Mobile Robotics and Intelligent Systems

COMPUTER SCIENCE 417

Gregory Dudek

www.cim.mcgill.ca/~dudek/417.html

Course Objectives

- Robotics, and especially mobile robotics.
- What are real robotics like?
- How can they sense their environment?
- How are the hard problems, how can they be addressed?
- Core algorithms and methods.
- How are these related to human perception or other research domains?

- This course serves as an introduction to the broad area of robotics; intelligent machines that can interact directly with their environment. We will deal primarily with algorithmic issues, but will survey the relevant hardware to ground the work.

Your instructor

- Gregory Dudek
  - Call me: Greg, Professor Dudek, or “Professor” if you forget my name.
- Full professor; been at McGill a long time.
  - Former Director of CS and CIM.
  - Current Director of the NCFRN.
- My own research has dealt with many kinds of robotics:
  - Field robotics (outdoor robots).
  - Algorithms for robots.
  - Coined the term “localization” for robots.
  - Vision-based robots.
  - Underwater robots.
- I feel lucky to be part of this exciting area!

Syllabus

- How can we approach the three key issues in mobile robotics: building a map of our surroundings, knowing where we are, and formulating a plan to get use where we want to go (mapping, localization and path planning)?

- Some broader aspects of spatial representation related to computational vision and graphics, and more tangential issues in mobile robotics will be examined. The emphasis will be on algorithms and techniques.

- **Topics include**
- * alternative methods for representing spatial information such as occupancy grids, potential fields and multi-scale elevation maps,
- * algorithms for estimating a robots position within a (partially) known environment from sensor data and for limiting uncertainty during data acquisition,
- * algorithms for exploring and mapping space.

Topics

1. History and background
2. Planning: deterministic and static, complete and incomplete
3. Vehicle design and kinematics
4. ~~Effectors (Motors)~~
5. Control
6. Sensors: Sonar, Vision, GPS, LIDAR, …
7. State estimation
   - Kalman filtering
   - Particle filtering
8. Mapping and localization (SLAM)
9. Human-robot interaction
10. Selected additional topics (cars, etc)

Note: these topics and their ordering is subject to revision.

See web site for detailed outline and topic sequence.

http://www.cim.mcgill.ca/~dudek/417.html

Topics

1. History and background
2. Planning: deterministic and static, complete and incomplete
3. Vehicle design and kinematics
4. ~~Effectors & hardware (motors)~~
5. Sensors
   Sonar, Vision
6. State estimation
   Kalman filtering
   Particle filtering
7. Control
8. Mapping and localization (SLAM)
9. multi-robot systems
10. sensor networks
11. selected additional topics

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Reference material

Text:

- Computational Principles of Mobile Robotics, by Dudek and Jenkin. Cambridge University Press, 2010.

Selected research papers will also be assigned as reading.

Supplementary texts:

- Autonomous Robot Vehicles, by Cox and Wilfong. Springer-Verlag, 1990.
- Probabilistic Robotics, by Thrun, Fox, and Burgard, The MIT Press, 2005.
- Planning Algorithms, by Steven Lavalle, Cambridge University Press, 2006.
- More on the web site…

Other Material

- Beyond Webcams: An Introduction to Online Robots, Edited by Ken Goldberg and Roland Siegwart, MIT Press, 2001.

- 2 key journals: **IEEE Transactions on Robotics and Automation, Autonomous Robots.**
- Key conference series held by library: **Proc. IEEE Conference on Robotics and Automation (ICRA).**

Evaluation

- The mark breakdown will be:

- 4 assignments worth 10% each = 40%
- 4 quizzes worth 1.25% each = 5%
- 1 midterm exam worth 15%
- 1 final exam worth 40%
- The final exam grade can replace the midterm grade if it improves the student's final mark.

Final Project

- The project used to be a key part of the course. Due to the size of the class it will not be used.

Independent Work Requirement

- Unless explicitly stated, you are expected to work independently on your homework.
- See the course outline on the web for details.

http://www.cim.mcgill.ca/~dudek/765.html

Questions to Consider

Philosophical:

- What is a robot?
- How close are we to having robots?
- What are they good for?

