The Compass DeRose Guide to Ethernet computer network wiring
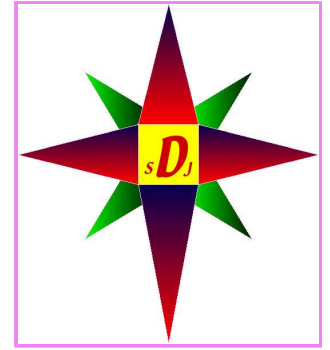
CAT3, CAT-3, CAT5, CAT-5, CAT-5e, 10base-T, 100base-T

This document was written by Steven J. DeRose around 1998, and was last updated May 9, 2003.

This page should give you all the information you need to be able to install a small CAT5 or CAT5e wired computer network, such as in your home or a small office. I wrote this page to make network wiring easier after I spent too much time digging up the pieces individually in order to wire my house. For more detail, a few relevant books are listed near the end.

If you just need pinouts, they're in a special section.

Basic types of networks

There are several basic types of networks appropriate for connecting computers, printers, and other devices in a small area such as a home or small office building:

- **Twisted-pair Ethernets**: These run on wire that looks much like telephone wire, and are appropriate for any number of nodes within a radius of 100 meters (or somewhat larger if you add devices called "routers"). This web site tells you how to set up twisted pair Ethernets.

- **Coax-cable Ethernets**: These are very much like twisted-pair Ethernets, but use wire that is more like cable-TV cable (but the cables are *not* interchangeable). These have a longer range, about 300 meters, but are much harder to install.

- **Fiber-optic networks**: Fiber supports very high data rates, and longer distances, but is more expensive and much touchier to work with. I do not recommend trying fiber without special training.

- **Wireless networks**: These are increasingly popular, and can't be beat for convenience. Within a radius of about 150 feet no wires are needed. On the other hand, range and reliability vary with wall materials,

humidity, etc; and security is relatively poor. There are several variations, IEEE 802.11a (rare), 802.11b (very common), and 802.11g (new, but backward compatible with 802.11b). You need a special card for each machine, for about $80, and a base station or "wireless access point" for about $250.

For the typical home or small office, twisted pair is the best choice for reliability, speed, and security, while wireless is the best choice for convenience. Wireless will likely be cheaper than putting connections ("drops") in every room, but more expensive than just a few drops, such as in an office and bedroom. If you have a laptop, wireless is handy because you can use it in many airports, hotels, and even Starbucks, via the TMobile service.

Converters exist to connect any of these network types to the others. The most common cases are connecting two distant twisted-pairs nets via a cable or fiber backbone; and adding a wireless access point to an existing wired network (the latter is pretty trivial -- buy the access point box, plug it in, and make a few settings -- I may add more on this sometime).

Basic networking requirements

Twisted pair Ethernets carry from 10 million bits (not bytes) per second (10Mbps) to 1 billion (1000Mbps or 1Gbps). For home use 10Mbps is typically plenty, especially because the connection out to the Internet is generally far slower than that (even a "T-1" business line is only 1.5Mbps). The wiring to support 10Mbps is called "10base-t", or CAT-3. To get a higher rate, each part of the path involved must support it: the type of wire and connectors, workmanship of wiring, Ethernet card, and hub. CAT-5 parts and workmanship can support 100Mbps or "100base-t". CAT-5e or CAT-6 parts and workmanship can support 1Gbps.

Fortunately, high-speed networks also work fine at lower speeds: If you set up a CAT-5 network and plug in a machine whose Ethernet card only supports 10MBps, that's generally ok. *Most* new hubs and cards can switch automatically between 10 and 100 Mbps as needed.

Whether doing your own work or not, top-rated wire costs very little extra. The bulk of the cost or effort is in pulling wiring into place through walls. Because of this it almost never makes sense to use less that CAT5 or CAT5e wire. Other parts such as sockets cost a little more as you go up the CAT scale, perhaps a couple dollars total per connection. If you want to save money, save on connectors not wire: that way you can upgrade later without digging around in the walls again.

A twisted-pair network *must* be arranged in a "star". That is, every device must have a separate wire back to a central point, where a device called a "hub" (under $50) passes data from one wire to another. You cannot just bring the wires from multiple devices together and have it work -- unless you have only two devices total, and a special "crossover" cable (see below).

New phone wiring (say, from the 1990s on), is usually 3-pair (that is, 6-conductor) wire rated "CAT3", with the blue/blue-white pair used for the primary phone line. The two other pairs should handle Ethernet up to 10M bits/second. You can try wiring the other 2 pairs to an Ethernet connector as shown below and see, but it's unlikely to work. This is because house phone wiring is seldom set up as a star. Instead, builders usually hop from each room to the next with one long wire (to get them to do a star, order "home runs" for all sockets). Typically you'll have to install lots of new wire instead.

I have never seen CAT5 wire that is rated for outdoor or underground use. Thus, if you need to connect 2 separate buildings, you should bury a conduit and run the wire through it, rather than burying the wire directly. This will also save a lot of time when you want to make some kind of change later, such as adding more wires, upgrading, etc. Same thing for going up an outside wall to get between different floors. Never have more than 180 degrees of bends without an access point (such as a "pull elbow"), or you'll have a very hard time pulling wire through at all.

Hiring wiring done may cost $100 to $350 per connection. If you pay to have it done, make sure your contract requires the contractor to test and certify every line for the quality you are buying. Not all electricians, carpenters, phone installers, or handypeople know how to do it right. If you're considering a big job, you may want to consider my notes on how to save on drops.

Words of caution

This page, all by itself, should give you enough basic information to get going. However, don't try this if you're not fairly mechanical, or adept at similar tasks. CAT5 wiring is touchy, and it's easy to make bad connections (or worse, wiring that almost or usually works, but fails under stress such as high data rates). Diagnosing such problems can be hard, even with expensive test equipment.

I don't discuss here how to drill and fish wires through walls, how to mount a box, etc. This is all the same as for any other kind of wiring, and you can learn it from tons of books available in your local book or hardware store, Amazon, etc. But you'll do more of it than for just adding a new electrical outlet, since for network cabling you can't just shortcut to the nearest one. On the other hand, you can use "low voltage" boxes that have no back, which might be a little easier.

Warning: Wiring of any kind is potentially dangerous. Apart from the usual dangers of tools like wire cutters and drills, you could encounter electrical wires, pipes, etc. when drilling through walls, or encounter other potentially dangerous conditions. If you aren't sure you know what you're doing, don't take the risk, just hire a professional (that will also surely be less stressful, because *something* unexpected always goes wrong!). I'm not responsible if you get hurt.

