Master's Thesis

From Parameter Tuning to Dynamic Heuristic Selection

submitted by

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Aufgabenstellung für die Masterarbeit

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Studiengang: Master DSE Matr. Nr.: 4 7 3 3 6 8 0

Thema:

From Parameter Tuning to Dynamic Heuristic Selection

Zielstellung :

Metaheuristic-based solvers are widely used in solving combinatorial optimization problems. A choice of an underlying metaheuristic is crucial to achieve high quality of the solution and performance. A combination of several metaheuristics in a single hybrid heuristic proved to be a successful design decision. State-of-the-art hybridization approaches consider it as a design time problem, whilst leaving a choice of an optimal heuristics combination and its parameter settings to parameter tuning approaches. The goal of this thesis is to extend a software product line for parameter tuning with dynamic heuristic selection; thus, allowing to adapt heuristics at runtime. The research objective is to investigate whether dynamic selection of an optimization heuristic can positively effect performance and scalability of a metaheuristic-based solver.

For this thesis, the following tasks have to be fulfilled:

- Literature analysis covering closely related work.
- Development of a strategy for online heuristic selection.
- Implementation of the developed strategy.
- Evaluation of the developed approach based on a synthetic benchmark.
- (Optional) Evaluation of the developed approach with a problem of software variant selection and hardware resource allocation.

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Verteiler: 1 x SCIS, 1x HSL, 1x Betreuer, 1x Student

Statement of Authorship

I hereby certify that I have authored this Master Thesis entitled “From Parameter Tuning to Dynamic Heuristic Selection“ independently and without undue assistance from third parties. No other than the resources and references indicated in this thesis have been used. I have marked both literal and accordingly adopted quotations as such. There were no additional persons involved in the preparation of the present thesis. I am aware that violations of this declaration may lead to subsequent withdrawal of the degree.

Dresden, February 23, 2020

Yevhenii Semendiak

Yevhenii: should I add a disclaimer like this?

Contents

0.1 abstract

Abstract will be available in final versions of thesis.

1 Introduction

Intent and content of chapter. This chapter is an self-descriptive, shorten version of thesis.

1.1 Motivation

Structure:

- optimization problem(OP) → exact or approximate (+description to both) → motivation to use **approximate solvers** →
- impact of parameters, their tuning on solvers → motivation of **parameter control** (for on-line solver) →
- but what if we want to solve a class of problems (CoP) → algorithms performance is different →
- user could not determine it [1] → exploration-exploitation balance
- no-free-lunch (NFL) theorem [2] → motivation of the thesis

thesis motivation The most related research field is Hyper-heuristics optimizations [3], that are designed to intelligently choose the right low lewel heuristics (LLH) while solving the problem. But the weak side of hyper-heuristics is the luck of parameter tuning of those LLHs [links]. In the other hand, meta-heuristics often utilize parameter control approaches [links], but they do not select among underlying LLHs. The goal of this thesis is to get the best of both worlds - algorithm selection from the hyper-heuristics and parameter control from the meta-heuristics.

1.2 Research objective

The following steps should be completed in order to reach the desired goal:

Analysis of existing studies of algorithm selection. *(find a problem definition, maybe this will do [1])*

Analysis of existing studies in field of parameter control and algorithm configuration problems *(find a problem definition)* [4]

Formulation and development of combined approach for LLH selection and parameter control.

Evaluation of the developed approach with

Yevhenii: family of problems??? since it is a HH, maybe we should think about it...

.

Research Questions At this point we define a Research Questions (RQ) of the Master thesis.

- **RQ 1** Is it possible to select an algorithm and it hyper-parameters while solving an optimization problem *on-line*?
- **RQ 2** What is the gain of selecting and tuning algorithm while solving an optimization problem?
- **RQ 3?** How to solve the problem of algorithm selection and configuration simultaneously?

1.3 Solution overview

- described problems solved by HH, highlight problems of existing HHs(off-line, solving a set of homogeneous problems in parallel)
- create / find portfolio of MHs (Low level Heuristics)
- define a search space as combination of LLH and their hyper-parameters (highlight as a contribution)
- solve a problem on-line selecting LLH and tuning hyper-parameters on the fly. (highlight as a contribution? need to analyze it.)

Thesis structure The description of this thesis is organized as follows. First, in chapter 2 we refresh readers background knowledge in the field of problem solving and heuristics. In this chapter we also define the scope of thesis. Afterwards, in chapter 3 we describe the related work and existing systems in defined scope. In Chapter 4 one will find the concept description of dynamic heuristics selection. Chapter 5 contains more detailed information about approach implementation and embedding it to BRISE. The evaluation results and analysis could be found in Chapter 6. Finally, Chapter 7 concludes the thesis and Chapter 8 describe the future work.

