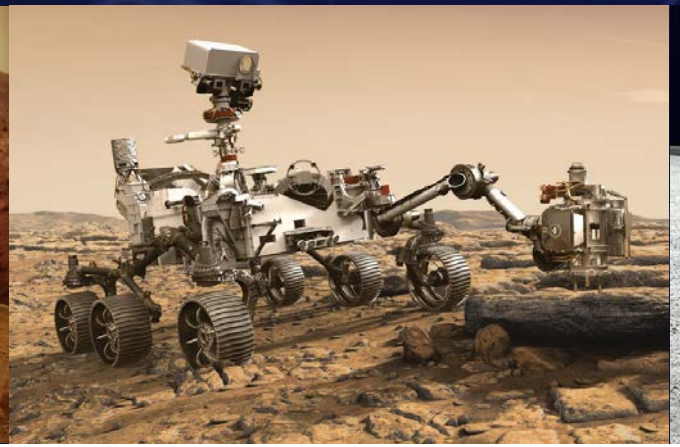
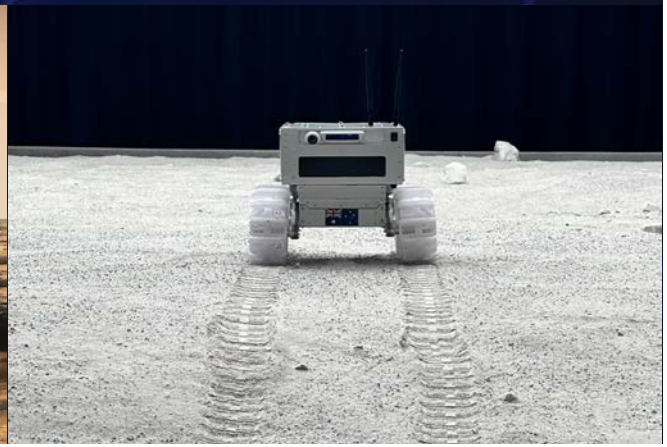
QUT Centre for Robotics

Planetary Rovers - Autonomous Navigation in Extreme Environments

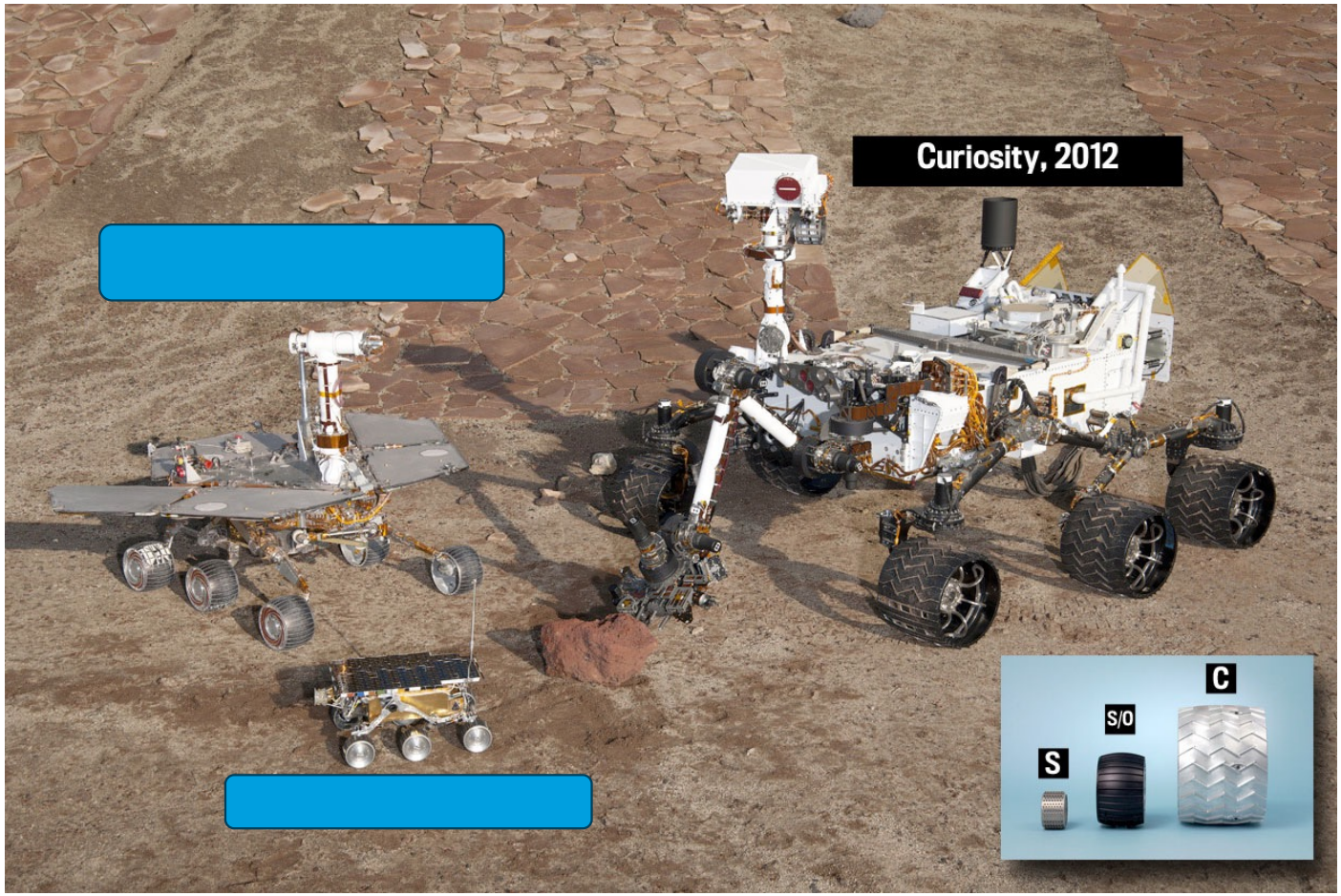
A/Prof. Thierry Peynot

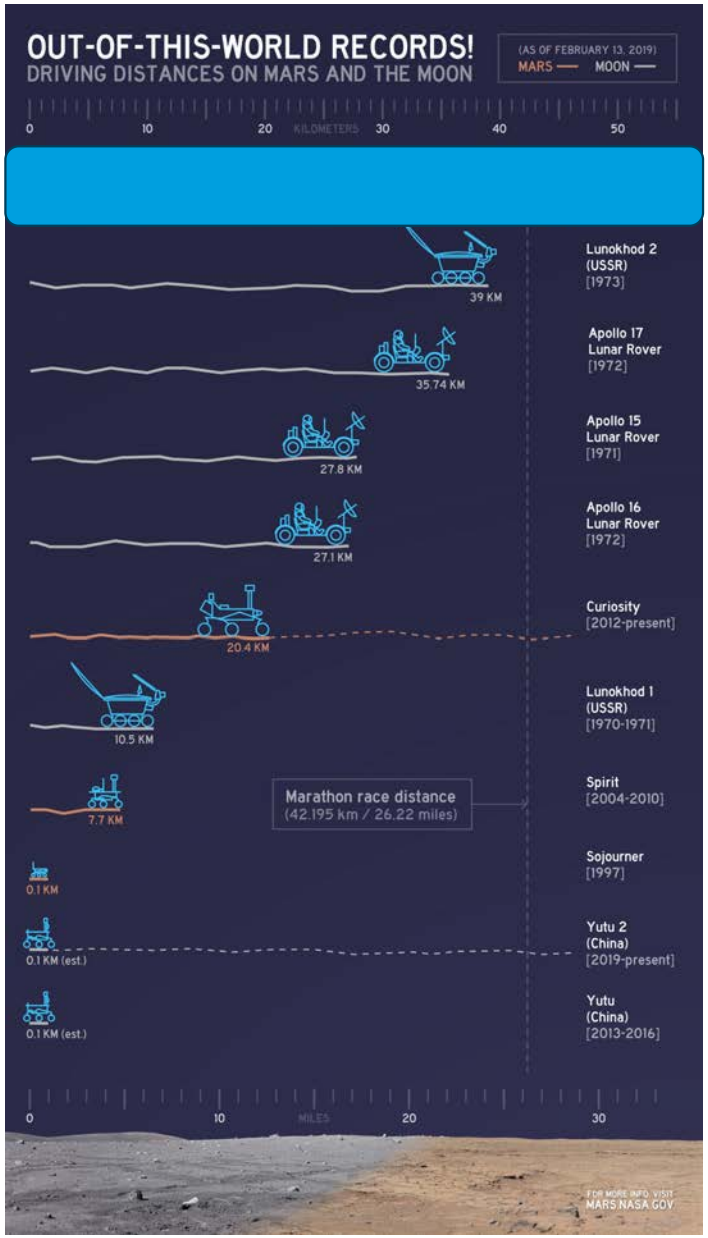
QUT Centre for Robotics





Planetary Rovers: Endurance race





ROVER MISSION

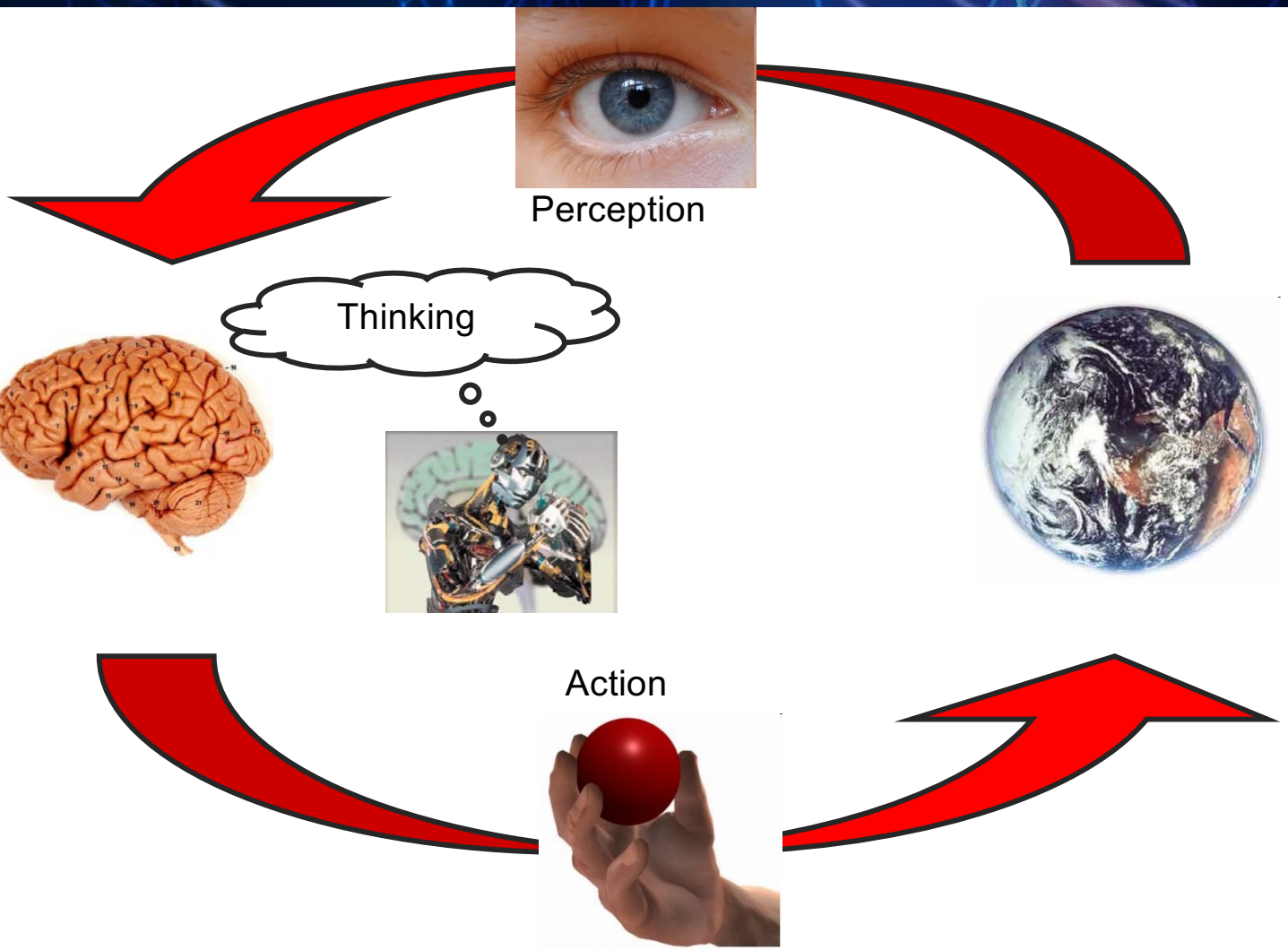
ELO2
EPE + LUNAR OUTPOST
OCEANIA CONSORTIUM

Yandiwanba: QUT Lunar Testbed & Space Lab

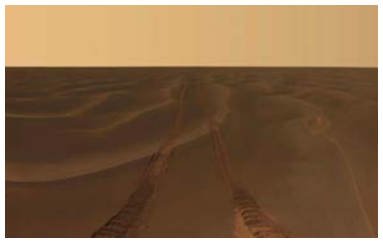

COMMUNICATIONS
ONLINE
FOUNDATION SERVICES
ONLINE
HEALTH SYSTEMS
ONLINE
Australian
Space Agency

