

# Shovel Folding: Algorithmic Origami Design of Words and Other Line Drawings

by Wensdy Whitehead

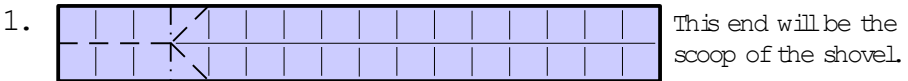
Shovel folding techniques provide a systematic approach to box-pleating to allow quick 3D origami design of line drawings without massive collapses. It is a family of related origami techniques that work very powerfully together. It includes basic shovel folds, inverse shovel folds, half shovel folds, half inverse shovel folds, sliding shovel folds, hesitating shovel folds, null shovel folds and a corner-turning procedure. The various types of shovel folds work together in sequence across pleated paper, generating three-dimensional structures seen edge-on, rather like a line drawing with three-dimensional ink hanging in mid air. Inverse techniques create the same structures as their non-inverse counterparts but in reverse, causing the working end of the developing model to become narrower rather than wider. This sequential and complementary nature allows a very algorithmic approach to design, including subroutines for all the capital letters of the English alphabet. These subroutines provide enough power that the total design time for eight new words for an exhibit was under five minutes and the first execution of all eight designs were display quality. This paper will address the underlying shovel folds, however, rather than specific subroutines built upon them.

The techniques of shovel folding are not inordinately difficult. Intermediate folders with precision and patience can handle all the folding techniques required; most models developed under this method will be intermediate or high intermediate.

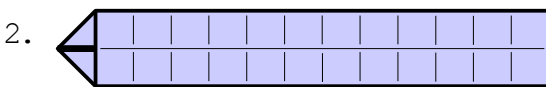
Shovel folding starts on any grid. Powers of two (2) are particularly handy as grid dimensions, so the following explanations use 1/2 paper with an 8x16 grid to illustrate the techniques. Start with the long eighths other than the half folded.

## Basic Shovel Fold

The basic shovel fold gives the family of techniques its name. Repeated application can create the same result as an Elias stretch. This breakdown makes it easier to reposition the stretch or stop partway. The shovel fold starts from the center of the stretch rather than the outside ends. There is no additional difficulty if the center of the stretch is off-center or positioned at any particular distance from the end. After each shovel fold, the paper is ready for the next.

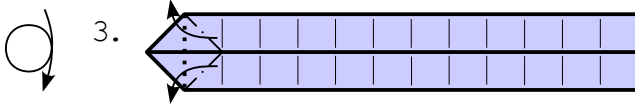


Rabbit-ear. Leave the ear upright (rather than folding it down to either side).

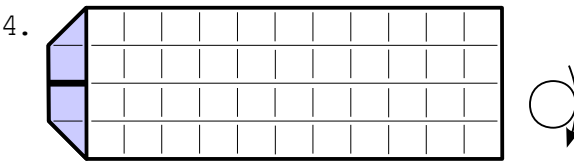


The ear flap is standing upright, so only the end edge-on is visible here, shown by a thick line. If seen from the long side, it would look as in 2<sub>eye</sub>. From the end, it would only be edges.

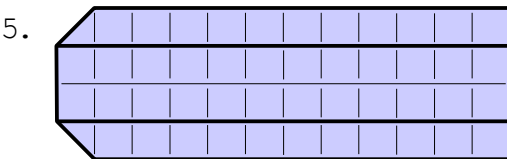




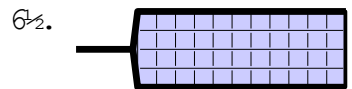
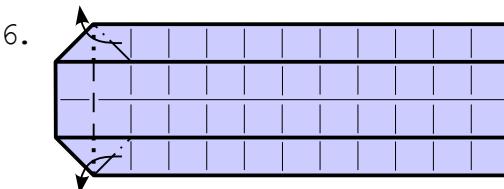
On the side without the ear flap, pick up all the edges along the center and open outwards like opening cupboard doors, but the paper is trapped at one end and gets pulled around. When the doors open about  $90^\circ$ , the paper looks like a coal shovel, as shown in diagram 3½. (This is the stereotypical form, but the handle of the shovel could be either complex or missing.) Fully open the doors  $180^\circ$ . It is possible to see a shovel fold two different ways. If the scoop of the shovel is stable, the handle of the shovel (ear flap from the rabbit-ear) is pulled around. If the handle (ear flap) is stable, the scoop flips over. Both feel the same when folding in the air, but the latter perspective leaves the paper ready for the next shovel fold, whereas the former requires turning the paper over afterward. The latter cuts down considerably on the number of diagrams. Just this once, this introduction uses the former in order to show both sides of the result.



