What the Future Holds

Faculty tackle a big question: Where will science take us in the next 25 years?

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We asked 10 faculty from the College of Natural Sciences a big question: "What development in your field is likely to have the greatest impact on the way that we live over the next 25 years? How?"

Here are their answers. Select the faculty names below to jump to the expanded answers.

- **J Strother Moore** on machines that think
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J Strother Moore
The Admiral B. R. Inman Centennial Chair in Computing Theory
Department of Computer Sciences

In the next 25 years I believe we will see something fundamentally different from today's computers. We will see machines that think. They won't think as well or flexibly as we do, but they will think well enough to cause us to relate to them in more anthropomorphic ways. They will become our assistants. For many tasks, we will tell them what we want—where we want to go, who we want to see, what we want to buy, what our ambitions are—and they will offer advice, propose plans and, in many cases, carry out those plans for us. The critical scientific advances will be in language, speech, vision and image understanding, in learning and data mining, and in deductive and inductive reasoning.

Right now you can go to Google to ask a question, and if you ask it right you'll get useful information, but these "assistants" of the future will be much more proactive. You'll be walking around wearing 15 microprocessors in your clothes, perpetually connected to the Web, and we can imagine, for instance, how such an assistant would react if you're in a car accident. Not only does the machine, as some do now, notify the police and ambulance dispatch that you've been in an accident. It also tells you, "Get out of the car and go to the side of the road, and remember to get the other person's driver's license." Or it automatically takes a picture of the scene and the other car's license plate.

They will be invisible agents that surround us and step in when it's time. Given a system that's described by a collection of rules—a software program, laws, social norms, the tax code, whatever it is—they'll be able to determine, within limits, whether or not a given behavior achieves some goal within those rules.

They may also change the way we interact with the world in more subtle, but also more profound, ways. They'll liberate us from certain kinds of tasks that computers are better suited to doing than we are, and at the same time they'll augment our capacity to reason. The thing about computers is that, compared to humans, they're very dumb in most ways. But they're also, compared to humans, extraordinarily reliable and powerful and precise in other ways. So there's a kind of symbiosis that we can achieve with computers because the human has creative insights that are beyond our abilities to formalize or even reverse engineer, and computers can do things and be precise in ways that are beyond human capacity. So there's an interplay.

We'll be able to reason about things, with the help of machines that can do millions and millions of computations, that we wouldn't be able to reason about ourselves, and the human's insight and creative hints will allow the machine to go to places that no amount of computation could have led it. It's not me against the machine, it's the machine and me against the problem.

I don't think machines will be threatening to take over in 25 years. Augmented by them, humans will make unimaginable advances on many vexing problems. But I also think that we will have to confront some deep economic, ethical and philosophical questions because of the presence among us of these thinking machines.

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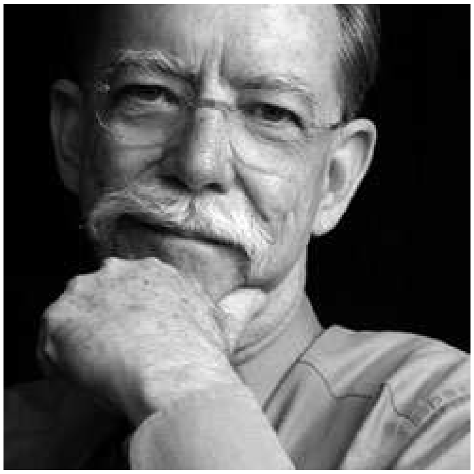

R. Adron Harris
The M. June and J. Virgil Waggoner Chair in Molecular Biology
Section of Neurobiology

I would say that the $1,000 genome—the ability to sequence anyone's genome at a relatively low cost—is going to profoundly change the way we do medicine. Right now only Craig Venter and James Watson, two of the pioneering geneticists, have their genomes completely sequenced, and there are only a few small parts of the genome that have been sequenced in multiple people. So even though we've sequenced the human genome, in some sense, we don't know very much about what this mass of genetic information means.

