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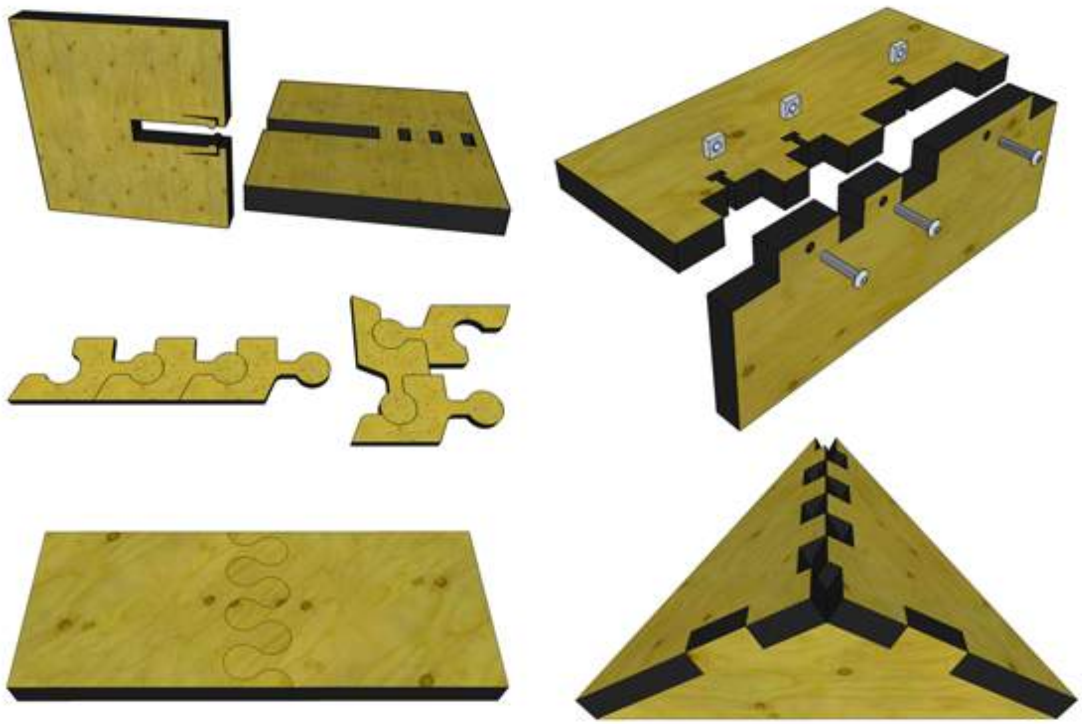
METALS

CNC Joinery

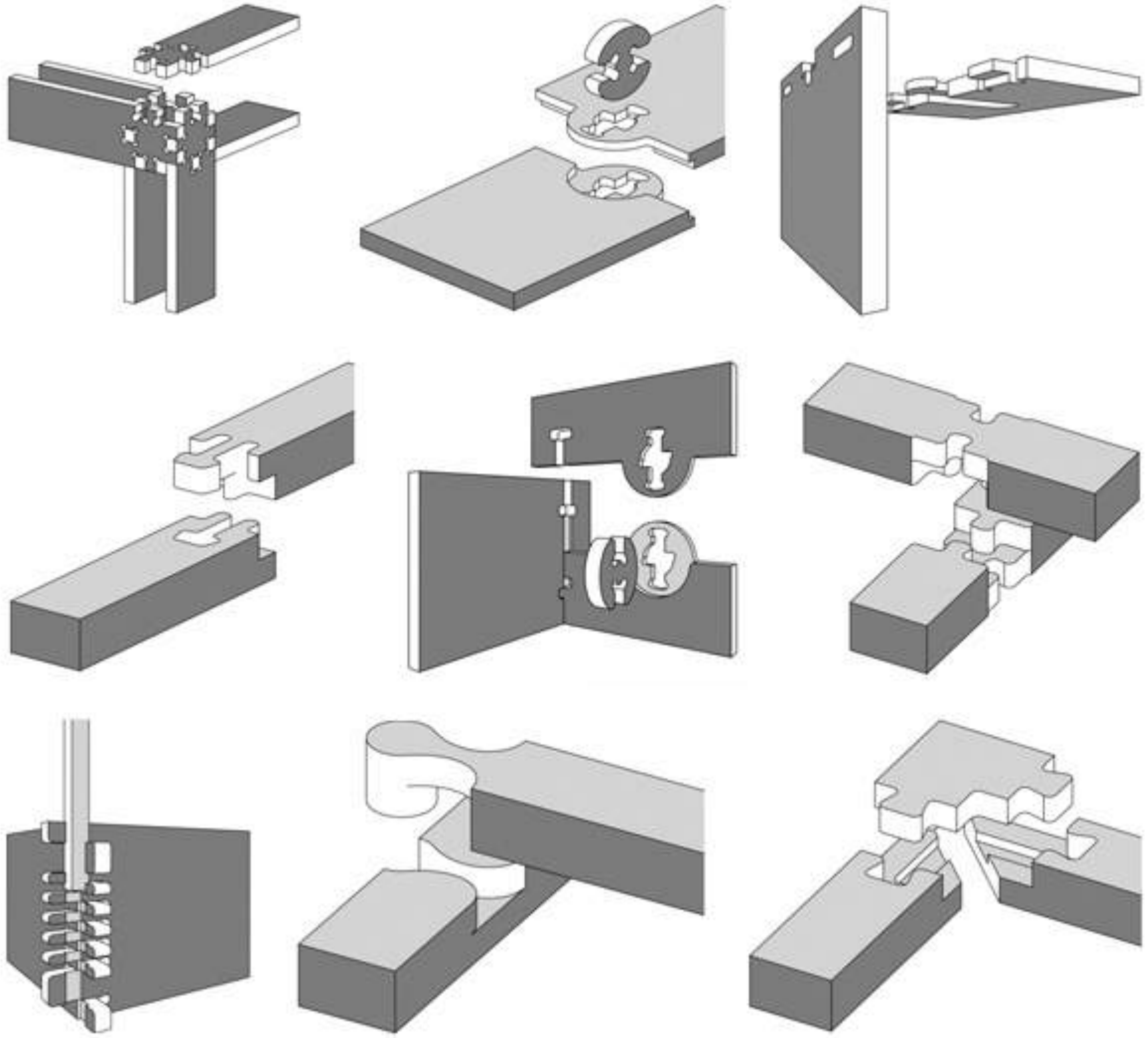


I've been collecting clever ways of slotting flat stock together since I first read Nomadic Furniture back in 1999, well before the advent of the accessible hobby-class CNC tools that, today, make manufacturing parts like these pretty easy. Now, the world is full of people designing models, project enclosures, sculpture, furniture, and all kinds of other cool stuff to be assembled from parts made on laser cutters and CNC routers, and I keep expecting a definitive book or website to emerge that covers the "bag of tricks" in an organized way. So far, I haven't found it. I may have missed it. Or maybe this article can serve as a jumping-off point. In any case, I think it's time to open up my file.

