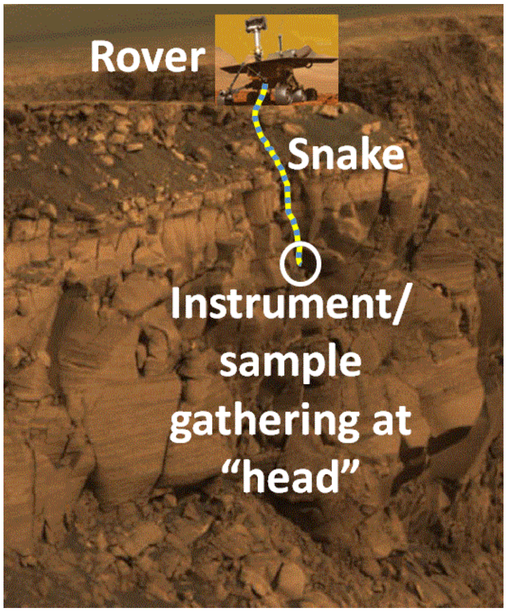
SNAKES ON MARS – FOR EXPLORATION OF EXTREME ENVIRONMENTS. M. S. Feather[1], H. Choset[2] and R.R. Murphy[3], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109; Martin.S.Feather@jpl.nasa.gov, [2]Biorobotics Laboratory, Carnegie Mellon University, [3]Center for Robot-Assisted Search and Rescue, Texas A&M

Introduction: Robotic "snakes" offer low risk and low cost approaches for enabling Mars missions to explore otherwise inaccessible extreme terrains – often the very locations of greatest interest as potential sources of resources (water, minerals) and science data. As a simple cable, deployed by gravity, a snake could access sites at or beyond the angle of repose (near vertical cliff- and crater-walls), and could even access the lower surfaces of overhangs. They could potentially scale down cliff walls from above and could access inside of crevices and into restricted spaces for exploration purposes. More advanced implementations could utilize articulated motion to provide self-propulsion as real snakes do. Snakes could be equipped with instruments, tools, and sample collection mechanisms.



Notional illustration of a rover deploying a snake (Mars scene http://apod.nasa.gov/apod/ap070703.html)

The growth of terrestrial interest in robotic snakes makes this an opportune time to for NASA to work in collaboration with other organizations pursuing this technology, such as CMU's developments of experimental robotic snakes and Texas A&M's Center for Robot-Assisted Search and Rescue. For exploration of Mars or its moons, robotic snakes would have to function in conditions rarely, if ever, encountered on Earth (low gravity, vacuum, temperature extremes, etc.), fulfill high expectations of reliability and success, not be reliant on anything to retrieve or repair them, and operate autonomously without minute-to-minute "joysticking" control.

Motivated by this realization, this concept paper advocates a focused effort in which key leaders in the field of snake robotics work with NASA to mature these technologies for deployment in Mars exploration missions.

Rationale: Robotic snakes are one possible motive approach for exploring at close range (close enough to gather a sample) features of the Martian surface. The factors that would motivate when to use a robotic snake design rather than alternative approaches are as follows:

Terrain	Mechanisms
Benign modestly upward or downward (<20^o) slope	Ideal for a rover with wheels, tracks or legs.
Cluttered modestly upward or downward (<20^o) slope	Progress of a rover with wheels, tracks or legs *may* be impeded and overall risk increases. Suitable for snake or other versatile mechanism.
Moderate upward (20^o – 40^o) slope	Suitable for snake or tracked vehicles; snake maximizes ground hugging contact, so better suited to higher slopes.
Modest terraced (< 0.5m vertical steps) in terrain	Suitable for snake or long-legged vehicles
Steep upward slope (>40^o)	Challenging for even an advanced snake; harpoon may be the only recourse! (but its retrieval may be problematic).
Moderate - very steep downward (20^o – 90^o) slope	Suitable for "Axel" – a belayed two-wheeled single axle concept, and snake.
Access from above to underside of an overhang	Snake the only option?
Access into crevices and other constricted spaces	Snake, or very small independently propelled "insect" like designs, the only options.

Alternately, a short robotic snake could be deployed as an appendage to some other mechanism, essentially giving that mechanism a highly articulated short-range extension to its reach.