Pragmatic:

- Can I use the skills from this course?
- What kind of research/work is robotics?
- Who does robotics?

What is a robot?

Generic Problems for Intelligent Systems

- How to represent the world?
- How to represent the problem(s) of interest?
- How to break a problem into solvable parts?
- What should I do next?
- How to model errors/unceratinty?
- How to I accommodate surprises (including errors)?

Core Problems for *mobile robots*

Base problem is getting from here to there to do something.

Issues: uncertainty, sensing, planning.

- Where am I? (pose estimation)
- What is the world like? (mapping)
- How can I get there? (path planning)

Notions and terminology

- As we move, we lose track of our position.
  - Odometry error (inaccurate motion) is a generic and unavoidable issue.
- *Sensors* measure the world and our state. *Effectors* allow us to change the world and/or our state. (what are some examples?)
- Passive sensing measures the world without any output.

Specific Sub-problems/domains

Sensor networks. "Robots that don't move".

- Sensing and planning (computation) without action.
- Computer-based sensors "scattered around".

- Places emphasis on estimation problems, as well as communictations, architecture and other infrastructure issues.

Vision-based pose estimation

From a picture, the "vision problem" includes:

- what are we looking at (recognition),
- what is the 3D geometry of the scene we are looking and (reconstruction or *shape-from-X*),
- where are we looking from?

These are *very difficult* in their general form.

Can we define a more restricted instance of these problems that can be solved?

My own research

- Primary focus: **computational mobile robotics**

- Related problem dom
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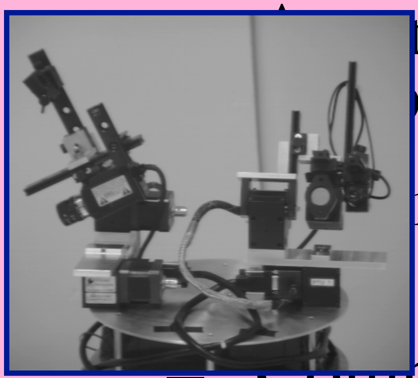
    uter graphics
  - igent systems fo
  - Computer vision



Mobile Robotics

- How machines can understand space, map it out, represent it, and navigate within it.
- Inspired by cognitive science.
  - Tied to key aspects of biological intelligence.
- Motivated my many applications that require mobility.
  - Delivery within facilities.

