THE PURPOSE OF JOINERY

Now that you know the basic types of joinery, how do you choose the right joint for a particular woodworking job? Consider that every joint must fulfill two important requirements:

- It must support the load of the other parts and any external weights or forces that might be applied to the completed project.
- It must let the wood move as it expands and contracts with changes in temperature and humidity.

And if the joint is to be glued or fastened, as most are, there is a third requirement:

- It must provide a suitable gluing surface or anchor for a fastener.

Use whichever joint best fulfills these requirements.

SUPPORT THE LOAD

The parts of a woodworking project are elements of what engineers call a "stress system." Each joint must withstand a certain amount of stress pushing or pulling at the members of the joint. This stress comes from many different sources. It could be external (coming from outside the structure), for example, when you sit on a chair, your weight stresses the chair joints. If you scoot the chair across the floor, the friction between the floor and the chair legs creates stress. Or the stress could be an internal factor, inherent to the structure. The tension in a woven seat, for example, stresses the joints between the rails and the legs. Even the weight of the individual chair parts, no matter how small or light they may be, is an internal stress to be reckoned with.

There are four types of stress, categorized by the direction of the force relative to the joint (See Figure 1-3):

- **Tension** pulls the members of a joint apart.
- **Compression** squeezes the members together.
- **Shear** pushes the members in opposite directions. The lines of force are parallel, but not aligned as they are with tension and compression.
- **Racking** (or bending) rotates the members around one another.

Although there are hundreds of fitted joints, they can all be organized into four categories — simple joints (1) such as the rabble-and-dado joint, reinforced joints (2) such as the dowel joint, mortise-and-tenon joints (3) such as the haunched mortise and tenon, and interlocking joints (4) such as the through-dovetail joint.
**Types of Joints**

**Three Basic Operations**

Boards can be joined in three different ways:

- **Fitting** joins the mating surfaces of the parts with no gaps or openings. The boards are cut to fit one another. These cuts can be as simple as those in a butt joint or as intricate as the tails and pins of a dovetail joint.

- **Gluing** bonds two boards with a chemical adhesive, such as animal hide glue, aliphatic resin (yellow) glue, or epoxy.

- **Fastening** secures one board to another with wood or metal fasteners, such as pegs, nails, and screws.

To make most wood joints, you must combine two or more of these basic operations. For example, you might fit a simple butt joint and reinforce it with nails. Dovetail joints are typically fitted and glued. And a few joints, such as a pegged mortise and tenon, combine all three activities — fitting, gluing, and fastening. (See Figure 1-1.)

**Four Ways to Fit**

Of these three operations, however, fitting is the most essential. You can join wood without glue or nails, but not without fitting. Even a simple butt joint requires that you cut one board to fit flush against the surface of another. Gluing and fastening are important — and I’ll refer to them from time to time — but fitting is the essence of joinery. Most of this text focuses on how to fit four basic types of joints (See Figure 1-2):

- **Simple joints**, such as dados and rebates, require only a few simple cuts to assemble two parts.

- **Reinforced joints** use a secondary piece of wood, such as a dowel or spline, to strengthen the joint between two or more principal parts.

- **Mortise-and-tenon joints** have one part that is bored or recessed to hold a second part, and are mostly used to join the parts of a frame.

- **Interlocking joints** use multiple cuts to increase the adjoining surface area, and usually join the parts of a box.

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**Figure 1-1** Most woodworking joints combine two joining operations — either fitting and fastening, as with the nailed butt joint (1), or fitting and gluing, as with the dovetail joint (2). Some combine all three, such as the pegged mortise-and-tenon joint (3) — it's fitted, fastened, and glued. Note that all of these joints require some degree of fitting. Just as joinery is the heart of woodworking, fitting is the heart of joinery.
EXAMPLES OF SIMPLE JOINERY

- Butt Joint
- Miter Joint
- Dado Joint
- Rabbet Joint
- Edge Joint
- Compound Miter Joint
- Lap Joint
- Dado-and-Rabbet Joint
- Blind Dado Joint
- Blind Rabbet Joint
- Tongue-and-Groove Joint
- Scarf Joint
Even before they've been glued or fastened, fitted joints resist one or more types of stress. (See Figure 1.4.) After they're assembled, they resist all types to a greater or lesser degree. When choosing a joint, try to pick one that will withstand the anticipated stress without glue or fasteners. That way, if the glue bond or the hardware fails, the joint will stay together.

