Image Credits and Technical Descriptions

Page ii

Wing scale of a Monarch butterfly. Image by Scott J. Robinson, Imaging Technology Group, Beckman Institute for Advanced Science and Technology, University of Illinois, Urbana-Champaign

Robinson comments: A wing scale is what makes a butterfly or moth feel slick when you handle it by the wings. Scales are tiny and fragile – they're easily dislodged from the wing. Being so loose, they are notoriously difficult to photograph, because they cannot easily be electrically grounded. They readily charge up with electrons, producing horizontal streaks, or worse, that can ruin an image. Even my image has some evidence of charging in it.

Single scales vary in size but can be about 180 microns (micrometers) long by 70 microns wide and maybe 15 or 20 microns thick. For comparison, a human red blood cell can be 8 to 14 microns across, and a rod-shaped bacterium is often 2 microns long. The image size is about 10.7 megabytes.

The microscope is a Philips/FEI environmental scanning electron microscope (SEM) with a field emission electron gun (XL30 ESEM-FEG). The ultra-high-definition option is something we've had for only a few months. It required a new high-end video card and software that allows us to collect images with many more lines per frame than previously possible – enabling us to enlarge images without making the scan lines visible to the viewer. With older SEMs, we used film, but the film had to be exposed, line by line, to the signal from a small high-definition TV monitor. Now we take digital images, without film and without the extra monitor, but we still have to depend on line-by-line assembly of the image.

Page iv

Visualizations by Chris Henze, NASA Advanced Supercomputing Division

Henze comments: The high-resolution GCM runs on a "half-degree" computational grid: The dimensions are 576 (east-west) x 361 (north-south) x 32 (up-down) = 6.65 million gridpoints. I'm plotting the dynamical variable "q," which is the specific humidity. This is the ratio of the mass of water vapor to the total mass of air in a parcel, and it varies from about 2 to 25 g/kg as you go from the poles to the equator. For the images, I integrated q in the vertical direction across all 32 model layers – that's the white swirly stuff. Note that the specific humidity is not the same as cloud cover – clouds are not directly resolved by large-scale models like this one. The continental background shows various surface and vegetation types provided by the GCM's "land surface model." The distinct light-gray area in the arctic regions, and north of Antarctica, is sea ice. I also calculated the gradient of the surface pressure and used this in a bump map to produce relief shading. This is largely obscured by q, but you can see shadows in high-gradient areas like the Andes.

Page vi

Simulations by Phil Smith, Rajesh Rawat, and James Bigler, Center for the Simulation of Accidental Fires and Explosions (C-SAFE). Images courtesy of the Scientific Computing and Imaging Institute at the University of Utah

The authors comment: These simulations of the spread of a fire in a 10-meter heptane pool were performed on a 300^3 uniform computational mesh, using sophisticated highly scalable radiation and turbulence models to show the temperatures from 250^3 and 300^3 data sets. From the simulation data generated by C-SAFE, the real-time ray tracer software can visualize multiple time steps of the fire using direct volume rendering. The time-dependent data are visualized using a flip book- style animation to show the progression of the fire. The simulations capture the fine vortical structures formed at the base of real large-scale fires and also the roll-up of vortices observed in real fires. [NOTE: Full-color versions of these images showing temperature variations in red, yellow, and gray are viewable in the Web gallery of the Scientific Computing and Imaging Institute at the University of Utah (http://www.sci.utah.edu/galleries_front.html).]

Pages 4-5

a) U.S. Air Force photo by Staff Sgt. Shane A. Cuomo

b) U.S. Air Force photo by Staff Sgt. Jeremy T. Lock

c) DoD photo by Chief James Krogman, U.S. Navy

d) U.S. Air Force photo by Master Sgt. Terry L. Blevins

e) U.S. Air Force photo by Tech Sgt. Richard Freeland

f) Image courtesy of Sea-Viewing Wide Field-of-View Sensor (SeaWIFS) Project, NASA/Goddard Space Flight Center, and ORBIMAGE

