

the winged insects. The authors took each of the 13 protein-coding genes typically found in animal mitochondrial genomes and aligned them with those of other arthropods whose mitochondrial genomes have been completely sequenced. To root their phylogenetic trees, they also included mitochondrial genome sequence data for several out-groups, making a total of 35 taxa subjected to phylogenetic analysis.

Their initial phylogenetic analysis is interesting because it reveals the effects of systematic biases in sequence data on the recovery of a believable tree of relationships. The most spectacularly unbelievable result of this intentionally naïve analysis is a strongly supported grouping of two insects (honeybee and louse) with two ticks (chelicerates). Inspection of the data reveals at least part of the reason for this obvious anomaly—a convergent high A + T base composition in the mitochondrial genome sequences. Another potential source of systematic bias is the lineage-specific differences in rates of evolution—rapidly evolving lines may group artifactually, the so-called “long branches attract” phenomenon (5).

Nardi and colleagues mitigate the effects of these biases by winnowing their data to remove taxa that are not compatible in base composition and relative rates of evolution with the taxa (collembola and silverfish) that they deem crucial for testing the hypothesis of hexapod monophyly. They lose more than half their taxa in this exercise, leaving 15, but they remove obvious bias from the remaining data. Now they find strong evidence linking hexapods with crustaceans. This in itself is another point of major contention among those studying arthropod phylogenetics. For many years, Myriapods have been considered the closest relatives of hexapods. But, more recently, new data from molecular phylogenetics and developmental biology support a close relationship between hexapods and crustaceans. This grouping has had its proponents in the past: A hundred years ago a former director of my institution—then known as the British Museum (Natural History)—placed the hexapods and crustaceans together (6). The findings of Nardi *et al.* and other recent work force a careful look at data from all sources (7).

The final analyses of Nardi and co-workers appear to be very conservative and strongly support the separation of the collembolans from the insects by the two remaining species of crustaceans (see the figure). Many arthropod experts will not be entirely convinced by these data. Systematics is a very contentious field, so we can count on criticisms about the small number of species, the single data type, and the method of analysis. But at the very least, these data will spur both the collection of more sequence data from more taxa and also the extension and reevaluation of morphological work. Whatever the outcome, we will have a more solid understanding of how six-legged animals colonized and then took over the terrestrial world.

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GEOPHYSICS

Sandbars in Motion

Marcel J. F. Stive and Ad J. H. M. Reniers

Below the apparently chaotic sea surface of surf zones, complex sandbar patterns with intricate structure are frequently observed (see the left panel of the figure). Increasing ability to monitor these morphodynamic patterns has so far met with modest success in explaining their complexity. Near-shore morphodynamic models are therefore restricted to short time scales (a few weeks or less) and energetic storm conditions. On page 1885 of this issue, Hoefel and Elgar (1) introduce a new transport mechanism based on flow acceleration within the waves that may help to extend the prediction time scales of these models.

Interest in sandbar patterns first arose when it became clear that they play a role in predicting the likelihood of rip currents, which form a hazard to swimmers. In a pioneering study, Wright and Short (2) examined near-shore variability on Australian beaches and introduced a classification of

observed beach states. Lippmann and Holman (3) extended this classification on the basis of their examination of day-to-day variability of near-shore morphology at Duck, North Carolina, with video techniques (see the figure). These and other observations have shown that sandbar dynamics are often complex, sometimes showing spatial or temporal periodicity along the shore and at other times displaying more chaotic behavior (3).

Surf zone processes are highly nonlinear, creating nontrivial responses to input forcing. To understand and predict sandbar behavior, it is crucial to establish whether we are dealing with a deterministic forced response, a deterministic chaotic response, or a stochastic chaotic response—and, if so, when. Offshore bar migration, which occurs under highly energetic conditions, is an example of a deterministically forced response, where perturbations are suppressed and are advected offshore by negative feedback between water motion and bed motion (4, 5).

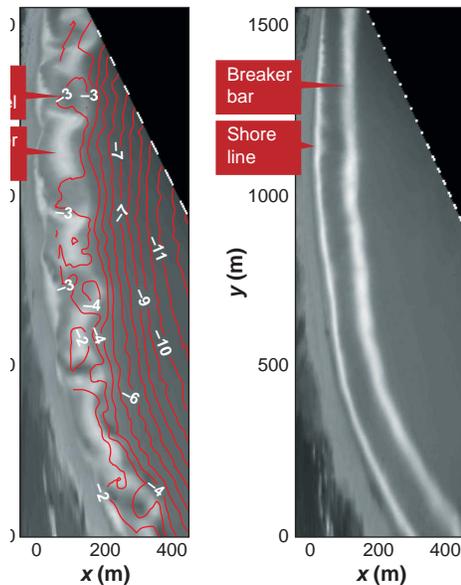
In the case of chaotic behavior, positive feedbacks promote the selective growth of small perturbations, leading to self-organization. Whether the chaotic response is de-

terministic or stochastic depends on how long the forcing conditions prevail. A simple example of deterministic chaos is an undulating coastline exposed to dominant incident wave angles greater than 45°, causing initially unlimited growth of coastline perturbations (6).