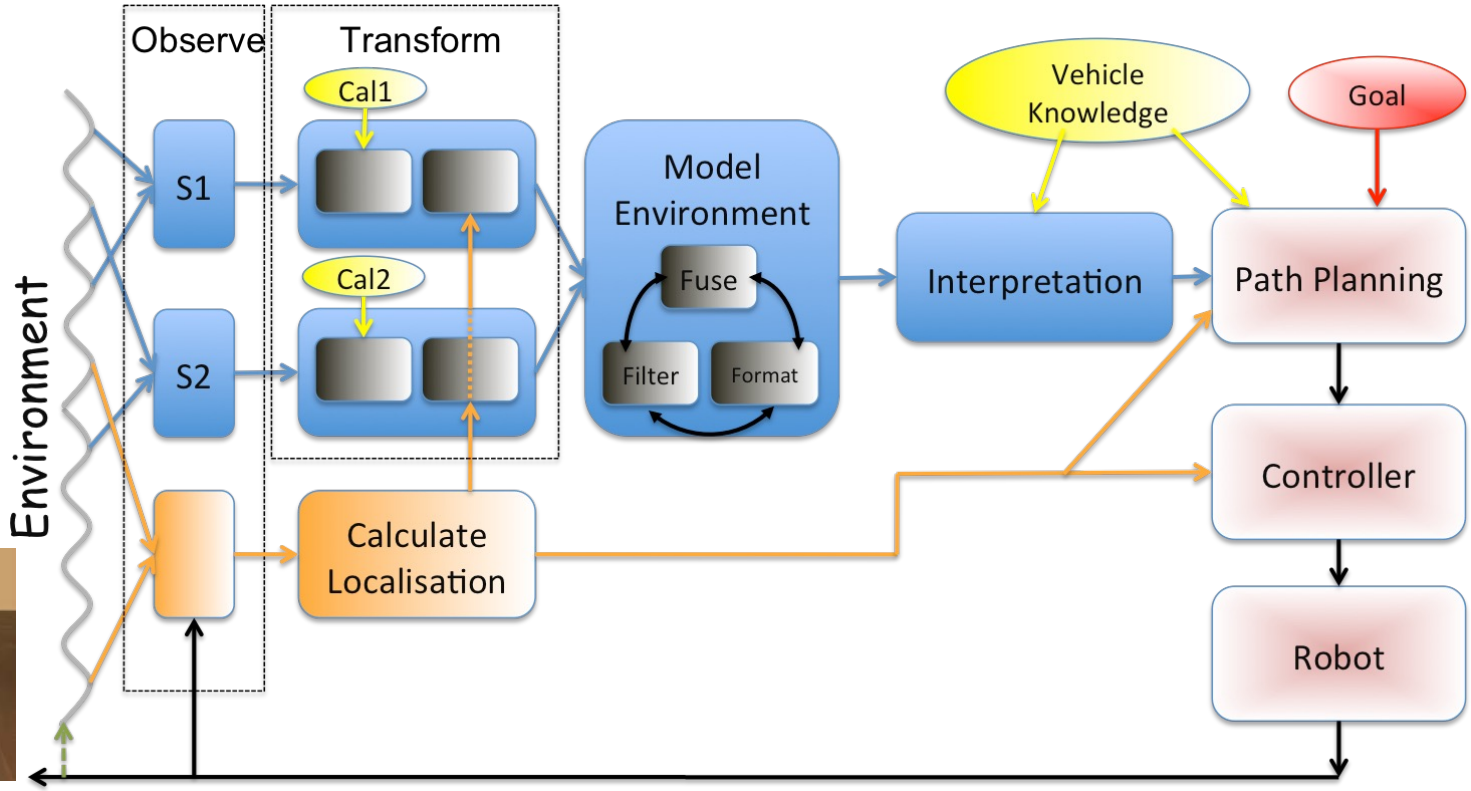
Centre for Robotics

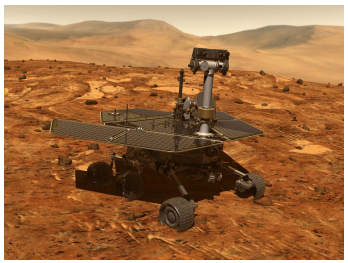
Autonomous Robot



Autonomous Navigation (Architecture)







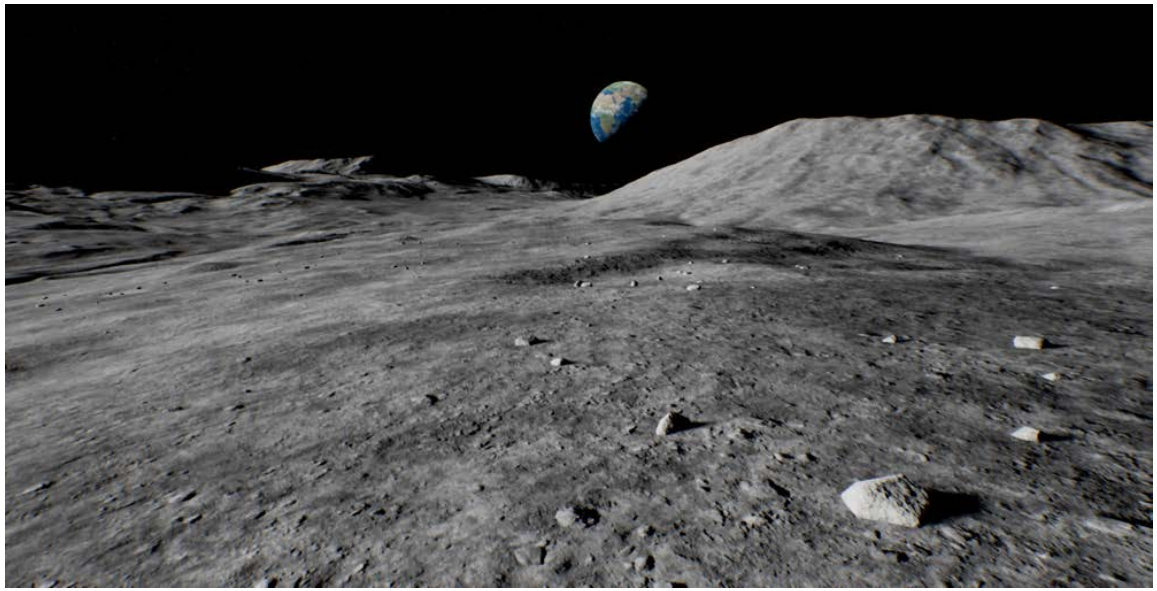
Environmental Constraints

And other external constraints

Centre for Robotics

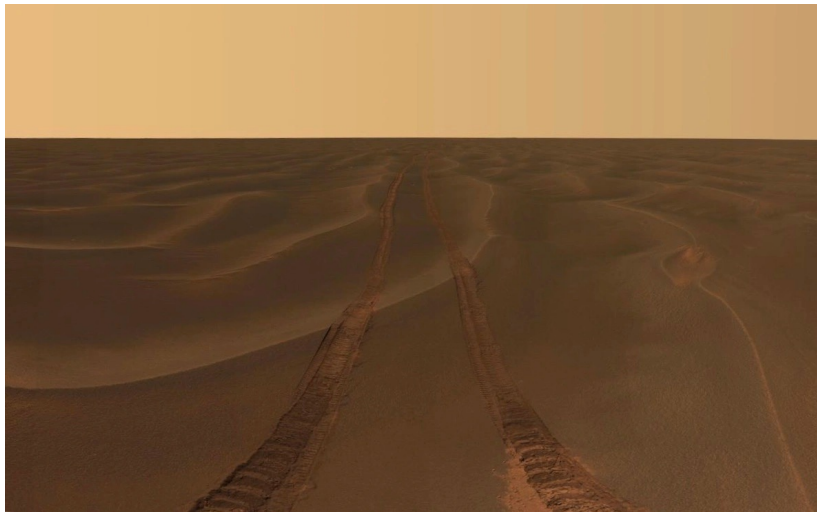
Environmental Constraints (Moon, “Near Side”, South Pole)

- Vacuum (no atmosphere)
- Radiations
- Temperature range
- Lower gravity (about 1/6 of Earth gravity)
- **Lunar regolith**
- **Distance to Earth** (Comm. delays: ~2.5s)
- Strong **Shadows**



Environmental Constraints (Mars)

- Lighter atmosphere
- Radiations (less than on the moon, but 40-50 times more than on Earth)
- Temperatures
- Gravity (~2.6 times lower than Earth)
- **Mars Dust / Soil**
- **Great distance to Earth** (=> Large Communication delays)



Localisation & Mapping

Centre for
Robotics

ORB-SLAM2: an Open-Source SLAM for Monocular, Stereo and RGB-D Cameras
https://www.youtube.com/watch?v=ufvPS5wJAx0

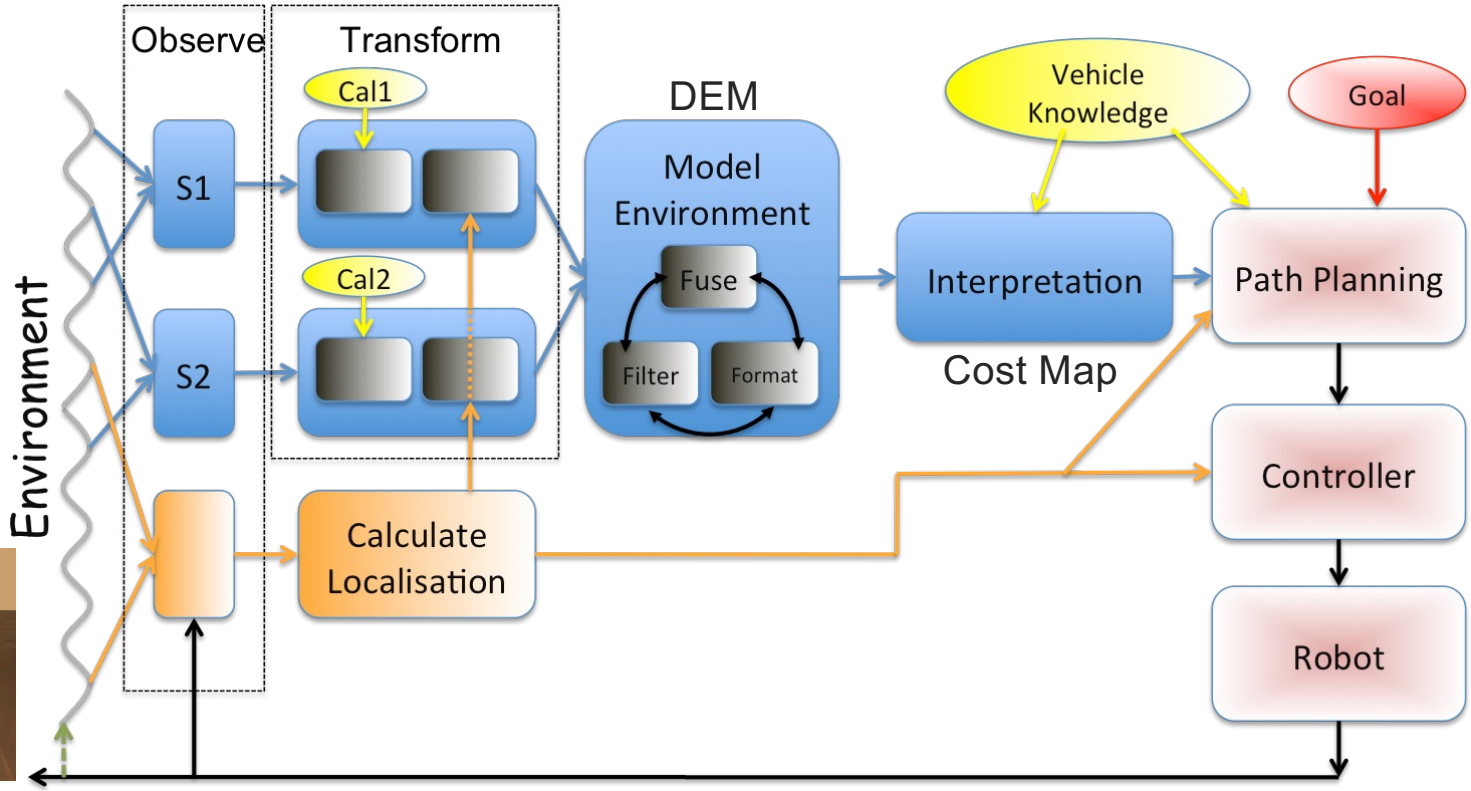
Next Challenges in Localisation

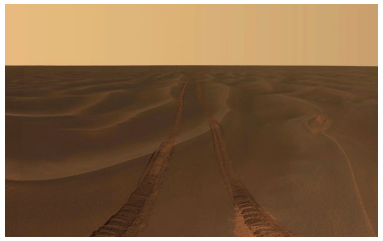
- Extreme lighting conditions
- Textureless environments
- Edge cases
- **Introspection**

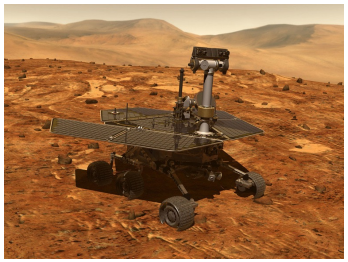
Terrain Traversability Estimation / Cost Maps

Centre for Robotics

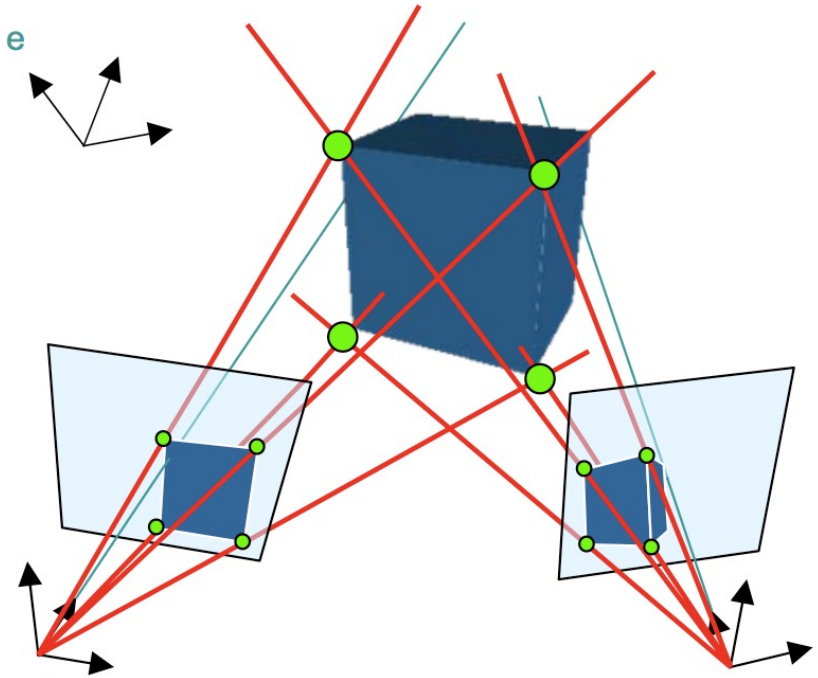
Autonomous Navigation (Architecture)

