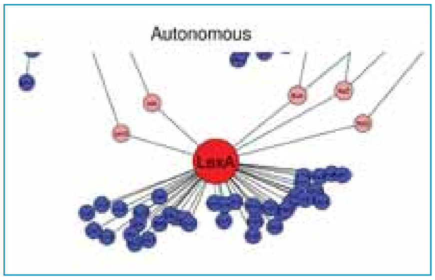
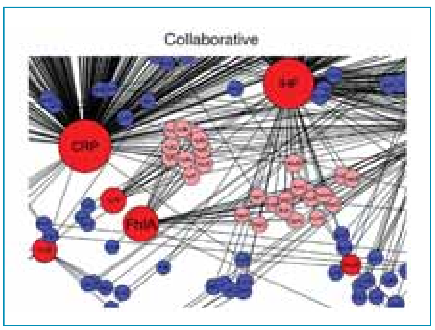
are they something that is emergent because of the complexity of the system and has no consequence whatsoever?"

Regulatory networks are definitely important for organism function, Gerstein notes. So the question of whether the networks emerged in response to complex roles or the sys-





Diagrams of hierarchical networks: In an autocratic network, such as the military, there is a clear chain of command. In a democratic network, many members interact and regulate each other. And in an intermediate network, such as exists within a law firm and many cells, the hierarchy shares features of both types. As biological organisms become increasingly complex, their organization becomes more democratic.

tem's complexity allows organisms to carry on these complex interaction is a "chicken and egg type of issue."

—By Sarah A. Webb, PhD

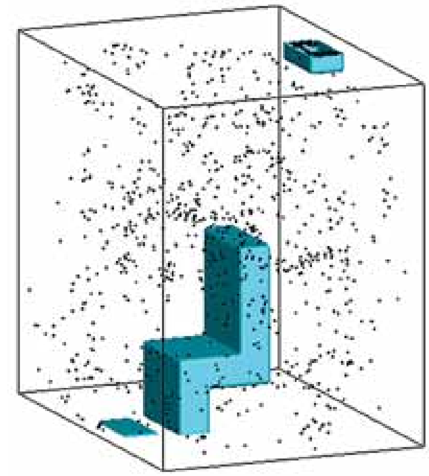
Hot Bodies a Lure for Unseen Specks

We can't see them, but tiny particles—dust, pollen, microbes, and the like—swirl around us in complicated, turbulent pathways. New numerical simulations suggest that, at least in tiny indoor spaces, our body heat may pull them even closer, where they have a better chance of eventually landing in our lungs.

"The conventional wisdom is that the thermal plume from your body protects you from particles falling from above," says **John B. McLaughlin, PhD**, professor of chemical and biomolecular engineering at Clarkson University and coauthor of the study. "We found that, in our small room at least, that is not true." Such findings can help engineers design better ventilation systems, McLaughlin says. "Studies have shown that schoolchildren learn more and office workers are more productive in environments where the concentration of particles in the air is very low."

Airflow dynamics are notoriously tough to model computationally, largely because of the huge range of physical scales in equations for turbulent fluids. McLaughlin and his colleagues used a direct numerical simulation approach that offers accuracy but requires intensive computational resources. Their computational models of airflow and particle paths were built in a 4.8-square-meter virtual room at two-centimeter resolution using three-millisecond time steps over about three minutes of total simulated time. In each simulation, a mannequin sits motionless in the middle of the room. A stream of air suffused with particles—each with the density of sand and about the size of a grain of pollen—shoots up through a floor vent in front of the chair. Particles fan out throughout the room, with a ceiling vent as the only exit.

In simulations where the mannequin was bestowed with realistic body heat, researchers could see the hot air surging off the body and interacting with particulates. This thermal plume pulled rising particles directly into the mannequin's breathing zone. At the same time, the plume blocked the path of particles traveling near the ceiling, forcing them to fall down into the mannequin's personal space, doubling the trapping effect of the plume. The work was presented in March 2010 at the American Physical Society meeting in Portland, Oregon.



