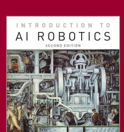
15b



Terrain Mapping and Traversability

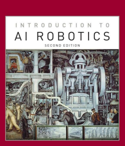
Sections 15.7 and 15.8

15b

Specific Learning Objectives
Sections 15.7 and 15.8

Motivation
Local
-Markov
--EKF
Global
-Grid
-MCL
Dynamic
Summary

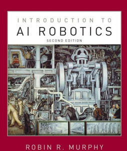
- List the possible uses of terrain data by a robot and the impact of terrain on its functions
- Describe the difference between DTED, DEM, DSM, and orthomosaics
- Give examples of two types of methods for proprioceptive terrain identification and exteroceptive terrain identification by ground robots and limitations of each
- List and describe the five attributes of traversability: Verticality, Surface properties, Tortuosity, Severity of obstacles, Accessibility elements
- Give the ratio for each of the 3 scales of an agent to the environment and what it means for a robot



15b

Terrain Mapping

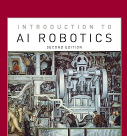
Motivation
SLAM
Exploration
-Frontier
-GVG
Sym-Grnd
Terrain
-Maps
-Impact
-Sensing
Summary



- What does terrain mapping mean?
- Terrain Maps Types
  - Elevation-oriented
  - Imagery
    - Mostly manual interpretation
- Usually terrain mapping means getting elevation data
- But in robotics, elevation maps are available so it's more about mapping things that aren't elevation

15b Components of a Terrain Map

- Natural terrain
  - Surface configuration such as landforms, slope or gradient
  - Vegetation features such as trees or bushes
  - Soil features
  - Water features
- Man-made features
  - Urban areas
  - Transportation: highways, railroads, bridges, tunnels, ferries, fords, … shipyards, naval bases, landings, airfields



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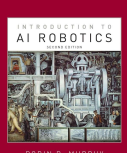
15b DTED Maps

Motivation
SLAM
Exploration
-Frontier
-GVG
Sym-Grnd
Terrain
-Maps
-Impact
-Sensing
Summary

- Digital Terrain Elevation Data (DTED)
  - maps showing the elevation of the ground.
  - Produced by NIMA (National Imagery and Mapping Agency)
- Five Levels of Resolutions
  - 3-5 are classified by US
- But <10m data sets are commercially available

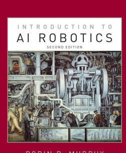
DTED Level	Post Spacing
1	100m
2	30m
3	10m
4	3m
5	1m



15b Terrain Identification

- Digital terrain elevation maps are not sufficient for navigation
  - because they do not show locations of trees, large rocks, slick muddy areas of low traction, and so forth.
  - Surface properties of water, sand, and different soils can impact movement
  - They may be outdated and, therefore, not reflect the true conditions

- Therefore, robots need algorithms for terrain identification to enable a robot to adapt to its environment