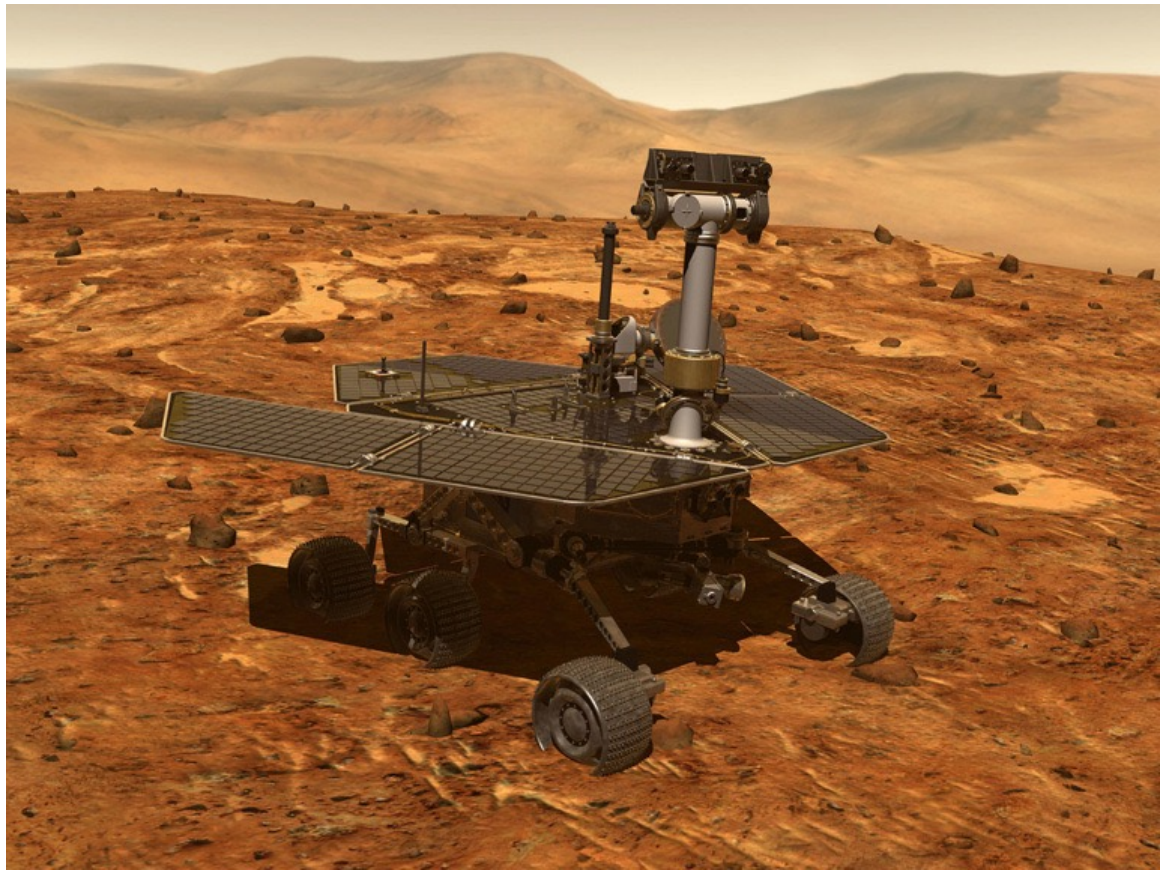






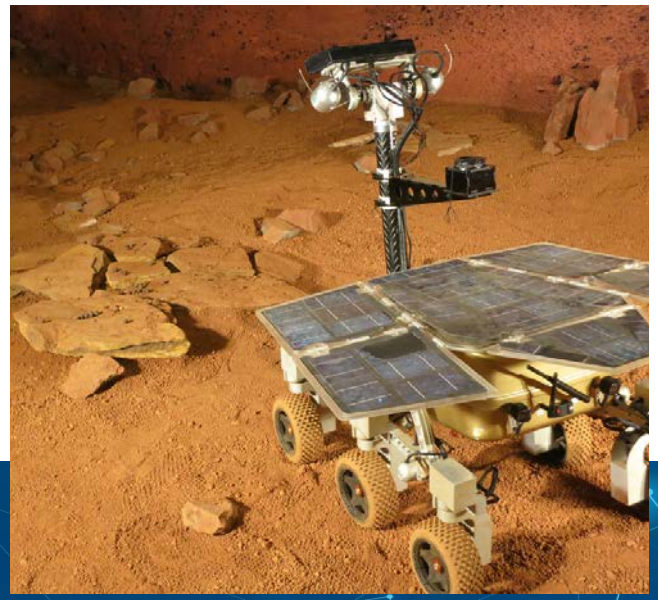
Stereovision



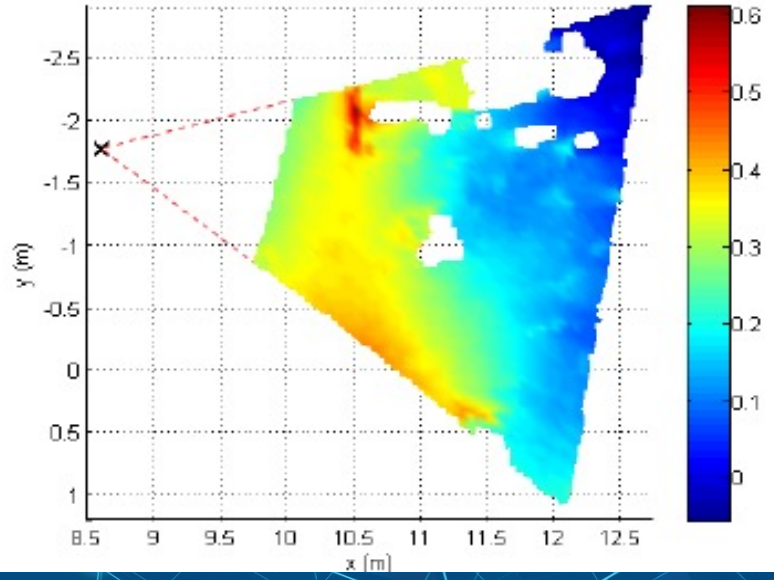


Digital Elevation Map (DEM) / 2.5D Map

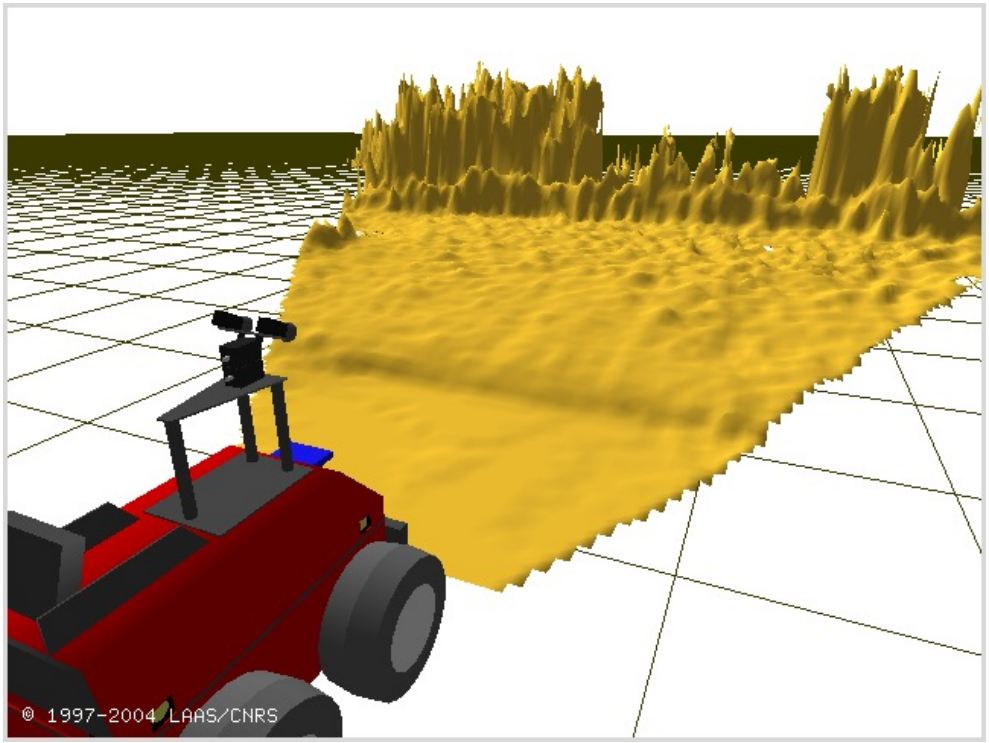
- For each position (x,y) in a 2D map/grid, the DEM contains **one** elevation value z=f(x,y)
- Distinct from a 3D Map, which can contain multiple elevation values for each position (x,y) (e.g. voxel map)

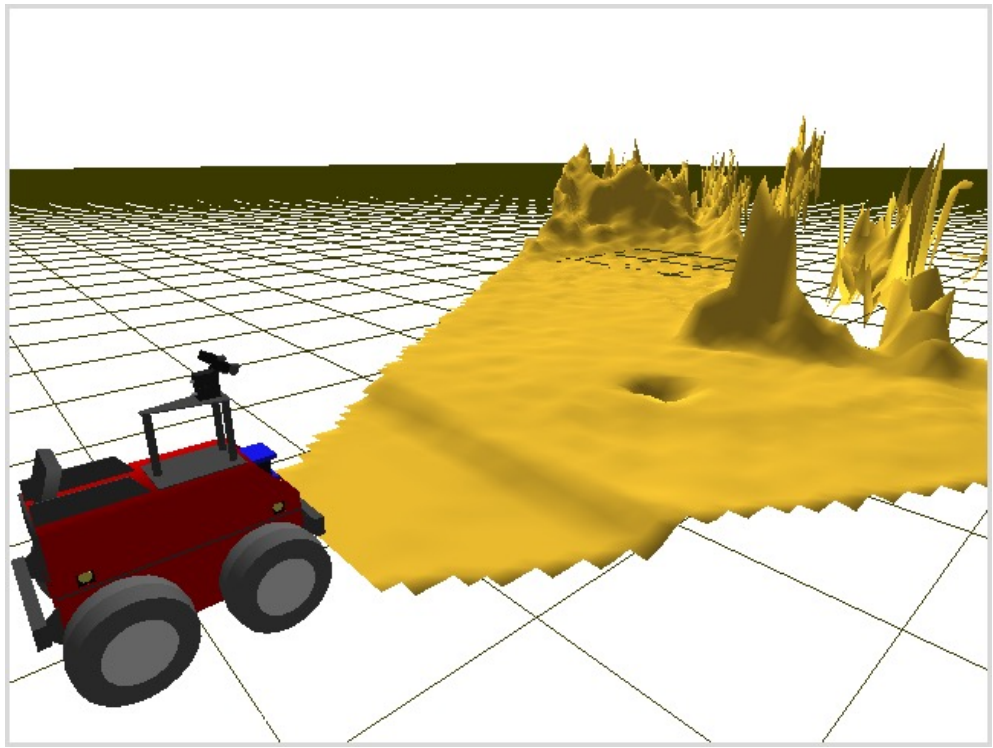


DEM (coloured by elevation)



Digital Elevation Map (DEM)





From Occupancy maps to traversability/cost maps

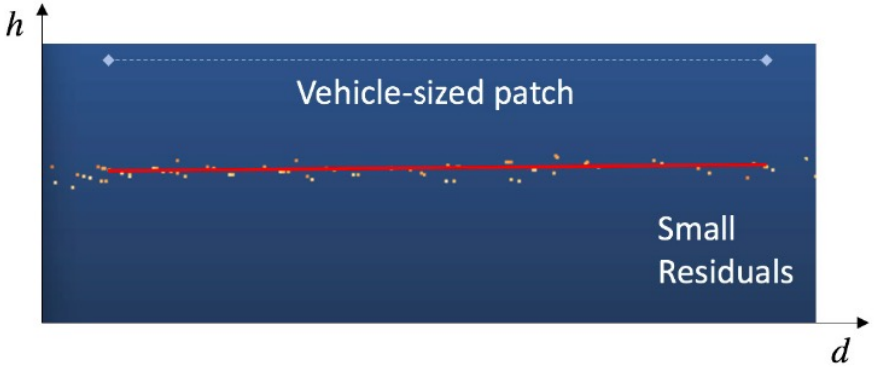
- **Occupancy map/grid**:
  - Usually discrete (grid) but can also be continuous (map)
  - each grid cell or point in the map contains either:
    - A binary, e.g. occupied (1) / free (0)
    - A probability that this cell is occupied
- **Cost map** for navigation (a.k.a. difficulty map, (terrain) traversability map):
  - Usually discrete but can also be continuous
  - each grid cell or point usually contains:
    - a (normalised) value of cost/difficulty*, from 0 to 1
    - Other characteristics such as the features that led to the cost computation (e.g. slope, rugosity etc.)

