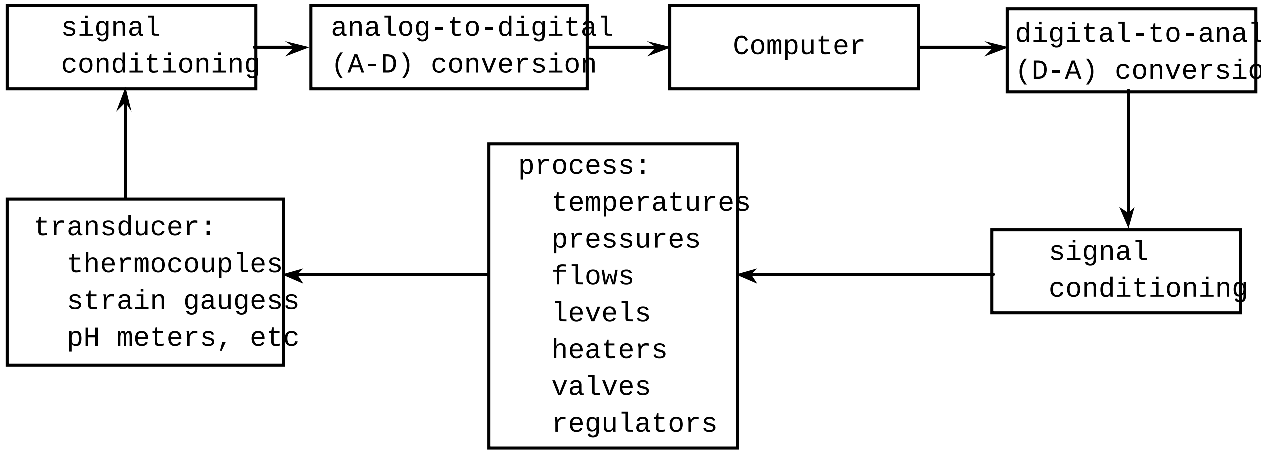
Bio 595 **Computers in Biomedical Research** Fall 2003

Laboratory data acquisition and control

Data acquisition: there are several levels of sophistication that can be provided in using a microcomputer to acquire data in the laboratory (or, for that matter, in the field): (1) “Data logging” is exemplified by a person sitting at a control panel, reading a meter periodically, and copying the numbers onto a pad. (2) An “electronic data logger” is a circuit box which records a value (like a voltage) periodically, then prints it out or records it on magnetic tape or a disk. A personal computer can be used to "record" the data for later examination. (3) In a “data acquisition system with alarms”, input values monitored from one or more instruments in an experiment are compared with one or more limit values imposed on the system (maybe both minima and maxima); an alarm output occurs when some limit is passed. The computer’s response might include ringing a bell, displaying a flashing message on the screen, or turning on an electric device (like a cooling fan). (4) In “on-line data analysis” the computer may provide output to the screen showing averaged readings from instruments, data trends, and other graphic and pictorial representations. (5) In “real-time control” the computer is used to provide, in addition to the preceding, outputs that directly or indirectly control parameters being monitored by controlling heaters or coolers, positioning motors, valves, etc.

Communications between the computer and the 'real world": the physical interface (cf the graphical user interface). The crudest is a person reading the dials and meters, copying readings into the keyboard. This “interface” is slow, error-prone, and gets tired. The two common ways to establish electronic communications between the computer and a laboratory experiment is by “serial” communication and by “parallel” communication. In parallel communication mode, the computer (like a PC) has data, address, control and power busses. Commercially marketed laboratory interfaces (like the MacLab for the Macintosh) can be connected to these busses to communicate with the computer. Parallel interfaces can involve (1) memory mapping, where data flow to and from the device is accomplished by writing to or reading from memory addresses assigned to the interface; (2) or, it can involve I/O (input/output) ports on some older computers like the Apple, where ports can be connected to external devices like disk drives, the keyboard, etc. Bus-compatible hardware is marketed for several versions of the PC bus like the PCI, the Multibus, the IEEE-488 and the GPIB (general purpose instrumentation bus). Serial interfaces utilize the so-called RS-232C standard. The original MacLab device used this interface, while the newer MacLabs employ a higher speed SCSI (Small Computer Systems Interface) port.