Pages 6-7

a) Photo by Randy Montoya, DOE/SC

b) Image courtesy of U.S. EPA Scientific Visualization Center; research principal investigator Dr. Alan Huber

c) Image courtesy of IBM Business Consulting Services

d) Image by Christopher L. Barrett, National Infrastructure Simulation and Analysis Center

Pages 8-9

Visualization by Chris Henze, NASA Advanced Supercomputing Division

Henze comments: This image is from work I'm doing with Gwen Jacobs at Montana State University. The research area is neurobiology, or neuroinformatics, or neurophysiology, etc. We are investigating the cricket cercal sensory system, which works roughly as follows: On the hind end of the cricket (or any orthopteran) are two antenna-like structures called cerci. Each cercus is covered with approximately 1,000 fine hairs that are deflected by impinging air currents. Each hair is mechanically constrained to move in a plane, and when it does so a transducer at its base creates electrical signals in an associated sensory neuron. The axons from all the sensory neurons project in an orderly fashion into the abdomen of the cricket, where they form a three-dimensional "neural map," whose global excitation patterns correspond to global movement patterns of the entire ensemble of receptor hairs.

The neural map is "read" by interneurons, whose intricate dendritic arbors (input branches) form synapses (electrical connections) with the sensory neurons. There are far fewer interneurons than sensory cells, and many of them are "identified," which means they can be found reproducibly – with largely the same branching pattern – in any cricket. Each identified interneuron receives input from a substantial volume of the three-dimensional neural map, and by a computational process it converts this time-varying spatial pattern into a sequence of action potentials, or "spikes" – essentially a bitstream. These bitstreams can represent simple air movement parameters, such as direction or velocity, or they may represent complex features like vortices shed from the wings of an approaching predatory wasp. The processing and representation of information about the environment in terms of neural activity is the essence of "neural coding" and "neural computation."

The image shows an identified interneuron (named "10-2"). Gwen collected the geometric information ("morphometric data") for the identified interneurons by painstaking 3D microscopy. The 3D location and diameters of every branch point or place where the diameter changes (about 10,000 such segments here) are recorded. Here I've colored each segment by four stripes – red-black-white-black – partly for fun, but partly to visualize the extent of each segment. This is important because we are constructing electrical models of these cells, and the models' accuracy is dependent on the segment lengths.

Pages 10-11

a), b), c), d) NOAA Geophysical Fluid Dynamics Laboratory

e) Visualization by National Center for Supercomputing Applications; model and data by Carl Cerco, Environmental Laboratory, Engineer Research and Development Center, U.S. Army Corps of Engineers, in partnership with EPA Chesapeake Bay Project

f) Visualization by Emad Tajkhorshid, Peter Nollert, Morten O. Jensen, Larry J. W. Miercke, Joseph O'Connell, Robert M. Stroud, and Klaus Schulten, Theoretical and Computational Biophysics Group, Beckman Institute for Advanced Science and Technology, University of Illinois, Urbana-Champaign

Tajkhorshid explains: The image illustrates the results of computer simulation of a protein complex that forms channels in the membranes surrounding cells of bacteria, plants, and higher animals, including man. The simulation describes the protein complex (four identical proteins forming the complex) in a membrane made of 320 lipid molecules (bright red) immersed in more than 17,000 water molecules (blue). The system includes 106,000 atoms the motion of which has been calculated, dividing time into 5 million small steps. For each step the forces between all 106,000 atoms needed to be calculated. The computer simulations of these proteins, conducted at the NIH-funded Resource for Macromolecular Modeling and Bioinformatics, are a prime example of advances in biomedical computing. The computations not only for the first time simulated completely the transport of materials across the membranes of living cells in full detail, but also answered questions that had puzzled biomedical researchers for many years.

The simulated protein, called aquaporin, forms membrane water channels that can transport water efficiently across cell membranes. In the human body, more than ten different types of aquaporin have been found. These proteins play critical roles in control of water in various organs, and in kidneys conduct large volumes of water, concentrating urine through reabsorption of more than a bathtub (200-250 liters) of water every day. Impaired function of aquaporins is associated with several common diseases, such as diabetes insipidus and congenital cataracts. Although each single protein provides an independent conduit for water transport, water channels form tetramers (sets of four) in the membrane. These proteins are shown as rods of four different colors in the image.