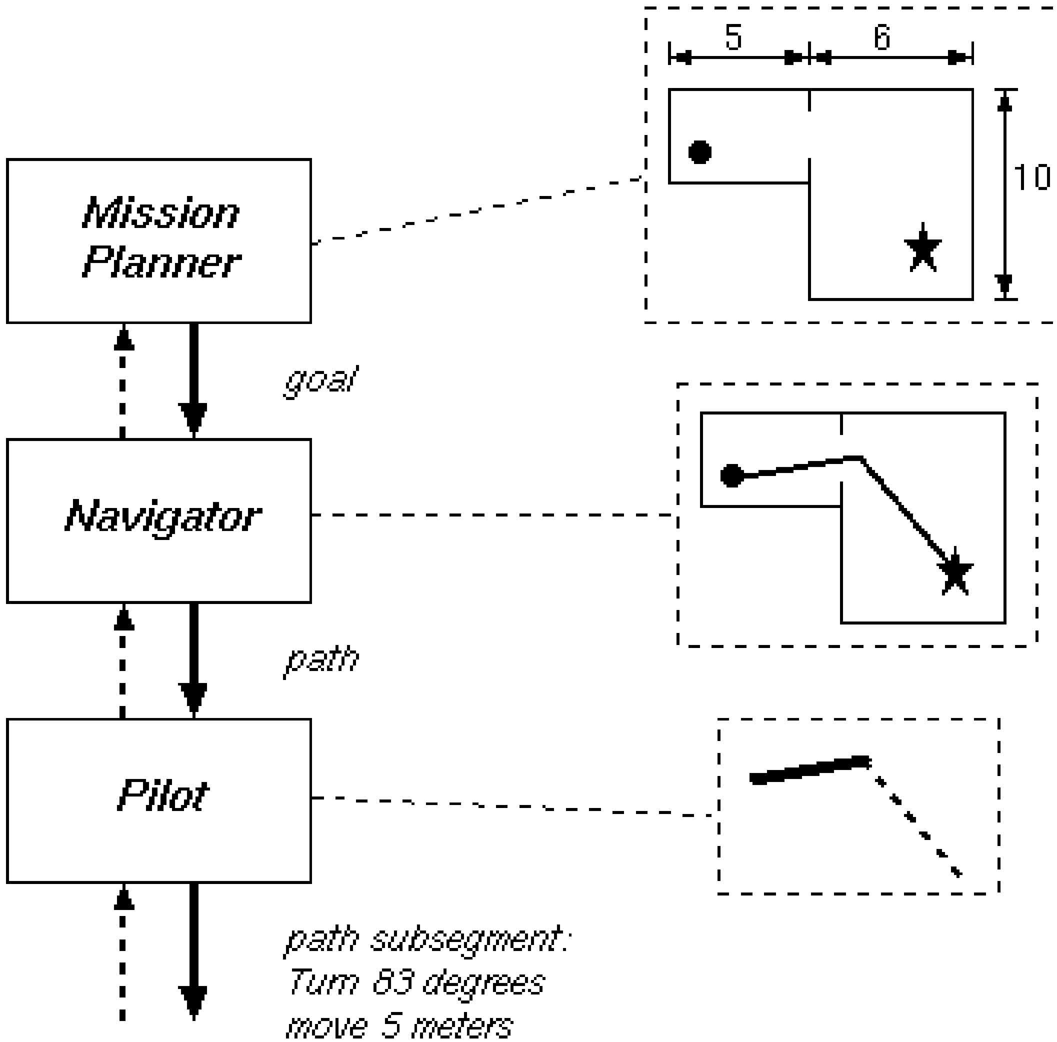


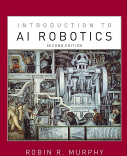
15b Recall: NHC Navigation Planning

Reasons about goals, ROE

Path Planning, any navigational constraints

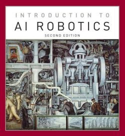
Instantiates behaviors & monitors progress





15b How Robots Use Terrain Maps

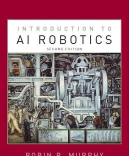
- Mission Planner, Navigator path planning
  - 10m x 10m or 30m x 30m is sufficient
  - Path planning, estimation of transit time, project mobility suitability and energy costs (DARPA Grand Challenge, Mars Exploratory Rovers)
  - Stay hidden behind a ridge line (DARPA UGV programs)
  - Avoid certain man-made features
- Pilot or Behaviors: How it relates to immediate traversibility
  - 10m or less problem (which we don't have)
  - So <=10m is "sensed" terrain



