VAN course
Lesson 12

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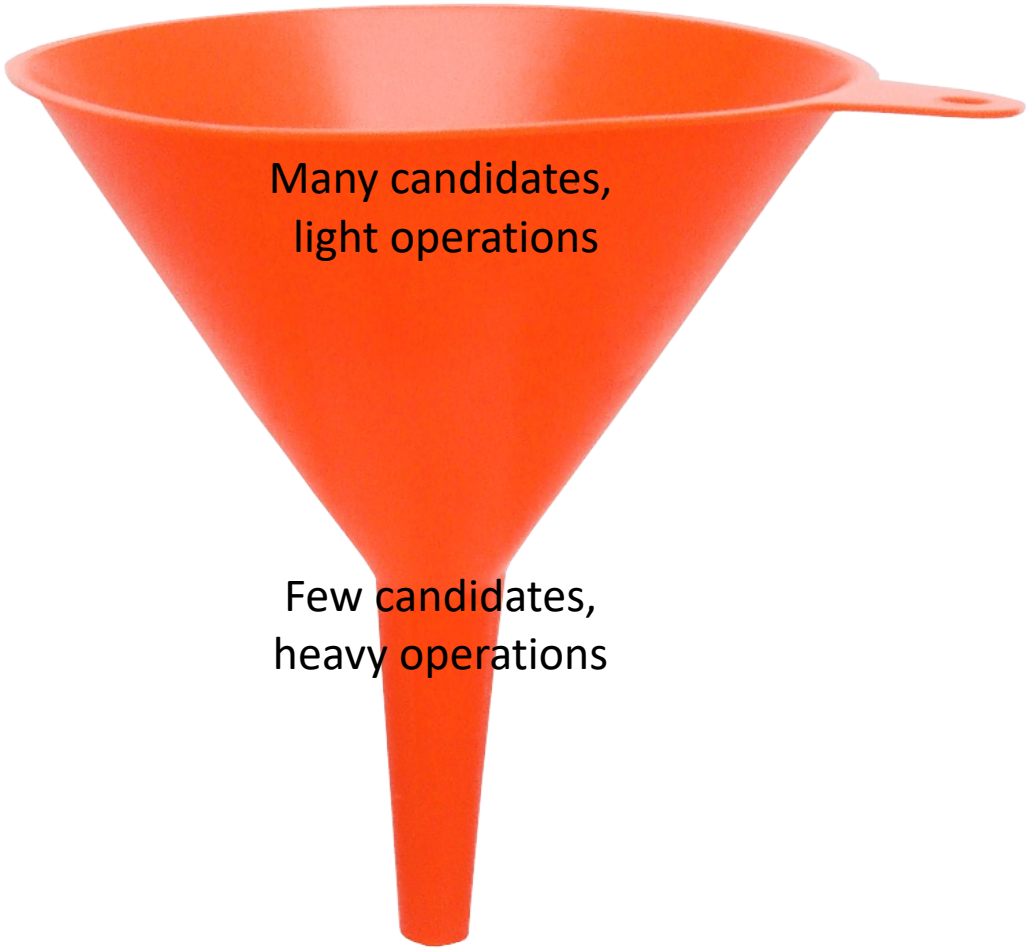
Loop Closure

