

## Mapeamento

1

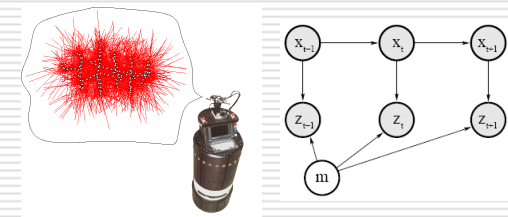
## Mapeamento na robótica móvel

- Representações do ambiente (mapas) são fundamentais para diversas tarefas executadas por robôs móveis como: localização e planejamento de trajetória.
- O mapeamento depende da capacidade de interpretação das informações obtidas por sensores. A maioria dos sensores fornece dados extremamente limitados sobre o ambiente, o que torna difícil o mapeamento do mesmo.

SSC-5880 Denis F. Wolf

2

## Mapeamento: problema de estimação



SSC-5880 Denis F. Wolf

3

## Tipos de mapas

- Mapas métricos: representam propriedades geométricas do ambiente de forma quantitativa, normalmente, discretizando o espaço representado. A ocupação é uma das propriedades mais representadas nesse tipo de mapa
- Mapas topológicos: representam a conectividade entre determinados locais do ambiente. Normalmente são utilizados grafos na representação, onde as regiões de importância são os nós e a conexão entre elas, os arcos.

SSC-5880 Denis F. Wolf

4

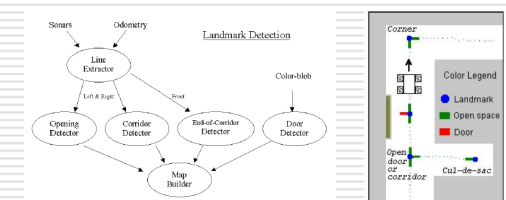
## Problemas no mapeamento

- Imprecisão na informação obtida por sensores e atuadores.
- Alta dimensionalidade dos modelos utilizados nas representações do ambiente.
- Complexidade do ambiente.
- Correspondência entre regiões do ambiente.  
(Como determinar se informações obtidas por sensores em diferentes momentos representam o mesmo local?)

SSC-5880 Denis F. Wolf

5

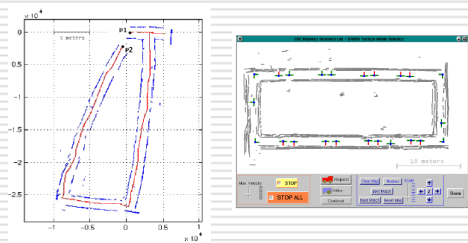
## Mapeamento topológico: landmarks



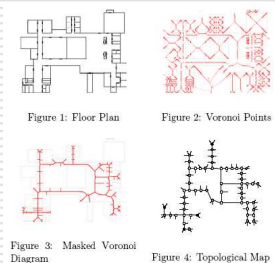
SSC-5880 Denis F. Wolf

6

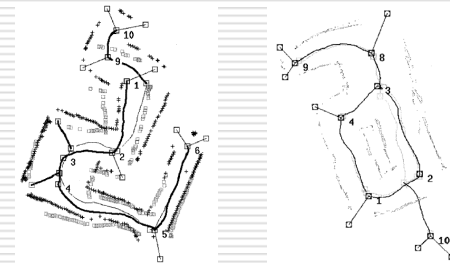
## Mapeamento topológico: landmarks



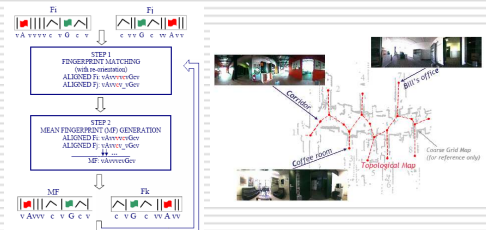
## Mapeamento topológico: diagramas de Voronoi



## Mapeamento topológico: diagramas de Voronoi

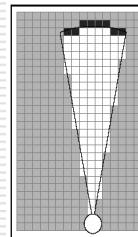


## Mapeamento topológico: landmarks (câmera + laser)



## Mapeamento métrico: occupancy grids

- Dividir o espaço em células e estimar a probabilidade de ocupação de cada célula individualmente baseado na informação obtida pelos sensores.
- Ao final, cada célula é classificada como ocupada, livre ou indefinido.



