SESSION VII TUTORIALS

Walter Schneider, *Presider*

Basic computer troubleshooting and preventive computer maintenance operation

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A tutorial on operating a computer to minimize hardware failure and board-level troubleshooting is presented. The benefits and risks of doing your own computer maintenance are described. The paper discusses major causes of computer failures and how to prevent them. Functional descriptions of major computer modules are provided. Troubleshooting for both operative and nonoperative systems is described. Basic troubleshooting symptom analysis, fault isolation, and board swapping are illustrated.

Microcomputers have become an indispensable research tool for many psychologists. Unfortunately, these computers break down and their repair is time-consuming, difficult, and expensive. The present paper describes how a typical researcher, with only a limited electronics background, can do board-isolation troubleshooting on his/her own computer, and how to prepare and operate the computer to reduce maintenance problems and down time.

Let me begin by describing those who need to be able to do board-level troubleshooting. If you cannot afford a service contract or you purchase equipment from multiple vendors, you will probably have to arrange for your own maintenance. Many psychologists simply do not have sufficient research funds to cover maintenance contracts on their equipment. Annual maintenance contracts typically cost over 10% of the total acquisition price of the equipment. A number of granting agencies have decided that maintenance contracts are overpriced and have restricted amounts budgeted for computer maintenance. Doing your own board-level isolation is probably the easiest way to substantially reduce maintenance costs. If you can isolate the computer malfunction to a given board and send that board back to a manufacturer, you can typically save 70% of your maintenance budget (e.g., reduce a \$500 repair bill to \$150).

A second category of researchers that must arrange

their own repair are those who purchase equipment from multiple vendors. For example, a researcher may purchase the computer main frame from a single distributor and then purchase additional memory at a later date from the vendor who provides it at the best price. Many computer maintenance organizations will not service equipment that is not their own. Hence, if you put any additional non-vendor-supplied equipment in your computer, it is your responsibility to isolate and remove the other vendors' equipment from the system. So, even before you can call in the computer vendor's maintenance personnel, you must isolate the problem to his portion of the machine and remove all other pieces of equipment in the system.

If your department has sufficient funds to hire electronic technicians for computer repair, you may not need to know how to do board isolation. But this approach also has problems. First, computer electronic technical personnel are in high demand. Hence, they must often be paid more than assistant professors and it may be difficult to keep them. Second, when computer technicians are available, it may take several days before they get to your machine once it breaks down. With sufficient knowledge to swap out boards, you should be able to isolate the problem to the appropriate board, get a spare board from a departmental supply, and be operational again within 1 h of machine breakdown.

Of course, the risks of not having a maintenance contract must be considered. The first is that you are not insured against excessive repair bills. A maintenance contract has a fixed rate (e.g., 10% of acquisition cost annually), whereas doing your own board-level maintenance will average much less but have a greater variability (e.g., mean, 2%; SD, 20%). So, in general, money

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is saved without a contract, but some years you should expect large repair bills. It is advisable to develop a repair fund so that excessive maintenance bills can be absorbed. The second risk involved in not having a contract is that the correction of complex repairs may be slowed. If the repair requires that a new component be shipped or a board be sent to a company for repair, the system will probably be down for 1 week or more. Developing a departmental or campus wide set of spare boards can greatly reduce this problem. If you must call in the manufacturer's repair personnel, you are typically serviced only after all contract systems are operating, so there may be a delay of several days before they get to your system. A third risk is that you may damage your machine, and this would result in emotional as well as economic hardship. I believe that for most psychologists the economic savings outweigh the risks. Funding support, maintenance needs, and maintenance capability must be evaluated before deciding whether to purchase a maintenance contract or perform your own repairs.

Anyone who has the competence to get a PhD can do board-level computer troubleshooting with only a few hours of training. Board-level troubleshooting can be thought of as a multiple-choice test. Troubleshooting at the board level typically requires very little equipment (often just a screw driver and a voltmeter), generally costing less than \$30. It also requires only a conceptual understanding of the primary units of a computer and their interactions. Most board-level debugging does not require detailed knowledge of electronics or circuit design.

OPERATING PROCEDURES TO MINIMIZE MAINTENANCE PROBLEMS

In operating your computer, keep in mind considerations relating to operating temperature, power surges, lubrication, cleanliness, alignment, and static discharge (see Table 1). Proper concern about these factors will substantially reduce the need for troubleshooting. Electronic gates typically fail because components either melt or crack. Mechanical systems typically fail due to lack of lubrication or improper alignment. Read heads fail because of dust.