Once sequencing becomes realistically available for a lot of different people, however, we'll have thousands or millions of complete sequences, and we'll be able to analyze that genetic information in light of everything else about people's health and medical history. We'll be able to ask what kinds of diseases they have, what behaviors—like addiction, for instance—they exhibit. There may even be a kind of genetic MySpace or Facebook.com where people make their genetic information available for researchers. (Maybe there will even be a genetic Match.com, a dating site that gives you not just what someone looks like, but what his or her genes are.)

How many people would choose to do this? Some people will want no part of having their genomes sequenced. But I think enough people will do it, assuming that we can protect their privacy, that it will dramatically improve our ability to understand the relationships between genetics and disease. I can foresee the day where everyone has a little memory chip they'll carry with them that will have their gene sequence on it, and any medicine or diagnosis that's done on them will take their unique genetic information into account.

The genome doesn't, of course, tell us everything. With a few exceptions, genes are not destiny. In most of the things we're going to be interested in, like heart disease and cancer, there are very strong environmental factors, and the genes will only tell us so much. It's like being given a blueprint of a house. It doesn't tell you what the neighborhood looks like, what kinds of materials were used in its construction, whether it's going to flood or not.

In a way, this is just a very definitive family history. Any good physician already asks you what diseases your parents had, how long they lived, etc. But it will enable us, with far greater precision, to select and develop better therapies for individuals. We'll be able to offer counsel about what kinds of environments and habits will best ward off the conditions that we're predisposed to suffer from. And we'll be able to intervene earlier with all sorts of conditions that right now we typically treat only when they're very advanced.

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Jaquelin Dudley
Professor
Section of Molecular Genetics and Microbiology

We made a huge leap in the last century by using antibiotics to treat bacterial diseases and prolong life. In this century, I think we're going to witness similar kinds of life-prolonging advances with the development of anti-viral and anti-tumor agents. In particular, I think that we will improve our understanding of how viruses and tumor cells replicate. Then we'll be able to develop designer drugs and treatments that target the specific steps in the replication of viruses, or cancer cells, and inhibit that replication without affecting the normal processes of healthy cells.

You can already see the efficacy of these kinds of treatments, for example, with HIV drugs. A number of the ingredients in the "drug cocktail" intervene in the replication of the virus without affecting healthy cells. But progress, to this point, has been limited and is proportional to the amount of resources that are devoted to a particular disease or condition. Currently, federal funding for research on cancer and most infectious diseases has been cut dramatically.

With cancer, for example, we mostly rely on slash-and-burn treatments. We either cut out the tumor, which doesn't work if the cancer has metastasized beyond the initial site, or we use chemotherapy, which targets rapidly dividing cells but isn't specific to tumor cells (which is why patients' skin and hair cells, which also divide rapidly, are affected). There are a few treatments that target specific characteristics of cancerous cells. However, tumor cells that can evade single drugs are rapidly selected and, therefore, we need to develop cocktails of drugs that can target multiple specific defects in individual tumors.

In general, as we understand the process of viral replication more thoroughly and the mechanism of tumor formation at the molecular level, we will develop not just tumor- and virus-specific treatments, but patient-specific treatments. And we'll live longer as a result.

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Allen Bard
The Norman Hackerman-Welch Regents Chair in Chemistry
Department of Chemistry and Biochemistry

I think you'll see electrochemistry making major contributions in the fields of energy and health.

For one, I think there will be an efficient, stable, cheap, photoelectrochemical system that will be a game-changer in the energy field for electricity or fuel (for example, hydrogen) production. To make a system that's practical you have to have high efficiency, low cost and very good stability over years and years. Nothing is around right now that has all of these characteristics, but there are no fundamental limitations to why you couldn't do it. It's a matter of finding the right materials.

I can imagine that we'll get this material where, instead of making solar cells by growing single crystals at high expense, which is what we largely do now, we'll just print out sheets of a polymer with the material on it, build the cell, put it on the roof, and hook it into a home's electrical system. Or generate electricity at a large scale. It doesn't necessarily have to be distributed.

