New tools for drafting weaves for independent multi-layer fabrics

Multi layer fabrics are used to:
- increase fabric thickness, e.g., for greater warmth
- allow use of finer yarns on one or both exposed faces while maintaining fabric thickness
- permit certain figuring (ornamentation) techniques

Double-layer fabrics are the most common, but similar considerations apply to fabrics with 3 or more layers. A 4500 years old fragment of 4 layer fabric discovered in Peru indicates this is a very ancient technique.

There are 3 fundamental techniques for weaving multiple layer fabrics:

1) shared weft with separate warp systems for each layer, e.g., using odd-numbered warps to weave the top layer, and even-numbered warps to weave the bottom layer,
2) shared warp with separate weft systems for each layer, e.g., using odd-numbered wefts for top, even-numbered wefts for bottom
3) separate warp and weft systems for each layer, e.g., odd-numbered warps and wefts to weave top layer, even-numbered warps and wefts for bottom layer, which produces truly independent layers

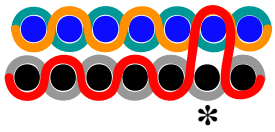
The first two techniques share either a common warp or common weft, thus result in a single composite fabric that incorporates two or more stacked layers of warp yarns in shared weft fabrics, or of stacked weft yarns in shared warp fabrics.

In a fabric using shared warp with separate weft systems, the blue and black circles in the figure to the right would represent the cut ends of the two weft systems while the red represents the shared warp. The relationships would be reversed in a fabric using a shared weft with separate warp systems (red would be shared weft, blue and black would be the separate warp systems)...

Since the shared system tends to reside in the middle, shared weft fabrics will be predominantly warp faced while shared warp fabrics will be predominantly weft faced.

The third technique - separate warp ***and*** weft systems - can create truly independent fabric layers. Generally these layers are "bound" together into a single fabric through "binders" - cuts or misses in the weaves which intentionally violate the separation of the layers in order to bind them together. Exceptions to the use of binders include the weaving of double or triple width fabrics on shuttle looms and the creation of "tubular" fabrics; in such cases it being desired to create truly independent fabric layers, at least over some portion of the cloth.

This figure shows the two separate warp & weft systems weaving independent layers - blue weft with orange & green warps for the top layer and black wefts with grey & red warps for the lower layer. A "binder" is shown above the "*" where a lower layer warp (red) intentionally violates the layer separation rule in order to penetrate and bind the upper layer.



All else remaining unchanged, converting from single layer to double layer requires dividing warp or weft, or both, into two separate systems which requires twice as many yarns in total. For example, a single layer fabric woven at 30 wefts/inch when being converted to double layer shared warp fabric will require 60 wefts/inch - 30 for the bottom layer and another 30 for the top layer.

Doubling the number of warp ends involves major changes to the harnessing. Doubling the number of wefts is much simpler - just halve the fabric take-up per weft insertion.

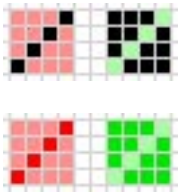
Consequently "shared warp with separate weft systems" is the easiest and most popular multi-layer fabric construction. Shared weft with separate warp systems or separate warp and weft systems are certainly used,

but they do require changing the warp and more extensive loom adjustments, hence are less attractive for short production runs.

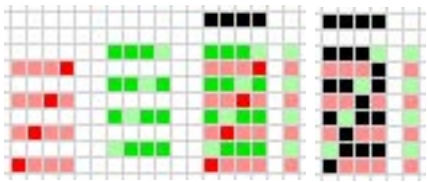
Double layer fabrics using separate warp ***and*** weft systems do have the great advantage of allowing fully independent fabric in each layer. All ornamentation techniques are available, allowing the two visible faces to be truly independent designs. Although the two layers are independent, the "binders" added to join them into a single fabric need careful design to ensure that they have minimal effect on the visible surfaces; in practice this means that binding positions must be found where the lower warp is already up towards the centerline and can be passed over a top-layer weft which is already down towards the centerline, or vice-versa. Spacing of binders is also important: too frequent binding reduces the flexibility of the fabric while too infrequent binding results in "blister" areas where the two-layer nature of the fabric becomes too apparent (sometimes done intentionally).

