Universitat de Girona

Topology Estimation and Global Alignment

Ricard Campos

Nuno Gracias

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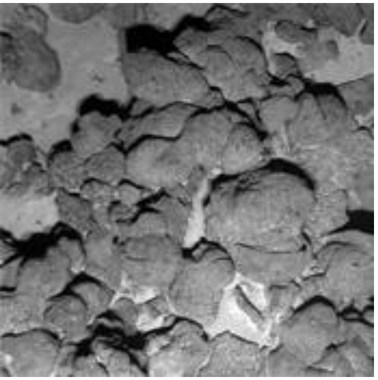

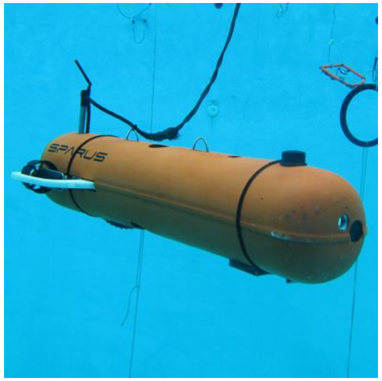

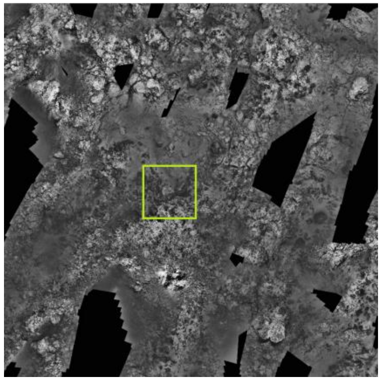

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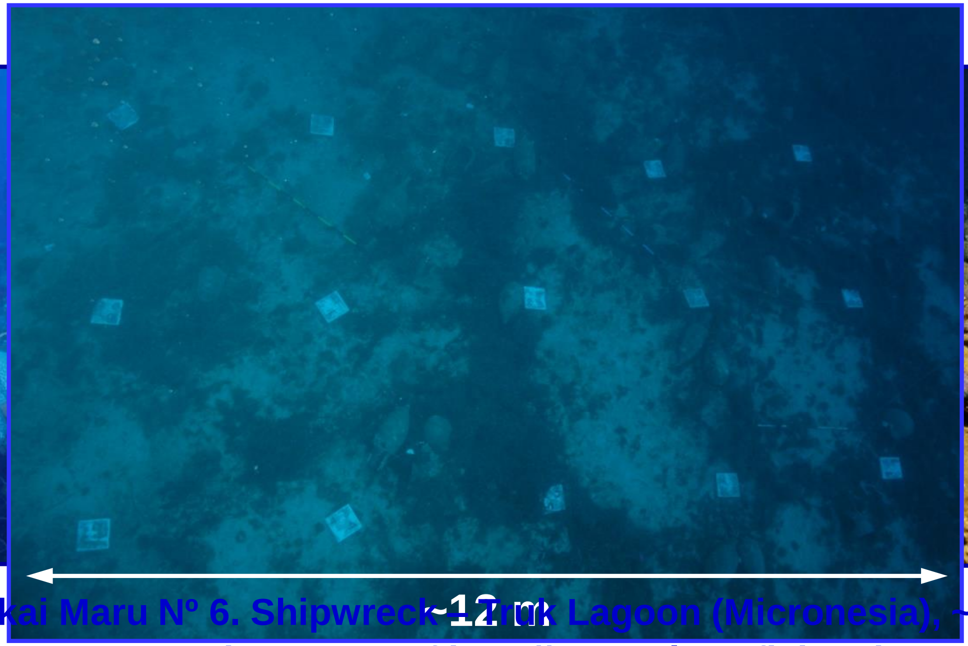
- A single shot cannot provide a global perspective of the area:



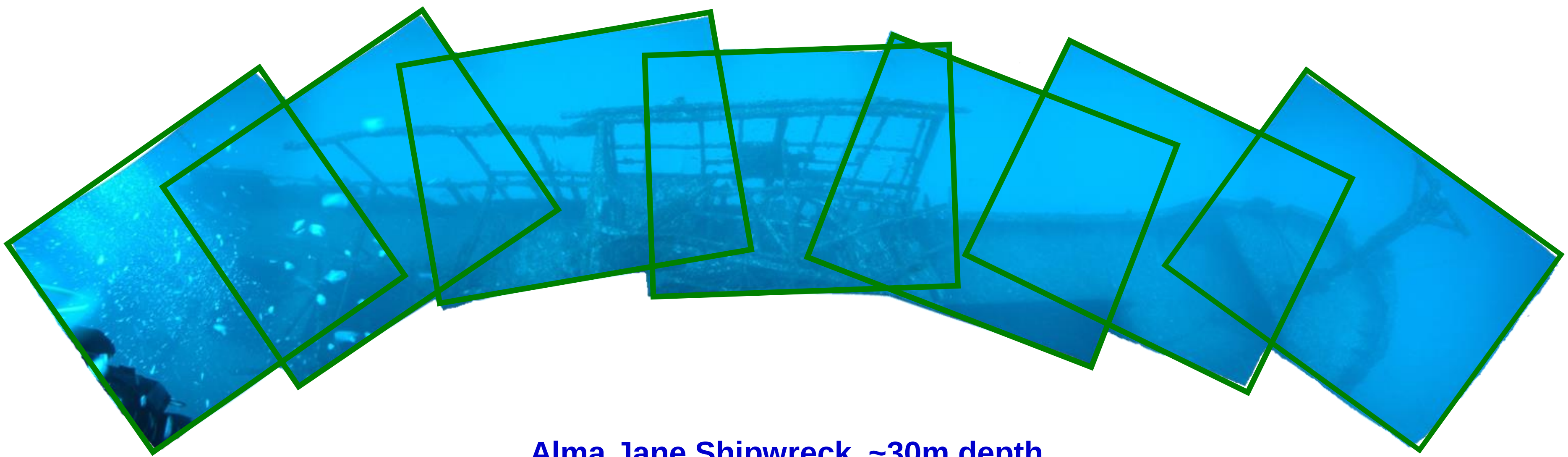
Unkai Maru Nº 6. Shipwreck - Truk Lagoon (Micronesia), ~40m depth
(Courtesy of http://www.clownfish.nu)

Pianosa Amphoras, ~32m depth (~10m from camera to scene)
(Courtesy of Venus Project)

Solution: Build a photomosaic!

Photomosaic

Compose a single image from a set of overlapping images:

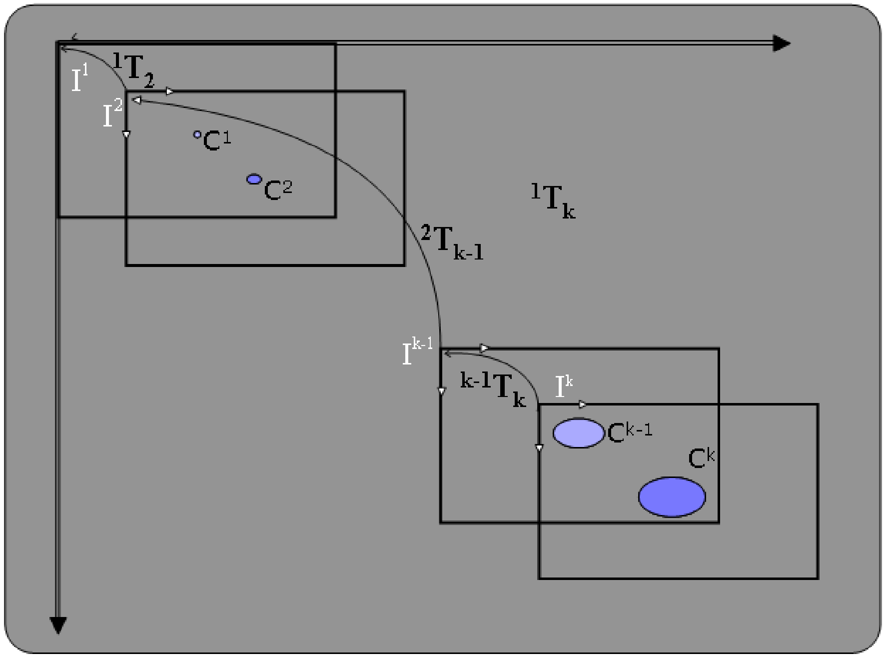


Alma Jane Shipwreck, ~30m depth
(Courtesy of David Habi)

Topology

Photomosaic: Initial estimation – Cascade of homographies

- So far, we have seen how to find the motion between pairs.
- How does this relate to global motion?
- Cascade the relative homographies:

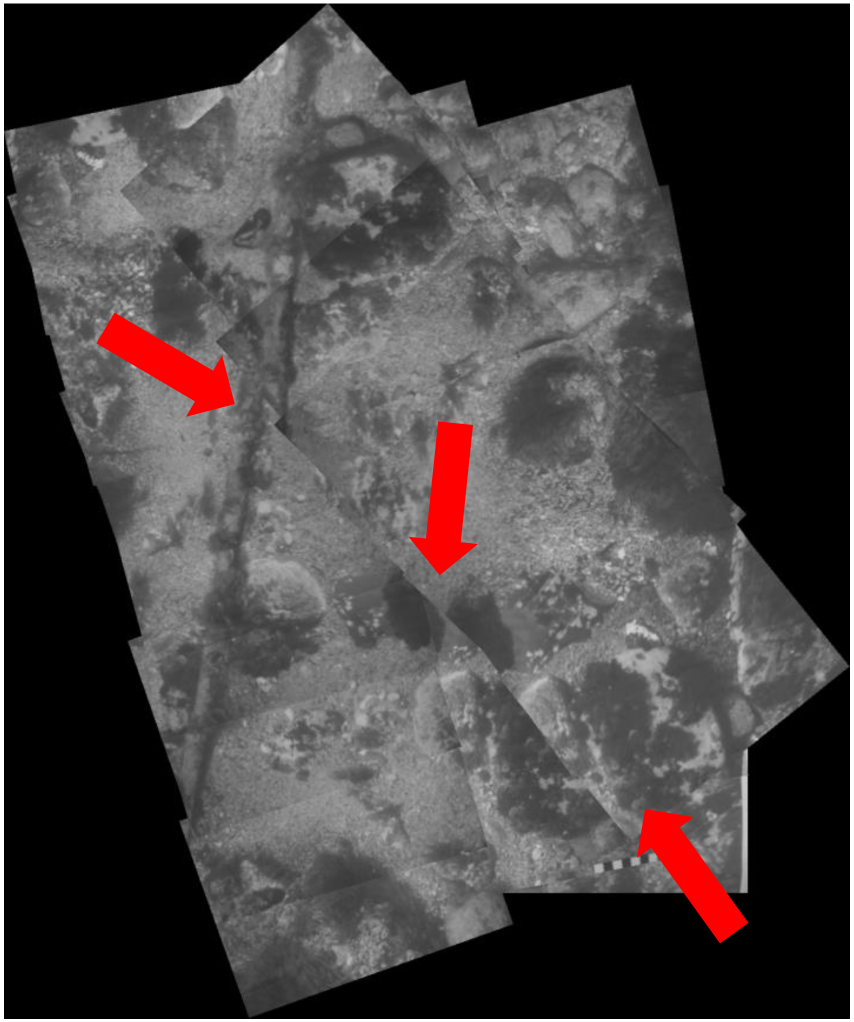


$$^1T_k = {}^1T_2 \cdot {}^2T_3 \cdot \ldots \cdot {}^{k-2}T_{k-1} \cdot {}^{k-1}T_k$$

Problem: Drifts quickly.

