# Generalized Routing Problems with Continuous Neighborhoods

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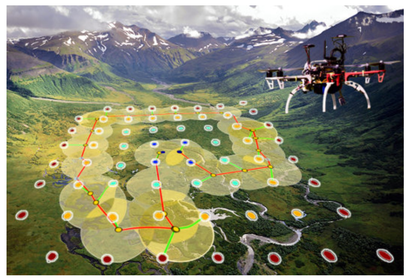
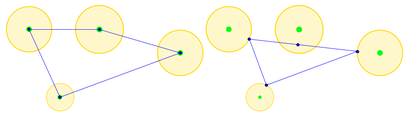
## Motivation – Robotics Routing Problems

- Data collection with aerial vehicles.
- Inspection tasks with mobile robots and manipulators.
- Robotic tasks sequencing in industrial robotic applications.
- Multi-goal planning problems can be formulated as robotic variants of the **Traveling Salesman Problem (TSP)** to find the optimal sequence of visits to the goal locations.

## Solutions of Practical Problems can Benefit from more Advanced Problem Formulations



- In many practical cases, an exact visit to the point goal is not required.
- Exploiting a certain degree of freedom by visiting goal regions (neighborhood) instead of exact point locations.
- The required travel cost can be significantly saved by determining optimal waypoints.



- The desired combinatorial and continuous optimizations can be combined in the **TSP with Neighborhoods (TSPN)**.
- The TSPN is known to be **APX**-hard in general.
  - Approximation algorithms exist only for specific types of neighborhoods.
  - Fast heuristics, with only empirically evaluated performance.

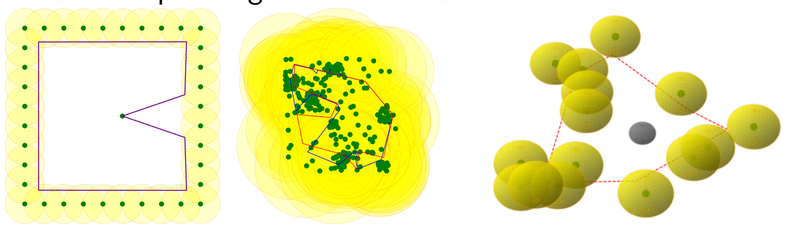
## Thesis Goals

- Address multi-goal planning problems as robotic variants of the TSPN motivated by practical deployments.
- Study **lower and upper bounds** of the TSPN variants.
- Establish a **relative optimality gap** as the solution quality.
- Develop **fast heuristics** with solution quality estimation.
- Use established tight lower bounds in **optimal solutions**.

## Addressed Variants of the TSPN

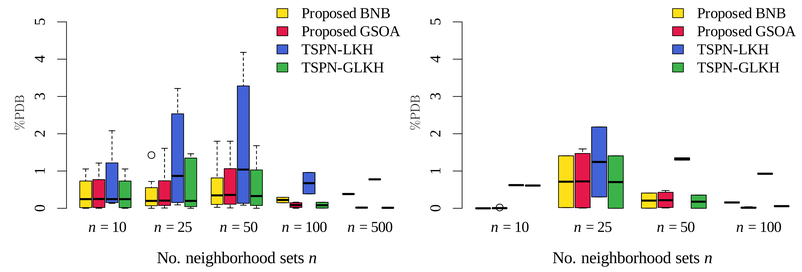
### 1. Visual aerial surveillance and data collection missions

- Problem formulated as the **Close Enough TSP (CETSP).**
- Disk-shaped neighborhoods in 2D and 3D.



### 2. Multi-goal planning in UAV-based Reflectance Transformation Imaging (RTI) of cultural heritage objects

- New non-Euclidean TSPN with disk-shaped neighborhoods on a sphere called the **TSPN on a Sphere** (**TSPNS**).