Also, although I've tried hard to get this all right, it is entirely possible I've made mistakes here, or that your circumstances may require special materials or procedures beyond the simple cases I describe. Again, I can't predict or evaluate that, and it is your responsibility to ensure that any work you do is safe and legal. I am not a professional sysadmin, electrician, network-builder, etc.; I do software, develop markup language standards (like XML), study linguistics, and do other things involving information not electrons. This page is here to be helpful, but you use it at your own risk.

Guide to what follows

Since you're still reading, here's what's included in the rest of this document:

- What you will need

- My favorite sources for tools and materials

- [How to do the wiring itself](#)

- [Pinout diagram and color codes](#)

- [Relationship to phone wiring](#)

- [Some notes on hooking your net to a DSL line](#)

What you will need

Materials

If you're doing CAT5 or higher wiring, make sure of the rating for every part you use. The various grades of parts look about the same, but aren't. Any given branch of your network will only work at the speed of the worst-rated part it contains.

- The wire. Just buy a 1000-foot reel and do a random act of kindness by giving someone the leftover or helping them wire their house. For a very small installation (say, under 4 drops), you could just buy patch cables with plugs already attached. This can work, but has big drawbacks: it costs much more; patch cables are usually made with stranded wire that has worse performance; and it can be a real pain getting wires through holes with their plugs intact. Still, for very simple installations you could just run patch cables, plug in, and be done with it (make sure they can't be stepped on).

- Appropriately rated 'RJ45' sockets for the equipment end of your wires

- Appropriately rated modular plugs for the hub end of your wires

- An Ethernet hub to plug all those plugs into

Don't forget Ethernet cards for your devices (most new machines have them off-the-shelf), and short Ethernet cables to go from outlets to devices.

For big projects, you may want a CAT5 "patch panel" at the hub end where all your wires come together. I wouldn't bother, since (a) wiring a plug is not much harder than wiring a panel; (b) you would then need to buy patch cables to go from the panel to the hub; (c) the patch cables are a lower-performance item; and (d) this method adds parts and connections, and so lowers reliability. If you do want to do it this way, you'll need a few extra tools and techniques I'm not going into here other than brief mention under [pinouts](#).

Very similar materials and techniques also apply to phone wiring, so you can use this Guide to help with that, too. Phone wiring can be a lot sloppier and still work, and CAT3 wire is just fine for it (though if you bought a roll of CAT5 or better, you might as well use it for everything). If (like many) you are tempted to use the "extra" wire in Ethernet cable for telephone lines, see [Relation to phone wiring](#) below. It often works fine, but there are no guarantees, and it complicates managing the wires at both ends.

CAT5, CAT5e, and CAT6 wire

Ethernet wire has 8 wires in it, usually solid 24-gauge copper. The wires are divided into 4 pairs, and each pair is twisted tightly together. It may look a lot like any old phone wire, but it's not. Details like the *twists* are what make the stuff work. If you look closely, you'll notice that each of the 4 pairs has a different number of twists per inch -- the exact number is not as critical as the fact that they're *different*. The entire cable is designed to associate the 2 wires in any pair very closely, and to dissociate them from the other pairs.

So make sure the cable says CAT5 or whatever grade you intend to use (see labeling). If it doesn't say it, the manufacturer didn't do it. CAT3 wire can handle a 10MB net, but that just means it's already obsolete. It's not enough cheaper to justify using it. I'd go for CAT6 at this time; definitely no less than CAT5. Using *higher* quality cable than you technically need may also buy you a little leeway to make small wire-handling errors and still succeed.

Cable comes shielded ("STP") and unshielded ("UTP", shown at right). Unshielded is fine for most applications. Shielded is harder to work with, since you need to ground the shield at each end, which means you need metal connectors ($1.75) instead of plastic connectors ($.30), etc.

The outer casing comes in normal (vinyl, PVC, etc.) which is just fine for most residential use; or the much more expensive "plenum" kind (teflon?) which is needed if you're running the wire in heating system plenums or certain commercial settings; check your local fire and electrical codes to be sure. Non-plenum CAT5 wire goes for about $80 per reel; CAT6 for about $120. Many hardware stores stock it at ok prices.

There are bundled cables that include some combination of Ethernet, cable TV, and phone wires, for example from SmartHome. The plus is that it's significantly easier to pull everything at once: less tangling, fewer boxes and spools to manage, etc. The downsides would include price (from $600 to $1400 per 1000 feet, depending mostly on whether fiber optic cables are added), lower flexibility (physical and in terms of your cable planning), and the fact that you'd have to be *very* well organized at the place where all the cables come together to hook to Ethernet hubs, video splitters, phone patch panels, and so on (they'll sell you nice "distribution panels" to help with this).
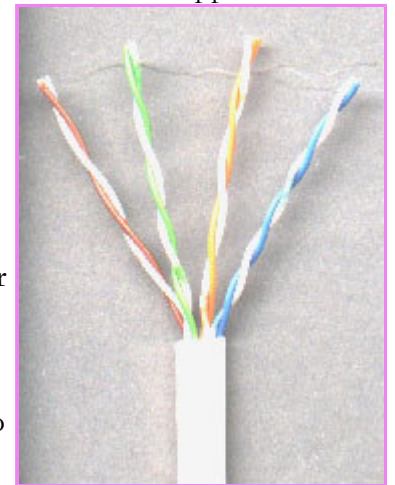
> **Geek note**: One site I found gives this information on the electrical characteristics of CAT5 cable: Impedance: 100 Ohms, Frequency rating: 100MHz, Capacitance 13.5 to 17 picofarads per foot, Attenuation (low is good) 23 to 67dB per 1000 feet, Crosstalk (low is good) 32 to 51 dB at 1000 feet. I have no information on the signal characteristics used, other than that we're talking maybe 2.5 volts. Cat5E and CAT6 wire have higher frequency rating and probably improve on all the other characteristics too.
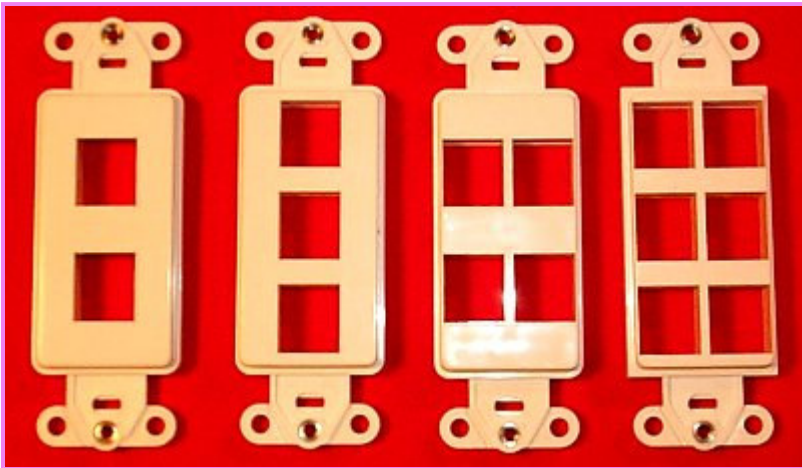
CAT5, CAT5e, and CAT6 Sockets

You can get sockets in a variety of forms (much like phone sockets), even at Radio Shack and Home Depot. Surface-mount blocks cost about $6. If you're using in-wall boxes, you can get CAT5 sockets on whole wall plates for maybe $4. I much prefer modular plates and inserts as shown at right, because you can use them for Ethernet, phone, video, audio, etc. at the same time.

