Order or Not: Does Parallelization of Model Building in hBOA Affect Its Scalability?

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Motivation

Background

- hBOA can solve nearly decomposable and hierarchical problems scalably, often in $O(n^2)$ evaluations or faster.
- $O(n^2)$ is sometimes not enough...
- We may need efficiency enhancement techniques
  - Parallelization, evaluation relaxation, hybridization, ...

Parallelization of model building

- Among the most powerful efficiency enhancements.
- But modifies the model building procedure.
- Speedups obtained were analyzed.
- But effects of modifying the model building procedure on hBOA scalability were not analyzed thoroughly.

Purpose

- Study the effects of model-building parallelization on hBOA performance.
1. Hierarchical BOA (hBOA) basics.

2. Parallelization of model building in hBOA.

3. Experiments.

4. Summary and conclusions.
Hierarchical BOA (Pelikan & Goldberg; 2000, 2001)

- Build and sample a Bayes net instead of crossover/mutation.
- Use local structures and niching.
Bayesian network has two parts

- **Structure**
  - Structure determines edges in the network.

- **Parameters.**
  - Parameters specify conditional probabilities of each variable given its parents (variables that this variable depends on).
  - Example: $p(X_2|X_0, X_1)$. 
Efficiency Enhancement of hBOA

Potential bottlenecks

1. Model building.
2. Evaluation of candidate solutions.

Efficiency enhancement

1. Parallelization.
2. Hybridization.
3. Time continuation.
4. Fitness evaluation relaxation.
5. Prior knowledge utilization.
6. Incremental and sporadic model building.
7. Learning from experience.
Parallel hBOA

What to parallelize?

1. Model building.
2. Fitness evaluation.

Parallelizing evaluation

- Same situation as for other evolutionary algorithms.
- Use master-slave architecture to distribute evaluations.

This work

- Focus on parallelization of model building.
Components of model building

1. Learn structure (dependencies).
2. Learn parameters (conditional probabilities).

Learning structure

- Start with an empty network.
- Add one edge at a time (without creating cycles).
- Choose edges that improve the network the most.

Learning parameters

- Compute frequencies from selected solutions.
- Estimate probabilities from computed frequencies.
Complexity Analysis of Model Building

Notation

- Upper bound on the number of parents: \( k \)
- Population size: \( N \)
- Number of bits: \( n \)

Analysis

- Learn structure: \( O(kn^2N) \).
- Learn parameters: \( O(knN) \).

Bottom line

- Learning structure = most expensive part.
- Should parallelize the greedy algorithm for learning structure.
Parallelizing Structure Learning

Master-slave approach (Ocenasek & Schwarz, 2000)

1. Master sends each node to a separate slave processor.
2. Master distributes the population to all slave processors.
3. Each slave processor determines parents for its node.
4. The master collects the results and learns parameters.

Variations

- Each processor deals with multiple nodes.
- Parameters are also learned locally in slave processors.
Ordering Nodes to Avoid Cycles

Motivation

▶ Master-slave approach looks great.
▶ But Bayesian network cannot contain cycles!
▶ Communication required after each new edge on any slave.
▶ This leads to a LOT of communication.

Ordering nodes (Ocenasek & Schwarz, 2000)

▶ Order the nodes randomly before learning the structure.
▶ Only allow edges consistent with the ordering.
▶ No need to check for cycles.
▶ Each processor can deal with edges into a single node.
▶ Communication needed only before/after the learning.
Consider ordering \((X_1, X_3, X_2, X_4, X_0, X_5)\)

- **Consistent network**
- **Inconsistent network**
Example Speedups with Parallel hBOA

Results from Ocenasek et al. (2004)

- Nearly linear speedups even for relatively small problems.
- No need for parallel computers with shared memory.

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Parallelization of Model Building in hBOA and Scalability
Effects of Node Ordering

Positive effects

▶ Straightforward parallelization with little communication.
▶ Slightly faster model learning even on a sequential computer.

Negative effects

▶ Model structures are restricted.
▶ Models may become less accurate.
▶ Population size and number of generations might increase.
Description of Experiments

Test functions

- Concatenated trap of order 3 and 5.
- Hierarchical trap.
- Ising spin glass (2D).

Scalability analysis

- Number of function evaluations with respect to problem size.

Parameters

- Population size from bisection to ensure 30/30 successful runs.
- Number of generations upper bounded by $n$.
- Window size in RTR: $w = \min\{n, N/20\}$. 
Results on dec-3

- hBOA with node ordering needs slightly more evaluations.
- But differences are relatively small.
Results on trap-5

- Results are mixed (no approach consistently better).
- But differences are again relatively small.
Results on hTrap

- hBOA with node ordering in fact outperforms standard hBOA.
- But differences are again relatively small.
Results on 2D Ising Spin Glass

- hBOA with node ordering needs slightly more evaluations.
- But differences are relatively small.
Summary and Conclusions

Summary

- Tested scalability of parallel model building in hBOA.
- Analyzed the results.

Conclusions

- Parallelization leads to a slight increase in the number of function evaluations.
- But the negative effects are negligible compared to the gains.
- Bottom line: If model building is the bottleneck, parallelize the model building!
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