The main puzzle was how aquaporins conduct water very quickly and in large amounts, but prevent any electrically charged molecules, in particularly protons, the smallest charged atom, from participating in the flow. If charges would move along, cells would loose their electrical potential that provides the energy fueling for many cellular processes. To prevent such discharging, the import and export of water needs to be very carefully screened against charges; the ensuing problem is what one witnesses at border crossings where careful screening necessarily leads to slow traffic. But somehow aquaporins manage screening against protons without any traffic delay.

The solution to the puzzle was revealed by a combination of observation and calculation, where calculation showed the key detail: The flow of water molecules through the channel was found to arise with water molecules streaming fast, but always in single file through a narrow channel, as shown in the figure for one of the four channels by highlighting water molecules (small blue elements in center). During their passage, the water molecules are forced to line up all in the same direction and rotate in the middle of the channel by 180 degrees before they continue their path. This orientation of the flowing molecules turned out to be the basis of an extremely strict selectivity that prevents the discharge of electrical charge through a proton current.

g) Simulation images by Gordon Kindlmann, courtesy of the Scientific Computing and Imaging Institute at the University of Utah

Pages 12-13

a), b), c) Michael S. Warren, Los Alamos National Laboratory, DOE/SC

d) Image generated by Aleksander Stompel, courtesy of Visualization and Computer Graphics Group, Center for Image Processing and Integrated Computing (CIPIC), University of California, Davis

e) Image by Charbel Farhat, University of Colorado, Boulder

f) Simulation by John B. Bell and Phillip Colella, Center for Computational Sciences and Engineering, Lawrence Berkeley National Laboratory, DOE/SC

g) Andreas Adelmann and Cristina Siegerist, Lawrence Berkeley National Laboratory, DOE/SC

Pages 14-15

a) STAR Project, Brookhaven National Laboratory

b) Image courtesy of Michael W. Davidson, Florida State University

c) Image by Dr. Jiri Vondrasek, Macromolecular Crystallography Laboratory, National Cancer Institute. Courtesy of HIV Protease DataBase, NIH and NIST

Page 16

a) Visualization by David R. Nadeau and Erik Engquist, San Diego Supercomputer Center, University of California, San Diego. Data by Stuart Leavy and Bob Patterson. National Center for Supercomputing Applications, Urbana-Champaign; Ryan Wyatt, Clay Budin, Mordecai Mac Low, and Li, Norman, Heitsch, and Oishi, Hayden Planetarium, American Museum of Natural History, New York; Tom Abel, Pennsylvania State University, and John Hawley, University of Virginia

Image Credits and Technical Descriptions, continued

Pages 18-19

a) Kenneth Downing and colleagues, Lawrence Berkeley National Laboratory, DOE/SC

b) NASA/Wilkinson Microwave Anisotropy Probe Science Team

c) Center for Extended Magnetohydrodynamic Modeling, DOE/SC

d) Perspective views of rat ventricular myocytes rendered by Alex DeCastro at the San Diego Supercomputer Center using NPACI Scalable Visualization Tools. The work is from John W. Adams, Amy L. Pagel, Christoper K. Means, Donna Oksenberg, Robert C. Armstrong, Joan Heller Brown, Department of Pharmacology, University of California, San Diego.

e) Image by Don Appleman, Imaging Technology Group, Beckman Institute for Advanced Science and Technology, University of Illinois, Urbana-Champaign (http://www.itg.uiuc.edu)

Appleman comments: The original image is black & white (gray scale), because it was made using a HiVac Environmental Scanning Electron Microscope (ESEM), which produces images with electrons rather than photons, and therefore does not capture color information. I later colorized the image.

