CSE-571
Robotics

Mapping

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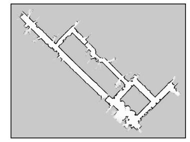
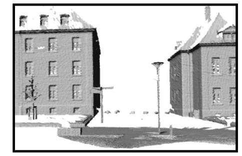
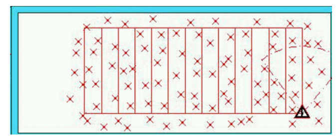
Types of SLAM-Problems

Grid maps or scans





Sparse landmarks



RGB / Depth Maps

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Problems in Mapping

- Sensor interpretation
  - How do we extract relevant information from raw sensor data?
  - How do we represent and integrate this information over time?
- Robot locations have to be known
  - How can we estimate them during mapping?

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Occupancy Grid Maps

- Introduced by Moravec and Elfes in 1985
- Represent environment by a grid.
- Estimate the probability that a location is occupied by an obstacle.
- Key assumptions
  - Occupancy of individual cells is independent

$$Bel(m_t) = P(m_t \mid u_1, z_2 \ldots, u_{t-1}, z_t) = \prod_{x,y} Bel(m_t^{[xy]})$$

  - Robot positions are known!

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Updating Occupancy Grid Maps

- Idea: Update each individual cell using a binary Bayes filter.

$$Bel(m_t^{[xy]}) = \eta \; p(z_t \mid m_t^{[xy]}) \sum_{m_{t-1}^{[xy]}} p(m_t^{[xy]} \mid m_{t-1}^{[xy]}, u_{t-1}) Bel(m_{t-1}^{[xy]})$$

- Additional assumption: Map is static

$$Bel(m_t^{[xy]}) = \eta \; p(z_t \mid m_t^{[xy]}) Bel(m_{t-1}^{[xy]})$$

- Log odds representation:

$$l_{t,i} = \log\left(\frac{p(m_i|z_{1:t}, x_{1:t})}{1 - p(m_i|z_{1:t}, x_{1:t})}\right)$$

$$l_{t,i} = l_{t-1,i} + log\left(\frac{p(m_i|z_t, x_t)}{1 - p(m_i|z_t, x_t)}\right) - \; log\left(\frac{p(m_i)}{1 - p(m_i)}\right)$$

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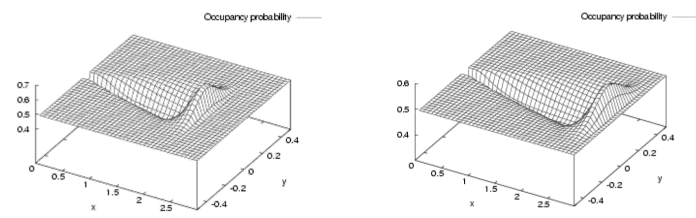
Inverse Sensor Model for Occupancy Grid Maps

Combination of linear function and Gaussian:



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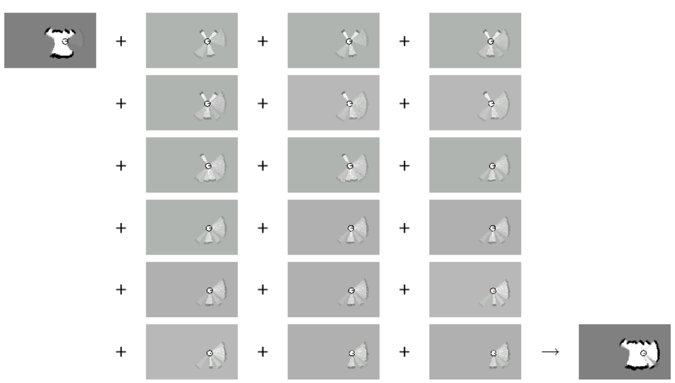
Incremental Updating of Occupancy Grids (Example)



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Alternative: Simple Counting

- For every cell count
  - hits(x,y): number of cases where a beam ended at <x,y>
  - misses(x,y): number of cases where a beam passed through <x,y>

$$Bel(m^{[xy]}) = \frac{\text{hits}(x,y)}{\text{hits}(x,y) + \text{misses}(x,y)}$$

- Assumption: *P*(*occupied*(x,y)) = *P*(*reflects*(x,y))

