JUNE 18-22, 2023
CVPR VANCOUVER, CANADA

Tutorial: Automatic 3D modeling of indoor structures from panoramic imagery

Giovanni Pintore[1], Marco Agus[2] and Enrico Gobbetti[1]

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SESSION1: OPENING

Speaker: Enrico Gobbetti

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Automatic 3D modeling of indoor structures from panoramic imagery

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Organizers and lecturers

Giovanni Pintore
CRS4, Italy

Marco Agus
HBKU, Qatar

Enrico Gobbetti
CRS4, Italy

Schedule

- Before the break:
  - **Opening**
  - **Indoor capture and modeling basics** Definition and Application; Tasks and model; Data Capture; Artifacts; Reconstruction priors; Open Research Data;
  - **Room modeling**
    - Bounding surfaces, exploiting priors, deep learning solutions
- After the break:
  - **Integrated indoor model computation**
    - Multi-rooms; Ensuring consistency; Finding and modeling connections
  - **Visual representation generation and exploration**
    - Beyond geometric reconstruction; Appearance; panoramic exploration
  - **Wrap-up, conclusions, Q&A**

Supporting material

- **Course web site**:
  - http://vic.crs4.it/vic/cvpr2023-tutorial-pano/
  - Updated in coming weeks with slides and bibliography

- **STAR + Tutorial notes on indoors**
  - G. Pintore, C. Mura, F. Ganovelli, L. Fuentes-Perez, R. Pajarola, and E. Gobbetti. **State-of-the-art in Automatic 3D Reconstruction of Structured Indoor Environments**. Computer Graphics Forum, 39(2): 667-699, 2020. DOI: 10.1111/cgf.14021
  - G. Pintore, C. Mura, F. Ganovelli, L. Fuentes-Perez, R. Pajarola, and E. Gobbetti. **Automatic 3D Reconstruction of Structured Indoor Environments**. In SIGGRAPH 2020 Courses. Pages 10:1-10:218, August 2020. DOI: 10.1145/3388769.3407469