First, step 4 shows the result from the side with the rabbit ear as if the scoop of the shovel remained stable and the handle swung around. At first, it may seem more natural to keep the majority of the paper steady. Working across the paper with a sequence shovel folds, this shifts until the whole scoop is used up, making it natural for the scoop to move rather than the handle. This view provides consistency and keeps the mind focused on the part of the paper that changes.

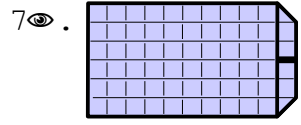
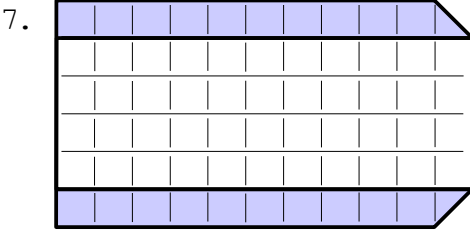


The paper is ready for the next basic shovel fold (or many of the variants), but the internal edges no longer run down the center of the paper. Instead they are located to either side, one grid square from each long edge. Actually, one grid square from the edge is exactly the same location that they were the first time - when the center was one grid square from the edge. Now the paper is wider.



A second shovel fold works just like the first, but there is a gap between the inner edges.

Partway through the second basic shovel fold, the paper again looks like a shovel but wider and one grid square shorter. From here, continue to open the sides as before, flipping the scoop around.

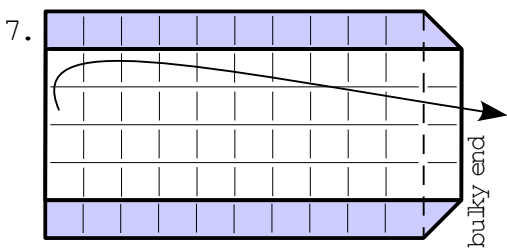


View from the flip side.

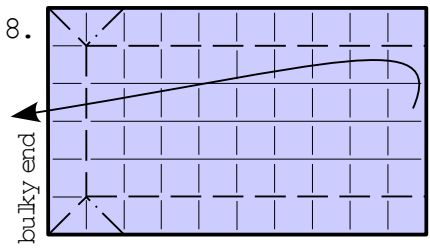
Again the result is ready for the next shovel fold, which would complete the Elias stretch and use the full width of the paper.

## Inverse Shovel Fold

An inverse shovel fold creates exactly the same structure as a shovel fold, but it attacks the problem from the other direction. Instead of spreading a pleat, it takes an unfolded and returns an end to a pleated state. Like the basic shovel fold, a series of inverse shovel folds can perform an Elias stretch step by step. An inverse shovel fold could start a sequence, however it usually occurs after one or more non-inverse shovel folds, so the following example continues from above.

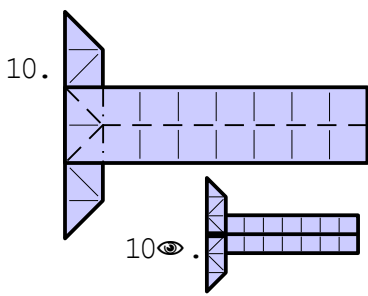
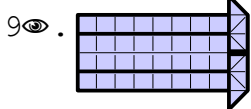
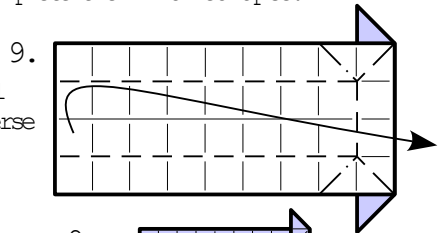


Valley fold to get the paper ready for the first inverse shovel fold. If the design calls for it, a space may be left by skipping crease lines or multiple pleats may be made. This is the most common option however.



