COLORADO SCHOOL OF MINES

GOAL ORIENTED, RISK MITIGATING AUTONOMOUS BEHAVIOR FOR EXTRATERRESTRIAL ROVERS

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Current Practices

Mars Exploration Rovers (MER):

- A list of targets is assigned at start of each Martian day
- Rover navigates between points with minimal obstacle avoidance
- Requires remote operation for difficult terrain (sand and steep slopes)
- Target decisions made by Earth-based operators

Photo Credit: NASA JPL

Current Practices cont.

- Only viable due to relatively short active time, about 4 out of 24.5 hours a day
- And relatively short communication delay, averaging 20 min

Deeper space, more active missions will require more decision making autonomy

Requirements for Autonomous Behavior

i. Ability to Analyze Risks

ii. Ability to Evaluate Rewards

iii. A Process to Weigh the Risks and Rewards and Make Decisions which Maximize Scientific Returns

iv. Ability to Take Action on Decision

Proposed Algorithm

Goal-Oriented, Risk Attitude-Driven, Reward Optimization

(GORADRO)

Defines α as the Reward Potential of a state:

$$\alpha = \zeta_1 \cdot \text{Reward}_{present} - \zeta_2 \cdot \text{Risk}_{present} + \zeta_3 \cdot \text{Reward}_{future} - \zeta_4 \cdot \text{Risk}_{future} - \zeta_5 \cdot \text{Cost}_{energy}$$

where ζ is the Risk Attitude Parameter associated with that term.

Applications

- Can be applied to any system moving between multiple risk-inherent states
- Quantitatively compares the risks and rewards associated with a state
- Provides a basis for comparing states and finding the most favorable

Risk Attitude Background

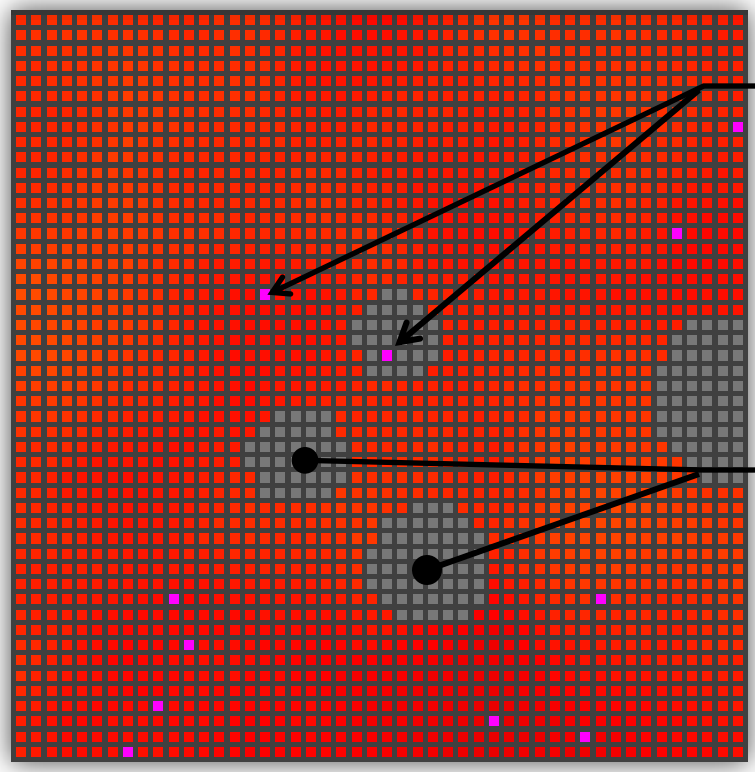
- Derived from psychology
- Defines how people approach risky conditions
- Ranges from Risk Adverse to Risk Tolerant

Here, the Risk Attitude is the set of Risk Attitude Parameters (ζ), where each Parameter defines the approach to a specific risk or reward factor