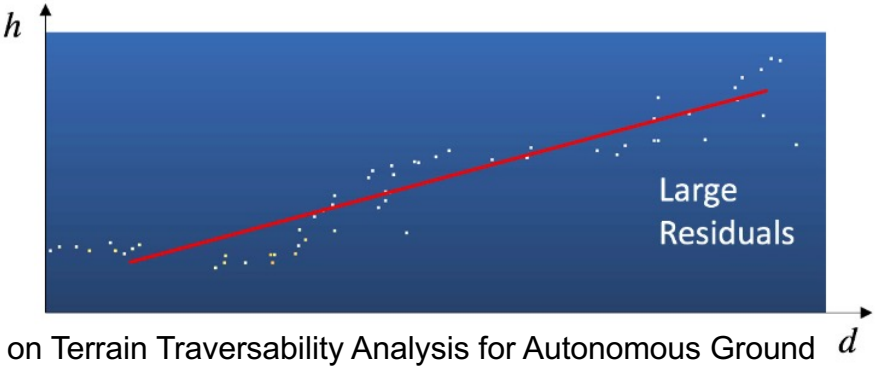
Terrain Traversability Estimation

Traversability metrics:

- Slope
- Roughness

Independent from platform?

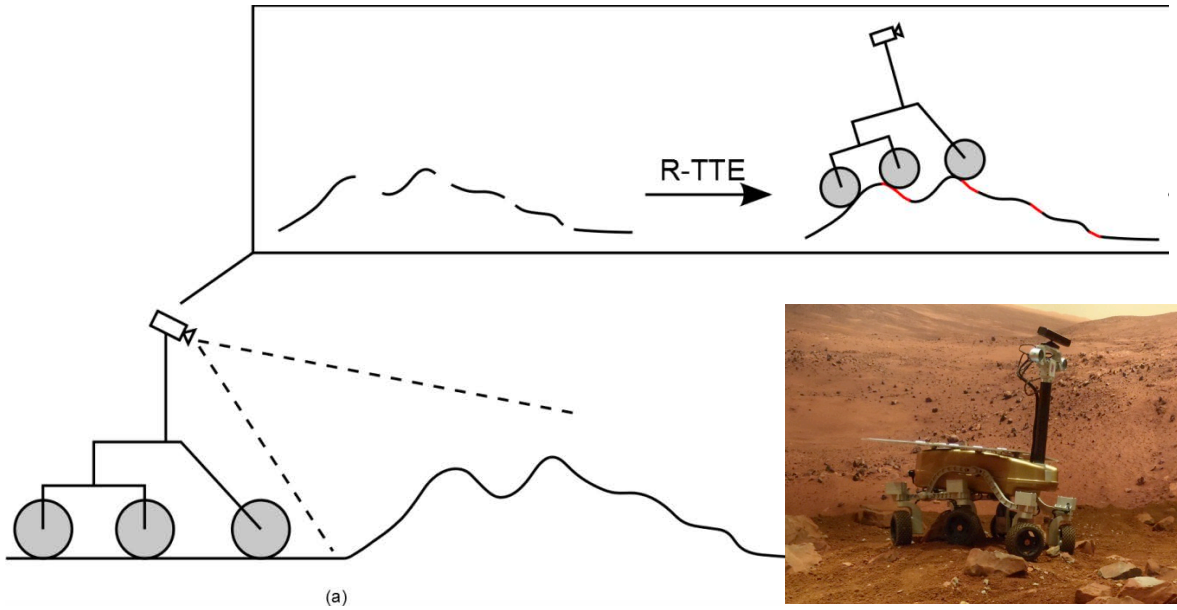


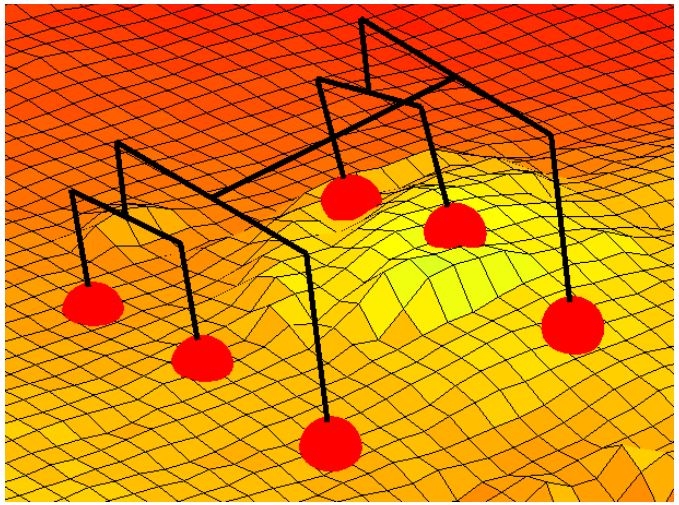


P. Borges, T. Peynot, et al. A Survey on Terrain Traversability Analysis for Autonomous Ground Vehicles: Methods, Sensors, and Challenges. In Field Robotics, Vol. 2, July 2022.

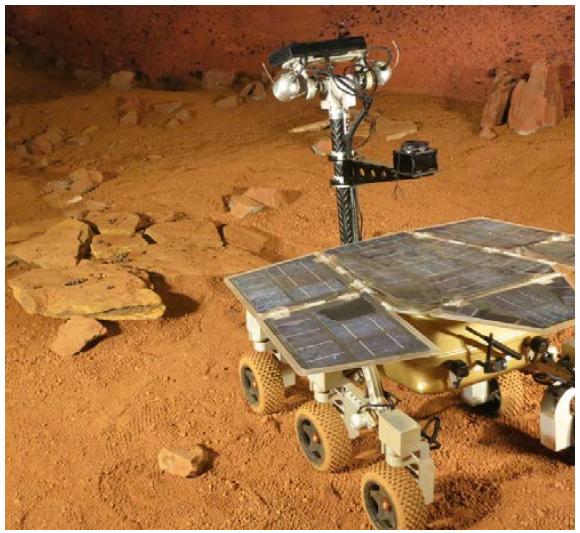
Digital Elevation Map and Terrain Traversability Estimation

- Evaluation of the configuration of the rover (roll, pitch, chassis configuration) when ‘placed’ on the terrain

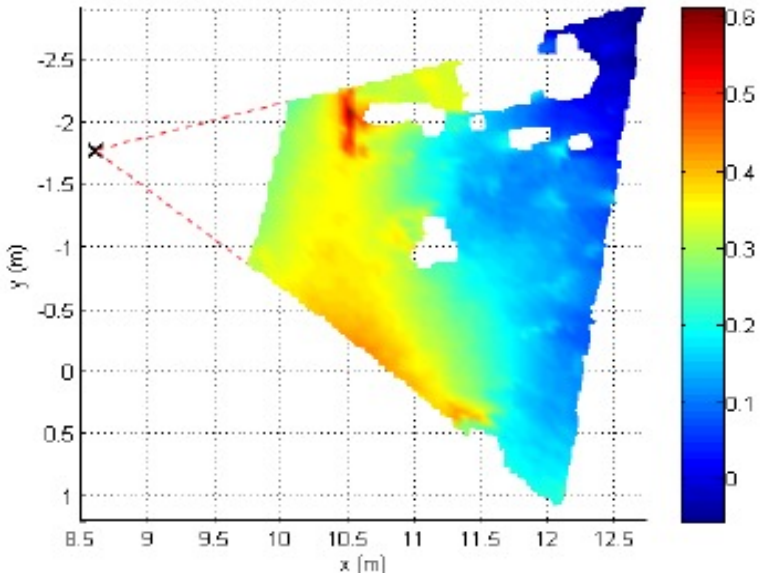




Challenge 1

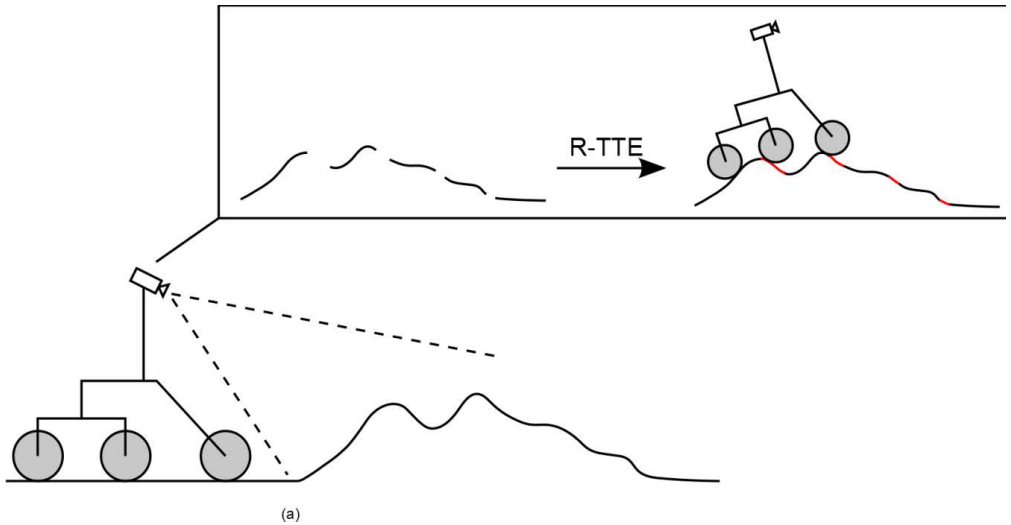


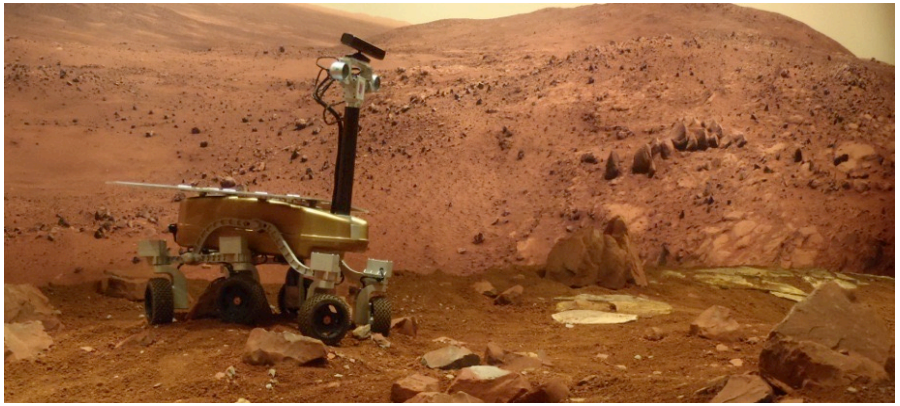
DEM (coloured by elevation)

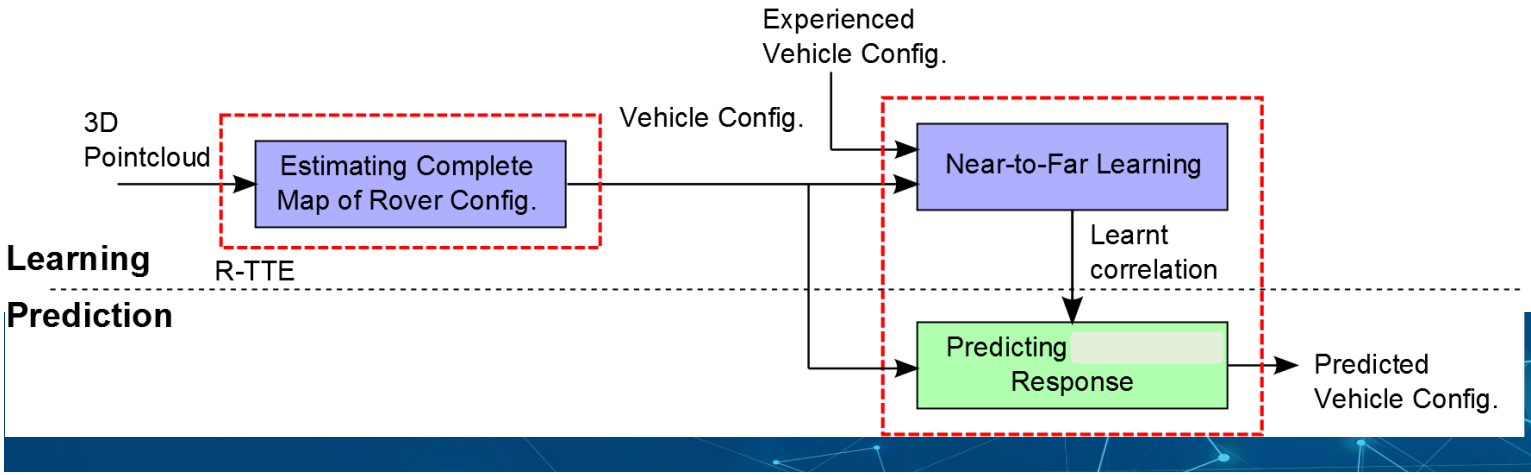


[Ho-JFR-2016]

