team has found that the *p21* gene is turned on during terminal differentiation of several other cell types, including cartilage, skin, and the lining of the nasal passages. Other researchers including Paolo Dotto of Harvard Medical School, working with skin cells, and Bert Vogelstein of Johns Hopkins University School of Medicine, working with cells of the intestinal lining, are finding correlations between p21 expression and commitment of cells to their mature fates.

In spite of this accumulating evidence, the link between p21 and terminal differentiation is not airtight. For one thing, the results from embryos differ in a significant way from the cultured cell data: The myogenic bHLH protein MyoD turned on p21 expression in the cultured cells, but it is not necessary for activation of the gene, because p21 production occurred even in embryos in which the MyoD gene had been inactivated. Elledge says this doesn't necessarily mean the myogenic bHLH proteins have no role in turning on p21. He notes that another of these proteins, Myf-5, has the same range of activities as MyoD and might be doing the job in MyoD's absence.

But perhaps the biggest caveat is that the researchers are still working at the level of correlations. Simply finding that p21 is turned on as cells differentiate doesn't necessarily mean it plays the postulated role in coupling differentiation to growth cessation. Although molecular biologist Robert Weinberg of the Whitehead Institute for Biomedical Research says he finds the correlations "interesting," he nevertheless cautions that "correlations are no longer as exciting as they were." Weinberg is referring to the fact that there are now more direct ways to test whether a protein has a particular function. Its gene can be knocked out, for example, or specific antibodies can be used to block the protein's activity.

The researchers doing the work are the first to concede that these more definitive tests need to be done. As Lassar says, "The proof of the pudding for the speculated role [of p21] awaits the functional inactivation of the gene product." But even if p21 itself strikes out as a link between the cell cycle and differentiation, other cell cycle inhibitors are waiting their turn at bat. Kohtz says, for example, that his work points to one of these, dubbed p27, as possibly important in muscle. In fact, there's already preliminary evidence that several cell cycle inhibitors besides p21 may be involved.

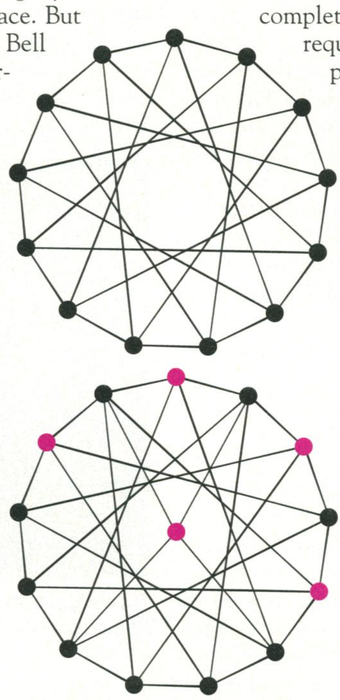
Indeed, Elledge says, efforts to pin down the role of the cell cycle inhibitors in differentiation is just getting off the ground. But exploring just when and where they are turned on in the embryo may eventually give researchers a more precise view of how organisms develop.

–Jean Marx

MATHEMATICS

A Visit to Asymptopia Yields Insight Into Set Structures

With computer circuitry and telecommunication networks growing in complexity by leaps and bounds, researchers who analyze the fundamental mathematical features of these finite but increasingly large systems often must scramble to keep pace. But Jeong-Hon Kim of AT&T Bell Labs in Murray Hill, New Jersey, decided to beat technology to the punch. Kim was trying to determine the size at which networklike systems inevitably develop certain specific structures, but he gave up examining systems of finite size because they became too complex. Instead, he took a new approach. He looked for *asymptotic* results: theorems that set bounds on the behavior of large systems rather than describing it exactly. Such theorems still apply—indeed, they grow more precise—as the systems grow infinitely large.



Sets and structure. A "graph" of 13 connected points can be drawn to have no triangles and no set of five points without one link in common *(top)*, but when the graph grows to 14 points, one constraint or the other breaks down *(red)*.

ILLUSTRATION: C. FABER SMITH

Kim's effort yielded a major step forward in Ramsey theory, a branch of mathematics concerned with the unavoidability of "accidental" structures in large systems. His success is also a vindication of a strategy that a growing number of researchers are adopting, as Joel Spencer of the Courant Institute of Mathematical Sciences described last month in San Francisco at the joint meetings of the American Mathematical Society and the Mathematical Association of America. Searching for asymptotic rather than exact solutions has a key advantage, Spencer argued in a talk called "Adventures in Asymptopia": It makes available the arsenal of tools from calculus and differential equations, which don't readily apply to finite-sized systems. Speaking with the enthusiasm of a mathematical travel agent, Spencer described Asymptopia as "a magical place where all the problems that you have with discrete calculations just melt away!"