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SESSION2: INTRODUCTION

Speaker: Enrico Gobbetti

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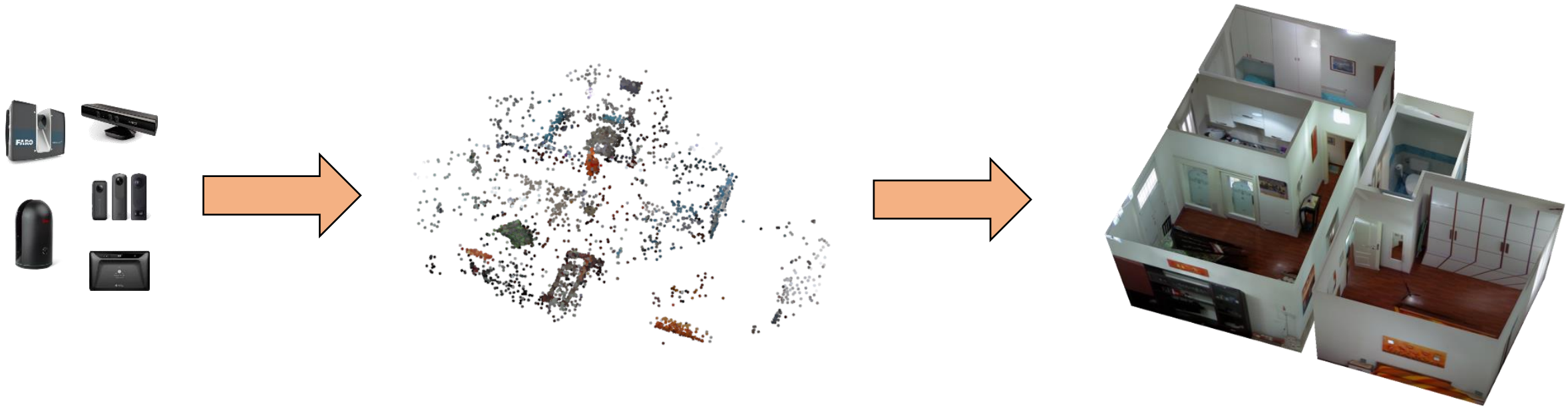
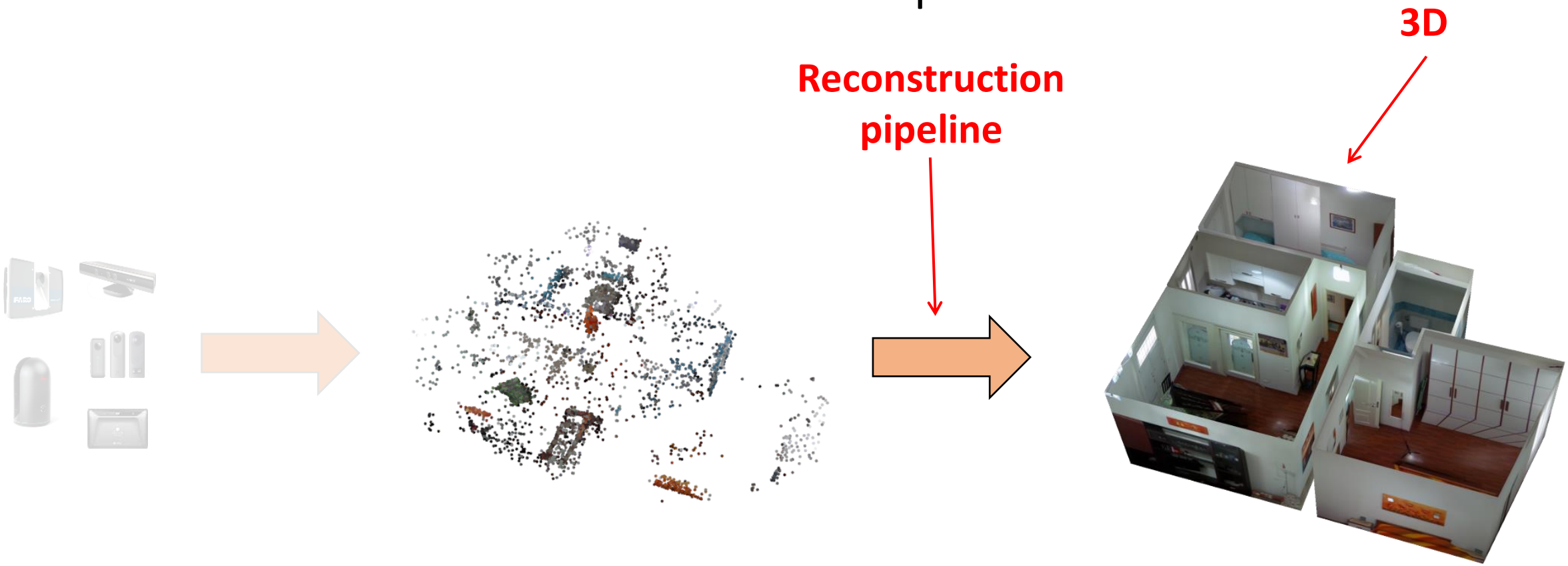
Automatic 3D reconstruction of structured indoor environments from acquired data