"HiVac" refers to "high vacuum." The ESEM pumps the air out of the chamber that holds the sample so that air molecules will not interfere with the electron beam. The magnification was 13,199x. The reason the diatom is unidentified is that there are over 10,000 varieties of diatom. I can tell you that this is a "pennate" diatom, but as I am not a marine biologist, I cannot narrow it down further. The holes in the hard, outer silica shell of the diatom allow the soft internal parts of the diatom to contact the environment. When the diatom dies, the silica shell is left behind. That's what is shown here.

f) Image generated by Gunther Weber, courtesy of Visualization and Computer Graphics Group, Center for Image Processing and Integrated Computing (CIPIC), University of California, Davis

g) Image courtesy of Scientific Computing and Imaging Institute, University of Utah

Institute researchers comment: Visualization by means of a computer monitor is only the first step in presenting information to the viewer. Three-dimensional displays are one of the next steps and provide a much more realistic rendering of physical space. SCI Institute investigators seek to provide even more complete interaction with data by making use of additional sensory input and control mechanisms. Specific examples include the use of position and motion tracking devices, three-dimensional cursors, and "data gloves" that provide intuitive ways of merging the user and image spatial domains. We also employ "haptic" feedback devices that generate physical forces in the user's hands based on the material properties of the data sets under examination. The goal of this research is a complete immersion of the user into the data to provide more intuitive, efficient, and synergistic interaction than is possible with conventional visualization techniques.

By doing a good job with design and implementation, we hope to achieve bounded error interaction, where a single bound describes the combined system errors throughout the workspace. Ultimately, we want our system to be capable of quantifying the synergistic effects through user studies.

Our software architecture is an integration of custom components and commercial application program interfaces (APIs). The individual software components communicate via shared memory and UDP messages to the application process. The two custom software components are the Synergistic Data (SD) Library and the Virtual GL (VGL) Library. The SD Library provides visualization methods, haptic rendering methods, data set support, and interface widgets. The VGL Library provides the device and display management for virtual environment rendering. We currently use SensAble's GHOST API for basic PHANToM interface and NCSA's Vanilla Sound Server (VSS) for simple audio-reinforcement feedback.

Our very first demonstration using the prototype system was an analytic simulation of an electrostatic point charge field. We have two sources (red and green spheres) and one sink (blue sphere) in this field. In the image, a researcher explores the electrostatic point charge field on the Visual Haptic Workbench. Streamlines show the global structure of the field, colored by proximity to the charge sources (red and green spheres) and charge sink (blue sphere). A bounding box widget shows the extents of the data set. The streamspheres between the red and blue spheres are locally advected in both directions from the local interaction point, shown as a purple proxy widget and yellow force vector to the left of the PHANToM stylus.

h) Image by Chris Henze, NASA Advanced Supercomputing Division

Henze explains: "Virtual mechanosynthesis" (VMS) is a computational steering facility that couples an ongoing molecular dynamics simulation with a virtual-reality environment. The molecular dynamics part uses the "Brenner potential," which is an empirical reactive bond order force field specifically parameterized for hydrocarbons. The "reactive" part means you can make or break atomic bonds. The virtual-reality environment consists of a headtracked active stereo display (the glasses I'm wearing have high-speed shutters that alternately block one eye or the other – allowing different left and right eye views, with stereo disparity; the glasses also have a sensor – the wire appearing to come out of my ear – that relays my head position to the graphics engine so I can change the view appropriately), a six-degree of freedom handtracked input device (essentially a 3-D mouse, the wand in my left hand), and a haptic (force feedback) device (black device in my right hand). The total effect is that you can float around in 3-D and grab and rearrange atoms, and they respond "realistically." So you can try to build things and the molecular dynamics keep you honest – insofar as the dynamics are accurate, you should only be able to build physically plausible structures. This facility allows nanotechnologists to explore structures on an atomic scale, to rehearse and debug complicated assembly sequences, and in general to develop chemical intuition.

