VILNIAUS UNIVERSITETAS
MATEMATIKOS IR INFORMATIKOS FAKULTETAS
PROGRAMŲ SISTEMŲ STUDIJŲ PROGRAMA

Hibridinio genetinio paieškos algoritmo transporto maršrutų optimizavimo uždaviniams spręsti lygiagretinimas

Parallelization of Hybrid Genetic Search Algorithm for Solving Vehicle Routing Problem

Kursinis darbas

Atliko: 4 kurso 1 grupės studentas
Domantas Keturakis

Darbo vadovas: Doc., Dr. Algirdas Lančinskas

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Turinys

Terminai

Įvadas

paragrafas apie VRP relevance

Plačiau apie VRP constraints

Galimi constraints, kuriuos galima uždėti ant VRP problemų:

- kiekviena transporto priemonė gali turėti (skirtingą) maršruto pradžios laiką
- kiekviena transporto priemonė gali turėti (skirtingą) maksimalų atstumą, kurį gali nukeliauti
- kiekviena transporto priemonė gali turėti (skirtingą) maksimalią talpą
- kiekvienos transporto priemonės vairuotojas gali turėti (skirtingą) tvarkaraštį (skirtingas pamainos laikas, su arba be pertraukų)
- kiekvienas taškas gali turėti (skirtingas) veikimo valandas (galimai su pietų pertraukom, etc...)
- kiekvienas taškas gali turėti (skirtingas) service time
- kiekvienas taškui gali būti arba nebūti griežtas reikalavimas jį aplankyti
- apmokėjimo constraints:
  - per tašką
  - per atstumą
  - etc...

Metodai

- Exact methods / Mathematical models (google or-tools)
- Heuristic – A problem-specific rule or method to quickly find a good (not necessarily optimal) solution.
- Metaheuristic – A higher-level strategy/framework that guides heuristics to explore solutions more effectively.
  - Adaptive Large Neighborhood Search / Hybrid Adaptive Large Neighborhood Search

    🛠️ https://reinterpretcat.github.io/vrp/
  - Hybrid Genetic Search (HGS)

    🛠️ https://github.com/vidalt/HGS-CVRP

    🛠️ https://pyvrp.org/
  - Simulated Annealing Algorithm (SAA)
  - Ant colony optimization (ACO)

Konkursai

- DIMACS [DIM22]
- "2021 Amazon last mile routing research challenge: Data set" [Mer+24] (2024) TODO: properly cite the challenge, not just the dataset
- EURO meets NeurIPS 2022 vehicle routing competition

Įrankiai

- Matrix
  - OSMR
  - GraphHopper
  - Valhalla
  - BRouter
- Simulation https://roadsimulator3.fr/these/chapters/chapitre00.html

Hibridinis genetinis paieškos (HGS) algoritmas yra vienas iš efektyviausių būdų spręsti transporto maršrutų optimizavimo uždavinius. [Citation needed?]

Pirma aprašytas "A Hybrid Genetic Algorithm for Multidepot and Periodic Vehicle Routing Problems" [Vid+12] (2012) ir patobulintas [Vid+14], [Vid+16], [Vid17], [Vid+21].

- > We propose a metaheuristic that combines the exploration breadth of population-based evolutionary search, the aggressive-improvement capabilities of neighborhood-based metaheuristics, and advanced population-diversity management schemes. The method that we name *Hybrid Genetic Search with Adaptive Diversity Control (HGSADC)*
>
> *— Thibaut Vidal, Teodor Gabriel Crainic, Michel Gendreau, Nadia Lahrichi, Walter Rei [Vid+12]*
- > *HGSADC proves to be extremely competitive CVRP.*
>
> *— Thibaut Vidal, Teodor Gabriel Crainic, Michel Gendreau, Nadia Lahrichi, Walter Rei [Vid+12]*
- maintains diversity in search -> avoids local minima ir dar aukštesnės kokybės sprendimai ir reduced computational time.

Per daugelį iteracijų patobulintas aprašytas "Hybrid genetic search for the CVRP: Open-source implementation and SWAP* neighborhood" [Vid22] (2022).

