Real-time RGB-D Mapping and 3-D Modeling on the GPU using the Random Ball Cover Data Structure

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Reconstruction Framework

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Generation of 3-D Scene Model

- Working principle
  - Given a global scene model
  - Successively register the latest point cloud to the previous one
  - Merge the global scene with the aligned data

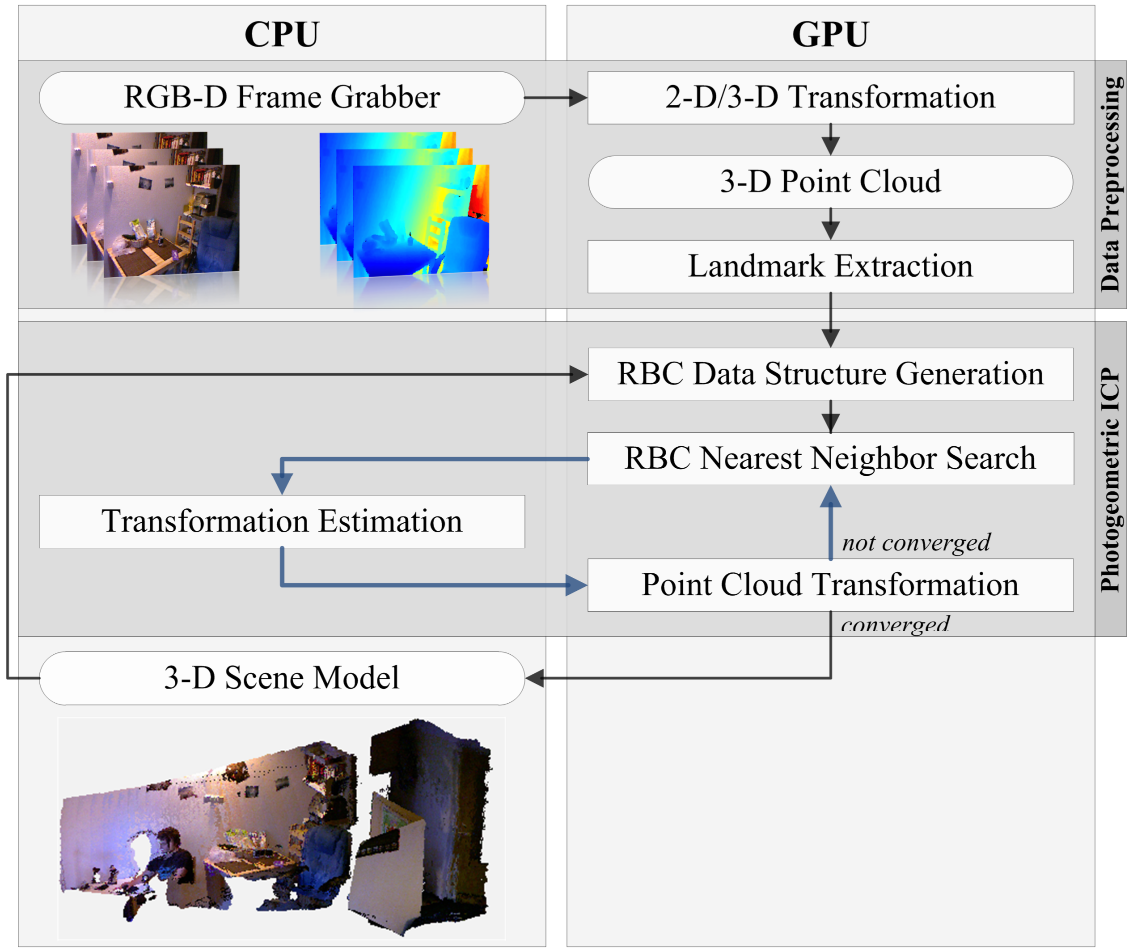
Global scene

Previous point cloud

New point cloud

Alignment

Reconstruction Framework



Methods

Iterative Closest Point Algorithm [1]

[1] P. Besl, N. McKay: “**A method for registration of 3-D shapes**”. In *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 1992, pp 239-256.