In presenting this material, I want to first acknowledge my respect for the world's established and ancient traditions of joinery. I do not for a moment imagine that any of this is fundamentally new. But I do see a need to organize this information to address the needs of the the small CNC tool operator who wants to make interlocking, self-aligning and/or demountable joints in flat stock, for instance plywood or sheet plastic. Or just to inspire her.

I may abuse some terms, without meaning to, and I am glad to be corrected by those who are in the know about traditional joinery. Generally, I have tried to use descriptive terms instead of "proper" names to avoid confusion, but here and there I may have slipped up and called a rose by some other name.

To simplify things, at first, I'm only considering joints between two panels. Also, again for the sake of simplicity, I've limited myself to techniques that use all-the-way-through cuts, orthogonal to the plane of the stock. For a taste of how complex this subject can become, without these limitations, and how quickly, check out Jochen Gros's 50 Digital Wood Joints project. Here's a montage of teaser thumbnails to whet your appetite:

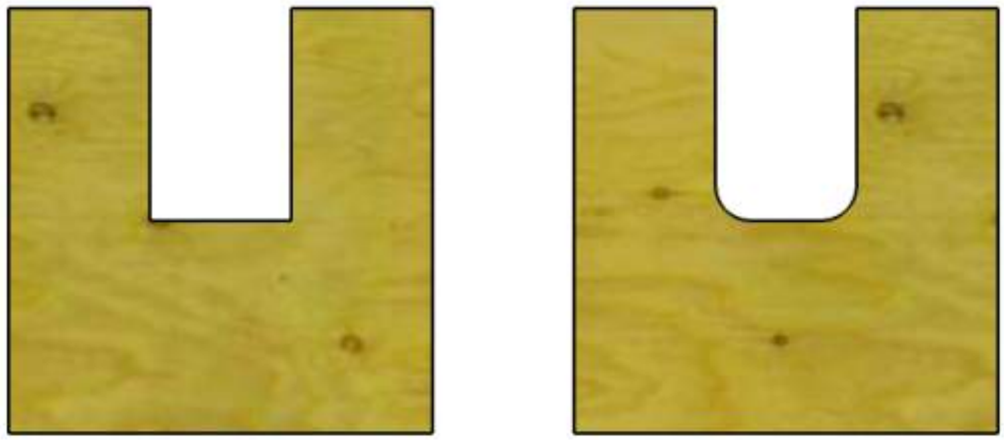


For this article, though, I'm deliberately considering a very limited case: Two (or even just one) cut parts, no partial-depth cuts, and a cutting axis always at 90 degrees to the surface of the stock. Even with these limitations, the possibilities are rich.

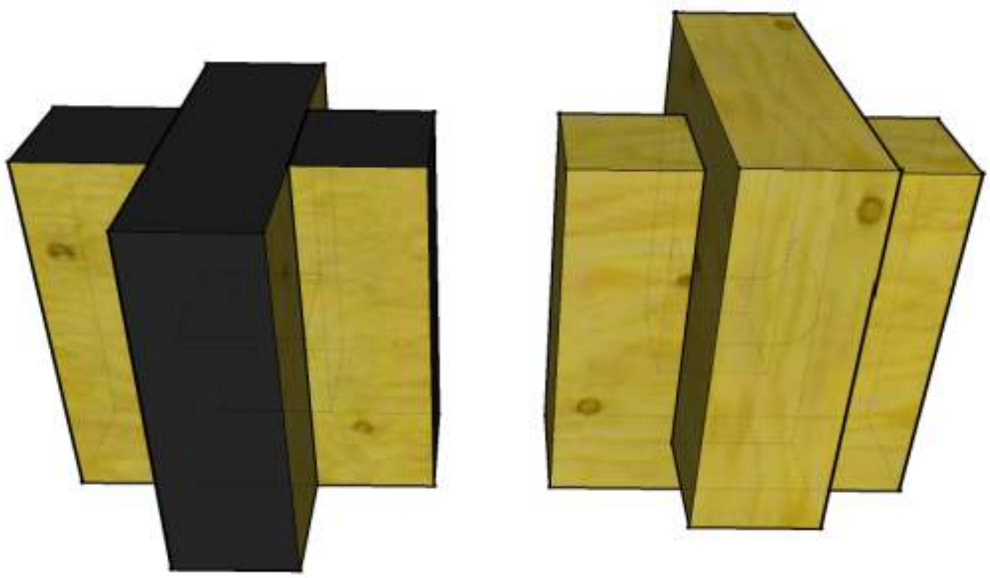
Laser vs. Rotary Cutters – The Inside Corner Problem

Hobby class laser cutters and CNC routers each have advantages and disadvantages. Laser cutters can cut much finer details because they have very small "kerf." On the other hand, they're more expensive and can't do partial-depth cutting or "pocketing" like a CNC router can. They also use heat, which can burn the substrate and/or generate nasty off-gassing. On the other hand, the burning effect can be used decoratively. A CNC router can change bits and cut complex relieved surfaces, or make cuts with mitered or otherwise profiled edges. I don't think either tool can be described as simply "better," and, with one minor caveat, all of the techniques presented here can be used equally well with either a laser cutter or a router.

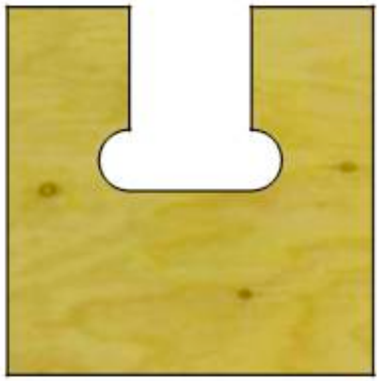
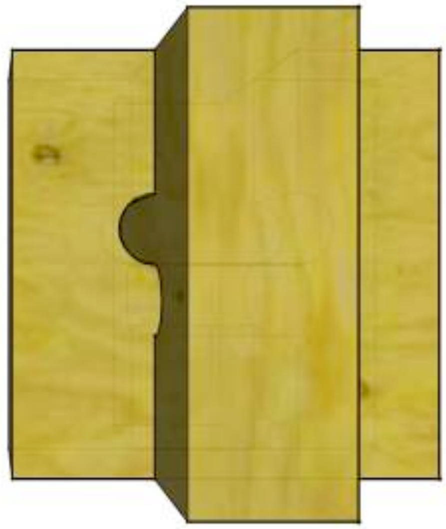
Because of its very small cutting channel, a laser cutter can produce an inside corner with a sharp angle, whereas a rotary cutter using a physical tool is limited to inside corners rounded at the cutting tool's radius:



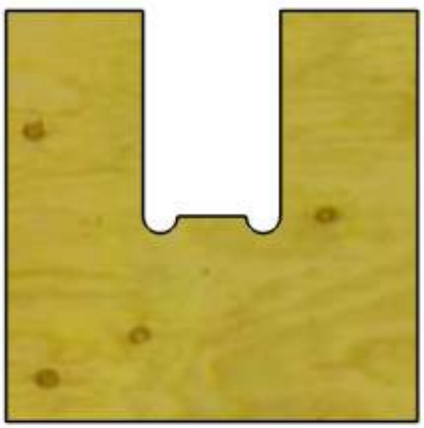
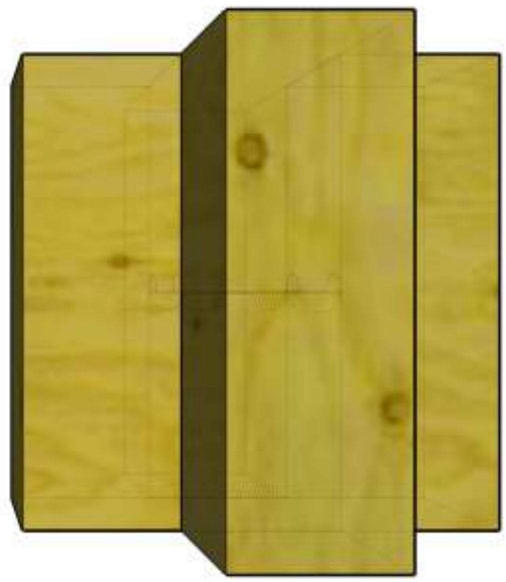
The laser-cut version, with its sharp 90 corners, is suitable for use in a simple edge-lap joint:



The router-cut version, however, doesn't work. The radiused corners bump into each other and the part edges don't line up. You can cut each slot a bit deeper, of course, and in some applications this may be OK, but doing so leaves a void in the center of the joint and concentrates stress on the radiused corners. A better solution is this:

Now the inside faces of the edge laps mate cleanly. On the other hand, the round divots are visible in the assembled joint. If that bothers you, of course, you can also do it this way, if your cutter is narrow enough:

On average, this method offers the best compromise, IMHO: The flat areas between the divots seat against each other firmly and the divots themselves are concealed inside the joint.

To simplify presentation, the joints below are presented with ideal "laser cut" inside corners. But all of them should be readily adapted to rotary cutting by using the divot method shown above.

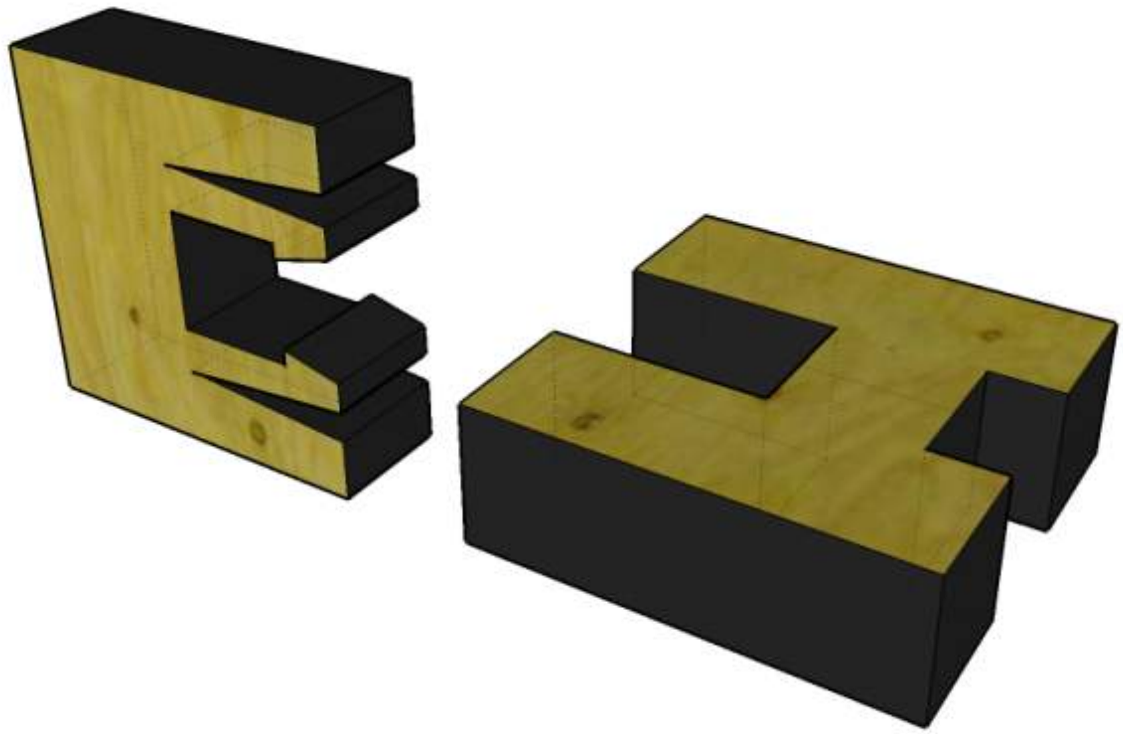
Biasing

Many of these joints are symmetrical, and can be assembled in more than one way. The joint above, for instance, can be assembled in two different ways (four if approaches from below are allowed). Which is correct?

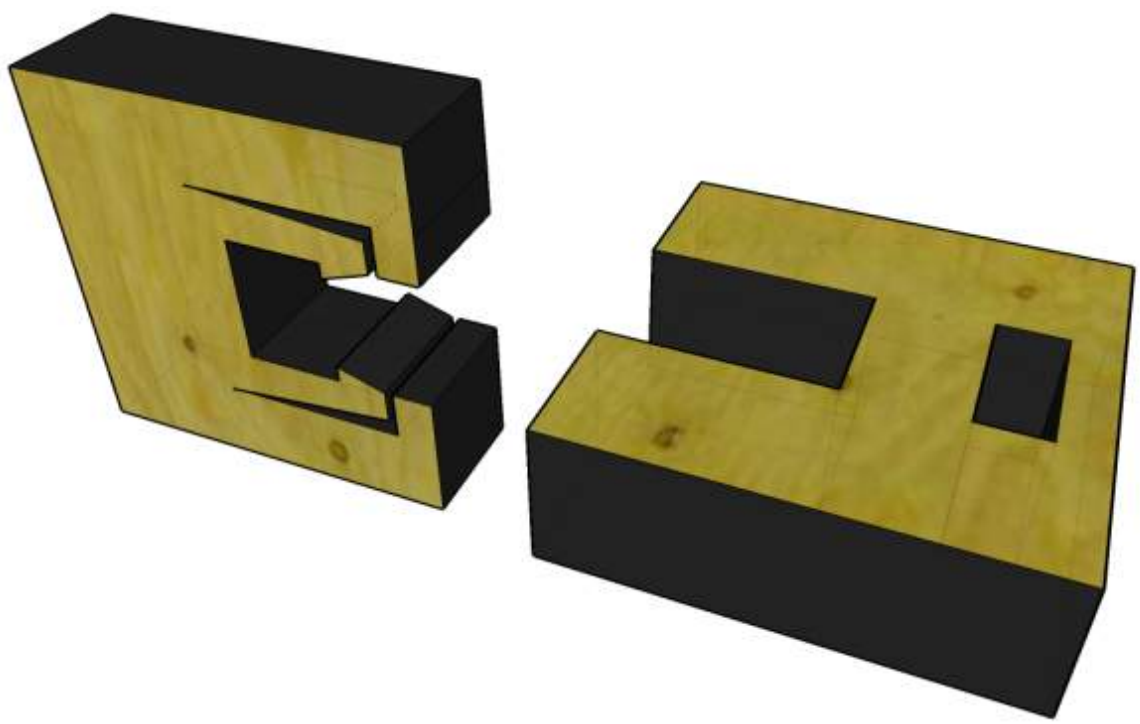
Often it is possible to deliberately break this symmetry so that the parts can only be assembled in one way, or at least in fewer or more obviously correct ways. Now the joint can still be assembled incorrectly, but the disfavored orientations are more obviously wrong, because the part edges no longer align.