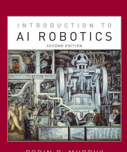
15b How Sensed Terrain Affects Robots

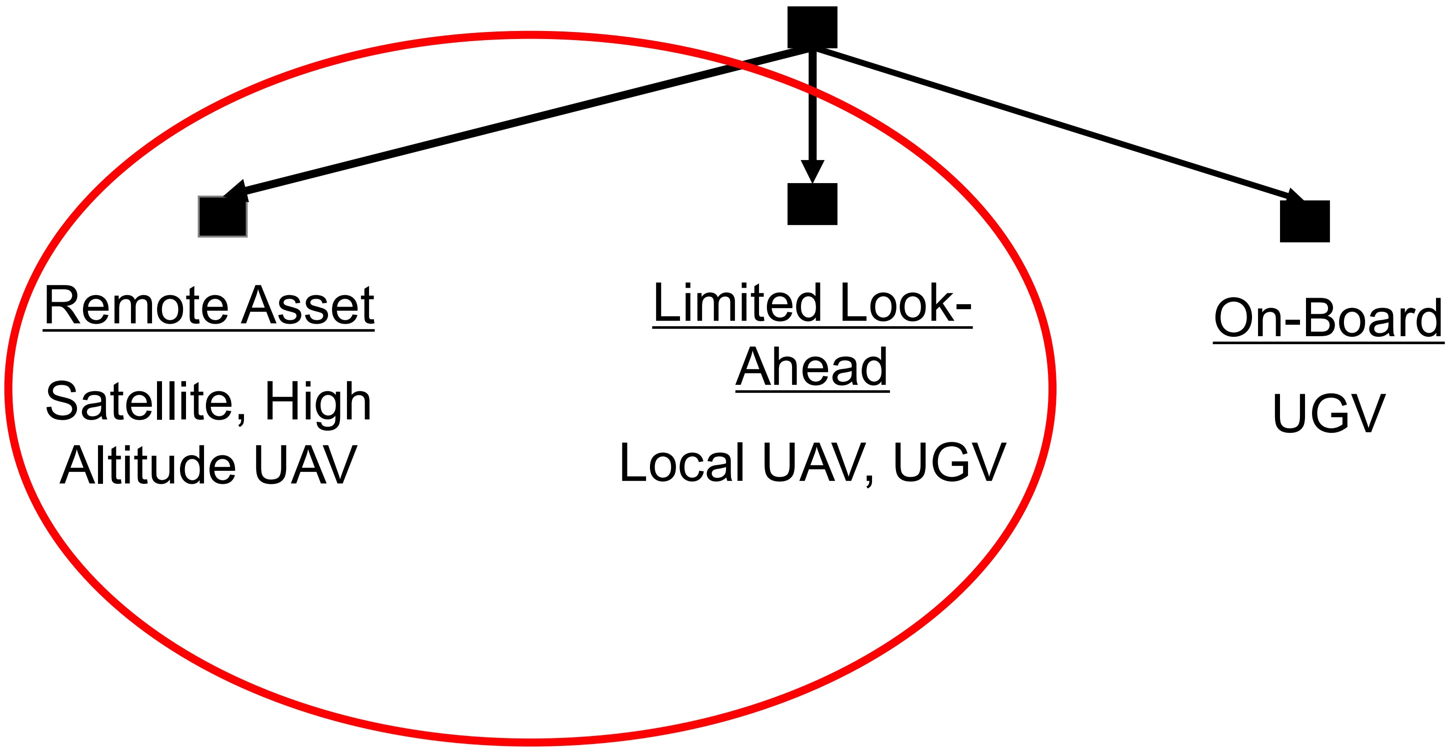
Motivation
SLAM
Exploration
-Frontier
-GVG
Sym-Grnd
Terrain
-Maps
-Impact
-Sensing
Summary

- Sensory-motor changes (behavioral gains)
  - Changes parameters of active behaviors
    - "bumpy" == slow down
- Schematic changes (cues within the script)
  - Changes the set of active behaviors
    - Substitute a different sensor
    - Change subgoal
- Deliberative changes (machine learning)
  - Associate what works with current situation
- Distributed changes (multiple robots)
  - How to propagate to other robots
  - How to divide up computation task



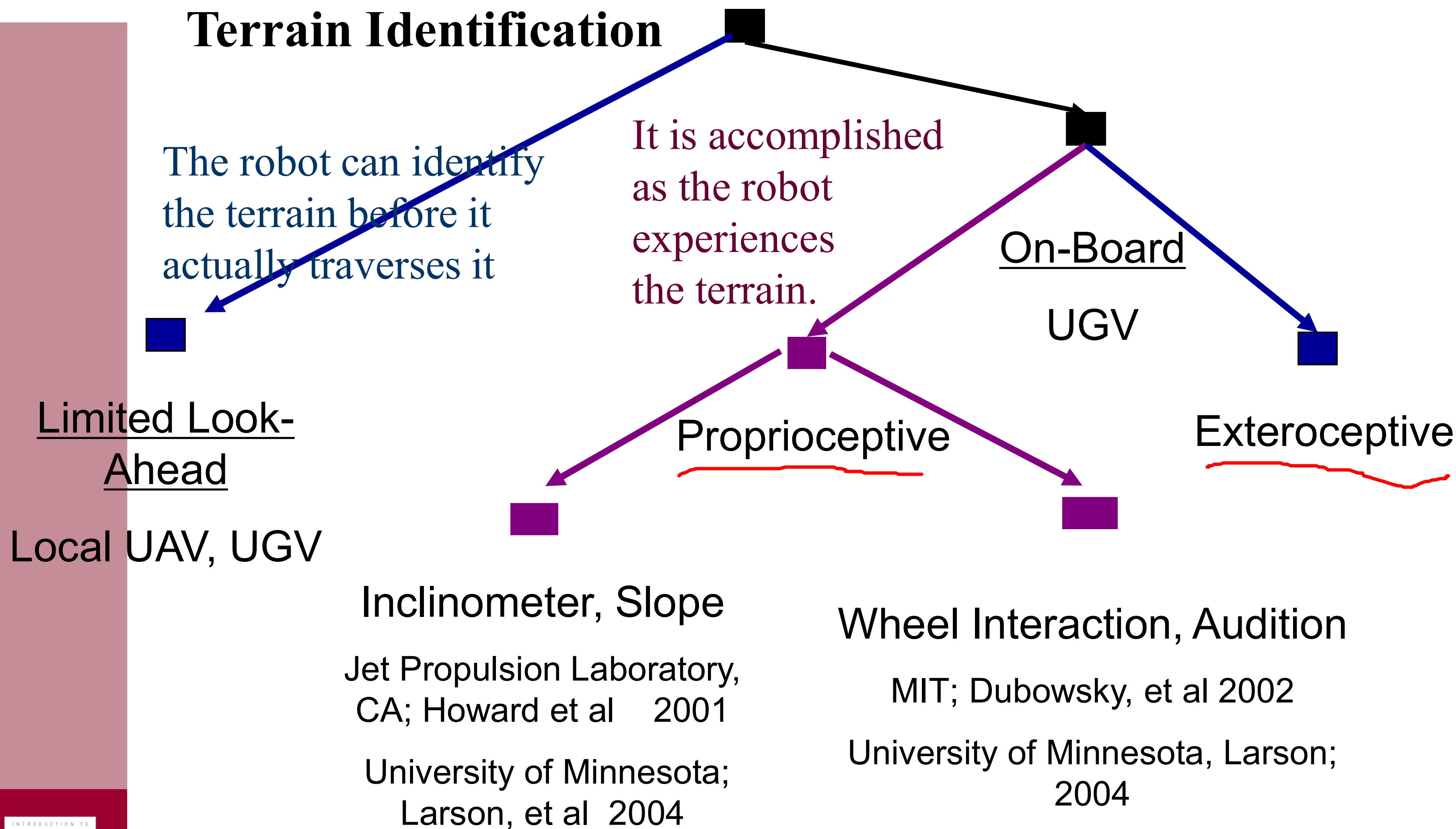
15b Sources of Terrain Information for a UGV

