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Summary and perspectives

# Efficient GPU-based Construction of Occupancy Grids Using several Laser Range-finders

## M. Yguel<sup>1</sup> O. Aycard<sup>2</sup> C. Laugier<sup>3</sup>

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<sup>2</sup>University of Joseph Fourier

<sup>3</sup>Institut National de Recherche en Informatique et Automatique

International Conference on Intelligent Robots and Systems, 2006



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### Enforce vehicle safety by

- percieving the whole robot surroundings,
- being robust to false measurements,
- having precise map,
- providing real-time map.



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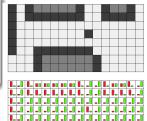
Summary and perspectives

### Definition

An OG is a stochastic tessellated representation of spatial information that maintains probabilistic estimates of the occupancy state of each cell in a lattice [1].

### eatures:

- no assumption about environment geometry,
- simple fusion process,
- occultation information,
- each cell is independent.



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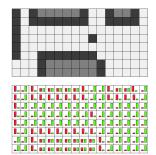
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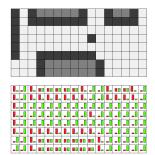
#### GPU Implementation General Algorithi Architecture

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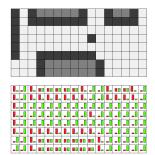
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## Grids have image-like structures:

huge amount of data

*e.g.* 100mx100m grid with cell side of 5 $cm \rightarrow 4M$  cells

- enlarging the field of view
  - ightarrow increases the amount of data
- increasing precision
  - ightarrow increases the amount of data

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Summary and perspectives Grids have image-like structures:

- huge amount of data
  - *e.g.* 100mx100m grid with cell side of  $5cm \rightarrow 4M$  cells
- enlarging the field of view
  - $\rightarrow$  increases the amount of data
- increasing precision
  - $\rightarrow$  increases the amount of data

## The Graphical Hardwares

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### Graphical processor units (GPUs):



- dedicated to work with images,
- high level of parallelism,
- easy to program with shading languages,
- cheap.

### Objective:

accurate implementation of OG fusion with the GPU

## The Graphical Hardwares

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- Variables:
  - $\vec{Z} = (Z_1, \dots, Z_n)$  a vector of *n* random variables,
  - $O_{x,y} \in \mathcal{O} \equiv \{\text{occ}, \text{emp}\}. O_{x,y}$  is the state of the cell (x, y),
- joint probability distribution:

$$P(O_{x,y}, \overrightarrow{Z}) = P(O_{x,y}) \prod_{i=1}^{n} P(Z_i | O_{x,y})$$

• inference:

let  $\overrightarrow{z} = (z_1, \dots, z_n)$  a vector of sensor measurements:

$$p(o_{x,y}|\overrightarrow{z}) = \ rac{p(o_{x,y})\prod_{i=1}^n p(z_i|o_{x,y})}{p(_{\mathrm{occ}})\prod_{i=1}^n p(z_i|_{\mathrm{occ}}) + p(_{\mathrm{emp}})\prod_{i=1}^n p(z_i|_{\mathrm{emp}})}$$

## OG Bayesian Model

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• inference: let  $\overrightarrow{z} = (z_1, ..., z_n)$  a vector of sensor measurements:  $p(\underbrace{o_{x,y}}_{i=1} | \overrightarrow{z}) = p(\underbrace{o_{x,y}}_{i=1}) \prod_{i=1}^{n} p(z_i | \underbrace{o_{x,y}}_{i=1}) p(\underbrace{o_{x,y}}_{i=1}) p(z_i | occ) + p(emp) \prod_{i=1}^{n} p(z_i | emp)$ 

## OG Bayesian Model

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$$p(o_{x,y}|\overrightarrow{z}) = \ p(o_{x,y})\prod_{i=1}^n p(z_i|o_{x,y}) \ \overline{p(\operatorname{occ})\prod_{i=1}^n p(z_i|\operatorname{occ})} + p(\operatorname{emp})\prod_{i=1}^n \overline{p(z_i|\operatorname{emp})}$$

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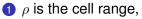
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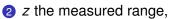
Summary and perspectives

## Values of sensor model characteristics for a beam:

position	$\rho$ dependent	z dependent		
if $z << \rho$		×		
if z around $\rho$	×	×		
of $z >> \rho$		×		

### where:





3 gaussian sensor uncertainty,

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### Values of sensor model characteristics for a beam:

position	$\rho$ dependent	z dependent		
if $z <<  ho$				
if z around $\rho$	×	×		
of $z >> \rho$				

where:

- 1  $\rho$  is the cell range,
- 2 z the measured range,
- 3 gaussian sensor uncertainty,
- 4 very weak occupancy *a priori* : world almost empty.

## **1D Occupancy Function**

Efficient GPU-based Construction of OGs

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Occupancy Grids Bayesian Model Sensor Model

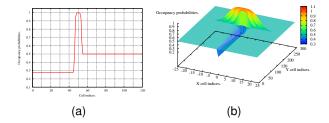
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Extension from 1D to 2D OG. (a) 1D OG (b) 2D OG of a sensor beam.

The sensor is positioned in (0,0).