Try to keep your machine operating at a temperature lower than 80°F (27°C). If the computer overheats, gates are likely to melt. Operating a computer at 95°F for a couple of hours can produce serious maintenance problems. Also, computer cabinets need to be ventilated. Be very careful never to block an air vent or place a computer under a shelf so that heat builds near the top of the computer. Air filters should be inspected and cleaned regularly. If a fan begins to squeak, fix or replace it immediately. If a fan breaks, it is quite possible for the inside temperature of the machine to exceed 100°F, causing extensive damage before the fuse finally blows. Once a fan begins to squeak, it may run for 3 h or 3 months before it fails. If it fails on a weekend or late at night, the effects can be disastrous. If the

Table 1
Operating Procedures to Minimize Maintenance Problems

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1. Keep temperature between 60-80 F (16-27 C)
 - a. Keep air flowing
 - b. Replace or repair squeaking fans immediately
 - c. Install thermal cutoffs
 2. Minimize power ups and power downs
 3. Perform necessary alignment and lubrication and handle with care
 4. Keep the computer system clean
 5. Do not expose your media to dust or extreme swings in temperature or humidity
 6. Connect your computer to stable AC power lines and install despikeys if necessary
 7. Minimize static discharge
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building has occasional air conditioning problems, it may be worth investing in a thermal cutoff. For approximately \$40 in parts, a thermal sensor can be constructed that will shut off power to the computer when overheating begins.¹ A cutoff can be a good investment, particularly if you leave the computer operating over weekends. Gradually acclimatize new equipment. If a computer is shipped in the winter, let it come to room temperature before powering it up.

A second major category of component failures is due to powering up and powering down the computer. Components making up a small microcomputer include potentially millions of electronic junctions. Whenever the computer powers up or powers down, these junctions expand and contract. Gates are much more likely to fracture during this expansion and contraction than they are during the normal operating period. Hence, if you use your system on a daily basis, do not have to worry about air conditioning failures, and have few power surges, then you will probably reduce failures by not powering down your computer.²

A third category of computer maintenance considerations is careful handling and performing necessary alignment and lubrication. These considerations relate primarily to input/output (I/O) devices such as floppy disks. On floppy disks, rough handling, either in shipping or when opening and closing the floppy drive door, quickly degrades the alignment, requiring frequent realignment. Preventive maintenance on a floppy drive typically requires lubricating the worm screw every 6 months. This is easy to do, but if it is not done, the alignment becomes distorted and parts wear out more quickly, resulting in larger repair bills.

Preventive maintenance requires keeping the computer system clean. Dust and smoke particles cause failures on computer disks. For example, recently my hard disk was failing randomly. After cleaning out about 15 individual dust particles from the interior housing of the disk, the problems were eliminated. When placing a disk in the disk drive, make sure that the case

has no dust particles on it. Devices such as tape drives should never be operated without dust covers in place. Cleanliness requirements for modern disk drives are high. A .001-in. oxide deposit on a disk or a tape head can cause read or write failures. Specialized cleaning solutions and materials are available from a number of distributors. In addition, air filters should be checked regularly and cleaned or replaced when appropriate. Prohibiting smoking near the computer and installing electrostatic air cleaners reduces maintenance problems.

To prevent I/O errors, be very careful with recording media (cartridges, floppies, tapes). Computer tapes are far more sensitive to dust, temperature, and humidity problems than are high-fidelity audiotapes. Protect your media so dust will never settle on it (e.g., keep your floppy in its jacket and the jackets in a sealed box). Recording media should not be exposed to extreme temperature (e.g., 50°F, 27°C) or humidity shifts. For example, placing the media near a hot air vent or an outside window can cause the loss of data in less than 1 month. Keep recording media away from magnetic fields (e.g., do not place a floppy next to a cooling fan motor).

Proper computer operation requires that line voltage be free of voltage fluctuations and spikes. If there is a line voltage problem, the computer will randomly fail. Large power surges (e.g., someone in the next room turns on a coffee pot) can cause a spike that will pass into the processor and may cause a temporary malfunction. Despiking plugs, available at moderate cost (e.g., \$50), remove most spiking problems. If line voltage fluctuates, move your computer to another circuit or buy voltage conditioners (these are expensive).

Preventive maintenance requires that static discharges to the computer be minimized. A static discharge can put several hundred volts across a transistor gate. This may cause the gate to fire inappropriately or cause a gate failure. Since your computer will perform better in a low-static environment, use specialized carpeting, carefully ground all equipment, and humidify the air during periods when static charges are a problem.

MAINTENANCE PREPARATIONS

It is important to prepare for troubleshooting maintenance before the computer breaks down (see Table 2 for a list of maintenance preparations). You can safely assume that in a 3-year period of daily use, your computer will fail at some point. If you make the effort to perform diagnostic checks and have the appropriate materials available, troubleshooting will be much more efficient when the first breakdown occurs.