This trick can be very handy in complex structures, particularly for kit parts, to keep end users from putting the joint together backwards. I call a joint that has its symmetry deliberately broken in this way "biased."

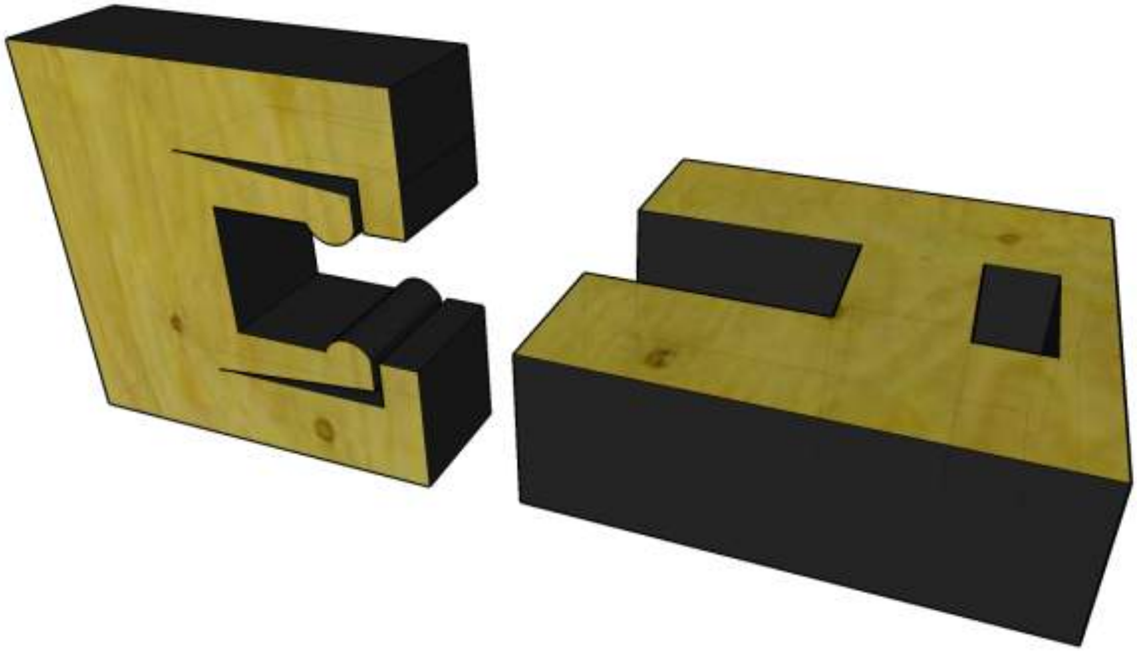
Cross ("X") Joints



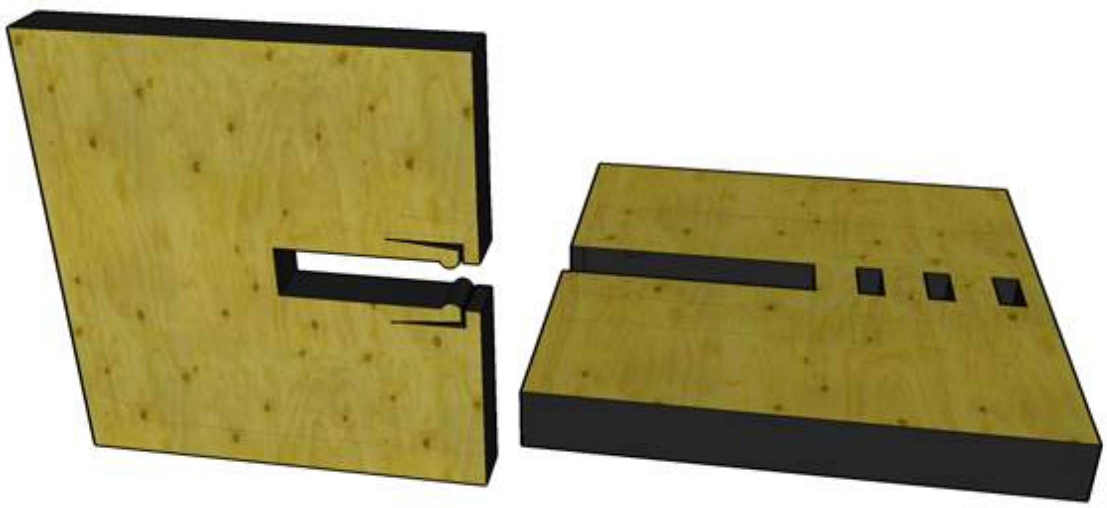
Here's a version of the basic slotted "edge lap" joint in which one side has an integral snap-lock feature. The snap hooks are accessible from the end of the joint. Insert a small flat-blade screwdriver, pry a bit, and they can be popped loose and the joint opened again.



But move the hook and the catch away from the edges of the stock, and the snap-lock action becomes "irreversible." Note that both pieces of stock could include both hooks and catches. I'm only showing "one sided" snapping joints for clarity.

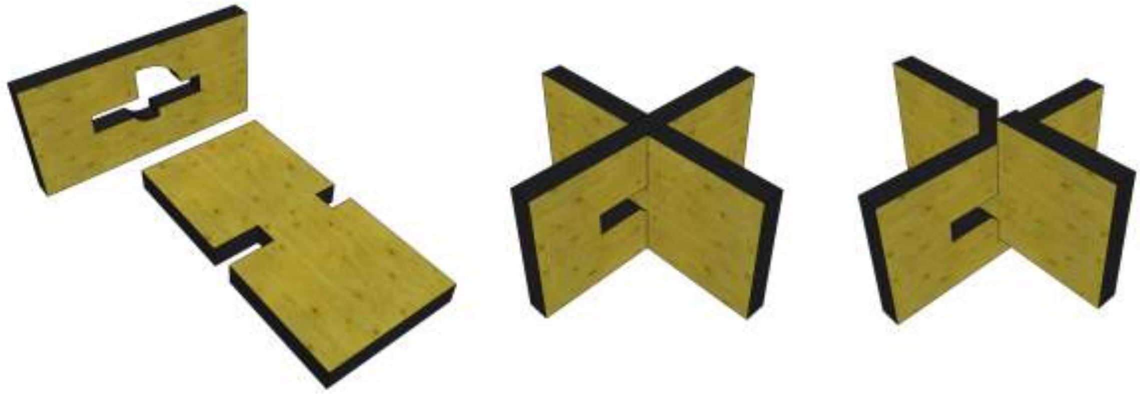


Replace the hook with a bulge and the snap becomes a detent: The part will "stick" in place but can be removed with sufficient force.