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## Laser Beam and Grid Geometry

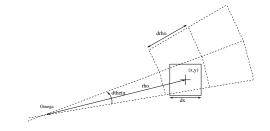


Figure: Polar and Cartesian grids parameters.

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# Moirage problem with Bresenham algorithm

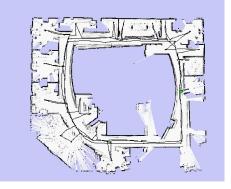


Figure: Grid based slam (from Dirk Hähnel home page).

## Moirage problem with Bresenham algorithm

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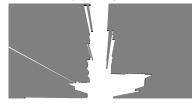
Bresenham algorithm (standard plot)



Bresenham algorithm (log plot)



superposition problem



exact algorithm

## Moirage problem with Bresenham algorithm

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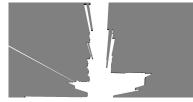
Bresenham algorithm (standard plot)



Bresenham algorithm (log plot)



superposition problem



exact algorithm

## Moirage problem with Bresenham algorithm

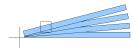
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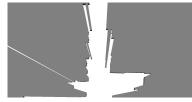
Bresenham algorithm (standard plot)



Bresenham algorithm (log plot)



superposition problem



exact algorithm

## Moirage problem with Bresenham algorithm

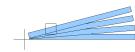
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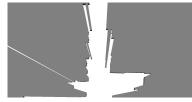
Bresenham algorithm (standard plot)



Bresenham algorithm (log plot)



superposition problem



exact algorithm

# Moirage problem with Bresenham algorithm

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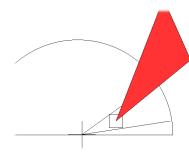
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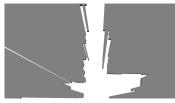
Bresenham algorithm (standard plot)



Bresenham algorithm (log plot)



superposition problem



exact algorithm



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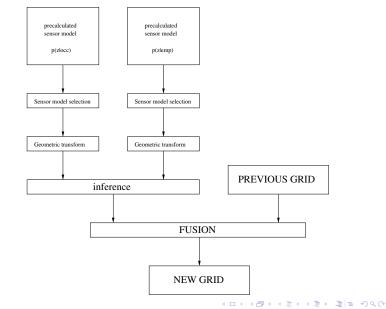
# General Algorithm Architecture

Gaussian model

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## General Algorithm Architecture



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#### General Algorithm Architecture

Dirac model Gaussian mode

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## General Algorithm Architecture

precalculated precalculated sensor model sensor model p(zlocc) p(zlemp) GPU STEPS Sensor model selection Sensor model selection Geometric transform Geometric transform PREVIOUS GRID inference FUSION NEW GRID

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Efficient Polygons geometric primitives GPU-based Construction of OGs Dirac model

# Efficient Result with Dirac model GPU-based Construction of OGs Dirac model Figure: Occupancy grid generated by the GPU, polygon mode

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Gaussian model

Bayesian Model Sensor Model

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## **Texture Mipmaps**

Efficient GPU-based Construction of OGs

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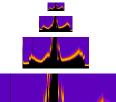
From range information to 2D grid Previous Work

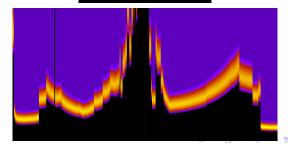
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### Angle beam in abscissa and $\rho$ in ordinate at different scales





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## Result with gaussian model

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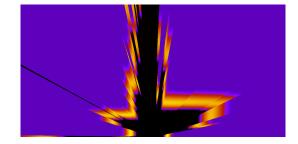


Figure: Occupancy grid generated by the GPU.

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## Exact Algorithm: Map Overlay



Occupancy Grids Bayesian Model Sensor Model

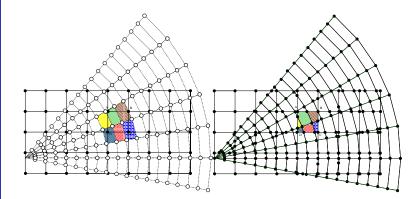
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## Algorithms for sick sensors with Dirac model

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### exact,

Bresenham,

- 3 adaptative sampling,
- GPU (polygon mode)

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Method	Avg. Error	Max. Error	avg. time
exact	0	0	1.23s (CPU)
line drawing	0.98	25.84	0.22s (CPU)
sampling	0.11	1.2	1.02s (CPU)
			0.049s on MS
GPU	0.15	1.8	0.0019s on
			board

Table: Comparison of change of coordinate system methods (MS: master storage).

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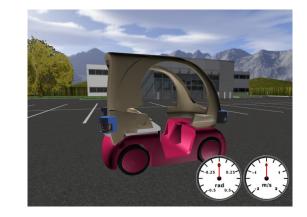
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Fusion of four SICK laser range-finders surrounding a vehicle.

Summary

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- 1 correct sampling is necessary,
- 2 graphical hardwares for sensor geometry,
- graphical hardwares for multiple sensor fusion and grid handling,
- 4 on board: fusion of 50 sensors is possible in real-time.

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## Handling with GPU:

- 1 angle uncertainty,
- 2 sensor position uncertainty,
- 3 scan matching.



Occupancy grids: a probabilistic framework for robot perception and navigation. PhD thesis, Carnegie Mellon University, 1989.