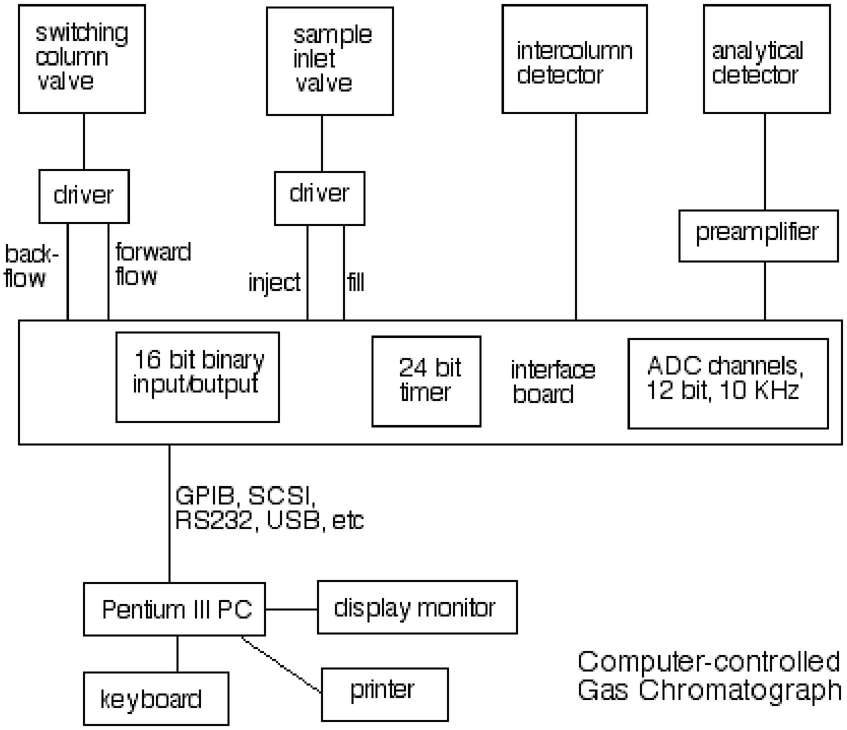
Generalized process or experiment control system:



'Signals' in the lab: various physical parameters in the 'real world' can be converted to analog voltages by the appropriate transducers and signal conditioners. These phenomena include temperature, humidity, pressure, force, level, displacement, velocity, etc. A 'signal conditioner' converts transducer output into a suitable standardized form for an analog-to-digital (A-D) converter: for example, transducer output is typically a high impedance low voltage: this must be converted to a low impedance signal, with voltage appropriately scaled for the A-D converter, typically to the 0 to 1 volt range. The signal conditioner generally provides for amplification (and attenuation), input/output isolation (from shock hazard) and often a transducer excitation voltage. Isolation circuits utilize transformers or optical coupling between a light-emitting diode and a light-sensitive transistor. The conditioner may also filter the signal (e.g., eliminate high frequency noise, or low frequency oscillations like 60 Hz line voltage frequency). Some transducers produce a variation in resistance, capacitance or inductance in response to the applied mode of energy being detected, instead of a change in output voltage. Temperature gauges include bimetallic strips, thermocouples, or thermisters. Strain gauges can be used with a Wheatstone bridge to measure pressure, force, weight, acceleration and (small) displacements.