**For Your Information**

Of the four types of stress, racking is the most destructive. A racking force bends the members of a joint like levers. A lever, as you know, will move a heavy object when you apply a relatively small force — the force is multiplied by the pivoting action of the lever. For this reason, a small amount of racking will pop a joint that might otherwise withstand large amounts of tension, compression, or shear.

For most woodworking projects, however, you must do more than pick a joint or two. You must design an entire system of joints — this is what a structure is. To build a structure, you must determine not only the types of joints in it but also their size and location relative to each other. This isn't difficult; it just takes some thought. There are a few simple commonsense methods for designing a strong, durable structure:

- Use larger joints and structural members. This distributes the load over a larger area and larger mass. (See Figure 1.5.)
- Use smaller members, but more of them. This too increases the area and mass that supports the load. (See Figure 1.6.)
- Triangulate the members. Rearrange the structural members or add new members, braces, glue joints, or fasteners to create structural triangles. When a triangle is fastened at all three corners, it's very rigid. This is why engineers triangulate bridges and roof trusses. (See Figure 1.7.)
- Orient the wood grain properly; wood is always strongest parallel to the grain. A tenon or dovetail cut across the grain will soon break.
- Increase the glue surface in a joint by making the fitted surfaces more intricate. (See Figure 1.8.)
- Increase the size or the number of fasteners.
- Use both glue and fasteners.

1-3 Four types of stress may tear a wood joint apart — tension, compression, shear, and racking. Of these, racking is the most destructive.

1-4 Even before a butt joint is glued or fastened, it will withstand compression, but any amount of tension, shear, or racking will pull it apart. A mortise-and-tenon joint, on the other hand, will resist compression, shear, and racking. Only tension can pull it apart before it's secured.
1-5 The racking force applied to both of these mortise-and-tenon joints is equal. But on the large mortise and tenon (bottom), the load is distributed over a larger area and more mass. The stress at any one point in the joint is a good deal less than that on the smaller mortise and tenon (top).

1-6 You don’t have to use massive structural members or joints to support a large load. On this Shaker rocker, the load is distributed over many small, round mortise-and-tenon joints. The chair’s frame and joinery appear very delicate, yet it has survived constant use for almost two centuries.

1-7 Structural triangles don’t all have to look like roof trusses. On a table, the upper part of the leg and the apron form a hidden triangle that keeps the structure rigid. On a board-and-batten door, the nails form triangles that keep the door square.
LET THE WOOD MOVE

Wood shrinks and swells with changes in the relative humidity (the amount of moisture in the air relative to the temperature). When the relative humidity goes up, the wood absorbs some of this moisture and swells. When the relative humidity goes down, the wood loses moisture and shrinks. Since the average relative humidity in much of the world is lower in the winter than it is in the summer, wood tends to shrink each winter and swell each summer.

This movement, although it may seem slight, is extremely important to woodworkers. To see why, try this experiment: Using waterproof glue, attach a small, narrow board to a wide one so the grain directions are perpendicular. Set this assembly outside on a rainy day and the boards will separate, despite the waterproof glue. As the wide board expands in the opposite direction of the narrow one, the joint is subjected to an increasing amount of shear stress. Eventually, it breaks. More joints fail from wood movement due to changes in moisture than from abuse and neglect. You must take this movement into account and accommodate it in your joinery.

Wood moves in three planes, and it moves differently in each plane. (See FIGURE 1-9) All three types of motion are relative to the direction of the wood grain and annual rings:
- **Longitudinal** movement is parallel to the wood grain.
- **Radial** movement is perpendicular to the annual rings and to the wood grain.
- **Tangential** movement is tangent to the annual rings and perpendicular to the wood grain.