Double layer fabrics using a shared warp or weft are more constrained. In a shared warp fabric the warp is part of both layers, so designing a warp-faced surface forces the other layer's visible surface to be weft-faced. The layer binding is an integral part of the weave, not a separate consideration as in the true double-layer fabrics.

A quick overview of drafting shared warp, separate weft constructions



Consider the 4x4 twills to the right. The first is a weft faced twill we want to weave on the top surface of a shared-warp double fabric; the second is its inverse, i.e., a warp-faced twill when viewed through the fabric, which is to say a weft-faced twill when viewed from the back side, to be used for the bottom layer. Combining these two weaves will create weft-faced surfaces on both the fabric's visible surfaces (and warp-face twills facing the center of the fabric). In the second row I've "colorized" the cut marks so we will be able to tell them apart - strong red for the top (#1) layer's weave and strong green for the bottom (#2) layer's weave.



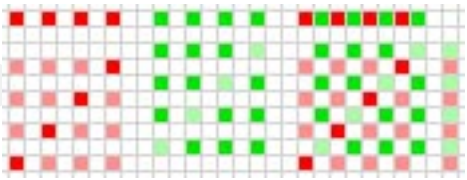
These weaves are expanded to place the top layer weft first (reading upwards) and bottom layer weft second as shown here. We are simply alternating the wefts, one top, one bottom, one top, one bottom,... The warps, of course, are common to both layers.
First I show the top layer weave (red) on the odd-numbered wefts and the bottom layer weave (green) on the even-numbered wefts, then I slide them together into the composite weave. The black line above the composite indicates that all warps are shared; the colored column to the right indicates the alternation of the two separate weft systems. The composite is also shown in standard "black = cut" format.

Once the layer weaves have been selected, the only remaining choice is the alignment of those weaves with each other. As shown at the right, there are 4 possible alignments of these two weaves. Some may produce good results, others poor ones, and sometimes it is impossible to find any useful alignments; as mentioned earlier, the shared system imposes many constraints… The analysis of such alignments in shared warp multi-layer fabrics is discussed in a separate paper.

A common example of shared warp separate weft fabrics are the widely used *Pick and Pick* or *Pick Pick and Pick* upholstery constructions in which 2 or 3 different colored wefts inserted in rotation are stacked by shared-warp weaves so as to lift one (or more) color towards the surface while burying the other weft(s) into a lower layer. This creates a double-layer fabric in which the top visible layer displays only the desired weft colors while the remaining wefts form the lower layer.
Figuring is done by choosing which weft(s) to stack near the surface. Note that because of the shared system (warp in the example) such fabrics are inherently a single structure, albeit with multiple stacked layers. No separate binding is required.

Separate warp and separate weft - weaving independent layers

When drafting weaves for fabrics with independent layers, each layer's weave must be expanded onto its own **separate** set of warps and wefts. This is the central point about independent layers - each layer is assigned its own unique set of warps and wefts which are not used (except for binding) by any other layer.



The figure to the right shows the same two 4x4 twills used in the previous example, this time being expanded into fully independent layers.

The composite reveals that there are actually 4 different types of crossings:

In-layer thread crossings:

L1 (Layer 1) warp crossing L1 weft - (reds) cut/miss is controlled by the weave assigned to Layer 1

L2 warp crossing L2 weft - (greens) cut/miss is controlled by the weave assigned to Layer 2

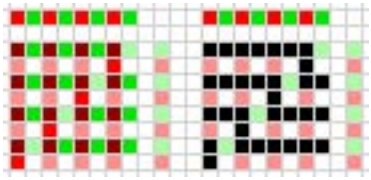
Between-layer crossings:

L1 warp crossing L2 weft - (white) to be controlled by what?