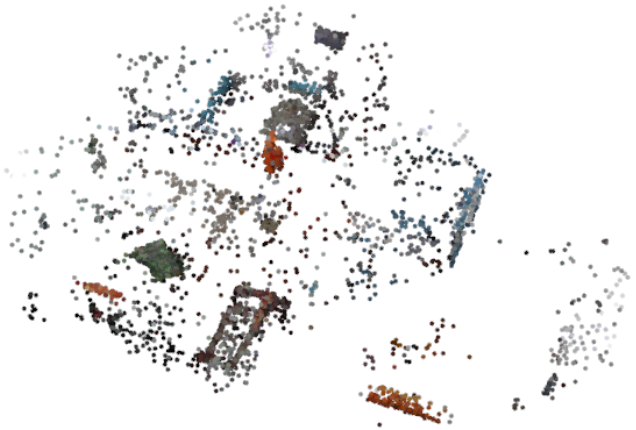


Automatic 3D reconstruction of structured indoor environments from acquired data

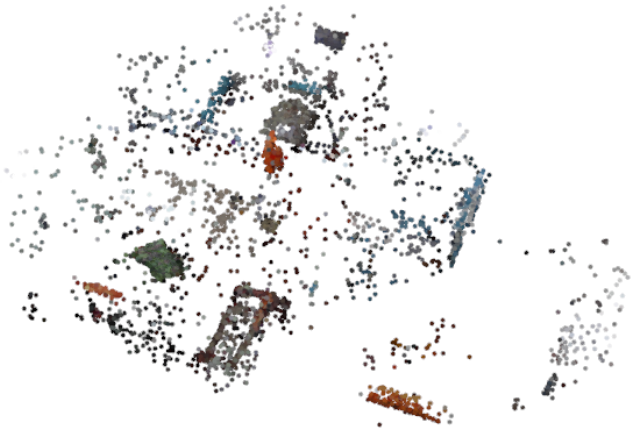


Automatic 3D reconstruction of structured indoor environments from acquired data

Automatic pipelines

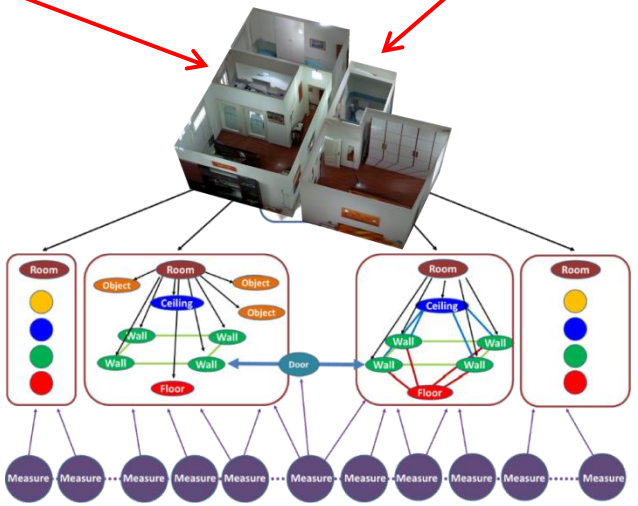


Automatic 3D reconstruction of structured indoor environments from acquired data



Topology
Structure
(Semantics)

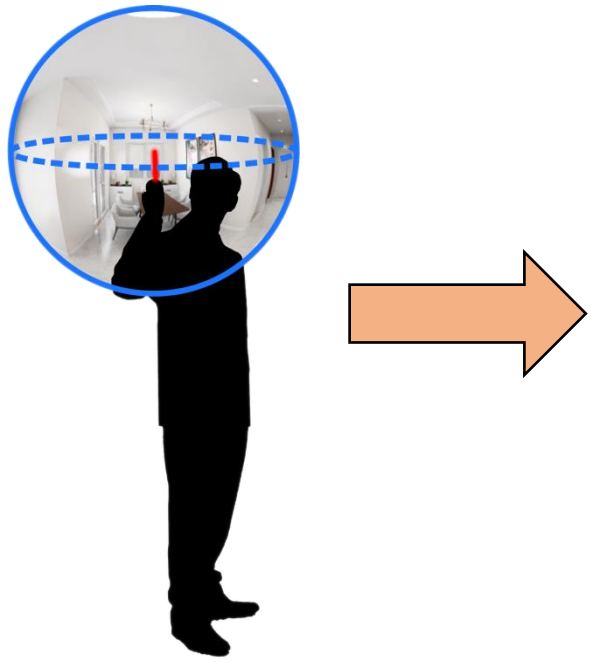
Shape &
Appearance



Link to captured data

Today’s focus: panoramic imaging for indoors

Why focusing on panoramic imaging?