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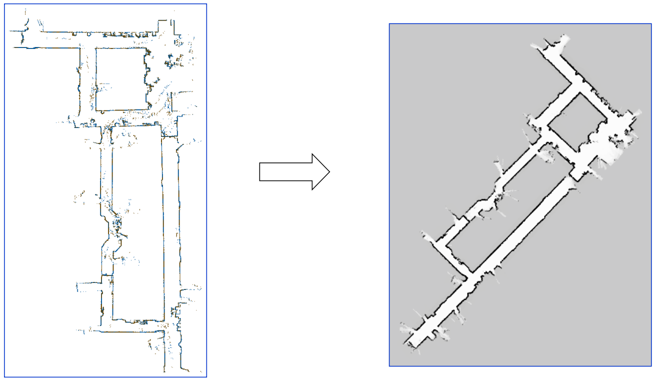
Occupancy Grids: From scans to maps



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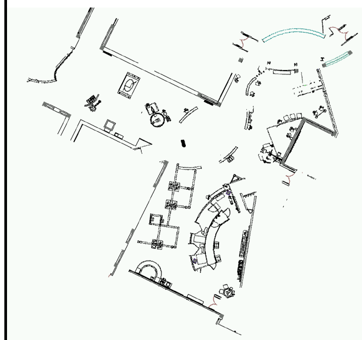
Tech Museum, San Jose



CAD map

occupancy grid map

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OctoMap

A Probabilistic, Flexible, and Compact 3D Map Representation for Robotic Systems

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AiS Autonomous Intelligent Systems

Humanoid Robots Lab
University of Freiburg

http://octomap.sf.net

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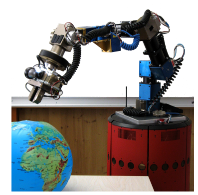
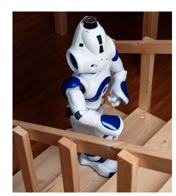
Robots in 3D Environments

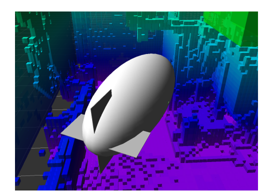


Mobile manipulation

Outdoor navigation



Humanoid robots



Flying robots

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3D Map Requirements

- Full 3D Model
  - Volumetric representation
  - Free-space
  - Unknown areas (e.g. for exploration)
- Can be updated
  - Probabilistic model
    (sensor noise, changes in the environment)
  - Update of previously recorded maps
- Flexible
  - Map is dynamically expanded
  - Multi-resolution map queries
- Compact
  - Memory efficient
  - Map files for storage and exchange

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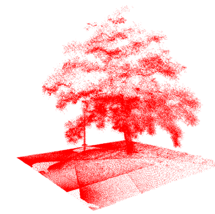
Map Representations

Pointclouds



- Pro:
  - No discretization of data
  - Mapped area not limited
- Contra:
  - Unbounded memory usage
  - No direct representation of free or unknown space

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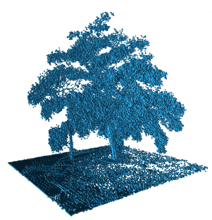
Map Representations

3D voxel grids



- Pro:
  - Probabilistic update
  - Constant access time
- Contra:
  - Memory requirement
    - Extent of map has to be known
    - Complete map is allocated in memory

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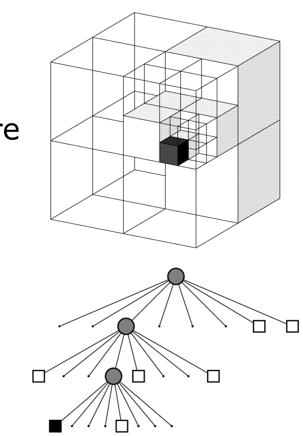
Map Representations

Octrees



- Tree-based data structure
- Recursive subdivision of space into octants
- Volumes allocated as needed
- Multi-resolution

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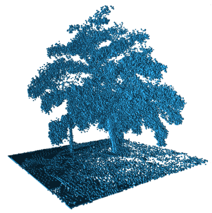
Map Representations

Octrees



- Pro:
  - Full 3D model
  - Probabilistic
  - Flexible, multi-resolution
  - Memory efficient
- Contra:
  - Implementation can be tricky (memory, update, map files, …)