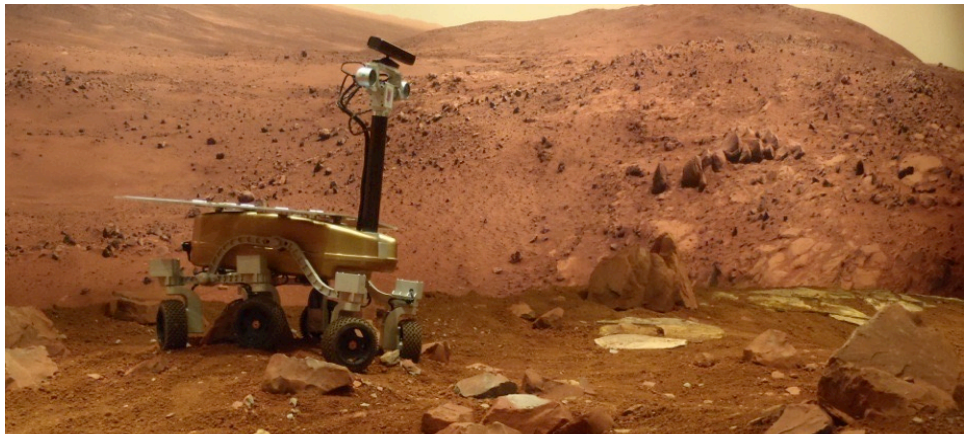
Near-to-Far Learning



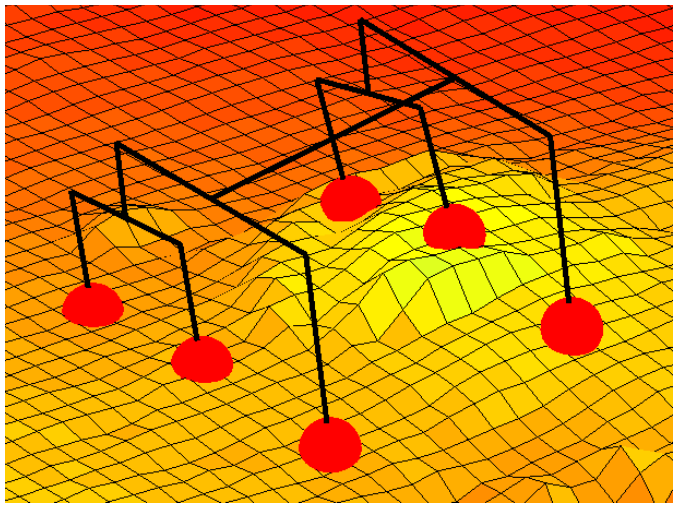




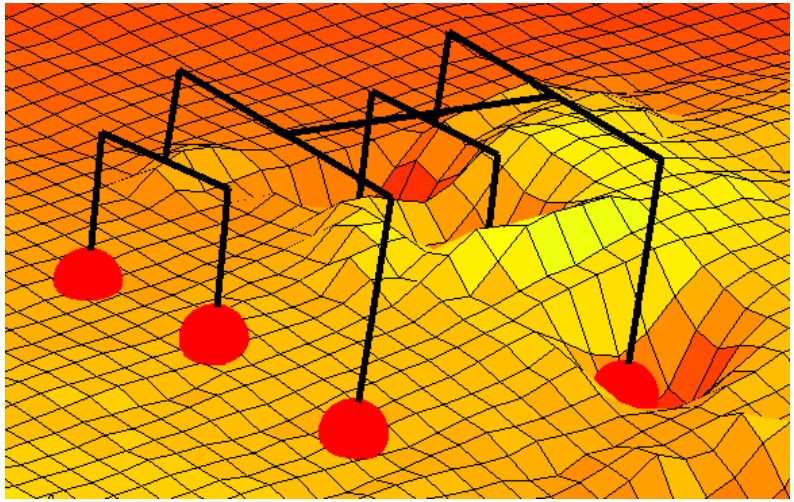
Challenge 2



Without terrain deformation

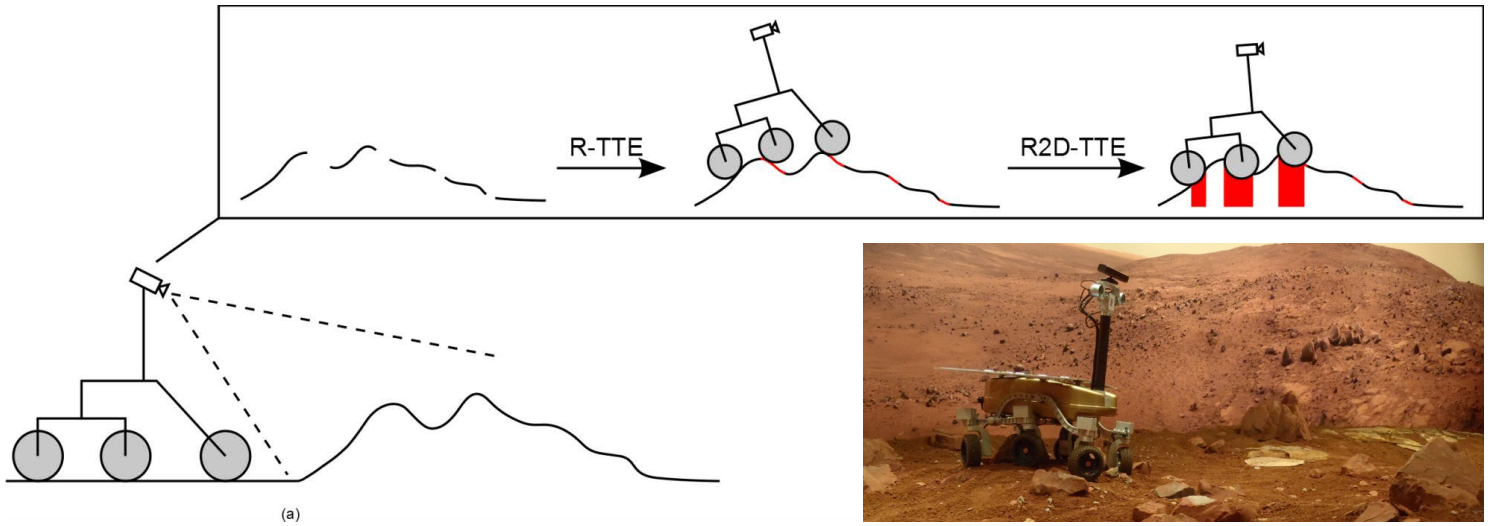


With terrain deformation

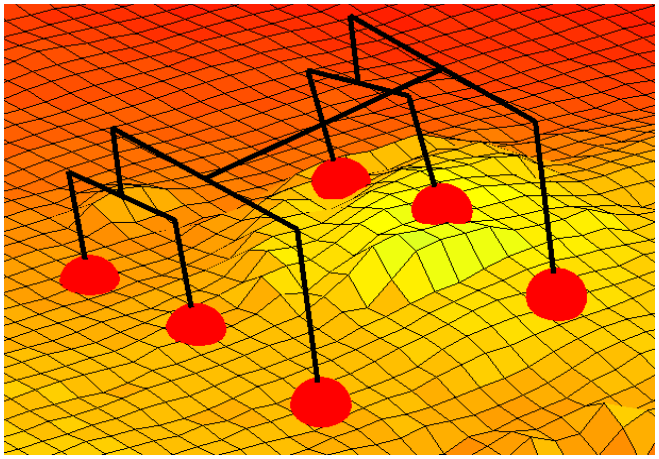


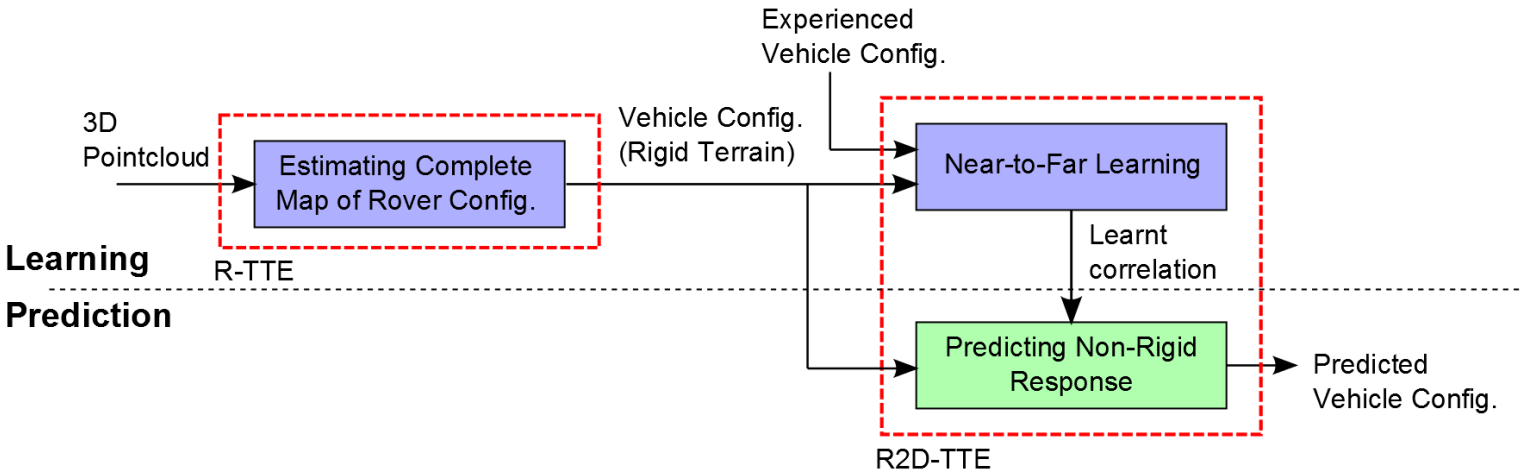
Rigid-to-Deformable Terrain Traversability Estimation

[Ho-JFR-2016]