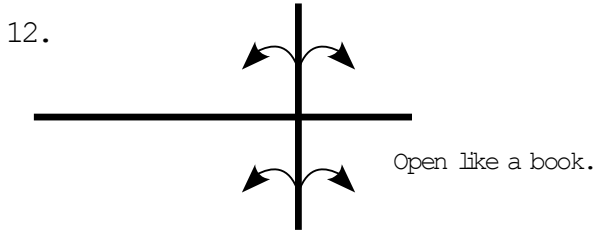
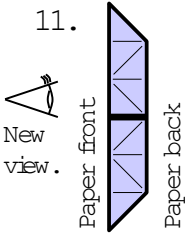
The inverse shovel fold brings the long sides in while flipping the end back where it came from on the next crease. It is easiest to start by making the 45° valley folds bisecting the corners. This pulls the paper into a useful shape to complete the minor collapse.

Like the basic shovel fold, one inverse shovel fold leaves the paper ready for the next inverse shovel fold. The paper is narrower, but otherwise, it is the same fold.

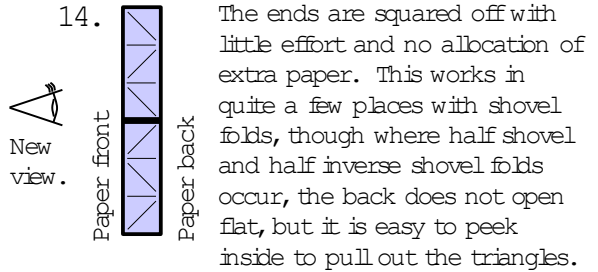
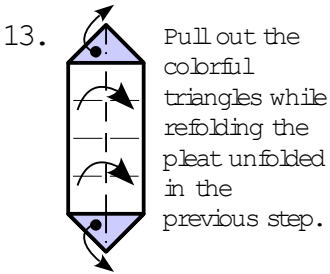


View from the flip side.

The series of shovel folds started from a rabbit-ear; the series of inverse shovel folds is the same thing working backwards, so it ends in the very same rabbit-ear. As before, leave the ear upright (rather than folding it down to either side).

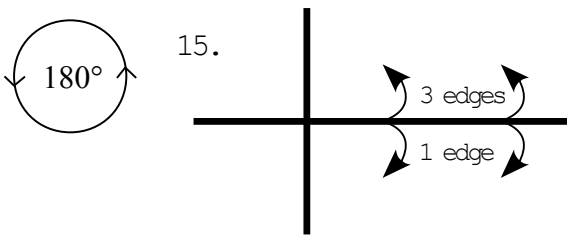


Shovel folding is convenient for models of line drawings such as stick figures, numbers, letters and other symbols. The lines should generally be neat and clean and even, not tapering off here and there in little points. The ends could have been made square by adding a pleat in the shift from shovel folds to inverse shovel folds, but that would be neither convenient nor efficient. It's better to pull out a bit of paper that's hidden inside. Here it can open flat like a book.

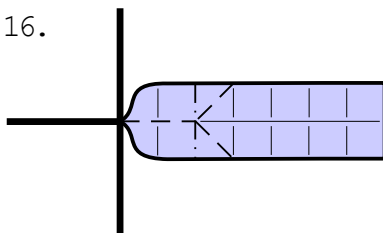


## Starting Another Sequence of Shovel Folds

After those inverse shovel folds, more shovel folds are needed; most models are more complex than an 'X,' 'T' or sword. The center of the new sequence need not be the same as the center of the preceding sequence. It is not possible to open the pleats flat to put in another new rabbit-ear, but it is possible to peek inside and hold the paper open long enough to make that rabbit-ear. For demonstration, continue from the end of the inverse shovel folding example (14).

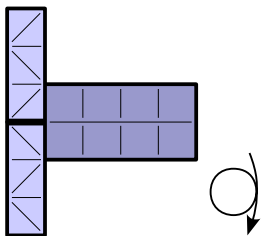


Peek inside by opening the pages of the pleat. Any layer from either side is appropriate, but an example must pick one, so start with the colorful side of the paper up and open such that one edge (or page) goes down and three go up. This starts a shovel fold off-center.



Rabbit-ear. Leave the ear upright (rather than folding it down to either side). The ear has a complex structure attached. The rabbit-ear could be at any pleat including the next one, eliminating the horizontal valley fold. The distance is not significant to the ability to shovel fold.

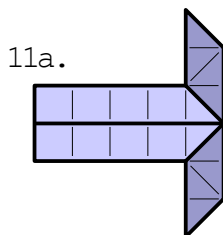
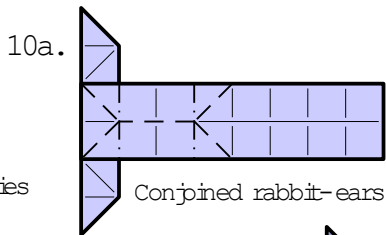
17.