Related Terrestrial Activities: Several examples of terrestrial efforts to further the development and use of robotic snakes are listed below. The leaders of the first two of these efforts are involved as co-authors of this concept and would be instrumental in teaming with NASA in a coordinated activity to mature these technologies for NASA use.

Biorobotics Lab, Carnegie Mellon University. Howie Choset's lab at CMU is active in design and demonstration of "serpentine style robots". "Snake robots can use their many internal degrees of freedom to thread through tightly packed volumes accessing locations that people and machinery otherwise cannot use. Moreover, these highly articulated devices can coordinate their internal degrees of freedom to perform a variety of locomotion capabilities that go beyond the capabilities of conventional wheeled and the recently developed legged robots. The true power of these devices is that they are versatile, achieving behaviors not limited to crawling, climbing, and swimming." [1]

Center for Robot-Assisted Search and Rescue, Texas A&M University. http://crasar.org/ Robin Murphy has experience with a variety of robots intended for search and rescue, robotic snakes among them. Under her direction CRASAR has used a snake-like robot at the 2007 Jacksonville parking garage collapse to navigate through rubble less than 1 inch wide. She reports on an NSF-JST-NIST Workshop on Rescue Robotics held at Texas A&M in 2010 in [2]

The concept of serpentile style robots is rapidly maturing for a variety of search and rescue operations and an operational extension to otherwise hard to reach planetary terrain is the logical next step.

Considerations and approach: There are many variations to the concept of robotic snakes, ranging from highly articulated, (such as the CMU snake robot able to wrap around a pole or tree trunk and climb it!), untethered ("free-slithering"?), through to such simple designs as to barely qualify as snakes (e.g., fling out a long strip with sticky paper on the end, and reel it in with the sample, dirt from the ground, stuck to the end). For the purposes of this concept paper, snakes that employ some form of surface-based locomotion are the primary consideration (thus ruling out articulated arms that don't need to touch the ground).

A key feature of resilience in the snake approach would be the ability to retract the snake from above by winching it back up to the topside rover from which it would be deployed. Then the rover could reposition itself, and another try could be made to deploy down the terrain of interest, be it a cliff wall or a cave.

To be deployed in planetary exploration settings robustness and reliability will be driving requirements. There are several robust techniques for robotic snakes to achieve locomotion. The "Toroidal Skin Drive" [3], and the "Ciliary vibration drive mechanism" [4] are among the most promising.

In this field, terrestrial applications for search and rescue are driving the advances of closest relevance to Mars exploration use. Overall the technology could be characterized as in the mid-range (4-6) of NASA's Technology Readiness Level (TRL) scale [5]. A focused effort is needed to mature these emerging robotic snake technologies to suitability for use on Mars missions.

Summary: Robotic snakes have the unique potential to provide low-cost and low-risk access to locations on the Martian surface that are likely to be of greatest interest (e.g., water seeps on slopes) but which pose the greatest challenges for other approaches. The co-authors on this concept abstract are leaders in the field of terrestrial applications of robotic snakes, notably for search and rescue applications. Their work is driving the development of the robotic snake technologies well suited to NASA's uses. They are eager to work with NASA in a joint effort to mature robot snakes for NASA's Mars missions, both to serve NASA's needs as well as further the development of these societally interesting technologies.

References: [1] CMU's Snake Robots website: http://www.cs.cmu.edu/~biorobotics/serpentine/serpentine.html [2] Murphy, R.R. (2010) *Findings from NSF-JST-NIST Workshop on Rescue Robotics*, IEEE Int. Workshop on Safety Security and Rescue Robotics, Bremen, Germany. [3] McKenna, J.C. et al, (2008) "Toroidal Skin Drive for Snake Robot Locomotion", IEEE Int. Conference on Robotics and Automation, Pasadena, CA, 2008. [4] Tadokoro, S. et al. (2010) *System Integration in R&D of Active Scope Camera*, IROS'10 Workshop on Robots and Sensors integration in future rescue INformation system (ROSIN'10), Taipei, Taiwan [5] Mankins, J.C. (1995) *Technology Readiness Levels: A White Paper*, NASA Office of Space Access and Technology, Advanced Concepts Office