


What's in nanotech for Missouri?



P. Fraundorf
 UM-StL Center for Molecular Electronics'
Scanned Tip and Electron Image Lab

email: pfraundorf@umsl.edu
 web: <http://www.umsl.edu/~fraundorf>






Can anyone guess what these images are of, as well as what kinds of microscope took them? For example, in which might a nanophotographer have inadvertently captured her own shadow on film, a 10-fold symmetry reveal something unexpected, or a pattern arise that looks like the glow-in-the dark footprint of a recent UFO landing?

A goal of this presentation is to convince you that thinking on multiple scales of space and time is not just a fad. Of course nanoscale science (which by the way includes cooking and sex) is hardly new. It is increasingly relevant as we uncover new tricks. More importantly, nanoscale insight is important for each of us in taking responsibility for such simple things as our own health. A community of scale-aware observers will respond to challenges (like epidemics) more effectively. An informed public may also need to put less energy into blaming others for their individual decisions, say of what to eat and breathe and touch.

For example the perspective of a cell is as different from that of a virus molecule, as human perspectives are from the cell's. Recognizing the different relationship that these perspectives has to our life is a challenge for the observer of nature in each us. Nanoperspectives also bring the process of emerging complexity up close and personal. The magic of atoms organized into cellular engines, partnering with molecular codes, is perhaps our best cross-disciplinary training ground for understanding that even rarer phenomenon: multi-celled organisms partnering with idea codes. But I'm getting ahead of myself.

Outline

- Multiscale thinking and convergent disciplines

Illustration: *Compromise between levels*

- Cross-institutional resource pooling to compete

Illustration: *Views from aSmall*

- Regional tales of nanoworld adventure/success

Illustrations: *Stardust at home, Chips in your computer, and much new in the works...*

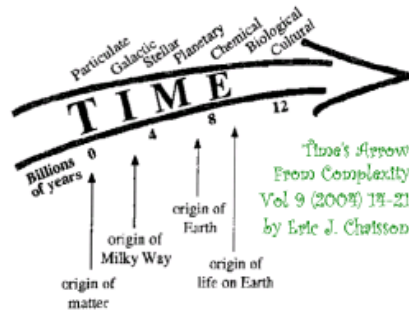
Three elements here: (i) multiscale thinking as it relates to “nanoeducation for consumers”, (ii) pooled resources in nanocharacterization that could give Missouri businesses an advantage, and (iii) past and future contributions from the region.

I. *Convergent disciplines:*

- **Nanoscience** – where *chemistry, physics, biology, engineering, medicine, CSI, ethics,* and complex system studies of *emergence* run together...
- **Informatics** – where the code-based sciences (genetics, computer science, linguistics), thermal physics, journalism, networks & statistical inference join up...

Also referred to as elements of “disruptive science” because of the cognitive dissonance or culture shock that occurs when disciplines merge. Look for slow integration of these concepts throughout the education infrastructure in years ahead, with even more impact than the concepts of ecosystem, niche, and web of life that worked their way in (across disciplines) some years back.

Multiscale Awareness in Time



- Astrophysical observations are telling us that planets suitable for multi-cell life as we know it are rare, and that earth will likely support such life only for about a billion years (now half gone).
- One 3000 year success story, according to Jared Diamond, is a small south pacific island (Tikopia) that turned toward forest management as they saw their soil resources slowly going away.

This slide discusses a synthesis between two interesting books, one on time's arrow by astronomy book author Eric Chaisson at Tufts University, and the other by geologist Peter Ward and stardust mission PI Don Brownlee (at UW Seattle) on earth's clock. Eric optimistically discusses the cosmic evolution of steady-state systems that trade free energy for increasingly complex subsystem correlations. This integral view of evolution lets students see how real-time observations of stellar and planetary evolution are a seamless part of the living fabric on earth. Ward and Brownlee, who elaborated on the rarity of planetary chances for metazoan evolution in their book *Rare Earth*, discuss on the billion year time scale how earth is only a temporary home for such complex systems. If one zooms in on the present in a calendar made by combining these billion year clocks, you'll find that we're in the middle of what is likely the third multi-glaciation ice age since metazoan lifeforms on our planet came into their own a half-billion years ago. Moreover, solar evolution and carbon loss processes suggest that this age of plants and animals will have run its course on a comparable time scale in the days ahead.