## Cálculo das probabilidades

- Idea: Utilizar um filtro de Bayes para estimar a ocupação das células:

$$Bel(m_t^{[xy]}) = \eta p(z_t | m_t^{[xy]}) \int p(m_t^{[xy]} | m_{t-1}^{[xy]}, u_{t-1}) Bel(m_{t-1}^{[xy]}) dm_{t-1}^{[xy]}$$

- Importante: o mapa é estático.

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

## Cálculo das probabilidades

$$Bel(m_t^{(xy)}) =$$

$$\frac{p(m_{x,y} | z_1, \dots, z_t)}{1 - p(m_{x,y} | z_1, \dots, z_t)} = \frac{p(m_{x,y} | z_t)}{1 - p(m_{x,y} | z_t)} \frac{1 - p(m_{x,y})}{p(m_{x,y})} \frac{p(m_{x,y} | z_1, \dots, z_{t-1})}{1 - p(m_{x,y} | z_1, \dots, z_{t-1})}$$

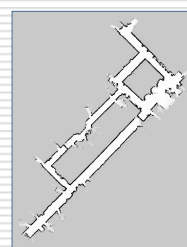
equivalente a:

$$l_{x,y}^t = \log \frac{p(m_{x,y} | z_t)}{1 - p(m_{x,y} | z_t)} + \log \frac{1 - p(m_{x,y})}{p(m_{x,y})} + l_{x,y}^{t-1}$$

ou alternativa simples:

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

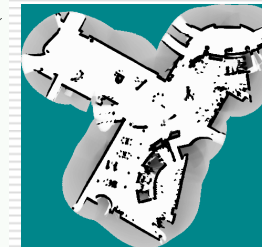
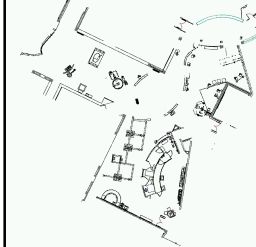
## Mapas



Dados do laser

Occupancy grid

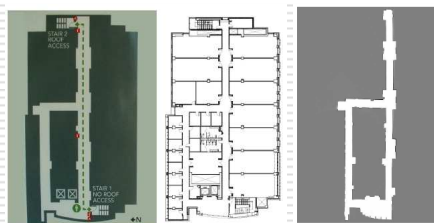
## Mapas



CAD map

occupancy grid map

## Mapas

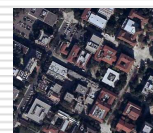


USC Ronald Tutor Hall

## Mapeamento em ambientes urbanos

### Problemas:

- Complexidade
- Escala
- Irregularidade do terreno
- Difícil representação



## Mapeamento 3D

- Com base na localização estimada, as informações do laser são projetadas no espaço 3D.
- Os mapas são visualizados em VRML

### Plataforma experimental:

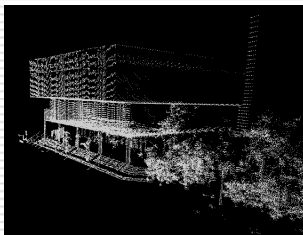
- Robô Segway RMP
- Laser SICK
- GPS
- IMU



## Mapas 3D



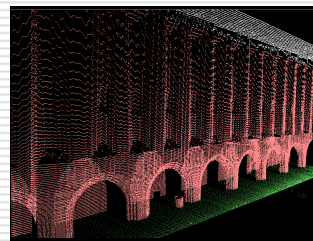
Livraria da USC



SSC-5880 Denis F. Wolf

19

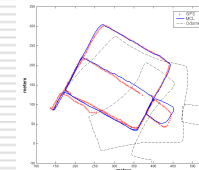
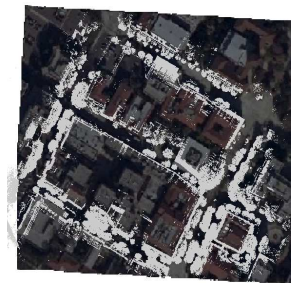
## Mapas 3D