Modular plates are about $1.50 and you can get them with 1, 2, 3, 4, or 6 holes (also double-width plates with 12 holes). A wide variety of "inserts" are available: CAT6 ones are about $4.50, CAT5 about $4 (see picture); phone ones $3, and so on. Get plates with more holes than you need now, and buy a lot of extra blank inserts ($0.20 or so) to fill extra holes until you discover what you need them for (for audio, video, security, etc.). You can buy inserts with a wide variety of connectors already mounted, or just drill holes in blanks and mount your own connecters. For example, behind my stereo I have speaker connections on a plate with off-the-shelf binding posts screwed into blank modular inserts.

Note: There are several manufacturers of modular plates and inserts, and inserts from one may not perfectly fit plates from another. They are usually close enough to work with a little persuasion. Leviton makes a nice line, called "Quickport" (see their site under "Data Transmission"), including my new favorite: "insert plates" that hold the inserts, but then can be covered with any decorative cover plate (GFI-shaped opening), to match your decor (see below). One snag with these is that the 4- and 6-hole plates have the holes very close to each other horizontally -- only Leviton's RJ45 inserts seem to be narrow enough to fit side-by-side. No such problem with plates having 3 or fewer holes. The other problem is that nobody seems to stock them except HomeTech, which has them here.

CAT5, CAT5e, and CAT6 modular plugs

These look just like phone plugs, only wider. (Make sure you get the right crimping tool for whatever plugs you get. Some manufacturers make slightly different plugs for solid vs. stranded wire, and for shielded vs. unshielded. As far as I can tell, they all work fine, and I haven't been able to determine if there's any different between CAT5, 5e, and 6 plugs. Plugs are cheap, about $0.20.

If you want to be fancy, you can buy little rubber "boots" to cover where the wires go into the plugs, in various colors for about $0.30. I seldom bother, though they do nicely prevent breaking off the little plastic latch. The latches do tend to catch on everything in sight otherwise, so if you will be moving cables around much, the boots are worth it.
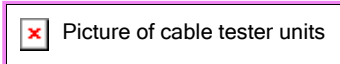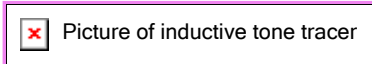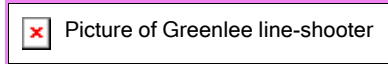
A hub to plug everything into

For simple nets you won't need a filtering bridge or router, just a plain unfiltering hub (though if you've got a DSL

or cable modem connection, you may want one as a firewall). In large nets routers are crucial so that heavy internal traffic in one group doesn't slow down people in other groups. Hubs can be added most anywhere, and are a great way to save on extra wiring.

Hubs are available cheaply from most any computer mail-order house, or a good local shop. Get more ports than you need now. Hubs can be 10Megabit per second, or 100, or able to auto-switch between the two; I use a 10MB, 8-port hub I got for under $50; probably about $15 now); 16-port 10/100 speed hubs are under $100. Routers have dropped greatly in price; they can provide load-balancing and firewall features that hubs don't. I've had good experiences with a LinkSys router/firewall box.

Tools

A friend (Richard Ristow) once gave me a bit of advice on tool-buying that I recommend to you: "Buy the cheapest tool that is *clearly better* than what you need." For this work you'll need:

- A modular plug crimping tool. Phone ones won't do it.

- A cable tester. Don't skip this. I use the Progressive Electronics 468T and the matching receiver; the newer Test-Um TP500 looks like a good deal at $80. Wire an Ethernet plug to some alligator clips and you can use the tester for lots of other things too (but don't try it on live power circuits!).

  Picture of cable tester units

- An inductive tone tracer like the Test-Um TT100 (about $50) is also a really good investment: you clip the tester on one end of a wire, and the tracer lets you follow the wire even hidden behind walls, or obscured in bundles.

  Picture of inductive tone tracer

- Cable-labelling tape. 3M's Write-On Tape System is nice though a little pricey at $23.50. It has the advantage that half of each label is clear, so as you wrap it onto the wire, the clear part covers and protects the written-on part underneath.

- A punchdown tool (probably comes free with the sockets).

- Typical stuff like screwdrivers, wire cutters, pliers, sledgehammers, etc.

- If you're running wires between floors, try the very long, flexible drill bits, such as from Ideal Industries. They're perfect for going through the hole you make to put in a box, and then bending to drill straight through the sole plate. They also have a hole in the tip so you can tie on a wire and pull it back up. You may be able to find similar bits at local hardware outlets, but be sure to get the auger type (with a screw point that pulls the bit ahead) -- I've found the others almost useless, but with my first auger-tipped one it went so fast I had drilled about 8" down into a vertical stud *below* the sole plate before I realized there was a problem (lucky me to pick exactly that spot to drill).

- If you're extravagant about tools, and likely to run lots of wire above suspended ceilings or through crawl-spaces, Greenlee makes a great toy I bought that you'll want too. It's a dart gun with a fly-casting reel: you shoot the dart and it carries a line with it; attach the wire to the end and reel the dart back. It has a mounting for a flashlight on top, but you really

  Picture of Greenlee line-shooter

should use a laser pointer and quote Arnold Schwarzenegger.

- Safety glasses, dust mask, gloves, and other safety equipment as appropriate. Easy to skip; I did once and ended up with a dozen trips to the eye doctor.

- Oh, one last detail: if you're using a typical wooden folding ladder, take a minute to tighten all the wires going across under the steps. It will make the ladder a lot safer and steadier.

My favorite sources for tools and materials

I have no relationship to these companies, except as a satisfied customer.

- Altex Electronics. 11342 IH-35 North, San Antonio TX 78233-5792. Phone 800-531-5369. Carries a huge selection of cable and parts, and some tools, with excellent prices and service.

- Jensen Tools. 7815 S. 46th St., Phoenix AZ 85044-5399. Phone 800-426-1194. Carries individual tools and well-organized kits, plus some materials. Ask for their "Communications Products Resource Guide".

- MilesTek. 1506 Interstate 35W, Denton TX 76207-2402. Phone 800-524-7444. Carries a wide variety of cabling equipment and parts, for data, telephone, audio, video, etc. Catalog available from the website. One item I've only found here is a punch-down block designed for distributing a small number of lines to many extensions each, instead of the usual setup for many lines to one extension each (item 50-44032).