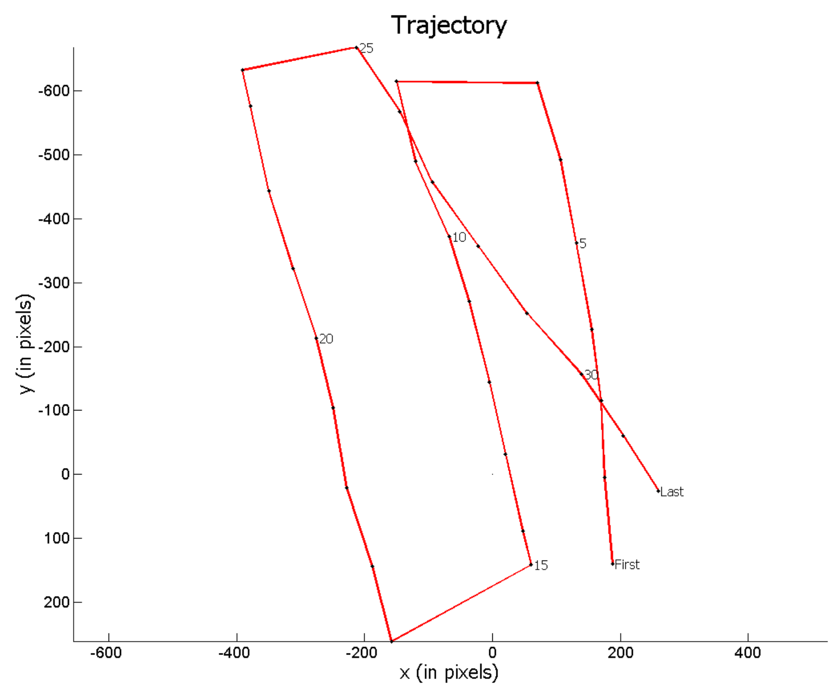
Topology

Definition



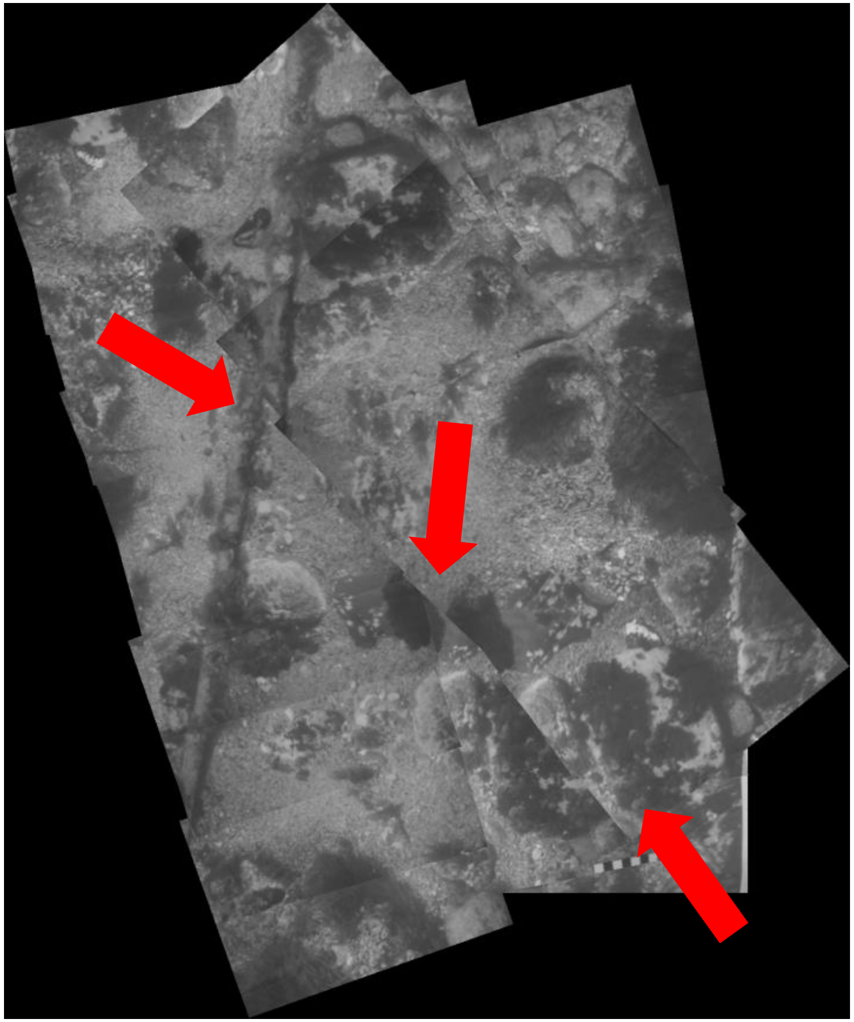
Topology refers to:

- Trajectory and
- Links among images



Topology

Definition



Topology refers to:

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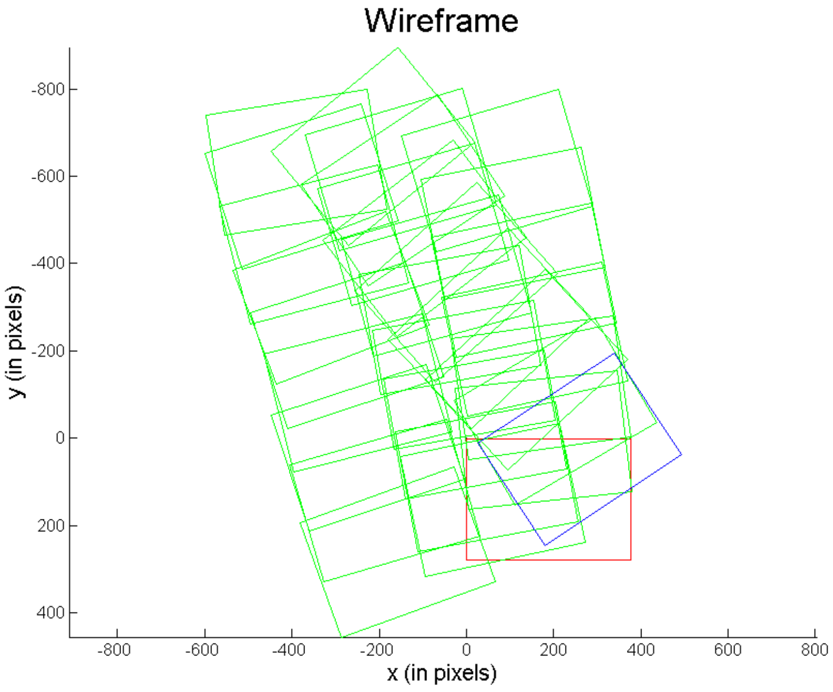
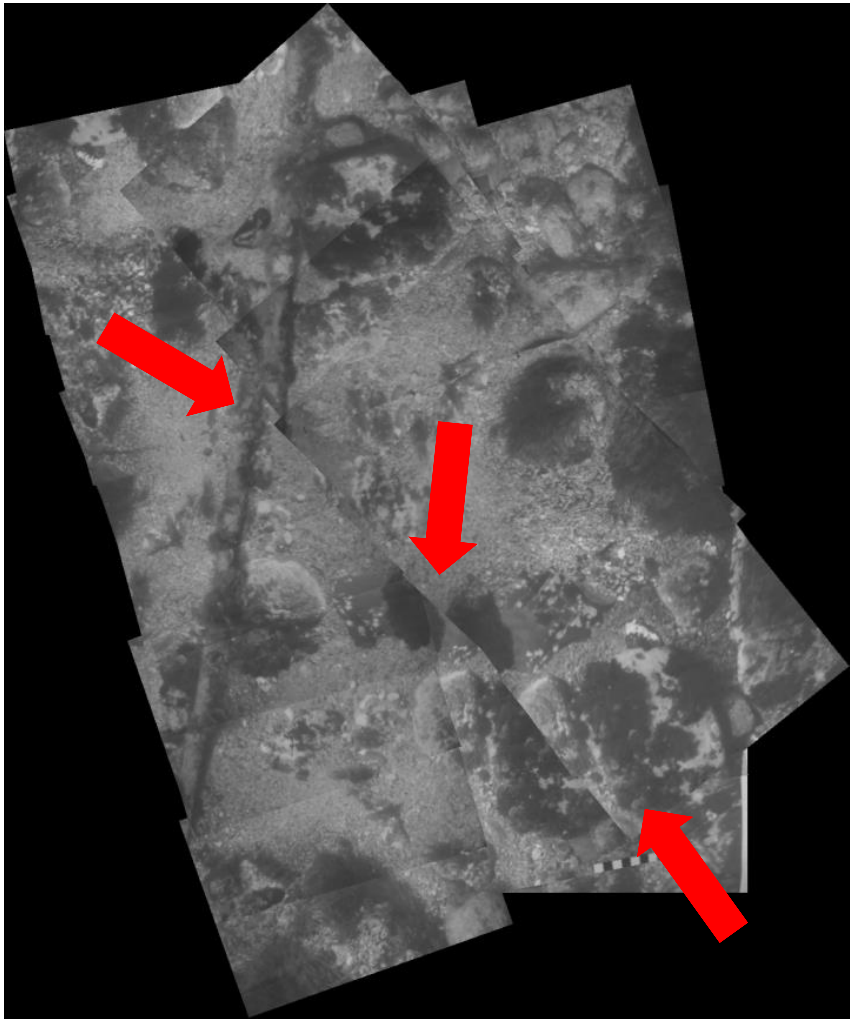


