Computers have become faster, smaller, and cheaper at an unthinkable pace. These developments have largely resulted from scaling the transistor to smaller and smaller sizes. Each transistor contains a channel that electrons must pass through as they make their way through a circuit.

The flow of electrons across the channel can be controlled by a voltage applied to the gate of the transistor. In order to speed up electron flow and reduce the energy required to cross the channel, computer architects want to make transistor channels as short as possible.

In addition to increasing computer speed, shortening the channels allows transistors to be packed closer together on a chip. However, computer designers are quickly approaching a roadblock. The gap between the control gate and the transistor channel is becoming so short that electrons will soon be able to cross the gap and move into the channel, thereby short-circuiting the basic transistor mechanism. This phenomenon, called quantum tunneling, is expected to fundamentally limit transistor size by 2010.

When quantum tunneling and other physical limitations take over, continued advancement in computer technology will require a revolution in how the machines are designed and built. The leaders of the revolution are a diverse group of scientists working in the quickly developing field of nanoscience and nanotechnology.

Although research in this field takes many different directions, everyone involved “thinks small.” The new Pentium 4 chip has 42 million transistors on a chip the size of a postage stamp. These transistors still haven’t reached the fundamental physical size limits, which occur when the channel width reaches 25 nanometers.

To comprehend just how small the nanoscale is, consider nanotubes. These are carbon tubes about one nanometer in diameter that show promise as one-dimensional wires. If a line of nanotubes were stretched the 250,000 miles between Earth and the moon at perigee and then loosely bunched together, the resulting bundle would be about the size of a poppy seed!

Although electrical and computer engineers might not have a history of working at such small scales, biologists and chemists have done so for years. After all, molecules and cells have nanodimensions. Hence, electrical engineers are teaming up with biochemists to explore these scientific frontiers together. Here at the University, a unique interdisciplinary collaboration supports and encourages professors and students to work together...
on cutting-edge nanotechnology research. Known by the acronym MONALISA (MOlecular Nanoscale Alliance for Interdisciplinary Studies and Activities), this endeavor is the brainchild of electrical engineering professor Rick Kiehl.

Kiehl came to appreciate the power of interdisciplinary scientific research during 20 years of working at various research centers, including Sandia National Laboratory, AT&T Bell Laboratories at Murray Hill, IBM’s T.J. Watson Research Center, and Fujitsu Laboratories in Japan. In these research centers, scientists align themselves according to their research goals and not according to their backgrounds.

"[In research centers] you are there with people of different backgrounds, and you don’t know what their degree is in. You don’t think about it, and sometimes you are surprised," recalls Kiehl.

Unlike academia, where professors of different backgrounds have offices in separate buildings, researchers naturally collaborate with one another at the research centers.

"You have the ability to spontaneously bump shoulders with someone at a lunch table. As you talk about your interests, you develop new ideas and directions," says Kiehl.

"The University isn’t like that. I see those barriers more, having been in a research center environment." MONALISA is Kiehl’s attempt to break those departmental barriers.

When looking for academic positions, Kiehl tried to find universities that would welcome the interdisciplinary research program required by nanotechnology. During his visits, he noted whether each institution had a number of big research groups focused on narrow topics or more collaborations and interdepartmental centers. "Minnesota was a place that seemed interested in interdepartmental efforts," says Kiehl.

He has put together an interdisciplinary research group that includes students from physics, materials science, and electrical engineering. Together with chemistry professor Tom Hoye, he funds the work of a chemistry student. In addition, the postdoctoral researcher who works with Kiehl has a chemistry background.

When he was establishing himself in Minnesota in spring 1999, Kiehl was pleased to find the chair of the electrical engineering department supportive of his proposed collaborations.

"Too often, department heads find interdisciplinary things hard to swallow," he says. "They are afraid that the individual department will lose students or resources." However, Kiehl’s work in developing MONALISA has only strengthened the resources available to all the departments involved.

MONALISA moved from idea to reality as a result of the Minnesota Nanotechnology Summit. Held on campus in March 2000, this one-day event featured national speakers and attracted people from academia, government, business, and the general public. Kiehl was on the organizing committee.

"[In part, the summit] came from President Yudof’s desire to create momentum in the direction of nanotechnology, but we didn’t have the critical mass or the mechanism for collaboration," recalls Kiehl.

MONALISA was the answer. The collaboration consists of about a dozen faculty members from electrical engineering, mechanical engineering, chemical engineering and materials science, chemistry, physics, genetics, cell biology and development, and
One example of the interdisciplinary efforts in nanotechnology is the use of DNA scaffolding to assemble nanocomponents into circuits using selective binding.

Programs supported by MONALISA are aimed at increasing interdisciplinary work. During fall semester, the alliance hosted weekly seminars given by University professors about aspects of their research that could benefit from or advance developments in nanotechnology.

This semester, MONALISA is hosting a series of three or four seminars by national nanotechnology experts, and this fall a mini-symposium on nanoscience and nanotechnology will involve lectures and lab tours, with the hope of attracting industry interest.

The alliance also includes funding to support a floating research assistantship for a graduate student whose research bridges departments. Funds are also available for some lab fees and supplies associated with collaborative research projects between faculty and students in different departments.

One example of such an interdepartmental research effort is Kiehl’s own work with chemistry professor Karin Musler-Forsyth and Ned Seeman, a professor at New York University. Together the trio is working on using DNA scaffolding to assemble nanocomponents.

DNA consists of four nucleotide bases that bind selectively: adenine, cytosine, guanine, and thymine. Adenine binds only with thymine and cytosine binds only with guanine. If nanocomponents were attached to an appropriate DNA strand, as that strand binds with a complementary strand, it will bring the associated nanocomponents together in an electrical circuit.

In addition to nanoscale fabrication techniques, Kiehl is also interested in nanodevices. One possible technology would replace current transistors with single-electron devices. These devices are single quantum dots that allow only one electron to move onto or off of the active area.

Kiehl is studying a new method of logic for these devices called tunneling phase logic (TPL). In current circuits, information is coded by the configuration of charge on a circuit element. In TPL, information is coded in the phase between an AC reference signal and oscillations of electrons tunneling through the single electron device. With chemistry professor Tom Hoye, Kiehl is working to find a molecular counterpart to TPL.

Kiehl also collaborates with Professor Leon Chua of the University of California at Berkeley. Their research aims to implement nanotechnology in a large-scale architecture using cellular nonlinear networks. These networks process information by performing operations on spatial input patterns rather than on individual bits of information. This type of information processing is similar to that believed to occur in certain parts of the brain.

The variety of collaborations might lead one to wonder how Kiehl is able to keep up with such a diverse array of projects. He places great value on researching a wide range of topics, and he feels such diversity is necessary if nanotechnology is going to become technologically feasible.

“My research has three levels: devices, fabrication, and the circuit and systems level,” says Kiehl. “There are people who do research at just one level, without much idea about the other two. But if you know how to make a device, but you don’t know how to use it in a powerful way, then it isn’t going to be worth much. My research is a broad umbrella that covers a variety of things, and I try to think about all levels at the same time.”

If nanotechnology is going to be successful, it will have to include a complete reworking of devices, materials, and processes. MONALISA’s integrated approach to research is helping to ensure that University faculty are constantly pushing all aspects of the expanding frontier associated with nanotechnology.

“I think what comes next will be a big jump and a paradigm shift,” speculates Kiehl. “Everyone uses that phrase ‘paradigm,’ but this is a big change. Everything changes together with nanotechnology: the device, the fabrication and the circuit technology. I think it will be revolutionary rather than evolutionary.”