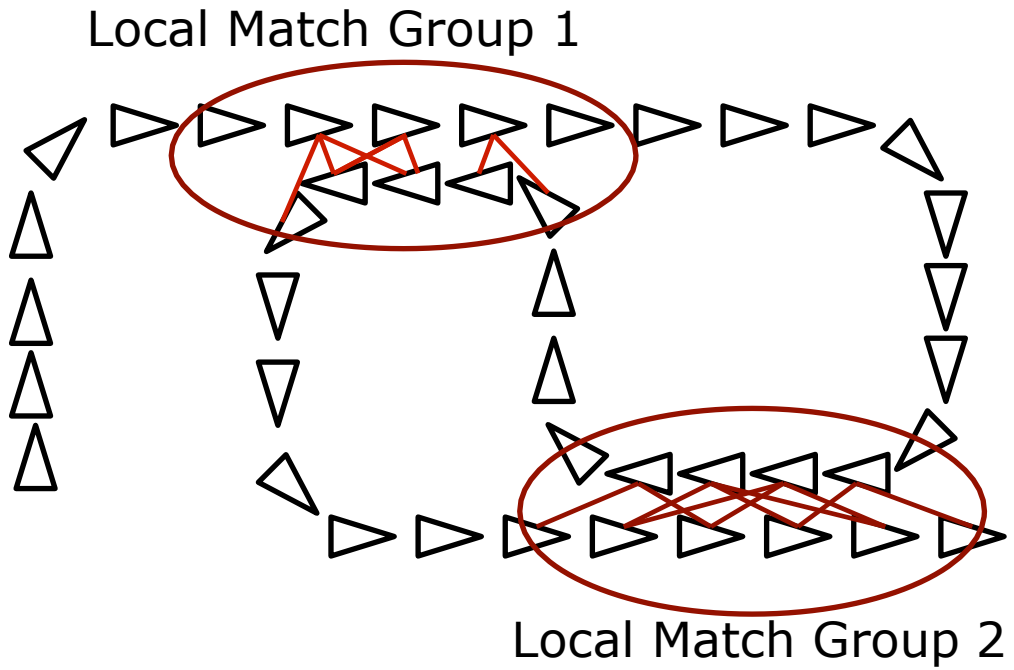
- How can we spot a loop closure?
  - Find candidates (light):
    - Geometric intersection
  - Validate candidates (heavy):
    - 3D points clouds matching using ICP
    - Descriptor-based matching
  - Calculate edges and factors:
    - Find transformation using matches/ICP
  - **Outlier removal:**
    - **Olson's method**



Loop Closure – outliers removal

Topological Grouping

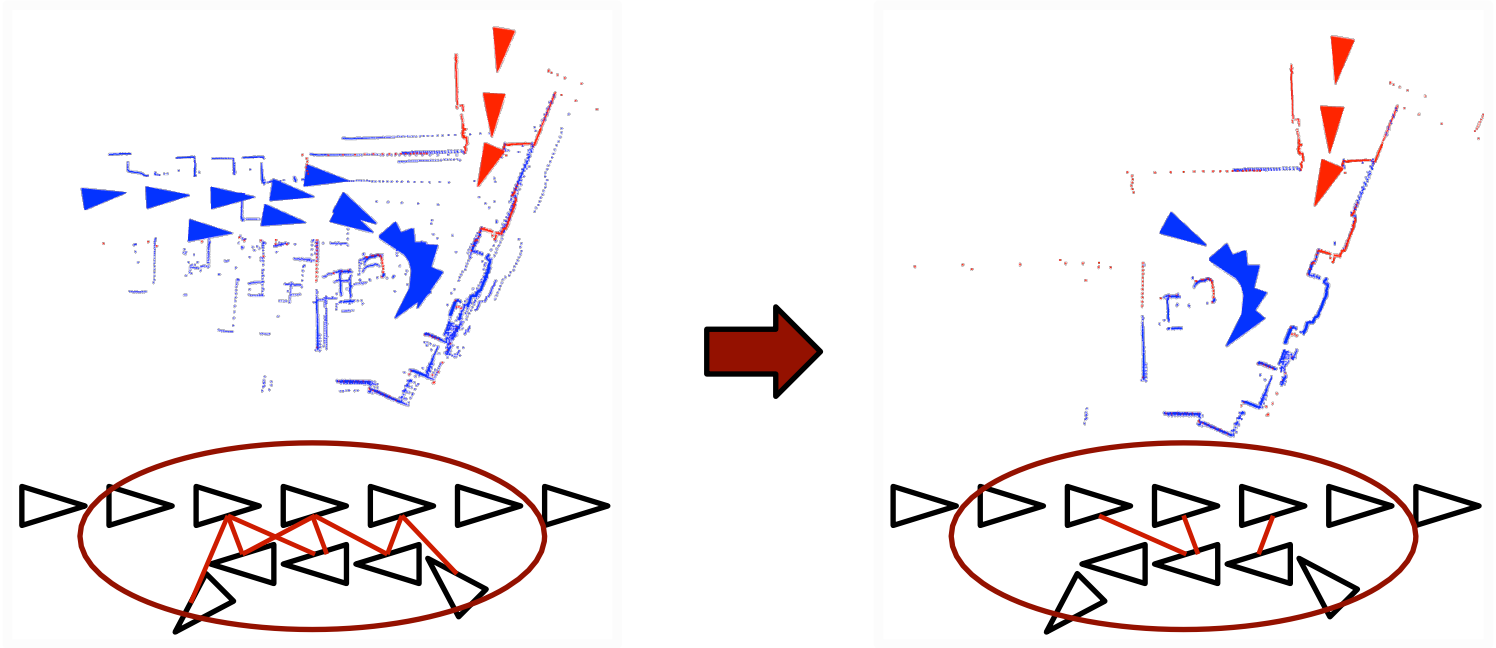
- Group together topologically-related pose-to-pose matches to form local matches
- Each group asks a "topological" question: Do two local maps match?