Wood is fairly stable longitudinally—it will only shrink or swell 1 percent of its length when originally cut. However, it's unstable radially and tangentially. Furthermore, the tangential movement in most woods is about twice the radial movement. Radial movement averages 4 percent (of the original cut dimension) and tangential movement averages 8 percent.

> **For Your Information**

On the average, the moisture content of wood changes 1 percent for every 5 percent change in the relative humidity.
Across the grain, it's a different story: Some woods may move up to ¾ inch for every 1 foot of width or thickness. Furthermore, there is a big difference between radial and tangential movements. Most wood species will shrink or swell about twice as much tangent to the annual rings as perpendicular to them.

"Tangential/Radial Movement of Common Wood Species" on the facing page compares the movement of several species along these different planes. As the ratio of tangential movement to radial movement becomes greater, it becomes increasingly important that you properly align the tangential and radial planes of adjoining parts.

The disparity between radial and tangential movement causes yet another type of movement to consider as you choose the joinery. Depending on how a board is sawed from a tree, it may deform as it shrinks and swells. For example, if the annual rings run from side to side in a square table leg, the leg may become rectangular as the wood shrinks faster from side to side than from front to back. If the rings run diagonally from corner to corner, the leg may shrink to a diamond shape. A round dowel becomes an oval as the wood shrinks, and a flat board cups in the opposite direction of the annual rings. (See Figure 1-10.) Sometimes you can use joinery to help control this deformation; other times you must simply plan for it.

This is a lot to think about. Joinery would be far simpler if wood were the relatively stable building material that many beginning woodworkers take it to be. But it's attention to details such as wood movement that marks the difference between a true craftsman and a novice. To properly join wood, not only must you plan a joint system that allows the wood to move, but you must also "read" the wood figure as you make each joint. Study each board, then orient the grain and the rings so the anticipated movement creates the least possible stress on the joint.

There are several simple joinery techniques that help reduce stress and/or control deformation caused by wood movement. Use those techniques that apply to the structure of your project.

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**Try This Trick**

To help visualize the wood movement in a joint, sketch the boards as they will be assembled, showing the wood grain and annual rings. Mark each board with a small arrow to indicate radial movement and a large arrow to indicate tangential movement. Try to orient the wood figure so the large arrows are all parallel.

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1-10 Because the radial and tangential movement of wood is uneven, boards tend to deform as they go through an annual moisture cycle. The way a board will deform depends on how it is cut from the tree.
Orient the wood figure so the parts move in unison. Whenever possible, join the boards so the wood swells and shrinks in the same direction. When the wood grain must cross at right angles, align the tangential planes. (See Figures 1-12 and 1-13.)

Cut large boards into smaller parts. When you must glue or otherwise fasten two boards with opposing wood grain, make sure they are as narrow as possible without compromising the strength of the structure. (See Figures 1-14 and 1-15.)

1-12 On the corner butt joint shown at the left, both the wood grain and the annual rings are opposed to one another. The joint will soon fail. On the middle joint, the wood grain is aligned, but the annual rings are not — the tangential planes are perpendicular to one another. This joint will fail too, though not as quickly as the first. On the joint at the right, both the wood grain and the annual rings are properly aligned. This joint will last for a long time.

1-13 The wood grain on all three of these mortise-and-tenon joints is properly aligned. But on the joint at the left, the tangential planes are directly opposed on the broadest possible surface — where the cheeks of the tenon meet the sides of the mortise. This greatly diminishes the useful life of the joint. On the joint in the middle, the planes are in some what better alignment. The tenon moves radially at right angles to the tangential movement of the mortise. But the joint at the right shows the best possible arrangement — the tenon moves radially at right angles to the radial movement of the mortise, and the tangential planes are aligned.
PROVIDE A SUITABLE GLUING SURFACE OR ANCHOR

As mentioned previously, the most obvious thing you can do to increase the strength of a glue joint is to increase the gluing surface. However, this isn’t always as simple as it sounds. There are four different ways to glue one board to another, and some are stronger than others. (See Figure 1-21.) In descending order of strength, you can glue wood:

- Long grain to long grain, with the grain parallel
- Long grain to long grain, with the grain perpendicular
- Long grain to end grain
- End grain to end grain

If you increase the gluing surface by fitting the joint differently, don’t sacrifice long-grain surface for end-grain surface — that may actually weaken the joint. Nor do you always want to increase the long-grain-to-long-grain surface where the wood grains are perpendicular. If these surfaces become too broad, the wood movement might pop the joint. Consider other ways to expand the surface — make several small joints, or reinforce the glue bond with dowels or splines.

Try This Trick

To increase the strength of end-grain glue joints, paint the end grain with a thin coat of glue and wait about half an hour. Apply another coat of glue — this time, apply it as thick as you would normally — and clamp the parts together. The first thin coat prevents the end grain from absorbing the second coat, resulting in an even and continuous glue bond. However, don’t rely on end-grain glue joints alone when strength is important.

1-21 The strongest glue joint you can make is long grain to long grain with the grain parallel (1). Long grain to long grain with the grain perpendicular (2) is almost as strong, but the members of the joint move in opposite directions. This weakens the glue bond. A long-grain-to-end-grain joint (3) has some strength, but the end grain absorbs much of the glue and the adhesive film isn’t continuous; consequently, the bond is weak. In an end-grain-to-end-grain joint (4), this problem is aggravated. Since both boards absorb the glue, the bond is even weaker.
**FIVE CUTS**

If you have any remaining doubts about how simple and straightforward wood joinery really is, consider this: There are only five joinery cuts! Every fitted joint is made with these:

- **Butt cut** involves a sawed end, edge, or face that is square to the adjoining surfaces.
- **Miter cut** leaves a sawed surface at an angle other than 90 degrees to one or more of the adjoining surfaces.

**Basic Woodworking Cuts**

<table>
<thead>
<tr>
<th>THROUGH</th>
<th>BLIND</th>
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<tbody>
<tr>
<td><strong>Butt</strong></td>
<td><strong>Rabbet</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Corner Notch</strong></td>
</tr>
<tr>
<td></td>
<td><strong>End Rabbet</strong></td>
</tr>
<tr>
<td><strong>Compound Miter</strong></td>
<td><strong>Blind Corner Notch</strong></td>
</tr>
<tr>
<td><strong>Miter</strong></td>
<td><strong>Blind Rabbet</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Blind End Notch</strong></td>
</tr>
<tr>
<td><strong>Crosscut</strong></td>
<td><strong>Blind Dado</strong></td>
</tr>
<tr>
<td><strong>Slot</strong></td>
<td><strong>Blind Mortise</strong></td>
</tr>
<tr>
<td><strong>Angled Slot</strong></td>
<td><strong>Blind Groove</strong></td>
</tr>
<tr>
<td><strong>Mitered Kerf</strong></td>
<td><strong>Hole or Round Mortise</strong></td>
</tr>
<tr>
<td><strong>Bevel</strong></td>
<td><strong>Stopped Holes</strong></td>
</tr>
</tbody>
</table>

A **rabbet cut** makes an L-shaped notch in an arris, or edge, of the board. The bottom and side of the rabbet are usually square to one another.

- A **dado cut** creates a U-shaped channel in one surface. Like a rabbet, the bottom and the sides of a dado are usually square.
- A **hole** or **round mortise** is a cylindrical cavity bored into the wood. Holes can be drilled at any angle. When making these five cuts, you can saw or drill completely through the board, or you can halt partway through the cut, making it **blind** or **stopped**. When a cut is **blind**, its length is limited (like a blind alley). A blind dado is closed at one end; a **double-blind dado** is closed at both ends. “**Stopped**” refers to the depth of the cut and usually applies to holes. A stopped hole has a bottom; it doesn’t run through the board.