We already understand the basics of a lot of what's required to find such a material, but what you never understand very well in science is how to design a new material from first principles with specific desired properties. We do, however, know how to synthesize test materials and screen them for good performance rapidly. We'll make an educated guess about what to try. We'll try to understand what happens with this material so that we can go on to the next one, and then the next one, and so on. Eventually, I think a good material will be found.

In the field of health, I think that we're on the verge of a different kind of medicine that will depend on the ability of electrochemists to develop inexpensive and easy-to-use sensors (which is something that electroanalytical chemists are good at) so that we can do a continuous analysis of unique biochemical footprints. For each of us, there are baseline levels of key biological markers, like proteins (for example, antibodies, enzymes) that are at relatively consistent levels over time. If all of the sudden you get a big change, you know something is happening physiologically and can take action, even before symptoms of a disease appear.

We might be doing a daily analysis of blood, or saliva, or urine (I could imagine a sensor in the toilet), sending reports to the doctor's office. For this to be effective, of course, we'll have to learn a lot more about what to do with the information we're getting. Detection, right now, is well ahead of the advances in understanding the data, but it's reasonable to foresee that we'll be able to diagnose many conditions and diseases at a much earlier (presymptomatic) stage, and therefore intervene earlier and more effectively than we can now.

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Jennifer Brodbelt
Professor
Department of Chemistry and Biochemistry

As environmental concerns become overwhelming, and especially with the growing public awareness that our society has a huge impact on the environment, I think we'll see the field of chemistry respond in two ways. There will certainly be more research aimed directly at addressing environmental concerns, but I think there will be an even greater transformation related to how chemists do research.

Right now chemists generate a lot of waste (mixtures of chemicals, solvent waste, etc.) in the process of doing our experiments. We're doing it in the name of better science for mankind, but we're going to have to change, both because it's the morally and economically right thing to do, and because we'll need to respond to the taxpayers' justifiable concern about the effect that our work, including all the work done in the chemical industries associated with development of new drugs and new materials and fuel processing, is having on the environment.

The whole research process is going to be pushed toward the miniaturization of everything, as well as toward increasing the efficiency of chemical processes. We'll cut down on solvent consumption. We'll use more renewable and recyclable chemicals. We'll miniaturize our analytical methods. And I think you'll see this kind of change in other disciplines as well. Everybody is going to be adopting more environmentally conscious research practices.

Another change that I see coming is the rise of personalized medicine. It's going to happen, I think, not so much because of any particular technological breakthrough, but because of much greater collaboration between scientists across disciplines. A lot of the science is already out there, but right now it's not well integrated.

What we'll see are biomedical engineers, who are designing polymers that can deliver drugs, working with biochemists who understand how enzymes work. They'll work with medicinal chemists who know about pharmacokinetics, and with chemists who are able to analyze the metabolite levels and map biomarkers of disease. It's this collaboration that will make possible, for instance, implantable devices that release drugs that have been tailored to a person's own metabolism and biochemical pharmacology. I believe that the increasingly cooperative vision of scientists is going to lead to some fantastic outcomes.

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Chris Bielawski
Assistant Professor
Department of Chemistry and Biochemistry

Chemistry, I believe, will be a driver in shaping contemporary society of the future. Perhaps the greatest impact will be in the utilization of energy. Since all of our energy ultimately comes from the sun, the key to solving the world's current energy problem is figuring out how to capture sunlight and use it in a cost-effective manner. I don't think it is a question of if this will be accomplished. Rather, it is a question of when. However, the energy problem is multi-faceted and will require teams of chemists, physicists and engineers addressing challenges in essentially all aspects of consumption, storage and transport.

Within 25 years, I predict enough technological advances will be made such that a number of alternative energy sources will be widely available and as cheap as fossil fuels. For example, I predict electronic devices like cell phones and portable computers will be powered by fuel cells, ultra-efficient solar panels will be used to light significant portions of our cities and a considerable number of cars and trucks will run on combustible fuels that have originated from cheap biomass.

Another change that we're likely to see over the next few decades is in the way chemicals are made—everything from plastics to pharmaceuticals. Currently, many of these materials are made using multiple-step procedures in organic solvents, which generate lots of environmentally "unfriendly" by-products. While chemists do all we can to minimize these deleterious effects and make the processes more "green," we are inspired by nature, which makes many of the same or similar materials in water with virtually no waste.