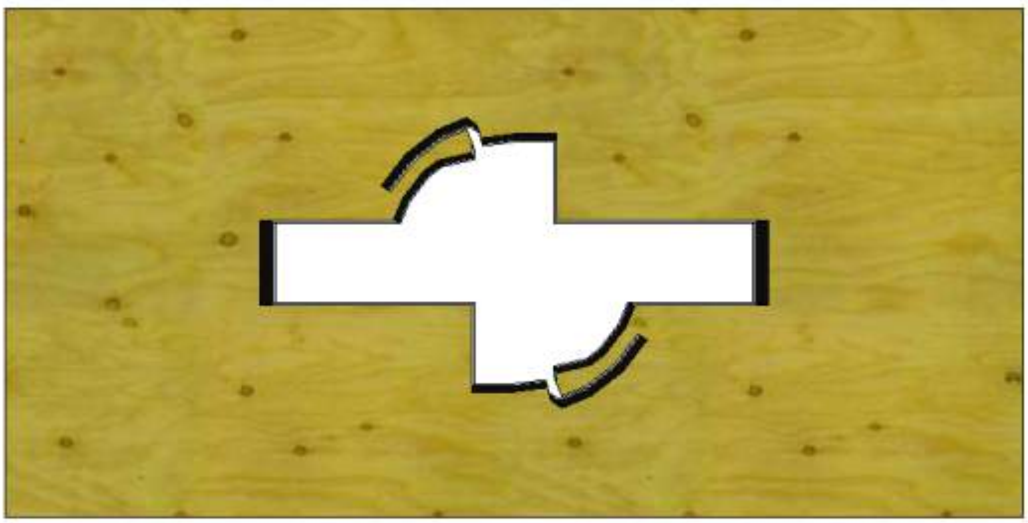


The detent could catch in one position, or many.

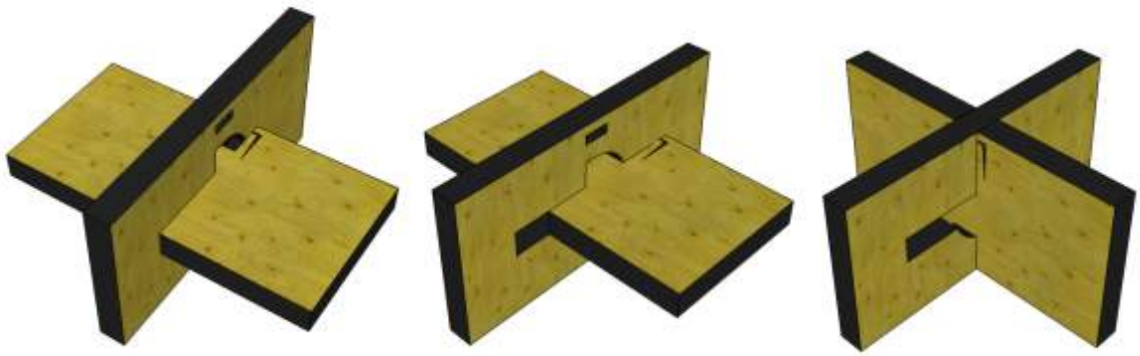
Here's a more unusual "X" joint that uses a radial interlocking motion to seal the deal.



A biased version is also possible. Here's a similar joint with the symmetry broken shown disassembled (left), assembled in favored orientation (middle), and assembled in its "disfavored" orientation (right).



Locks or detents can be added to the stationary member, as shown above…

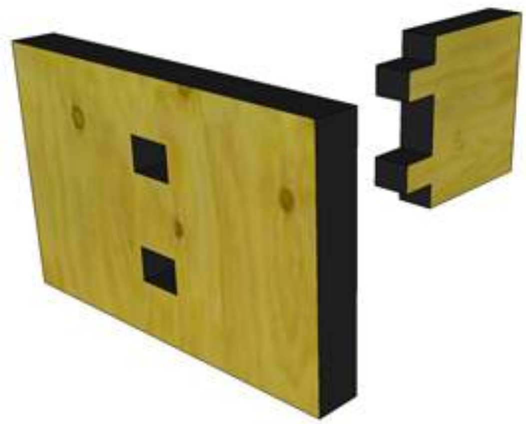


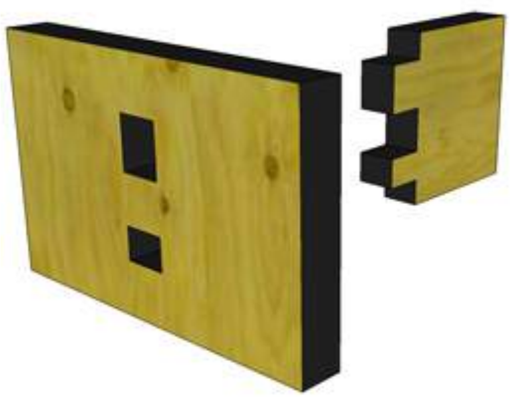
…and/or to the rotated member, as shown here. Note, in this case, that it doesn't matter if the profile of the catch is hooked or rounded: Once the catch pops into the slot, it'll be very hard to get out. For the reversible version, move the slot and the catch out to the edge of the stock.

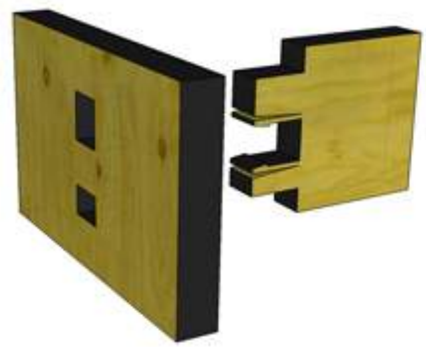
Finally, in the case of "X" joints, if one member is narrower than the other, a full-width slotted arrangement becomes possible:

Such joints may be useful especially for shelves or other upright applications where gravity can be exploited to keep the pieces engaged, and may be biased or otherwise modified like the "T" joints described below.