Try to have available diagnostic programs for each of the modules you have in your computer, and know how to use them. Remember to order machine readable diagnostics when you order each new unit. Diagnostic programs frequently need to be tailored (constants set) for the particular hardware and options set in the system. Hence, it is important to be sure that you can

Table 2
Maintenance Preparations

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1.	Have diagnostic programs available in machine readable form and know how to use them
2.	Have available service and repair manuals
3.	Have access to necessary test equipment
4.	Document and label all possible modules, selected options, and cables
5.	Arrange access to critical spares
6.	Learn how to strip down your computer bus to the critical modules
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successfully run the diagnostic programs before the computer malfunctions. I recommend that you run each diagnostic and file the printout for successful execution of the diagnostic. In this way, you are much more likely to run the diagnostic successfully during troubleshooting. Running diagnostics on a regular basis is an important component of preventive maintenance. For example, a disk read check will indicate potential disk I/O errors that might result in future random data loss. In addition to running complex vendor-provided diagnostics, it is useful also to know how to run very short diagnostics that can be input directly into the machine. For example, being able to input seven instructions to print a single letter can allow you to quickly test the central processing unit (CPU), memory, and serial I/O port. Most diagnostic programs are used mainly to check peripherals, not the critical computer components (see below).

Equipment service and repair manuals should be readily available. Major computer manufacturers generally develop service manuals for each major piece of equipment. Manuals frequently provide step-by-step troubleshooting guides and repair procedures for correcting specific problems. When available, these manuals are extremely valuable and generally worth the cost. Hence, whenever you order a piece of equipment, order the service manuals and other maintenance aids (e.g., machine readable diagnostic programs) for that piece of equipment. The service aids are generally not included in the normal purchase price of a piece of equipment.

Try to have access to the necessary test equipment. Probably 95% of computer repairs can be done with a low-cost voltmeter and screwdrivers. It is important to know how to use the voltmeter, but this can typically be learned with 15 min of instruction. For complex problems, it is important to have access to an oscilloscope. It is useful to have an insulated rod (piece of plastic or wood) for tapping on computer components or cables to move them without causing shorts.

Document and/or label all of the possible modules and/or switches within the computer. Occasionally, through vibration or through moving a board in or out of the computer, one of the selection switches changes state. By documenting the position of all switches, you can quickly verify that none of the switches has changed

state. If you set any options on a board, label the documentation for that board so that you know the options selected for that particular serial-numbered board. Label and/or make a diagram showing the position of each of the modules in your computer. This will allow you to remove modules and return them to their original positions. In addition, label cables that may be removed so that they can be plugged back in the proper slot and in the proper position. Note that many computer cables can be plugged in upside down, causing severe damage. Try to keep an up-to-date listing of all critical hardware addresses in the computer (addresses of I/O registers, interrupt vectors, and priorities). It is worthwhile to tape the list to the top of the computer.

If at all possible, try to arrange to have access to critical spares at least for testing. Most computer vendor repairmen bring with them a full set of basic computer modules to repair your machine. The principal method of repair (see below) is substituting modules until the machine works again. Try to arrange to have spares available so you can do this yourself. At the University of Illinois, spares for the most frequently used computer modules are kept in a central campus site. Users can borrow (for a fee) these spares for checkout work or temporary use while their modules are being repaired. If you have several users of the same machine, all would benefit from joint purchasing of the appropriate spares, thus sharing the cost of stocking spares. The second approach to having spares is to find someone else with the same machine and negotiate a reciprocal board-swapping arrangement. In such an arrangement, you agree to allow someone else to move individual modules from their computer to your computer to determine whether their modules are functioning properly. It is unlikely that careful swapping of modules will hurt either machine. It is much better to negotiate such an agreement before either machine has failed. Then both parties can perceive the benefit of formally agreeing to share computers. When you are considering purchasing a system, give important weighting to its compatibility with existing equipment for such swapping arrangements.

Before a breakdown occurs, try to strip down the computer to basic bus components. Stripping down a computer means removing all components of the computer that are not necessary to perform the simplest diagnostic tests. Do not try to strip down the computer alone the first time. Arrange to have someone who has done it before show you. When you purchase a computer, request instruction on how to strip down the bus. With sufficient knowledge, this job can usually be done in 5 min.

FUNCTIONAL UNITS OF A COMPUTER

A computer system contains a number of modular units that interact through a data bus or cable connectors. In order to isolate hardware problems, it is

critical to understand the function of each of these modular units, the effects of a failure of each of these units, and the nature of the interactions between units. It is not necessary to understand the detailed operation of any of these units. It is sufficient to know what the unit is supposed to do and how it communicates to other units.