In this mock-up, I'm manipulating a piece of hydrogen-terminated graphite. The gray spheres represent carbon atoms, and the green spheres around the edge are hydrogens. I've just inserted the pink atom (another carbon, but colored pink because I'm hanging on to it) into the graphite sheet, creating a seven-membered ring (a septagonal defect) that gives rise to negative curvature (potato-chip, or saddle-like).

i) Image by Chris Henze, NASA Advanced Supercomputing Division

Henze comments: This is a visualization of quantum chemistry data. It is a portrayal of a water molecule. The surfaces are separation and attachment surfaces (precisely analogous to those in fluid flow fields) in the gradient field of the Laplacian of the electronic charge density. The black stripes are contour lines in the Laplacian field (clearly indicating that the surfaces are *not* isosurfaces). The green and red lines are streamlines showing the stable and unstable (respectively) manifolds of saddle points in the gradient field.

Following ideas of Richard Bader, we are trying to understand the electronic structure of matter by applying vector field topological techniques to the charge density of atoms and molecules. The Laplacian of the charge density is a measure of its curvature, or "lumpiness" – and its structure reveals a wealth of chemical behavior.

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Illustration by NASA Jet Propulsion Laboratory/Cornell/Daniel Maas/ Maas Digital LLC

Pages 22-23

a) Visualizations by David Feder and Peter Ketcham, NIST

b) Image by Paul Trombley, Center for Biologic Nanotechnology, University of Michigan

Nicholas W. Beeson, senior research associate in the NIH-supported work, comments: This image is a composite of several sources. The background green is a microscopic image of living cells stained with a fluorescent dye. Overlaying it are computer-generated models of the PAMAM dendrimer, which were used to guide our initial synthetic work three years ago. These models depict generations 3 to 5 of the dendrimer. Then our graphics artist overlaid these models with a highlighting semi-transparent sphere. The final image is an artist's conception of how the nanodevice targets cancer cells.

We are currently testing a nanodevice in mice with cancer. This nanodevice recognizes cancer cells, enters them, and then delivers a chemotherapeutic agent (an anti-cancer drug). Since the anti-cancer drug never gets to any of the healthy cells, the systemic toxic effects of the drug are greatly reduced (the mice do not lose their hair). Since the anti-cancer drug is specifically delivered to cancer cells, the tumor is greatly reduced in size. The nanodevice work has progressed to the point where we are conducting our third set of animal trials. We are seeing a 100-fold improvement in therapeutic index. The therapeutic index is a combination of reduced toxicity and increased efficacy. In short, the mice receiving our nanodevice are not showing toxic effects, and their tumors are dying.

There is much testing yet to do, but we have in hand a real nanodevice that performs a biomedical function.

c) Image by J.C. Lee, Sungkyunkwan University, Suwon, Korea, courtesy of the Center for Microanalysis of Materials, Seitz Materials Research Laboratory, University of Illinois, Urbana-Champaign

Pages 24-25

a) U.S. Fish and Wildlife Service

b) Images by F. Spoor, University College, London, using Voxel-man

c) NASA Advanced Supercomputing, NASA Ames Research Center

d) Image courtesy of Montemagno Research Group/Cornell University

Pages 26-27

a) Image by Nissen, H., Damerow, P. and Englund, R. (1991) _Frühe Schrift und Techniken der Wirtschaftsverwaltung im alten Vorderen Orient : Informationsspeicherung und -verarbeitung vor 5000 Jahren_. Bad Salzdetfurth [Germany]: Franzbecker, pp. 92-93. Courtesy of Cuneiform Digital Library, University of California, Los Angeles

CDLI staff comments: This large tablet, known as Erlenmeyer 152, is an account of workmen from the Southern Mesopotamian city of Umma (modern Tell Jokha, Iraq), from the time of the Third Dynasty of Ur (ca. 2036 B.C.). A fuller description and translation of this text can be found in the electronic publication, Englund, R. "The Year: "Nissen returns joyous from a distant island"," _Cuneiform Digital Library Journal_ 2003:1, §21 (http://cdli.ucla.edu/Pubs/CDLJ/2003/CDLJ2003_001.html).