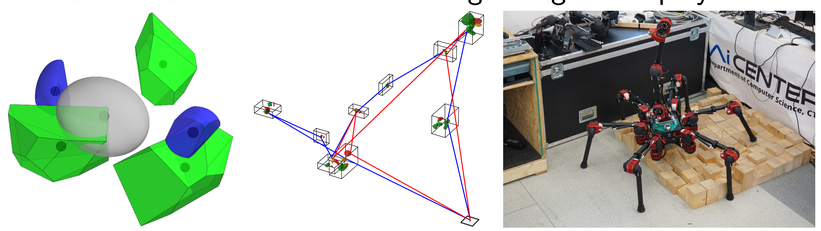

3D non-overlapping instances of the TSPNS




3D overlapping instances of the TSPNS

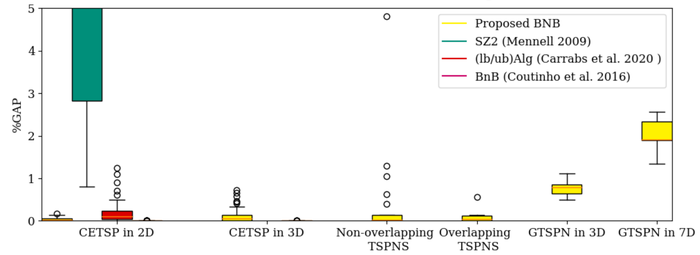
### 3. Robotic-arm tasks and mobile robotic arm inspections

- Improved flexibility of the problem formulation using sets of target regions in the **Generalized TSPN** (**GTSPN**).
- 3D and 7D instances with sets of goal regions as polyhedrons.



## Contribution Highlights

- Introduction of the **TSPNS** for UAV-based RTI.
- New **quick heuristics** with a real-time response based on
  - unsupervised learning of the Growing Self-Organizing Array (GSOA);
  - transformation to the (G)TSP and solution using (G)LKH solvers.
- Branch-and-bound framework for the **optimal** solution and **lower bound** estimation of the optimal solution value.
- **Tight lower bounds** and **optimal solver** for the CETSP.
- **First reported lower bounds** for the TSPNS and GTSPN.
  - Lower bounds for the TSPNS are considered tight.




Relative optimality gap of the addressed variants of the TSPN

- **A general solution framework for lower bounds and feasible (optimal) solutions of the generalized routing problems with neighborhoods.**

## Publication activity

- Thesis consolidated in [1], [2], [3] and further in preparation [4] and [5].
- Optimal solution of multi-goal planning for mobile manipulator [6].
- Solving routing problems with profits and neighborhoods [7].

[1] J. Faigl and **J. Deckerová**, "On unsupervised learning based multi-goal path planning for visiting 3d regions," in *International Conference on Robotics and Artificial Intelligence (ICRAI)*, 2018, pp. 45–50.

[2] J. Faigl, P. Váňa, and **J. Deckerová**, "Fast heuristics for the 3-d multi-goal path planning based on the generalized traveling salesman problem with neighborhoods," *IEEE Robotics and Automation Letters*, vol. 4, no. 3, pp. 2439–2446, 2019.

[3] **J. Deckerová**, V. Krátký, and J. Faigl, "Traveling salesman problem with neighborhoods on a sphere in reflectance transformation imaging scenarios," *Expert Systems With Applications*, 2020, (in review).

[4] **J. Deckerová**, P. Váňa, and J. Faigl, "On combinatorial solution of lower bounds for the generalized traveling salesman problem with neighborhoods," 2021, (in preparations).

[5] **J. Deckerová**, P. Váňa, and J. Faigl, "On optimal solution of non-linear traveling salesman problem with neighborhoods," 2021, (in preparations).

[6] **J. Deckerová**, J. Kubík, and J. Faigl, "Optimal multi-goal path planning for mobile robotic arm on hexapod walking robot," *IEEE International Conference on Robotics and Automation (ICRA)*, 2021, (in review).

[7] **J. Deckerová** and J. Faigl, "Hopfield neural network in solution of the close enough orienteering problem," in *Conference Information Technologies - Applications and Theory (ITAT)*, 2020.