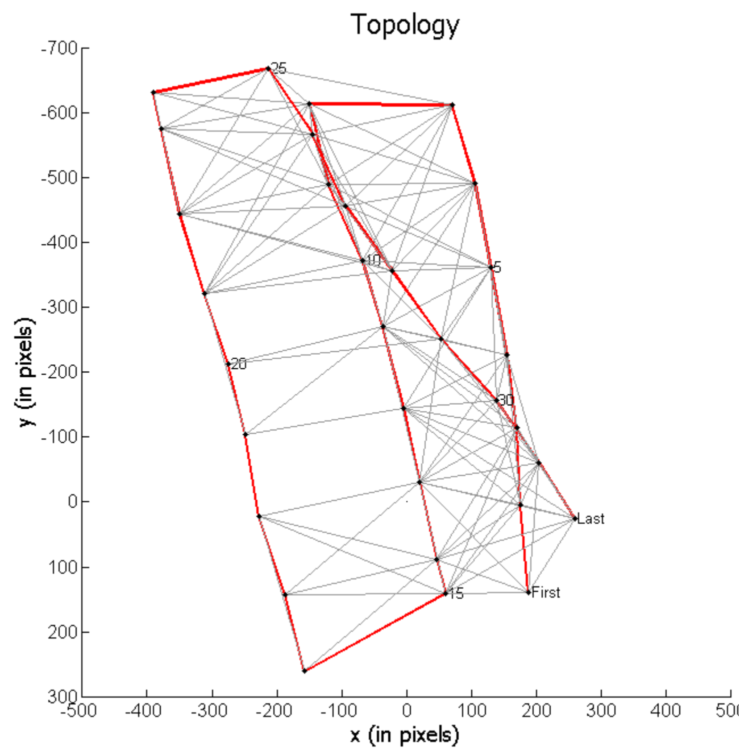
Topology

Definition



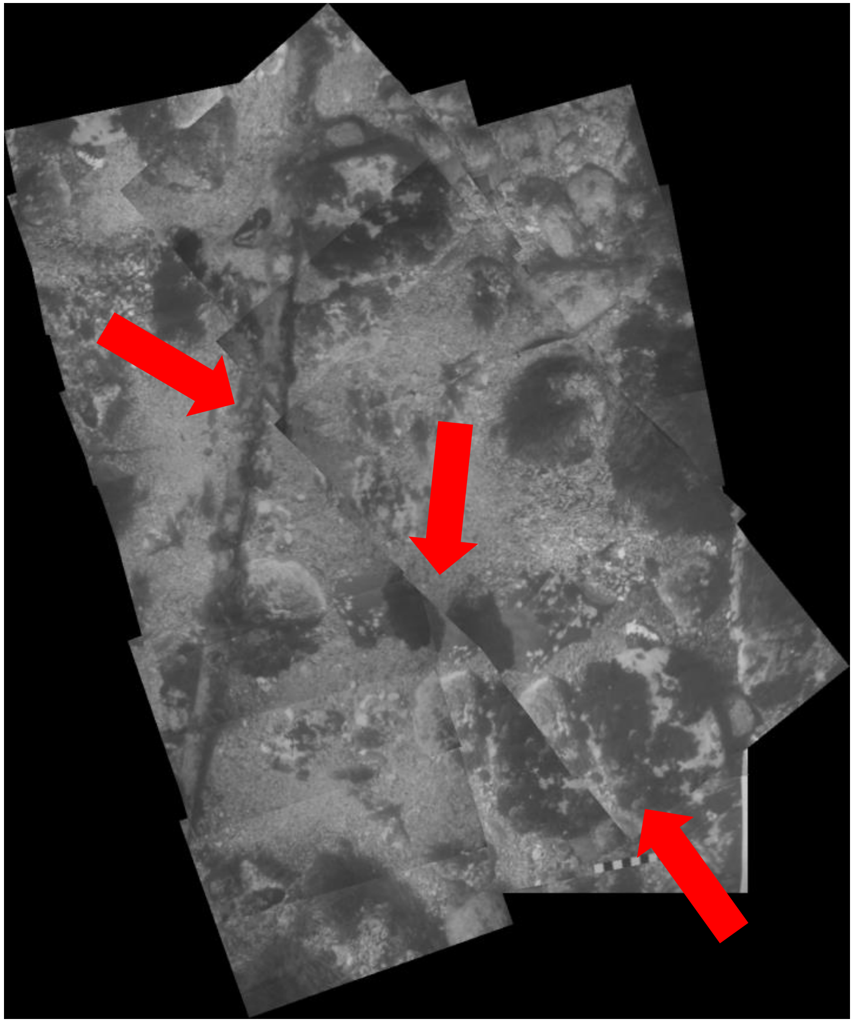
Topology refers to:

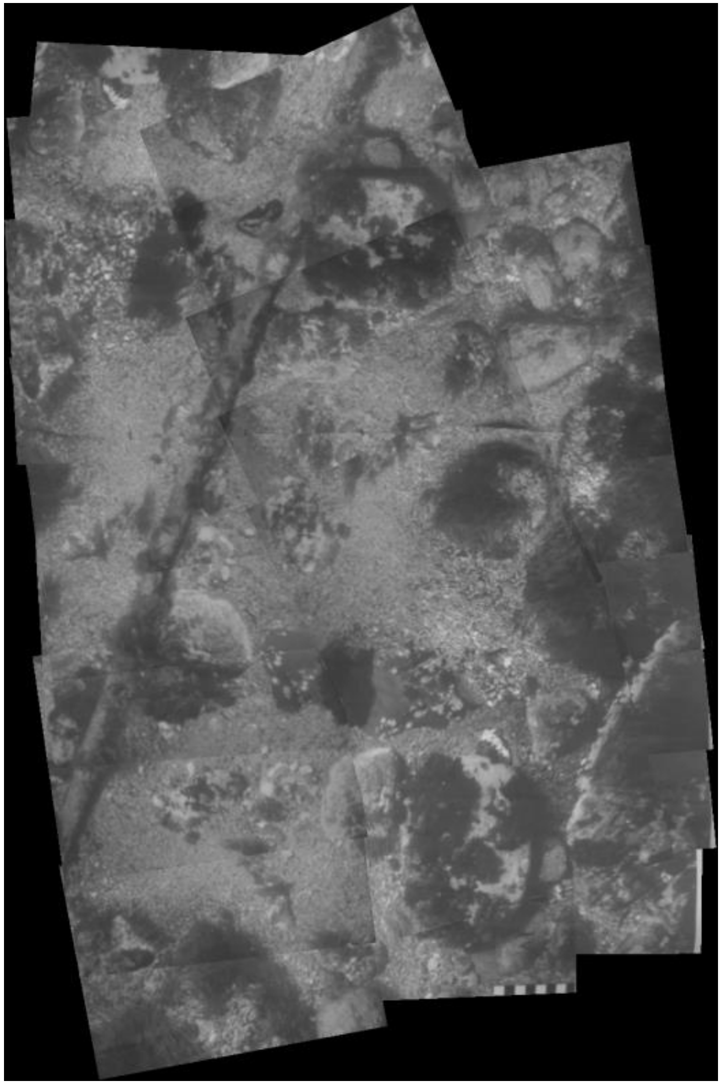
- Trajectory and
- Links among images



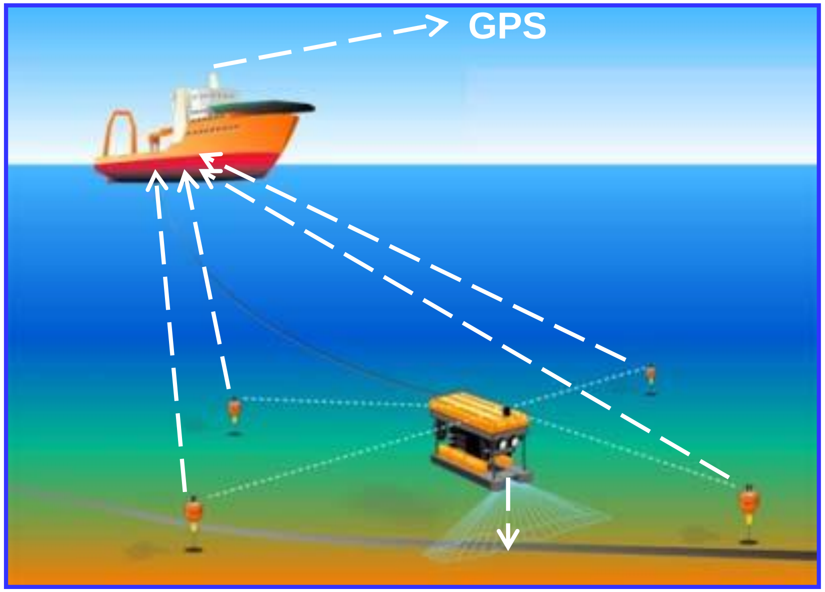
Topology

Definition





Vehicle Navigation Pose



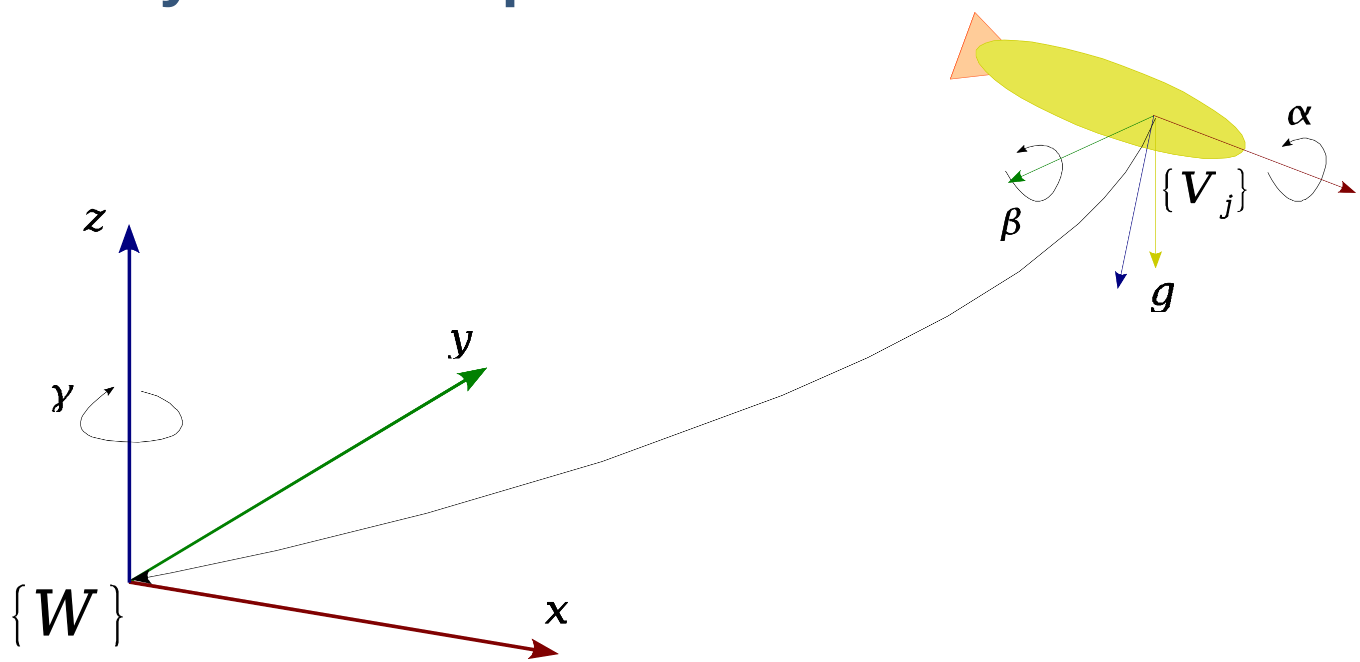
- **Global Position:**
  - X, Y from LBL Transponder Network or USBL
  - Z (Seafloor depth) from acoustic Altimeter
- **Orientation:**
  - Vehicle Roll & Pitch from Inclinometer
  - Heading from Compass

Topology

Photomosaic: Initial estimation – Navigation information

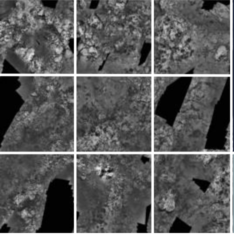
$\{W\}$ 3D World Frame
$\{V_j\}$ Vehicle Poses