b) Image courtesy of Digital Content Group, University of Wisconsin-Madison Libraries. Copyright 2000 © Board of Regents of the University of Wisconsin System

c) Image courtesy of Todd Library, Middle Tennessee State University

d) Image courtesy of Digital Collections and Archives, Tufts University

e) Image courtesy of the Coolidge Collection of Thomas Jefferson Manuscripts, Massachusetts Historical Society. The "Thomas Jefferson Papers: An Electronic Archive" project is supported by the Save America's Treasures program established by Congress in 1999.

f) Image courtesy of the Hoagy Carmichael Collection, Indiana University Digital Library, Bloomington, Indiana. Project supported by the Federal Institute of Museum and Library Services.

g) Images courtesy of the Open Video Project, Interaction Design Laboratory, School of Information and Library Science, University of North Carolina at Chapel Hill

No Ordinary Table: Image courtesy of Large-Scale Structures Laboratory, University of Nevada, Reno

Page 28

a) North America Tapestry of Time and Terrain compiled by Kate E. Barton, David G. Howell, and José F. Vigil, U.S. Geological Survey, Department of the Interior

Vigil comments: The North America Tapestry of Time and Terrain is a product of the U.S. Geological Survey in the 2003 Geologic Investigation series (I-2781). The map was prepared in collaboration with the Geological Survey of Canada and the Mexican Consejo Recursos de Minerales.

This cartographic Tapestry is digitally woven from a geologic map and a shaded relief image. This digital combination reveals the geologic history of North America through the interrelation of rock type, topography, and time. Regional surface processes as well as continent-scale tectonic events are exposed in the three dimensions of space and the fourth dimension, geologic time.

The geologic map carries two types of information - the age of surface or near-surface bedrock and the type of rock. The topographic map started as a digital elevation model (DEM), a data file containing measurements (spaced at a 1-kilometer interval) of height of the land surface above sea level. From that we prepared the shaded relief map, produced using Spatial Analyst extension with HILLSHADE command in ArcGIS. Vertical exaggeration is 10x. The bedrock and relief maps were merged by computer to form the Tapestry.

The geology was generalized from the forthcoming Geologic Map of North America, compiled by John C. Reed (USGS) and John O. Wheeler (Geological Survey of Canada) for the Decade of North American Geology and sponsored by the Geological Society of America. Geologic map data were processed and reprojected in ArcINFO geographic information system (GIS) software. The shaded relief map, derived from a DEM contributed by EROS Data Center, provides the underlying cartographic structure. The two component maps were

Image Credits and Technical Descriptions, continued

georeferenced to one another using GIS software, and the final images were combined using graphics software. Scale: 1:8,000,000; Projection: Lambert Azimuthal Equal Area.

The colors on the main Tapestry represent different ages of the bedrock that makes up North America. For example, the various rocks that form the ancient Canadian Shield are shown in shades of red. For some areas, we do not know exactly when the rocks formed, but only a general range of likely ages. We have grouped these rocks of uncertain age into broad categories, so that instead of representing a brief geologic Period, they are assigned to an Era or combination of Eras.

Page 30

a) Satellite image courtesy of NASA Earth Science Enterprise

b) Photo by Randy Montoya, DOE/SC

c) Sandia National Laboratories, DOE/SC

Pages 32-33

a) Image courtesy of Interactivity Lab, Computer Science Department, Stanford University

b) Photo by Thomas Jordan, Fermi National Accelerator Laboratory Education Office, DOE/SC

c) Photo courtesy of NASA and Colorado School for the Deaf and the Blind, Colorado Springs, Colorado

d) COSPAS-SARSAT schematic courtesy of NOAA

[NOTE: Reflecting its Cold War origin, COSPAS stands for Cosmicheskaya Sistyema Poiska Avariynich Sudov (Space System for the Search of Vessels in Distress). SARSAT stands for Search and Rescue Satellite-Aided Tracking.]

e) Screenshot of ASPIRE software courtesy of Cardiovascular Biomechanics Research Laboratory, Division of Vascular Surgery, Stanford University

f) Photo by Pote Pothongusan, Cape Henry Collegiate School, Virginia Beach, Virginia