Seminar: The Evolution of Motion Estimation and Real-time 3D Reconstruction

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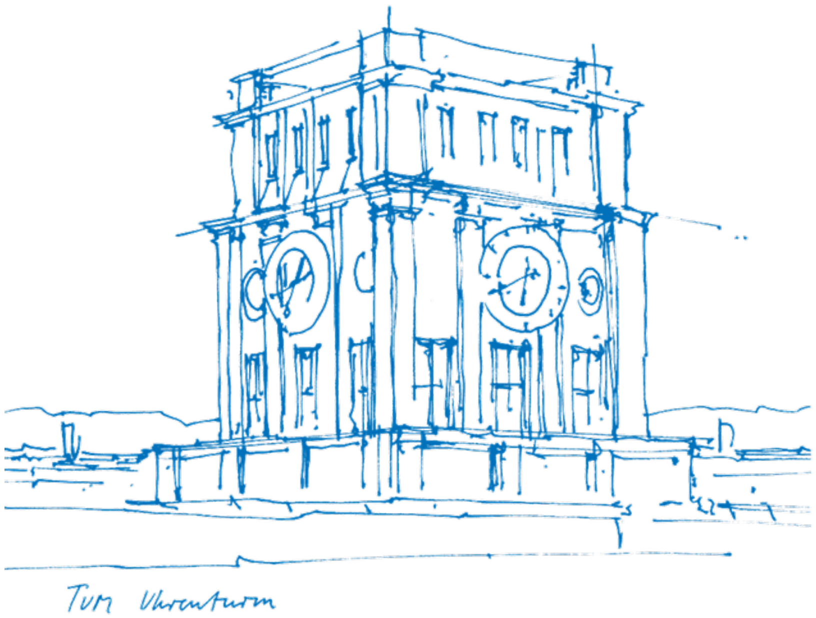
Computer Vision Group

Technical University of Munich



How can I access these slides?

- `https://vision.in.tum.de/teaching/ws2022/seminar_realtime3d`
- Material page will go online after this pre-meeting

Outline

- General Information
  - About the Seminar
  - Registration
- Possible Papers
  - Bundle Adjustment
  - Monocular Cameras
- Questions

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How is the seminar organized?

- Seminar meetings: Talks and discussion
  - Day: Tuesday, approximately every second week (TBA)
  - Time: 14:00–16:00 (seminar) & 16:00–18:00 (supervisor meetings)
  - Location: hybrid (room TBA)
  - In case of special circumstances please let us know and we will find a solution
  - Each session will consist of two talks which are held in English
  - **Attendance is mandatory!**
- Talk preparation / contact with supervisor
  - One month before talk: meet supervisor for questions (optional, but recommended)
  - Two weeks before talk: meet supervisor to go through slides (optional, but recommended)
  - One week before talk: send slides to your supervisor (mandatory)
  - Two weeks after talk: submit your report via email (mandatory)

What about the presentation?

- General set-up:
  - Duration: 20–25 minutes talk + 10–15 minutes discussion
  - Make sure to finish on time - not too early and not too late!
  - Rule of thumb: 1–2 minutes per slide $\rightarrow$ 10–20 slides
  - Do not put too much information on the slides!
- Recommended structure (talk):
  - Introduction
  - Overview / Outline
  - Method description
  - Experiments and results
  - Personal comments
  - Summary

What about the discussion after each talk?

- Discussion afterwards **will** influence your grade
- Ask questions!
- There are **no** stupid questions!

What about the final report?

- General set-up:
  - Use LaTeX template provided on web page
  - Length: 3-4 pages
  - Submission deadline: **Two weeks after talk**
- Recommended structure (main text only):
  - Introduction
  - Method description
  - Experiments and results
  - Discussion of results
  - Summary

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How do you register for the seminar?

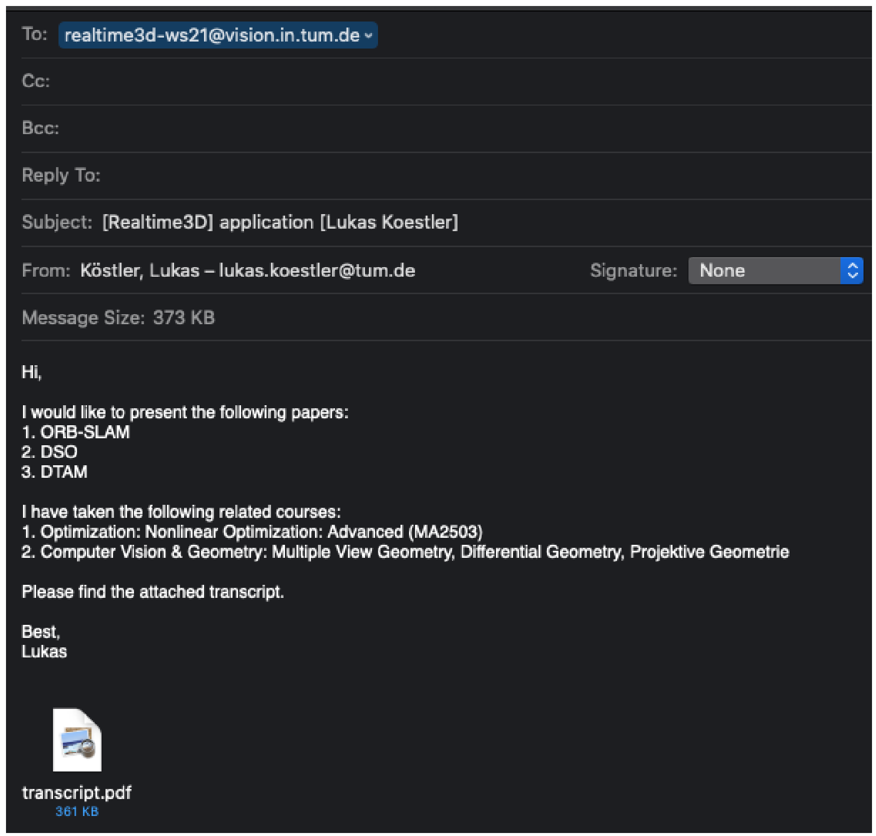
- Step 1: Official registration via TUM matching system
  - Go to `https://matching.in.tum.de`
  - Register for: *The Evolution of Motion Estimation and Real-time 3D Reconstruction*
- Step 2: Personal registration via email
  - In the list of papers on the web page, select your three favorites
  - Write an email ranking these three favorites to the seminar email address
  - Email subject: "[Realtime3D] application [your name]"
  - List how you fulfill the lecture requirements: See next slide
  - Attach your transcript(s)
  - Registrations without email / emails with missing information will be ignored!
- Deadline for both registrations: around July 21, 2022