- Those in the DC area should check out Capitol Cabling and Technology at 7905 Airpark Road, Gaithersburg, MD 20879, phone 1-800-899-9059. Excellent selection and service, and astounding cable prices. They have a website, but apparently no online sales.

Radio Shack and Home Depot have begun to carry a decent selection of basic parts as well.

How to do the wiring itself

First pick a location for your hub, preferably centered to keep cable runs shorter. A basement wall not too close to your electrical panel is fine, or a wall in a closet. If you are doing a lot of connection points, it may save you some wire pulling if you use a separate hub for each floor: weigh your time and the cost of wire, versus the cost of an extra hub(s) and the pain of having to go look at status lights in more than one place when something goes wrong. You probably don't want to put a hub in an attic or crawl space, for lots of reasons.

Map out your wiring plan and decide how many wires go to each place. You may want to pull cable TV, phone, audio, intercom, etc. at the same time. If I'm going to go to much trouble, like fishing wires from basement to attic to wire a second floor, I pull more wires than I need and also leave a string in to pull more later (this also means you drill larger holes). Wire is far cheaper than labor. You may want to install flexible conduit ("blue pipe") if you anticipate adding wires later.

Figure out how you will get a wire(s) from each place you want a connection, to the hub location. This may involve painful vertical runs, slogging through attics full of fiberglass dust (don't skip the mask!), drilling through walls and sole plates, etc. If you've got more than one floor, consider putting plates directly above each other to save on vertical drilling.

> **Warning**: any time you drill between floors you are giving fire (and cold air, and insects,...) a place to get through too. Check whether local fire codes require you to seal such holes in some special way. Even if they don't, you might want to anyway. There is a lot of information on kinds of "fire-stop" caulk, putty, and other materials here, and some caulk and foam products are available here. 3M Fire Barrier Caulk; Dow Corning Fire Stop Sealant; and Standard Oil Fyre Putty are other products usable for such purposes.

Plan wire placements to avoid anything that puts out much of a magnetic field. Stay at least 6" from electrical wires if running parallel to them, and stay well away from flourescent lights.

Make a materials list and then order materials. Plan to leave a couple extra feet at each end of each wire run. Buy at least 10% more of everything (especially wire) than you think you'll need.

Choose whether you are going to use "T568A" or "T568B" wiring. It doesn't matter which, but be consistent throughout your net or you'll confuse yourself later. I've heard varying stories on which is officially "preferred" when; but B seems more common. One site I saw said that US government contracts require use of T568A, though I can't confirm that. Most sockets I've seen are clearly marked for both A and B.

> **Geek note**: These standard wiring arrangements are defined by joint work between the American National Standards Institute (ANSI), the Telecommunications Industry Association (TIA), and the Electronics Industry Alliance (EIA). As far as I can see the specs themselves are not available online, though you can buy them from via TIA here.

Start getting wires in place. Use most anything *but* staples to support long runs and to ensure gradual rather than sharp curves (the key thing is not to crush the wire). Do **not** pull hard on the wire, stomp it, crimp it, bend, fold, spindle, or otherwise mutilate. You can easily make the wire no good for 100MB (not to mention 1GB), even with no visible sign of damage. If you puncture or badly crimp a wire, just replace the run. Start with the longest runs first: that way if you do damage a wire, you have a better chance of cutting out the damage and having enough to be useful for a short run (or two) later. This is also a reason to pull an extra wire along, especially on long or difficult runs.

Don't forget to label each cable at the hub end as soon as you pull it in -- if you wait, you'll probably have a painful sorting job later (for which you would be wise to buy the inductive tone tracer I mentioned earlier). Writing room names is good, but I've recently started using color-coding too, because it's much easier to scan a bunch of wires for bands of color: you don't have to find and read fine print on each wire. Just put 2 bands of color on each wire, the same two colors at both ends (and in the same order, counting from the end you're labeling). Colored vinyl tape works fine; I prefer enamel paint (which now comes in very nice little paint-pens at your local craft store, or from Tamiya). I use the pens to mark the same colors right on the RJ45 sockets, which makes it really easy to find and plug in the wire for any given socket I might want to activate (or deactivate, or test, or troubleshoot, or...).

> **Note**: I strongly recommend marking all crossover cables (see below) with a wide band of red at each end, or using red-jacketed wire; and not using red for anything *but* crossover cables.

Put a socket on the equipment end and a plug on the hub end of each cable as described next. I prefer to finish each cable and test it before going on to the next.

Install **sockets** at the device ends (typically wall-plates all over). Don't strip the wires. Remove only as much outer cover as you need to do the connections (see picture)

> **Tip**: If you're new to this, practice on scrap cable until you can cut the outer insulation without nicking the inner insulation. The best bet is to cut only partway through, and pull to snap the last little layer. Most wire has nylon threads included for strength, you can just trim them off.

Sort the wire ends into the right order for the socket. Untwist each pair *just* enough to get the wires placed neatly into the right slots, and never over 1/2 inch (the twists are so critical that sockets have hidden twists inside -- which is why the wires don't connect to the sockets in the obvious order you might expect). Depending on the particular socket, you may be cutting the wires to slightly different lengths. Don't let copper hang beyond the ends, it can easily bend and short out the cable. Then put a wire into the right slot on the socket. If your sockets (unlike the one shown) have a channel down the middle, with half the punch-down slots on each side, then bring the main cable down the middle, with the wires bending toward the *outside*. Align the wire over the correct slot and punch it down to the bottom of the slot with a punchdown tool. Repeat for the rest of the wires. I find it easiest to punch each wire into its slot with a fingernail, so it holds better while you're trying to align the punch-down tool. Some sockets have a cover that you can put on afterwards; it's not critical, though it's neater and slightly more secure.

Double-check which wire is in which slot (particularly, make sure you're consistent about T568A versus B).
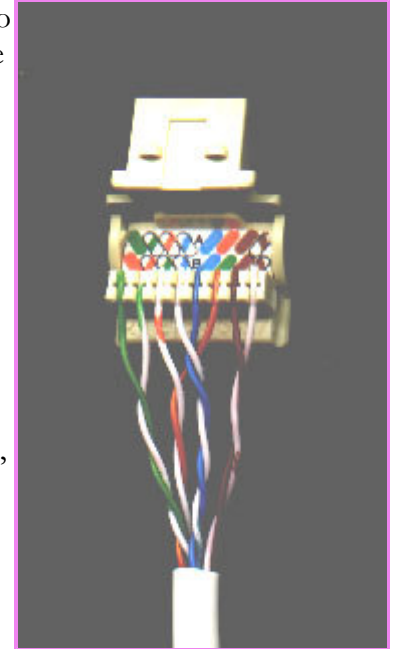
Plugs are a little touchier. Remove the outer cover about 1/2 inch. There will need to be intact outer insulation under the strain relief once the wires are seated. The strain relief is a bit of plastic near the back of the plug that gets crimped down at the same time as the connector pins do (practice on scrap the first time). After removing the outer cover and any hanging nylon threads, sort the wire ends into the right order for the plug. Again be sure to be consistent about whether you're using T568A or B. Untwist each pair *just* enough to get the wire ends all even and in the right order. Never untwist for over 1/2 inch.