Forward/backward looking powers of ten in time: For more on what one sees as one "zooms in toward the present" on these calendars, cf. <http://www.umsl.edu/~fraundor/ifzx/earthtimes.html>.

Multiscale Awareness in Space

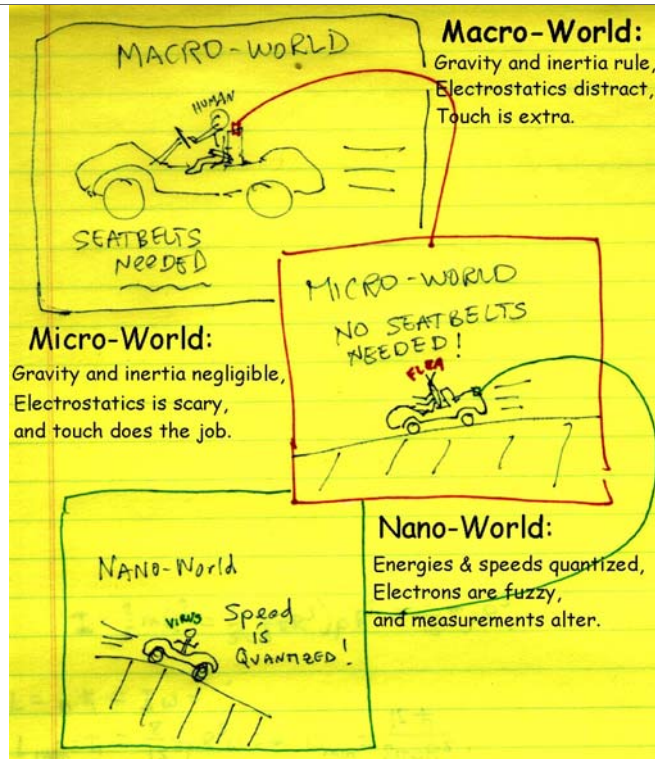
- What do you know about iron that suggests it might do unexpected things when in nano-powder form?
- Why does this ferrofluid behave like a critter with shape when a magnetic field is applied?

Hint 1: An iron roof might survive the typical house fire, but steel wool will burn reluctantly over a flame...

Hint 2: A flying fish pulls the water surface up as she punches through the surface, while iron filings adopt a spiky configuration when in contact with a magnet...

Challenges differ according to their size scale, as well as their time scale.

What examples come to mind for you?



Here are few examples of how the physical world around you changes as your size goes from macro to micro to nano. What other things change according to size in interesting and practical ways?

Other size effects include...

- Thick-cut french fries absorb some oil, but thin-cut fries (because of their larger surface to volume ratio) may absorb much more. Where else is this effect important?
- Large objects fall quickly, feathers fall more slowly, but particles smaller than 0.1 micron may never make it to the ground 'cause of molecule impacts! Where else is this effect important?
- Iron roofs don't burn, steel wool burns reluctantly, but nano-iron may oxidize so fast that it catches things around it on fire! Where else is this effect important?
- Ballet dancers can be spun on point (it would seem) *as slowly* as they like, but not so with a virus particle. Why not?

Other size effects involve shape (e.g. gold leaf is flexible, and gold foil less so, while gold bars are not), ability to be cut (e.g. a diamond knife will break before going through a hand specimen of chromite, but that chromite might slice nicely if it's only 0.1 microns across), settling in liquids (e.g. colloids with sufficiently small particles in them, like ink or milk, may never separate into liquid on top of solid unless one increases gravity with help from a centrifuge), hetero-catalysis (catalytic converters and manufacture of the herbicides can be made more efficient and economical with control of the nano-size particles that make them possible), porosity (e.g. aerogel can be made less dense, zeolites more useful as catalyst supports, and activated-charcoal more effective as a water purifier with control of nanosize pores), adhesion (e.g. flour glue and concrete both depend on the fact that touching between very tiny particles has noticeable macroscale effects on material strength, as does a gecko's ability to walk on the ceiling), combustability (like nano-metals, airborne flour particles in a mill are also a combustion hazard), surface effects (e.g. structural uses for surface-tension give us microscopic "fingers" with which to manipulate nano-meter thick films, as well as lily pads an ability to prevent water spots and dirt-buildup on their surfaces). And then there are spiders keeping webs taut, insects water striding, and what else?