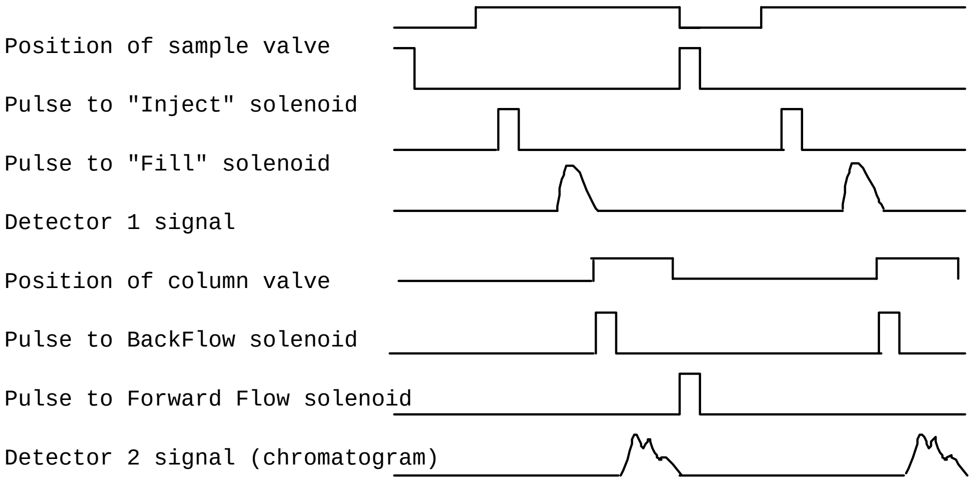
Analog-digital conversion: the A-D converter samples the continuously variable analog voltage from a transducer/signal conditioner and provides a digital value (from 8 to 16 bit resolution - 1 part in 256 to 1 part in 65,536 sensitivity) which can be stored in the computer's RAM. The digital output can connect directly to the computer's data bus and appear as a number stored in an assigned memory address (memory-mapped) or as output from an I/O device. Maximum converter speed can be in the range of Hz, KHz or MHz (for example, the 'flash' converters used for video signal processing). There are two common types of converter designs. One is the 'successive approximation' type, where a 'sample and hold' circuit first stores the analog voltage level, followed by successive approximations of the digital bits matching the sampled level through an internal digital-to-analog converter until output equals the held analog input. The 'integrating' type of A-D converter is used for lower sampling frequencies (under 1 KHz). The A-D integrates the input over time (usually 1/60 sec) to yield an averaged value filtered of 60 Hz hum. D-A converters sum the current fed to an output from a series of internal switches controlled by the digital inputs; the output is usually converted to a signal in the +1 v to -1 v range.

Computer-controlled GC system: here’s an example of a computer-controlled process system. Gas chromatography is a separation method in which a sample gas is injected into an inert carrier such as helium or nitrogen that carries the sample into a series of columns that separate sample components in time. Two columns are usually employed in series; the first column holds up sample components that may damage the second column (e.g. water, acid gases like SO_2, NO_2, HS) and materials with high boiling points that might never elute from column 2. After the sample (less the undesirable components) have passed through column 1, the flow is reversed in the first column while retaining the forward flow in the second column. The unwanted components stripped from the sample are then vented from column 1. The sample component concentrations are determined from the detector response (peak height, peak area), calibrated against known standards.