I strip a little more than I need, untwist, straighten each wire, then sort the wires into the right order. Squeezing the sorted wires between your fingers, and twisting very slightly from side to side, will help them sit neatly side-by-side. During this process, wires will often creep out of order, so double-check yet again. Then trim them off evenly to the right length. Don't let copper hang beyond the ends. Diagonal cutters are the right tool for this, but the wire is thin enough that swiss army knife scissors will work fine. Right after trimming, use one hand to hold them straight (I keep this hand there from the beginning of the twisting), check the color order again, and use the other hand to slip the plug on. Look into the plug (normally transparent plastic), and check:

1. that the wires are seated under the connector pins;

2. that the wires are still in the right order (the most common problem I have is the pair that is spread wider

apart, and goes to pins 3 and 6; it all-too-easily slips towards the middle);

3. that there is intact outer insulation under the strain relief (if there isn't, you may be able to shift the outer cover along the wire by gripping it gently a foot or two back, and pulling gently toward the end);

4. that you don't have the plug on backwards.

Then put the crimp tool on and squeeze. See the picture at right, **but** note that this picture shows much more stripped than you want, so that you can see the colors clearly.

> **Tip**: Remember to **test** the cable. But understand that the *468T* tester I mentioned above (about $70) does not stress-test cables at high bit rates; it just tests that you've got the connections right. It also can't detect a "split pair": for example if you switched the orange/white with the blue/white wire, which definitely won't work. The Test-Um *TP500 can* also detect split pairs, for around $80. If you're doing only a little of this, it's probably not worth buying a higher end tester than that, so just resign yourself to the possibility of troubleshooting or replacing a wire or two later.
>
> One nice step up in testers is the Psiber Data Systems *Pinger60*, which adds many nice features for about $350. Prices of highly capable testers have dropped a lot -- the Progressive Electronics *PE-K01* does an awful lot for $340. The Fluke *Inline Network Tester* can also identify devices and open ports on your network. The high end is probably the Fluke *DSP-4000* series.
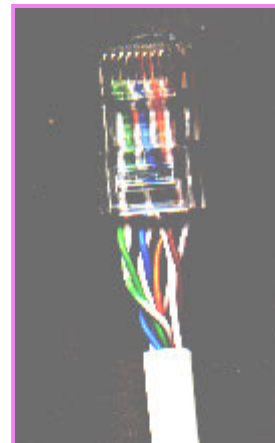
If you're running only 10Mbps on CAT5 wiring, you'll likely be just fine even with a few small mistakes, such as slight kinks, periodic sags, or a little too much untwisting at some ends. But since most Ethernet devices are now 100Mbps it would be a shame to lose 90% of your bandwidth for being sloppy. If you want to go to even higher speeds eventually and are pulling CAT5e or CAT6 wire, be extremely careful about all these rules. Be especially zealous about minimizing the untwisting you do at connections.

Once you have all your cabling done, plug into the hub or switch and go. Then comes the *really* arcane art of setting up your servers, DNS, etc., about which this document will tell you almost nothing. Sorry. There is some information on how to configure some systems here. On Macs, just turn on File Sharing and AppleTalk and you should be fine.

Detail checklist

- Never pull CAT5 or higher wire with more than 25 pounds of force.

- Never step on or otherwise crush, kink, or crimp the wire (don't staple or use tight wire ties or clips).

- Never put a staple, nail, etc. through the wire (you knew that, I'll bet). In fact, don't even allow the cable to *see* pointy objects, or it may get scared and stop working just out of spite.

- Avoid periodic sags; if the cable must sag, vary the intervals. This is especially critical with CAT5e and CAT6, so use j-hooks, loose velcro wire-ties, or other things to manage the wire. In commercial settings the electrical

code probably prohibits just laying the wire on top of a suspended ceiling.

- Never bend CAT5 or higher wire tightly around a corner; make sure it bends gradually, so that a whole circle would be at least 2" across. Watch especially when the wire comes out a drilled hole and turns; don't let knots or kinks happen even temporarily.

- Don't put so many wires in any conduit that it ends up more than 40% full. Never do more than 180 degrees of conduit bends without putting in a "pull elbow" (an elbow with a plate you can open), or your chances of pulling wires through are poor.

- Never untwist the 2 wires in a single pair for more than 1/3-1/2" to make a connection (the twists are critical to cancel out interference between the wires).

- Avoid running the wire parallel to power wiring nearer than 6" away (the longer the wires run parallel, the further away you want them). Also stay well clear of flourescent lights. I ran some of my network wiring right alongside intercom wiring (since I'd pulled them into place together). One day I was using the tone tracer to locate a wire, and heard music through the tone tracer, because it was being played through the intercom system and coupled right across into the Ethernet wires. Didn't seem to hurt anything, but it made me take the rules about parallel runs more seriously.

- No run (hub to device) may be over 100 meters long (if you had a 100-meter long house, you'd be hiring this done anyway!). The limit in practice could be a little higher or a lot lower depending on quality of wire and workmanship.

- Try to run the wire where it is unlikely to be drilled, nailed, kinked, stepped on, or otherwise damaged by later tradespeople, picture-hangers, or anyone else.

  Geek note: The reason for all this hoo-hah about twisting is that CAT5 signals are "balanced": the striped and solid wires in a pair carry the same information negated, so their electromagnetic fields tend to cancel each other out. This makes them interfere less with other pairs. Balanced wiring can also use about half as much power in each wire (since you get two copies of the signal); that reduces the field even further. Untwisting de-couples the pair, and it then radiates an awful lot more energy, thus potentially interfering with other pairs.

Pinouts

CAT5 and higher connectors look just like telephone connectors, only slightly wider, to allow 8 wires instead of 6. You can physically plug a 6-pin plug into an 8-pin socket, but it may damage pins 1 and 8 of the socket (I personally haven't seen that happen). Cat5 and CAT5e Ethernet only use 4 wires, but running 8 will save enormous time the first time a wire fails: you can just switch to another pair.

Since there are extra wires, you can try splitting them out into two sets of 4, and put 2 Ethernet connectors at the end of any wire. There are handy adapters for this, similar to a one-to-two phone line adaptor. If you have trouble finding them, you can make one with a plug and two sockets. The wiring pattern for this is shown here. You can similarly use the other pairs for phone lines, as discussed below.