Things of everyday use...

- Recognizing when processes on multiple size scales are at work in our “regular existence”, as well as in new products (e.g. lotus-effect paint, gecko technology shoes, nanosilver for happy socks, nanogold-based medicine, etc.)
- Guessing the effects of size, e.g. on making protein spheres “taste” like rich and creamy fat, on making a thin film change color, on making a rope stronger, on keeping particles from settling out of air or water, or on making a sno-cone more likely to give you an “ice-cream headache”.
- Awareness of possibilities and limits of our current tools for interacting with things on small size scales.

Life has been using nanoscale processes (as well as genetic engineering) for billions of years, many of which are still being discovered by us. Thus cooking is not typically recognized as nanoscience, even though is a time-honored form of exactly that. On the other hand, people are now trying out new nanoscale processes everyday. Thus insight into their capabilities, and their shortcomings, will be increasingly important. This is also true about the tools, like microscopes, that we use to figure out how these nanoscale processes work. For example, there are some structures that we can examine on the nanoscale, but an equally large number that we can only infer by indirect means...

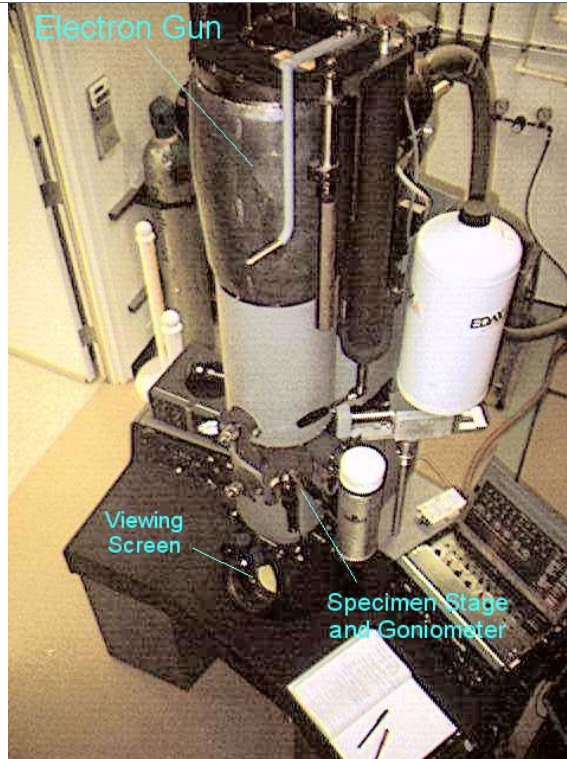
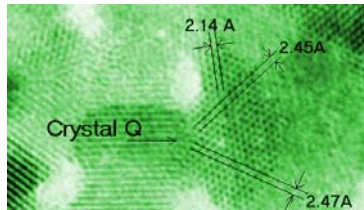
II. *Cross-institutional resource pooling to compete:*

- A key enabling element of current generation nanotechnology has been “new eyes on small size”.
- Detective work one atom or molecule at a time costs millions of dollars to set up, and thrives in a “multi-institutional mode”.

Regionally-available nano-characterization tools: A strength of the region that industries and universities and state government have shown an interest in developing further...