1) **MANY ACQUISITION SOLUTIONS AVAILABLE** (commodity and professional devices, stitching, …)

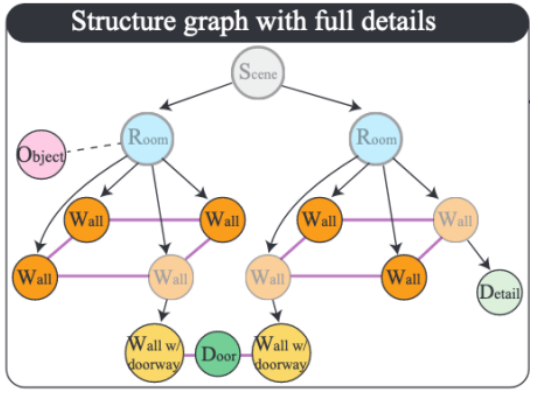
2) **EASY AND FAST ACQUISITION** (single shot takes few seconds and covers all scene around the viewer)

3) **GLOBAL/WIDE CONTEXT FACILITATES ANALYSIS** (no clipping of objects/areas, possibility to look at scene regularities, …)

4) **EXPLORATION OF SINGLE IMAGE IS DYNAMIC/IMMERSIVE** (fundamentally different than standard 2D counterparts)

Why specialized solutions for interiors?

- Strong need for *structured indoor models*
  - High-level representation of main elements and their relations
  - Optimized to meet requirements of specific fields of application
    - Building Information Models (AEC domain): bare architectural structure
    - Emergency management, location awareness, routing: also interior clutter
  - Standard surface reconstruction does not guarantee this



Ikehata et al. ICCV2015

- Deal with specific challenges of input data
  - Technological limitations of acquisition devices
  - Artifacts caused by properties of real-world interiors
    - Clutter, unreachable areas
    - Transparent/reflective + textureless surfaces

Common artifacts

Noise & outliers

Sampling density

Misalignment

Missing data

Common artifacts

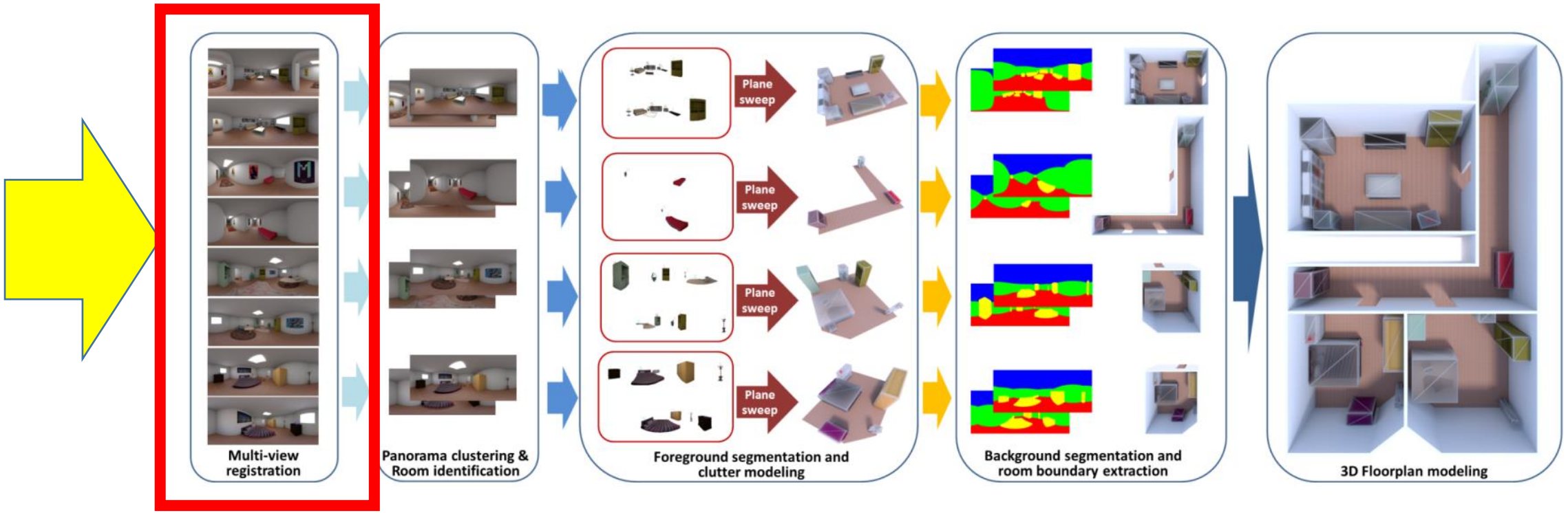
Noise & outliers **Sampling density** **Misalignment** **Missing data**