There are eight functional units that make up the typical research computer system (see Figure 1). The first is the CPU, which is usually housed on one board. It performs all of the instructions of the machine (e.g., addition and branching). The second unit, the memory, stores information (either program control or data) that is fed into the CPU so that the CPU can perform instructions and modify memory. The third unit, a serial I/O port, takes characters that are represented by a set of 8 bits and serializes that string of bits (e.g., transmits 1 bit every .0001 sec) so that the data can be transferred on a cable connected to a terminal. The fourth unit, a video or hard-copy terminal, stores the bit stream or characters sent to it in its own memory and displays the characters so humans can read them. The fifth unit is the computer bus, which is primarily a party-line connection over which the modules within the computer can communicate. The sixth unit is the computer power supply, which provides the energy to drive all of the modules.

In order to operate even a simple diagnostic, almost all of the functions of all six units must be operating. For example, a simple diagnostic program may try to output a string of As on the computer terminal. In order to run the diagnostic, all the modules must be getting power near the acceptable tolerance range of the power supply specifications. The CPU must be able to put the proper addresses on the bus to fetch

Figure 1. Functional components of a computer: (1) CPU—performs instructions; (2) memory—stores data and instructions; (3) serial input/output port—transmits data to the terminal; (4) terminal—displays and inputs character information; (5) computer bus—transmits data and power between modules plugged into the bus connectors; (6) power supply—provides energy to drive all modules; (7) peripheral devices—provide external storage; (8) specialized data acquisition equipment.

the instructions. The memory must read the addresses and put the data in those memory locations on the computer bus. The CPU must then read the instruction data from the bus and properly execute the machine instructions. One of the instructions must be outputting to the serial I/O port. To do this, the CPU board must put appropriate address for the serial I/O port on the computer bus and put the data for that character on the computer bus. The serial I/O port must recognize its address on the data bus, accept the data, and generate an appropriately timed bit stream for the bits of that character. The serial bit stream is transmitted to the terminal across a cable. The terminal must then interpret the bit stream and proper timing intervals in order to reassemble the bits into an 8-bit stream representing the character. Then the terminal must display the character on the screen. A failure of any of these units will cause a simple seven-instruction diagnostic program to fail. The importance of the availability of spare modules is that it allows you to individually test (through substitution) the critical six components that must be operating before you can successfully execute diagnostic programs.

In order to isolate problems, it is important to have a conceptual understanding of how the computer bus operates. The computer bus or backplane is a series of slots that individual computer boards plug into. All connections between boards are done by wires connecting pins from one slot to the next. Most of the connections on the bus are connected in parallel to the same position on all slots. These bus lines are a party line; when one module talks to the bus, all other modules can "listen" to the information placed on the bus. If a module does not relinquish control of the computer bus, none of the other modules can communicate on the bus. In this way, a module that is not even being utilized can cause the computer to fail. For this reason, a first step in isolating a computer failure is often stripping down the bus to only those critical modules which are necessary to run simple diagnostics. Modules communicate on the bus not by placing power on the bus line, but rather, by shorting the power that is provided on the bus line to ground, causing an effective 0 voltage on the bus. If none of the modules are shorting the voltage to ground, there is typically a positive voltage (e.g., 5.0 V). This is important because it makes it very unlikely that a bad module will ever harm any other module on the bus. If you accidentally short one of the bus data wires to ground, no harm is done, since the circuit is designed to do this during normal operation. Also, if a gate fails, that gate can typically no longer short that voltage to ground; the voltage remains at its normal high state, and no harm is done. The only way to damage modules on the bus is by putting an inappropriate voltage on one of the bus lines. As long as you are very careful checking bus voltages (i.e., do not allow voltage probes to short pins on the backplane), you are very unlikely to damage

modules by moving boards around on the bus. However, if you do short power pins, causing an inappropriate voltage to be placed on the bus, it is possible to burn out every gate on every module that connects to that particular line on the data bus.

In addition to the six components mentioned above, most computers have peripheral storage devices (e.g., disks, tapes, floppies). These units typically read or write information from some storage media (e.g., floppy disk) to and from the computer's memory. These devices are composed of several functioning units. There is a controller that connects to the computer's bus and communicates between the computer and the specialized peripheral device. The peripheral device itself often contains its own power supply, electronics to control the peripheral device, and mechanical components (e.g., tape reels, motors, tape heads). A failure in the controller board may disable the computer entirely. Failures in the rest of the peripheral device generally will not disable the computer completely but will only disable the use of the peripheral device.

Finally, most experimental computer systems have specialized equipment for data acquisition and experimental output. These units come in many forms (e.g., digital I/O bits, analog-to-digital converters, crystal clocks). These units generally include a control module that plugs into the data bus. Sometimes there are cables that connect to external pieces of equipment and additional circuitry that is not part of the main computer. These external devices are peripherals, and a failure in the control board can disable the computer; a failure in other components will generally disable only the peripheral.