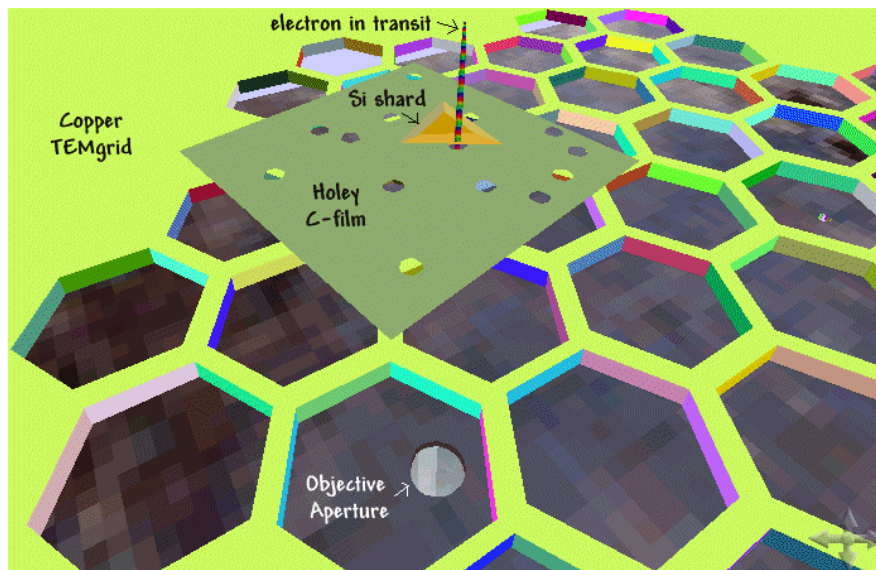
Transmission electron microscopes

This 300 keV hi-res system at UM-StL requires that the specimen be thin enough for electrons to go through it, but then allows you to analyse local lattice structure in direct and diffraction space, as well as to analyze the composition and density of the specimen one zeptoliter sized region at a time.

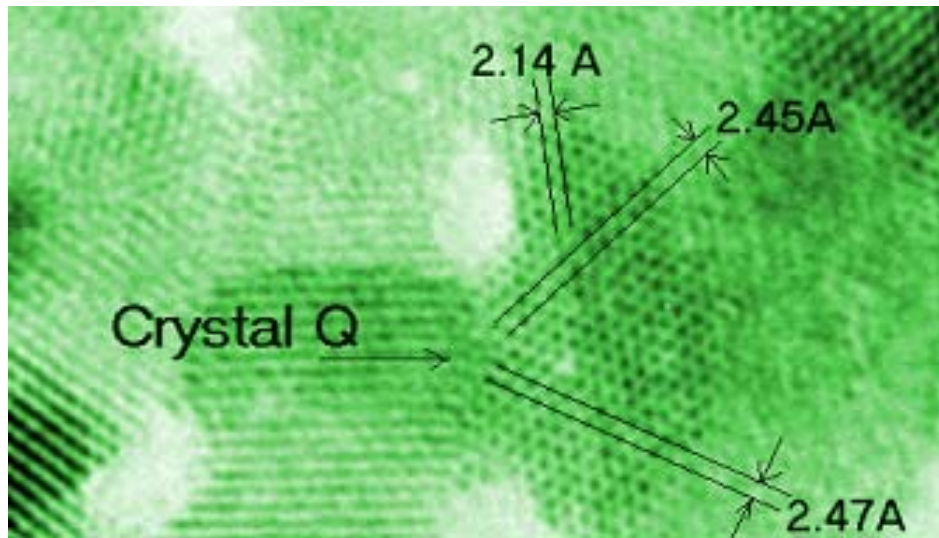


The images from these instruments are more two dimensional, but very high resolution is possible as shown in the photo of tungsten atom columns (with one missing) in nanocrystals of tungsten carbide by Wentao Qin (UM-StL, now Motorola/FreeScale). Although transmission electron microscopes typically start at \$100k, instruments with point resolution below the spacing between atoms are typically \$1M or more. These instruments are more like “clothes for visiting small places” than xerox machines, for example, in that they do little by themselves and do a wide range of different things in the hands of different operators.

What happens inside that microscope,
from the vantage point of a sub-millimeter sized observer...

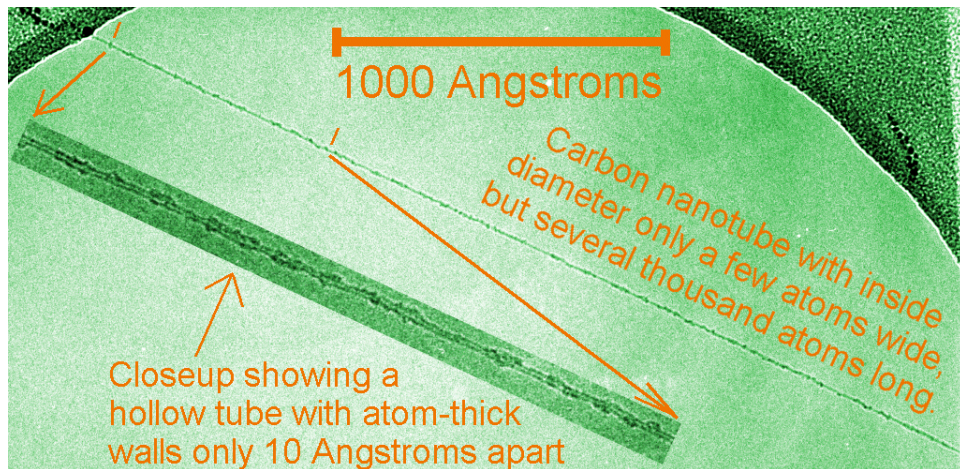


This shows what goes on inside a transmission electron microscope, where electrons having significant longitudinal and transverse coherence width pass through a delicately suspended thin specimen and then pass through an objective aperture, a few tens of microns across, located a couple of millimeters below the specimen.