What Kim found in Asymptopia was the solution to a vexing problem in Ramsey theory that is sometimes described as the party problem. Suppose you want to throw a party and are deciding on a guest list. On the one hand, you want people to mix, so you don't want to wind up with any "triangles" consisting of three people each of whom already knows the other two. On the other hand, you don't want to wind up with any large groups of complete strangers, so you decide to require that among any, say, five people, at least two should know each other. Satisfying both constraints gets harder as the guest list gets longer, but just how large can the party get before the constraints break down? And how does the possible size of the party grow as you change the group size from five to, say, 10,000?

Mathematicians usually frame the problem in terms of graphs, which consist of points connected by line segments, or edges. Ramsey's theorem, which dates back to the 1920s, implies that for any number k (say $k = 5$), every graph with "sufficiently many" points either contains at least one "triangle"—that is, three points each connected to the other two—or else it contains a set of k "independent" points, none of them connected to each other. More generally, Ramsey theory says that almost any pattern can be found in a system with sufficiently many parts—a fact that undoubtedly helped early stargazers see constellations and is a bane of network designers, who can be blindsided by unexpected connection patterns.

The sticking point is the phrase "sufficiently many." Some graph theorists have focused on looking for exact values for the function they dub $R(3,k)$—the smallest size at which graphs are guaranteed to contain either a triangle or an independent set of size k. They have succeeded in finding values up to $k = 9$. But there the search has stalled as the proofs became increasingly intricate. So other graph theorists have concentrated their efforts on the asymptotics of $R(3,k)$—looking for formulas that, while not precise, give bounds that hold no matter how large k is.

By the early 1980s, graph theorists had succeeded in boxing the values of $R(3,k)$ between multiples of $k^2/(\log k)^2$ and $k^2/\log k$.

Narrowing those limits proved difficult—until Kim, then at Rutgers University, returned from Asymptopia with a differential equation that solved the problem.

Kim's proof starts with a graph that has no edges. He then picks pairs of points at random and connects them whenever doing so does not create a triangle. By working in Asymptopia, he can view the graph as being arbitrarily large, and consequently each edge represents an infinitesimal change. That allows him to describe the process of adding edges with a differential equation, which relates the rate at which edges are added to the total number of additions attempted.

Roughly speaking, the solution to the differential equation shows that edges are added at too high a rate for a large independent set of points to remain unless the graph is very large. When the asymptotic dust settled, Kim found he had bumped the lower bound for $R(3,k)$ up to a multiple of $k^2/\log k$, thus bounding $R(3,k)$ between two different multiples of $k^2/\log k$. "It's an exciting achievement" in Ramsey theory, says Spencer.

Graph theorists aren't the only ones who can benefit from a trip to Asymptopia, Spencer notes. Physicists, especially in statistical mechanics, are accustomed to blurring the line between finite and infinite systems, turning sums into integrals and differences into derivatives. Their intuition is usually very good, says Spencer, but he thinks they might also profit from the mathematicians' rigorous approach. "The hope here is that one can think like a physicist and prove like a mathematician," says Spencer. "If you can do that, then you're way ahead of the game."

–**Barry Cipra**

ARCHAEOLOGY

Shuttle Radar Maps Ancient Angkor

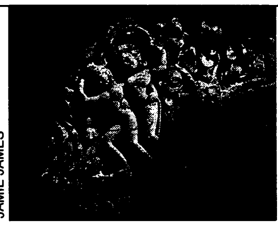
One morning last April, John Stubbs, program director for the World Monuments Fund (WMF) in New York, was leafing through the *New York Times* as he rode the subway to work, when his eye fell on a story about a new earth-imaging radar aboard the Space Shuttle. The story described how the radar had led to the rediscovery of an ancient city in the Arabian desert. Stubbs was so excited by what he read that he got off the subway at the next stop and put in a call to the National Aeronautics and Space Administration.

Stubbs was excited because the WMF has been working since 1989 at the ancient Cambodian city of Angkor, capital of the Khmer empire that ruled much of Southeast Asia from the 9th to the 13th centuries. Much of the site, however, is hidden in jungle, and some lies in territory controlled by the Khmer Rouge. Stubbs realized that the shuttle radar offered a way around these obstacles. NASA agreed, and on 30 September, the Space Shuttle Endeavour passed over Angkor, its radar on.