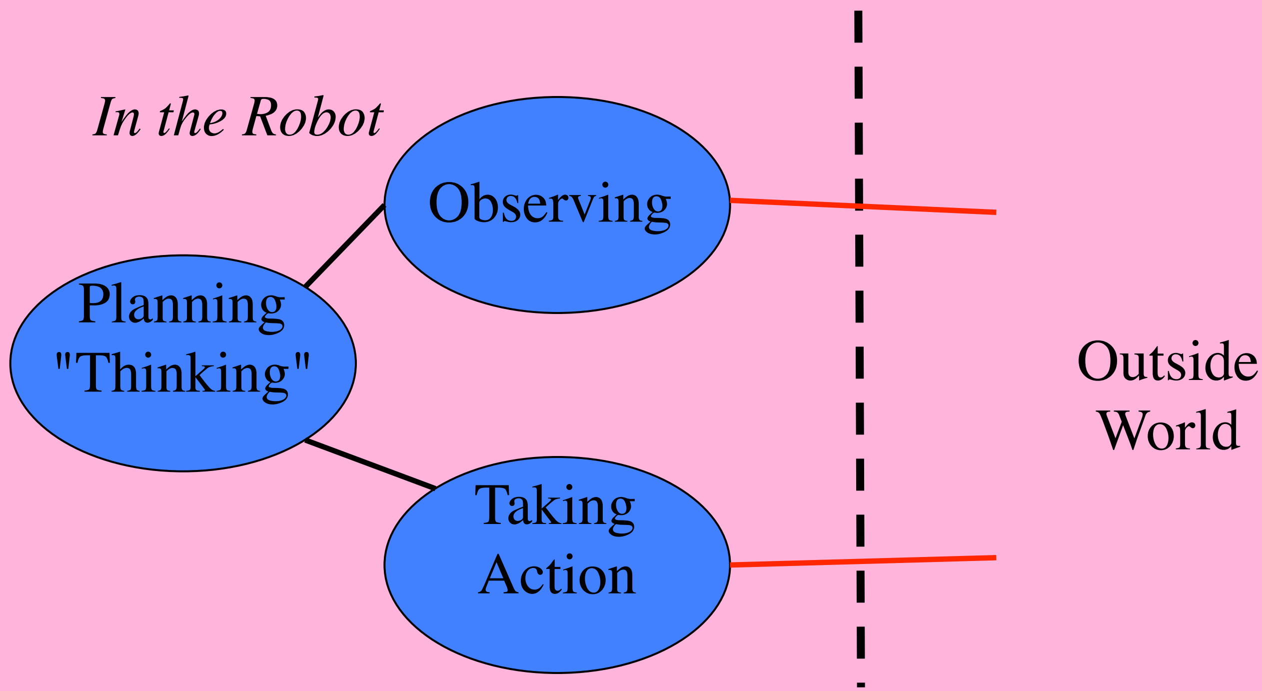
Scientific Activities

- Identify key problems
- Discover problem representations
- Analyze Problem Complexity
- Find Physically Appropriate Approximations
- Invent Algorithms

Necessary evils:

- Build hardware
- Construct electronics
- Develop software
- Invent communication protocols
- Create testbeds

Robotics: Characterization



The challenge

- Robotics combines issues of:
  - Computer science
    - Artificial Intelligence, algorithm design, user interface.
  - Mechanical engineering
    - Mobility, robustness, stability.
  - Electrical engineering:
    - Controllability, electronic design, power, …
- All this must be integrated, run in real time, and efficiently.

Real robots…

- are NOT very smart.

- Or, more precisely, the problems a *hard*.

Illustrative Problems

1. Robot **mapping and positioning**.
   - How do we model the variability of the visual world?
   - Competition robots.
     - Simple solutions by engineering the environment.
     - Undergraduate student teams partially funded by the Dean's special funds. (Won 1st place at the last 2 major AI-conference competitions.)
   - Solutions for arbitrary environments
3. Recovery of **3-D depth** information from limited information.
   - Probabilistic modelling of physical data.
   - Learn how the world is structured.

Mapping and Positioning

- Map construction and position estimation are problems of longstanding human interest.
- Essentially every intelligent organism is mobile, and every mobile organism needs these abilities.