CAT-5 wire for 2 Ethernet connections/T568A

Powered by ConceptDraw™
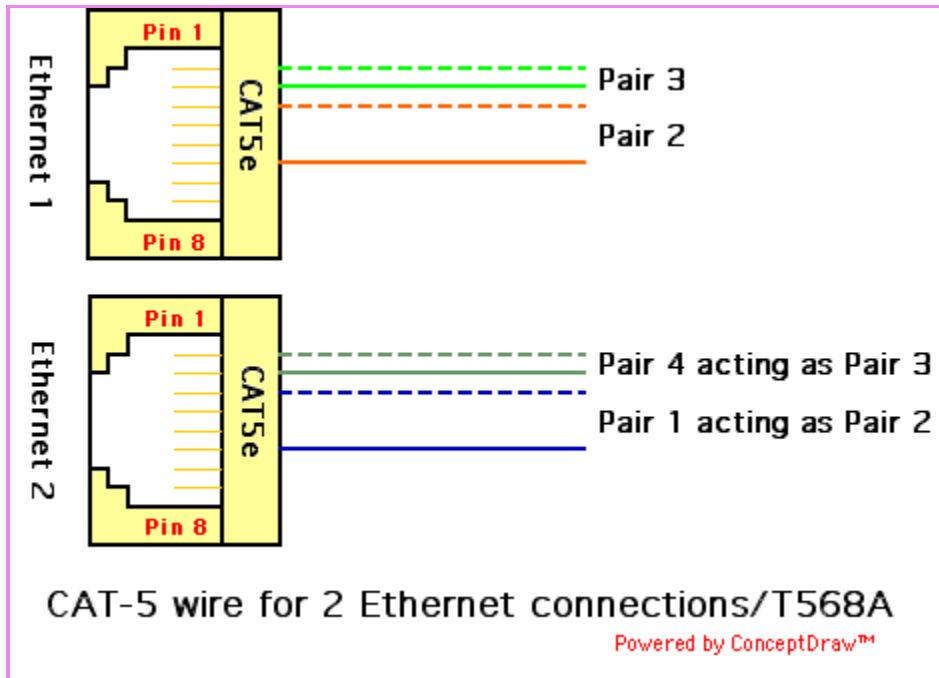
The formal CAT5 definition reserves the extra 4 wires, so neither kind of cable-sharing is technically allowed. However, several people have reported successfully doing it, and none have so far told me it has failed. See Relation to phone wiring, below. CAT6 wiring *does* use all 8 wires, so if you share cable in this way, you won't be able to upgrade to make use of the CAT6 quality -- then again, it may be a while before you really need 1 billion bit per second networks running in your house.

There are two wiring options, called T568A and T568B ("USOC" is for something else and won't work). Use either one but stay consistent. Every individual cable *must* be consistent (both ends the same) or it won't work; all cables in your installation *should* be consistent, or you'll get confused. You can use patch cables of either kind, they'll interoperate just fine. T568A looks like this (will add T568B picture once I get around to drawing it):

T568A pinout
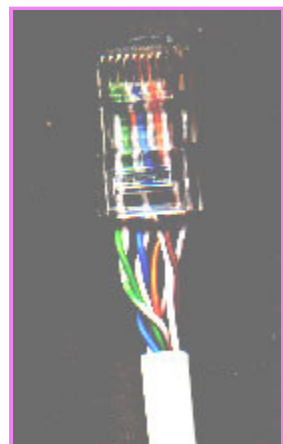
Or, in prose (and for accessibility), from pin 1 to 8 we have green/white, green, orange/white, blue, blue/white, orange, brown/white, brown. See also the wires in an actual plug.
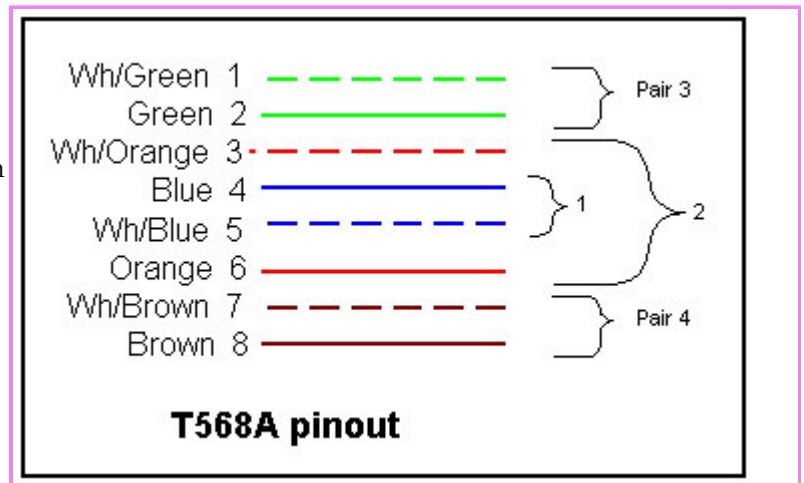
Pair 1 is the blue pair, 2 is orange, 3 is green, and four is brown. So far as I know Ethernet protocols can't photo-detect the insulation color, but don't mess with it anyway. Certain changes will work, but most will not. In particular, if you separate the two wires of a single pair, you're toast.

Only pair 3 (green, on pins 1 and 2), and pair 2 (orange, on pins 3 and 6) are actually used. So you can botch the other pairs and not get in trouble... until you want to use them later.

> **Note**: Old 10-base-t (CAT3) Ethernet specs called the green and orange pairs 1 and 2, apparently expecting you wouldn't have any other pairs around. But pair 1 in CAT5 is the blue pair in the center, which is not used. The blue pair in phone wire is for the primary telephone line, and goes on the same (center) pins. *Not* using it in the Ethernet spec makes it less likely that a telephone pair will get patched to an Ethernet pair (where the ringer voltage would probably cause trouble). It also means you could wire the blue pair to the phone line, and use the very same socket to plug in either phone or Ethernet at different times. However, this seems a bit silly when you could just run the blue pair to an adjacent phone socket instead. Might be a good design idea on laptops, though.

Be very sure you count the pins in the right order. Most connectors are color-coded directly for T568A and T568B; the connections are seldom in the obvious order. If you get things backward they won't work. You cannot swap wires across pairs (for example, to treat green and orange/white as a pair).

To determine where pin 1 is:

- If you're looking into a socket with the latch downward, pin 1 is on your left.

- If you're behind the socket with the latch downward, pin 1 is on the right (though the connection *for* pin 1 may not be).

- If you're looking at the contact end of a plug with the latch down, pin 1 is on the right.

- If you're looking at the wiring end of a plug with the latch down, pin 1 is on the left.

  Hint: Engrave "1" over pin one of the sockets on your tester and the opening on your crimping tool. Also draw your preferred color sequence on a sticker and put it in handy places like the back of the tester.