It is important to have a clear understanding of the information that is transmitted over the major cables in your computer. Cables and connectors are a major area of trouble in computers. Cables pull out, vibration loosens connectors, wires are bent, causing breaks in the wire itself, and wires often stick up out of boards, causing them to be cut when the board is inserted above them. Try to have a conceptual understanding of how a disconnected or shorted cable will affect the performance of your machine.

In order to effectively troubleshoot your computer, you must have a conceptual understanding of what each of these functional units does and how they interact. There are only six basic units, and with a little orientation you can gain a sufficient understanding to enable effective troubleshooting.

TROUBLESHOOTING

In order to isolate a computer failure, you must be able to analyze the symptoms of the malfunction and localize the trouble to a specific functional unit (see Table 3). Analyzing the malfunction requires that you understand the failure and know what else in the system works and does not work.

Table 3
Basic Troubleshooting

1. Analyze the symptoms of the failure
a. Is it reliable?
b. Is it due to a bad disk?
c. Is the computer too hot?
d. Is it an operator error?
e. Is everything powered on?
f. Are all cables connected?
g. What else works and does not work?
2. Localize the trouble to a functional unit
a. Methodically gather evidence
b. Find the malfunctioning unit
c. Verify it is the only malfunctioning unit

Be sure that you understand the failure before you try to repair it. Is the failure reliable; does it happen the same way every time? Check to see if it still fails if you boot (start up) from a different disk. If the computer is hot, does it still fail after it cools down? Could the problem be due to an operator failure? Operators sometimes inadvertently push buttons changing the operation of their device (e.g., changing baud rate on a terminal). If you have multiple pieces of equipment to turn on individually, are you sure that all pieces of equipment are on? Verify that all the cables are properly connected.

Determine what else works and does not work. It is important at this point to use all of your senses. If you are trying to boot your computer and you see nothing on the terminal screen, can you hear the floppy disk head moving or can you see any lights blinking? Sensing such events indicates that some of the devices are operating. If you can smell anything unusual, you probably have some type of power supply problem. If you place your hand on any of the modules and they feel particularly warm, you may be having cooling problems. Try to examine the symptoms to determine what modules are functioning. If your terminal can examine and deposit information to and from memory, the terminal, the serial I/O port, the computer bus, the power supply, and the CPU are probably all functioning.

After symptom analysis, you must perform tests to localize the trouble to a given functional unit. Your purpose is to find the functional unit that is the cause of the malfunction and to verify that it is the only unit that is malfunctioning. Troubleshooting is a problem solving enterprise. It is important not to be overwhelmed by a computer that appears to have violated your scientific integrity by failing when you were not expecting it. I have found that there is a strong propensity to look at the computer in a state of self-pity, mild panic, and disgust. Remember that the failure is probably limited to one of only eight functional units. Remember also that you get as many guesses as you want to figure out which unit is failing. Do not attack your computer

in a state of disgust or of fear. Methodically gather evidence to allow you to determine whether each unit is functioning properly or not. The following provides an illustrated sequence of steps that will allow you to isolate frequently occurring computer failures.

Prepare your work site for troubleshooting (see Table 4). Remove all food and liquids from the work area. Clear a clean work place on which you can place computer boards. Be sure that the area is free of any metal filings or wires (e.g., leftover wires from a previous project), is relatively free of dust, and is free of grease and oil. Make sure you have enough light to clearly see everything inside the computer. Move the computer if necessary to position it for easy handling of components. Clear the work place of everyone who is not there to help. Make arrangements so that you are not interrupted. Troubleshooting is problem solving and demands extreme concentration.

Before touching any computer components, remind yourself of the importance of carefully handling all computer components (see Table 5). When you pull out or plug in a board, make sure that you do not bend the board. When plugging in a board, be sure that it is properly seated in the socket before you exert pressure. (Note: It is not unusual to have to exert 15 lb of pressure to push in a computer board.) When you pull out a board, check all connectors to be sure they have not loosened, examine all chips and sockets to verify that they have not been pulled loose, and examine the board for any broken leads from components that stick up relatively high on the board. When using a probe for measuring voltage, be very careful not to short any pins neighboring the pin you are checking. Be sure you turn off the unit before you insert or remove any of the computer modules. Remove all rings and watches so you do not inadvertently short something. Since static discharges can damage certain chips, ground yourself (by touching a ground wire or computer chassis) before touching the board. While trying to repair one problem recently, I sat down on a plastic chair, which generated a static-electric build up. When I touched the board, a static discharge caused a new failure.