The paper is again ready to turn over and start shovel folding. It is set up for an off-centered shovel fold.

There is also the special case where the next series of shovel folds has the same center as the preceding series. Rather than peeking inside and holding the paper open, it is simpler to make both the closing and opening rabbit-ears simultaneously.

The new creases look a bit like a barbell, since the same portion of the paper is the ear section of both rabbit-ears. In that way, this "barbell fold" is just a set of conjoined rabbit-ears. To do this, replace step 10 with 10a.

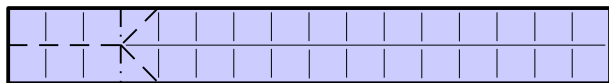


## Half Shovel Folds

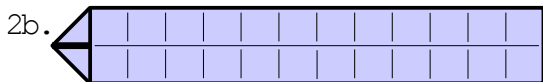
Centered shovel folds spread the paper out symmetrically, but asymmetry is useful, too. A shovel fold that starts off-center can break the symmetry once it reaches the edge. One side will lack the paper for another shovel fold, but the other side is ready for its half. Fortunately, the sequence can easily continue with half shovel folds.

For the following illustrative example, start with another 8x16 grid, but on it the long quarter rather than the half.

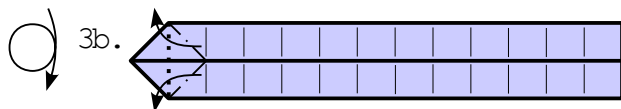
1b.



Rabbit-ear. Leave the ear upright (rather than folding it down to either side).

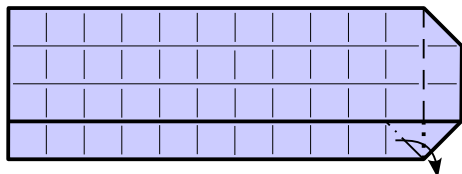


The ear flap is standing upright, so only the edge is visible here, shown by a thick line. If seen from the long side, it would look as in 2b<sup>eye</sup>. From the end, it would only be edges.

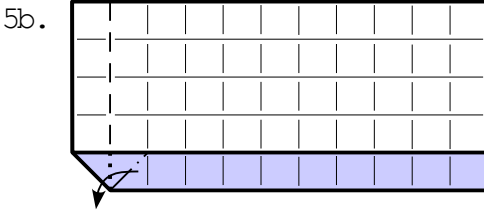


There is still paper for the full version of the basic shovel fold.

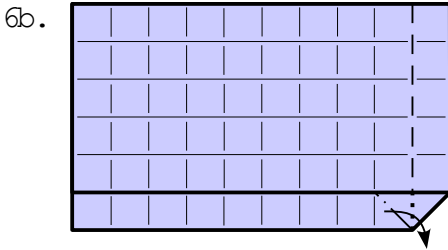
4b.



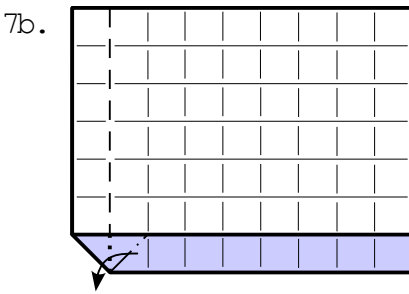
This time there is only one edge that can be pulled outward. This is the half shovel fold. It works just like the basic shovel fold, but operates on just one side instead of both sides.



The result of the first half shovel fold is ready for another half shovel fold. With each basic shovel fold, the paper becomes two grid squares wider; with each half shovel fold, it becomes one grid square wider.



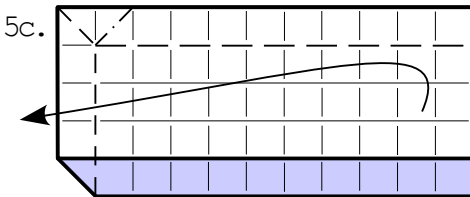
The second half shovel fold brings the width up to six grid squares, whence it would be possible to return to pleats with two inverse shovel folds. In fact, the inverse shovel fold can also be halved, so it would be possible to start backing up towards more pleats and narrower paper from an odd width, not just an even one. It is also possible to continue with half shovel folds until the paper is completely spread out.