Iterative Closest Point (ICP) Algorithm

transformation parameters

$$\left(\hat{\boldsymbol{R}}, \hat{\boldsymbol{t}}\right) = \arg\min_{\boldsymbol{R},\boldsymbol{t}} \frac{1}{|\mathcal{M}|} \sum_{\boldsymbol{m} \in \mathcal{M}} \|(\boldsymbol{R}\boldsymbol{m}_g + \boldsymbol{t}) - \boldsymbol{f}_g^m\|_2^2 \qquad \boldsymbol{f}^m \in \mathcal{F}$$

NN relation

$$\boldsymbol{f}^m = \arg\min_{\boldsymbol{f} \in \mathcal{F}} \|\boldsymbol{f}_g - \boldsymbol{m}_g\|_2^2 + \alpha \|\boldsymbol{f}_p - \boldsymbol{m}_p\|_2^2$$

➔ **photogeometric** ICP

rotation	$\hat{\boldsymbol{R}}$	$\hat{\boldsymbol{t}}$	translation
moving point set	$\mathcal{M} = \{\boldsymbol{m}\}$	$\mathcal{F} = \{\boldsymbol{f}\}$	fixed point set
geometric information	$\boldsymbol{f}_g, \boldsymbol{m}_g$	$\boldsymbol{f}_p, \boldsymbol{m}_p$	photometric information
Euclidean distance	$\|\cdot\|_2$	α	weighting factor ≥ 0

Methods

Random Ball Cover [2,3] – efficient NN search

[2] L. Cayton: "**A nearest neighbor data structure for graphics hardware**". In *International Workshop on Accelerating Data Management Systems Using Modern Processor and Storage Architectures*, 2010.
[3] L. Cayton: "**Accelerating nearest neighbor search on many-core systems**". In *Computing Research Repository* (http://arxiv.org/corr), 2011.

Nearest Neighbor (NN) Search

- Tree-based approaches
  - *k*d tree
  - PCA tree
  - Ball tree
  - …

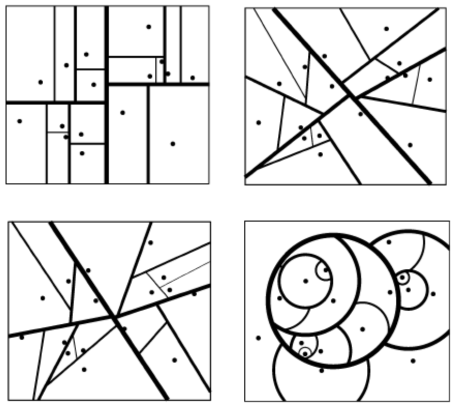
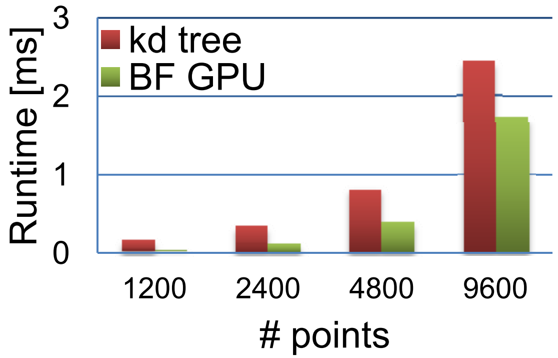


Image courtesy of L. Zhang

- Hardware acceleration techniques
  - Brute-force (BF) on GPU
  - … outperforms *k*d tree on CPU [4]