More complex deterministic chaos in surf zone topography structures may be understood through linear and nonlinear stability analyses. An initial equilibrium state is subjected to small perturbations in the forcing and/or water depth, and the fastest growing modes are identified as the most likely structures to appear (7, 8). An alternative approach is based on cellular automata (9), which can mimic both deterministic and stochastic chaotic behavior in beach cusps (10).

However, in the case of beach cusps, similar results can also be obtained based on deterministic forcing by phase-locked edge waves superimposed on the incident waves (11). Also, data analyses examining the measure of chaotic behavior in observed near-shore response (12) have not been conclusive (13). Because all these approaches predict morphodynamic responses that have frequently been observed in the field, we conclude that the three response mechanisms probably all occur and might even coexist. Identifying the range of time and spatial scales for the deterministic forcing of near-shore morphodynamic response remains an intriguing prediction problem.

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Highly energetic wave conditions often destroy the complex three-dimensional surf zone structures (3), resulting in one or more uniform linear bars along the shore (see the right panel of the figure). Although it has not been shown by any of the modeling efforts described above, this is generally considered to be a forced response. What has been shown to be a forced response is the offshore migration of the linear bars when energetic conditions continue to prevail (4, 5). The sediment transport formulation in all prevailing models is based on near-bed velocities derived from experiment or theory (14, 15). Applying a similar approach during mild wave conditions typically results in incorrect onshore motion of the bar, or even the failure of onshore motion (16).

Hoefel and Elgar (1) now show that this onshore motion can also be predicted with a deterministically forced sediment transport model, provided that the sediment transport induced by flow acceleration within the waves is included. They extend a formulation by Drake and Calantoni (17) based on detailed numerical modeling of particle-fluid interactions in a sediment layer to the case of random waves, appropriate for field conditions. Hoefel and Elgar (1) demonstrate improved prediction of near-shore bar motion over a 45-day period. This implies a substantial extension of prediction horizons of deterministic forced models.

The introduction of wave acceleration or, more generally, temporal and spatial pressure gradients (17–19) is an important paradigm shift in describing and modeling sediment transport. Prevailing concepts are based on shear stress or work exerted by fluid velocities. Introducing pressure gradients will give a new boost to understanding sediment transport near the shore.

Breaking waves. ARGUS stations (Coastal Imaging Lab, Oregon State University) overlooking part of a beach are used to obtain photographic images of incident wave breaking. Waves prefer to break over shallow bars, where the foam of the breaking waves shows up as an area of high light intensity. By averaging over a large number of images (equivalent to a photographic time exposure), a stable estimate of light intensity is obtained (3). The sharp contrast in light intensity between areas of breaking and nonbreaking waves reflects the position of shallow bar areas and deeper channels and troughs. (Left) A time exposure of Palm Beach, Australia, with superposed bottom contours (sea-floor depth in meters with respect to mean sea level) displays a complex pattern of shallow shoals (light areas) cut by deep rip channels (dark areas). The beach is located on the left. (Right) A time exposure at the same beach shows intense wave breaking on a linear bar and additional breaking at the shoreline.

Do these findings imply that surf zone bar structures are deterministically forced and thus deterministically predictable? The answer has to be negative. Many studies of seabed and land geomorphology (9, 20) show that self-organization processes lead to emergent properties, which cannot be predicted from the physics of fundamental particles.

What is shown, though, is that reductionist studies can still yield new insights and that the fashionable self-organizational research approach is not the only route to increased understanding.

What hampers reductionist research progress is the enormous effort required to unravel physical processes from first principles. Hoefel and Elgar show that it pays off. Their study is a first step toward an operational new sediment transport approach. Developing this model further will require new physical insights and capabilities for modeling such phenomena as nonlinear wave kinematics in the surf zone.

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NEUROSCIENCE

Gambling on Dopamine

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With bated breath, a player at a roulette table stares intently at the spinning wheel. As the ball comes to rest in one of the numbered slots, a smile crosses the gambler's face. This success strengthens his misguided belief in his ability to overcome the house advantage, and he prepares to wager again. The gambler's ability to detect the slot where the ball has settled depends on point-to-point connections between nerve cells at multiple levels of the visual system. The accompanying changes in emotion, attention, learning, and action depend on neurons with a very different pat-

tern of connectivity. Such neurons include midbrain dopamine neurons, which have cell bodies in the substantia nigra and ventral tegmental area of the midbrain, and highly divergent projections that connect with the frontal cortex, dorsal and ventral striatum, and other forebrain regions. Midbrain dopamine neurons go awry in Parkinson's disease, schizophrenia, and drug addiction. Data from both human and animal research implicate this small but widely connected neuronal population in motor control, motivation, effort, reward, analgesia, stress, learning, attention, and cognition. On page 1898 of this issue, Fiorillo *et al.* (1) report a new response mode for midbrain dopamine neurons and speculate how this new mode might contribute to the allure of gambling.

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