Required Lectures for the Seminar

- To understand the content of the seminar well, we recommend students to have completed
  - A lecture on optimization, similar to Nonlinear Optimization: Advanced (MA3503)
  - A lecture on computer vision that includes geometry, similar to Computer Vision II: Multiple View Geometry (IN2228)
- You can name **up to three** lecture from your transcript that, in combination, fulfill the requirements for subdomain. Example:
  - CV & Geometry: Computer Vision I (computer vision), Projektive Geometrie 1 (for geometry)
- Please list the lectures and brief explanations in your e-mail and attach your transcript(s) as proof. **We will not scan your transcript(s) for suitable lectures!**
- If you don't perfectly fulfill the lecture requirements you might still be able to join – this will depend on the other applicants! Thus: **Consider applying anyways if you really want to take the seminar!**

How do you register for the seminar?

Example registration email:


To: realtime3d-ws21@vision.in.tum.de

Cc:

Bcc:

Reply To:

Subject: [Realtime3D] application [Lukas Koestler]

From: Köstler, Lukas – lukas.koestler@tum.de Signature: None

Message Size: 373 KB

Hi,

I would like to present the following papers:
1. ORB-SLAM
2. DSO
3. DTAM

I have taken the following related courses:
1. Optimization: Nonlinear Optimization: Advanced (MA2503)
2. Computer Vision & Geometry: Multiple View Geometry, Differential Geometry, Projektive Geometrie

Please find the attached transcript.

Best,
Lukas

transcript.pdf
361 KB

How do we select candidates and assign papers?

- Candidate selection
  - Only students registered in the matching system **AND** emails containing all required information will be considered
  - Among students meeting all criteria, selection will be random. Other students will be ranked according to the requirement fulfillment.
  - You will get notified by the matching system about the decision
- Paper assignment
  - Papers are assigned after the participant list is finalized
  - We give our best to accommodate your preference list in the assignment

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Bundle Adjustment in the Large