Tee ("T") Joints

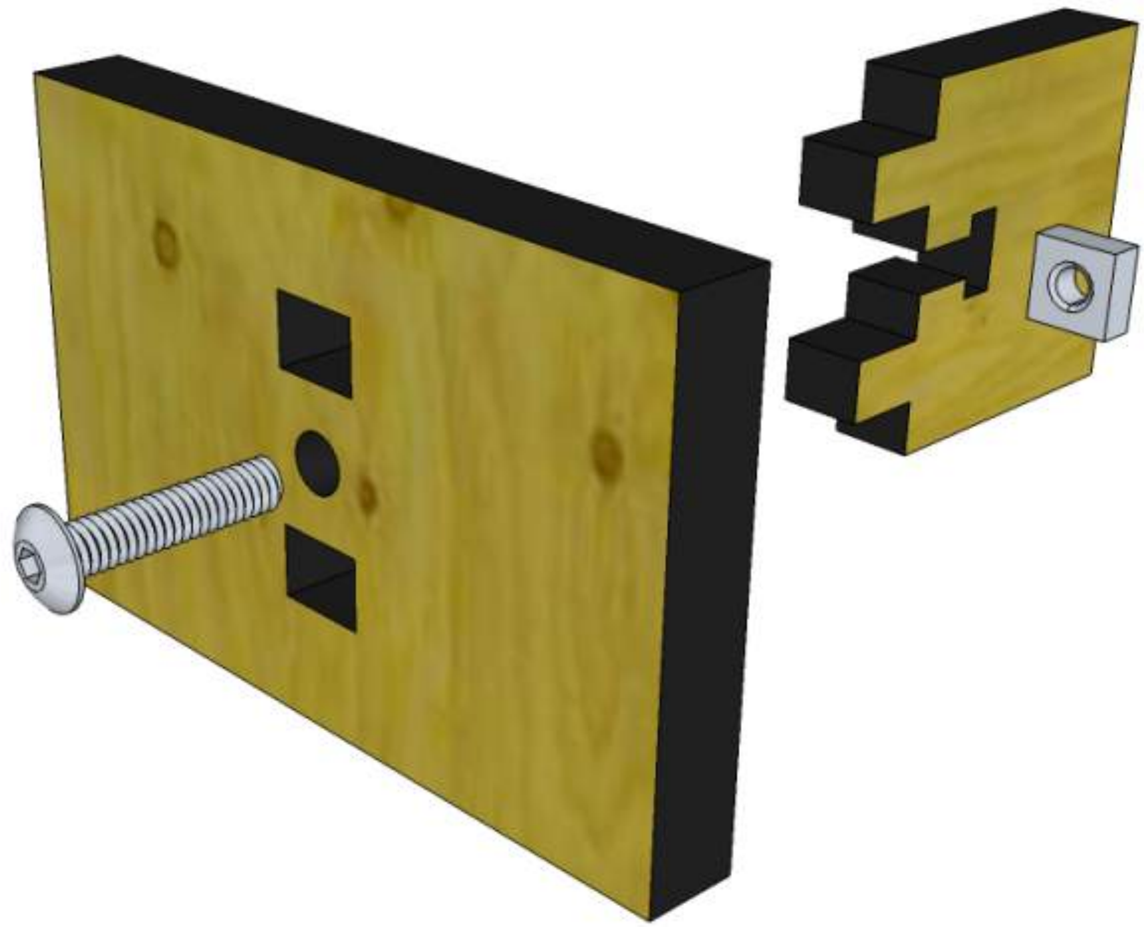






Here is a simple "mortise and tenon" type joint. We can split the "mortise" and "tenon" into two slots and tabs (or into as many slots and tabs as we like). If we break the symmetry of the slots and tabs, the joint becomes biased. And if we extend the tab a small distance past the thickness of the stock, we can add easily add snaps or detents that catch on the far side of the slotted part.

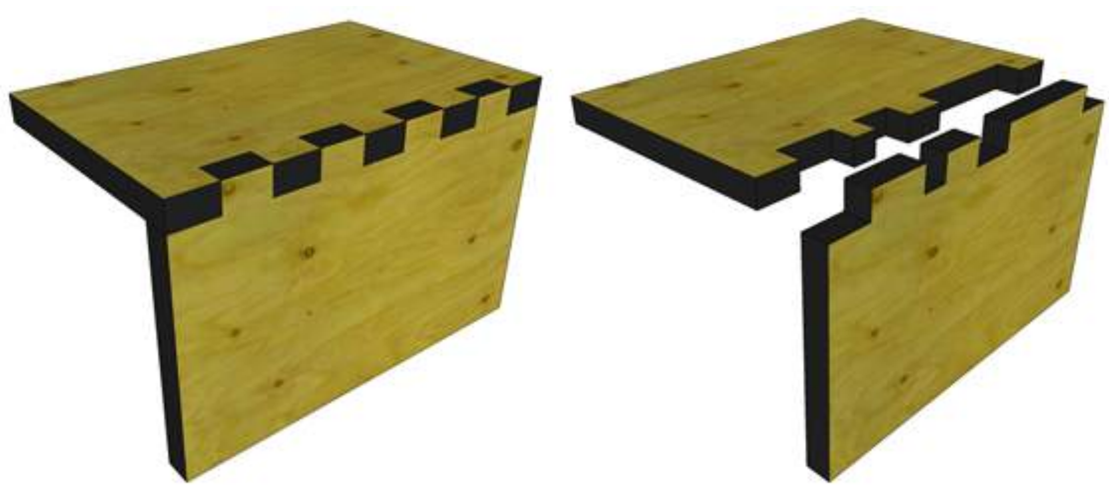
Fasteners in the plane of one of the pieces can now be introduced. This captive square nut joint is seen on a number of commercial products featuring CNC-cut parts, for instance the Phlatformer vacuum former kit and several popular 3D printer kits:



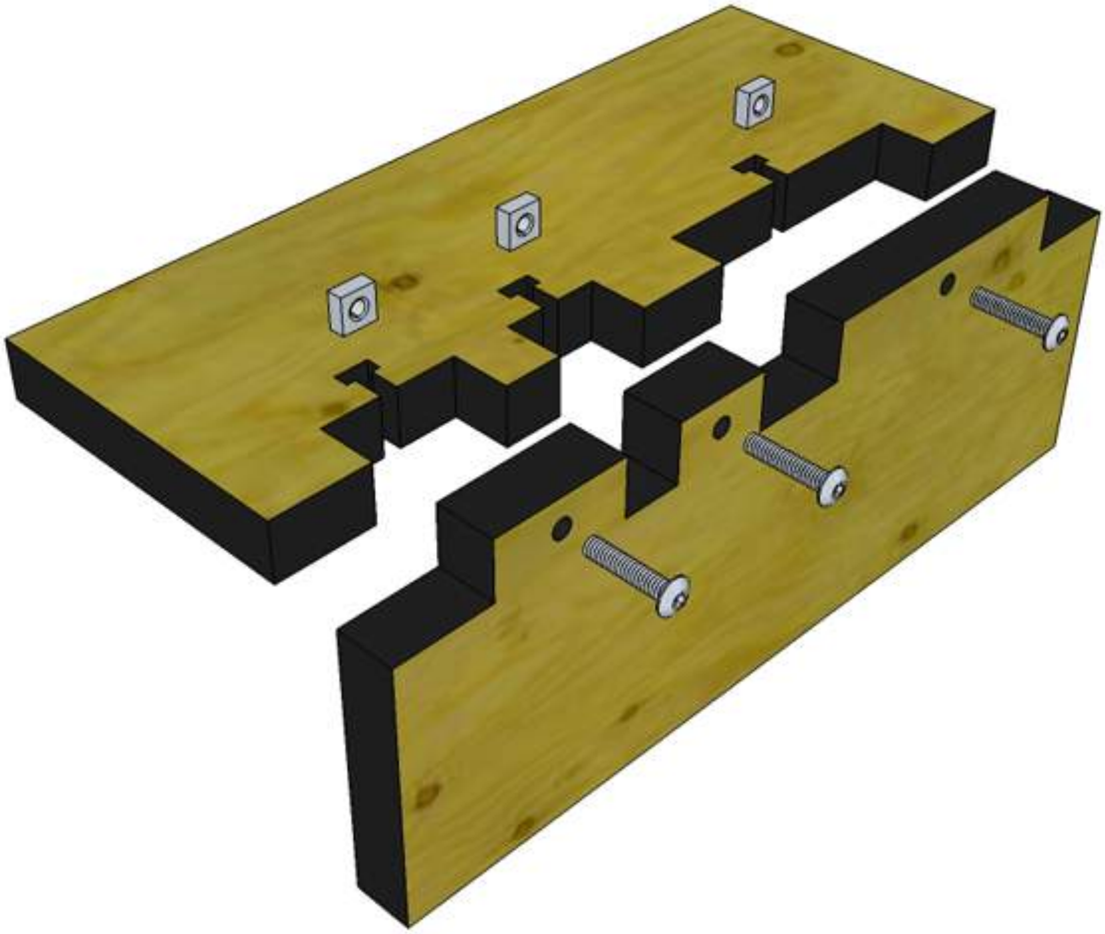
This particular configuration was the subject of a nomenclature debate here on the blog not too long ago, though I don't think any sort of consensus was achieved. Interesting possibilities include "captive nut joint," "bedframe joint," and "Pettis joint" (which is my personal favorite, because it observes Stigler's Law).

There are almost certainly other clever ways to incorporate metal fasteners or other bits of common hardware in this type of joinery that I haven't seen, and/or that have not been invented, yet.

Corner ("L") Joints



This arrangement of interlocking tabs and slots at a ninety degree angle is, of course, ancient and rudimentary. Most people call it a "box joint." It, too, can be biased by breaking symmetry.



And it is just as amenable to the bolted captive-nut arrangement.

Oblique ("V") Joints

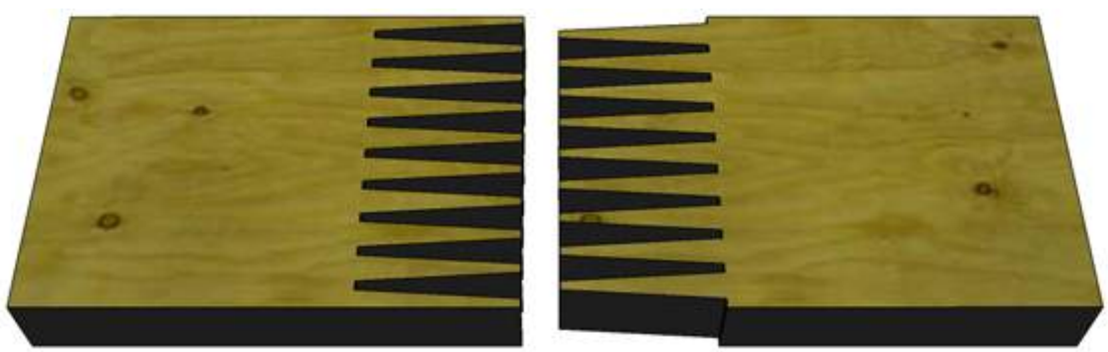
Though the captive-nut joint doesn't really work unless the two parts are at right angles to one another, generally the "L" joints can be pressed into service for acute or obtuse angles, as well.

The bottoms of the slots no longer index closely against the surface of the stock, but if the members are held in alignment by some other means, for example by glue or the introduction of a third panel (as shown to right), it may not matter.

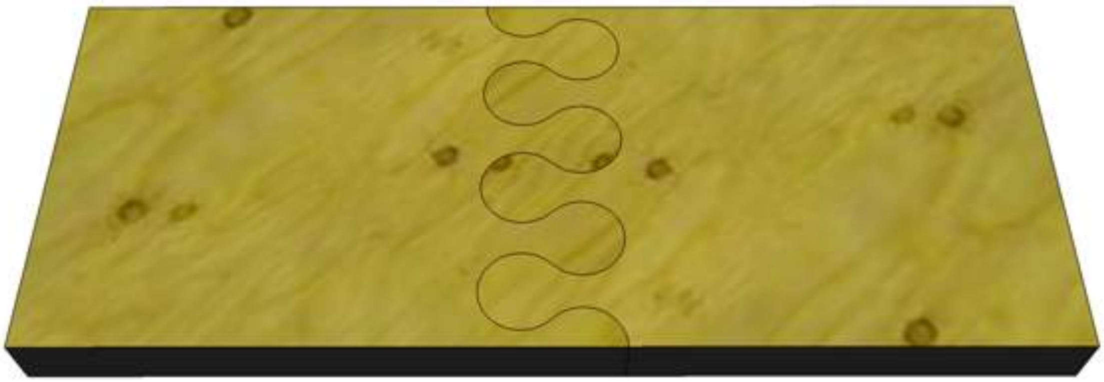
An interesting variation on this method, in which the fingers are rounded, has been used by Sebastien Wierinck in his Chair model 01, as shown:

Sebastien is using pins, I believe, running longways through both sets of fingers, along the axis of each joint, which requires an out-of-plane drilling operation that is technically disallowed under our rules. But these joints could certainly be glued. If using glue, however, the rounded fingers, through they may look better , will limit the surface area available to the adhesive.