The positions of 2-micrometer particles inside a 20-degree-Celsius room with a mannequin heated to 25 degrees Celsius, three minutes after particles were released through a floor event. In this simulation, 31 out of 1000 particles fell directly onto the mannequin's warm body; none managed to leave the room through the ceiling vent. Yet when the mannequin was the same temperature as the room, no particles fell onto the body, and 160 out of 1000 particles escaped. Results were similar for simulations with 10-micrometer-diameter particles.

"The computational and the experimental go hand in hand when studying complex turbulent flows such as those around human beings," says **Mark N. Glauser, PhD**, professor of mechanical and aerospace engineering at Syracuse University, whose empirical results helped guide McLaughlin's modeling. Fundamentally, experiments can help validate computational models and give physical insights that spur new simulations. "Then the simulation tools can be used to probe a broader range of parameter space 'virtually,' as well as look in more detail at flow physics," Glauser says. For example, the models from McLaughlin's team can track individual particles in a turbulent flow—a feat that's nearly impossible in real-life experiments.

—By Regina Nuzzo, PhD

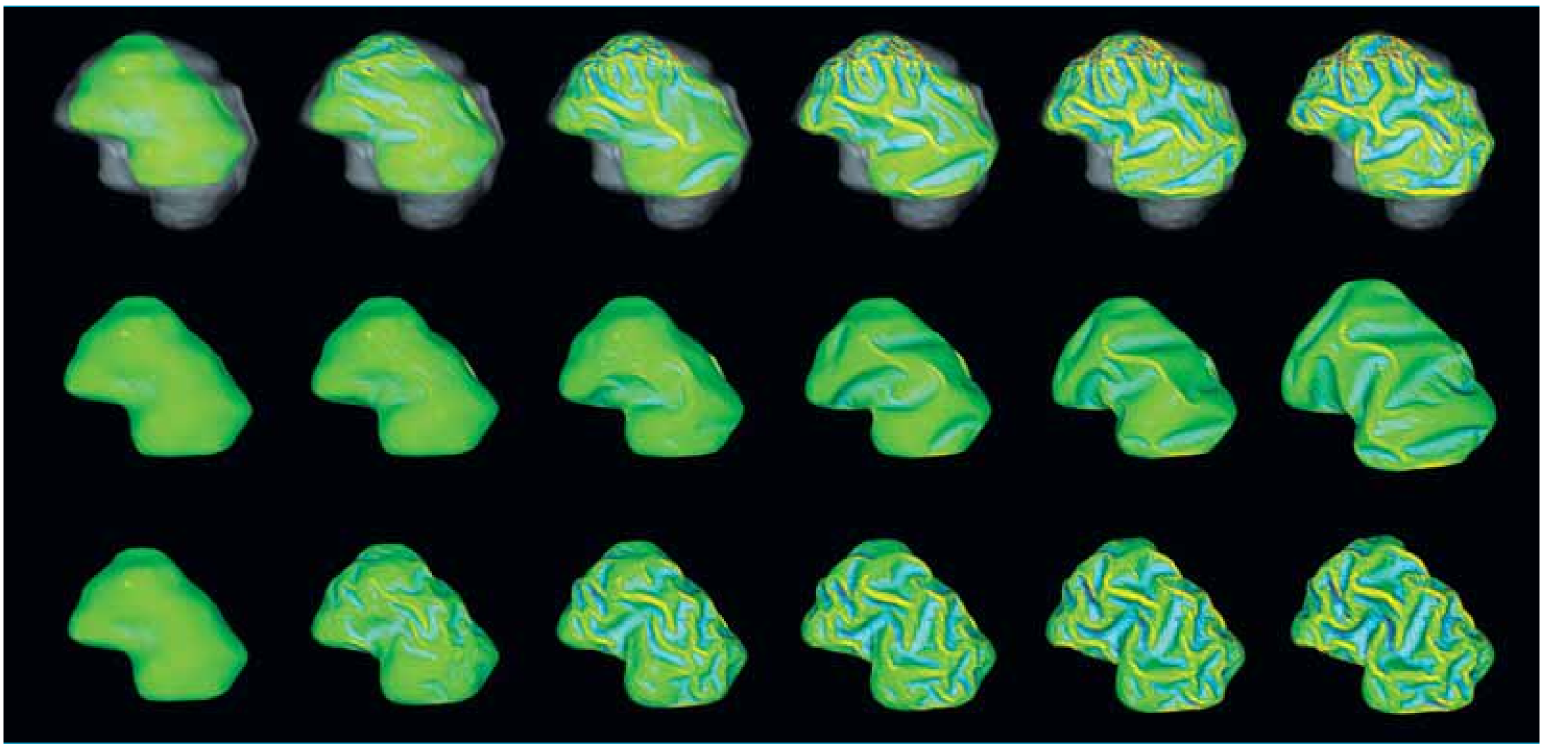
Brain Folding

In the four months before birth, a fetus's brain grows from a smooth tube of neurons into a highly crinkled, convolved mass of tissue. Because the cerebral cortex has a surface area nearly three times as big as that of its skull cavity, scientists have proposed that this real-estate-space squeeze is what drives the brain's folding process. Now results from a computational three-dimensional geometric model agree that the skull does help guide the wrinkling—but they also suggest that a growing brain folds up regardless of its container.

"Mechanical constraints imposed by the skull are important regulators," says **Tianming Liu**, **PhD**, assistant professor of computer science at University of Georgia and lead author on the study, which was published in May 2010 in the *Journal of Theoretical Biology*. "But our simulations indicate that skull constraint is not necessarily the dominant mechanism."

The computational model underneath the simulations had two main features: geometric constraints of the skull, and partial differential equations that model biological processes driving the growth of neurons. To start off the simulation, researchers used MRI data from the brains of two human fetuses; then solutions to the differential equations guided the changing surface geometry of the cortex.