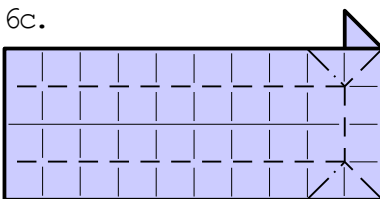
Because a half shovel fold only spreads out one pleat instead of two for a full shovel fold, this will eat more length than it did to reach the edge of the paper in the basic shovel fold example.

## Half Inverse Shovel Folds

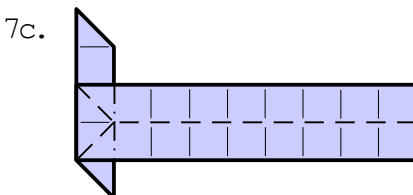
Inverse shovel folds split just as readily in half as the basic version. Half inverse shovel folds balance half shovel folds. To set up for the following example, fold through step 4b in the section of half shovel folds.



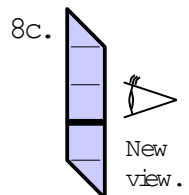
A half inverse shovel fold is just a one-sided inverse shovel fold. The valley fold that was in the center of the full version now extends to one edge. Notice that the half inverse shovel fold brings in the other edge (not the one the half shovel fold was spreading open).



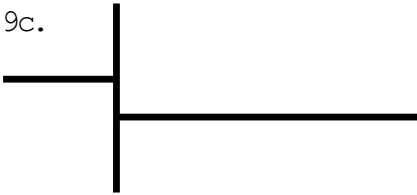
After one half inverse shovel fold, the paper is ready for the full version - or for a half inverse shovel fold on either long side. Here is the full version, to show how these folds mix.



As with the full version, a rabbit-ear finishes the re-pleating of the end. Now it is interesting to see the paper edge-on.



9c.

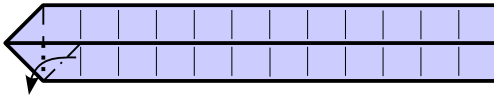


Because the half shovel and half inverse shovel folds used opposite sides of the paper, the pleat is off-set. This is very useful. Combined with the sliding shovel fold, it becomes more flexible.

## Sliding Shovel Fold

A sliding shovel fold is a half shovel fold plus a half inverse shovel fold performed simultaneously. One side spreads out a pleat while the other side refolds a pleat with no net change in width, but the offset that was observed at the end of the half inverse shovel fold example increases. A half shovel fold and a half inverse shovel fold bracket a series of zero or more sliding shovel folds to produce an offset. The offset measured in grid squares will be one greater than the number of sliding shovel folds. For the following example, fold through step 2b.

3d.

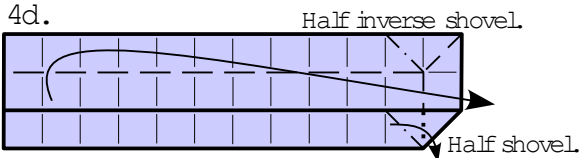


3d.

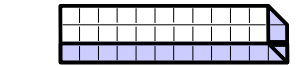


Start with a half shovel fold to set up for the sliding shovel fold. Notice that a full shovel fold need not precede a half shovel fold.

4d.



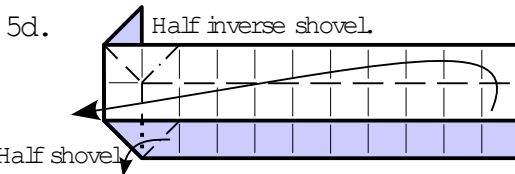
4d.



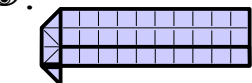
View from the flip side.

The sliding shovel fold combines a half shovel fold and a half inverse shovel fold.

5d.



5d.

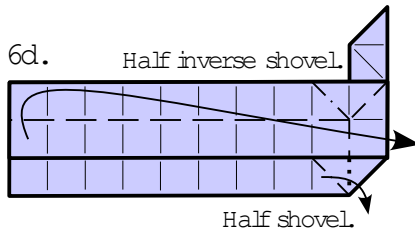


View from the flip side.

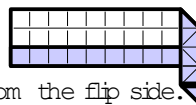
Half shovel

The sliding shovel fold leaves the paper ready for another sliding shovel fold.

6d.

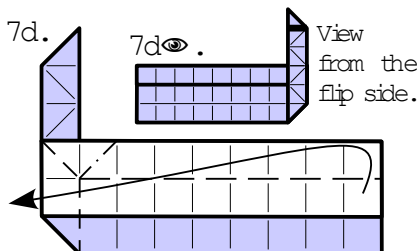


6d.