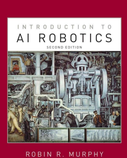




15b

Projective vs. Reactive





15b How UGVs See Terrain Ahead of Them

On-Board

UGV

Exteroceptive

MULTISPECTRAL Imagers

University of California Riverside; Bhanu, et al; 1997 TEXTURE

LIDAR

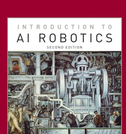
Carnegie Mellon; Herbert, et al; 2004 DENSITY, TEXTURE

Applied Perception Inc.; Ollis, & Jochem; 2003 DENSITY

COLOR Camera

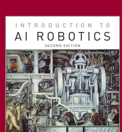
Carnegie Mellon; Dima, et al; 2003 COLOR, CAMERAS

Carnegie Mellon; Davis; 1995 COLOR, CAMERAS/NEURAL NETWORKS



15b Example of How Challenging

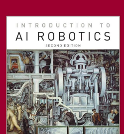
Motivation
SLAM
Exploration
-Frontier
-GVG
Sym-Grnd
Terrain
-Maps
-Impact
-Sensing
Summary



- Problem: Distinguishing navigable patches of vegetation (e.g. tall grass) from real obstacles

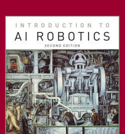
15b Stereophotogrammetry (1)

- Software packages such as:
  - Agisoft
  - PIX4D
- Stereo refers to getting the distance between two images of the same location taken by a UAV from two positions rather than a stereo camera
  - See chapter on sensing
- Unlike LIDAR, get elevation but also the visual image so the results can be a 3D visual reconstruction
- For UAVS
  - Fly at fixed altitude, collect images with overlap (planning for coverage)



15b Stereophotogrammetry (2)

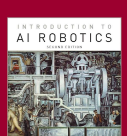
- Three caveats
  - Enough of the same location must be in both images, called the *image overlap*
    - Recall eyes and stereo cameras move to have as complete an overlap in image pair as possible, *vergence*
    - But UAVs are moving
  - Images should be taken as close in time as possible so that changes in shadows and brightness do not change the *interest points;* the interest points can form a point cloud
  - The elevation is consistent within the map (local coordinates) but the map has to be anchored to surveyed points in order to be in absolute coordinates. If anchored, can click on a point and get the GPS plus elevation.
    - Anchoring is by seeing the surveyed points in the imagery



15b

Some definitions

- Orthomosaic
  - A high-resolution master image compiled from multiple images that have been tiled together,
- Topographical maps
  - Contours of the terrain, both natural and man-made but without vegetation
- Digital elevation model (DEM)
  - Grid map with each grid element containing the height
  - Useful because it is independent of the vegetation and ground cover, and then gets to the underlying structure
- Digital surface maps (DSM)
  - DEMs that include vegetation and ground cover
  - Each pixel in the DSM map has the elevation of the highest surface, not the ground, for a grid area.