Table 4
Prepare the Work Site

1. Remove food and liquids from the area
2. Prepare clean work area free of metal, dust and grease
3. Bring in enough light to see clearly inside the computer
4. Move computer for easy handling of components
5. Move or restrain cables to prevent bending or shorting boards
6. Clear the workspace and make sure you are not interrupted

Table 5
Handle Components With Care

1.	Do not bend boards when inserting or removing
2.	Be sure the board is well seated before pressing into socket
3.	Check connectors whenever you move a board
4.	Verify cards held in card guides and that no drooping cards are shorting to the card below
5.	Avoid shorting pins while making voltage measurements
6.	Turn off the unit before you insert or remove any modules
7.	Remove all rings and watches to prevent inadvertent shorts
8.	Remove static electricity generators and ground yourself before touching boards

TRUBLESHOOTING A DEAD SYSTEM

What do you do when you cannot boot (start) your computer system at all? (See Table 6.) First, make sure that all of the equipment is turned on properly and all optional switches are in their proper locations. Examine all indicator lights to verify that they are in their normal states.

The first isolation tests should determine whether the problem is in the computer system, the terminal, or the cables. Check the terminal by switching it to local mode. When you type, does information appear on the screen? If so, the terminal is functioning properly. If not, the problem is in the terminal. Cables are a major source of problems between microcomputers and terminals. Most video terminals use standard RS-232 EIA connectors. If you pull the cable out of the computer and jumper the wires that connect Pins 2 and 3 of your terminal's EIA connector, typing on the terminal in remote should display information on the terminal. If it does, the problem is most likely not in the cable; if not, the cable is at fault. There is a clock both in the computer and in the terminal that determines the rate at which the two devices communicate information to each other. Should these clocks be operating at different speeds, then the two devices will not communicate properly. Usually, if the speed is wrong, when the computer transmits to the terminal or vice versa, some data get through, but the data are incorrect. If the terminal is typing strange characters for the characters you type into the computer, the transmit speed or baud rate is probably wrong. If you suspect this to be the problem, verify that all the switches that determine the baud rate (speed) on the computer serial I/O port and the computer terminal match. Try connecting your terminal to another computer that you know is working and that uses the same speed rate as the faulty computer. With an oscilloscope, it is very easy to check the speed of your terminal by examining the data output line while redundantly typing a given character. However, if you can type in local mode and the problem is not in

the cable, in all likelihood the problem is in the computer system itself.

The first functional unit to check within the computer system is the power supply. The power supply usually includes a large transformer, some large capacitors, and a small printed circuit board. From the power supply, you can see a series of wires running to the computer bus or backplane (the connectors that the computer boards are connected into). Usually, either the circuit board or the backplane connections are labeled, indicating what the proper voltage should be. A voltmeter is needed to check the voltages. Connect the groundside (black wire) to the ground (GND) or common (COM) wire from the power supply. Set the voltmeter to dc volts for a range greater than the expected voltage. Turn on the computer and check each of the voltages. Be very careful not to short any pins causing one voltage to be shorted to another voltage. This can cause severe damage. The voltage tolerances must be fairly exact. Errors greater than .25 V will cause malfunctions. Voltages that are off by .1 V may cause occasional errors. The voltage output of most power supplies is adjustable. Hence, if the adjustment has moved since it was delivered from the factory, the computer system may be getting the wrong voltage. A small voltage error (e.g., ± 2 V) is probably due to

Table 6
Troubleshooting a Dead System

1.	Verify that all equipment is turned on and all switches set properly
2.	Determine if failure is in terminal, cable or computer: <ol style="list-style-type: none"> Does the terminal operate in local? - No, terminal problem Does the terminal operate in remote with cable signal lines connected at computer end? - No, problem in cable Is terminal typing bad characters? - There may be a baud rate mismatch
3.	Check if power supply voltages are within tolerance <ol style="list-style-type: none"> If not, disconnect supply, check again, and repair if necessary
4.	If you are electronically sophisticated, check CPU for signs of life with oscilloscope
5.	Strip down the bus to minimal configuration
6.	If you can examine and modify memory on stripped bus, problem is most likely on one of the removed modules <ol style="list-style-type: none"> Insert remaining modules individually until failure Run diagnostics on any suspicious modules If module tests bad, test it on known good system
7.	If stripped bus does not operate, swap boards <ol style="list-style-type: none"> Verify all switches and straps, and visually inspect boards Move from bad to good system If bad boards found, move from good to bad system to verify
8.	If multiple boards appear to be failing, get expert help