T568B is identical to T568A except that pairs 2 (orange) and 3 (green) are swapped. Thus the order is: orange/white, orange, green/white, blue, blue/white, green, brown/white, brown. This is very common, and interoperates fine with T568A (as long as each cable is consistent in itself!). To avoid confusion, avoid mixing A and B in a single location.
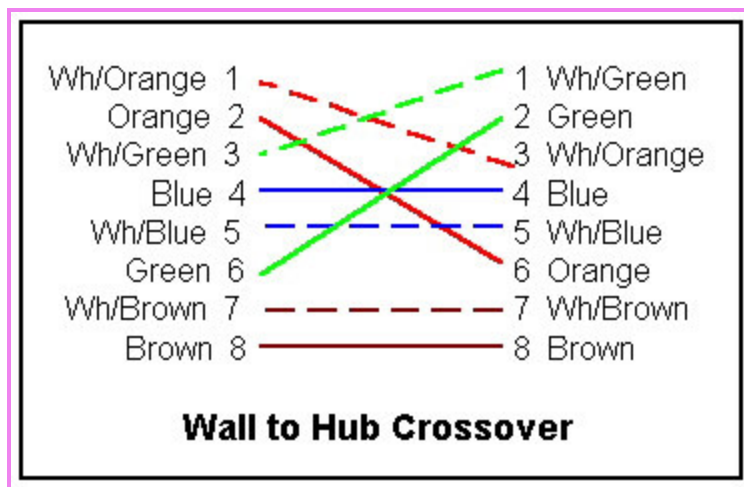
Crossover cables

When two computers communicate, you need the wire from each computer's "transmit" pin to go to the other's "receive" pin: thus the wires must cross over. Otherwise it would be like talking into someone's mouth and listening to their ear. Even so, CAT5 wires do *not* cross over: the same wires go to the same pin numbers at all connectors. This works because hubs all have built-in crossovers.

Using a normal cable to connect two computers together directly (instead of via a hub) involves no crossover, and so it doesn't work. Connecting one hub (or DSL router, etc) to another would involve 2 crossovers, which is

equivalent to no crossovers and also won't work. So these connections need a special "crossover cable".

Some hubs and routers have a special "uplink" port -- this is simply a port without a crossover. Thus, running a regular (non-crossover) cable from that port to a normal (non-uplink) port on another hub, ends up with exactly one crossover (at the other hub), and works fine. A crossover cable would not work there, because it would add a second crossover, effectively undoing the first one.

Crossover cables swap *pairs* 2 and 3 (not the wires within each pair). For CAT5, pairs 1 and 4 go straight through (they're unused anyway). This amounts to one end being wired as T568A and the other as T568B; there's probably some interesting history to that. So a CAT5 crossover cable looks like this:

Wall to Hub Crossover

If (I should say "when") you make one of these, mark it so clearly that you'll never confuse it. I recommend making all crossover cables, and only those, bright red, for example with some red paint or vinyl tape at each end.

For CAT6 you have to swap pairs 1 and 4 also, because CAT6 *does* use all 8 wires (I imagine CAT6 probably sends 2 bits at a time on separate wires, to double the bit-rate).

If you go on the road with a laptop, you'll want a crossover cable along for impromptu 2-machine networking (see my Road Warrior Guide for more on this). But instead of carrying two whole cables, make a short "crossover extension cord": put a little wire from a socket to a plug, wired in crossover fashion. You can use this to convert a regular Ethernet cable into a crossover (you *do* have a long regular Ethernet cable in your laptop bag, don't you?). Altex sells a simple crossover convertor for only $2.95 -- it's the only one I've found that goes male to female; the rest are all female to female, which means you'd have to have another patch cable to get back to male anyway.

> At this point I'll do like Herodotus and slightly break my promise about content, to tell you that for a 2-computer network you should just manually set a distinct IP address for each machine (that is, don't use DHCP). Each machine can address the other by that numeric address. Addresses starting 192.168 are reserved for private local nets, and a typical pair of IP addresses to assign would be 192.168.1.1 and 192.168.1.2.

Punchdown order

If you use a punchdown block, the convention is to punch down the pairs in numeric order. In each pair the striped wire precedes the colored wire. Thus white/blue, blue, white/orange, orange, white/green, green, white/brown, brown (or "BLOG" for short: BLue, Orange, Green (brown is the one left over).

Relation to phone wiring

It is tempting to use the extra pairs in a CAT5 (or even CAT3) wire for phone lines. This violates the CAT5 rules, but generally appears to work fine. When ringing, a phone line is carrying something like 90 volts, which generates a significant e/m field and seems like it could easily cause problems; but several people have written to report success sharing wires this way.

Since the blue pair is for the primary phone line in standard phone wiring, it makes sense to use it that way here too. When attaching wires to sockets, just remove more of the outer shielding, and bend the blue pair over to connect to the center two pins of an RJ-11 phone socket, as shown to the right. If you're doing this with CAT5 or better wire, you'll still have the brown pair left over. you can run it to a second phone jack for a second line, or to the next pair out (pins 2 and 5) of the first phone socket, which I believe is what 2-line phones expect (check their instructions to be sure).
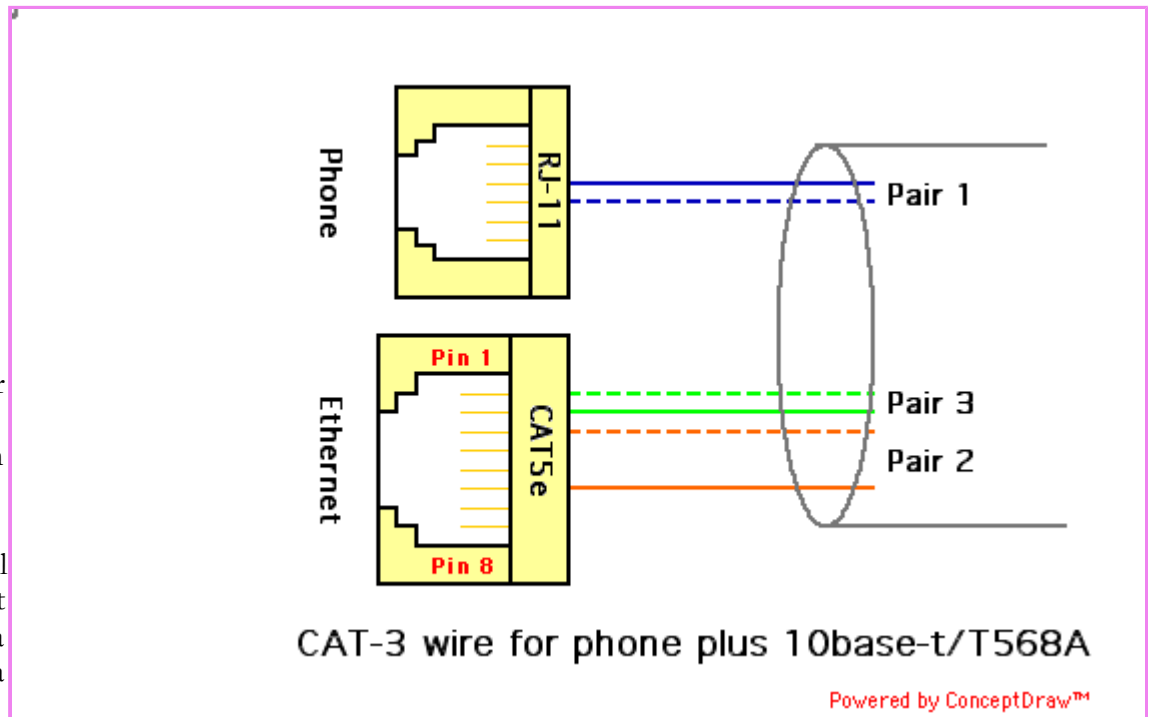
Older phone wiring often uses 4 wires, though an RJ11 jack can hold six and a single phone line needs only 2. Red and green are pair 1, the center 2 pins. Yellow and black are pair 2, the next pins out. The usual mapping to new wire colors uses pairs 1 and 2 likewise. This means than they go on the same pins if you use T568B (which may account for that being so common even though T568A is said to be preferred):

```
Red       Blue
Green     White/blue

Yellow    Orange
Black     White/orange
```