SSC-5880 Denis F. Wolf

20

## Mapas 3D



SSC-5880 Denis F. Wolf

## Mapas 3D



SSC-5880 Denis F. Wolf

22

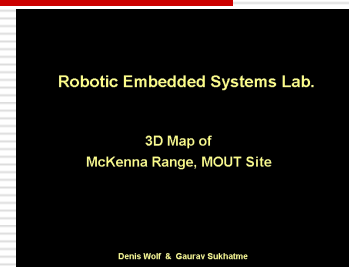
## Mapas 3D



SSC-5880 Denis F. Wolf

23

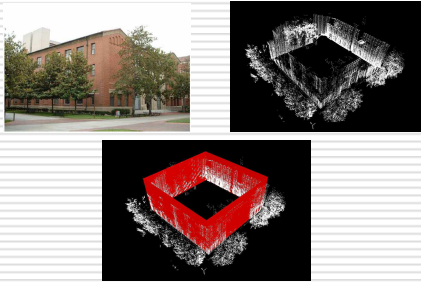
## Mapas 3D



SSC-5880 Denis F. Wolf

24

## Mapas planares

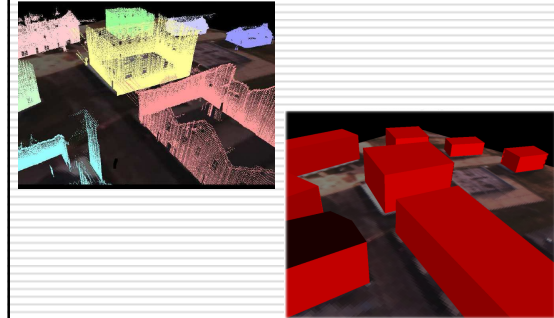


Transformada de Hough 3D

## Mapas planares



## Mapas planares



## Mapping dynamic environments

- Two different occupancy grids.
  - Map **S**  $\Rightarrow$  Static parts of the environment. (obstacles that have never been seen to move)
  - Map **D**  $\Rightarrow$  Dynamic parts of the environment. (obstacles that have been seen to move at least once)
- S U D**  $\Rightarrow$  Complete description of the environment.

## Map update equations

Modified update equations:

$$\frac{p(S^t | o^1 \dots o^t, S^{t-1})}{1 - p(S^t | o^1 \dots o^t, S^{t-1})} = \frac{p(S^t | o^t, S^{t-1})}{1 - p(S^t | o^t, S^{t-1})} \cdot \frac{1 - p(S)}{p(S)} \cdot \frac{p(S^{t-1})}{1 - p(S^{t-1})}$$

$$\frac{p(D^t | o^1 \dots o^t, S^{t-1})}{1 - p(D^t | o^1 \dots o^t, S^{t-1})} = \frac{p(D^t | o^t, S^{t-1})}{1 - p(D^t | o^t, S^{t-1})} \cdot \frac{1 - p(D)}{p(D)} \cdot \frac{p(D^{t-1})}{1 - p(D^{t-1})}$$

- $o^t$  - Observation at present time ( $t$ ).
- $S^{t-1}, D^{t-1}$  - Occupancy estimation at previous time ( $t-1$ )

## Map update

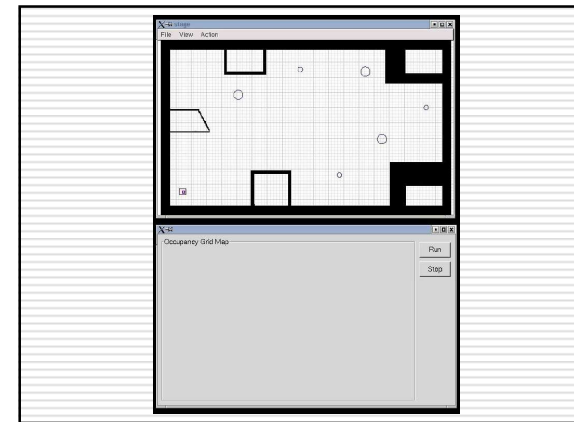
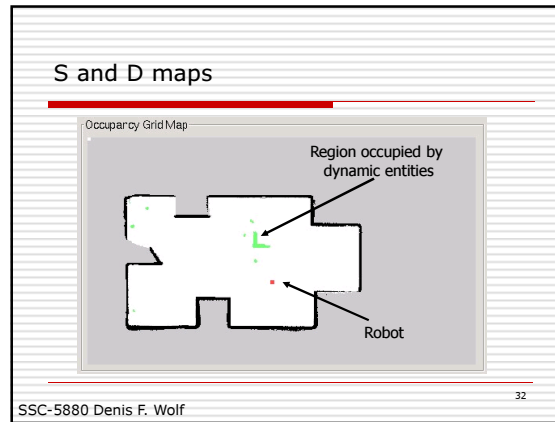
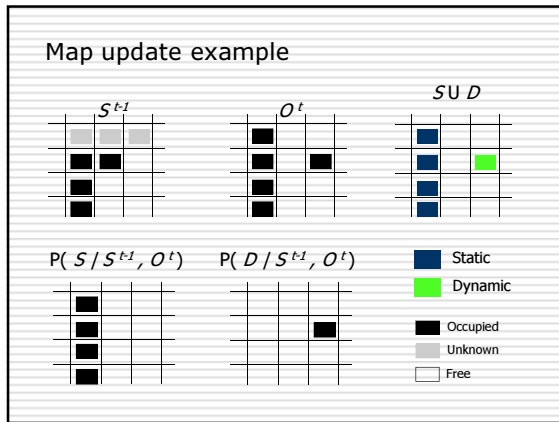
$S^{t-1}$	$o^t$	$p(S^t   S^{t-1}, o^t)$
Free	Free	Low
Unknown	Free	Low
Occupied	Free	Low
Free	Occupied	Low
Unknown	Occupied	High
Occupied	Occupied	High