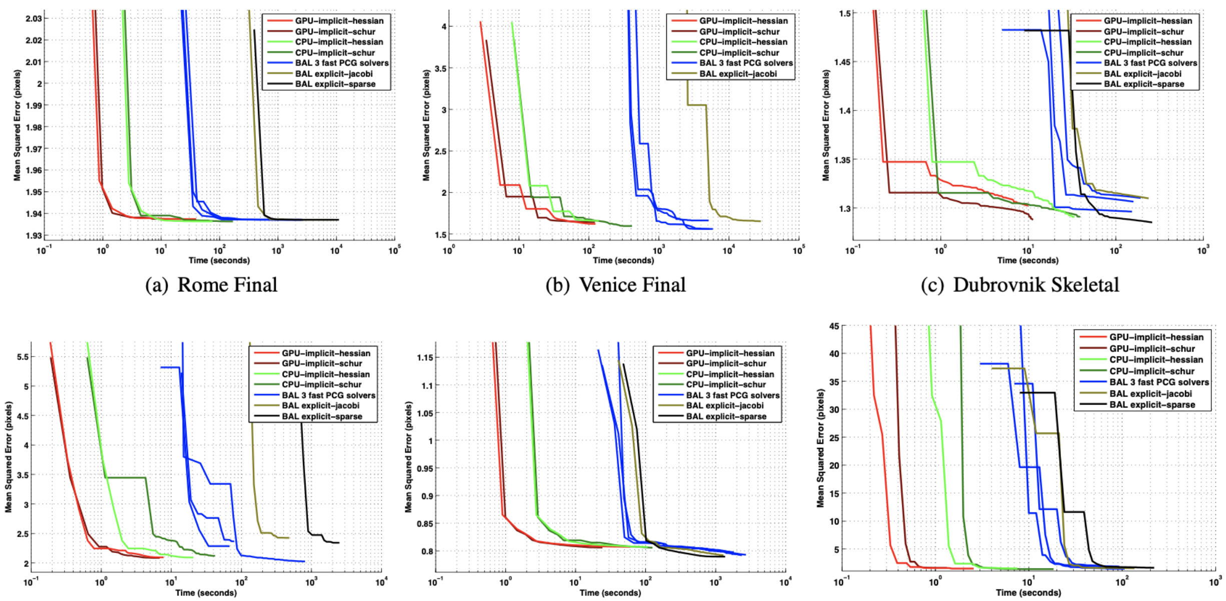
Agarwal, Snavely, Seitz, Szeliski 2010

(a) Structured - 6375 photos (b) Unstructured - 4585 photos

- Proposes to solve bundle adjustment problems with an inexact Newton method linked to a preconditioner rather than by a direct factorization
- Crucial for large-scale 3D scene reconstruction

Multicore Bundle Adjustment

Wu, Agarwal, Curless, Seitz 2011



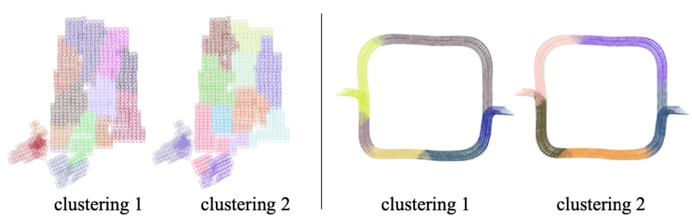
(a) Rome Final (b) Venice Final (c) Dubrovnik Skeletal

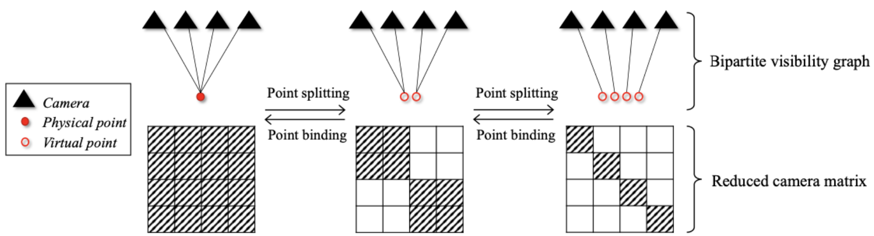
(d) Trafalgar Final (e) Venice Skeletal (f) Ladybug

- Presents multicore solutions to large-scale 3D scene reconstruction problems
- Based on a restructuration of the conjugate gradients solver into easily parallelizable operations

Stochastic Bundle Adjustment for Efficient and Scalable 3D Reconstruction

Zhou et al. 2020

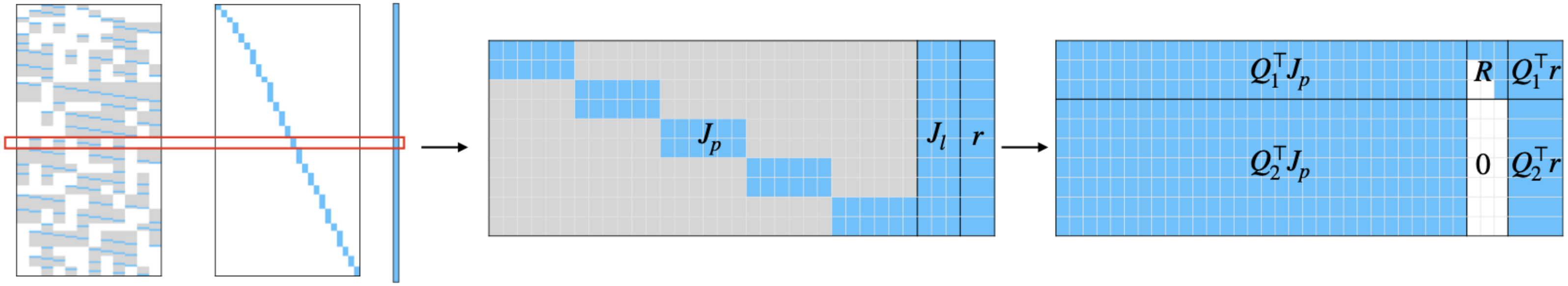




- Integrates a clustering scheme into solving bundle adjustment
- Drastically reduces the per-iteration cost and allows distributed computing by decomposing the reduced camera matrix into subproblems

Square Root Bundle Adjustment for Large-Scale Reconstruction

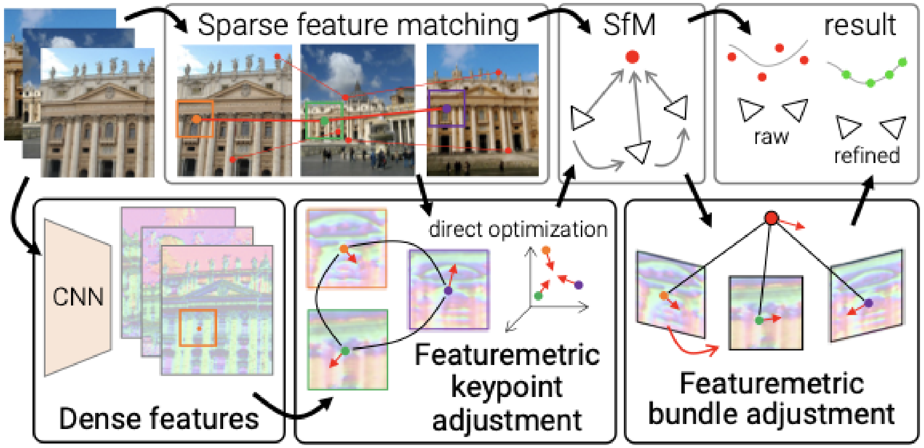
Demmel, Sommer, Cremers, Usenko 2021



- Challenges the traditional Schur Complement trick
- Combines a very general theoretical derivation of nullspace marginalization with the specific structure of bundle adjustment problems