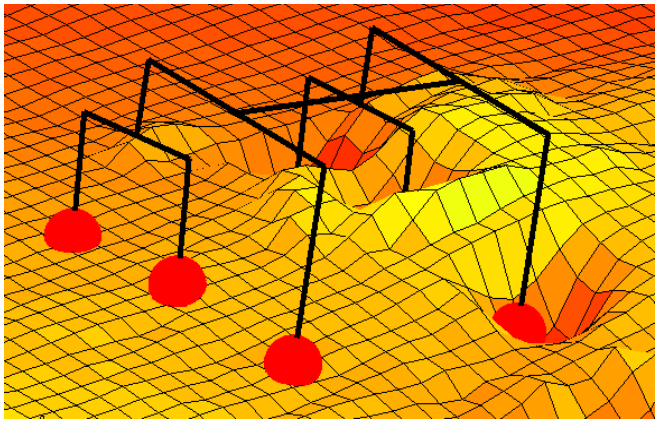


Without terrain deformation

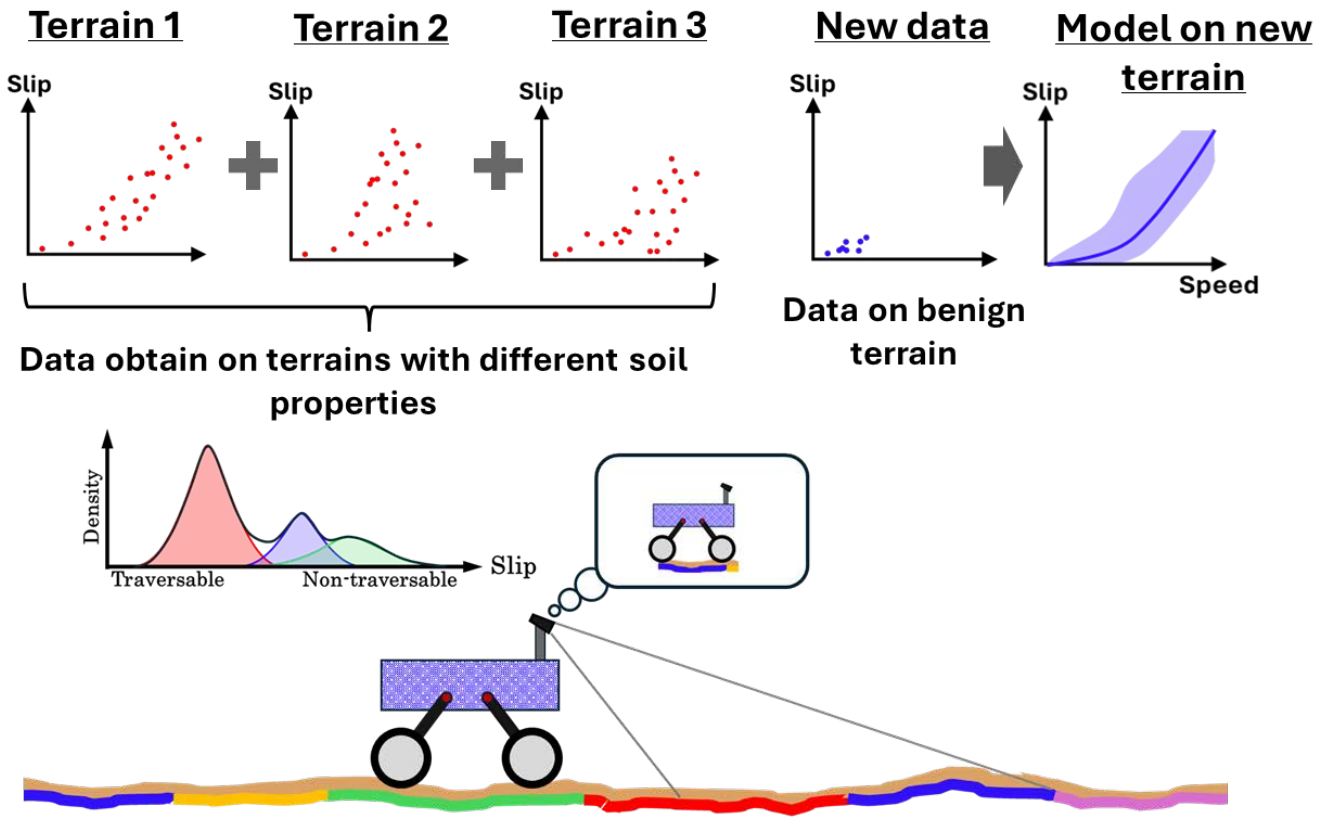




With terrain deformation

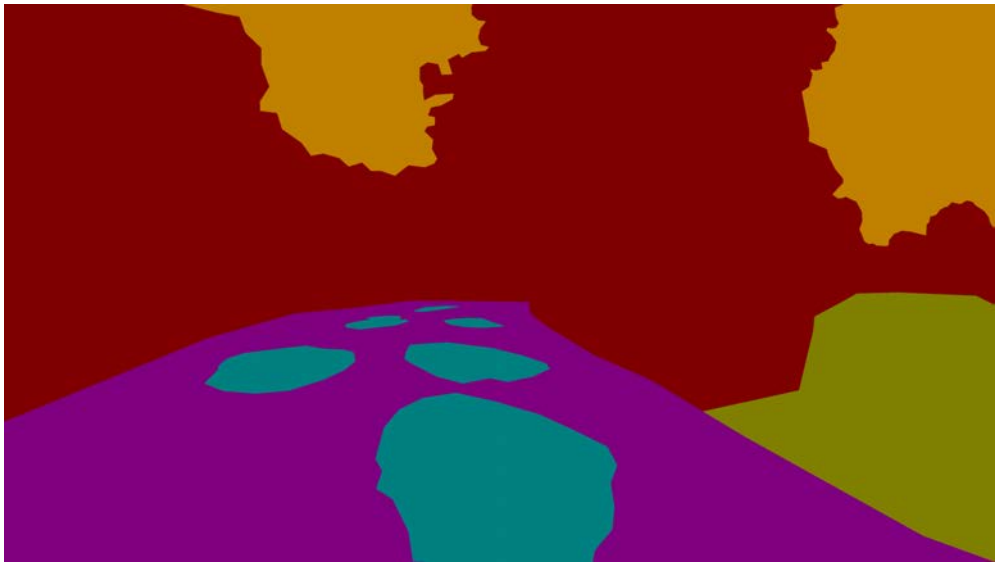


Slip

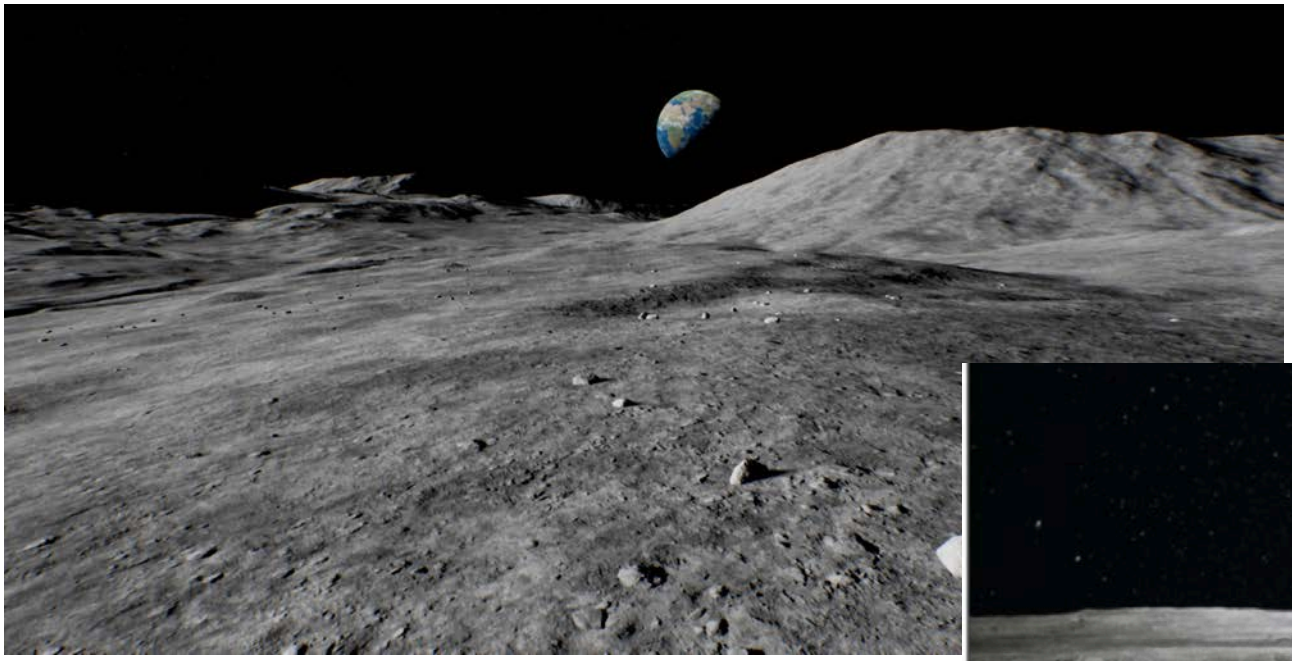


SlipNet: Enhancing Slip Cost Mapping for Autonomous Navigation on Heterogeneous and Deformable Terrains
https://arxiv.org/html/2409.02273v2