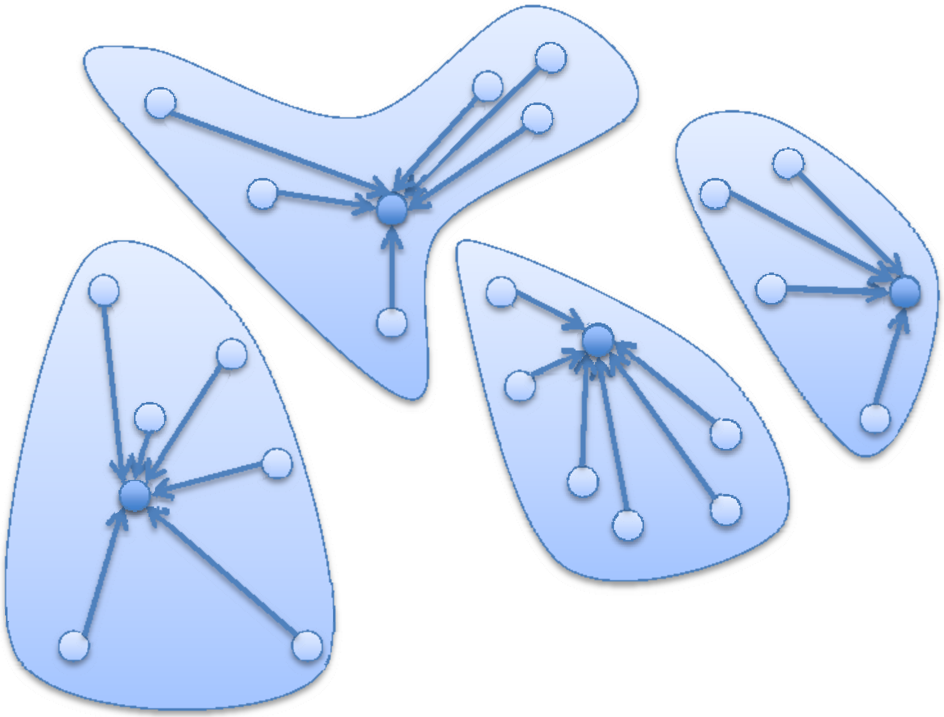
[4] V. Garcia et al. "**Fast k nearest neighbor search using GPU**". *In Proceedings of IEEE Conference on Computer Vision and Pattern Recognition Workshop on Computer Vision on GPU*, 2008, pp 1-6.

Random Ball Cover (RBC)

- Acceleration structure for efficient NN search
- Originally intended for high-dimensional search spaces
- Exploits parallel architecture of modern GPUs
  - Construction of data structure uses BF primitive
  - Dataset queries use BF primitive

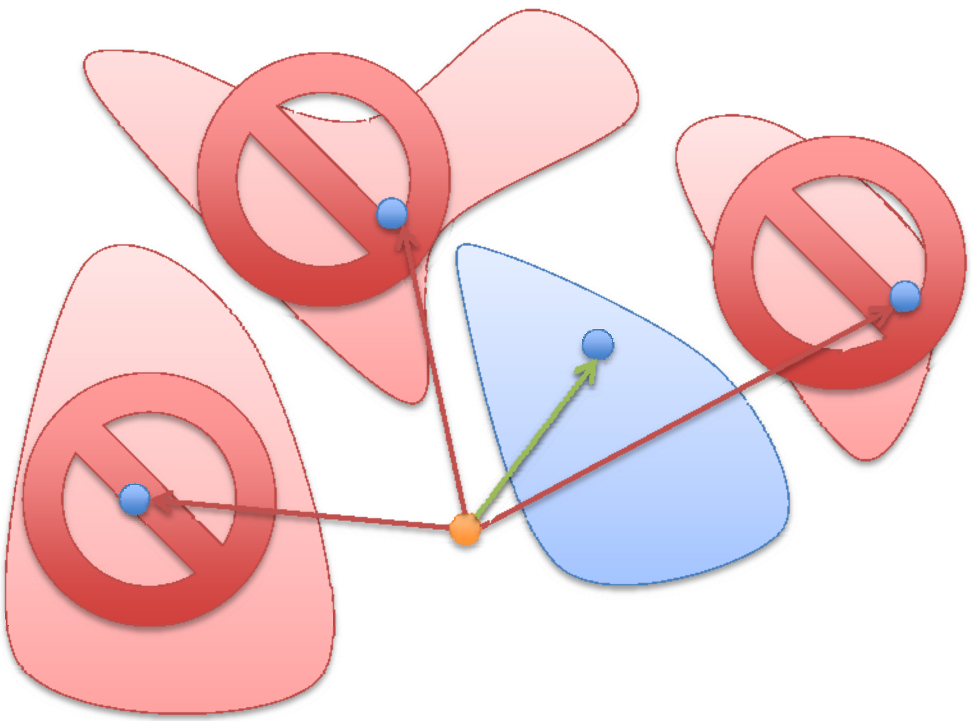
- Two approaches
  - Exact RBC: slower, exact
  - One-shot RBC: faster, not exact