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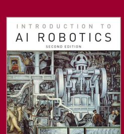
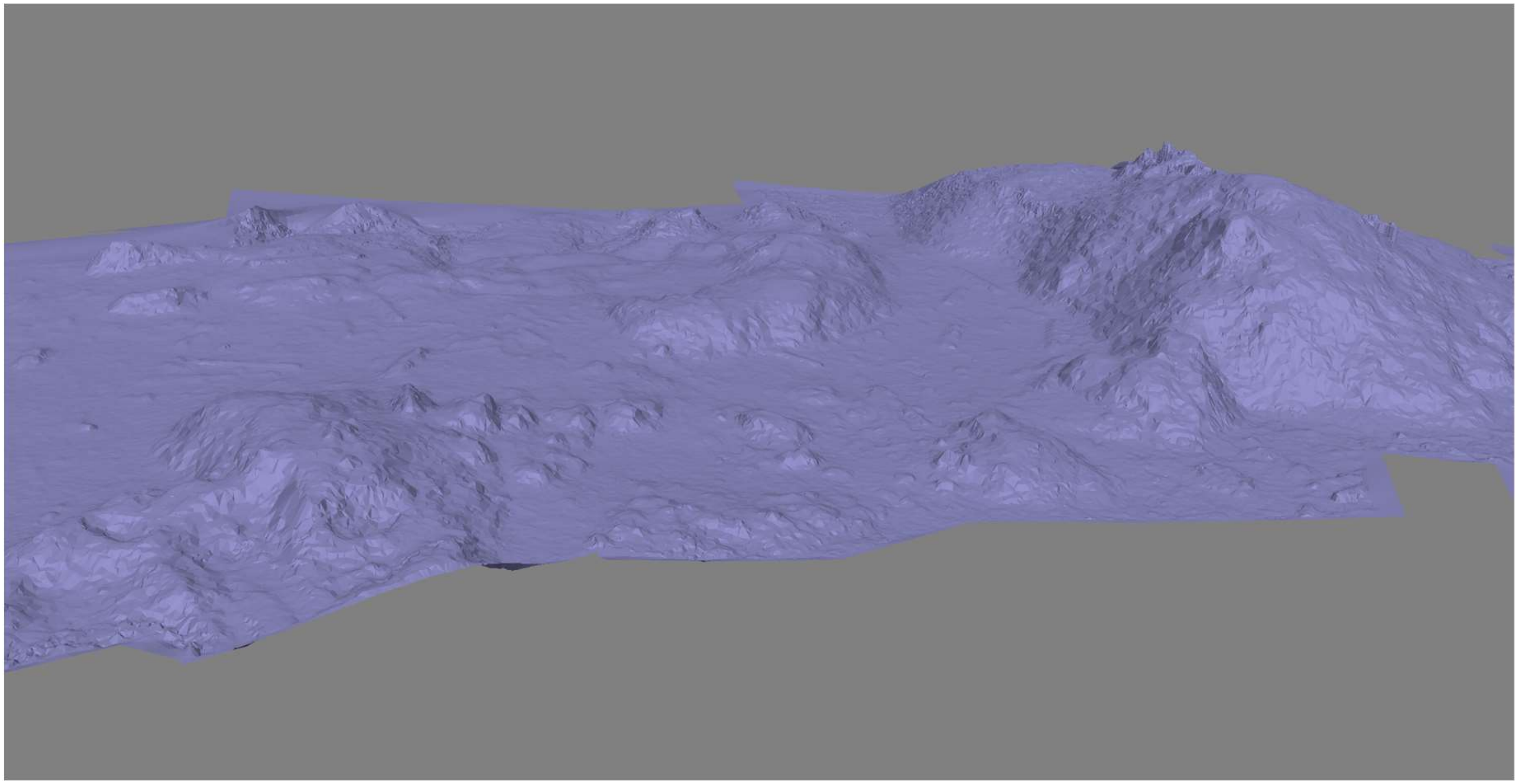
Orthomosaic

An orthomosaic of a mudslide derived from approximately 20 images taken by a small unmanned aerial vehicle



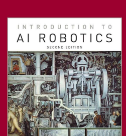
15b DSM shown as the elevation with the video imagery superimposed