L2 warp crossing L1 weft - (white) " "

To keep the two layers separate and independent we must obey the following rules:
when the top layer is being woven, the bottom layer warps must be left down below that top layer; and
when the bottom layer is being woven the top layer warps must be lifted up above that bottom layer.

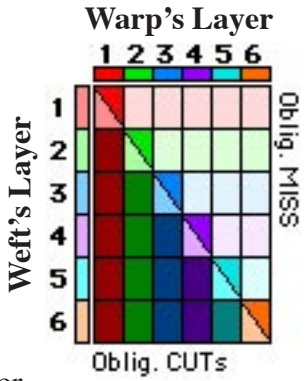
In other words, L1 warp crossing L2 weft must be Cut while an L2 warp crossing an L1 weft must be Miss. This is shown at the right where L1 warp crossing L2 wefts are colored dark red. The standard Cut=black form is also shown for clarity.



Similar logic applies to fabrics with 3 or more layers. Restated in more general form the rules become:

1) *in-layer crossings:* when a warp from any layer crosses a weft from the ***same*** layer, it is controlled by the weave assigned to that layer
2) *between-layer crossings:* when a warp from a higher layer crosses a weft from a lower layer it must be lifted (cut) up out of the way; when a warp from a lower layer crosses a weft from a higher layer it must be left down (miss) beneath the upper layer

With 6 layers there are 6 separate sets of warps and wefts, thus 36 types of warp x weft crossings. These are summarized in the figure to the right which shows the 6 warp systems (layers) as columns and the 6 weft systems (layers) as rows. For example, the cell in Colum 3 (warp layer 3) Row 2 (weft layer 2) represents an L3 warp crossing an L2 weft (and which must be Miss to pass under the higher layer's weft).



The six cells on the diagonal represent the *in-layer crossings*, e.g, L1 warp crossing L1 weft, L2 warp crossing L2 weft, etc. These are split to show that they can be either Cut or Miss depending on the weave assigned to that layer.

The cells to the right and above the in-layer diagonal represent *between-layer crossings* (also called *inter-layer crossings*) in which the warp's assigned layer is lower (higher layer #) than the weft's layer, thus must be left down beneath the weft being inserted. These "*obligatory MISS*" crossings are marked with pale shades of the weft layer's color (weft will be above warp).

The cells to the left and below the in-layer diagonal represent *between-layer crossings* in which the warp's layer is higher (lower layer #) than the weft's layer, thus must be raised up (cut) above the weft being inserted. These "*obligatory CUT*" crossings are marked with dark shades of the warp layer's color (warp will be above weft).

The rules for creating a multi-layer "weave draft" are basically simple - expand each layer's weave to match the occurence of its warps and wefts, combine them into a fully repeated out composite and then apply the "cut whenever a higher layer warp crosses a lower layer weft" principle.

The actual work is tedious, prone to errors and complicated by the need to determine the size of the composite such that every layer weave plays out fully on the number of warps and wefts assigned to it.

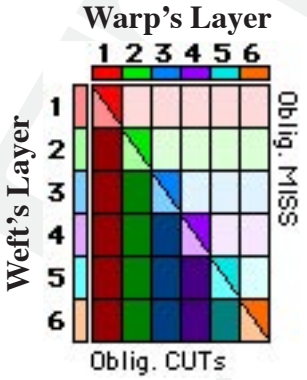
JacqCAD's ***ML Weave Template*** tool takes care of most of that tedium and complexity. It allows you to define the number of layers, up to 6 maximum, set the assignment of warps and wefts to layers, and select the weaves to be applied to each layer.

It then calculates the number of repeats required for full weave play-out and creates a colored weave draft using the color numberings shown in the table to the right of the chart. Color number = 10 x Warp layer + Weft layer.

The *in-layer* colors are 11, 22, 33, 44, 55 and 66 for Miss with colors 1..6 being the corresponding CUT colors. The in-layer Miss colors are bolded in the table.