Over the last few decades, we have made great strides in understanding how this is done and have found that such processes can be manipulated to our liking. For example, instead of making a new drug in the lab, scientists will take a biological process that normally makes an amino acid, for instance, and hijack it to produce the desired drug instead. Ultimately, I envision this being accomplished solely at the genetic level. However, in the shorter term, it is likely to be done through a combination of genetic manipulation and the addition of synthetic chemicals to natural processes.

I think we'll see a number of biological systems coaxed into "naturally" producing materials man wants. And, I predict, they will do so under extremely mild conditions that generate very little waste, making the overall process more cost-effective and environmentally friendly than conventional methods.

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Xiaoqin (Elaine) Li
Assistant Professor
Department of Physics

To the public, it may appear that physicists are only concerned with esoteric questions such as the origin of the universe or the relationship between space and time. This picture, however, does not capture the entire spectrum of activities pursued by physicists. One particular sub-field in physics, the study of condensed matter physics, focuses on understanding how solids behave, and it has changed and will continue to change how people live. The areas that condensed matter physics has had tremendous impact upon include microelectronics, communications and medical technology, among others.

The whole microelectronics industry, for instance, is based on the invention of transistors, which was first made possible by basic research in condensed matter physics. The future of the microelectronic industry will also, in my opinion, depend on our constantly improving understanding of condensed matter physics. Moore's Law states that the density of transistors we can pack on a microelectronic chip will increase exponentially over time, and that has, in fact, been happening for decades now. But this growth almost certainly has to saturate at some point. (It is generally believed transistors can't get smaller than an atom.) What then? Will the entire industry, and many other related technologies, run out of room for innovation?

One possibility of escaping this limitation lies in our ability to utilize our understanding of quantum physics. Information in current computing is represented by bits using a binary system. Every bit is restricted to either zero or one. Through quantum physics, however, a single "quantum bit" can be prepared in a state that is simultaneously a zero and a one. If we can exploit that, it will give us exponentially more space to store information.

It's very tricky to deal with quantum objects, because whenever you make a measurement on a quantum object, its properties change. I believe, however, that eventually we will learn to manipulate the quantum properties of individual electrons in solids. We'll also be able to take advantage of other counter-intuitive insights from quantum physics-the fact that an electron is both a particle and a wave, for instance.

Many other research areas in condensed matter physics have the potential of changing how people live in 25 years. Examples include spintronics and nanomagnetism, high temperature superconductors, molecular devices and metamaterials. It is often difficult to predict exactly what that impact will be because we are simply limited by our current understanding and imagination.

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Andy Ellington
The Wilson M. and Kathryn Fraser Research Professor in Biochemistry
Department of Chemistry and Biochemistry

I think the big story is going to be RNA (ribonucleic acid), which was long the neglected stepsister of the nucleic acids. Unlike DNA (deoxyribonucleic acid), RNA doesn't propagate information from generation to generation. It just (it was thought) acts as a messenger, passing easy-to-read notes between DNA and the protein machines that did the work of the cell.

It turns out, however, that small little snippets of RNA—sometimes located in the rundown, undeveloped "junk" parts of DNA neighborhoods—don't carry messages at all. Instead, they decide which messages should be read and which should be trashed. In other words, they regulate which genes are expressed.

These "microRNAs" are, I believe, going to prove to be incredibly significant. Synthetic equivalents, small interfering RNAs (siRNAs), are the most promising drugs to come along since antibiotics. They could be used for the inhibition of any of the RNA messages, including those for viruses or those for cancer. They could potentially even be adapted for recreational uses (leading to speculation that even this next Olympics may see the first "RNA doping" scandals).

Most important, though, they are an alternative to genetic tinkering in the germ line, the cells like sperm and eggs that pass genes down to a child. The ephemeral nature of siRNAs is an advantage, since they can be introduced into the body, do their job and disappear, leaving future generations untainted.