Courtesy of Cyrill Stachniss

Loop Closure – outliers removal
Locally Unambiguous Matches

Goal:



Unfiltered Local Match
(set of pose-to-pose matches)

Locally consistent and
unambiguous local match
(set of pose-to-pose matches)

Courtesy of Cyrill Stachniss

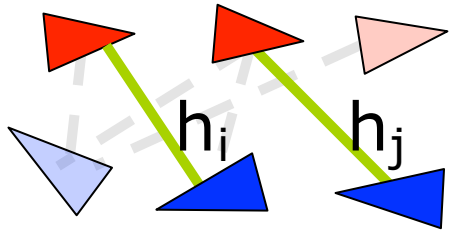
Loop Closure – outliers removal
Locally Consistent Matches

- Correct pose-to-pose hypotheses must agree with each other
- Incorrect pose-to-pose hypotheses tend to disagree with each other
- Find subset of self-consistent of hypotheses
- Multiple self-consistent subsets, are an indicator for a “picket fence”!

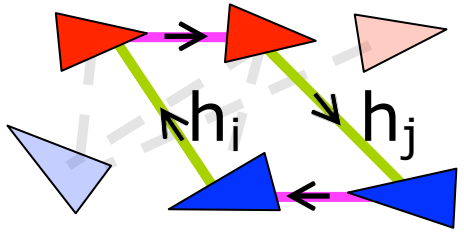
Courtesy of Cyrill Stachniss

Loop Closure – outliers removal
Do Two Hypotheses Agree?

- Consider two hypotheses **i** and **j** in the set:



- Form a loop using edges from the prior graph

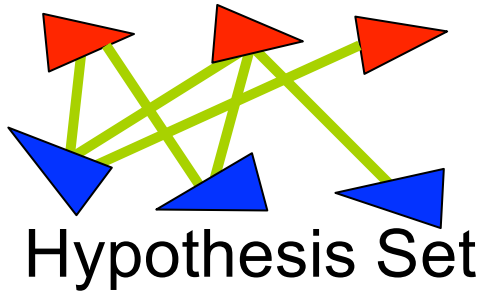


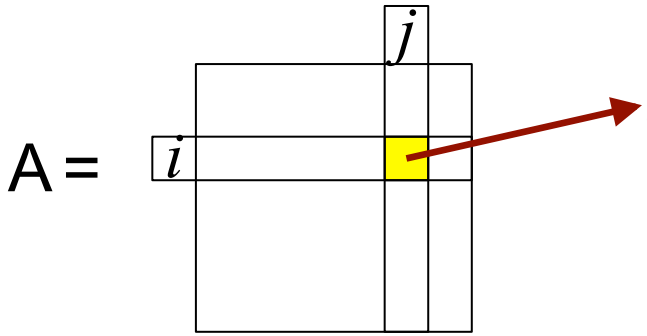
Rigid-body transformation around the loop should be the identity matrix

Courtesy of Cyrill Stachniss

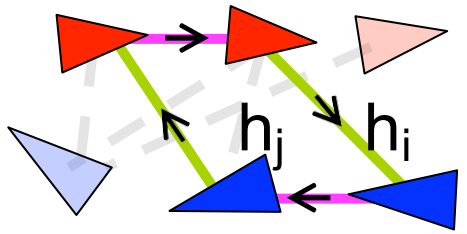
Loop Closure – outliers removal
Idea of Olson's Method