Common artifacts

Noise & outliers | **Sampling density** | **Misalignment** | **Missing data**

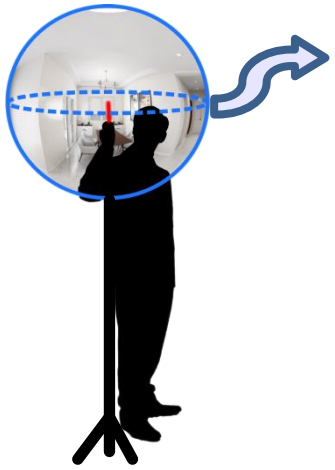
Common artifacts

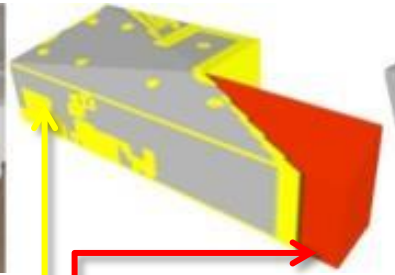
Noise & outliers **Sampling density** **Misalignment** **Missing data**



Common artifacts

Noise & outliers **Sampling density** **Misalignment** **Missing data**





Texture-poor surfaces

Occlusions from clutter

Self-occlusions

…

Ground truth

Plausible reconstruction

Pintore et al. TOG2021

Reconstruction of models from noisy, partial, imperfect data

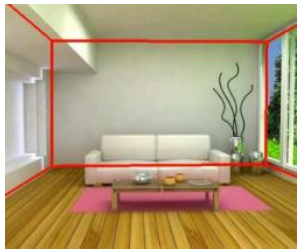
- Interpret the images / the images under the assumption that the photographed models has some known characteristics
- General surface reconstruction priors
  - Smoothness, continuity, …
  - Flat smooth surfaces surfaces joining at sharp angles…
- Architectural priors

Architectural priors

complexity

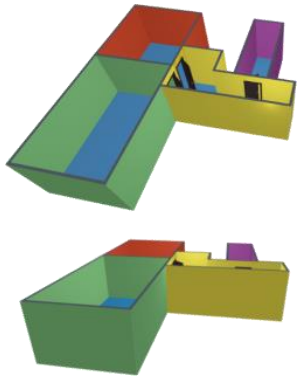
Floor-wall

Cuboid

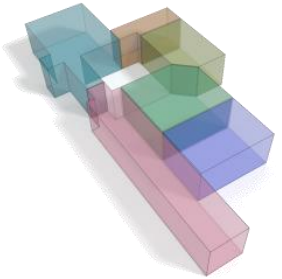


Indoor World

Manhattan World

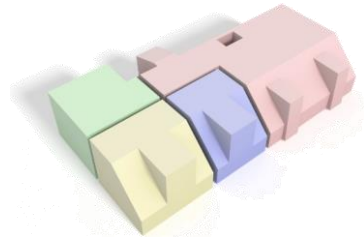


Atlanta World



Vertical Walls

Piecewise Planarity



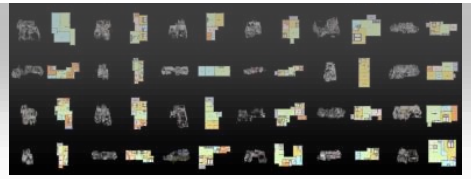
Reconstruction of models from noisy, partial, imperfect data