Validating GORADRO for Rovers

- Trials were run using a simulator to compare GORADRO to other driving techniques
- Techniques were Hands-On Operation and Point-to-Point as used in MER Missions
- Simulator generated random terrain maps for trial to be run on
- Comparison was done between techniques being operated on the same map

Defining Targets and Hazards on the Map



Altitude Scale

0 6 9 meters

- Points were randomly assigned as scientific points or hazards when map was generated
- Scientific points were spread out and individual targets
- Hazard values generated as small regions

Specific Model for Rovers

Defines Reward Potential (α) for a location on the map at (*x*, *y*)

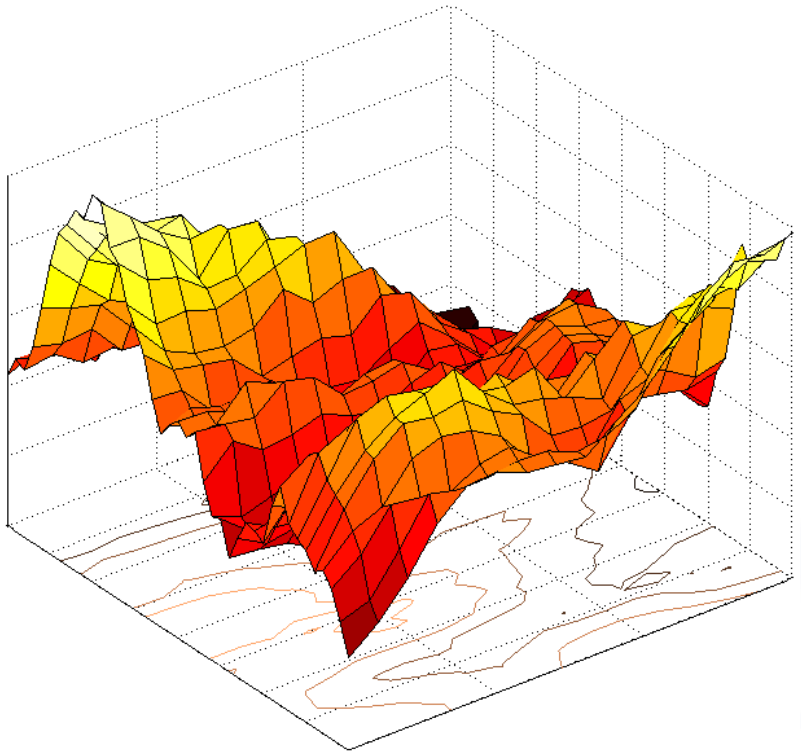
$$\alpha(x,y) = \zeta_1 \cdot V_{science}|_{x,y} - \zeta_2 \cdot V_{hazard}|_{x,y} + \zeta_3 \cdot \rho_{science,sur} - \zeta_4 \cdot \rho_{hazard,sur} - \zeta_5 \cdot \Delta z|_{x,y}$$

- The Reward is the Value (*V*) of Scientific Return
- The Risk is in the form of Terrain Hazards
- Future terms calculated using the density (ρ) of science/hazards in the surrounding area
- The Energy Cost is the change in gravitational potential energy, proportional to the change in Altitude (*z*)