- **Knowing:**
  - Camera Intrinsic Parameters
    - K
  - Vehicle Poses
    - (x, y, z, Roll, Pitch, Heading)
- **System Setup:**



g Gravity vector
α Roll
β Pitch
γ Yaw

ViCOROB



Topology

Photomosaic: Initial estimation – Navigation information

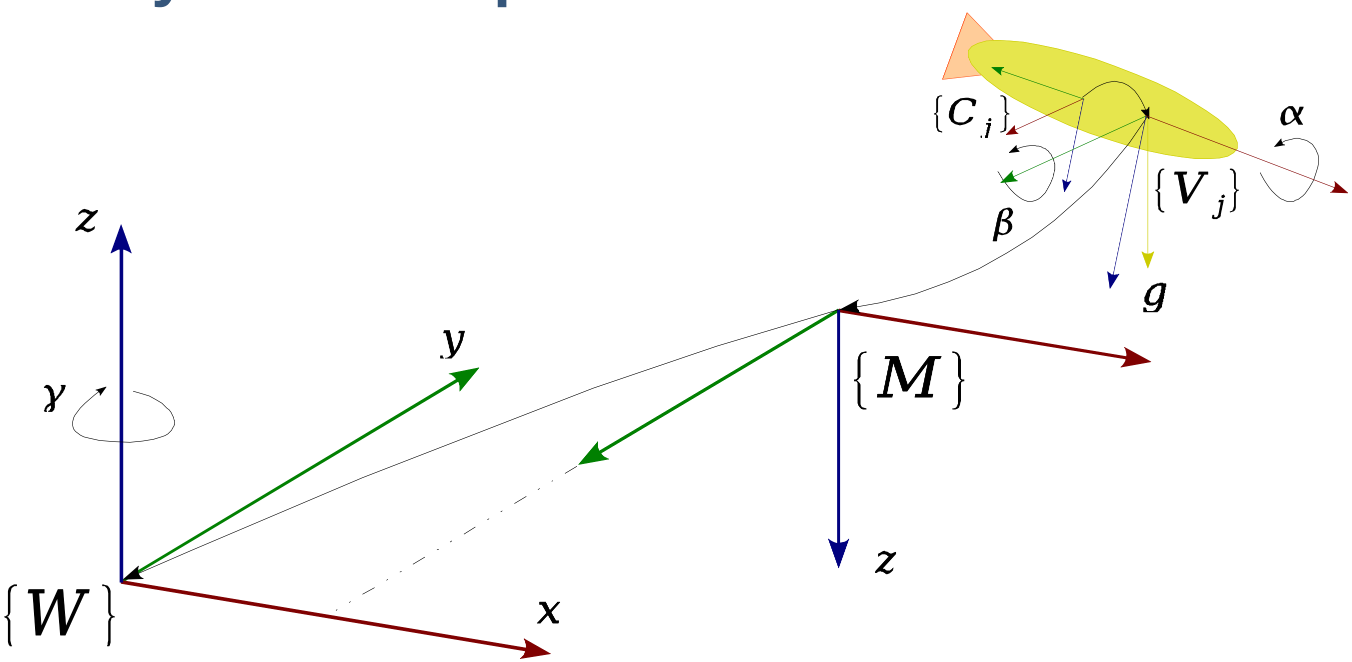
- **Knowing:**
  - Camera Intrinsic Parameters
    - K
  - Vehicle Poses
    - (x, y, z, Roll, Pitch, Heading)
- **System Setup:**

$\{W\}$ 3D World Frame

$\{V_j\}$ Vehicle Poses

$\{M\}$ 3D Mosaic Frame

$\{C_j\}$ Camera Frame



g Gravity vector

α Roll

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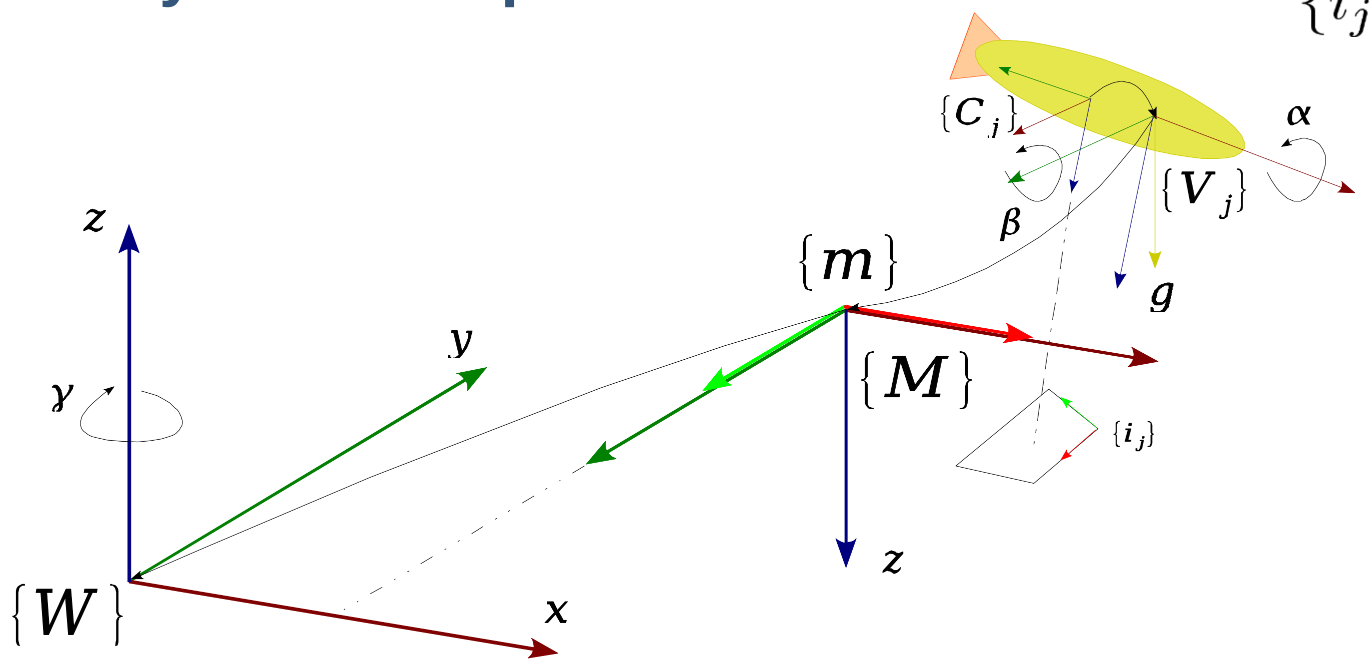
Topology

Photomosaic: Initial estimation – Navigation information

- **Knowing:**
  - Camera Intrinsic Parameters
    - K
  - Vehicle Poses
    - (x, y, z, Roll, Pitch, Heading)
- **System Setup:**

$\{W\}$ 3D World Frame
$\{V_j\}$ Vehicle Poses
$\{M\}$ 3D Mosaic Frame
$\{C_j\}$ Camera Frame
$\{m\}$ 2D Mosaic Frame
$\{i_j\}$ Image Frame



g Gravity vector
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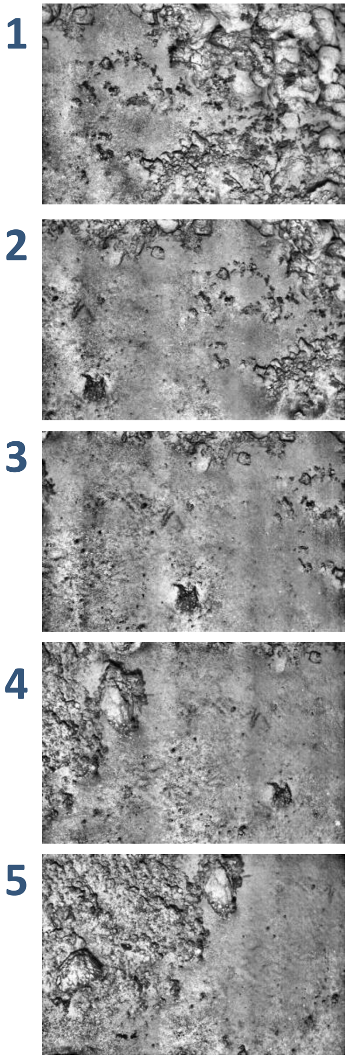
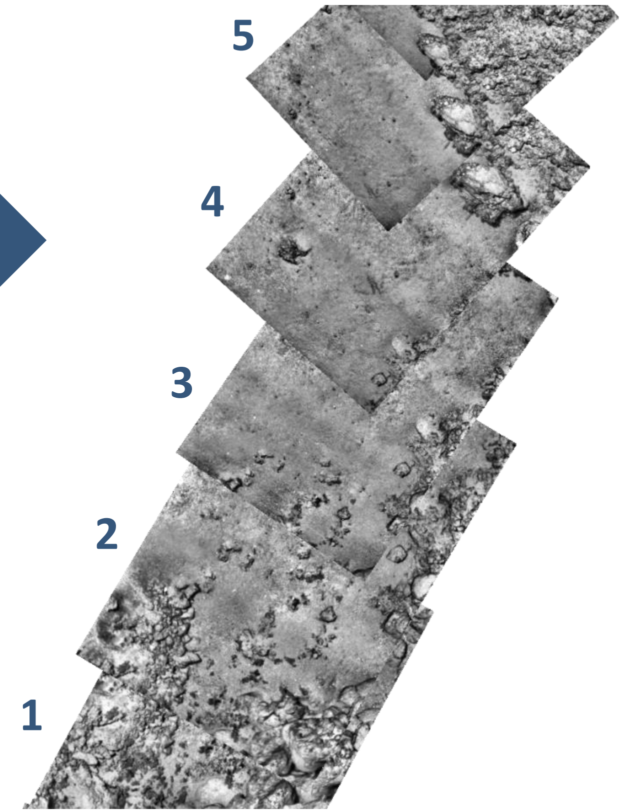
Topology

Photomosaic: Initial estimation – Navigation information



Project images to the zero-altitude plane

- **Mosaic from Navigation:**
  - **Very inaccurate**



Global Alignment

- Different sources of measurements:
  - Seen so far:
    - Navigation.
    - Optical.
  - Other possibilities:
    - Relative navigation.
    - Fiducial points.
- They all provide valuable information that needs to be taken into account to build the mosaic.
- We need a generic framework able to merge them.
- Non-linear minimization!

Global Alignment

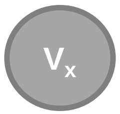
Factor Graphs

- **Factor graphs**: General tool to model factorizations of large functions with many variables into smaller local subsets.

- Problem as a bipartite graph with two types of vertices:
  - **Nodes**: corresponding to the variables to optimize (poses).
  - **Factors:** joining one, two, or more nodes representing a constraint on them, given a measure (encapsulates the error to minimize).

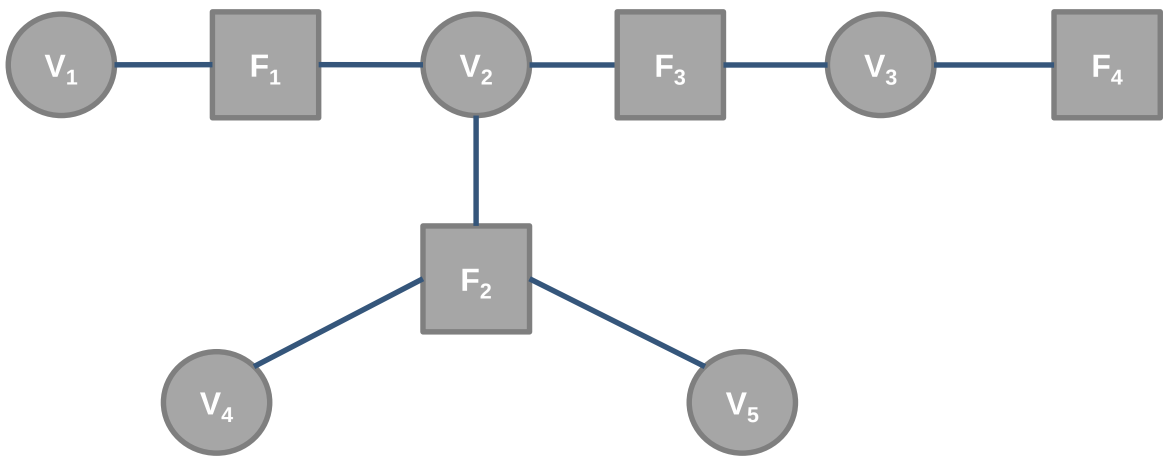
- **Problem**: find the node configuration minimizing the error introduced by the constraints.

- Pose Graph:



  - **Nodes represent Poses**:
    - E.g. Vehicle/camera pose at each time (6 DOF).

  - **Factors**:
    - Constraints for the poses w.r.t. some measures.