Tungsten carbide from UM-R used in Wentao Qin's thesis.

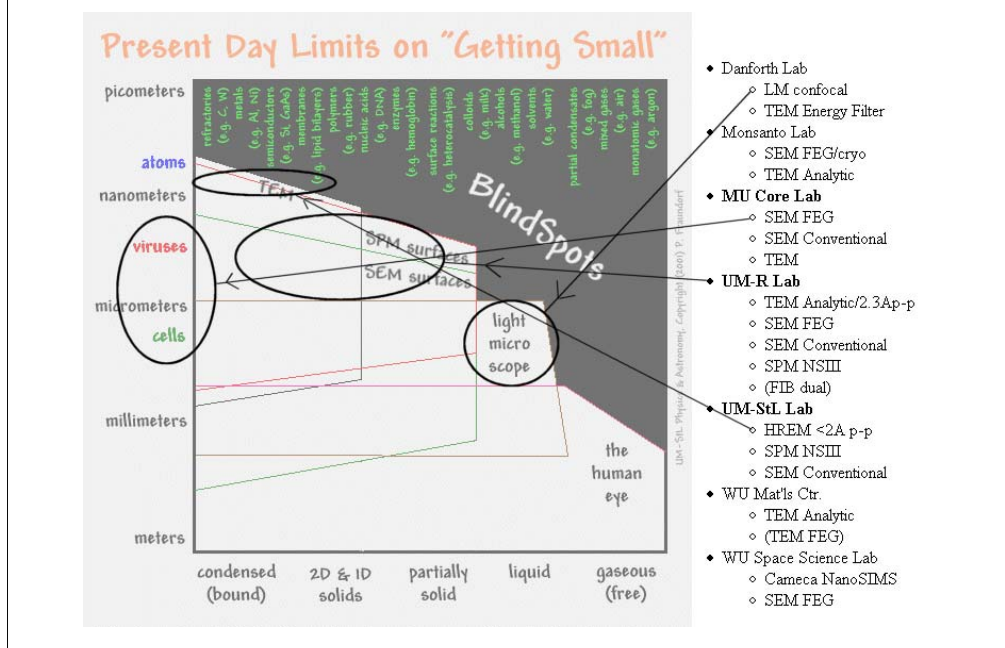
Here columns of atoms show up as dark spots in the image. Future-generation aberration-corrected electron microscopes, on the other hand, may eventually reveal individual atoms (even in disordered materials, provided they'll hold still) as "points of light" in the night sky.



Single walled nanotube only 5 atoms across, prepared by Washington University grad student Chad Unrau in work related to a DOE project on Multi-Pollutant Control through Novel Approaches to O-Enhanced Combustion. Such tubes also show potential as substrates for the study of individual small molecules.

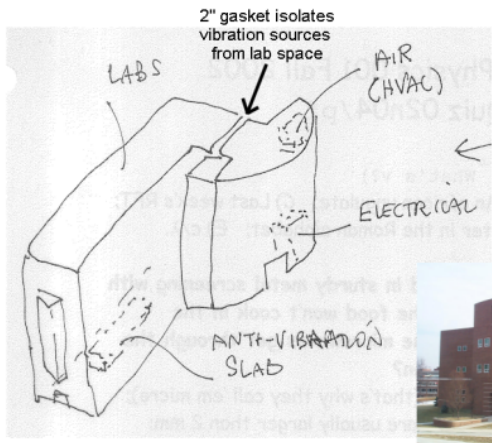
This 5-atom wide nanotube, prepared for a mechanical engineering project involving manufacture in turbulent flames, suggested to us the possibility of using such tiny cylindrical structures as “support stages” for the study of many types of individual small molecule, given that the support structure is both tiny and predictable in shape. On this scale a typical virus might cover up half of the scale bar, while the whole field width is less than a tenth of the diameter of a red blood platelet.