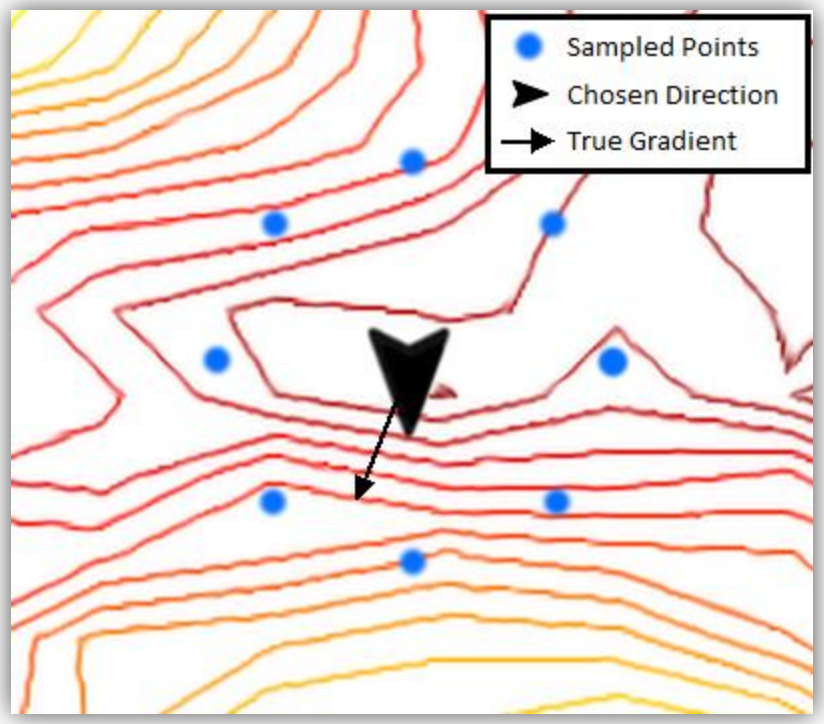
Implementing Model

- For validation, GORADRO was used as a path-finding method
- Reward Potentials form a mathematical surface
- Most efficient route (κ) to maximum is found by the gradient of the surface

$$\vec{\kappa} = \nabla \alpha$$



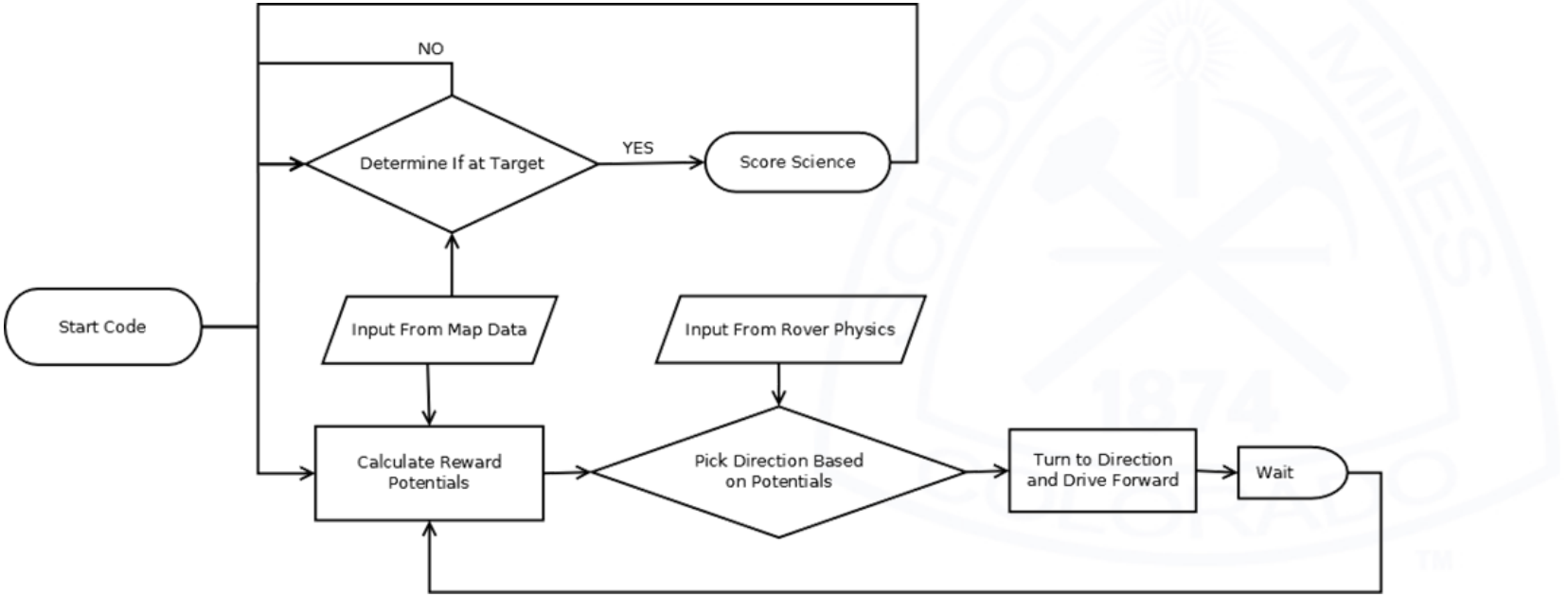
Implementing Model cont.