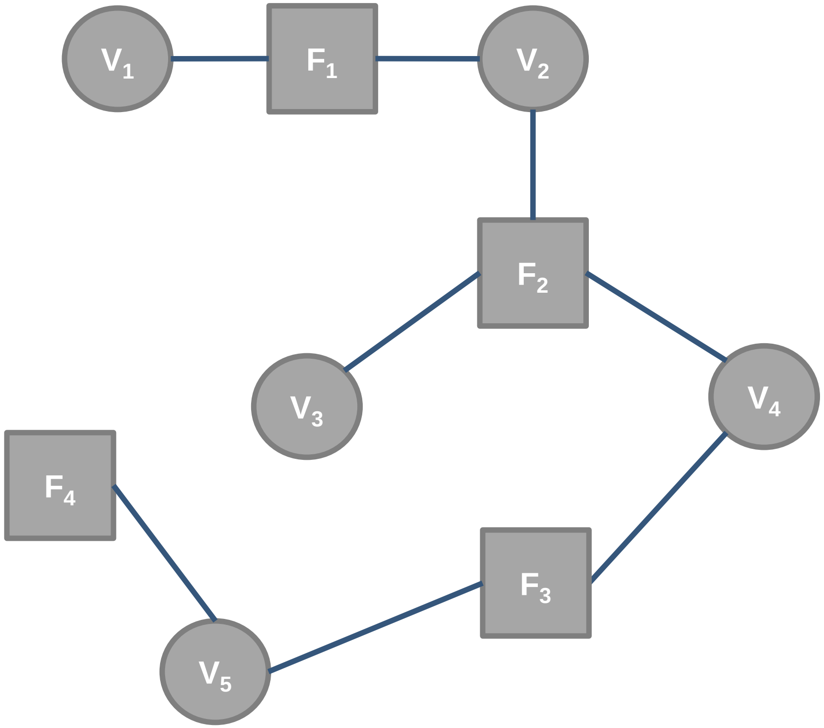


Global Alignment

Factor Graphs

Front-End

- Sensor data.
- Builds the factor graph:



Back-End

- Optimizes the non-linear problem described by the graph.
- Many available tools:
  - g2o (https://openslam.org/g2o.html)
  - Gtsam (https://collab.cc.gatech.edu/borg/gtsam)
  - iSAM (https://openslam.org/iSAM.html)
  - Toro (https://openslam.org/toro.html)
  - (…)
- Optimizers:
  - Gauss-Newton.
  - Levenberg-Marquardt.

Global Alignment

Factor Graphs – Back End

- The non-linear problem described by the graph:

$$\boldsymbol{x}^* = \underset{\boldsymbol{x}}{\operatorname{argmin}}\, \boldsymbol{F}(\boldsymbol{x})$$

$$\boldsymbol{F}(\boldsymbol{x}) = \sum_{\{i,j\}\in \boldsymbol{Factors}} \boldsymbol{e}(\boldsymbol{x}_i, \boldsymbol{x}_j, \boldsymbol{z}_{ij})^{\boldsymbol{T}} \boldsymbol{\Omega}_{ij}\, \boldsymbol{e}(\boldsymbol{x}_i, \boldsymbol{x}_j, \boldsymbol{z}_{ij})$$

- $\boldsymbol{e}(\boldsymbol{x}_i, \boldsymbol{x}_j, \boldsymbol{z}_{ij})^{\boldsymbol{T}}$ is a vector error function measuring how well the variables' blocks $\boldsymbol{x}_i, \boldsymbol{x}_j$ satisfy the measure $\boldsymbol{z}_{ij}$.
- $\boldsymbol{\Omega}_{ij}$ is the covariance associated to the measure.

- **Note**: a factor only involves some poses (variables).
  - Sparsity allows for faster solvers.

Global Alignment

Factor Graphs

- How to solve the problem (non-linear):
  - Good initial guess.
  - Error functions are supposed to be «smooth» in the neighborhood of the minima (may not be global!).
  - Thus, we can solve the problem by **iterative linearizations**.

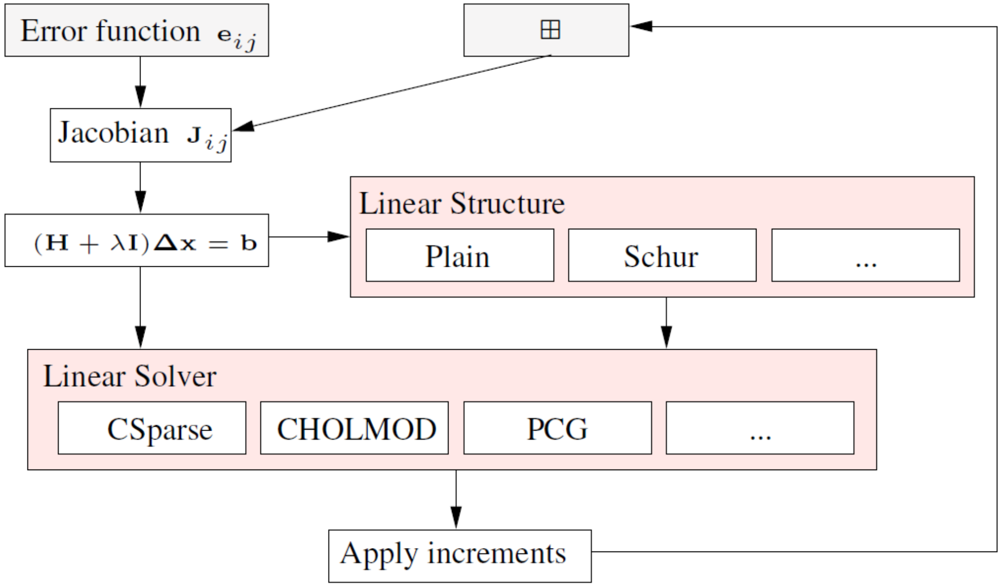
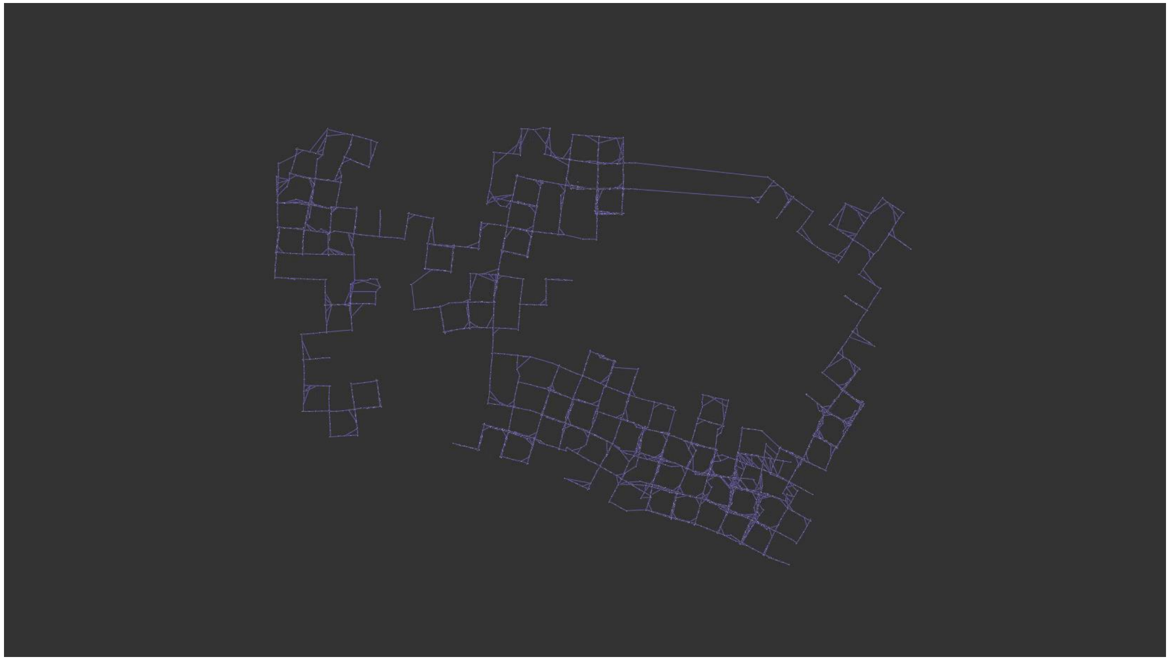


Figure extracted from Kuemmerle et al. "A General Framework for Graph Optimization". IEEE International Conference on Robotics and Automation (ICRA) 2011.

Global Alignment

Factor Graphs – Back End

- Optimizer:
  1. Linearize the error term around the current solution/initial guess.
  2. Compute first derivative of the squared error function, set it to zero and solve it.
  3. Obtain a new state, and iterate from 2.



Global Alignment

Factor Graphs - Photomosaics

- Global Alignment of a Photomosaic.

- Which are our *mesurements*?
  - Pairwise 2D Motion (Homographies).
  - Navigation priors (Nav. Poses).

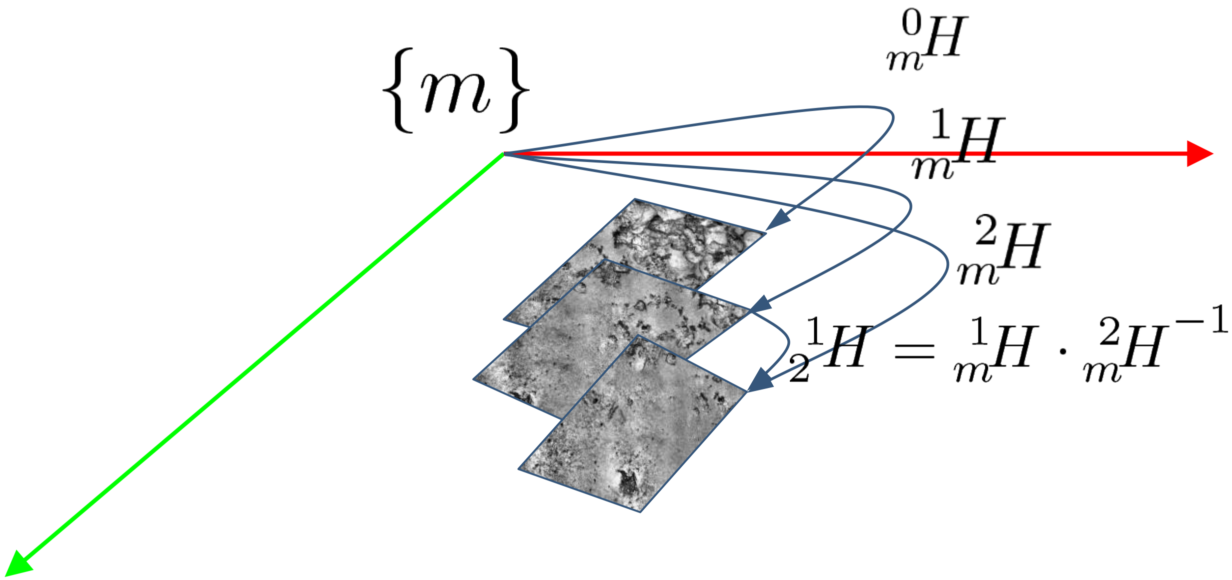
- Nodes: Pose of the camera/vehicle (6 DOF).

- Factors/Constraints?