improper adjustment of the voltage output of the power supply. If there is 0 voltage on any of the outputs, either the supply circuit itself has failed or possibly a fuse in that circuit has opened. Note that many manufacturers put fuses on individual circuit boards within the power supply. Hence it is important to visually inspect for those fuses and to check them individually. The fuses can be checked by using the ohm scale on the voltmeter (see the voltmeter instruction booklet). If power supply voltages are within range, then you can be reasonably safe putting known good modules onto the backplane without damaging them. If the power supply is far out of range (e.g., 10 V when you expected 5 V), it could have caused extensive damage to multiple modules, and hence be suspicious of malfunctions in any of the units that were plugged into that computer bus. In order to verify that the failure is in the power supply, disconnect the wires between the power supply and the computer bus, verify that all circuit breakers and fuses are not open, and check the voltages again. If the resulting power supply voltages are incorrect, the fault is most likely in the power supply. Then make arrangements for its repair. If the power supply uses sense lines, these sense lines must be connected in order to test the power supply voltages. If you have an oscilloscope available, it is useful to check for ac noise on the power supply. If at any point your voltage is not within the tolerance range due to ac noise, this will cause failures.

An oscilloscope can be used to quickly check for any signs of life. Is the computer clock working? Are any of the data or address lines changing? If there is no sign of life, the problem is either on the CPU board or something on the bus is keeping the CPU from operating normally. To isolate the problem to the CPU card, strip down the bus to only the CPU card. If there are still no signs of life, assume that the problem is in the CPU card and perform further testing through substitution. If you do not feel comfortable with a scope, skip this step.

The next step is stripping down the computer bus to minimal configuration (see Table 7). Unless you are experienced at troubleshooting, do not strip down the bus alone. Have someone else, preferably someone who has worked with electronic equipment, check every step you make. For example, if your department has an electronics technician, have that person check everything you do to be sure you have not made any mistakes. I would not recommend stripping down the bus unless you have someone there who has done it before or who can tell you what to do over the phone. Make or verify a diagram of the placement of all computer modules on the computer bus. Label each board with its slot position, so that later you can return the modules to their proper positions. Turn off the computer. Remove all boards that are not critical to performing the simplest diagnostic (all boards except the CPU, memory, bootstrap, and serial I/O port control boards). Rearrange the boards if necessary, and be careful about special slots. For example, in the Digital Equipment Corporation

Table 7
Stripping Down the Bus

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1.	Have someone there who has seen it done before
2.	Have someone else there to verify each step
3.	Make or verify a diagram of placement of computer modules on the bus
4.	Turn off the computer
5.	Remove all boards except CPU, memory, bootstrap, serial I/O port
6.	Rearrange boards if necessary
	a. Be watchful of reserved slots, jumper cards, and terminators
-

(DEC) LSI Q bus there are no special slots, but there can be no blank spaces between the first board and the last board on the bus. Hence, if you remove a series of boards, you may have to rearrange the existing boards so there are no blank slots and place the terminator board at the end of the current series of boards. Note that buses with multiple rows of boards are connected in different patterns. Check your manufacturer's manual to determine what the stripped down arrangement would have to be. Some computer buses use jumper cards (e.g., the DEC Unibus), so that whenever you remove a board, you must place a jumper card to connect critical pins across the connector. In addition, on some buses certain slots are reserved. Only certain boards may be allowed in certain slots. Check your manufacturer's documentation to verify that you can place boards in the given slots.

After the bus is stripped down to its basic components, turn on the computer and try to execute simple diagnostic tests (see Table 6, Point 6). Can you now get anything out on your terminal? Can you examine the contents of memory locations and change those contents? If so, then the problem is most likely on one of the boards you have removed. A failure on one of those boards is probably blocking the rest of the units on the bus from properly using the bus. Insert each of the remaining cards individually to see if you can still operate your basic diagnostic tests. If the test fails when only one of the modules is inserted, the problem is most likely on that module. If the diagnostics seem to operate with each of the individual modules replaced individually, then return enough modules to the bus so that you can run the manufacturer's diagnostic programs. Load the diagnostics and test each of the pieces of equipment that you have diagnostics for. You must be able to run the CPU diagnostics and the memory diagnostics before you can run any of the other diagnostic programs. Should only one of the diagnostics fail, the problem is most likely limited to that module. When a diagnostic fails, verify that you have tried to use that diagnostic carefully. Try to run the diagnostic several times before assuming that it is the module and not the operator that is at fault. If you have located a supposedly bad module, remove that module to a known function-

ally operating system to see if that system fails (see below).

You may find that after you have stripped down the bus, the computer works. Then each of the individual modules works. And when you put it all together again, the computer works. This is not unusual. The problem was most likely in dirty printed circuit card edge connectors or a loose cable. Clean all edge connector fingers, check all connectors, and be thankful.