$S^{t-1}$	$o^t$	$p(D^t   o^t, S^{t-1})$
Free	Free	Low
Unknown	Free	Low
Occupied	Free	Low
Free	Occupied	High
Unknown	Occupied	Low
Occupied	Occupied	Low

**High:**  
Increase occupancy probability

**Low:**  
Decrease occupancy probability

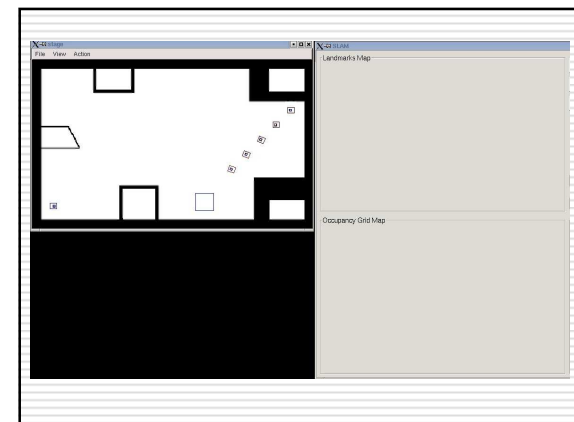
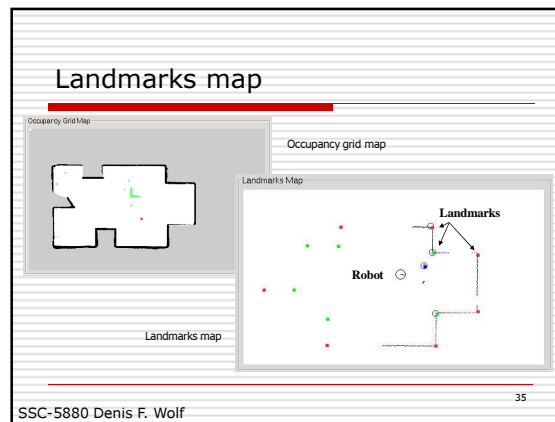


### Landmarks detection and data association

- Corners used as landmarks. (Tomasi & Kanade, 1991) used to detect corners from laser scans.
- Calculate  $\begin{bmatrix} \frac{\partial c(x,y)}{\partial x} & \frac{\partial c(x,y)}{\partial y} \end{bmatrix}^T$  for each point.
- Calculate covariance matrix and eigenvalues  $(\lambda_1, \lambda_2)$ .
- If  $\min(\lambda_1, \lambda_2) < threshold$ , then the point is a corner.
- Landmarks are differentiated and only static landmarks are used for localization.
- Data Association:
  - Differentiate concave and convex corners.
  - Nearest neighbor gating.

**Nearest neighbor of  $x$ :**  
 $\underset{y}{\operatorname{argmin}} d(x, y)$  for  $i = 0, 1, 2, \dots, n$   
 for  $d(x, y) < threshold$

SSC-5880 Denis F. Wolf 34



## Experimental Results

California Science Center



SSC-5880 Denis F. Wolf

37