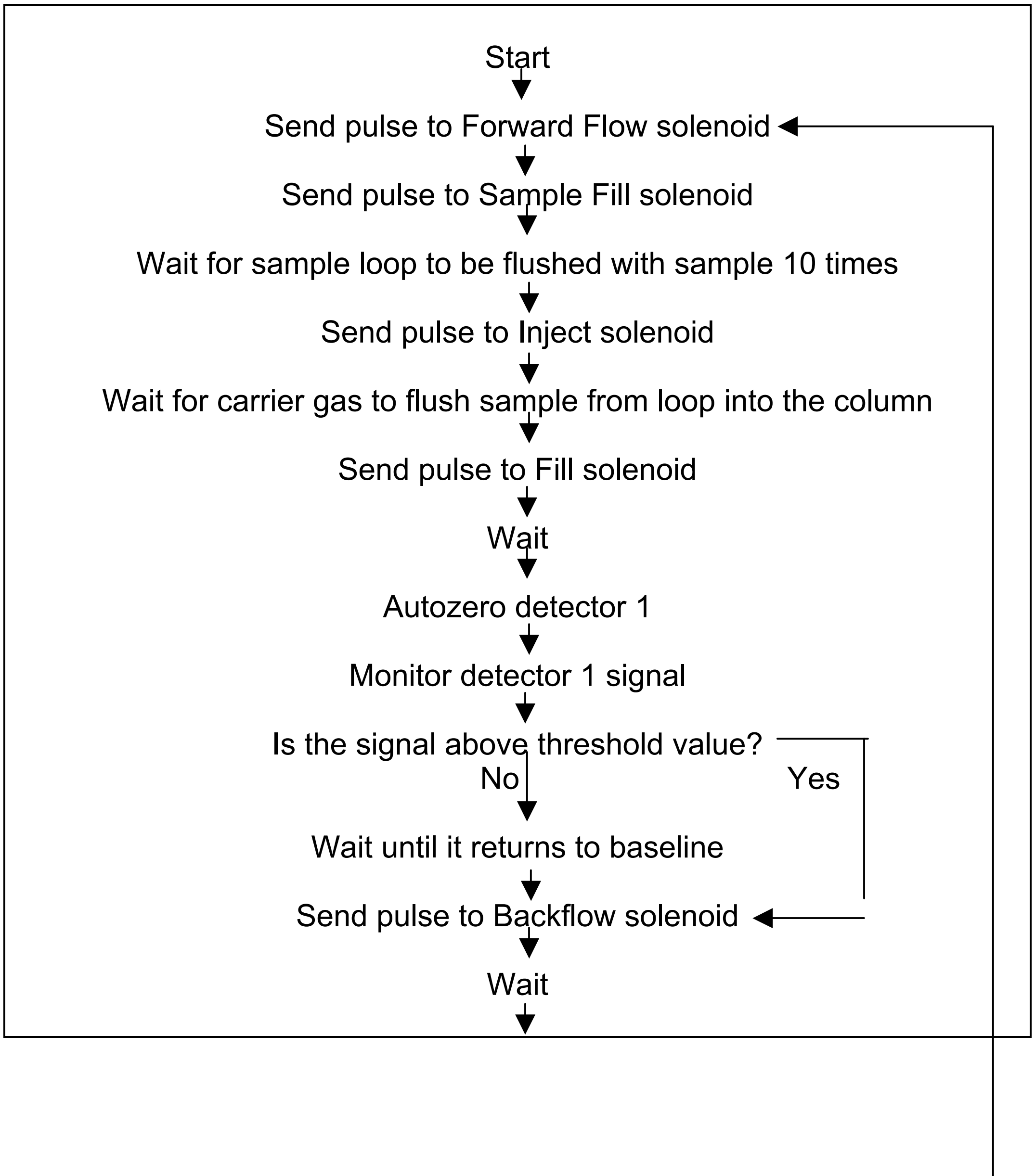


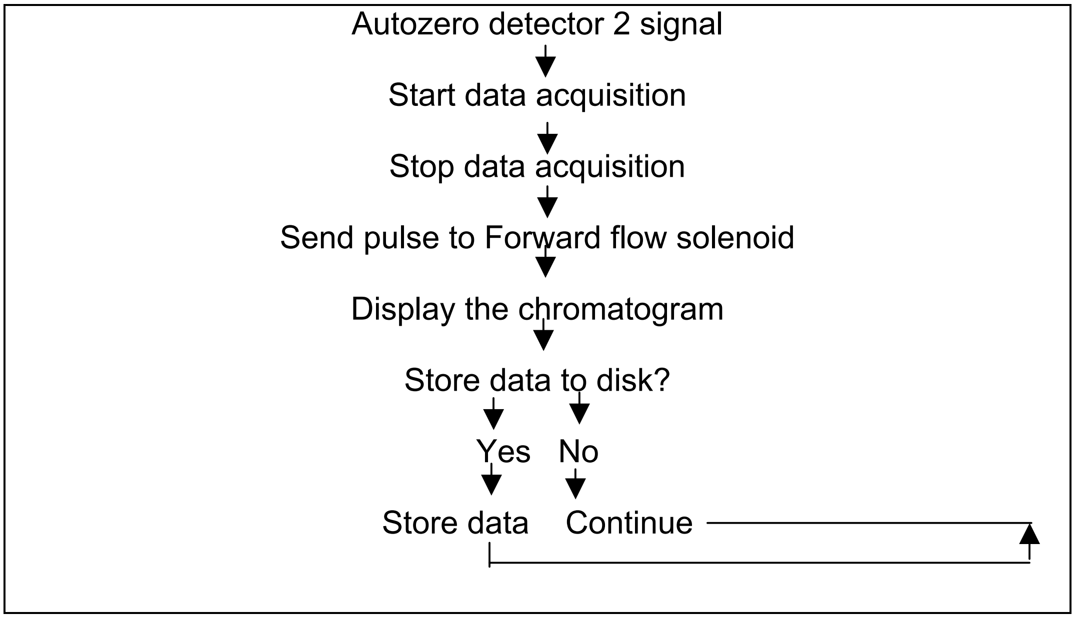
Computer-controlled Gas Chromatograph

The hardware required for a GC system includes (1) a sample injection valve; (2) a column switching valve to switch flows and backflush column 1; (3) an intercolumn detector (low sensitivity is adequate) to signal when the desired components of the sample have exited column 1; and, (4) a sensitive analytical detector to record the sample components as they elute from column 2. The valve solenoid actuators require 'drivers' which can be activated by a low voltage, very low current digital signal from the computer (going from 'low' to 'high') and provide sufficient current to actuate the solenoids. The analytical detector output is usually in millivolts and will require amplification before being fed to the analog-digital converter. The timing diagram below shows the sequence of operations which must be controlled by the computer:



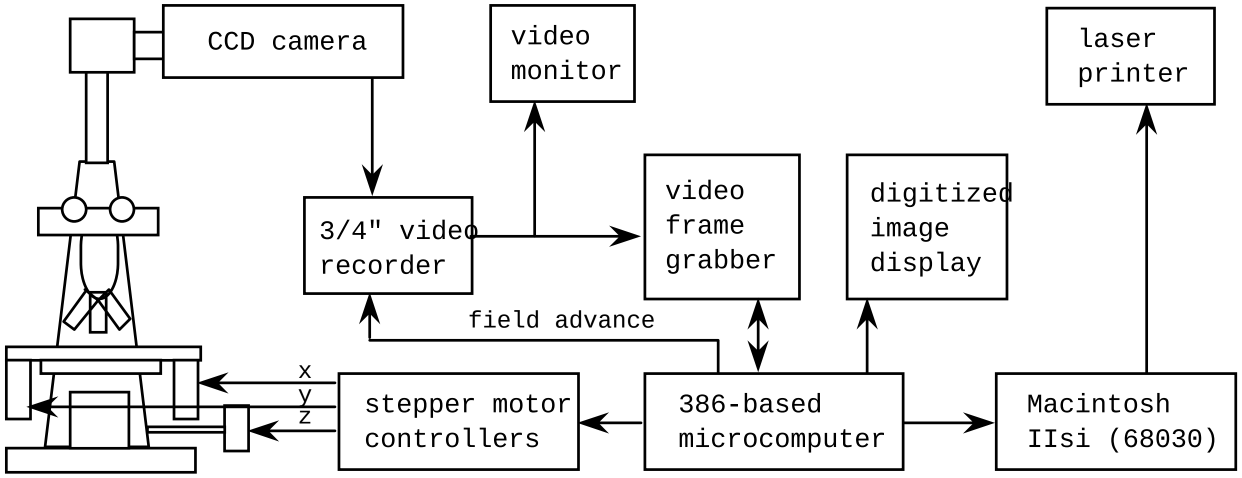
<u>The control software</u> required to operate such a GC can be summarized by the flowchart below. Here 'autozero' may be accomplished by appropriate hardware (circuitry that adjusts an offset voltage until the detector output reads zero) or software (by subtracting the baseline value from the signal). The sampling interval in this system might typically be about every 10 msec (e.g. 100 Hz digitizing rate).