- > *the generalization of this method into a unified algorithm for the vehicle routing problem (VRP) family (Vidal et al., 2014, 2016; Vidal, 2017; Vidal et al., 2021)*
>
> *— Thibaut Vidal [Vid22]*
- > *Beyond a simple reimplementation of the original algorithm, HGS- CVRP takes advantage of several lessons learned from the past decade of VRP studies: it relies on simple data structures to avoid move re- evaluations and uses the optimal linear-time Split algorithm of Vidal (2016). Moreover, its specialization to the CVRP permits significant methodological simplifications. In particular, it does not rely on the visit-pattern improvement (PI) operator (Vidal et al., 2012) originally designed for VRPs with multiple periods, and uses instead a new neigh- borhood called Swap*.*
>
> *— Thibaut Vidal [Vid22]*
- > *In HGS-CVRP, we rely on the efficient linear-time Split algorithm introduced by Vidal (2016) (autoriaus papildymas: [Vid16]) after each crossover operation.*
>
> *— Thibaut Vidal [Vid22]*

TODO: "Technical note: Split algorithm in O(n) for the capacitated vehicle routing problem" [Vid16] (2016)

- naudoja "New benchmark instances for the Capacitated Vehicle Routing Problem" [Uch+17a] (2017) metodiką rezultatų palyginimui

"A hybrid genetic search based approach for the generalized vehicle routing problem" [Lat25a] (2025)
grįstas HGS.
Pritaikytas *Generalized Vehicle Routing Problem* variantui
Nėra viešo source code.

> *We show that adapting the meta-heuristic strategies designed for the CVRP to the GVRP can be quite a straightforward process.*

—

> *we report the numerical results on the well-known instances problems for both the GVRP and CluVRP.*

—

Straipsnyje rezultatai palyginti tik su kitais CluVRP, GRVP-pritaikytais algoritmais.

"An application of a two-level genetic search for the soft-clustered vehicle routing problem" [Lat25b] (2025)
grįstas HGS.

> *we propose a tailored two-level HGS for the SoftCluVRP. Our approach integrates the efficient local search framework and data structures from [21] while restructuring HGS into a two-level algorithm.*
>
> —

pritaikytas SoftCluVRP/CluVRP VRP variantui
Straipsnyje rezultatai palyginti tik su kitais CluVRP-pritaikytais algoritmais.

Tikslas ir uždaviniai

Tikslas – Išlygiagretinti hibridinio genetinio paieškos algoritmą, skirto transporto maršrutų optimizavimo uždaviniams spręsti.

Uždavinai:

1. Išsirinkti duomenų rinkinį pagal, kurį galima būtų testuoti/analizuoti sprendimus, pvz.:
   - Solomon
   - CVRPLIB repository (repository of BKSs - Best Known Solutions)
   - Neural Combinatorial Optimization for Real-World Routing (2025)
   - Test-data generation and integration for long-distance e-vehicle routing (2023)
   - "New benchmark instances for the Capacitated Vehicle Routing Problem" [Uch+17b] (2017)
2. Išanalizuoti, kaip veikia HGS algoritmas
3. Atrinkti paralelizuojamas dalis, ar dalis, kurias galima galima pakeisti paralelizuojamomis
3. Palyginti rezultatus su kitais state-of-the-art algoritmais

Santrumpos

- VRP - *angl. Vechicle Routing Problem*.
- CVRP - *angl. Capacitated Vehicle Routing Problem*.
- VRPTW - *angl. VRP with Time Windows*.
- MVRP - *angl. Multidepot VRP*.
- PVRP - *angl. Periodic VRP*.