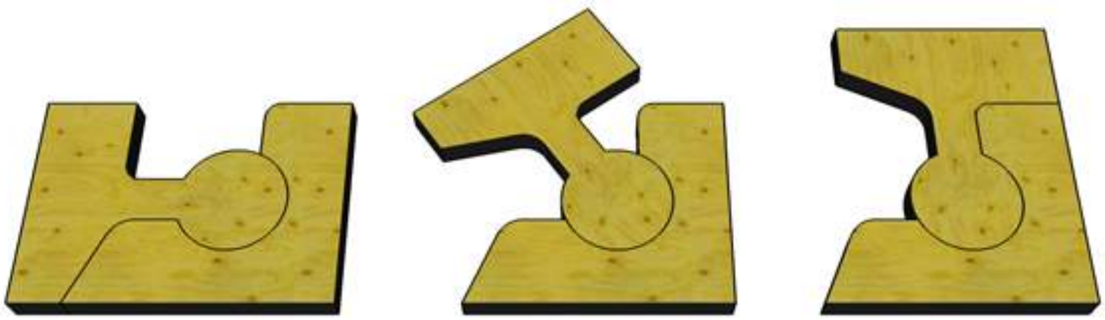
Coplanar ("I") Joints



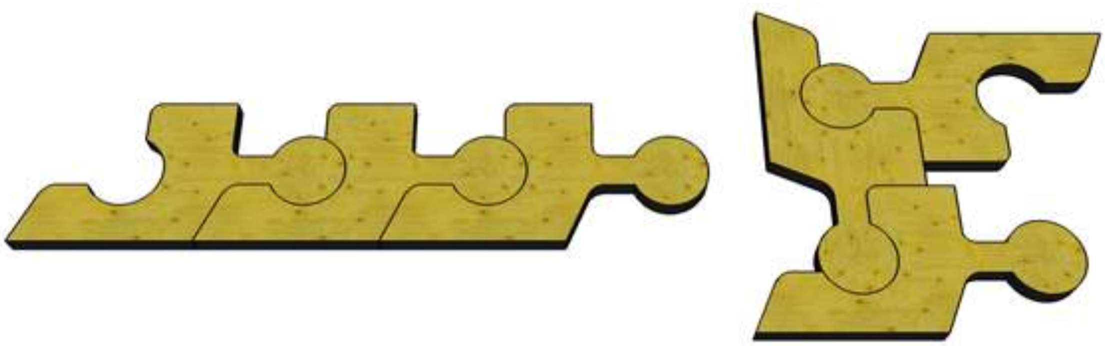
Here, for instance, is the classic "finger" joint, used to join members in the same plane for gluing.



This interlocking "bulbed" version doesn't depend on glue for its strength in tension. If left unglued, of course, these flat joints require some means to keep the two pieces in the same plane when the joint is in use. Here is a variation of the "bulb" joint that allows for in-plane hinging action:



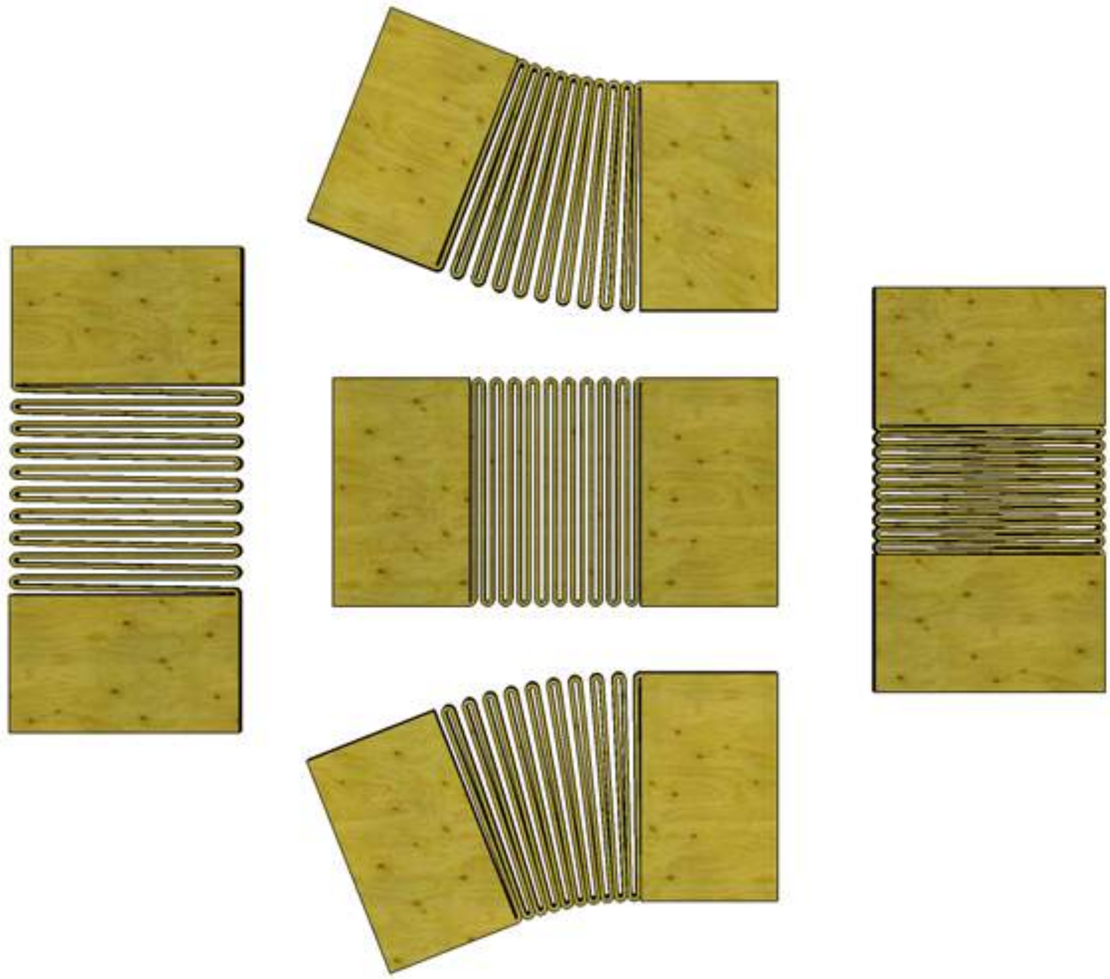
I want to call this a "Kanelba hinge," for George S. Kanelba, of New York, whose "Cube Desk" project in the 1984 Popular Science book 67 Prizewinning Plywood Projects is the only place I've ever seen it.



Kanelba hinges can be daisy-chained to make "snakes." The individual hinges, of course, can be set to "stop" at angles other than 90°.

Flexures

Though not strictly "joints," there is a class of clever CNC tricks that meet our criteria for inclusion here (two or fewer members, all-the-way-through cuts at 90 degrees) that are designed to exploit the natural elasticity of the panel material itself to create living hinges, springs, and other dynamic flexing elements. We have already broached the subject of integral flexures with our discussion of catches and detents, above.



This is an in-plane spring or living hinge element that is kind of like kerf-bending, but with “thru” cuts. If not constrained to motion in the plane, such a feature will be pretty unstable. Here’s a version more suitable for out-of-plane bending:

This is the somewhat famous Snijlab living hinge technique (which I continue to believe should be called a "sninge"), an accordion-cut pattern that allows for stable out-of-plane flexing. It is most commonly executed in laser-cut plywood, but there's no reason it couldn't be cut with a CNC mill and/or in other materials, though a router-cut sninge will have to be longer to achieve the same degree of flexibility as a laser-cut version, because the router slots will have to be considerably wider.

Finally, here's an oddball free-hanging spiral technique, courtesy of the good folks at PlasmaCAM. The spiral is cut out of a piece of steel using a CNC plasma cutter, but the same idea could work with a laser cutter or a mill, in a different material.

Frankie Flood: fflood@uwm.edu

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