Pixel-Perfect Structure-from-Motion with Featuremetric Refinement

Lindenberger, Sarlin, Larsson, Pollefeys 2021



- Refinements of keypoint and bundle adjustments by using a featuremetric error based on dense features predicted by a neural network
- Significantly improves the accuracy of camera poses and scene geometry

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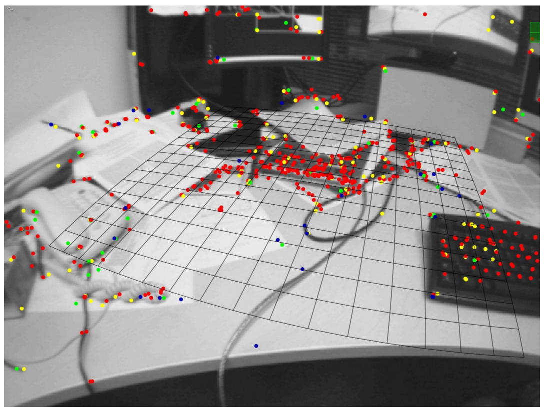
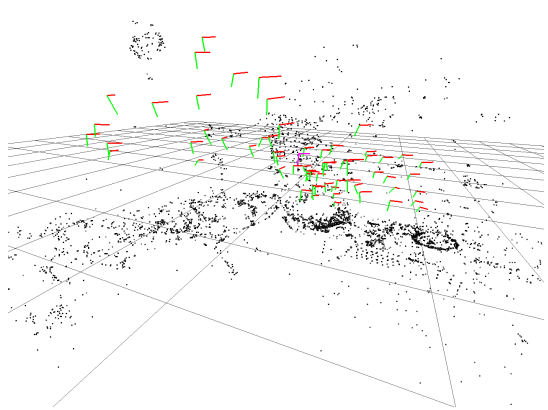
PTAM: Parallel Tracking and Mapping

Klein, Murray 2007

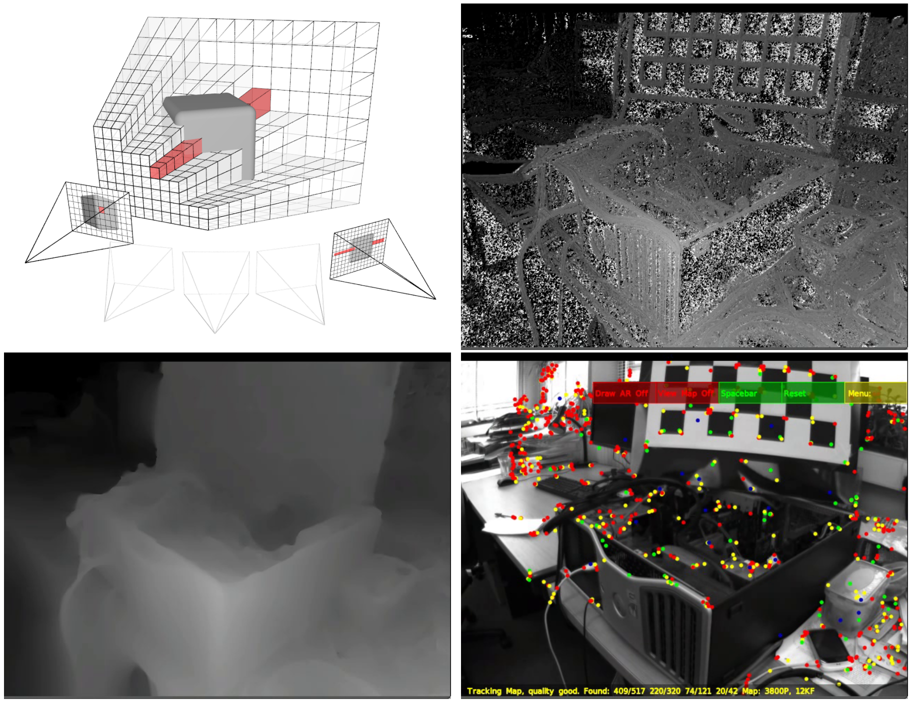




- One of the first systems capable of estimating both pose and geometry in real-time for handheld cameras
- Simple AR applications