View from the flip side.

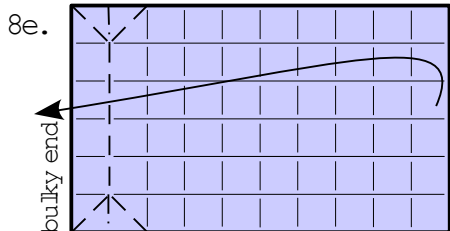
7d.



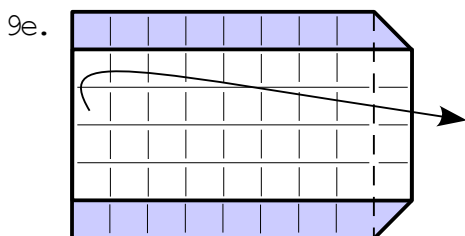
The half inverse shovel fold could have come after the previous sliding shovel fold or after the half shovel fold itself. It would also be possible to continue. Closing up before the edge leaves a triangle to pull out as in steps 12-14, though the paper will not open flat. Because there were an even number of sliding shovel folds, the triangles will be accessible from the same side of the model. If there were an odd number of shovel folds, they would be accessible from opposite sides.

# Hesitating Shovel Fold

A hesitating shovel fold starts to bring the sides inward like an inverse shovel fold, but halfway through it backs out. This helps reverse direction from inverse shovel folds to basic shovel folds spreading the paper. However, an inverse shovel fold could follow instead. Repeating a hesitating shovel fold is useful to create multiple short flaps. Like the basic and inverse shovel folds, the hesitating shovel fold can also be applied to just one side and combined with either a half shovel or half inverse shovel fold on the other side of the paper. Fuller exploration of the various combinations is left as an exercise for the reader.



Start by folding through step 7 of the inverse shovel fold example. Seen all together, the folds of a hesitating shovel fold clearly relate to other shovel folds, but they are easier to implement as first a valley fold then two inside-reverses.

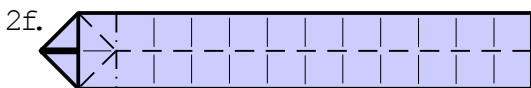


From here, it would be possible to spread the paper with another shovel fold. To repeat hesitating shovel folds, so just do a valley fold as shown to prepare for the next one.

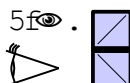
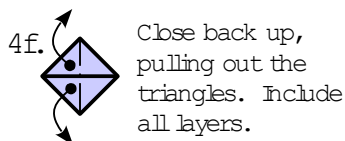
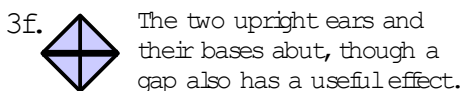
# Null Shovel Fold

The preceding series of shovel folds always started and ended with matching rabbit-ears. Shovel folds and half shovel folds spread the paper from the rabbit-ear which is already two grid squares wide, so these sequences always end up spreading the paper to at least three grid squares. To keep the width down to the two initial grid squares, eliminate the sequence shovel folds between the matching rabbit-ears. In essence, it becomes a sequence of length zero—a null sequence.

To try out the example below, fold to step 2 of the basic shovel fold.



There is no need to turn the paper over, just add the closing rabbit-ear, again leaving the ear upright.

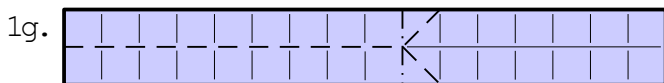


Since the triangles were pulled out as in step 25a after the matching basic shovel and inverse shovel folds, all the ends should be square, as in the other view.

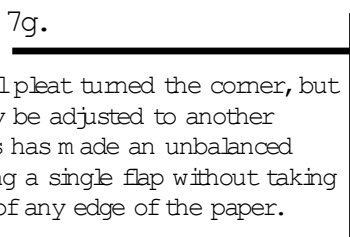
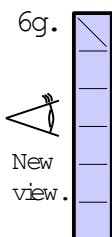
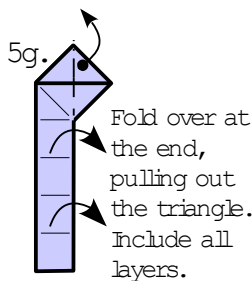
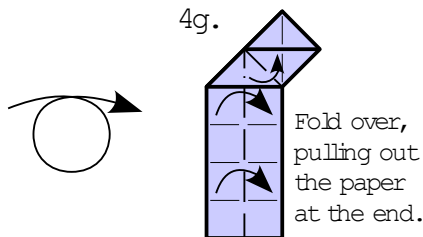
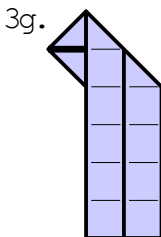
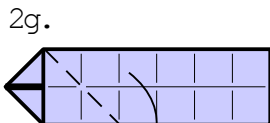