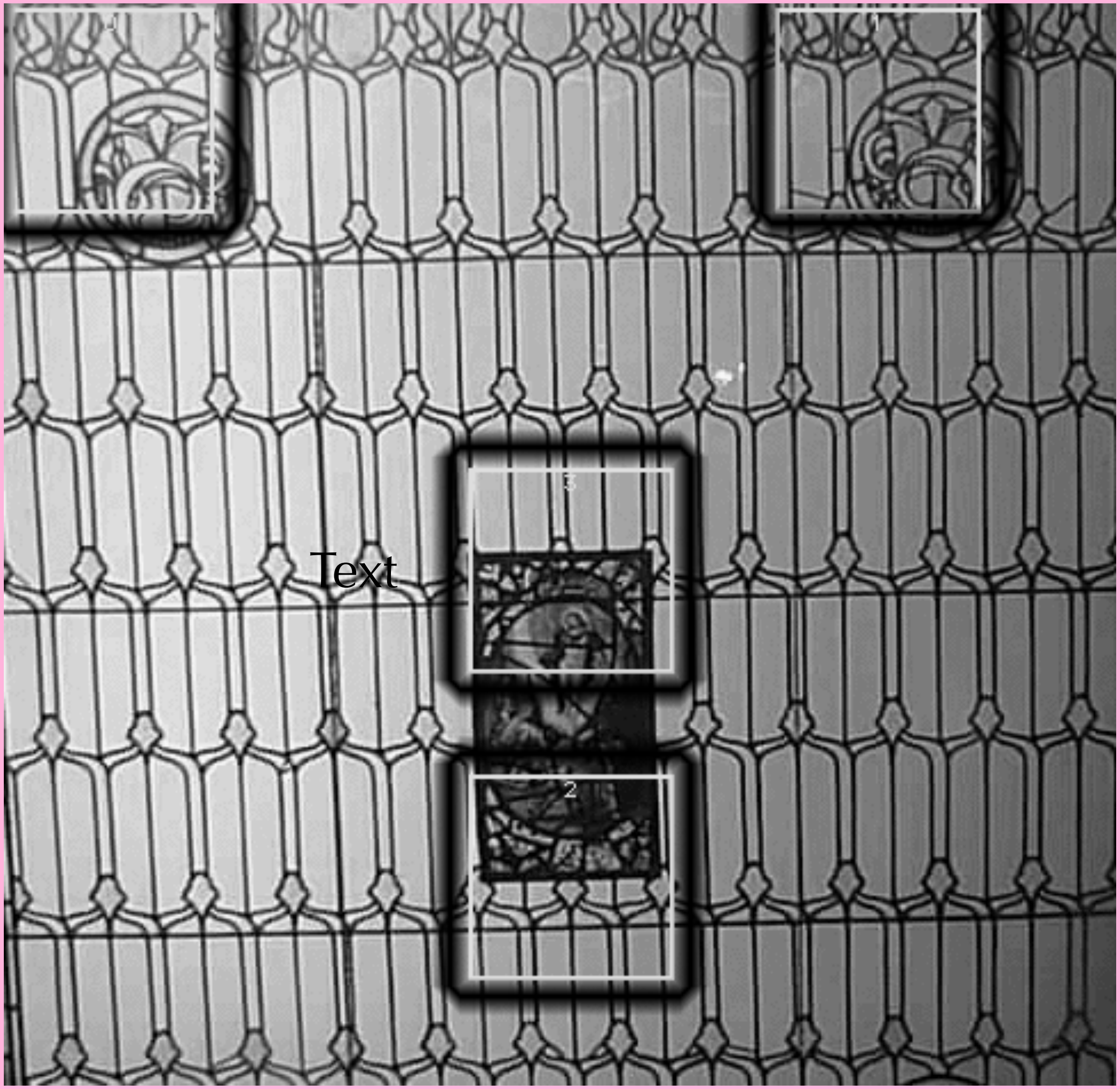
Example: Competition Robots

- In robotics competitions our teams have used a combination of color-based homing and triangulation to determine where it is on the field.

Arbitrary Environments: what landmarks ?

Much of our work has been inspired by visual attentional mechanisms from human psychology; in some cases, we have contributed to that domain.

Our robot would notice these points and attempt to remember them.



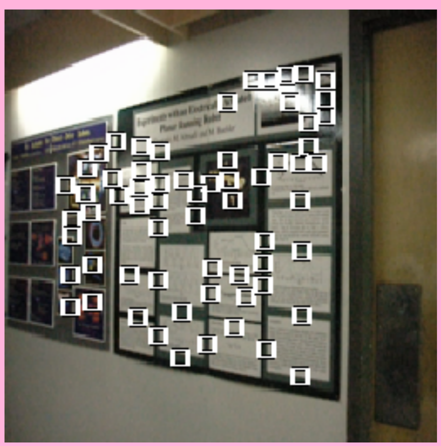
Results: Place Recognition

By remembering "interesting" points, we accomplish several recognition tasks

Test Images

Training Images

Best match



Best match

Object Recognition (2)

