Robot Mapping

Hierarchical Pose-Graphs for Online Mapping

Cyrill Stachniss

Graph-Based SLAM (Chap. 15)

- Constraints connect the poses of the robot while it is moving
- Constraints are inherently uncertain

Observing previously seen areas generates constraints between non-successive poses

Graph-Based SLAM (Chap. 15)

- Use a graph to represent the problem
- Every node in the graph corresponds to a pose of the robot during mapping
- Every edge between two nodes corresponds to a spatial constraint between them
- **Graph-Based SLAM**: Build the graph and find a node configuration that minimize the error introduced by the constraints
Front-End and Back-End

- Front-end extracts constraints from the sensor data (data association!)
- Back-end optimizes the pose-graph to reduce the error introduced by the constraints

Intermediate solutions are needed to make good data associations

Motivation

- SLAM front-end seeks for loop-closures
- Requires to compare observations to all previously obtained ones
- In practice, limit search to areas in which the robot is likely to be
- This requires to know **in which parts of the graph to search for data associations**

Hierarchical Pose-Graph

- There is no need to optimize the whole graph when a new observation is obtained

Hierarchical Approach

- **Insight:** to find loop closing points, one does not need the perfect global map
- **Idea:** correct only the core structure of the scene, not the overall graph
- The hierarchical pose-graph is a sparse approximation of the original problem
- It exploits the facts that in SLAM
  - Robot moved through the scene and it not “teleported” to locations
  - Sensors have a limited range
Key Idea of the Hierarchy

- Input is the dense graph
- Group the nodes of the graph based on their local connectivity
- For each group, select one node as a "representative"

The representatives are the nodes in a new sparsified graph (upper level)
Key Idea of the Hierarchy

- The representatives are the nodes in a new sparsified graph (upper level)
- Edges of the sparse graph are determined by the connectivity of the groups of nodes
- The parameters of the sparse edges are estimated via local optimization

Process is repeated recursively

Key Idea of the Hierarchy

- Only the upper level of the hierarchy is optimized completely
- The changes are propagated to the bottom levels only close to the current robot position
- Only this part of the graph is relevant for finding constraints
Construction of the Hierarchy

- When and how to generate a new group?
  - A simply, distance-based heuristic on the graph
  - The first node of a new group is the representative
- When to propagate information downwards?
  - Only when there are inconsistencies
- How to construct an edge in the sparsified graph?
  - Next slides
- How to propagate information downwards?
  - Next slides

Determining Edge Parameters

- Given two connected groups
- How to compute a virtual observation \( \mathbf{Z} \) and the information matrix \( \mathbf{\Omega} \) for the new edge?

Determining Edge Parameters

- Optimize the two subgroups independently from the rest
- The observation is the relative transformation between the two representatives
**Determining Edge Parameters**

- Optimize the two subgroups independently from the rest.
- The observation is the relative transformation between the two representatives.
- The information matrix is computed from the diagonal block of the matrix $H$.

$$\Omega_{ab} = (H^{-1}_b)^{-1}$$

**Propagating Information Downwards**

- All representatives are nodes from the lower (bottom) level.
- Information is propagated downwards by transforming the group at the lower level using a rigid body transformation.
- Only if the lower level becomes inconsistent, optimize at the lower level.
For the Best Possible Map...

- Make sure to run the optimization on the lowest level in the end
- For offline processing with all constraints, the hierarchy helps convergence faster in case of large errors
- In this case, one pass up the tree (to construct the edges) followed by one pass down the tree is sufficient

Stanford Garage

- Parking garage at Stanford University
- Nested loops, trajectory of ~7,000m

Stanford Garage Result

- Parking garage at Stanford University
- Nested loops, trajectory of ~7,000m

Stanford Garage Video
**Intel Research Lab Video**

**Consistency**
- Evaluation how well does the top level in the hierarchy represent the original input
- Probability mass of the marginal distribution in the highest level vs. the one of the true estimate (original problem, lowest level)

<table>
<thead>
<tr>
<th></th>
<th>Prob. mass not covered</th>
<th>Prob. mass outside</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intel</td>
<td>0.10%</td>
<td>10.18%</td>
</tr>
<tr>
<td>W-10000</td>
<td>2.53%</td>
<td>24.05%</td>
</tr>
<tr>
<td>Stanford</td>
<td>0.01%</td>
<td>7.88%</td>
</tr>
<tr>
<td>Sphere</td>
<td>2.75%</td>
<td>10.21%</td>
</tr>
</tbody>
</table>

- Low risk of becoming overly confident
- One does not ignore too much information

**Conclusions**
- Hierarchical pose-graph to estimate the structure to support efficient data association
- Designed for online mapping (interplay between optimization and data association)
- Higher level represent simplified problem

- **Red**: overly confident (~0.1% prob. mass)
- **Blue**: under confident (~10% prob. mass)
Literature

Hierarchical Pose-Graph Optimization

- Grisetti, Kümmerle, Stachniss, Frese, and Hertzberg: “Hierarchical Optimization on Manifolds for Online 2D and 3D Mapping”
- Open-source implementation hosted at http://openslam.org/hog-man.html