Terrain Classes



QUT Centre for Robotics

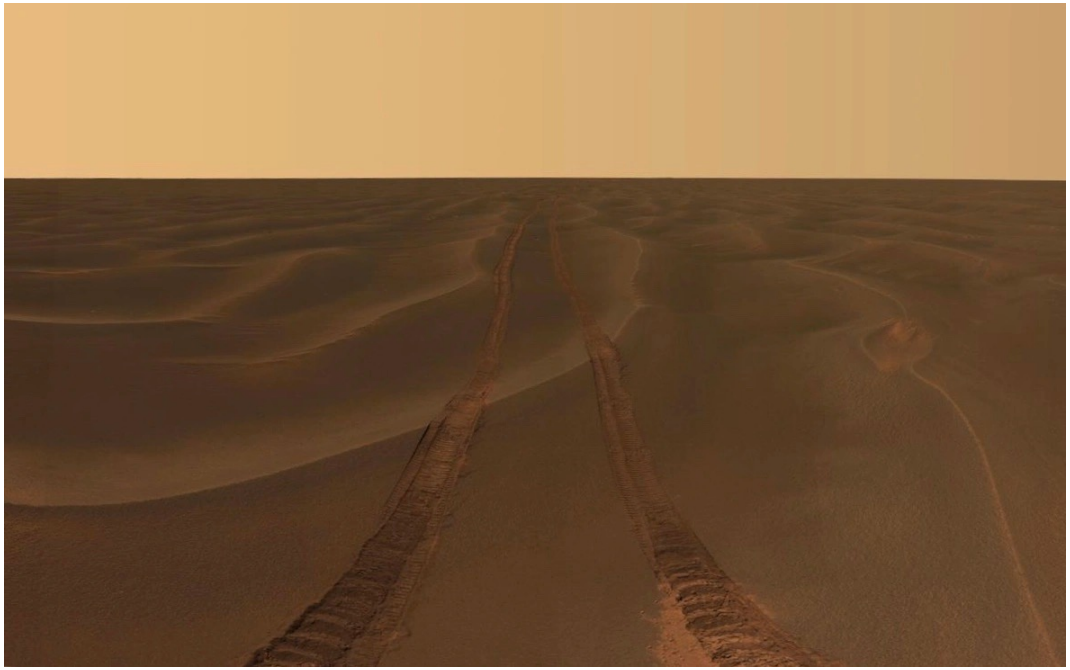


On the moon

QUT Centre for Robotics

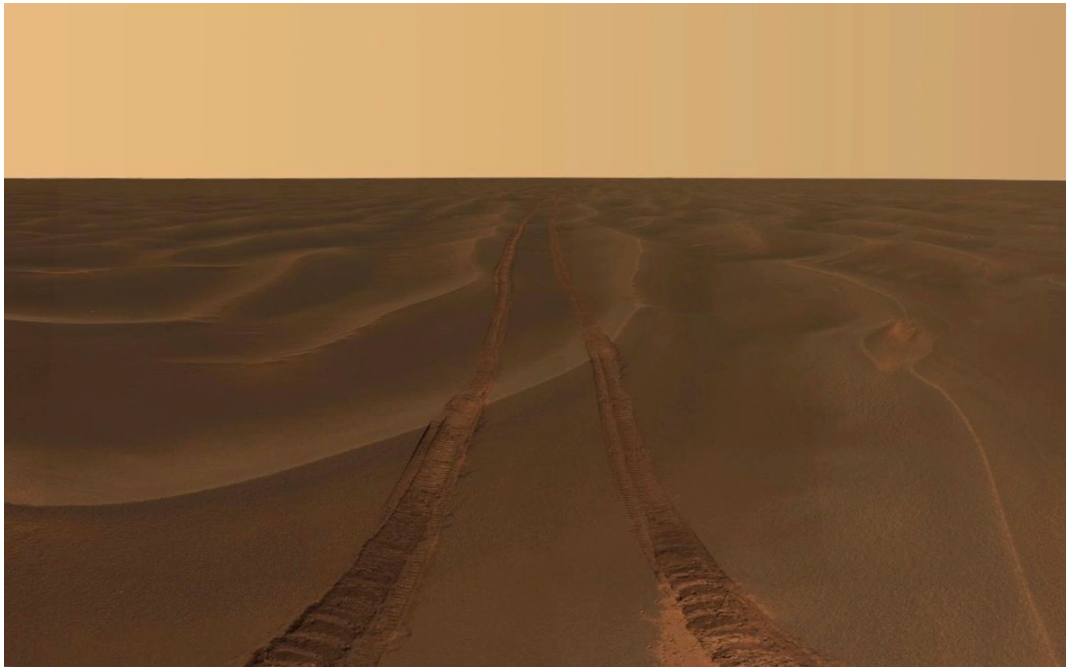
On Mars

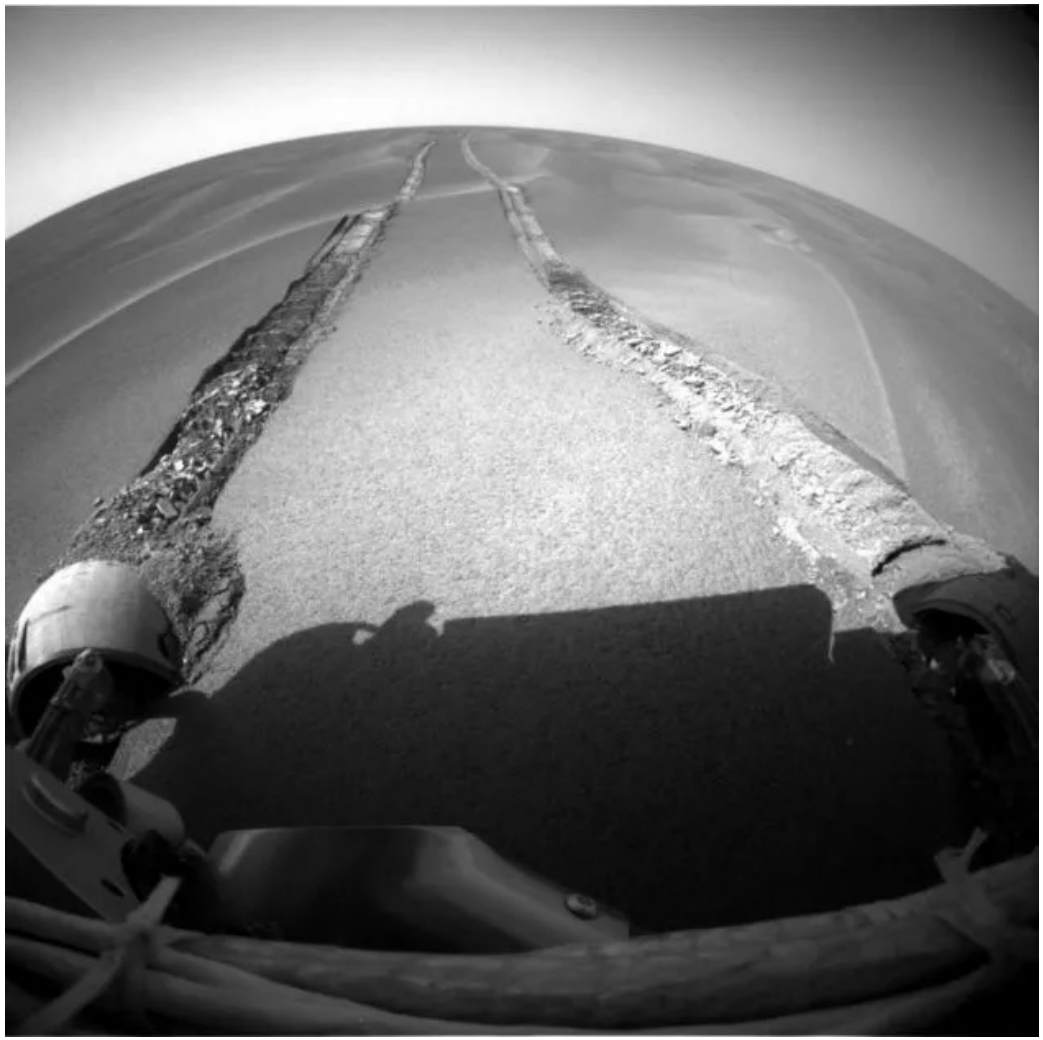
- Terrain traversability estimation



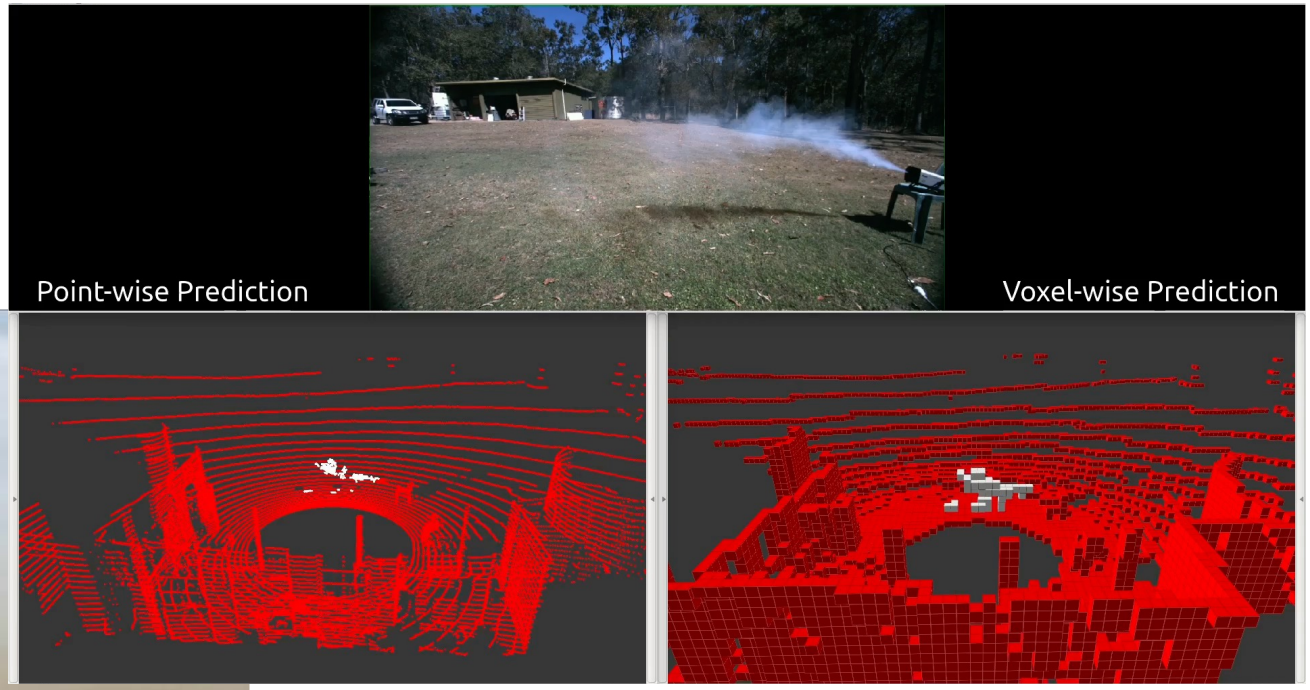
On Mars

- Terrain traversability estimation

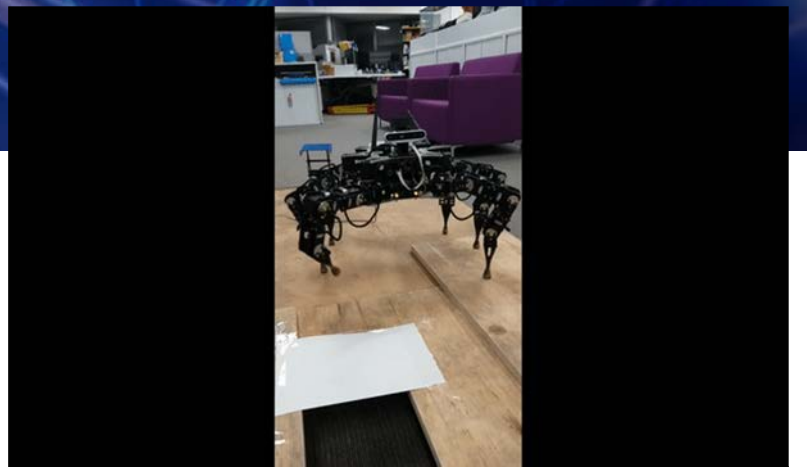




On Mars



QUT Centre for Robotics

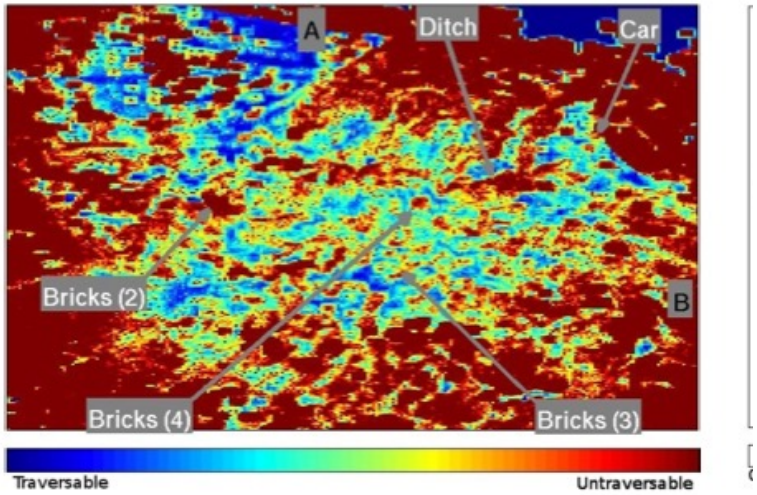


Current Challenges in Terrain Traversability Estimation

- Predict Rover-Terrain Interaction when there is no geometric or visual distinction (e.g. lunar regolith)
- Learn with limited negative examples
- **Introspection**
  - Known Unknowns
  - Unknown Unknowns

Queensland University of Technology

Terrain Traversability Estimation in Densely-Vegetated Environments (Earth)

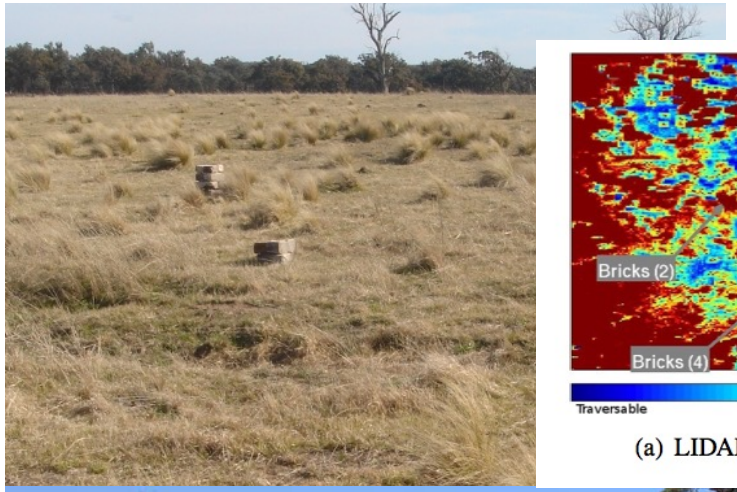


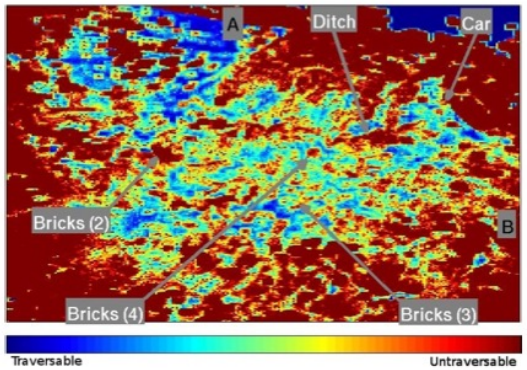
(a) LIDAR Traversability map (T_m)

[Ahtiainen-IROS-2013]
[Ahtiainen-FUSION-2015]

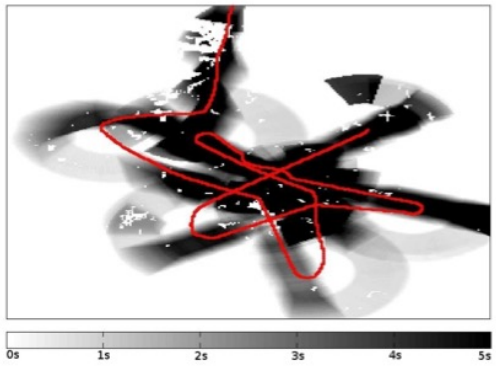
Queensland University of Technology

Augmenting Traversability Maps with UWB Radar to Enhance Obstacle Detection in Vegetated Environments

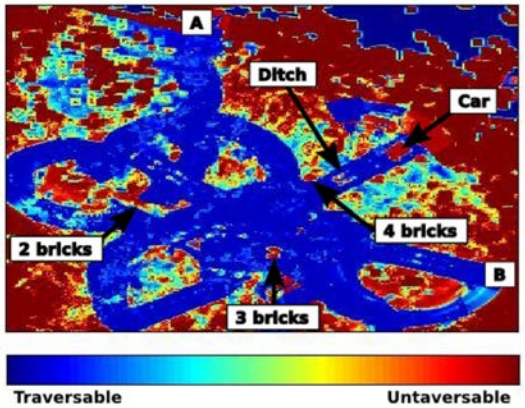




(a) LIDAR Traversability map (T_m)



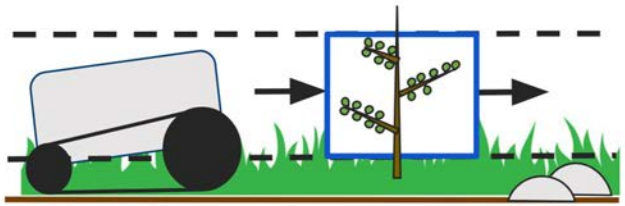
(b) Updated cells in radar FOV



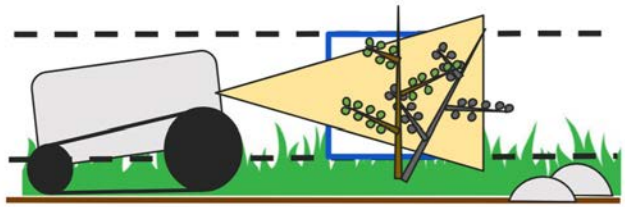
(c) Augmented traversability map (T_{ma})

[Ahtiainen-IROS-2013]
[Ahtiainen-FUSION-2015]

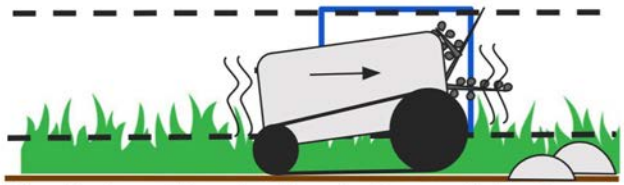
ForestTrav: Accurate, Efficient and Deployable Forest Traversability Estimation for Autonomous Ground Vehicles



Volume or instance for which to estimate "interaction cost"



Estimating "interaction cost" from afar using exteroceptive sensors

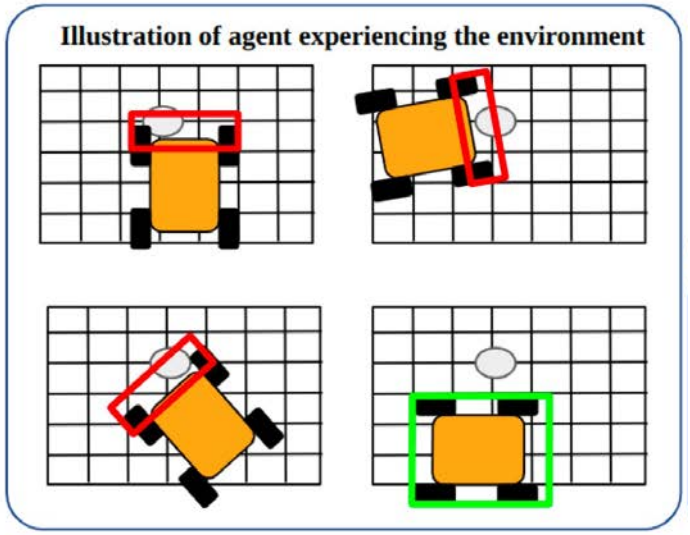


Attempting to push through and sensing the current interaction

[Ruetz et al, IROS 2022 & IEEE Access 2024]

Cell size for Occupancy Grid / DEM / Cost Map

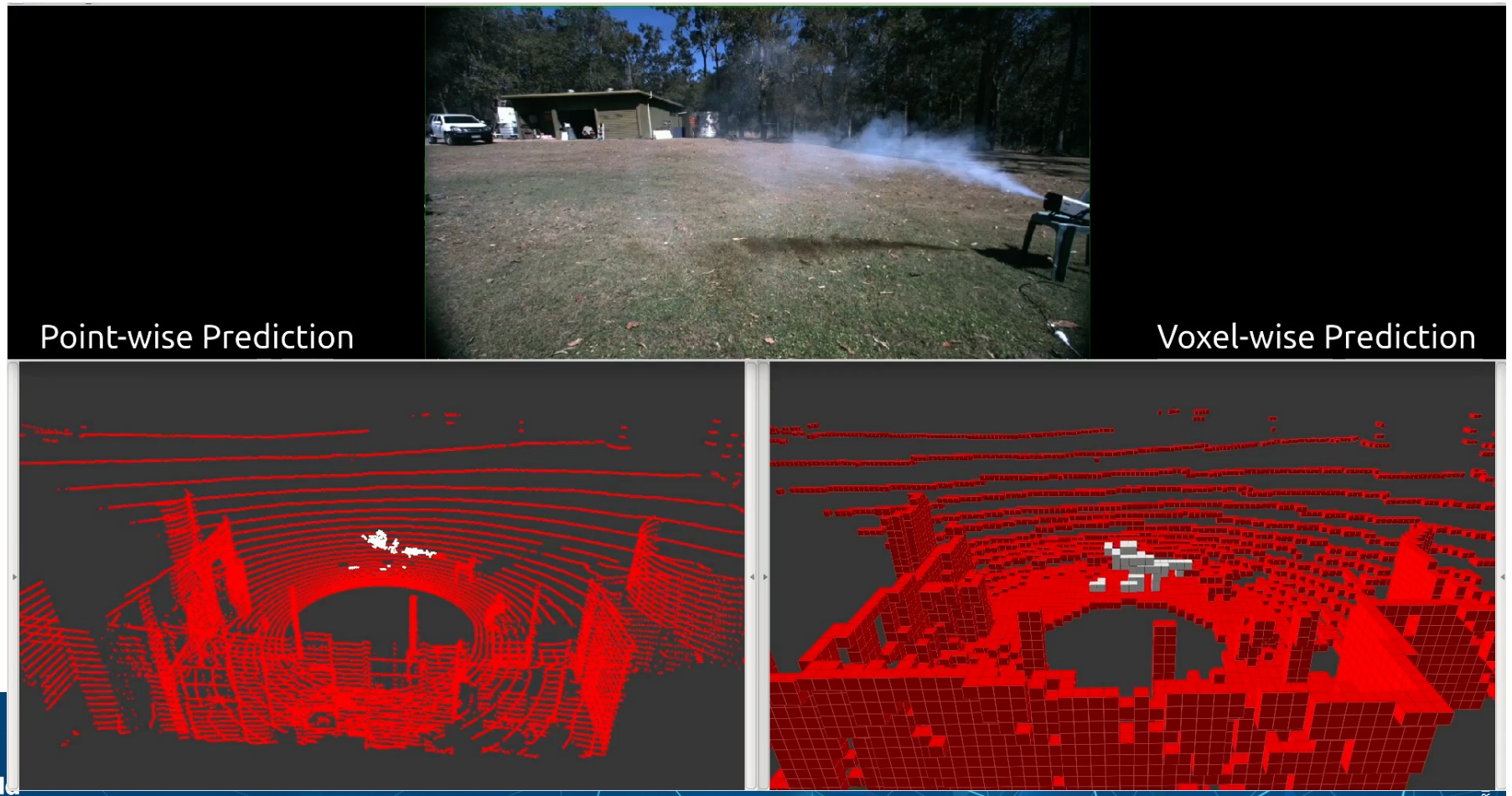
- To select the cell size, consider:
  - Size (footprint) of the robot
  - Size of the environment to be mapped
  - Computation resources, e.g. memory
- We usually would like the highest resolution possible, computation constraints



F. A. Ruetz, N. Lawrance, E. Hernández, P. V. K. Borges and T. Peynot, "ForestTrav: 3D LiDAR-Only Forest Traversability Estimation for Autonomous Ground Vehicles," in IEEE Access, vol. 12, 2024.