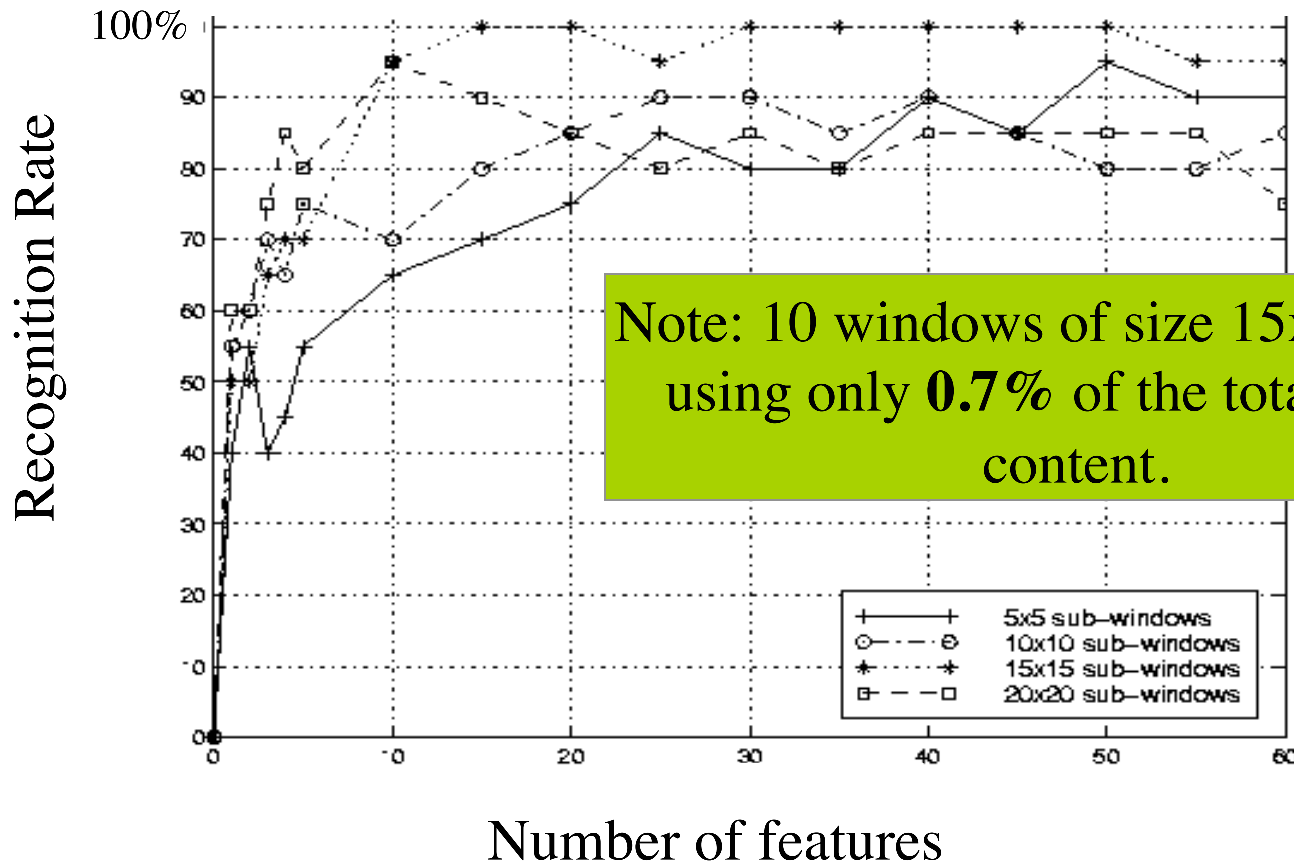
Test Image

Training Image

Best matches

Note:
background variation
and occlusion

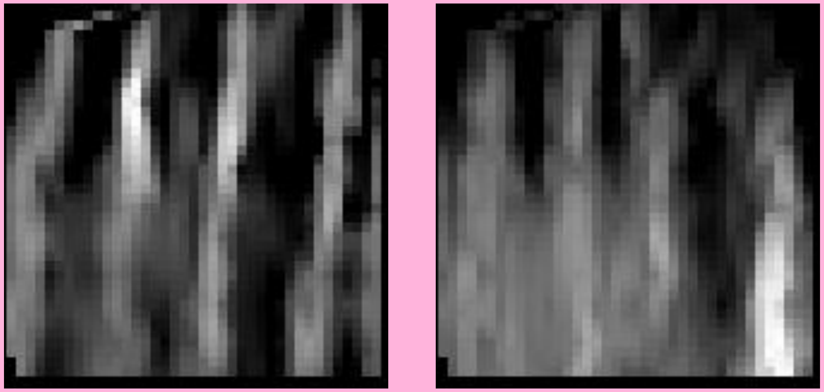
Performance Versus Number of Interest Points



Note: 10 windows of size 15x15 means using only **0.7%** of the total image content.