DTAM: Dense Tracking and Mapping in Real-Time

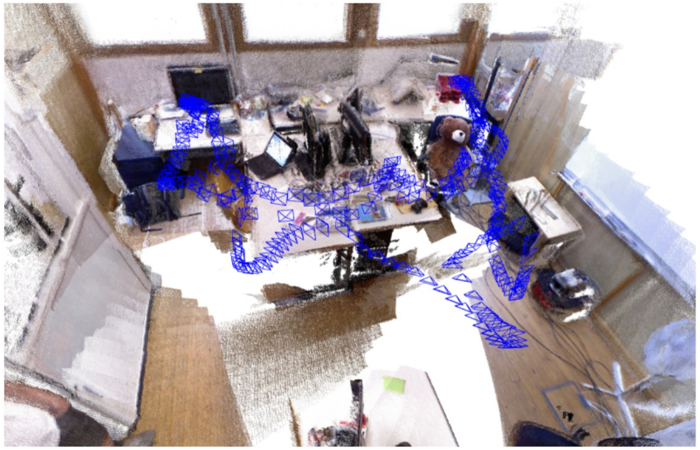
Newcombe, Lovegrove, Davison 2011



- One of the first monocular systems to create dense 3D models

ORB-SLAM: a Versatile and Accurate Monocular SLAM System

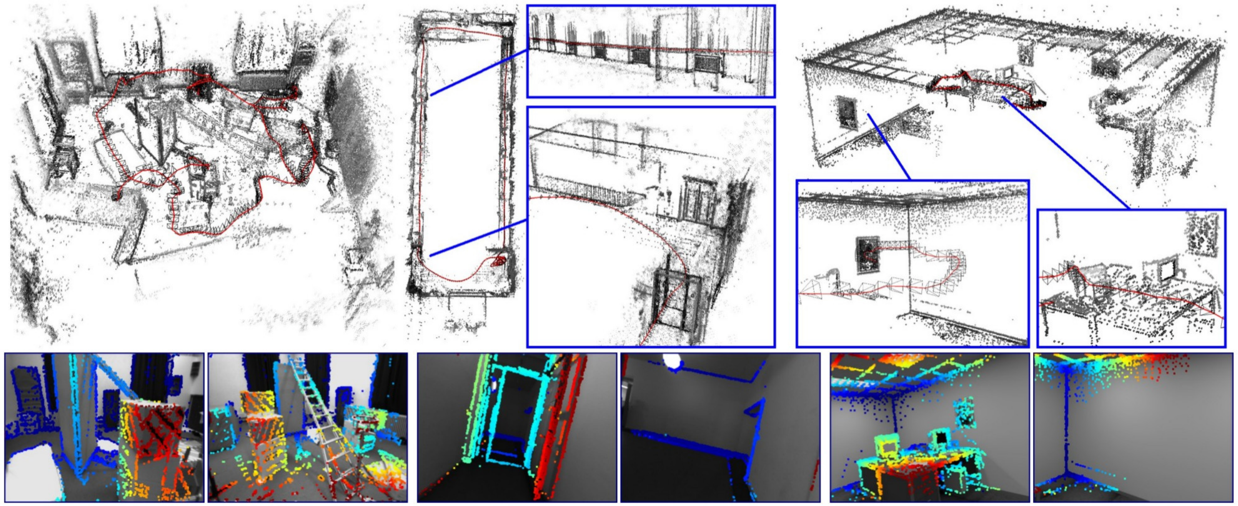
Mur-Artal, Montiel, Tardós 2015



- Use all depth and color data to obtain consistent mapping

Direct Sparse Odometry

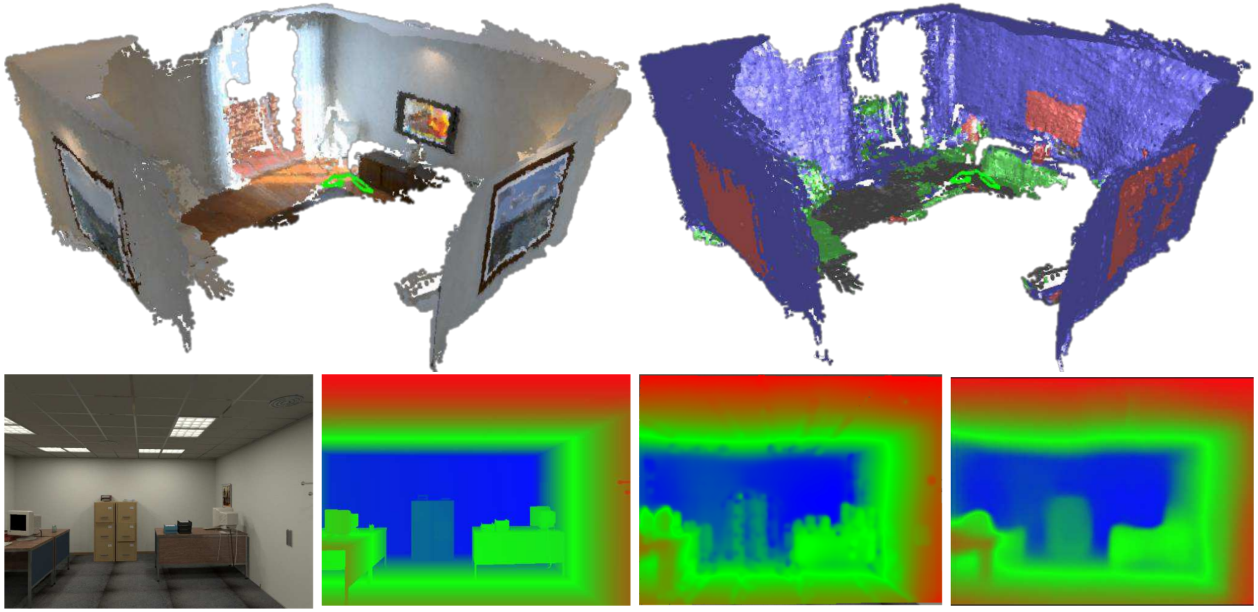
Engel, Koltun, Cremers 2016