15b DSM shown as a "Naked" Point Cloud



15b Overview of Scale and Traversability

- Workspace, or environment E, is divided into regions
- Each region may have unique traversability characteristics
- The traversability is also affected by the relative scale of the agent, A, to the environment, E
  - A small robot can work in smaller regions than a large robot can



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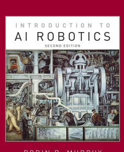
15b

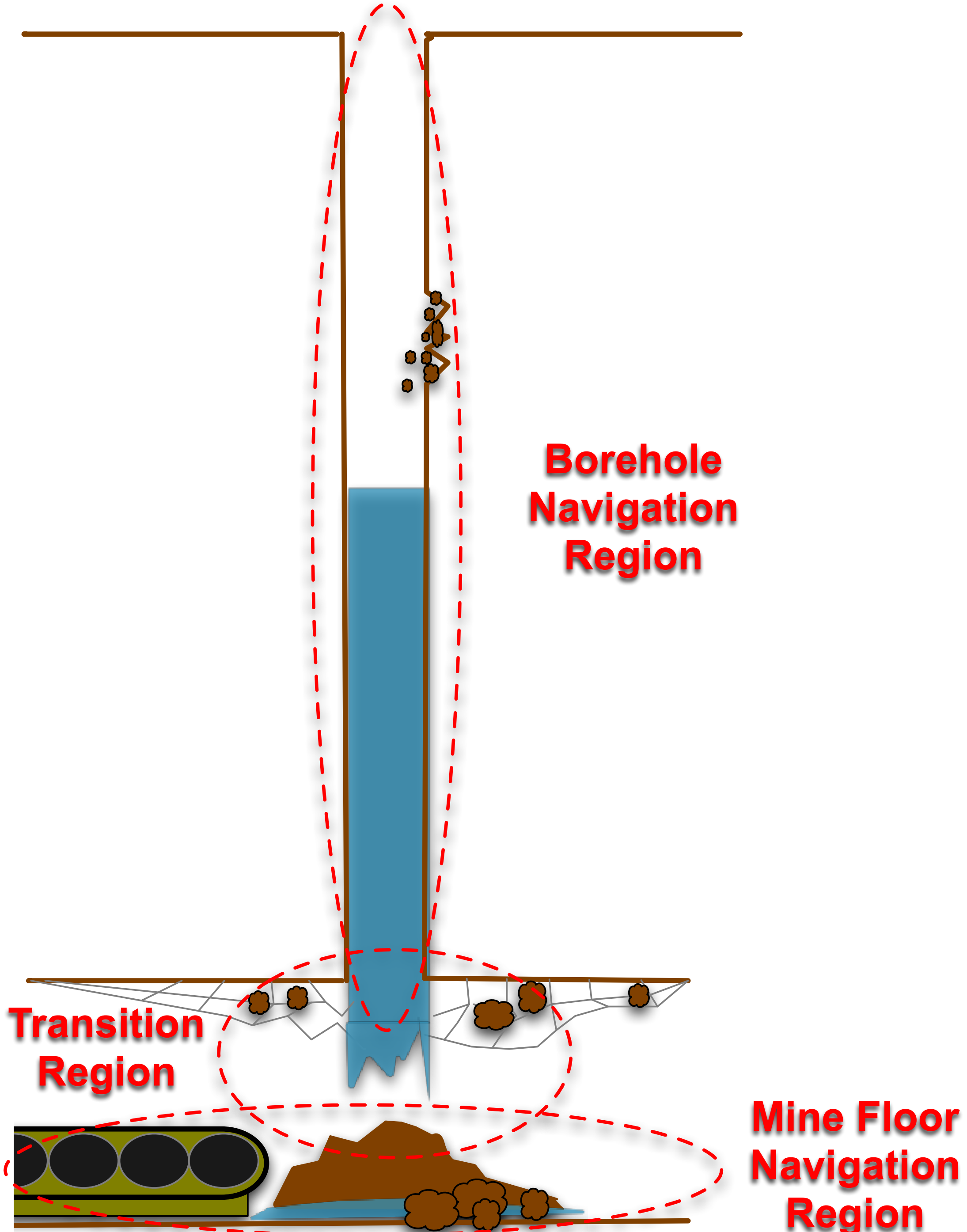
Regions

- Workspace for a mission may consist of distinct regions

- Examples
  - Outdoor, then go indoors
  - Wide hallway, up a stairway, suspended walkway, through a door, a small room
  - Road, to off-road, to forest, to hills, to mountain
  - Ocean surface, ocean, inside of a shipwreck