Observation Likelihood Distribution

- Based on basic recognition, can compute probability of being at any point: denoted by brightness.

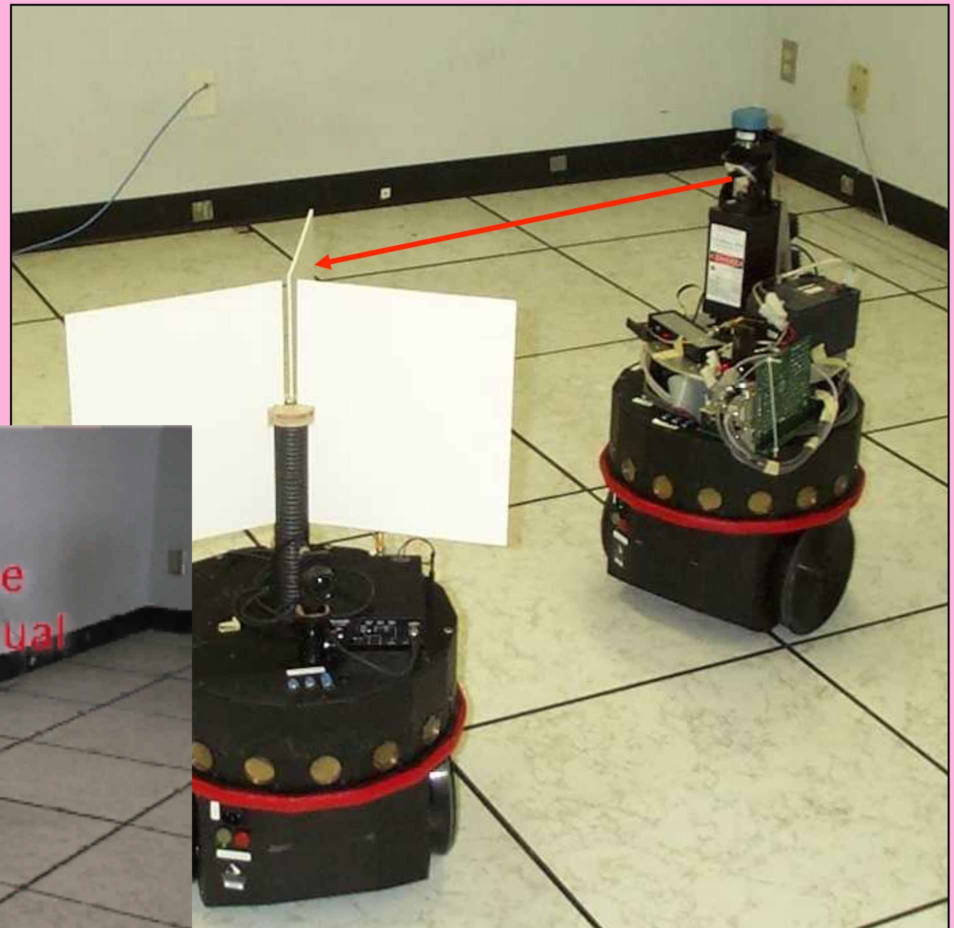


Probability
(top view)

Example image

Another Way to make Maps: Via Collaboration

Ro

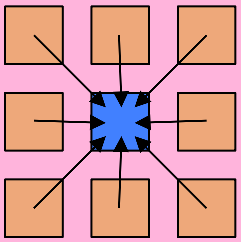


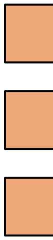
Laser Robot Tracker

Learning Probabilistic Models of Scene Structure

Key idea: build a probabilistic model of what is at any point based on knowledge of things in it's immediate vicinity.