Form pair-wise consistency matrix **A**





$$A_{ij} = P(\text{loop}(i,j) = I \mid h_i, h_j) = \Delta x^T \Omega \Delta x$$



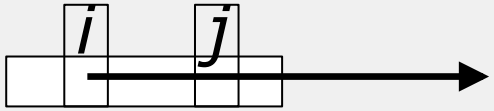
Courtesy of Cyrill Stachniss

Loop Closure – outliers removal

Single Cluster Graph Partitioning

- Idea: Identify the subset of consistent hypotheses
- Find the best **indicator vector** (represents a subset of the hypotheses)

Indicator vector v



v_i = 1 if h_i is correct,
0 if h_i is incorrect

Courtesy of Cyrill Stachniss

Loop Closure – outliers removal

$$\begin{bmatrix} 0 & 1 & 1 & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0.15 & 0.5 \\ 0 & 1 & 0.94 & 0.84 \\ 0.15 & 0.94 & 1 & 0.01 \\ 0.5 & 0.84 & 0.01 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 1 \\ 0 \end{bmatrix}$$

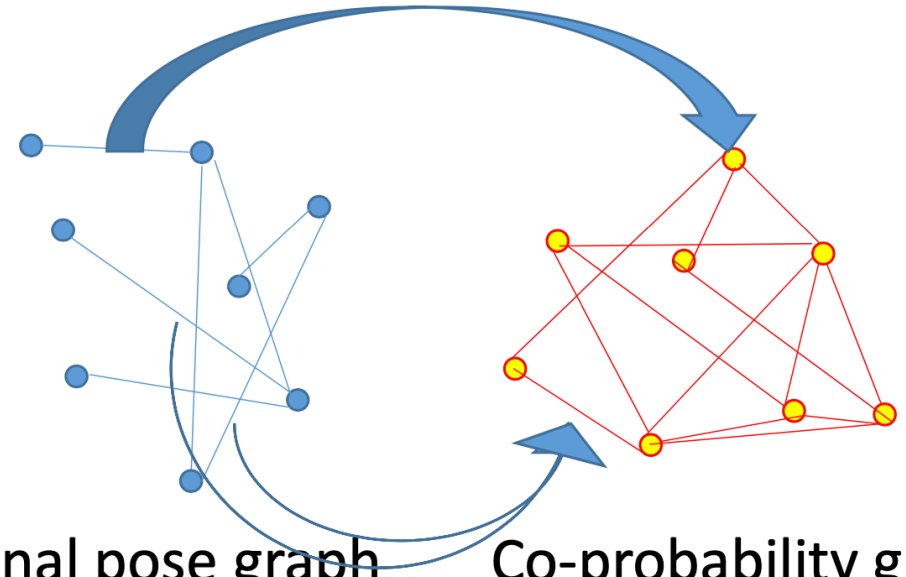
v^T A v

- We want find **v** that maximizes λ(**v**)

$$\lambda(\mathbf{v}) = \frac{\mathbf{v}^\mathbf{T}\mathbf{A}\mathbf{v}}{\mathbf{v}^\mathbf{T}\mathbf{v}}$$

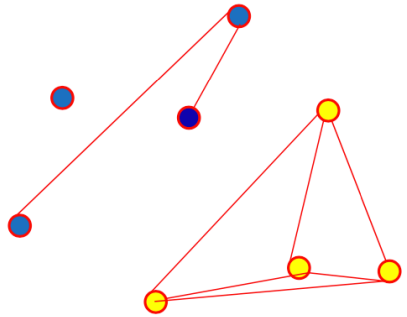
Loop Closure – outliers removal

Graph interpretation:

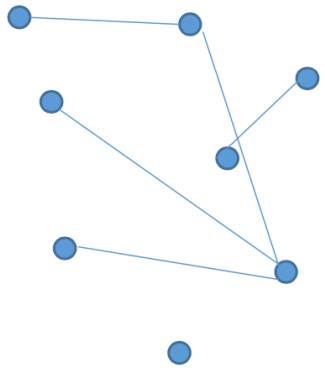


Original pose graph

Co-probability graph



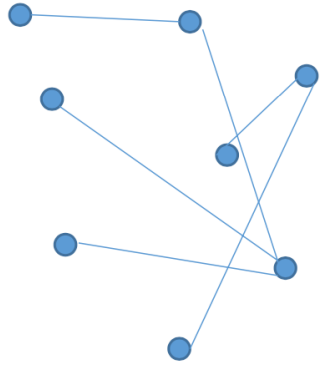
Result: partition



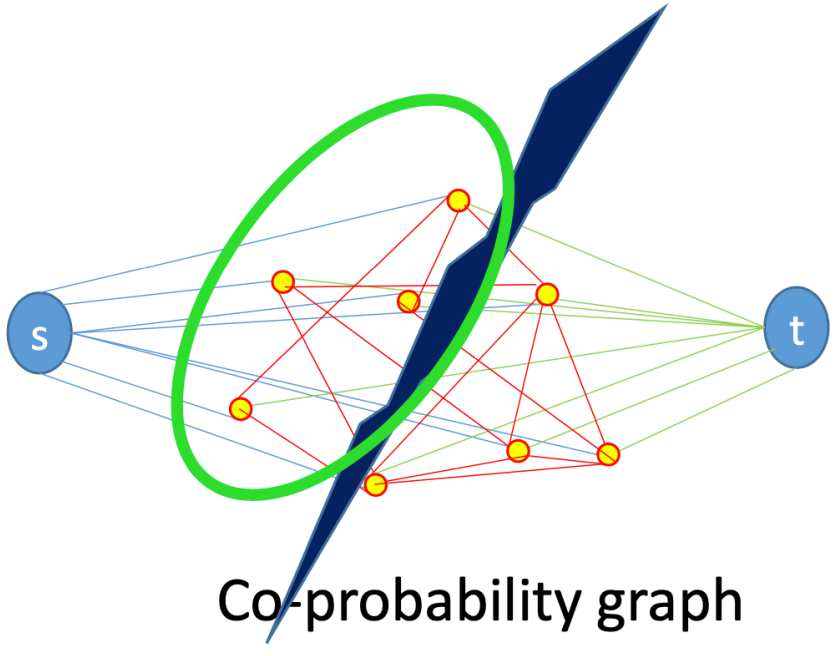
Result: less edges

Loop Closure – outliers removal

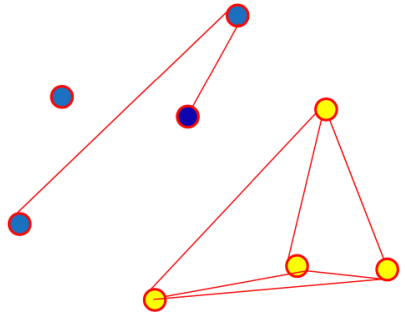
Graph cuts solution:



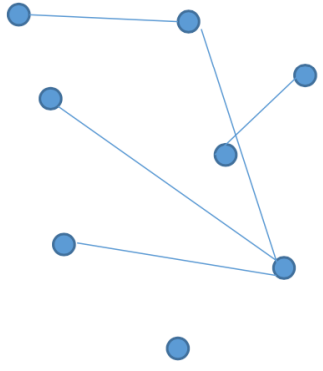
Original pose graph



Co-probability graph



Result: partition



Result: less edges

Loop Closure – outliers removal

Algebraic approach:

- We want find **v** that maximizes λ(**v**)

$$\lambda(\mathbf{v}) = \frac{\mathbf{v}^{\mathbf{T}}\mathbf{A}\mathbf{v}}{\mathbf{v}^{\mathbf{T}}\mathbf{v}}$$

- Treat as a continuous problem
- We want the dominant eigenvector of A
- We round it to get a binary vector

Loop Closure – outliers removal
Consistent Local Matches

- If λ_1/λ_2 is large (e.g., $\lambda_1/\lambda_2>2$) then $\mathbf{v_1}$ is regarded as locally unambiguous
- Else remove **all** candidates