- Historically, priors were exploited in **geometry-reasoning** solutions, that combined them with specific processes to extract models
  - E.g. extract edges and corners, filter according Manhattan direction, build model through connection/fusion, …
- Nowadays, more and more solutions exploit **data driven priors**, i.e., common characteristics extracted from large sets of examples
  - Esp. deep-learning solutions
- The most common approach is a combination of both

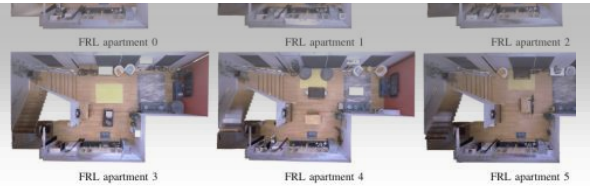
Open research datasets

Name	Data	Source	Coverage	Capture	Notes
SUN 360 Database [Mas12]	Individual RGB	Real	Panoramic	Tripod	Whole rooms;
SUN 3D Database [Pri13]	Registered RGB-D	Real	Perspective	Hand-held video	Whole rooms; PL; 3D models
UZH 3D Dataset [Uni14]	Registered PC	Real/Synth	Scan	Tripod	Large-scale; multi-room; 3D models
SunCG Dataset [Pri16]	CAD models	Synth	All	Manual modeling	Large-scale; FL
BundleFusion Dataset [Sta16a]	Registered RGB-D	Real	Perspective	Hand-held video	Room-scale; FL; 3D models
ETH3D Dataset [ETH17]	Registered RGB	Real	Perspective	Tripod	Scene parts; ground truth (PC+DM)
Matterport 3D [Mat17]	Registered RGB-D	Real	Panoramic	Tripod	Large-scale; multi-room; FL
ScanNet [DCS*17a]	Registered RGB-D	Real	Perspective	Hand-held video	Large-scale; multi-room; FL;3D models
2D-3D-S [Sta17]	Registered RGB-D	Real	Panoramic	Tripod	Large-scale; multi-room; FL
FloorNet Data [LWF18b]	Registered RGB-D	Real	Perspective	Hand-held video	Large-scale; FL
CRS4/ViC Datasets [CRS18]	Registered RGB	Real	Panoramic	Tripod	Large-scale; multi-room; 3D models
Replica Dataset [SWM*19]	CAD models	Synth	All	Manual modeling	Highly realistic; FL
Structured3D Dataset [ZZL*19]	CAD models	Synth	All	Manual modeling	Large scale; FL

CRS4/ViC Research Datasets



FloorNet Dataset



Replica Dataset

2D-3D-S Dataset

Wrap-up

- Panoramic imaging, single or multiview, has important characteristics that make it very popular and important for indoor reconstruction and exploration
  - Device availability, ease of capture, completeness, dynamic/immersive
- Indoor reconstruction seeks to build application specific models based on partial/noisy/imperfect images
  - Noise & outliers, sampling density, misalignment, missing data
- Reconstruction methods exploit priors
  - Surface reconstruction priors, architectural priors, data-driven priors

Next

- Room modeling
  - Bounding surfaces, exploiting priors, deep learning solutions
- Integrated indoor model computation
  - Multi-rooms; Ensuring consistency; Finding and modeling connections
- Visual representation generation and exploration
  - Beyond geometric reconstruction; Appearance; panoramic exploration

NEXT SESSION: ROOM MODELING

Speaker: Giovanni Pintore