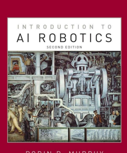


15b


Borehole
Navigation
Region
Transition
Region
Mine Floor
Navigation
Region

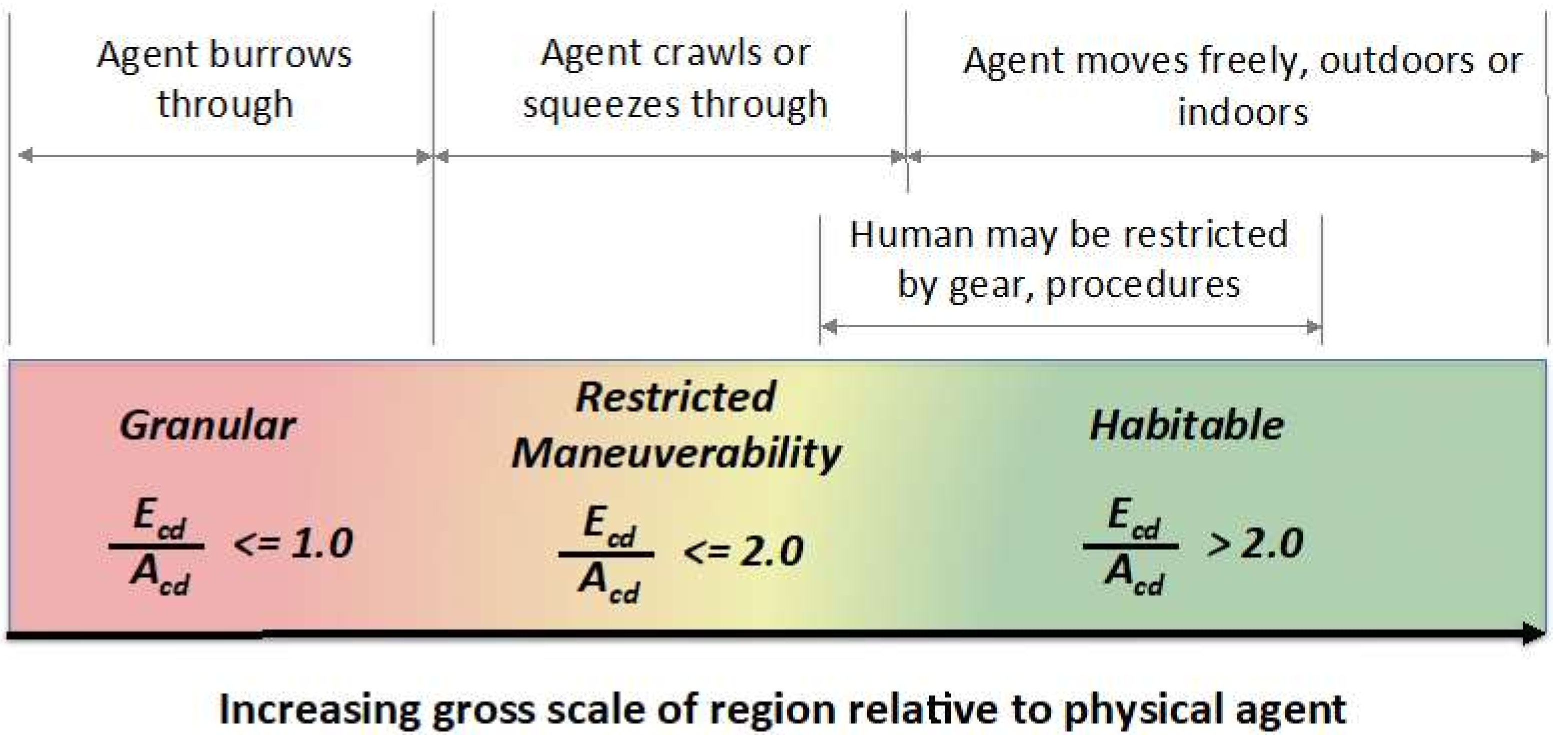
15b Characteristic Dimension cd

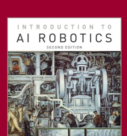
- The size of a robot or an environment can be expressed as the characteristic dimension cd
  - The characteristic dimension for a ground robot is its turning radius
  - For a UAV, it is the standoff distance it can safely hover from objects
  - The characteristic dimension of an environment is the cross section of the narrowest spot a robot would be expected to move through



15b Three Mobility Regimes

The ratio of the characteristic dimension of the environment E_{cd} to the robot (or a human or canine agent) A_{cd} roughly divides environments into three mobility regimes