RBC Construction



➔ BF search to find closest representative

RBC Query – Step 1



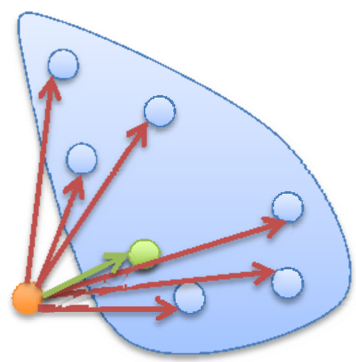
Query Point

Representative

NN List

➔ BF search among representatives

RBC Query – Step 2



→ BF search among NN list of closest representative

Performance Analysis

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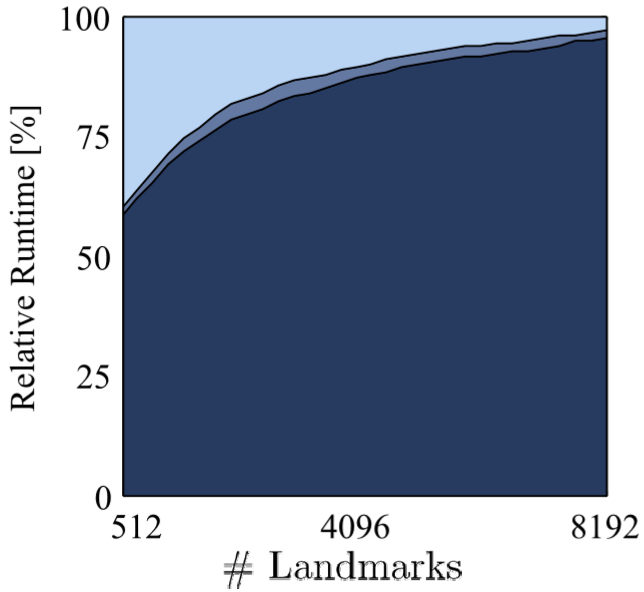
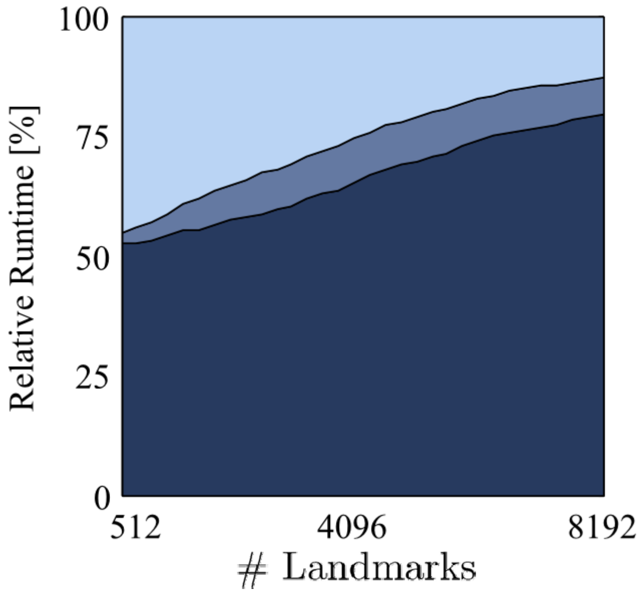
Runtime Partitioning

(regarding one ICP iteration)