Blindspots according to size scale, and regional highlights...



This slide shows one way to outline our blindspots in identifying nanoscale structure. Gases are toughest to look at in detail, because their atoms typically move so quickly, while high temperature solids are perhaps most likely to have atoms that will hold still. This slide also highlights the strengths of some regional labs that have expressed interest in serving others across the region, where possible.

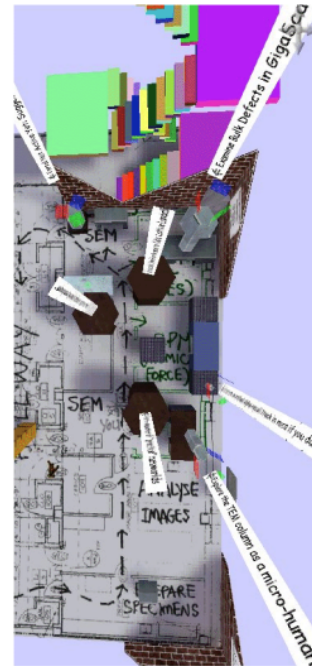
Triple bi-story building designed to isolate labs from vibration sources, along with three labs on a separate 2-foot thick concrete foundation: tabletop SPM oscillation $<1A$ rms



**CME's
outreach
facility**

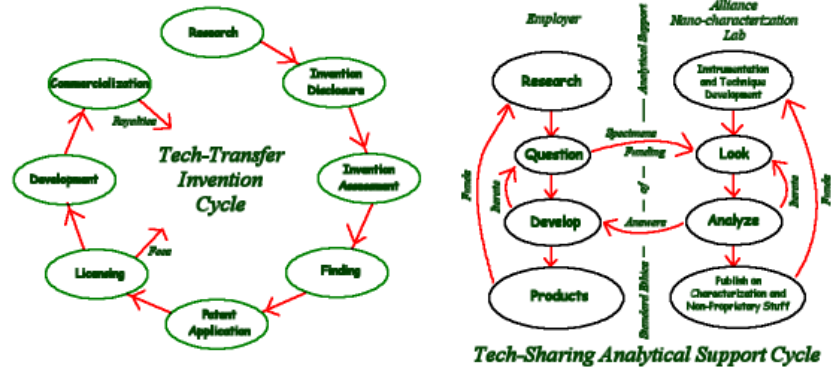


- Lab is equipped with 3 research instruments:
- (a) a Philips 300 keV analytical/HR TEM $\approx 2A$ p-p
 - (b) a DI SPM now undergoing a \$20k upgrade
 - (c) an SEM supported by UM-StL Biology



Here's a slide about one such regional facility, at UM-StL. If you have a question about nanoscale exploration, perhaps they can hook you up to resources in the area able to help. A Missouri-wide nanoalliance is being developed that may also be of help in this context.

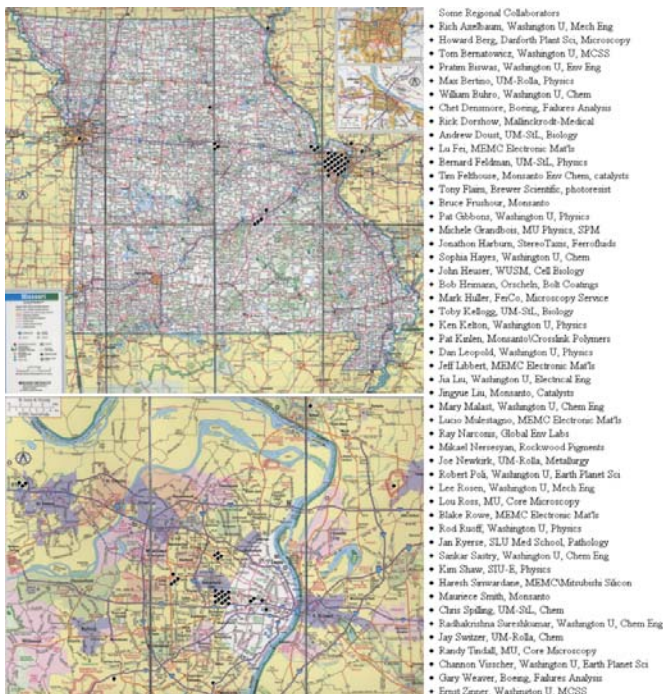
Tech-sharing and Tech-transfer



The invention cycle was largely the focus of the meeting on technology transfer. In addition to this, the support environment for researchers in industry and university can be a key to “which direction the action moves”. I’ll refer to this as tech sharing, and in particular concentrate on ways that nano-characterization and synthesis infrastructure is of increasing relevance, and can be improved.