If you have a lot of phone connections in your house, you are best off running them in a "star" or "home run", that is, all running back to one central point. This is not necessary for phone wiring, but it does mean that

- you can pull your phone wires right alongside your Ethernet wires;

- you can share pairs in a single cable (probably -- see above), and

- in a pinch you can use 2 spare pairs in a phone wire to run a 10MB Ethernet connection (or possibly higher speed if your cable is better than typical CAT3 phone wire).

At the central point, for phone wires I greatly prefer using a punch-down block. The problem is that standard blocks are meant to connect a many-wired outgoing cable, to 25 independent phone lines. What you want is to connect a whole bunch of phones to the same 1 (or maybe 2) phone lines. For that you either need an awful lot of jumper wires on a standard block (painful), or a special block. Leviton makes a nice block they call a "Bridged Telephone Distribution module" (model 47603-110). It's just a little circuit card with 10 rows of punch-down connectors like on the back of an Ethernet socket. You punch each phone outlet's wires down into one row, and you're done. I think it's overpriced at about $25-30, but it will save you a lot of work so it's probably worth it. If you have more than 9 phone outlets (one row is for the incoming line) just get 2 such panels. You can put them side-by-side or in completely separate locations (like one in basement and one in attic). You don't need any special panel to mount it to -- just screw it to the wall, using a few washers to keep it from actually *touching* the wall (this is especially important if the wall happens to be metal...).

Connecting to DSL or cable modems

I'm right at the length limit for DSL, so I had to learn a few tricks. For example, the provider's measurement of your distance out will likely be about 2000 feet too high -- merely plugging in the DSL modem may knock 2000 feet off the measurement (thus perhaps bringing you in range). Also, every splice in the line degrades the line -- especially things like wire nuts. It may help to install the DSL modem right where the line enters the house (in which case, be sure you've run a CAT5 or better line from there to your hub). My line was unreliable until they came in and removed 2 gratuitous splices.

Another common problem is "bridge taps" -- places where the wire forks. For example, the phone company may have a 100-pair cable coming down the street, and then fork the whole thing onto two side streets. This is flexible: all 30 houses on one side street can have two lines each if the other side street doesn't want any; or vice versa; or anywhere in between. Removing any bridge taps on your line will make a huge difference in DSL signal quality. Bridge taps can be detected and located to within a few feet, using standard high-end test equipment.

Typical DSL and cable modems connect to the carrier on one side, and have a standard Ethernet connector on the other. Probably the Ethernet is going to be 10 Megabit, since that's still way faster than DSL or cable speeds. The modem is essentially a hub, with translation from Ethernet to DSL built in. Once the modem is in, you should merely have to plug a *crossover cable* from it to your hub, and then have the fun of configuring. You should be able to hang printers and other devices on your internal net. But if you want more than one machine to have Internet access, you may need to do something special:

- If your provider uses fixed IP addresses, you can get an address for each machine from your provider (probably at extra cost).

- If your provider uses dynamically-assigned addresses ("DHCP"), you may be able to just plug in extra devices and they'll work. Or the provider may catch it and either refuse them, or quietly start charging you extra, or

something.

- **Or,** you can get a small router that you hook up as if it were a full-fledged machine. It takes the one IP address you have, and forwards messages back and forth between your other machines and the net. It will probably support DHCP on *your* side, so any machine you plug into your net gets assigned an IP address automatically (routers won't generally pass them through, so your internal traffic shouldn't be visible to your provider or neighbors). The router then uses "IP masquerading" or "Network Address Translation" to rewrite requests from your machines and forward them onto the Internet as if they were its own (and of course to forward the replies back the other way). Some DSL modems have such a router built in.

I use the Linksys Group Broadband EtherFast Cable DSL Router. It goes for well under $100, and nicely includes a 4-port *10/100Mbps* Ethernet hub. This seems like a really good investment. Linksys makes a similar device that also includes a wireless base station (for more $). I've also heard good reports on an "SMC Broadband router", which also includes modem and printer ports (the latter may save you from spending a lot more to get an Ethernet-equipped printer).

On security

Once you're connected, you're connected. Your machine is truly on the net, which is great since you get fast response and no setup time. It is also dangerous. A bug in any program you run (knowingly or not) that talks to the net, can expose your entire system to hacking. This is itself a good reason to put in a DHCP router as just described; it provides considerable extra protection.

Even with a firewall/router to maintain security, you may be giving up some privacy. Your machine sends your IP address to every server you talk to, because the server has to use the address to send anything (like a Web page!) back to you. With a fixed-IP-address cable or DSL connection, your IP address is trivially traceable to you, unlike a modem connection where your IP address is different on every call, and can only be traced if logs are kept by the ISP. There are many technologies to increase privacy (such as Crowds); if you care, use them.

Oh, and remember not to try to help smuggle ill-gotten money out of African nations.

Good luck!

Bibliography

Here are some additional relevant sites (thanks to Scott Fredrericksen for the first two):

- LAN Design Manual, CD ROM edition.
- Good info from Leviton can be found in their "education" area. They also have an impressive FAQ, glossary and other information available.

- An extensive FAQ, with many more technical questions, is [Ask Lennie and Uncle Ted](#). They also offer several books, a discussion list, training courses, etc.

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