (but how?)
  - delay the evolution of the better population until the worse one catches up

Problems with fitness assessment: N-pop. cooperative coevolution

Hijacking (in team of goalie, back, midfield, and forward):

- a really good forward takes over one population, any team will play well thanks to him
- members of all other populations have almost the same fitness ⇒ uniform random selection
- Solution: apply some form of *credit assignment*

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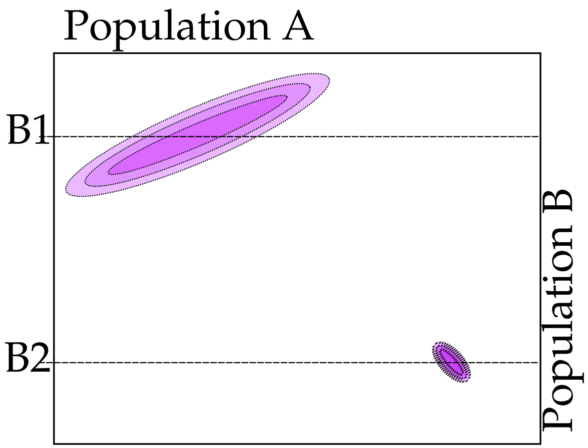
Relative overgeneralization

- when evaluated by average score, worse (but more robust) individual B1 will have higher score than better (but volatile) B2
- use maximum score (more tests needed)
- but again, the choice depends on what we want — a player able to get the highest score, or a player that would form a good team with the most other team members?



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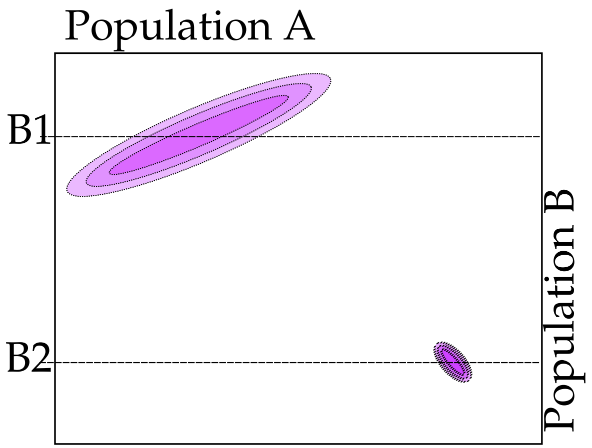
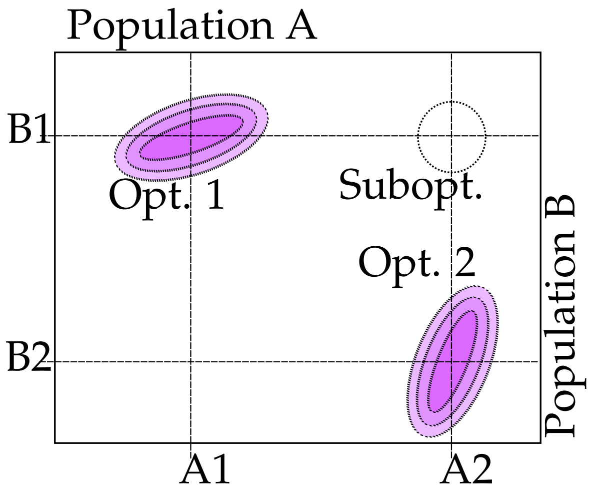


Miscoordination

- when the team components are not independent
- Pop. A evolved A2 (but not A1), pop. B evolved B1 (but not B2)
- Neither A2 nor B1 survives



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Appropriate when

- no explicit fitness function can be formed
- there are too many fitness cases
- the problem is modularizable (divide and conquer)

Learning outcomes

After this lecture, a student shall be able to

- define “coevolution”, explain what makes it different from ordinary evolution in the context of optimization algorithms;
- explain differences between *cooperative* and *competitive* coevolution;
- explain differences between *intra-* and *inter-*population coevolution;
- define features of fitness measure (static/dynamic, deterministic/stochastic, absolute/relative, internal/external);
- describe the features of an ideal external (and internal) fitness, and describe the features of internal fitness in coevolution;
- exemplify individual types of cooperative/competitive intra-/inter-population coevolution; and
- exemplify various types of issues that can be observed in them (how to order individuals based on inconsistent matches, loss of diversity when one population evolves faster than the other, hijacking, relative overgeneralization, miscoordination).