Gone are the concerns over genetically engineered microorganisms and cloned animals (although not the bioethical concerns over the true impacts of being able to control the human form at the genetic level). Because of this, the discovery and engineering of siRNAs should rank among the most important research results of the past several decades, and will greatly influence all of our lives for many decades to come.

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Shardha Jogee
Assistant Professor
Department of Astronomy

I will not even try to fathom the next big questions in the field of astronomy 25 years from now. This field is moving so fast that I would bet that in 25 years we will be working on questions that we cannot even pose now, questions that do not even puncture the fabric of our imagination today. I can venture some thoughts, however, on fascinating breakthroughs in the next 10 years, and on the challenges they will raise.

Over the next decade, new insights, and even more questions, will flow from the powerful synergy created by three upcoming cutting-edge facilities: the 25-meter Giant Magellan Telescope (GMT), the James Webb Space Telescope (JWST) and the Atacama Large Millimeter Array (ALMA).

The ALMA radio facility will be the world's most powerful probe of molecular gas and dust—the fuel from which new stars, planets and galaxies form. The GMT will allow us to map the kinematics of gas and stars in galaxies, as well as the properties of black holes out to very early epochs, when the universe was a mere few percent of its present age. The space-based JWST, one of NASA's flagship missions, will identify the first bright objects that formed in the early universe, ending the dark ages.

We may also have some answers to one of the most fundamental questions in science: what is the nature of dark energy, the mysterious component that dominates about 70 percent of the energy in the universe and will ultimately determine its fate?

I should mention that the Department of Astronomy will have the privilege of being in the center of these developments with its involvement in the GMT and the ALMA, and with its involvement in HETDEX, one of the planned dark energy experiments.

With these new insights into the dark side of the universe, and on how stars, planets and galaxies evolve, we may well have to drastically revise and discard many of our current hypotheses. The field will have to re-invent itself, sprouting new questions for 2020 and beyond.

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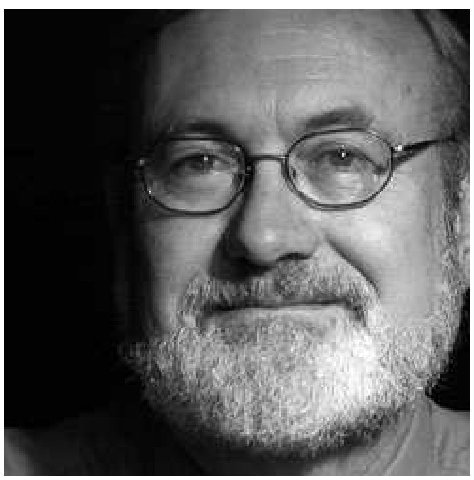

Daniel Johnston
The Karl Folkers Chair
in Interdisciplinary Biomedical Research
Section of Neurobiology

In the field of neuroscience, there are, without question, going to be major advances in our understanding of learning and memory—or, in more engineering terms, in information processing and storage in the nervous system. We'll also, from that, improve our ability to treat conditions like Alzheimer's, epilepsy and age-related dementia. We'll see advances in treating stroke-related brain damage, in helping soldiers recover from Post-Traumatic Stress Disorder, even in drug addiction, which is a form of memory in the brain's reward system.

At the same time, the system is so complex that it's hard to predict what the next advance is going to be, particularly since we're at such an elementary level right now. The brain processes information in ways we just don't understand, and the most subtle changes can have unexpected consequences. With epilepsy, for example, it's been discovered that it can be caused by mutations in ion channels, and yet the causal mechanism—how a certain ion channel mutation causes epilepsy—is unknown, and it turns out that there are hundreds of these mutations. Why? I don't know.

What I can say with some confidence is that the major breakthroughs will come from combining different approaches, which is what we're trying to do here at the Center for Learning and Memory. You can't just study the molecule, you then have to modify the molecule in the cell, then study the group of cells in a system, and then you have to study the behavior that results. It's this cross-fertilization of ideas that will really bear fruit in the future.

And there will be better interventions, some of them pharmacological and some of them strictly behavioral. Teaching people very well crafted mental exercises, for instance, to re-train their brain after a stroke. The progress is very, very significant. The problem is that everyone wants to have the answer tomorrow.

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