- Large-scale odometry
- Does not rely on keypoint detections

CNN-SLAM

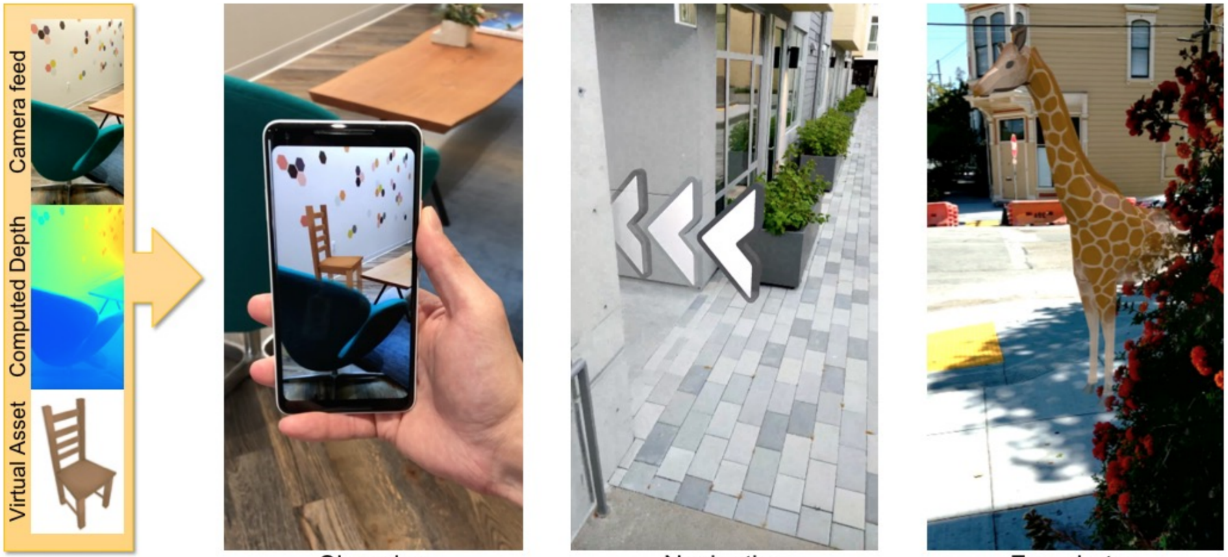
Tateno et al. 2017



- Dense monocular SLAM
- Use depth map predicted from CNN

Depth from Motion for Smartphone AR

Valentin et al. 2018

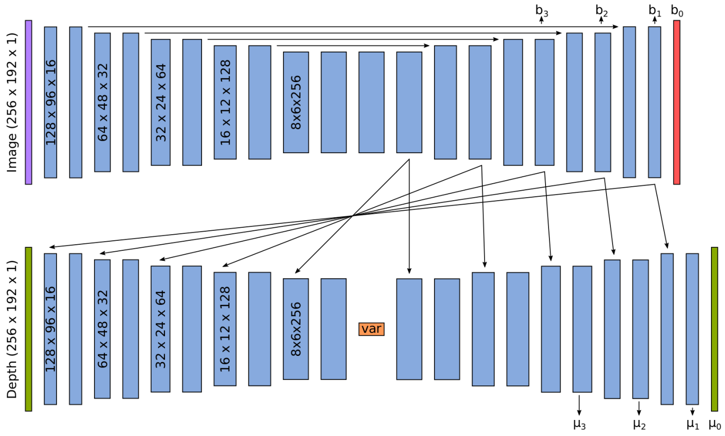


Shopping Navigation Fun photos

- Uses poses predicted by Visual-Inertial Odometry in a Multi-View-Stereo pipeline to predict depth
- More engineering focused work that shows impressive results on CPU

