Robotic Walking in the Real World
Melany L. Hunt
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mom-5, and Dishevelled/dsh-2/mig-5—lead to defects in mitotic spindle orientation and cell fate specification of blastomere and other cell types (11). Normally in these cells, the homolog of the transcription factor that binds to β-catenin, TCF/pop-1, is asymmetrically enriched in one daughter cell. However, mutations in TCF/pop-1 itself disrupt cell fate determination but have no effect on orientation of the mitotic spindle, indicating that Wnts act through a transcription-independent mechanism for initial cell polarization (11). Habib et al. did not assess TCF-family members in mouse ES cells nor perform loss-of-function studies for β-catenin or TCF. Thus, it is unknown whether there is a transcriptional requirement for the ability of Wnt3A to polarize ES cells. There are notable differences in the biochemical details between the vertebrate Wnt–β-catenin pathway and the C. elegans Wnt asymmetry pathway (12). It remains to be determined whether any aspects of this signaling are evolutionarily conserved.

Another possible mechanism of Wnt-dependent asymmetry involves the interaction between the canonical Wnt–β-catenin signaling pathway and the Wnt–planar cell polarity (Wnt-PCP) signaling pathway, which can polarize cells (13). Wnts that affect Wnt-PCP signaling, such as Wnt5A, can antagonize Wnt–β-catenin signaling (14). Habib et al. found no effect of Wnt5A beads alone; however, when dividing ES cells were bathed in Wnt5A, the ability of Wnt3A beads to promote asymmetry was inhibited. As cells in vivo are often exposed to multiple different Wnts, it will be informative to characterize the behavior of ES cells exposed to multiple beads with different Wnts acting through the Wnt–PCP and Wnt–β-catenin pathways. Alternatively, recapitulating Wnt3A-mediated asymmetry with microfluidic gradients (15) would make it possible to examine cell behavior in antiparallel or orthogonal concentration gradients of Wnts with opposing activities.

The study of Habib et al. is a modern response to questions posed by developmental biologists since the late 1800s and early 1900s regarding spatial asymmetries in informational molecules. Even after 30 years of study, molecular details of Wnt signaling are still being uncovered. Indeed, on page 1436 of this issue, Cruciat et al. (16) identify an RNA helicase (DDX) as part of the Wnt pathway, and on page 1441, Huang et al. (17) report that an enzyme (receptor interacting protein kinase 4) interacts with a Wnt receptor to control signaling. As our understanding of Wnt signaling keeps expanding, and experimental approaches to dissect the details improve, manipulating the Wnt pathway as an effective treatment for disease may become a greater possibility.

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Applied Physics

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Melany L. Hunt

Movement of robots over rough or unstable terrain is an outstanding challenge, especially for tasks such as remote planetary exploration, but animals manage such locomotion tasks every day. For example, in a natural environment, a lizard can traverse a sandy or pebbled surface in such a way that its limbs can push and move individual grains, which allow its limbs to penetrate beneath the surface of the loose layer. On page 1408 of this issue, Li et al. (1) present experiments and modeling of a biologically inspired, six-legged robotic device that was designed to move efficiently across a bed of dry, loose granular material. Based on the mechanics data, simulations were developed to identify designs that maximized walking speed.

The authors quantified the effect of the limb intrusion by measuring the lift and drag forces on a simulated leg (a small rigid plate) as it entered and was extracted from loose surfaces at different orientations to the granular surface. In the current experiments, flat beds of glass beads or poppy seeds were used. These measured forces were used to model the stresses, given the assumption that the stress was linearly dependent on depth within the layer and independent of the speed of intrusion.

The authors then used the stress relations to compute the forces, the overall movement, and the forward speed versus time of their robot. These simulations were then compared with experimental measurements for a range of stride frequencies and differing leg shapes. From their simulation methodology, the authors note that the design of the robotic legs can be optimized for speed—in this case, a maximum speed of 72 cm/s for a forward C-shaped leg at a stride frequency of 5 Hz.

Studies of the mechanical stresses on plates moving through loose materials were used to simulate and optimize robot locomotion over soft ground.

This field of research is often described as terramechanics, the study of vehicle performance relative to its terrain (1–3). Terramechanics includes the locomotion of small robots (4, 5) and lizards (5), as well as the transport of off-road vehicles (2, 3), tractors, military tanks, the Lunar Roving Vehicle (LRV) used in Apollo missions in the early 1970s (6), and martian rovers, including the Mars Exploration Rovers (MER) launched in 2003 (7) and the Mars Science Laboratory (MSL) that landed in August 2012 (8). The work by Li et al. used the term “terrodynamics” to emphasize the potential movement of the deformable terrain.

In terramechanics or terradynamics, the vehicle locomotion depends critically on the transmission of forces between the deformable terrain and the wheels, tracks, or legs of the vehicle. As illustrated by Li et al., the mathematical relations for the forces are often unknown and depend on the local state of the granular material, the properties of the
and MSL rovers based on electrical power, loads, and speeds (6–8). Overall, the performance of our machines does not match that of the walking animals. Hence, a better understanding of the underlying terrain such as that provided by the study by Li et al. may improve the performance of roving and walking robots.

**MEDICINE**

Spatial Turn in Health Research

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Developments in geographic science and technology can increase our understanding of disease prevalence, etiology, transmission, and treatment.

Spatial analysis using maps to associate geographic information with disease can be traced as far back as the 17th century. Today, recent developments and the widespread diffusion of geospatial data acquisition technologies are enabling creation of highly accurate spatial (and temporal) data relevant to health research. This has the potential to increase our understanding of the prevalence, etiology, transmission, and treatment of many diseases.

New approaches in geography and related fields, capitalizing on advances in technologies such as geographic information systems (GIS), the Global Positioning System (GPS), satellite remote sensing, and computer cartography, are often referred to collectively as geographic information science (1, 2). GPS and related systems make it possible to integrate highly accurate geographic location and time with virtually any observation. GIS provides the means to store, share, analyze, and visualize real-time and archived spatial data. It also permits the integration of multiple layers of interdisciplinary spatial data, such as health, environmental, genomic, social, or demo-

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