The "*obligatory MISS*" colors are 21,31,41,51,61, 32,42,52,62, 43,44,45,46, 54,64, and 65 - each representing a lower layer warp crossing a higher layer weft.

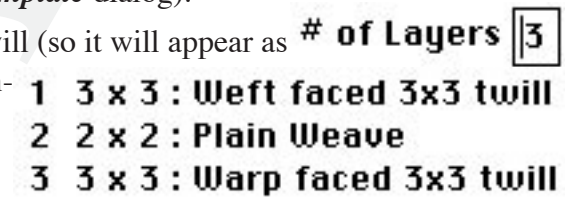
The "*obligatory CUT*" colors are 12, 13,23, 14,24,34, 15,25,35,45, 16,26,36,46, and 56 - each representing a higher layer warp crossing a lower layer weft.



Warp's layer	1	2	3	4	5	6
1	**11**	21	31	41	51	61
2	12	**22**	32	42	52	62
3	13	23	**33**	43	53	63
4	14	24	34	**44**	54	64
5	15	25	35	45	**55**	65
6	16	26	36	46	56	**66**

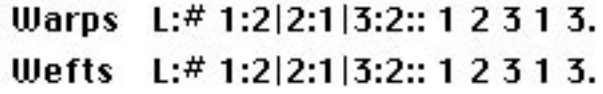
Lets work a simple example (figures from JacqCAD's ***ML Weave Template*** dialog):

3 layers, top is a weft-faced 3x3 twill, bottom is a warp-faced 3x3 twill (so it will appear as a weft-faced twill on the back surface), with the middle layer containing coarse "stuffer" wefts to add bulk, woven in plain weave at half the density of the surfaces.



Our warp assignment will be (rows are layer to which assigned, # = warp # in sequence, {xxx} = layer weave)

L1: 1 4 {3x3 twill}
L2: 2 {2x2 plain weave}
L3: 3 5 {3x3 twill}



So each repeat of that warp assignment pattern will provide 2 warps to the top layer, 1 warp to the middle layer, and 2 warps to the bottom layer. This sequence is entered as **1 2 3 1 3** indicating sequential assignments of warps to layers 1 2 3 1 2. Weft assignment will be similar in this example.

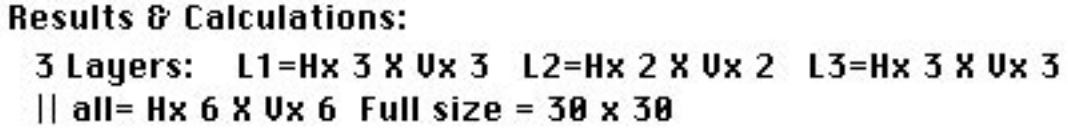
L1 receives 2 warps per repeat; its 3x3 twill thus requires 3 sequence repeats in order to roll out over 6 warps.

L2 receives 1 warp per repeat; its 2x2 weave thus requires 2 sequence repeats in order to roll out over 2 warps.

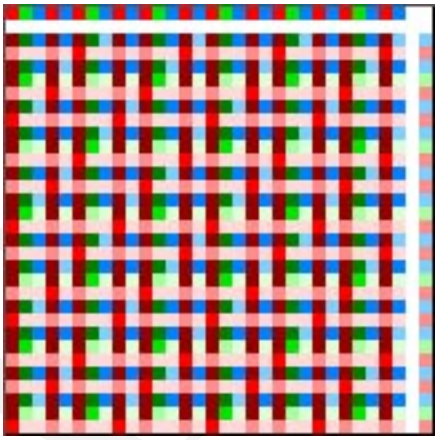
L3 is the same a L1

The composite must fit all the individual layers' sequence repeat requirements - 3 for L1 and L2, 2 for L3. The smallest number that is a multiple of both is 6, so our composite must be 6x5 = 30 warps wide.