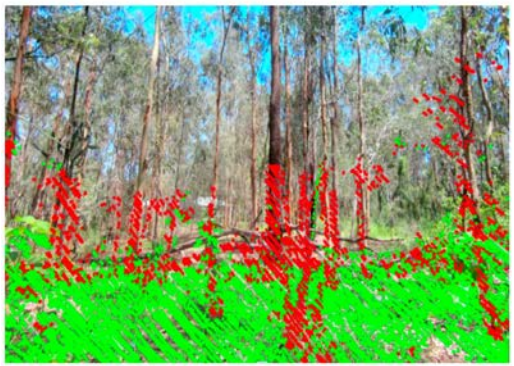
Occupancy Grid in 3D: Voxel map

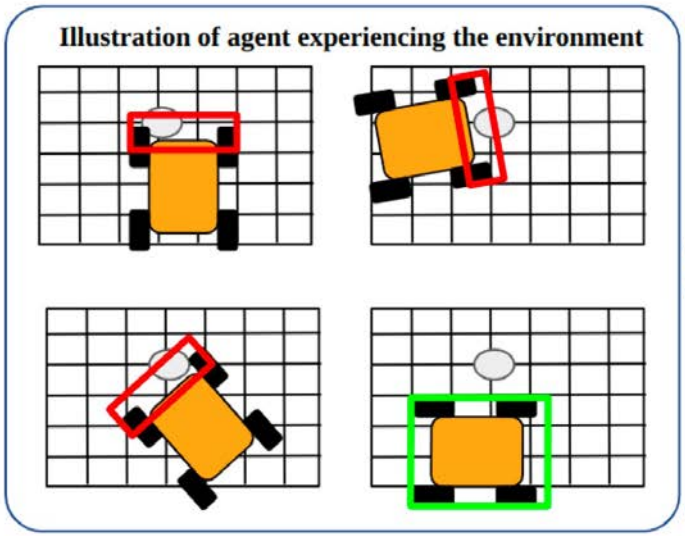
- Voxels

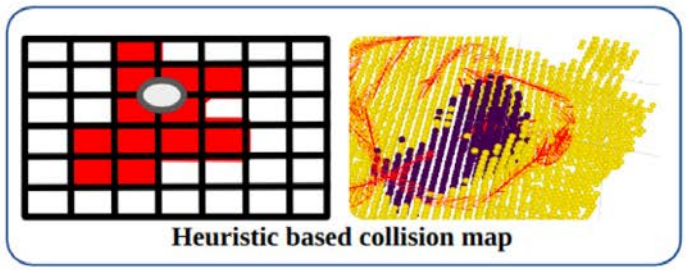


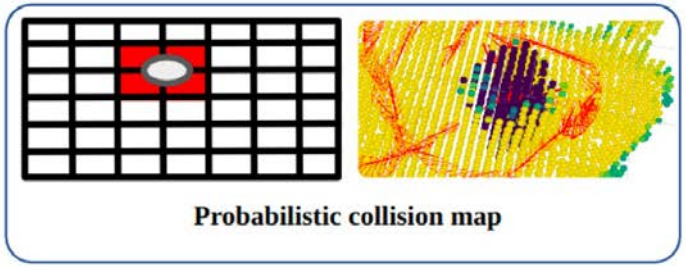
ForestTrav: Accurate, Efficient and Deployable Forest Traversability Estimation for Autonomous Ground Vehicles

Traversability Labelling





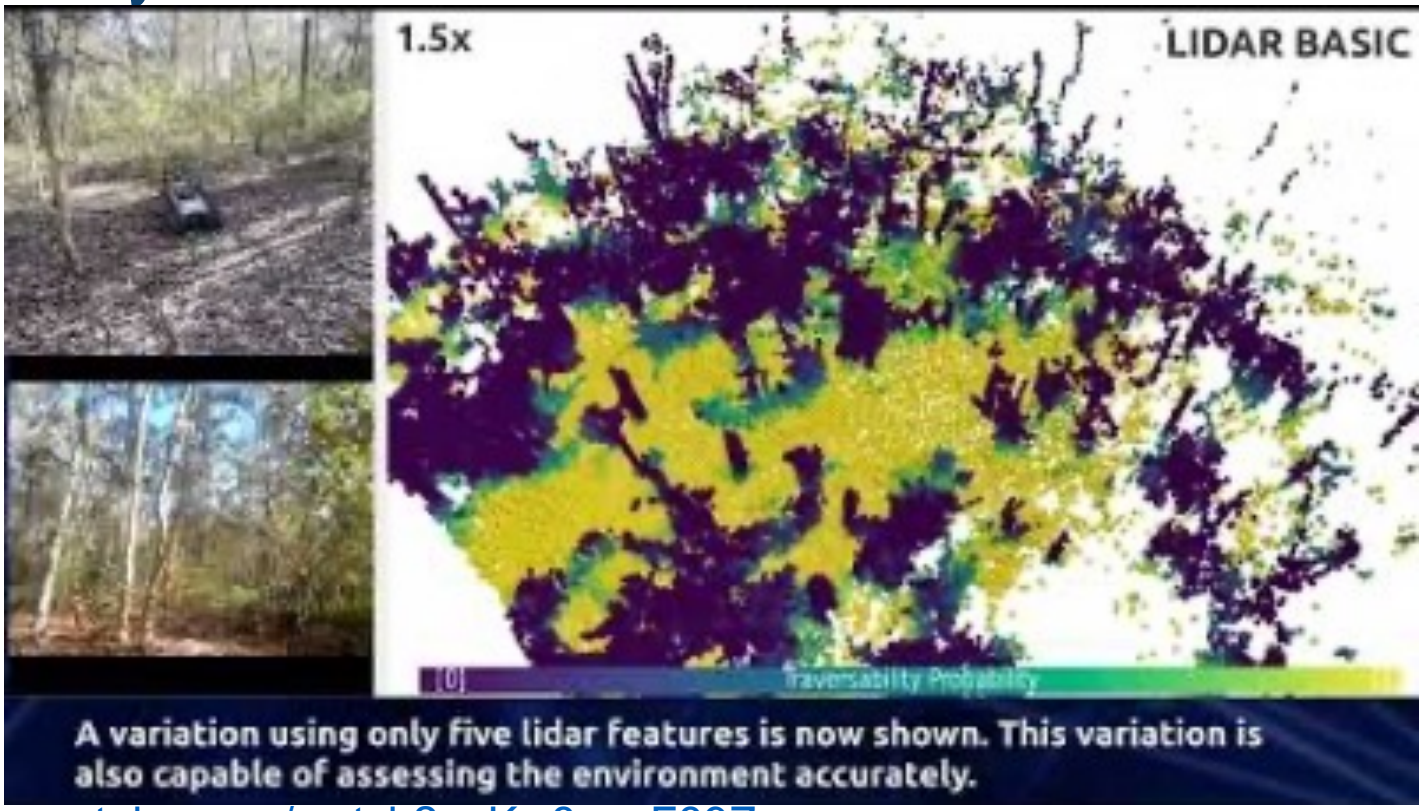




[Ruetz et al, arXiv & IEEE Access 2024]

Data Set: https://data.csiro.au/collection/csiro:58941

ForestTrav: Accurate, Efficient and Deployable Forest Traversability Estimation for Autonomous Ground Vehicles

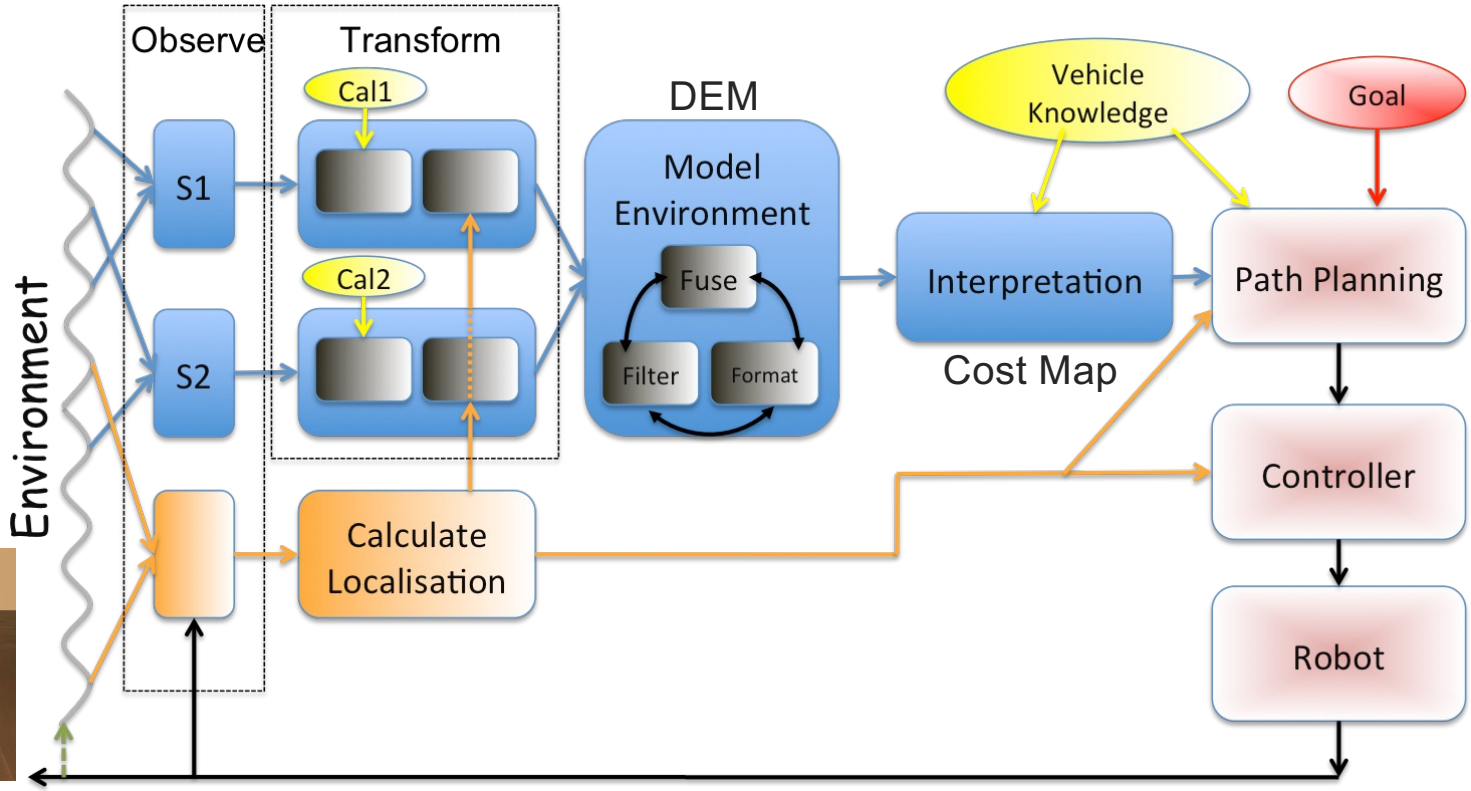


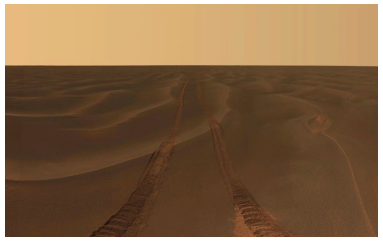
- https://www.youtube.com/watch?v=Kw8easF89Zg

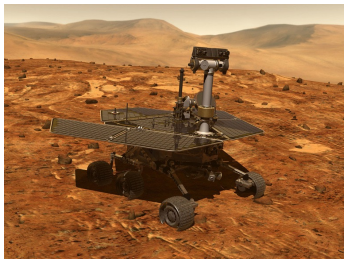
[Ruetz et al, IEEE Access 2024]

Self-Supervised or ‘end-to-end’ Traversability/Navigation

Autonomous Navigation (Architecture)







Planning (with Uncertainty)

Centre for Robotics

QUT Centre for Robotics

Learned Stochastic Mobility Prediction for Planning with Control Uncertainty on Unstructured Terrain

[Peynot et al. JFR 2014]

Centre for Robotics

Planetary Rovers - Autonomous Navigation in Extreme Environments

A/Prof. Thierry Peynot

QUT Centre for Robotics