NN search Transformation Estimation Transformation



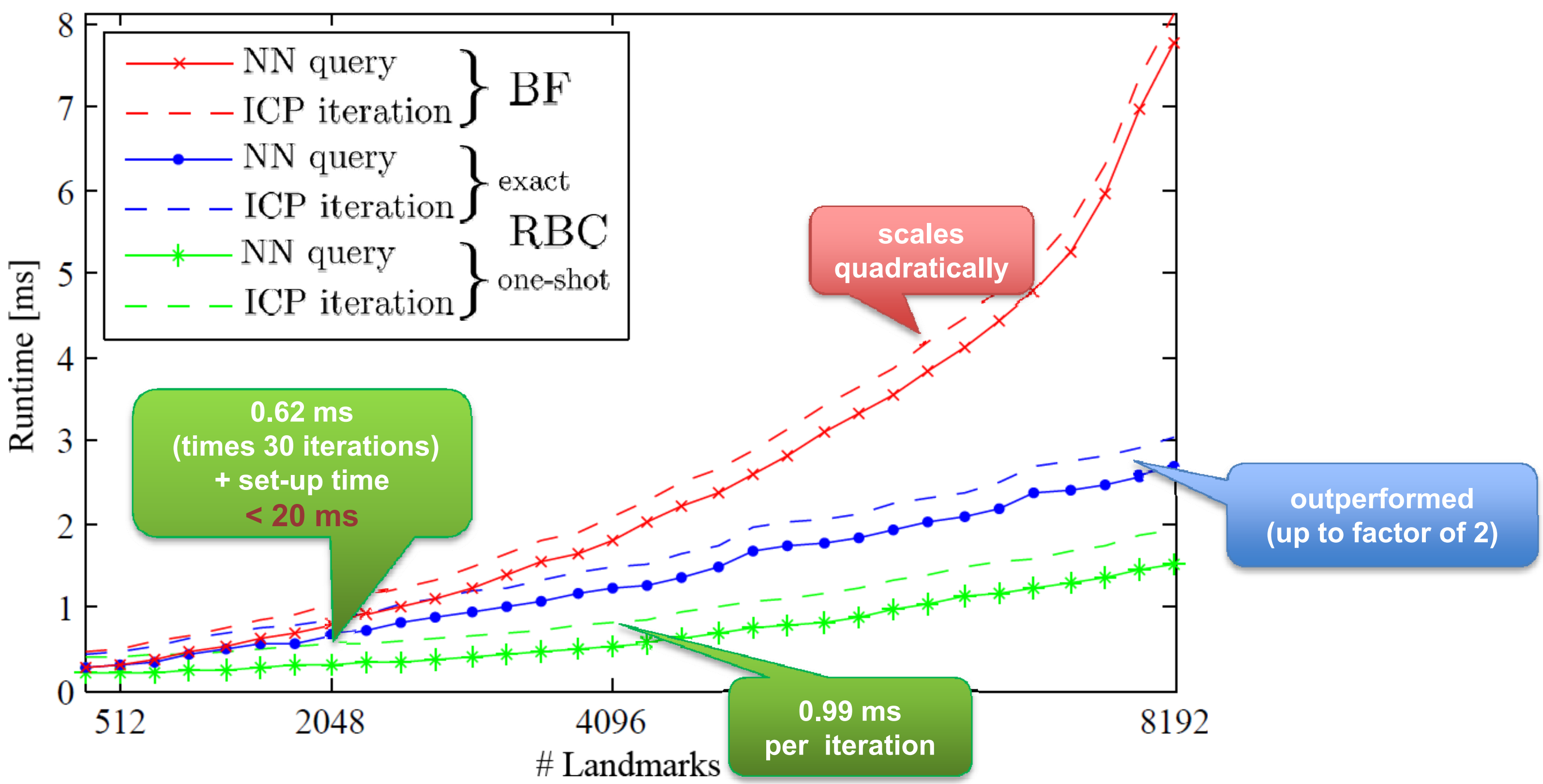
Brute-force



One-shot RBC