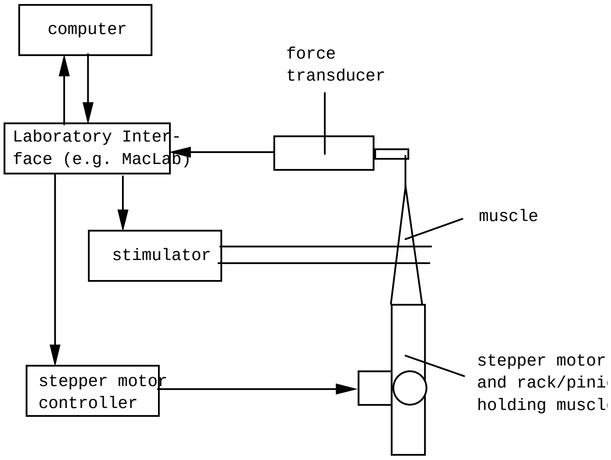


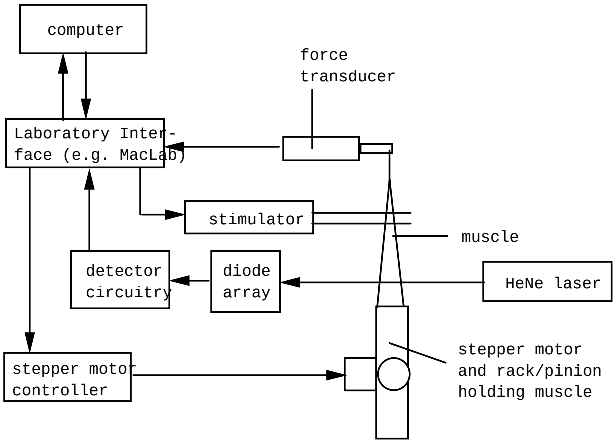


The 'wait' periods would allow time for solenoid valves to respond to activation (this might be as little as 50 msec or as long as a sec). Baselines are saved as an average of repeated conversions with no sample yet reaching the detectors. The digitizing rate is selected based upon the peak width: at least 20 points per peak would give adequate resolution for good peak definition. A spectrum in this case might consist of a digitizing rate of 20 Hz for 3 min, giving a total of 3,600 data points per chromatogram, requiring anywhere from 7.2 KB to 28.8 KB of storage space, depending upon the storage format of the numbers (integer, floating point, etc.). The software could provide for display of accumulated data (either after the acquisition is complete, or in real time, if appropriate assumptions are made about the scaling of the signal amplitude and the time axes to be set up on the screen).

More examples of data acquisition and control systems (these from our muscle physiology laboratory): (a) (upper figure) System for 3-d reconstruction of single muscle cell, using differential interference contrast microscopy and computer controlled (x,y position) stage with z-axis (focal plane) control. (b) (lower left figure) System used to 'clamp' the average contractile component length of a whole muscle by 'pulling out' the series elasticity: tension signal changes are fed back to the experiment by rapidly controlling the muscle's length. (c) (lower right figure) Similar system used to clamp average sarcomere length in the muscle by monitoring the spacing between first order laser diffraction lines, which varies inversely with sarcomere length.







Laboratory software languages for data acquisition and experiment control must be as user-friendly as possible. Most biomedical researchers don't want to spend all their time programming. Often these laboratory languages provide for extensions of popular general programming languages like Basic, Pascal or C. They may be menu-driven, high level languages which incorporate assembly language drivers to control devices where speed is critical. The minimum features desired in such a language include: (1) interface input commands: analog, digital, counter, trigger inputs; (2) interface output commands: analog, digital, trigger; (3) data display capabilities, for graphing time series data and (x,y) data on the screen and a hard copy output device of some kind. An example of an early laboratory control language was LabSoft, an extension of AppleSoft Basic (for the Apple) and BASICA (for the PC), designed to be used with a laboratory A-D and D-A device called the Cyborg Corp. ISAAC. An example of a command to read the voltage from channel 5 input, compare it to the value stored in variable Y, display it on the screen is: &AIN,(TV)=X,(C#)=5,(CV)=Y,(PR). An example of a command to output the value contained in Y to channel 4 is &OUT,(DV)=Y,(C#)=4. To count external events, clear the counter: &CLRCOUNTER; then count: &TIMERIN,(TV)=X. Other proprietary laboratory control languages include QUICK I/O, PCLAB, and Soft500 (this last for Keithley data acquisition and control hardware for both PC and Macintosh computers).

Macintosh Laboratory data acquisition software and hardware: MacLab laboratory interfaces and Macintosh computers are used in our Bio 436L (Principles of Human

Physiology) Laboratory to replace previous conventional lab instruments like a chart recorder, stimulator, oscilloscope, spectrum analyzer, and signal averager. Student lab data can be processed, reduced, and graphed. The most powerful of software packages for lab data processing is probably LabView, by National Instruments. LabView follows the concept of the 'virtual instrument', a software emulation of specific lab instruments; more than a thousand instruments are currently supported. Its language is icon-based and object-oriented. LabView allows the creation of applications for data collection and management, database functions, signal and transient analysis, and process control. New instruments can be constructed from basic 'tools' like dials, meters, terminals, etc. Programming is done by 'wiring' icons together in a block diagram window. Other features include full math functions (statistics, calculus, vector algebra), data logging to a spreadsheet like Excel, and error message generation for 'faulty wiring'. Other systems less complicated than this include Analog Connection Workbench, by Strawberry Tree Computers (this is also icon-based); LabTech Notebook, from GW Instruments, ported from the PC; and, MacLab, by World Precision Instruments, a Macintosh 'oscilloscope' with Chart and Scope software for recording system emulation (of a strip chart recorder or oscilloscope). Boards for installation into the Macintosh, provided with 'drivers' in C and Pascal, include BioPac Systems NuScope (for the Macintosh); and boards by Data Translation, Inc.; the MacAdios board by GW Instruments; and Lab Interface boards by Keithley Instruments.