If you strip down the bus to its minimal configuration and you can still not run the simplest diagnostic, the problem is most likely on one of the boards on the bus. Remove each of the boards and check them visually. Check all straps (connections), wired options on the board and small switches (DIP switches), to verify that all of these are in their proper states. If you have made previous lists of the positions of each of the switches when the system was operating, this check can be done very quickly. Visually examine all chips for components that are plugged into sockets on the board, verifying that they are all properly seated in their sockets. Check all cables to verify that they are tightly connected and that they look good (e.g., no stripped insulation). Visually examine for the presence of any metal on the board. Sometimes when manufacturers wire wrap options on the board, small bits of metal fall onto the board. After the warranty period, these metal pieces fall off and cause shorts on the board or in the data bus. (I once found a paper clip in my computer bus.) Examine the gold fingers on the edge connectors of the board. These should be clean and should not have spots at which the gold has worn through. If the fingers are not clean, it is best to clean them with a contact cleaner. After checking all of these items, replace the critical boards back onto the computer bus, and perform the simple diagnostic tests again.

Table 8
Swapping Boards With Two Systems

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1. Check all options and straps
 2. Visually inspect boards
 3. Check cables
 4. Visually search for dust and bits of metal
 5. Check edge connectors
 6. Retry boards in the bad system
 7. If system still fails - begin swapping
 8. Move least complicated boards from bad system to good
 - a. Verify straps and options
 - b. If board works, check next board
 - c. If it doesn't work, recheck straps
 - d. Recheck good system to make sure it works
 - e. Check next board
 9. If single bad board isolated, move good board from good system to bad system to verify problem limited to one board
-

If nothing works at this point, you need to substitute critical component parts in order to determine which unit is failing (see Table 8). It is best to move boards from the malfunctioning system to the good system one at a time. It is safer and more efficient to move boards from the bad system to the good system. This is because bad boards are unlikely to damage other boards, whereas power supplies can damage multiple boards. Assuming you have a working system that you can move boards into, move the least complicated board (e.g., the serial I/O port) from the bad system to the good system. Verify that all of the optional straps and switches are the same on the board from the malfunctioning computer and the board you will be removing from the good unit. If that board works well, your problem is probably limited to one module in the failing computer system. If the module does not work, verify the straps again to verify that the options selected on the two boards are equivalent. Return the original board to the good system and verify that the good system is still working, move the second least complicated module from the bad system to the good system. If the good system now continues to work, the problem is most likely on the first module checked. If the first and second module moved do not work, then you (1) are not performing the substitution properly, (2) have a multiple-board problem, or (3) have a power supply or computer bus problem. If any of the above are true, it is probably time to call in an expert.

After you have isolated the problem to a faulty module, you must repair or replace that module. Visually examine the module carefully under good lighting. Check for any chips pulled out of their sockets, any loose cables, any loose pieces of metal. Verify that all straps or options are properly selected. Shake the board so small metal particles might fall off the board. Clean the edge connectors if they look dirty. If you correct any problems, return the board to the computer to test it. If it still does not work, that module needs to be repaired. Most computer manufacturers and a number of service firms do depot board repair or replacement. For a fixed fee, the board can be sent to the company, which will repair or replace the board in a relatively short time (e.g., 72 h).

You cannot do component isolation within computer boards unless you have a detailed understanding of electronics, appropriate schematics, and the required test equipment. Component isolation is not something that the typical psychologist can or should do. Leave this job to the experts. Component repair requires specialized technical training and considerable experience (see Lenk, 1971; Maguire, 1973). There are also self-study books covering basic computer electronics that can enable you to conceptualize how each of the components within a circuit operates (e.g., Texas Instruments, Inc., 1978a, 1978b). It is important to note that board-level repair is too complex for most computer field service personnel. Hence, I recommend most psychologists not try it.

With a little effort, however, a psychologist without detailed knowledge of electronics can considerably reduce the number of maintenance and repair problems. By spending a day learning about troubleshooting, you can considerably reduce maintenance problems, maintenance bills, and your feelings of helplessness when the computer malfunctions. Do not expect to be able to find all of the problems. However, by understanding basic troubleshooting procedures and the functional components that make up the computer, you can probably isolate over 90% of the failures that will occur. If you must use a computer in your research program, learning how to bring the computer back to life can be time well spent.

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NOTES

1. Plans and parts lists for a simple thermal cutoff device can be obtained from the author.

2. At present, there appears to be no compelling empirical evidence that would enable one to say turning on/off the computer is equivalent to operating the computer for a certain number of hours. The experienced computer maintenance and system managers on my campus recommend minimizing power up/downs. In my laboratory, I power down mechanical systems (e.g., disk drives) when not in use for 1 h or more but power down the CPU only during week-long vacation periods, when the system overheats, and for repair and modification of components.