2 Background

Reviewer: add important terminology for parameter tuning

one-two sentence definition of

- Heuristic
- Meta-heuristic
- Hybrid-heuristic
- Hyper-heuristic

2.1 Meta-heuristics

2.1.1 Classification

- from the solution point of view (construction / perturbation)
  - solution availability (any-time / till the end)

2.1.2 Related meta-heuristics description

Reviewer: what does related mean? why did you choose exactly these 3(4) heuristics to be described? is there sth special the reader should know about them?

- GA
- SA
- ES
- would be cool to add VNS

2.2 Hybrid meta-heuristics and hyper-heuristics

2.2.1 Classification of hyper-heuristics

- heuristic selection
  - heuristic generation
  - on-line learning hyper-heuristics
  - off-line learning hyper-heuristics
  - no-learning hyper-heuristics

2.3 Scope of work defined

Reviewer: consider emphasizing the problem here. show, how do these algorithm perform with the problem you try to solve. Save a detailed explanation of TSP, etc. for later. But make a vivid example why single MHs are under-performing.

- on-line selection out of GA, SA, ES, parameter optimization to solve defined problem

Reviewer: shouldn't you first introduce parameter optimization to make such a conclusion?

3 Related work

Reviewer: what is the goal of this chapter? it should not be just an enumeration of approaches

utilize surveys

Yevhenii: Broad survey , Online algorithm selection at page 27

as [5]

Previously reviewed systems that could be refereed in Related Work: [1]

3.1 AUTO-SKLEARN

- CASH (Combined Algorithm Selection and Hyperparameter optimization) problem - pros and cons (on-line or off-line, problems to solve, extensibility) - [6]

3.2 BOHB

- possible to try, but model will be lost in 'holes' of search space (no tree structure) - should i cite it at all? (probably, it is not really relevant, since BOHB - Robust and Efficient Hyperparameter Optimization at Scale)

3.3 IRACE

- approach [7] - off-line tuning - is it really relevant?

Reviewer: BRISE?

4 Concept description

Reviewer: It is your concept section, do not put related work here. How do you solve a defined problem?

4.1 Considered approaches

Approaches to derive an information about configurations:

- "SPIRE" or heuristics (IRACE approach, all possible combinations are defined beforehand)
- switching (from one to another, which switch is better)
- picking (just, "run this particular heuristic now")

4.2 What is the problem with the Search Space?

Yevhenii: unofficial style? (not much, but at least to make some statements / headers catchy)

Reviewer: why is search space important? it just appears without an explanation

- tree-shaped search space
- heterogeneous data
- different algorithms (model) to traverse and optimize such a search space could require different information
  – generality
- top-down approach of optimization
  – different views of same Configuration (level-dependent) - filtering, transformation
  – problem features to consider while selecting meta-heuristic [1] page 6

Reviewer: more sections?

5 Implementation

5.1 Analysis of required changes in system

5.1.1 Description of BRISE v2.2.0

Data preprocessing

Model compatibilities

Search space compatibilities

5.1.2 Meta-heuristics repository

-table and short comparison of checked repositories

- Solid
- mlrose
- jMetalPy
- or-tools
- pyTSP
- LocalSolver

jMetalPy in more details

Available Meta-heuristics

Required features - any-time (or predictable) termination
- warm-startup

opened PR

5.1.3 Development planning

use-case definition

generalization with team

requirements engineering - interfaces

class diagrams

data flow

6 Evaluation

6.1 Problem

which problem I wanna solve with hyper-heuristic

- TSP
- n-Queens
- knapsack

Reviewer: what will you compare?

7 Conclusion

Reviewer: answer research questions

8 Future work

- more sophisticated models?
- dependencies / constraints in search space
- wider evaluation?

Reviewer: consider merging with conclusion, if too short

Yevhenii: is it correct style?

Reviewer: better the one with first letters of family names and year

Bibliography

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[7] M. López-Ibáñez, J. Dubois-Lacoste, L. P. Cáceres, M. Birattari, and T. Stützle, "The irace package: Iterated racing for automatic algorithm configuration," *Operations Research Perspectives*, vol. 3, pp. 43–58, 2016.

A Appendix

A.1 Additional Information

A.2 More Important Information

Confirmation

I confirm that I independently prepared the thesis and that I used only the references and auxiliary means indicated in the thesis.

Dresden, February 23, 2020