The resulting image was released last week by NASA's Jet Propulsion Laboratory (JPL) and discussed at a symposium at Princeton University sponsored by the WMF, the Royal Angkor Foundation, and the J. M. Kaplan Fund. The image lives up to Stubbs' hopes. It reveals new clues to the system of canals and reservoirs that sustained ancient Angkor—and has convinced archaeologists that the radar's sensitivity to slight variations in vegetation pattern could be a boon at Angkor and other poorly surveyed forest sites. It's "an unprecedentedly flexible research tool," says Elizabeth Moore, a specialist in Cambodian art and archaeology at the University of London.

The radar, developed by space scientists from JPL and the German and Italian space agencies, combines data collected over a long exposure from the moving spacecraft to simulate an antenna many miles long. The maps that result show features as small as a few meters. That's no better than the resolution of satellite photographs, such as Landsat images. But unlike Landsat, which is sensitive mainly to differences in composition, the shuttle radar, officially known as Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar, can discern subtle variations in texture. It collects data at three different wavelengths—3, 6, and 24 centimeters—each of which is sensitive to features of a particular size.

The longest of the three—24 centimeters—can also penetrate as deeply as 5 meters into dry ground. That's how an earlier version of the system disclosed the location of the 4800-year-old city of Ubar in the Arabian desert, and how the current radar revealed new details along the ancient Silk Road in the Taklamakan desert. The archaeologists and space radar experts at Princeton agreed that the instrument will never be much use for below-ground mapping in forested areas, because radar can't penetrate moist soil. But the Angkor image shows off the value of the radar's sensitivity to texture. Long after a forest has regrown to cover ancient fields, paths, or canals, subtle alterations of vegetation pattern trace the disturbed areas—clues that the space radar is adept at detecting.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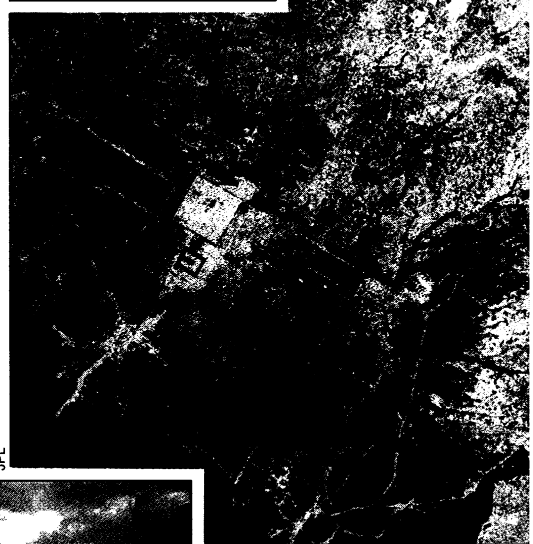
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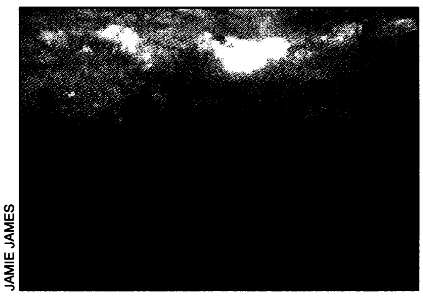
JAMIE JAMES

Views of Angkor. The main temple complex of Angkor Wat *(left)* is the bright square near the center of the space radar image; dark rectangles are ancient reservoirs. At top is a relief of a mythological scene.

When Stubbs analyzed the new radar image, he saw linear features to the north of Angkor that Diane Evans, the JPL project scientist, suggested were "residual tracks or paths that hadn't grown over by exactly the same amount as the surrounding areas." Moore, meanwhile, saw evidence of a dam she hadn't noticed in satellite images and aerial photographs. The dam, perhaps part of the ancient kingdom's irrigation scheme, could not have been detected on the ground either, she adds, as it lies in an area controlled by the Khmer Rouge.

Moore is eager to extract more information about ancient Angkor from the space radar image. She has asked Evans and her JPL team to manipulate the data to suppress the rectilinear structures characteristic of classic Angkor, which was under the influence of Indian civilization, and enhance preexisting native circular forms. Stubbs, meanwhile, is hoping to enlist NASA to do more high-tech archaeology, at WMF sites as farflung as Easter Island, the 2600-year-old city of Butrint in Albania, and the Katmandu Valley in Nepal.

–**Jamie James**

Jamie James is collaborating on a book about the archaeology of Southeast Asia with anthropologist Russell Ciochon of the University of Iowa.