of how photoperiodic flowering is controlled by the coincidence of light with circadian timing [the so-called external coincidence model (1)].

By analyzing the phenotype of plants with mutations in FKF1 and GI, Sawa et al. determined that GI function in photoperiodic flowering does not completely depend on FKF1. Thus, GI may regulate the activity of other ZTL-FKF1-LKP2 family members or that of additional proteins controlling circadian clock functions. The demonstration of such a possibility comes from a complementary study by Kim et al. (3) describing the relationship between GI and ZTL. Kim et al. show that GI interacts with ZTL in plants and that ZTL-GI complex formation is, as in the case of FKF1, triggered by blue light. Interaction between GI and ZTL cooperatively stabilized both proteins, thereby increasing their accumulation. This increase consequently amplified and sharpened the rhythmic expression profile of the clock protein TOC1, thus providing the clock oscillator with the robustness necessary to maintain proper circadian rhythms.

Both Sawa et al. and Kim et al. provide mechanistic views on how day-night cycles shape circadian clock oscillations and how light is integrated into the clock to precisely regulate expression of a gene (CO) that controls flowering. The studies raise many questions: What factors control ZTL, FKF1, and GI stability? What role(s) do other light receptors (phytochromes and cryptochromes) play in controlling light signaling to the clock? Are there more targets for the GI-containing complexes? These insights will help us to better understand why plants see changes in seasons by standing on the shoulders of GIGANTEA.

References
like magnetic vortex motion in superconductors and sliding of charge-density waves. Why is this? Surely the deformation of metals would rank just below earthquakes in the list of important depinning problems to study.

First, deformation of crystals seemed complicated. Yielding in solids is microscopically more complicated than in these other systems; studying avalanches of dislocation lines (each with a Burgers vector indicating the direction and magnitude of the dislocation, a slip plane, and a long-range interaction with all of the others) is daunting both analytically and numerically. Second, deformation seemed different from other phase transitions. The yield stress (the force per unit area at which the material begins to deform) depends on the deformation history. Roughly speaking, it grows to equal the previous peak stress, because the yielding leads to tighter dislocation tangles, resisting further deformation (a phenomenon called work hardening). In contrast, the freezing point for water doesn’t rise as the water heats. We should have understood work hardening as an example of self-organized criticality (6); the dislocations moved as far as they could under the previous stress, so they start moving again (the new yield stress) at the historical stress maximum. And finally, physicists were ignorant of the fluctuations. Textbooks treat the yielding of solids as a smooth process—oozing, not crackling.

Recent experiments in ice and recent simulations in two dimensions (7) show clear evidence for avalanches and crackling noise during yielding—completely analogous to that seen in earthquakes, magnets, and other depinning systems, and in complete contrast to textbook discussions. But why don’t we hear crackling noise every time we bend a paper clip? Is yielding in three dimensions different from that in two? Are metals different in some crucial way from ice? (Indeed, ice has a different crystal structure and different allowed dislocations than most structural metals.)

Csikor et al. address precisely these last questions, using a large-scale numerical simulation of the dislocation motion, designed to describe yielding in aluminum. Is aluminum different from ice? No, they find an excellent power-law distribution of avalanches; aluminum crackles just like ice. Are there enormous crackles, which should be visible in any experiment? No, they find a cutoff in their avalanche size distribution, and provide a theoretical explanation for their cutoff.

Why are there no large dislocation avalanches? The key observation of Csikor et al. is that the avalanches are not three-dimensional objects. They find that the avalanches have a fractal dimension of roughly two (see their figure 2); indeed, their avalanches are fractal versions of the pancake-like lamellar slip models long used by materials engineers. A two-dimensional slipped region of thickness δ extending entirely across a sample of length L can only relieve the strain in a fraction δ/L of the sample. Their theoretical explanation for the cutoff (involving work hardening and the limitations of the measuring device) gives a thickness δ that varies between one and a thousand atomic spacings. The largest avalanches in a centimeter-scale experimental sample (10⁶ atomic spacings) will thus have strains of 10 parts in a million—easily ignored in textbooks.

On geological length and time scales, continental drift is smooth; the fact that the motion of South America away from Africa is mediated by earthquakes may not be crucial for theories of plate tectonics, even though it is important to those living near fault lines.

Similarly, dislocation avalanches cause jerky bending fluctuations that can be ignored on the scale of automobile fenders and beer cans. But as we bend metals on the micrometer and nanometer scales (such as the wires attaching to computer chips), the irregular, jerky microscopic deformation will become a serious (and interesting) problem.

References

MATERIALS SCIENCE

Printing Cells
Paul Calvert

Inkjet printing technology offers a way to create three-dimensional biological structures for studying cell interactions and artificial organs.

Materials scientists and biotechnologists are eager to build three-dimensional structures of cells held together in a tissue matrix. With such structures, researchers could study how cells interact and perhaps fabricate implantable organs. Inkjet printing—essentially the same technology used in desktop printers—is a promising method because it is simple and versatile and avoids contact with the substrate. A number of groups have recently developed inkjet printing of various cell types, so this is a good time to consider what can be done and what remains to be resolved.

There are two main types of inkjet printer. In thermal printers, a pulse of energy boils liquid at the surface of a small heater, and the expanding bubble drives a drop of ink through the nozzle. In piezoelectric printers, an applied voltage pulse causes a glass tube or a bending plate to eject the droplet from the nozzle. Inkjet printers for the low-cost consumer market can use either type of drive, whereas most high-end commercial printers are piezoelectric. A number of researchers, including my colleagues and me, have simply rebuilt consumer printers to replace the paper-feed system with a computer-driven platform to move the sample under the nozzle (1).

As might be expected, bacteria and yeast can be readily printed, whereas animal cells vary in their ability to survive the process. In addition to selecting the right cell type, one can use a concentrated buffer solution to shrink the cells and so reduce the possibility of damage in the nozzle. Often a more complex growth medium may be necessary to protect the cells during printing, in which case viscosity may be a limiting factor. Sterility is of course also a major concern in cell viability. Consumer cartridges probably cannot be autoclaved and must be cleaned and washed with alcohol. In addition, the printing equipment must be sterilized and used in a laminar flow hood to avoid airborne contamination.

Recently, for example, Chinese hamster ovary (CHO) cells and motor neuron cells have been printed from 3x concentrated phosphate buffer with a thermal printer (2). For the CHO cells, about 20% were damaged during “ink” preparation and a few percent during the printing step. In our work with...
Crackling Wires
James P. Sethna (October 12, 2007)
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Editor's Summary

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