# The Corner Turning Maneuver

The corner turning maneuver is the oddball of shovel folding, but it is a vital component. So far, all the sequences of shovel folds have expanded the paper in both directions by at least one grid square. The corner turning procedure defies that balance. For the following illustrative example, start with another 8x16 grid, but on it the long quarter rather than the half as for the half shovel fold example.



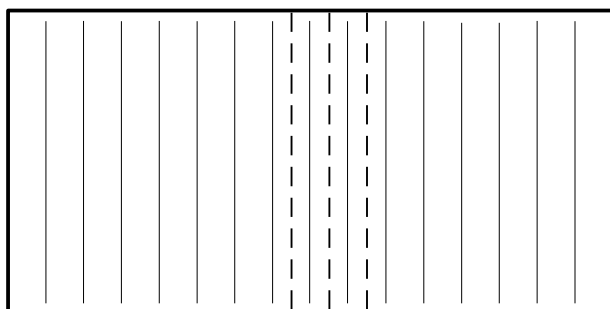
Rabbit-ear. Leave the ear upright (rather than folding it down to either side).



# Resolution of the Grid

All shovel folding happens on a grid. A larger grid allows more resolution, but doubling the resolution doubles the work and thickness of pleated paper.

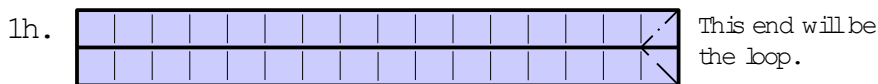
A little extra resolution can be pulled from the grid without actually increasing the overall resolution. While working across the paper with shovel folds, there are points at which the grid could be realigned. When there is any opportunity to skip a grid square (as when skipping squares or starting another sequence) it is possible to skip a fractional square. There need to be pleats at the new position of the grid, so it is best to plan ahead. This can be used to fit a design to a handier dimension of grid, such as 8x16 instead of 8x17.



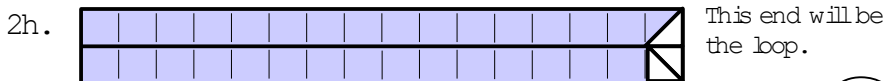
An example of offsetting part of the grid in the middle. The shovel folding sequence for this model will realign to this grid and shortly afterward realign again to the original grid. Halving the pleats is the easiest offset to create in the middle of a grid spanning the whole paper.

# The End Loop

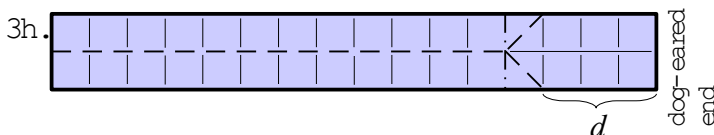
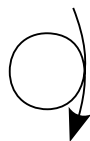
The end loop is a handy little trick to create a hollow loop at the end of the paper using basic shovel folds. The lock is sturdy enough to link two pieces of paper. For this example start with the a 8x16 grid on 12, pleated the long way except for the half, same as for the basic shovel fold.