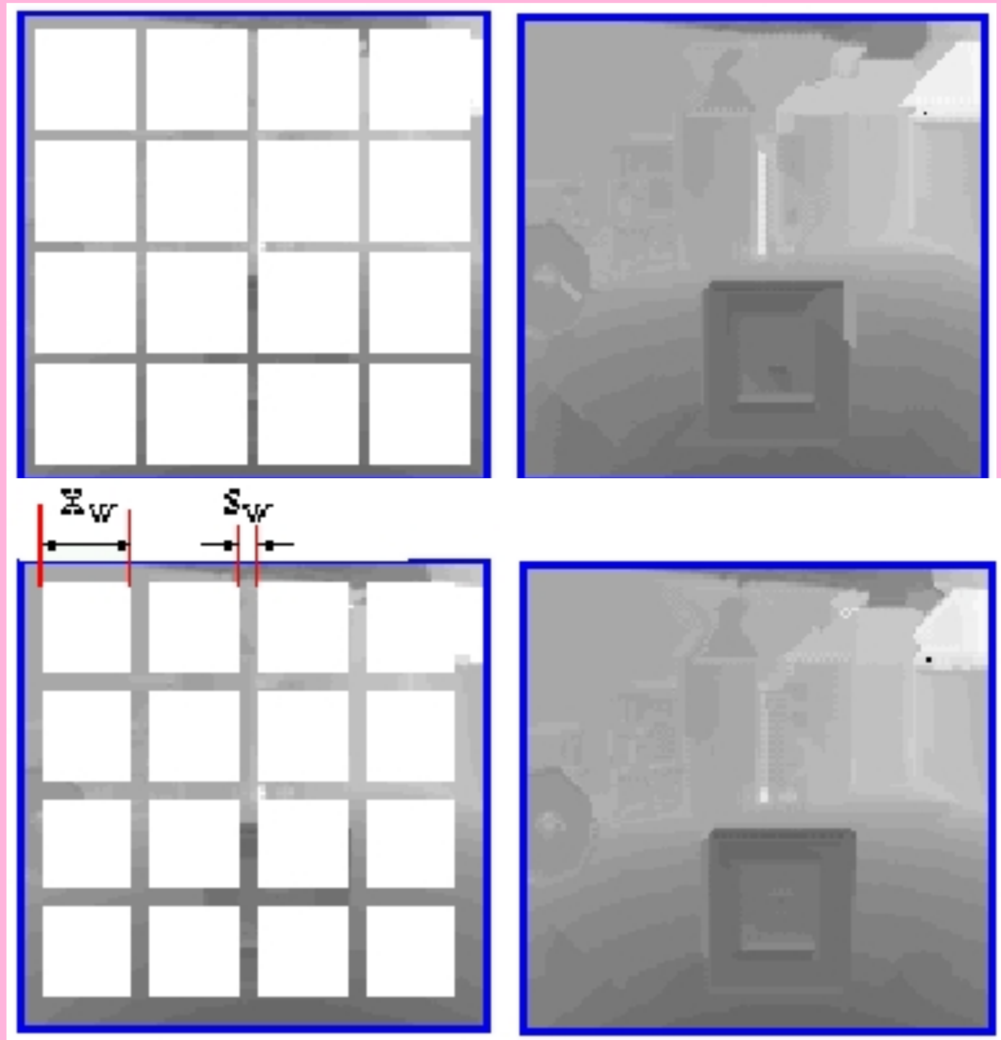
$$P(V_{x,y} = v_{x,y} \mid V_{k,l} = v_{k,l}, (k,l) \in N)$$