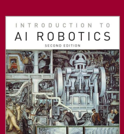




15b Traversability Attributes

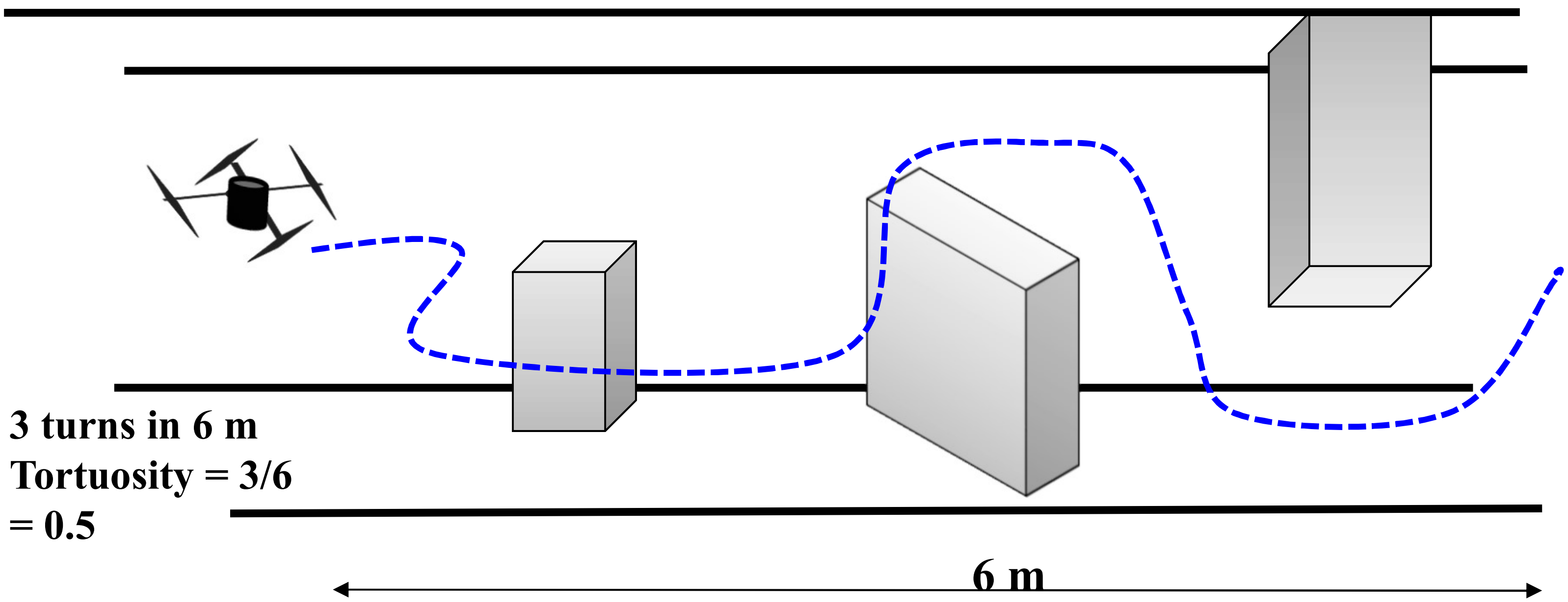
- Verticality (maximum slope)
  - Disasters- UGVs rappel down
  - Indoors: stairs, sloped floors in theaters
  - Tunnels
  - UMV: caves, sunken ships
- For ground robots: Surface properties
- Tortuosity
- Severity of obstacles
  - Outdoors: vegetation, rocks
  - Indoors: furniture
- Accessibility elements
  - Doors, windows, elevators, and stairs

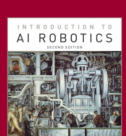
A function of the scale of the robot with respect to the environment (applies to: Tortuosity; Severity of obstacles)



15b Tortuosity

Tortuosity is calculated as the number of turns taken per unit distance. For UAV includes changes in altitude.





15b

Summary

Motivation
SLAM
Exploration
-Frontier
-GVG
Sym-Grnd
Terrain
-Maps
-Impact
-Sensing
Summary

- Ground terrain maps are available at low resolutions which are good for planning but terrible for execution
- UAVs are being used to create digital surface maps
- Outdoor navigation by UGVs requires being able to sense terrain, but currently there are no reliable proprioceptive or exteroceptive methods, though proprioception appears more promising in the short term
- Traversabilty has five attributes: verticality, surface properties, tortuosity, severity of obstacles, assessibility elements
- Traversability is also a function of scale, which leads to 3 categories of regions
  - E/A<=1.0 Granular
  - E/A <=2.0 Restricted manuverability
  - E/A >2.0 Habitable