CodeSLAM

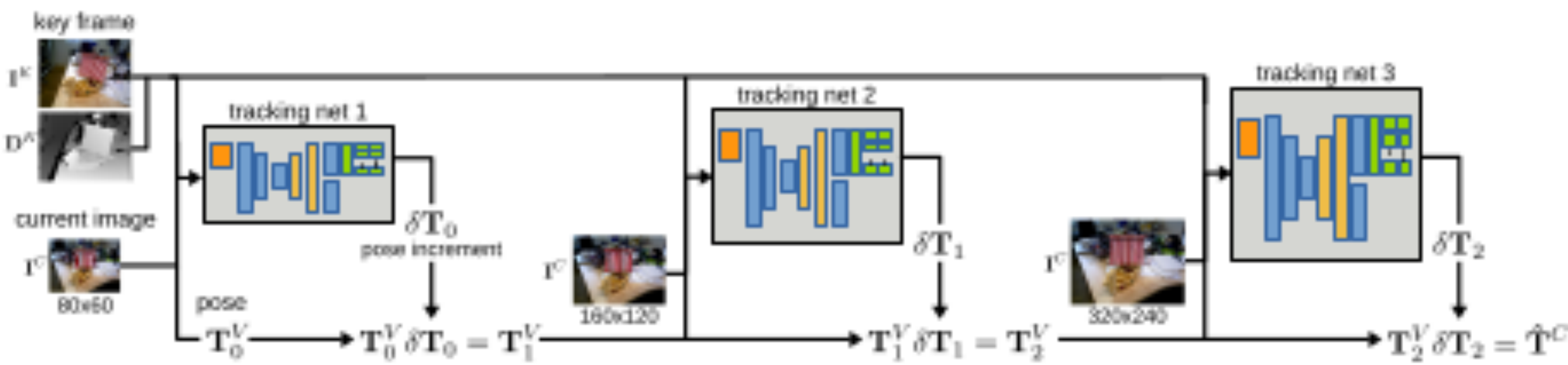
Michael Bloesch et al. 2018



- Learning a compact, optimisable representation of the scene geometry

DeepTAM: Deep Tracking and Mapping

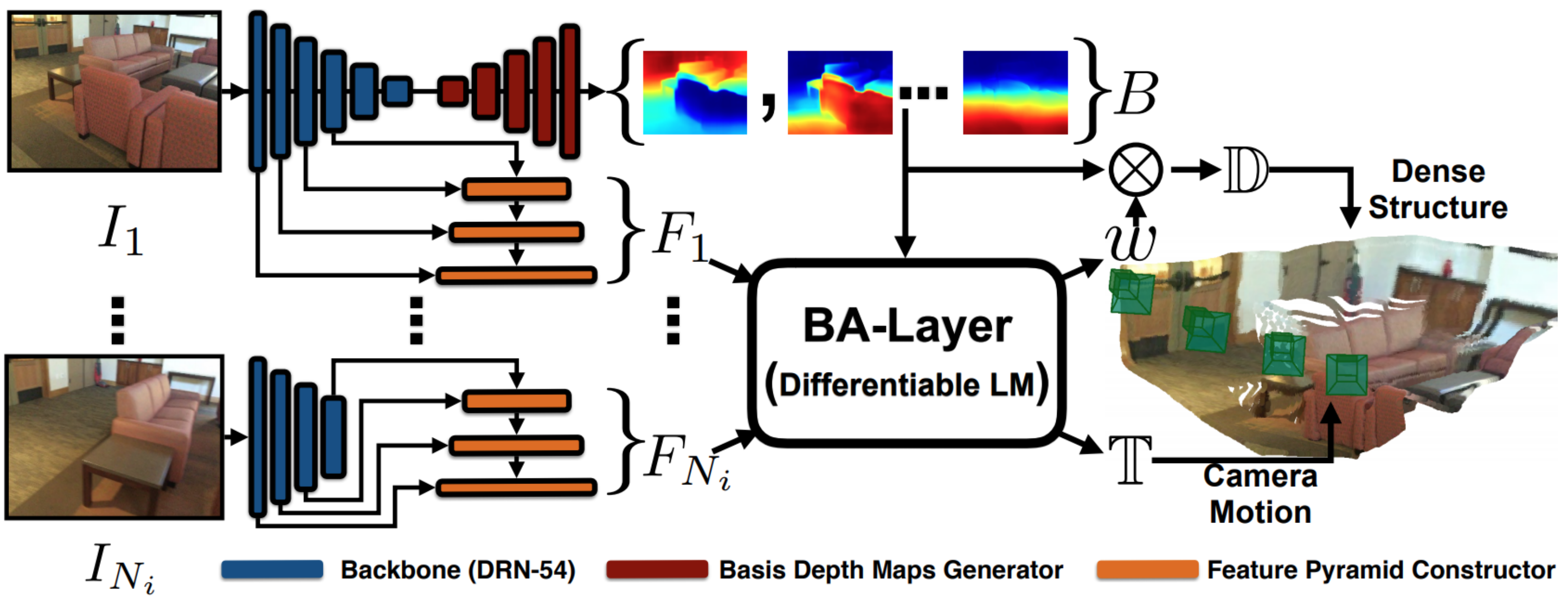
Zhou, Ummenhofer, Brox 2018



- Learn a network to predict the pose and generate depth images

BA-Net: Dense Bundle Adjustment Networks

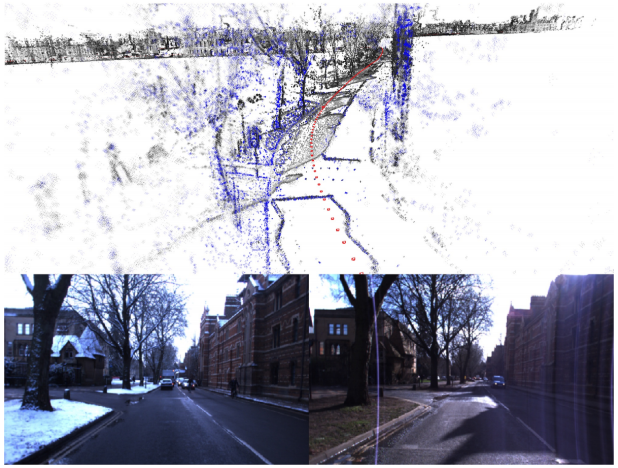
Tang, Tan 2019



- Use feature-metric Bundle Adjustment within a differentiable deep-learning pipeline
- Allows the end-to-end training of NNs for SLAM