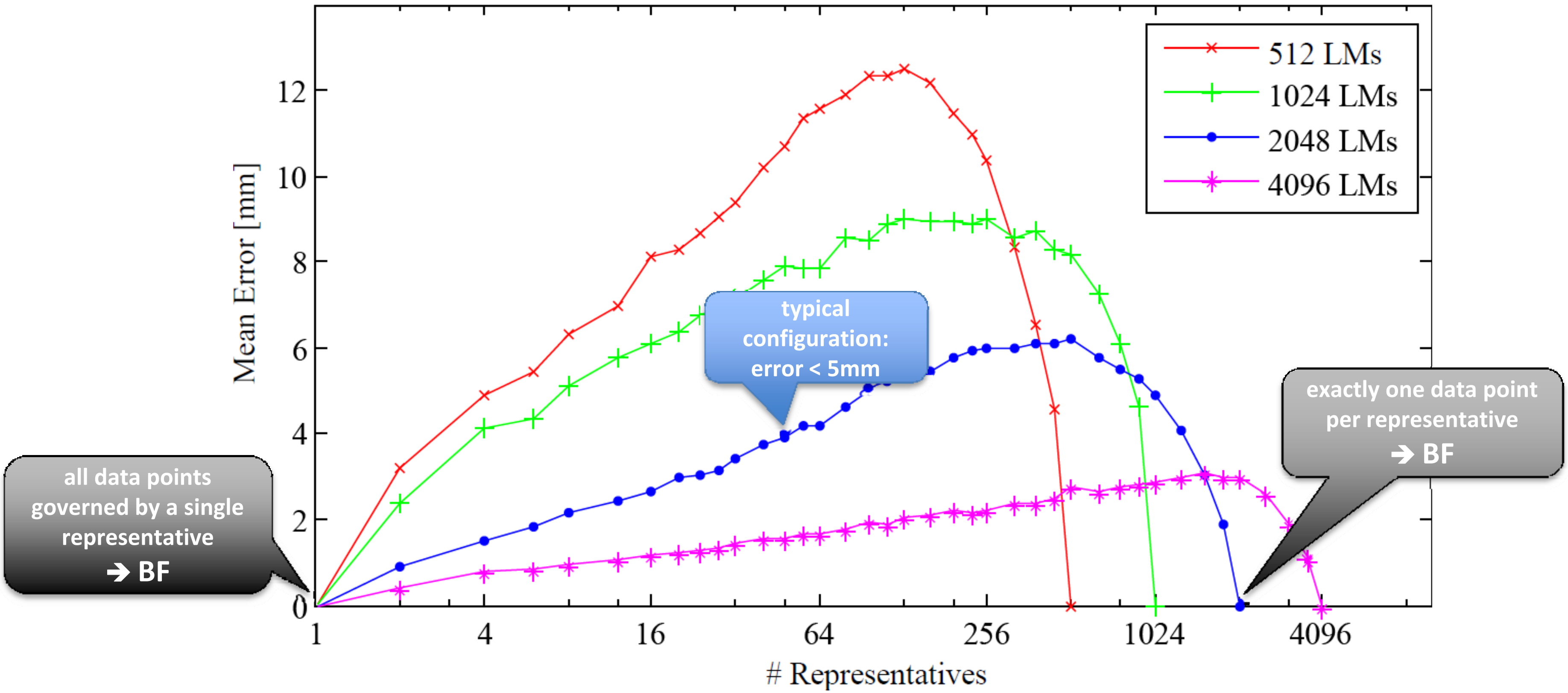
Absolute Runtime: Comparison

(NVIDIA GeForce GTX 460, Intel Core 2 Quad Q9550)