In this example the weft assignments and weave requirements are identical, so the composite must include 6 repeats of the weft sequence, thus 6x5 = 30 wefts tall. The results displayed at the bottom of the dialog indicate that L1 & L2 require 3 horizontal warp sequence and 3 vertical weft sequence repeats ("**L1=Hx 3 x Vx 3**") while L2 requires 2 x 2, and the composite needs 6 x 6 for a full size of 30 warps x 30 wefts.



It then creates the composite shown at the right. The color strip in the top row shows the sequence of layer assignments of the warps to layers 1 2 3 1 3… The color strip at the far right shows the sequence of layer assignments of the wefts (reading from bottom upwards to layers 1 2 3 1 3…



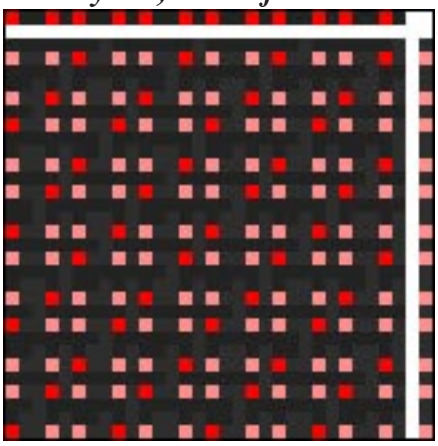
Warp's layer

	1	*2*	*3*	*4*	*5*	*6*
1	**11**	21	31	41	51	61
2	12	**22**	32	42	52	62
3	13	23	**33**	43	53	63
4	14	24	34	**44**	54	64
5	15	25	35	45	**55**	65
6	16	26	36	46	56	**66**

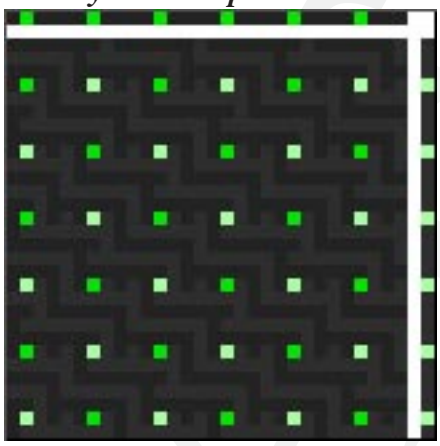
The color numbers are as described previously; the grayed areas are colors that would only be used if more than 3 layers were involved.

Below each layer is shown separately using JacqCAD's ***ML Wve Colors*** dialog to separately visualize each layer:

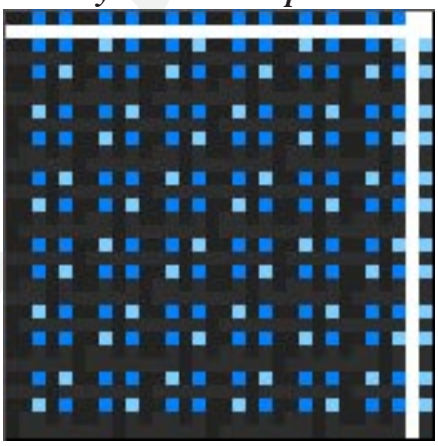
Layer 1, 3x3 weft twill



Layer 2: 2x2 plain weave

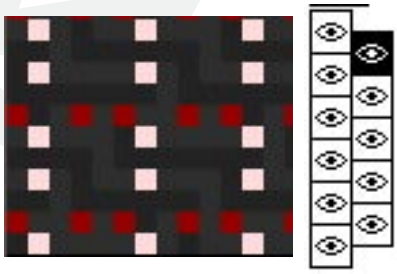


Layer 3: 3x3 warp twill



The ML Wve Colors dialog shows only Layer 1 selected for display - as in the first figure above. It dims all the other colors, showing only Layer 1 in-layer colors, i.e., #1 (cut) and #11 (miss). For the second figure (Layer 2) I simply de-selected the first "eye" and selected the second.