GN-Net: The Gauss-Newton Loss for Multi-Weather Relocalization

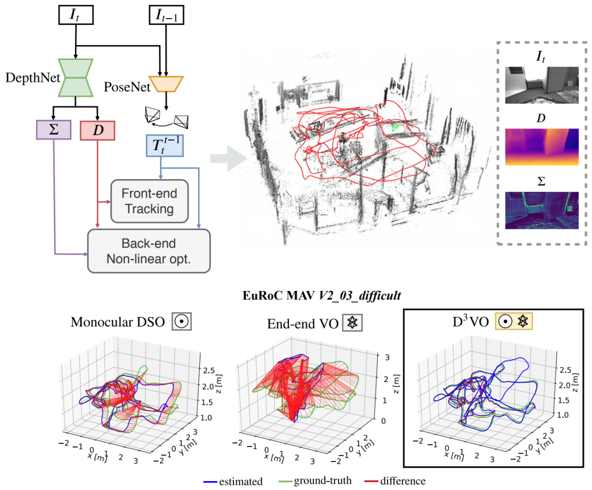
von Stumberg, Wenzel, Khan, Cremers 2020



- Use feature-metric Bundle Adjustment for multi-weather relocalization
- Propose the Gauss-Newton loss to train NNs which generate feature maps that are suitable for direct image alignment

D3VO: Deep Depth, Deep Pose and Deep Uncertainty for Monocular Visual Odometry

Yang, von Stumberg, Wang, Cremers 2020



- Monocular visual odometry framework that uses deep-learning on three levels: deep depth, pose and uncertainty estimation
- Shows impressive performance improvements in comparison to traditional methods (DSO, ORB)

DROID-SLAM: Deep Visual SLAM for Monocular, Stereo, and RGB-D Cameras

Teed and Deng 2021

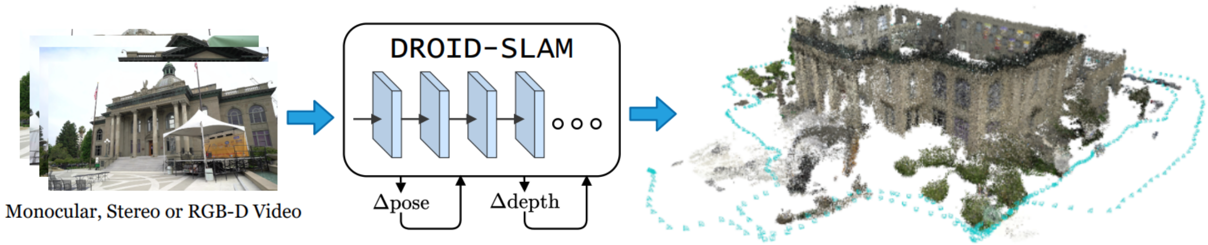
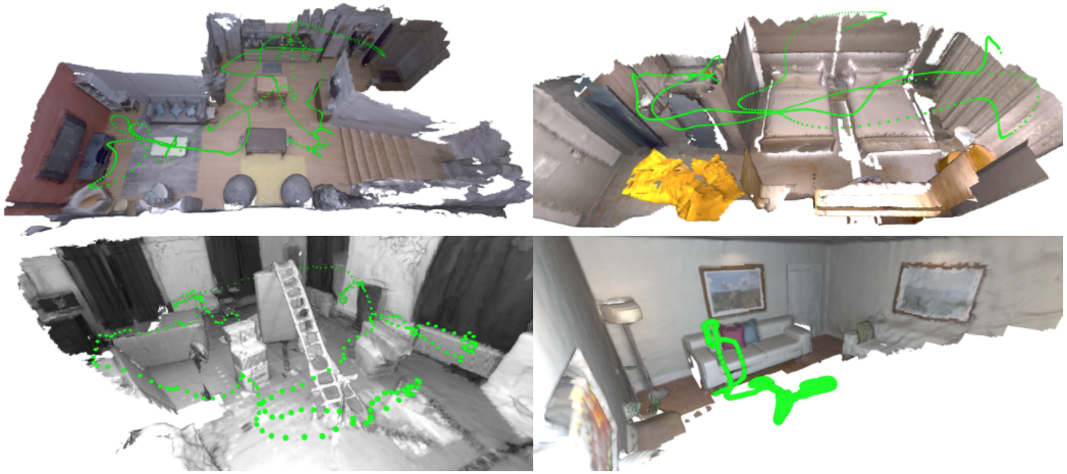


Figure 1: DROID-SLAM can operate on monocular, stereo, and RGB-D video. It builds a dense 3D map of the environment while simultaneously localizing the camera within the map.

- Monocular, Stereo, and RGB-D visual SLAM based on optical flow estimation (RAFT by Teed and Deng, 2020 ECCV best paper) and bundle adjustment
- Shows impressive robustness and accuracy across a wide range of datasets while trained only on the TartanAir dataset

TANDEM: Tracking and Dense Mapping in Real-time using Deep Multi-view Stereo

Koestler, Yang, Zeller, Cremers 2021



- Combines photometric tracking and deep multi-view stereo depth estimation into a monocular dense SLAM algorithm. Using depth maps rendered from the incrementally-built TSDF model improves tracking robustness.

Questions?

Reminder:

- Web page: `https://vision.in.tum.de/teaching/ws2022/seminar_realtime3d`
- Contact: `realtime3d-ws22@vision.in.tum.de`