- In practice generating a surface is impractical
- A discrete number of points is sampled
- The most favorable direction is chosen as the highest scoring point

Implementing Model cont.

For repeated instances of this calculation the process looks like:



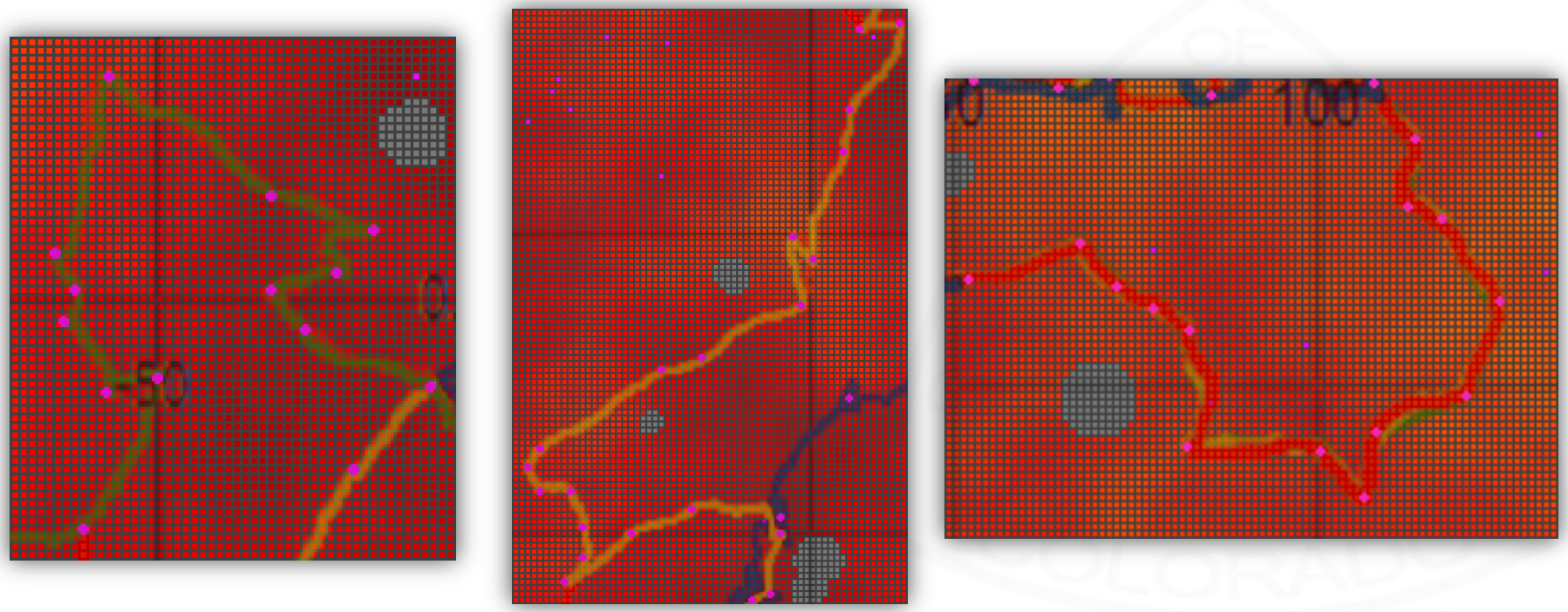
Results

Upon completion of trials, performance was analyzed based on:

- Efficiency of chosen path
- Rate at which targets were reached

GORADRO Compared to Itself

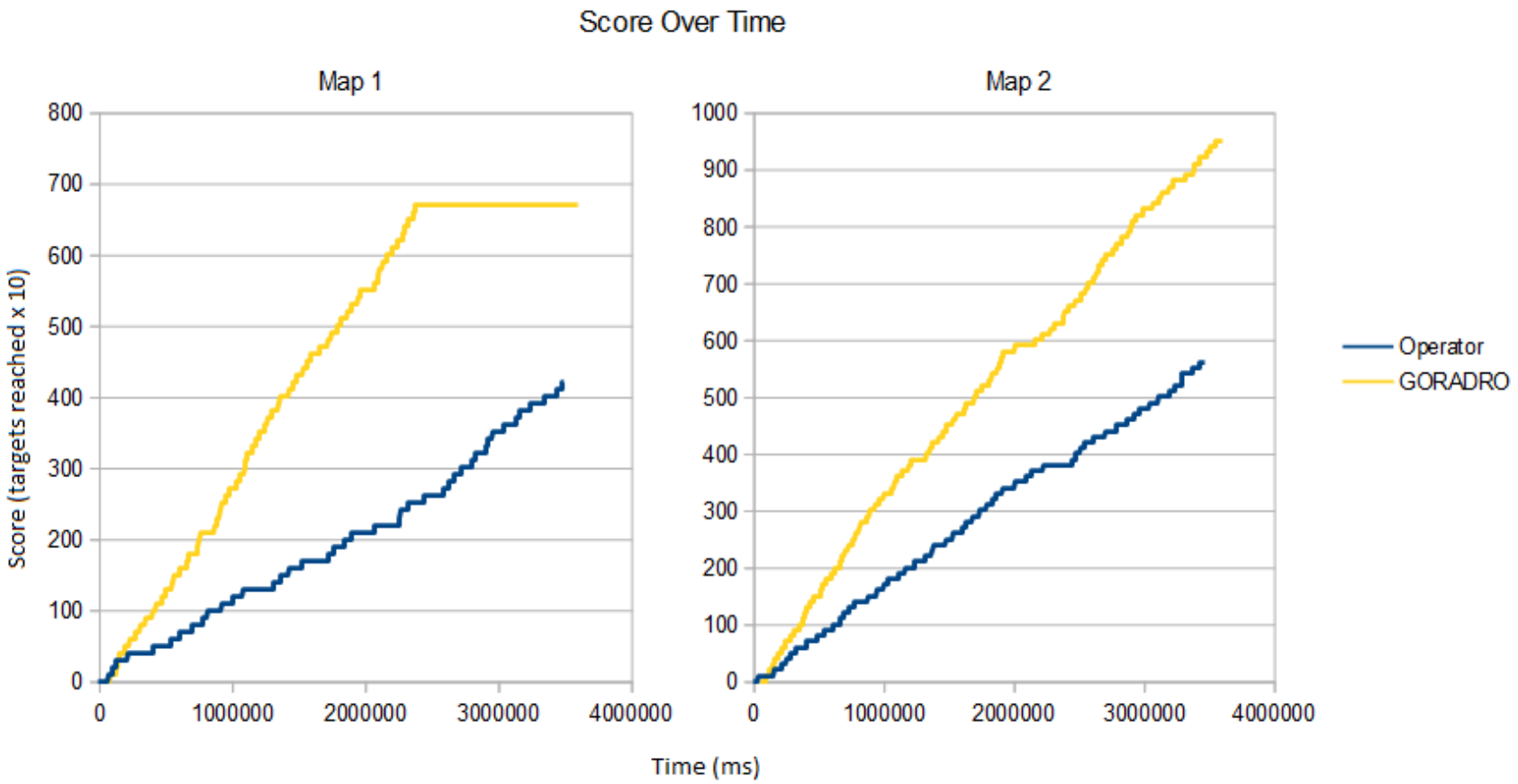
Three notable instances where rover chose the same path



Repeatability represents concrete decision process.