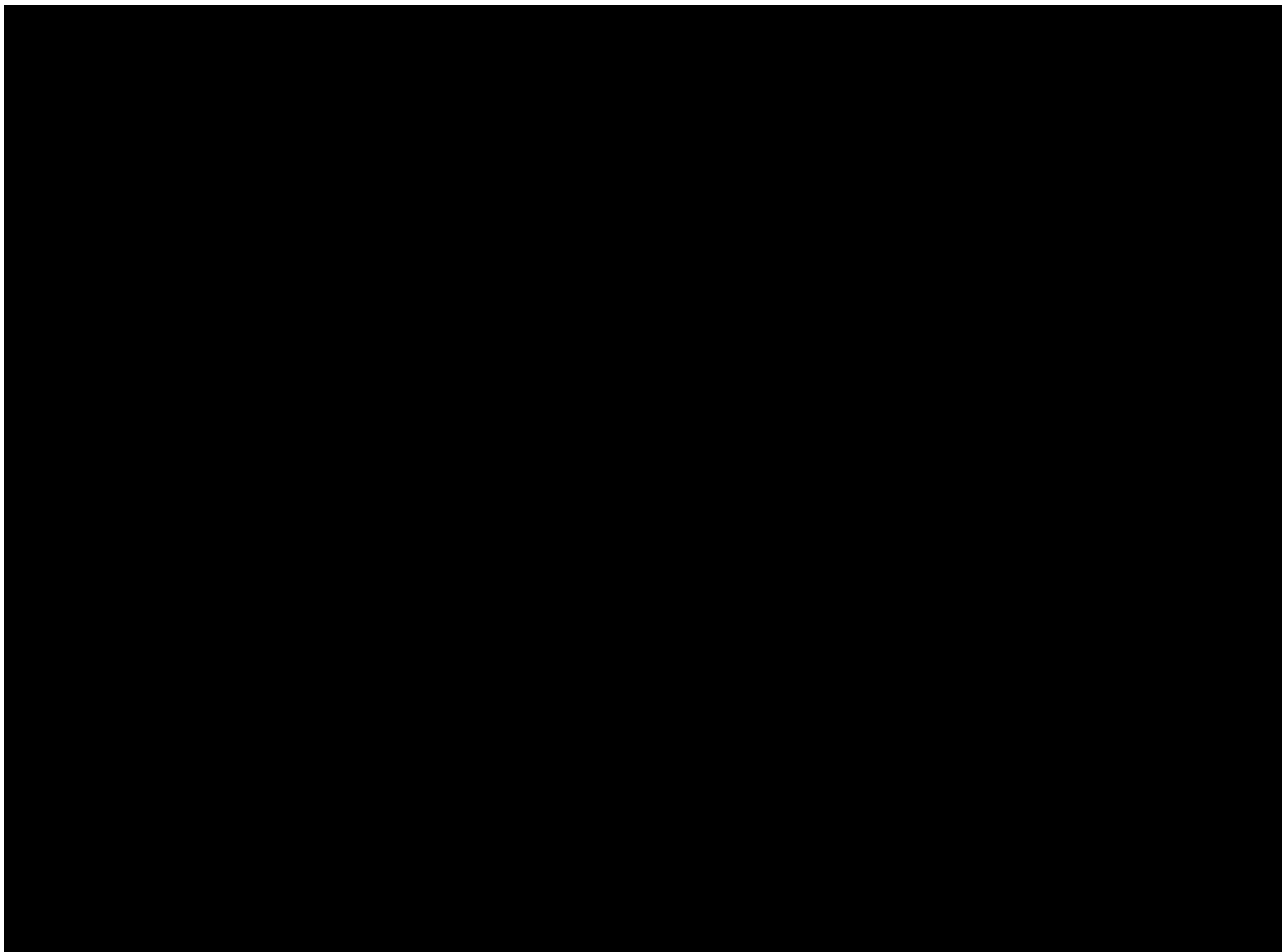
Error Evaluation

*(**approximative** NN search)*



Qualitative Results

On-the-fly Reconstruction



Summary & Outlook

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Summary & Outlook

- **Fast** ICP using the RBC data structure
  - Many algorithms rely on (real-time) ICP for surface alignment
  - RBC in low-dimensional spaces
  - Promising results: ICP runtimes < 20 ms

- Outlook
  - Improvements on reconstruction framework
    - Loop closure
    - SLAM
  - Application to other algorithms → feature matching

Thank you for your attention.

For further information (including source code requests) please contact the authors.
The implementation is based on the “Range Imaging Toolkit” (RITK).
≫ **http://www5.cs.fau.de/ritk**

RITK
THE RANGE IMAGING TOOLKIT

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