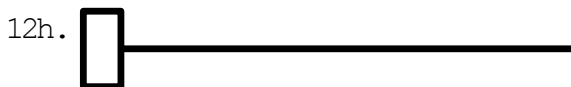
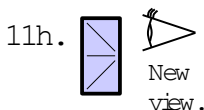
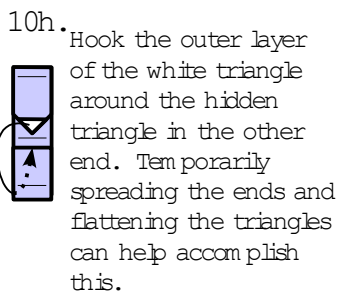
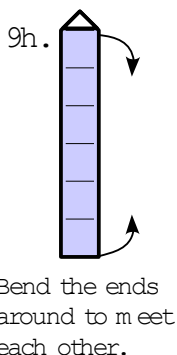
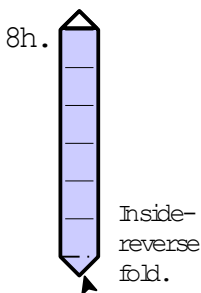
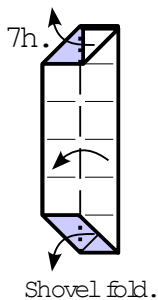
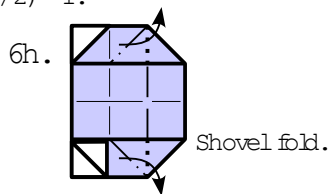
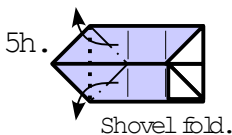
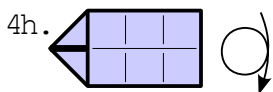
Dog-ear the corners at the end that will form the loop. One dog-ear is mountain and the other is valley. The one which is valley should leave a tiny fudge factor to accommodate the thickness of the paper.



Dog-ear the corners at the end that will form the loop. One dog-ear is mountain and the other is valley. The one which is valley should leave a tiny fudge factor to accommodate the thickness of the paper.



Rabbit-ear. Leave the ear upright (rather than folding it down to either side). If  $w$  is the width measured in grid squares, then  $d = (w/2) - 1$ .



The loop can be shaped however you please, such as round, teardrop, heart or star. The length of the loop is  $w-2$  grid squares. This is an easy shovel-folding way to make a fairy-godmother-style magic wand. To finish off the wand, just lock the end.

# Locking the End

These pleats like to splay out at the end. It is easy to lock the layers of paper together and keep the lock hidden. Lets finish off the wand from the end loop example by locking the other end. Fold through step 12h above.



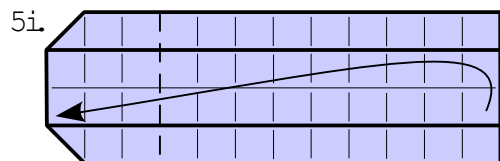
Dog-ear the inner layers together. It is that simple.



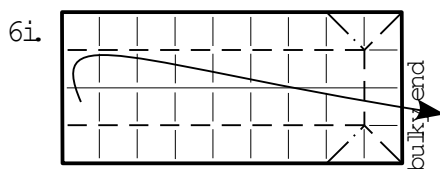
For a looser lock, dog-ear those layers individually.

# Skipping Squares

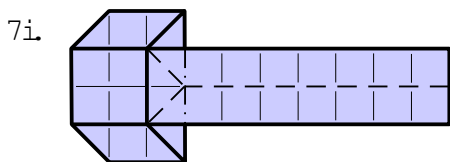
So far each shovel fold followed in the next pleat, but it is also possible to skip one or more squares. This is useful to create round or square elements efficiently.



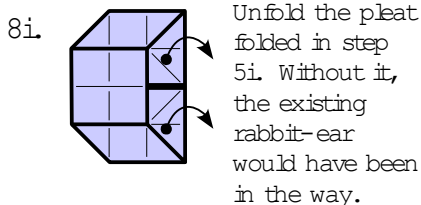
Fold through step 4. Valley fold to get the paper ready for an inverse shovel fold.



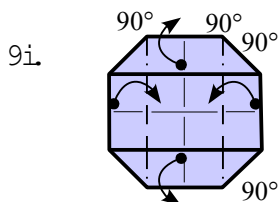
Inverse shovel fold.



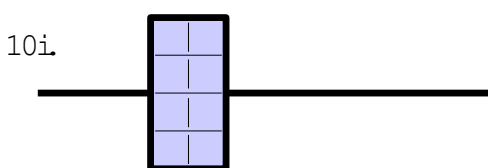
As usual, close up with a rabbit-ear and leave the ear upright.



Unfold the pleat folded in step 5i. Without it, the existing rabbit-ear would have been in the way.



Stand the sides upright, forming a box.



The box is one grid square deep. The upper edge can be shaped to make it rather round. Slightly crushing the corners can increase the effect.

# In Conclusion

These few techniques work together for a wealth of designs and sub designs. A sequence can be reused in other places, like a subroutine and greatly reduce design time and effort once developed and learned or in some cases immediately in the same model if it has repetitive parts. It is most useful for line-drawing style designs, but with a little imagination yields other results too, such as a *Bottomless Cup of Coffee*.