- Open source implementation as C++ library available at http://octomap.sf.net

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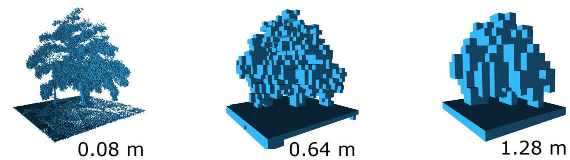
Probabilistic Map Update

- Clamping policy ensures updatability [Yguel '07]

$$L(n) \in [l_{\text{min}}, l_{\text{max}}]$$

- Update of inner nodes enables multi-resolution queries

$$L(n) = \max_{i=1..8} L(n_i)$$



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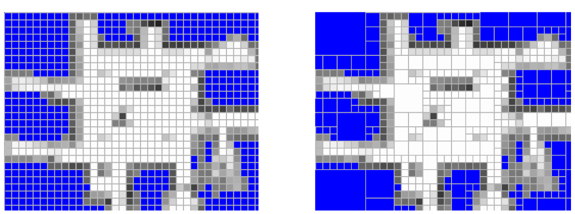
Lossless Map Compression

- Lossless pruning of nodes with identical children
- High compression ratios esp. in free space



[Kraetzschmar 04]

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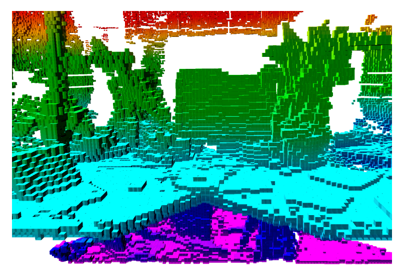
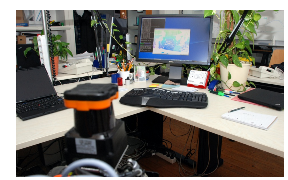
Examples

- Cluttered office environment



Map resolution: 2 cm



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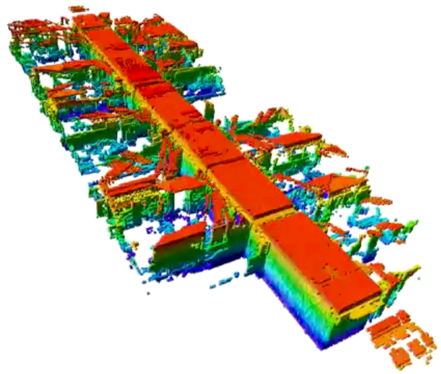
Examples: Office Building

- Freiburg, building 079



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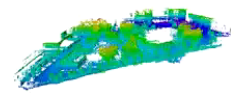
Examples: Large Outdoor Areas

- Freiburg computer science campus
  (292 x 167 x 28 m³, 20 cm resolution)



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Examples: Tabletop

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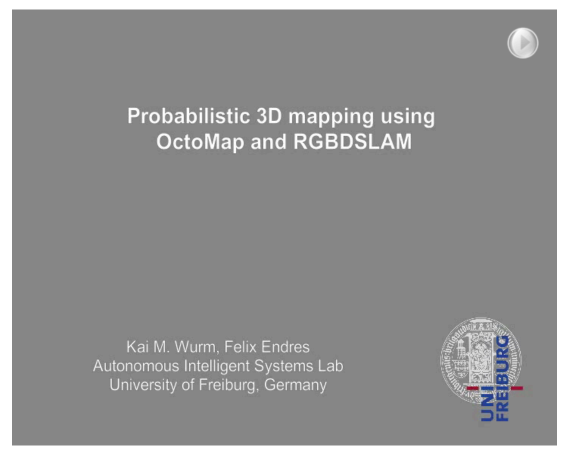
Adding Color



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Memory Usage

Map dataset	Mapped area [m³]	Resolution [m]	Memory consumption [MB]			File size [MB]	
			Full grid	No compr.	Lossless compr.	All data	Binary
FR-079 corridor	$43.8 \times 18.2 \times 3.3$	0.05	80.54	73.64	41.70	15.80	0.67
		0.1	10.42	10.90	7.25	2.71	0.14
Freiburg outdoor	$292 \times 167 \times 28$	0.20	654.42	188.09	130.39	49.75	2.00
		0.80	10.96	4.56	4.13	1.53	0.08
New College (Epoch C)	$250 \times 161 \times 33$	0.20	637.48	91.43	50.70	18.71	0.99
		0.80	10.21	2.35	1.81	0.64	0.05

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