Impact Map Engagement & Accountability

Consider *any part of a university* whose job is to impact the economy. Following up on Mike Cassidy's suggestion, that we start putting pins on a state map, here's a sample impact map from one lab only. Each line item can be linked to project information, so that taxpayers and media can explore connections that look relevant to them. Just imagine how a map of nano-alliance activity might look in 2 years if we put our mind to it...




Impact maps, with dots and line-items hyperlinked to story material and data, can be a crucial resource in “closing the loop” with the taxpayer. It can also provide media researchers with a way to find connections they would otherwise miss.

III. Regional tales of nanoworld adventure/success:

- What are these mysterious etch pits on a silicon wafer caused by, and are they friend or foe?
- What happens in the atmosphere of red giants involved in our carbon atoms' manufacture, and our sun's future?
- What size and shape of ferrofluid particle is optimum for repairing defects in a blood vessel?
- What makes these metal fuel-cell catalysts, on carbon nanotubes, work so well?
- How is the shape of these Alzheimer's-like amyloid protein aggregates affected by a change in acidity.


Examples of the kind of problem that such nanoscale science outreach facilities might get a chance to help out with.

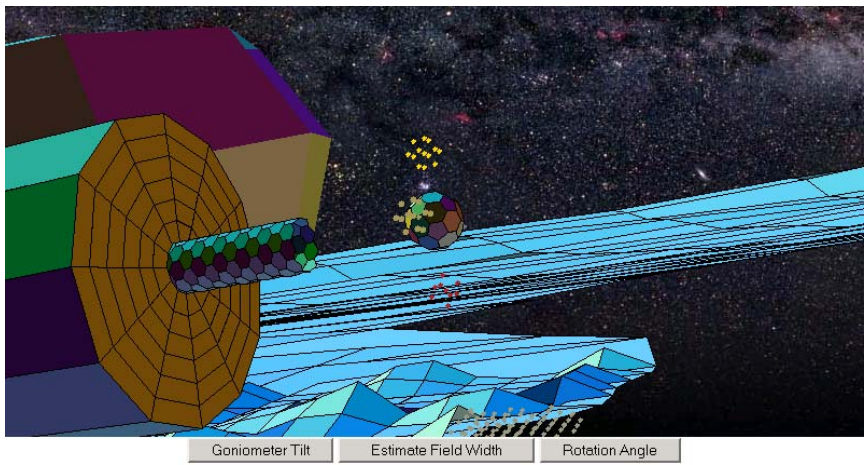
In addition to being home to consumers of present and future nanoscience products produced the world over, Missouri is making fundamental scientific and technological contributions. These include nano-initiatives in health care (what this session is about), in plant science (food is far from obsolete at this point), in extraterrestrial materials (where did our carbon atoms come from, and how will the sun behave in days ahead), in silicon science (that cell phone in your pocket and the next generation of video games), in catalysis (has this really made multi-billion dollar Missouri products cost significantly less), and in materials innovation.



A nanoscale detective trainer may be found on the web at
<http://www.umsl.edu/~fraundor/nanoworld/dtemspect.html>

A MissOuri NanoAlliance inventory may be found at
<http://newton.umsl.edu/~run/mona/default.htm>





This last slide illustrates one of our web-based virtual microscopes. These are designed to offer empirical observation exercises to students, patterned after challenges offered by real microscopes on real specimens. Strategies are being developed for their use in homework (lab notebook, scientific report, and peer review), in modeling workshops, through peer instruction, and even on timed in-class exams.

Of course, to return to the beginning, this discussion about nanoscience in everyday life is not only about progress. It is also about survival over a variety of time-scales on a planet attempting to preserve, or enhance, its correlation-based complexity even though our per-capita free-energy production plateaued at 2.2 kilowatts a quarter century ago, and a big bite out of our half-billion year's accumulation of fossil fuels has been taken in only the past few hundred years. To deal with this in style, we are called to leap beyond our stone-age programming with every bit of hard-won ingenuity we can put our hands on, spanning multiple scales of both space and time.