Global Alignment

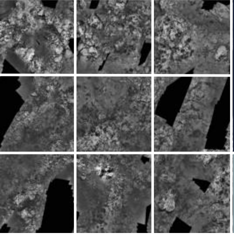
Optical constraint: matching error

- We optimize poses, from which we can derive absolute homographies.
- From the absolute ones, we compute the relatives:



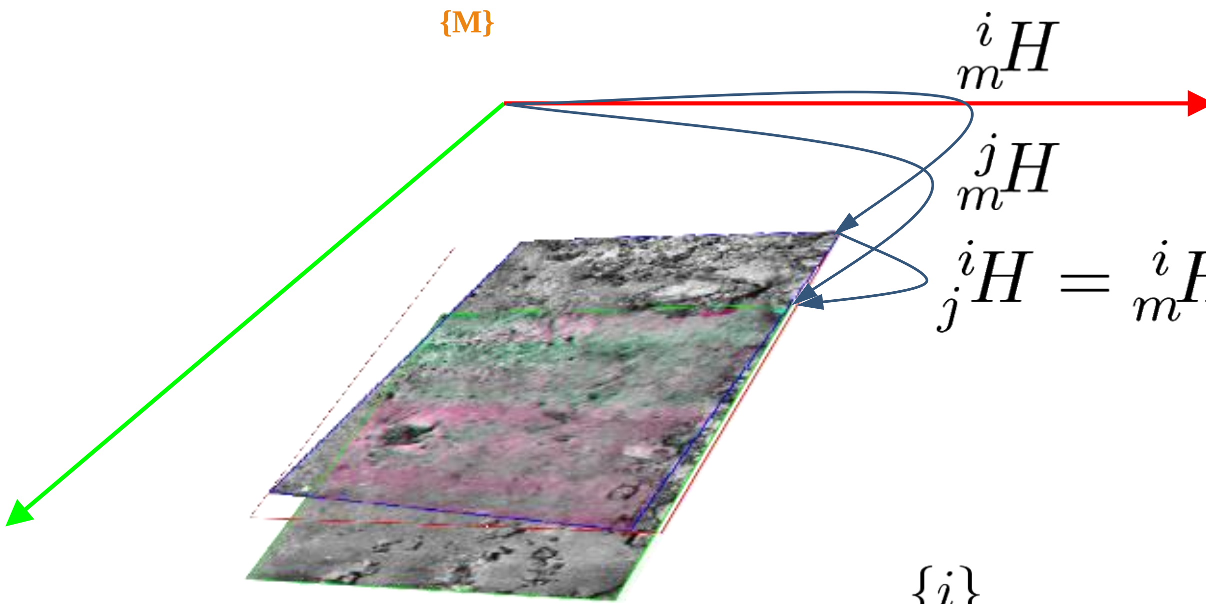
$$ {}^{1}_{2}H = {}^{1}_{m}H \cdot {}^{2}_{m}H^{-1} = {}^{1}_{m}H \cdot {}^{m}_{2}H $$

- And use them to compute the error with respect to the matches.



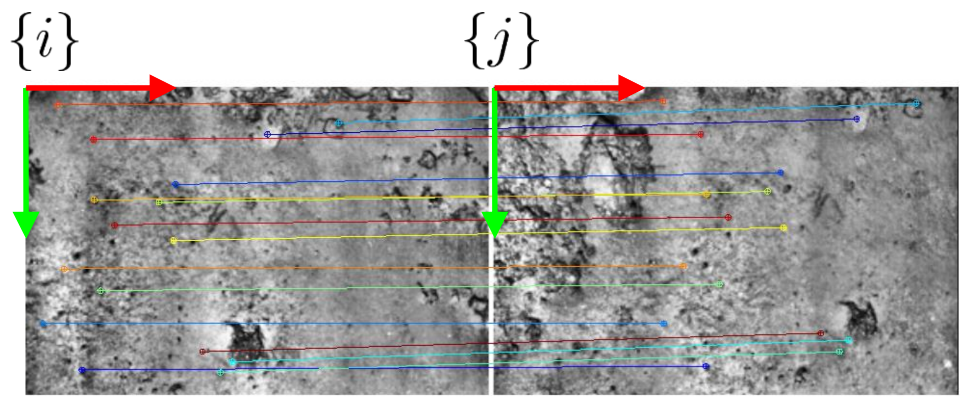
Global Alignment

Optical constraint: matching error



$$ {}^{i}_{j}H = {}^{i}_{m}H \cdot {}^{j}_{m}H^{-1} = {}^{i}_{m}H \cdot {}^{m}_{j}H $$

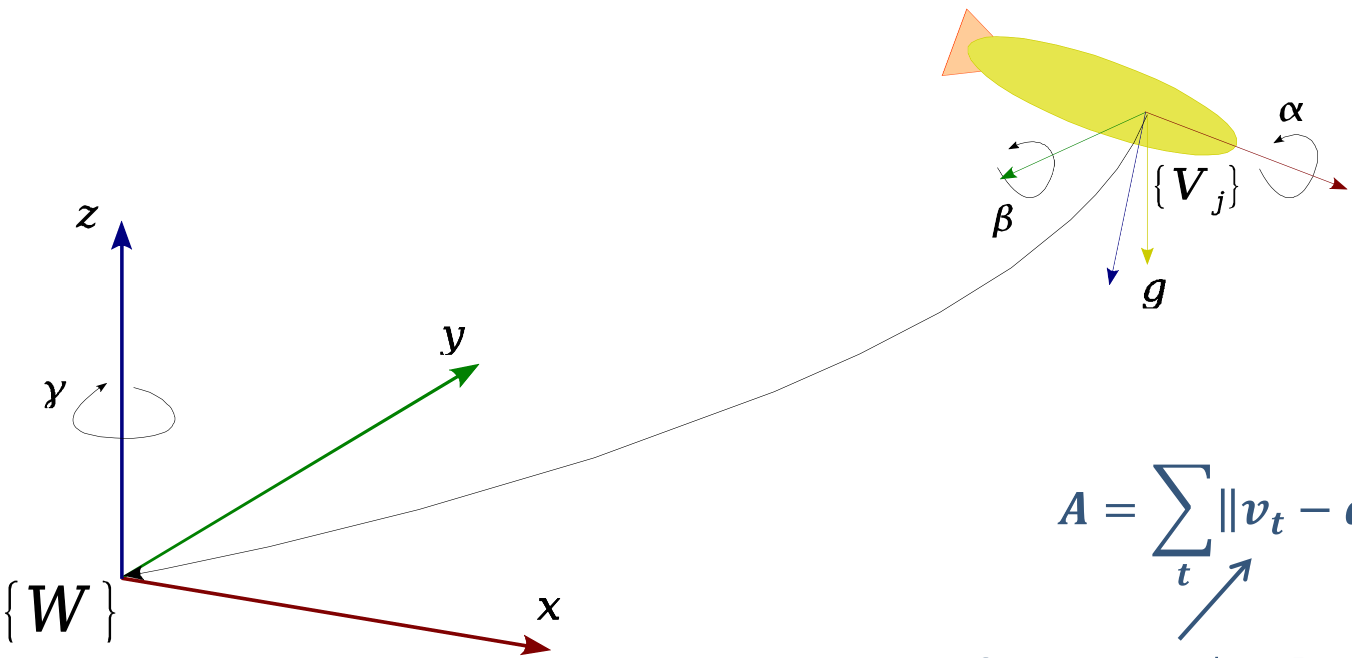
$$ \begin{aligned} {}^{i}e_k &= {}^{i}p_k - {}^{i}_{j}H \cdot {}^{j}p_k \\ {}^{j}e_k &= {}^{j}p_k - {}^{j}_{i}H \cdot {}^{i}p_k . \end{aligned} $$



How far a 2D point in an image falls from its match through the homography computed from the poses.

Global Alignment

Navigation Constraint: Absolute Pose Priors



$$A = \sum_t \|v_t - a_t\|_{\Sigma_{a_t}}$$

Current pose node on the graph

Pose measurement

- Absolute Pose Priors: Impose the navigation of the robot.
- Provides georeferencing of the mosaic!