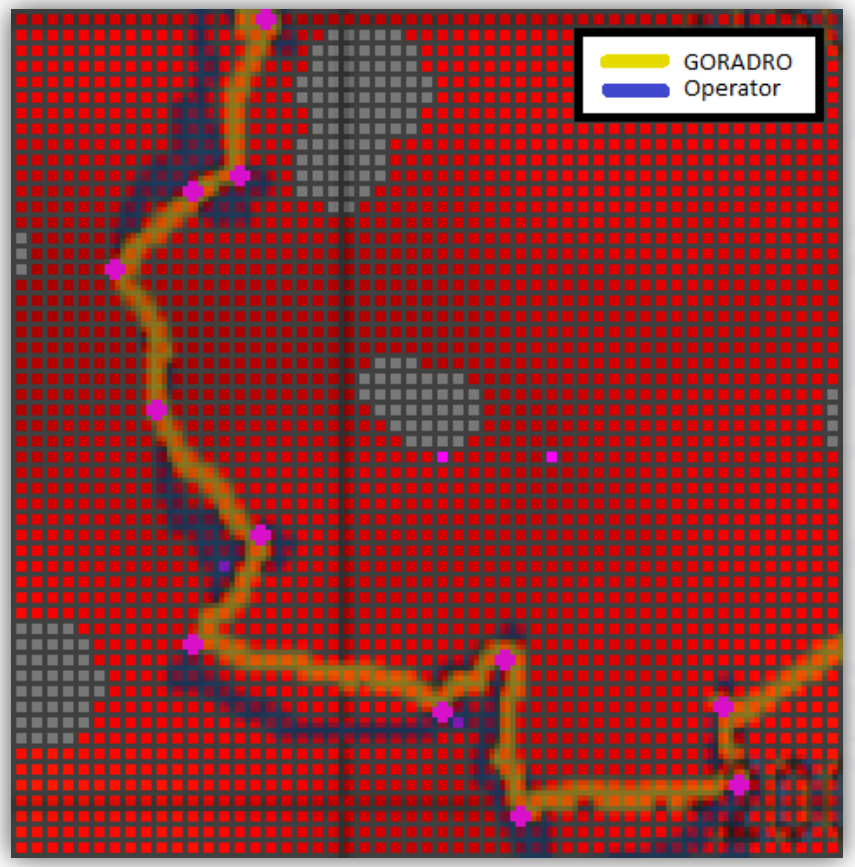
GORADRO Compared to Hands-On cont

And much higher science collection rates



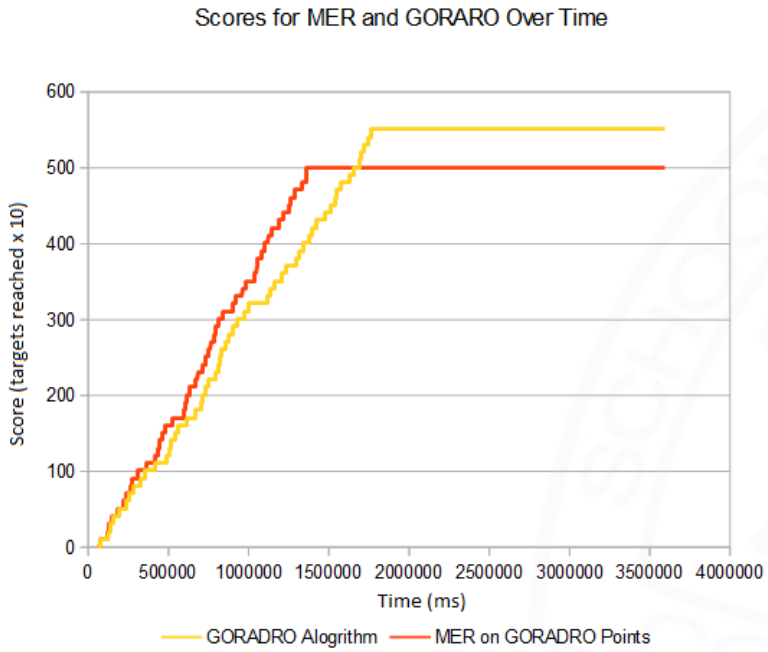
GORADRO Compared to Hands-On

Shows much greater efficiencies between points



GORADRO Compared to MER

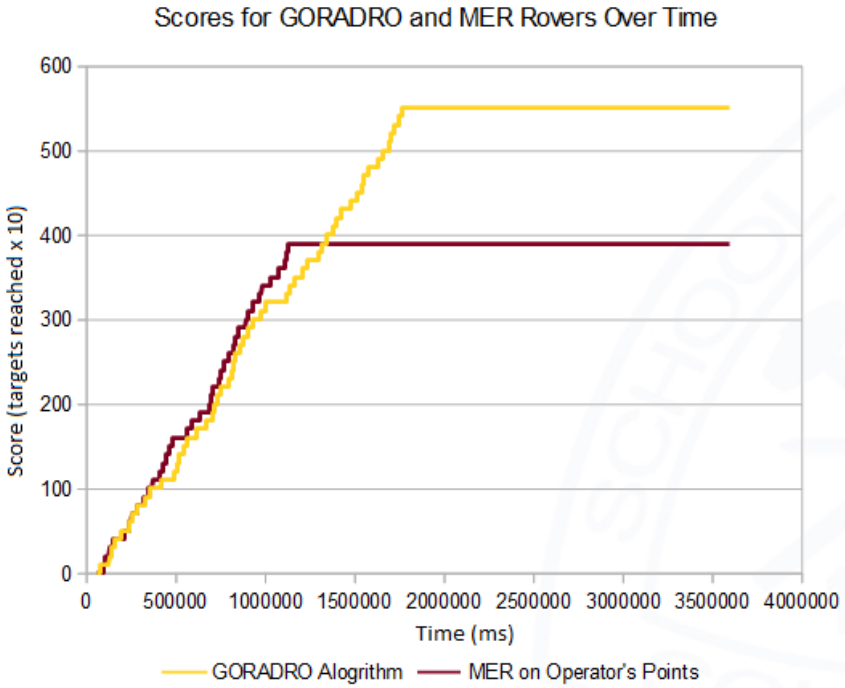
Two different MER trials were run: the first followed the points used by the GORADRO



On its own points, GORADRO is not as effective as MER, showing it does not move as efficiently between points

GORADRO Compared to MER cont

Second trial followed the points used by the operator



Here, GORADRO closes the gap indicating a better method for choosing targets in the long term

Conclusions

- GORADRO is a powerful method capable of competing with current techniques for managing extraterrestrial rovers
- However, Risk Attitude Parameters must be better tuned to reach the full potential of this model
- Generalized form makes this model usable in many setting, with correctly tuned Risk Attitude Parameters

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Nomenclature

Acronyms

- GORADRO: Goal-Oriented, Risk Attitude-Driven Goal Optimization
- MER: Mars Exploration Rover
- NASA JPL: National Aeronautical and Space Administration Jet Propulsion Laboratory

Nomenclature

Variables

- ζ – Risk Attitude Parameter
- α – Reward Potential
- V – Value at a point
- ρ – Density
- κ – Most Favored Direction of Travel
- z – Altitude
- x, y – Map Coordinates