Every woodworking joint, no matter how complex, is composed of these simple cuts. For example, a lap joint is made by fitting two dados to one another. The **mortise** in a mortise-and-tenon joint is a double-blind, stopped dado; the tenon is formed from a butt cut (to cut the end of the tenon square) and two or more rabbet cuts. A **dowel joint** is made of several butt cuts and stopped holes. The trick to making a well-fitted joint is not in making difficult cuts, but in making very simple cuts precisely and in the proper sequence.
You might also consider whether you need to increase the gluing surface at all. Providing a suitable gluing surface does not necessarily mean a large gluing surface. You can build strong, durable projects without oversize, intricate joints. (See Figure 1-22.) There are several other important things you can do to ensure a good glue joint:

- **Make the glue surfaces as smooth as possible.** A thin, even, continuous film of glue is essential for a strong joint. Rough surfaces make the film uneven and create voids.
- **Fit the surfaces properly.** The surfaces must fit together without any gaps. Gaps create an uneven glue film and weaken the bond. At the same time, the fit must not be too tight. A tight fit will squeeze the glue from between the boards, leaving a weak, "starved" joint.
- **Clean the surfaces.** Give the glue surfaces a light sanding with very fine sandpaper before applying the glue. This removes any foreign materials. It also helps the glue to soak in and form what chemists call an "interface" — an integral bond between the adhesive and the wood. As you sand, be careful not to round-over adjoining surfaces.

The considerations are similar if you're making a fastened joint. The first thing that comes to mind when you must provide a suitable anchor for a nail or screw is to beef up the wood around it. But this isn't the only thing you can do to strengthen a fastened joint. As with a glue joint, you must consider the orientation of the wood grain. Nails and screws hold better when you drive them through the long grain. They may pull out or even split the wood if you drive them into the end grain. You can also:

- **Use more, smaller fasteners instead of a few large ones.**
- **Drive fasteners at angles to one another, locking the parts together.** (See Figure 1-23.)
- **Use square-shanked nails or ring-shanked nails instead of ordinary nails with round, smooth shanks.** The large surface area of square-shanks and the protrusions on ring-shanks help to hold the nail in the wood.

If you must drive screws or nails into end grain, use fasteners that are as long as practical. The extra length helps them to hold tight.

1-22 You don't need beefy, intricate joinery to make strong glue joints. This reproduction of a Shaker lap desk is made from thin stock (many parts are only ⅜ inch thick) so it is as light as possible. With the exception of the dovetail joints at the corners, the joinery consists of simple butts, rabbets, and grooves. But the assembled desk is sound and solid.

1-23 Here are two ways you might lock boards together with nails. In the butt joint (top), the nails are driven at slight angles, alternating right and left with each nail. In the miter joint (bottom), the nails are driven at right angles to one another. In both cases, the opposing angles of the nails make the joint difficult to pull apart.
INCREASING GLUING SURFACE

Interlocking joints include various types of dovetail joints, finger joints, and lock joints, all of which require multiple cuts. (See Figure 6-1.) The common purpose of these joints is to increase the gluing surface in a corner joint. The mating surfaces of simple corner joints (butt joints, miter joints, and rabbet joints) are relatively small. Often, there are no long-grain-to-long-grain surfaces, just end-grain-to-long-grain and end-grain-to-end-grain. These circumstances combine to make a weak joint. The multiple cuts in an interlocking joint multiply the surface area and often provide a healthy measure of long-grain-to-long-grain gluing surface.

Despite these multiple cuts, interlocking joints are not difficult to make: It's the number of cuts that cause an interlocking joint to look intricate, not the complexity of the cuts. Most joints require just one or two simple cuts that are repeated over and over again. As long as your layout and setup are accurate, the actual cutting will prove very easy.

Of the many different types of interlocking joints, here are four of the most common: A finger joint (1), also referred to as a "box joint," is used to join the corners of boxes. A through dovetail joint (2) joins boxes, chests, and the rear corners of drawers. A half-blind dovetail (3), which can only be seen from one direction, is often used to join the front corners of drawers. A lock joint (4), also called a tongue-and-dado joint, is another joint that can only be seen from one side. It's often used to join the corners of drawers, especially small ones.