"Science on Saturday" spotlights technology

The winter 2007 series of Science on Saturday lectures at the Princeton Plasma Physics Laboratory has spotlighted the roles of technology in our lives. On 27 January Edward Groth of Princeton's Physics Department spoke about the GPS (Geographical Positioning System); on 10 February Scott Klasky of Oak Ridge National Laboratory spoke about petascale computing; on 3 March Charles A. Gentile of the Plasma Physics Laboratory addressed the quick detection and identification of radioactive isotopes; and on 10 March Michael G. Littman of Princeton's Department of Mechanical and Aerospace Engineering told how he taught engineering with antiques.

Although Groth's research interests lie in cosmology, he is teaching a freshman seminar focused on the GPS this year. He pointed out that the American GPS is only one of three intended systems to enable the owner of a receiver, whose cost he compared with that a of a physics textbook, to locate a position on the ground in terms of latitude and longitude. The Europeans are developing their own Galileo system, and the Russian Glonass system is already operating.

The American GPS consists of 24 orbiting satellites and spares, Groth said, four in each of six orbital planes, so that four (the minimum for a good fix) are always in view. The orbits all have a 26560 km radius and a twelve hour period (with slow drift), and orbital inclinations of 55o relative to the Equatorial plane. All the satellites broadcast at 1,575,420,000 Hz, but they can be distinguished because their signals are multiplied by a Pseudo Random Noise Bit 1,023,000 times a second, with the pattern repeating after 1023 bits, with a different pattern for each satellite (1540 carrier cycles per noise bit). Fifty times a second the signal is multiplied by a data bit, carrying information about time and the satellite almanac.

A GPS receiver determines its location by "listening" to four satellites and measuring its velocity relative to them by the Doppler shift. Locating a receiver with the precision of a meter requires time accuracy of three nanoseconds, the time for light to travel that distance. Part of that precision timing involves including the effects of general relativity, without which GPS clocks would gain 40 microseconds a day, the time it takes light to travel 12 km.

Among the applications of the GPS identified by Groth are planting precisely-spaced rows in agriculture, art, location of geocaches, and identifying the location of 911 callers from their cell phones. But Groth warned that the GPS doesn't work everywhere -- water in leaves causes trees to absorb signals, buildings and power lines cause unwanted reflection, and ionospheric refraction increases estimates of satellite distances -- and batteries can fail, so users should always have a backup to their GPS.

"Peta" is the prefix that stands for 1015, and Klasky began his talk on petascale computing by emphasizing the "petascale" is large. He noted that it represented gains by a factor of 1014 in 70 years, starting from the ENIAC in 1943, that used 18000 vacuum tubes to do H-bomb calculations at Los Alamos, with no central memory and a cost of a half million dollars. This was improved upon after World War II, Klasky went on, first by the MANIAC I in 1952, then by the Cray computers of the 1960s, which performed up to 10 Megaflops (a "flop" is a Floating Point Operation Per Second) with 512k memory and a cost of $5 million.

The birth of supercomputing was the 1976 Cray I, Klasky continued, capable of 250 Megaflops, with 16M memory. Its language, Fortran 77 (named for the year of its development) is still a popular language for computer programs, Klasky said. But each new record-setting development would be short-lived. The 1982 Cray XMP was capable of 942 Megaflops, with 128M memory. The 1987 CM2 had a data vault the size of a small room, and in 1990 Fortran 90 eliminated he previous restriction of statements to 72 characters (the maximum allowed on punch cards).

Intel got "into the game" with 3680 processors and a capability of 184 Gigaflops in 1994, but Hitachi had bettered that within two years. Computers with Teraflop capability were achieved by the end of the twentieth century, and this year the Los Alamos National Laboratory Road Runner has achieved Petaflop capability. Klasky identified several types of science that can benefit from petascale computing: climate modeling, nuclear fusion, nanoscience, computational biology, simulation of properties of matter from first principles, combustion with greater energy efficiency, turbulence, and supernovae. But he also pointed out that the interface between scientists and computers cannot keep up with the pace of the computer and emphasized that scientists as well as computers are needed. Other problems cited by Klasky are the limitation of programming languages and the problem of extracting the "needle from a haystack" in data analysis.

Although Gentile's responsibility at the Princeton Plasma Physics Laboratory is the detection of tritium in fusion reactors, his work in detecting and identifying radioactive isotopes from nuclear fission sprang from applying tritium-detection technology to meet the need perceived after 9/11 for *in situ* measurements by miniaturized detection systems to identify radionuclides associated with fission weapons and being able to distinguish them from radionuclides associated with medical treatment. As reported in our Fall 2006 issue, Jennifer Church of the Lawrence Livermore National Laboratory described one such system at last summer's meeting of the American Association of Physics Teachers. The system described by Gentile is the Miniature Integrated Nuclear Detection System (MINDS).

MINDS employs parallel detectors of x-rays, gamma rays, and neutrons combined with Support Vector Machine (SVM) algorithms written in C++ which identify radionuclides by peaks in their spectra. Its current library includes ^{241}Am, ^{133}Ba, ^{139}Ce, ^{252}Cf, ^{57}Co, ^{60}Co, ^{137}Cs, ^{67}Ga, ^{131}I, ^{192}Ir, ^{40}K, ^{237}Np, ^{226}Ra, ^{99}Tc^{m}, ^{232}Th, ^{201}Tl, ^{210}Po, and depleted uranium.

Gentile noted that in 1987 Saddam Hussein made so-called "dirty" bombs -- bombs that used conventional explosives to scatter radioactive material – as did also the former USSR, and not all these "dirty" bombs are accounted for. Dispersal of 1500 curies of ^{137}Cs in Manhattan, Gentile said, could cost the economy $200 million, and lesser amounts were improperly disposed of and dispersed in Brazil. [Science reported in its 16 March 1984 issue that a Picker C-3000 radiation therapy unit outfitted with 2885 curies of ^{60}Co in 1969 was breached in a Mexican junkyard in

December 1983.] Moreover, Gentile added, there is even radioactive material "missing" in the U.S. For all these reasons, MINDS is needed and is now deployed at the Plasma Physics Lab, Penn Station Newark, at military bases, airports, and mail sorting facilities. Gentile closed his talk by bringing a smoke detector up to a MINDS unit he had on display. In less than a second it displayed the radiation spectrum and displayed ^{241}Am as the identified radioisotope.

The antiques which Littman uses to teach engineering are very carefully chosen. He began by displaying a graph showing the percentage of American households owning five technological devices in different years -- electric light, radio, television, telephone, and automobile. He categorized these devices under the headings of power, information, and transportation, then explained how engineers view devices in terms of structures, machines, networks, and processes.

Littman then considered eight technological devices -- the clock, the pump, the automobile, the telegraph, the telephone, the phonograph, the lamp, and the bridge -- as expressions of six engineering ideas -- the pendulum, the piston, the electromagnet, the diaphragm, the filament, and the arch. In some cases he showed pictures of his students restoring devices to their original level of operation. In other cases, with help from audience volunteers, he demonstrated their operation.

Looking toward the future, Littman felt that he could not predict the engineering developments of the 21st century in reliable detail. But, he said, he expected power, information, and transportation in terms of structures, machines, networks, and processes to be important. In closing with a cartoon in which a doctor diagnoses "little Dilbert" as having "the knack" that would cause him to become an engineer, Littman concluded with the mantra, "Nerds change the world!"