The team simulated how the cortex grows under various conditions: without a skull, with a skull of fixed size, and with a skull that grows at the same time as the brain does. As expected, brains grown in a skull were more convoluted than those allowed to develop unfettered. But even without a skull to confine it, a cortex will still fold in on itself, results showed. This happens as a natural response in a fast-growing cortex, as the tissue attempts to reduce the increasing mechanical tension among axons, dendrites, and neuroglia, Liu says.



Growth of the cortex under different assumptions. From left to right, the images show simulated development of the cortex over time. The cortex grows (a) within a skull of fixed size, (b) without a skull, or (c) within a skull that also grows at the same time (which corresponds to a fetus' developing skull). Major cortical folds developed much earlier and faster during simulations with skull constraints. But the cortex increases its surface area and convolutes itself to reduce the fast-growing internal tension, with or without skull constraint.

Tweaking other parameters in the model revealed how cellular growth affects these folding patterns. When neurons themselves grow rapidly — during synapse development and neuron dendritic projection, for example—the cortical folding increases dramatically too. And when certain areas of the cortex grow more quickly than others, this imbalance subtly shapes what kinds of folds become most prominent.

Computational models can help explain normal brain development as well as what happens when things go wrong, says **Bernard S. Chang**, **MD**, assistant professor of neurology at Harvard Medical School. For example, in some forms of microcephaly, the brain surface is almost completely smooth with no folds; in others, the folding is normal. "A model that predicts how folding is affected by the skull's physical constraints might help us to understand why some patients have one form and not another," he says. Since animal models don't capture the complexity of the human brain, and doing repeated MRIs of developing fetuses for research isn't feasible, Chang says, "we need to rely on these theoretical models as tools to help us understand what we're observing clinically."

—By Regina Nuzzo, PhD □