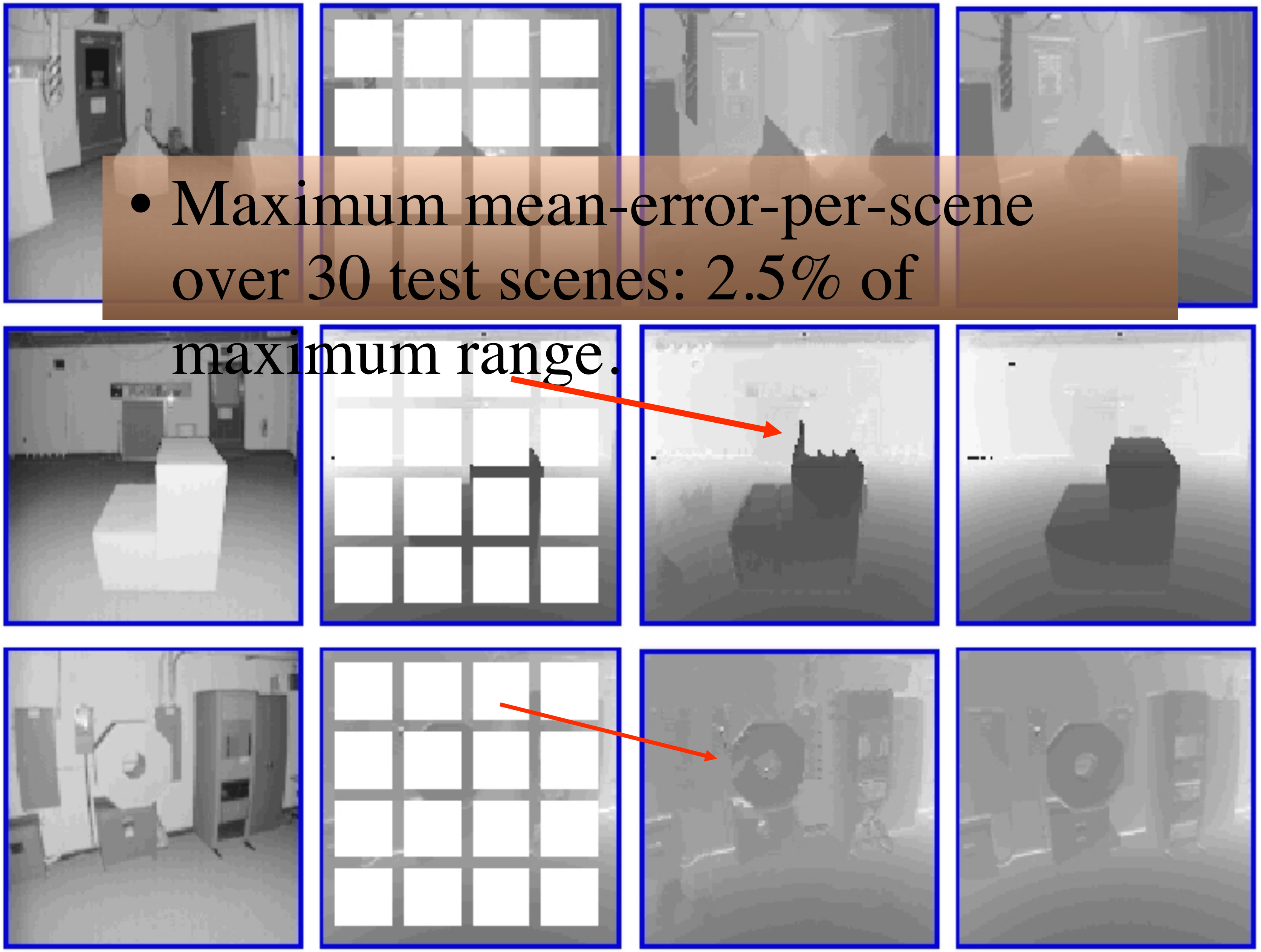


Reconstruction from Sparse Data

- From **sparse** range data and a picture, can be recover 3D structure using probabilistic rules learned from the environment?
- Yes!
- Mean error 0.9% and 1.2% of full depth range.



More examples



- Maximum mean-error-per-scene over 30 test scenes: 2.5% of maximum range.