> *In classical VRPs, typically the planning period is a single day. In the case of the Period Vehicle Routing Problem (PVRP), the classical VRP is generalized by extending the planning period to M days.*
>
> — https://neo.lcc.uma.es/vrp/vrp-flavors/periodic-vrp/

- MDPVRP - *angl. Multidepot Periodic VRP*.
- CVRP with Backhauls
- GVRP - *angl. Generalized VRP* -

> *In this problem each vertex belongs to a cluster, and only one vertex per cluster must be visited, satisfying the associated cluster demands.*
>
> — *Vittorio Latorre [Lat25a]*

- CluVRP - *angl. Clustered VRP* -

> *In the CluVRP, vehicles must visit all the nodes within a cluster before progressing to the next cluster, instead of visiting just one node per cluster as in the GVRP.*
>
> — *Vittorio Latorre [Lat25a]*

Matematinis formulavimas

TODO

Notes

- VRPTW ∈ CVRP
- Specializuota optimizacija specializuotam uždaviniui
  "The vehicle routing problem with service level constraints" [Bul+18] (2018)
- depots and periods. A second general observation is that most methodological developments target a particular problem variant, the capacitated VRP (*CVRP*) or the VRP with time windows (*VRPTW*), for example, very few contributions aiming to address a broader set of problem settings.
- idea:
  implement calculations on GPU to explore all possibilities (probs not faster, but might produce better results)

> *We therefore only evaluate Swap* moves between r and r' if the polar sectors (from the depot) associated with these routes intercept each other. As shown in our computational experiments, with this additional restriction, the computational effort needed to explore Swap* decreases*
>
> — *Thibaut Vidal [Vid22]*

Literatūros apžvalgos

- "A Detailed Review of the Capacitated Vehicle Routing Problem: Model, Computational Complexity, Solutions, and Practical Applications" [Ham+25] (2025)
  tl;dr: aprašto logistikos problemų kriterijus ir tipus, tada šias priskiria tam tikriem VRP tipams (e.g. VRPPD, VRPTW, etc...)
- "A review of recent advances in time-dependent vehicle routing" [Ada+24] (2024)
  tl;dr: pagrinde pristato ir aprašo CVRP. Išskiria metodų grupes (tikslūs; apytikslūs - heuristiniai ir metaheuristiniai). Iš metaheuristinių algoritmų grupių išskiria tris grupes:

> *•Evolutionary such as "Genetic Algorithm (GA)";*
> *•Physic - Based such as "Simulated Annealing Algorithm (SAA)"; and*
> *•Swarm Intelligence like "Ant colony optimization (ACO)".*
>
> — *Tommaso Adamo, Michel Gendreau, Gianpaolo Ghiani, Emanuela Guerriero [Ada+24]*

  pasirinkti ACO grįsti algortimai ir palyginti tarpusavyje.

- "Operational Research: methods and applications" [Pet+23] (2023)
  tl;dr: apriebia visą *Operations Research* iš 200 psl. 2 skirta VRP. Pateikia įvairius naujus metaheuristinius algoritmus, išskiria HGS kaip vieną iš geresnių.

  > *An up-to-date survey on recent trends can be found in Vidal et al. (2020) [[VLM20]]*
  >
  > —

  > *Clear standards have been set by the CVRP com munity around which benchmark instances should be used for testing the performance of an algorithm, and which are ways of testing a computer code for a fair comparison with other previously proposed algorithms. Uchoa et al. (2017) discuss the most widely used instances and provides a link to the repository, in which the input data, as well as the best known solu tions, are provided and kept up-to-date by the authors. A more recent set of instances and best known solu tions is available in Queiroga et al. (2022), where the authors provide data enabling the use of machine learning approaches to solve the CVRP. Accorsi et al. (2022) present the standard practices to test CVRP algorithms: how to determine computing time (typic ally on a single thread), common ways of tuning parameters, and providing best and average solutions on a specified number of executions, among others.*
  >
  > —

- TODO: "A concise guide to existing and emerging vehicle routing problem variants" [VLM20] (2020)

Algoritmai

Research areas

Related research:

- „A Parallel Hybrid Genetic Search for the Capacitated VRP with Pickup and Delivery“ (2023)
- „Effective Parallelization of the Vehicle Routing Problem“ (2023)
- "A hybrid genetic search based approach for the generalized vehicle routing problem" [Lat25a] (2025)

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[Vid+14] T. Vidal, T. G. Crainic, M. Gendreau, ir C. Prins, „A unified solution framework for multi-attribute vehicle routing problems“, *European Journal of Operational Research*, t. 234, nr. 3, p. 658–673, geg. 2014, doi: 10.1016/j.ejor.2013.09.045.

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