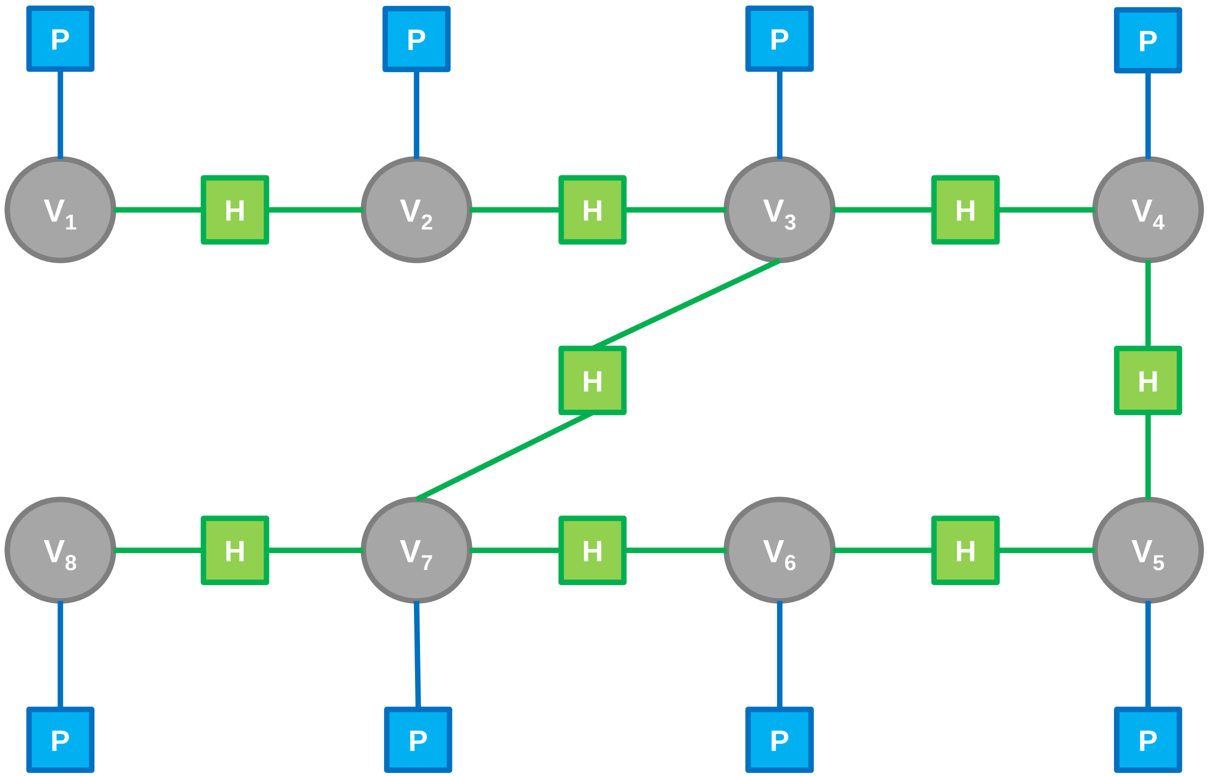
Global Alignment

Pose Graph Example

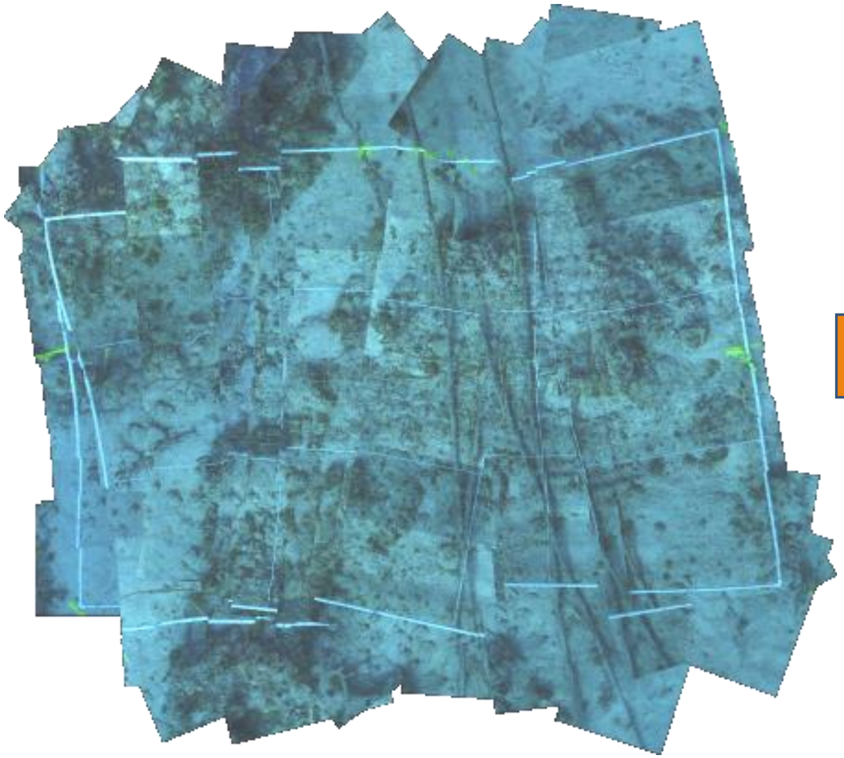
Absolute constraints P

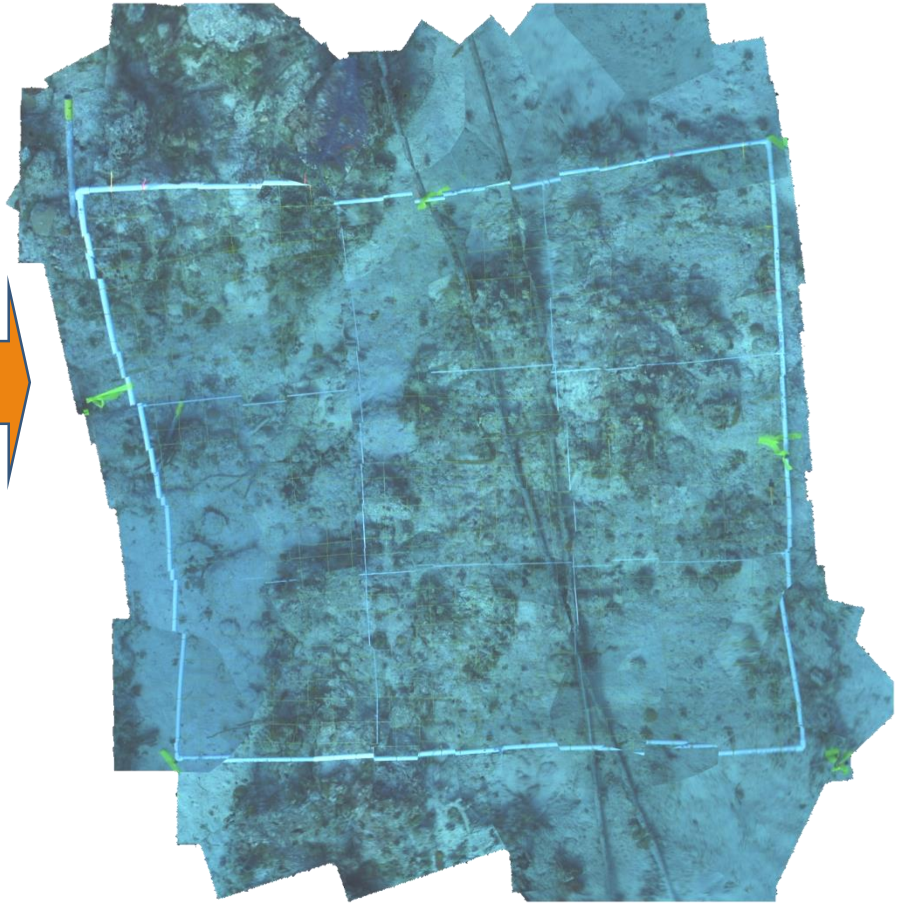
Homography constraints H

Camera poses V_1



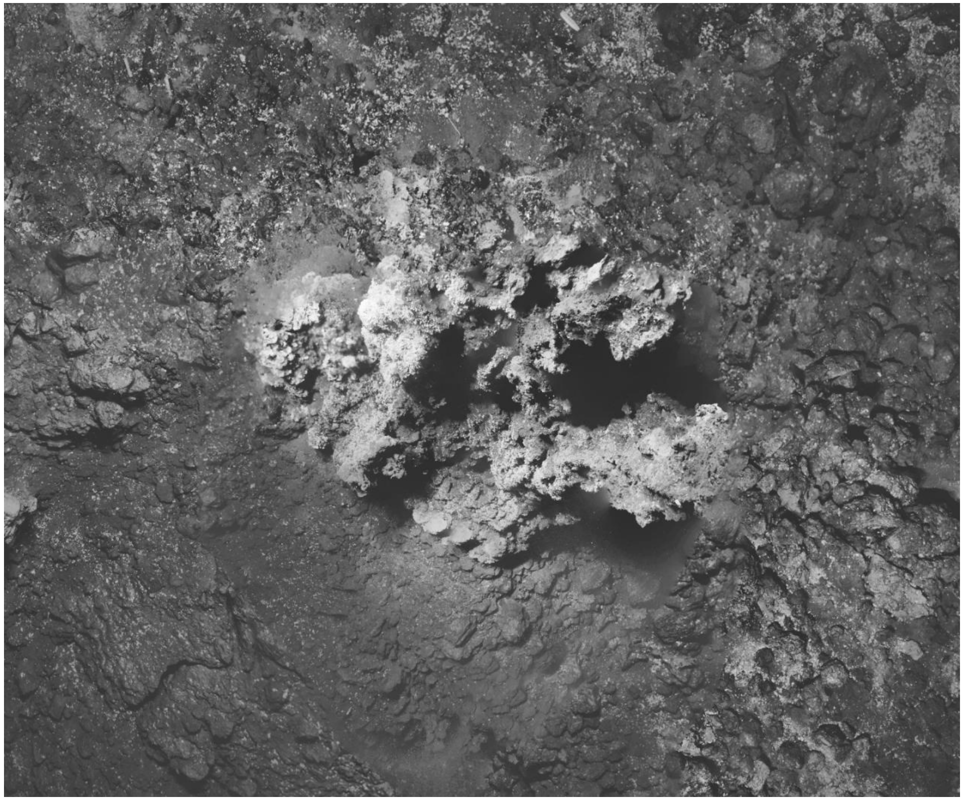
Examples





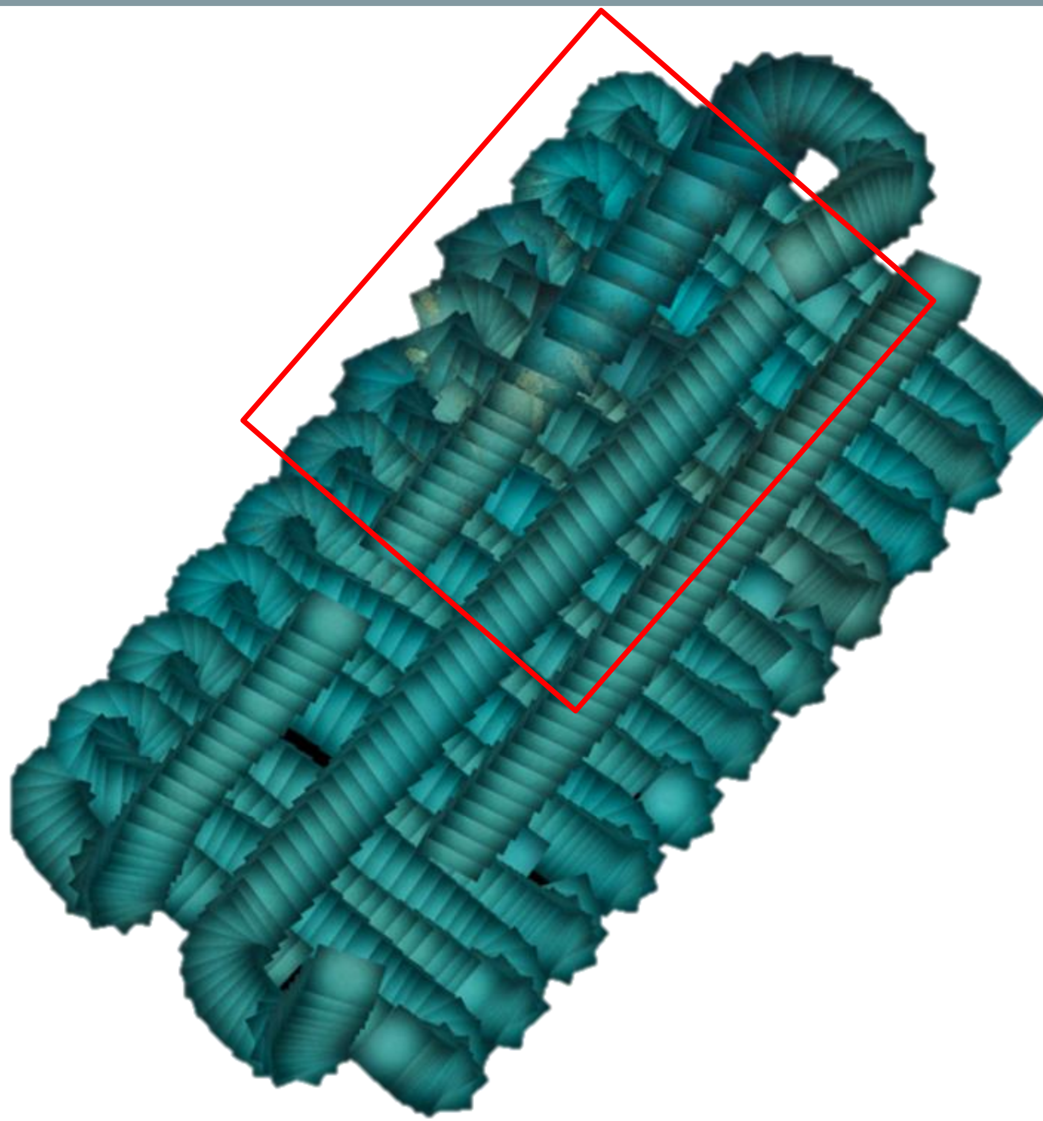
Examples

Large-scale Mosaicing



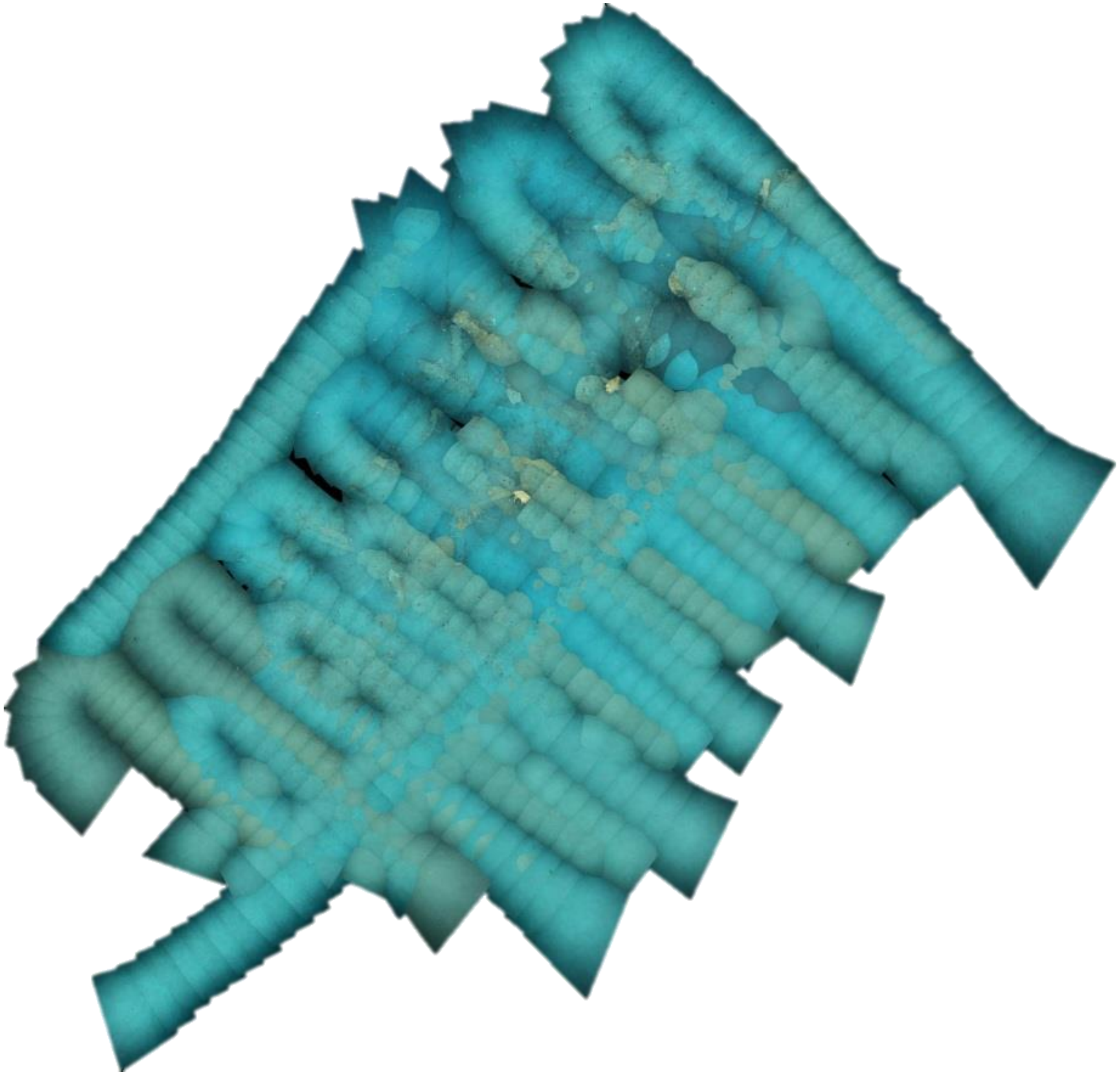
Examples

La Lune: Mosaic From Navigation (Initialization)



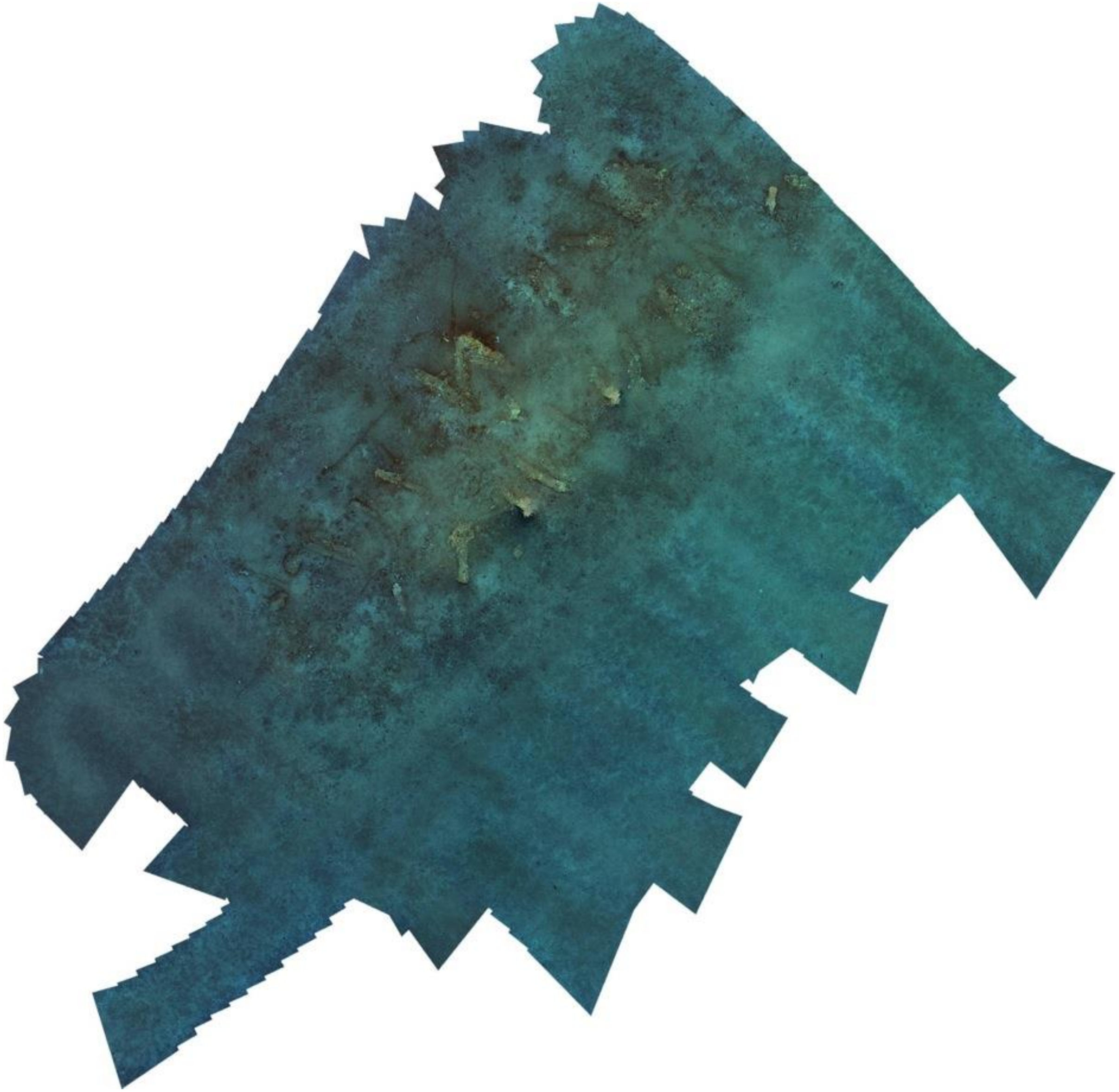
Examples

La Lune: Mosaic From Correspondences



Examples

La Lune: Mosaic From Correspondences (Blended)

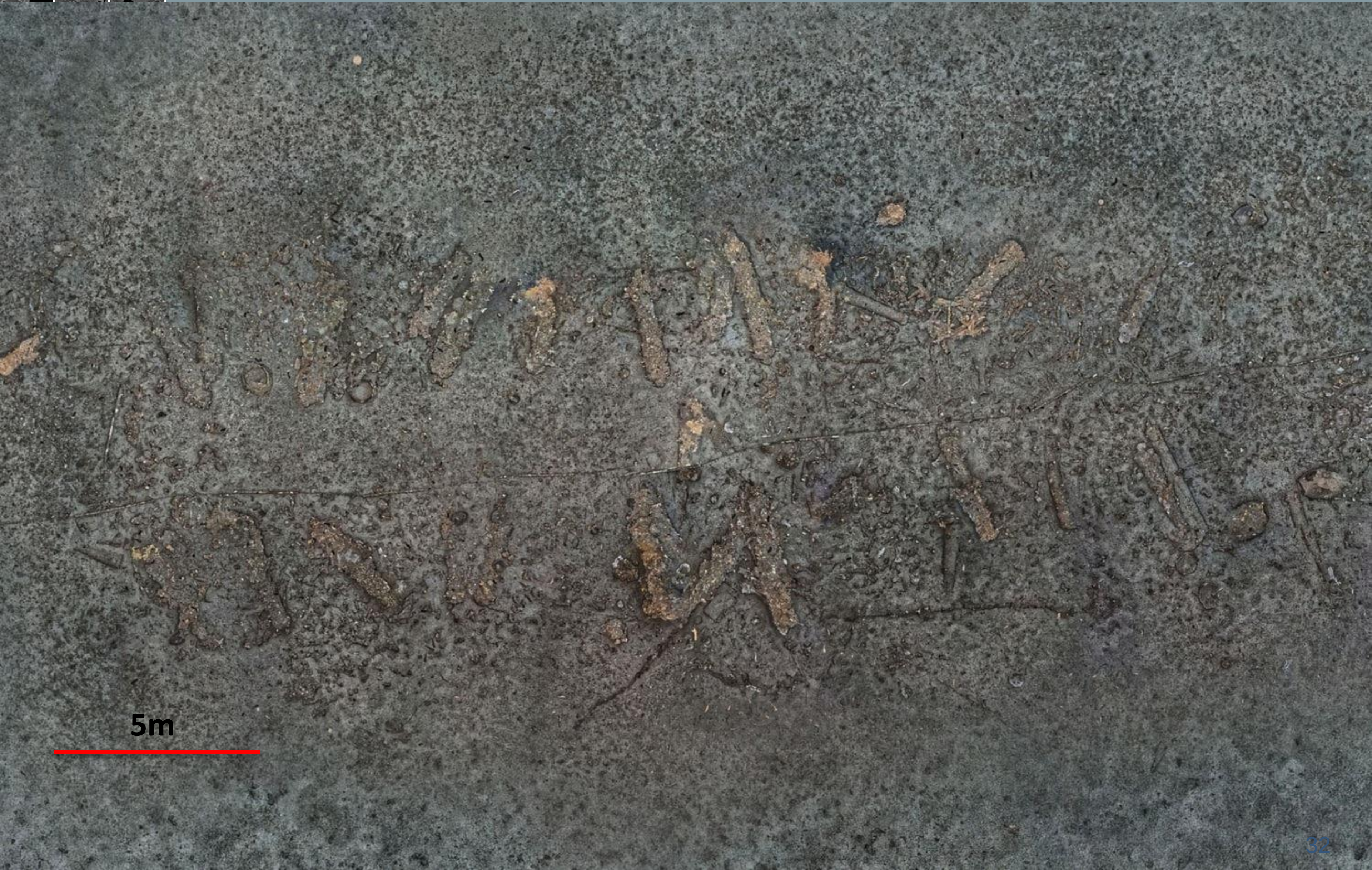


Examples

La Lune: Mosaic From Correspondences (Dehazed)

Examples

La Lune: Mosaic From Correspondences (Dehazed)



Conclusions

- Photomosaics:
  - Larger perspective of an area by composing individual images.
- We need to infer the topology of the mosaic:
  - Trajectory (navigation).
  - Links among images (sequential/non-sequential matches).
- The different measures taken are merged through global alignment (pose graphs):
  - Homographies.
  - Navigation priors.
  - Landmarks.
  - Etc.

Hands-on Mosaicing Tutorial

- Tutorial doc:
  - http://coronis.udg.edu/winter_school/hands-on_learning_building_a_photomosaic.pdf
- Code:
  - http://coronis.udg.edu/winter_school/strongmar_winter_school__mosaicing_code.zip
- Datasets:
  - http://coronis.udg.edu/winter_school/strongmar_winter_school__mosaicing_examples.zip