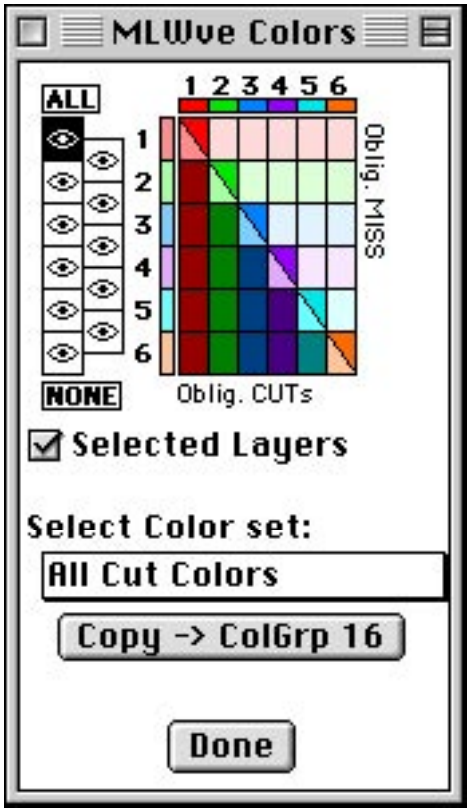
The "eyes" in the second (right hand) column of "eyes" select the between-layer crossings. Selecting only the first "eye" in that colum will display only those between-layer crossings which involve Layer 1 and Layer 2; i.e., colors 12 and 21, as shown magnified at immediate right. Note that the only colored crossings are where Layer 1 warp (darker red) is lifted over a Layer 2 weft, or where a Layer 2 warp is passed under a Layer 1 weft (light red or pink).



Any combination of "eyes" can be selected to isolate combinations of in-layer and between layer crossings. The between layer crossing are important in binding the layers together.

Checking "Selected Layers" changes your image's color table to show only the selected layer or inter-layer crossings. UNchecking it restores the full color table.

Clicking on Done returns you to your image with the color table as currently modified. Re-entering the MLWve Colors dialog lets you restore or otherwise change the current color table..



Color management:

Entering the *ML Wve Colors* dialog loads a special palette into your window, replacing any previous palette. Its colors are selected to help show the different layers.That palette is built-in to JacqCAD but can be changed by the user.

At start-up JacqCAD looks in its home folder for a "***JacqCAD MASTER Palettes***" folder. If it finds one then it looks inside and loads the palette files within into the bottom part of its Options » Change Palette… menu.

In addition, if it finds a palette named "***MLWve_Colors***" it will use that palette instead of the built-in version for the *ML Wve Colors* dialog. This makes it possible for the user to create their own set of multi-layer template colors by changing that palette file.

The important colors are: 11…16, 21…26, 31…36, 41…46, 51…56 and 61…66 which represent the 36 possible warp-layer x weft-layer crossing combinations for up to 6 layers. Colors 1..6 are used for in-layer CUTs.

In addition, colors 9 (cut) and 10 (miss) are used for displaying the "grayed out" crossings. For example if you have chosen to not display layer 1 in-layer crossings, then colors 1 (layer 1 cuts) and 11 (layer 1 misses) will be changed to match 9 and 10 respectively. Note that the pixels in the template still use colors #1 and #11; only the color table has been changed so that #1 and #11 instead of being bright red and pink will now match whatever you have placed in #9 and #10 (by default a dark and light gray).

For convenience colors 100..254 usually contain an abbreviated "system palette" range of colors, colors 0 and 255 as always are fixed at White and Black, and the remaining unused colors (7..8, 10, 17..20, 27..30, etc.) are set to a light gray.

To summarize how the colors are managed:

If Selected Layers is UNchecked, then colors 1..6, 11…16, 21…26, 31…36, 41…46, 51…56 and 61…66 are used as set in the built-in or "***MLWve_Colors***" palette (if found).

If Selected Layers is checked, then the UNdisplayed crossings are colored to match colors 9 or 10 depending on whether they are Cut (in-layer CUT or *obligatory CUT*) or Miss (in-layer MISS or *obligatory MISS*) .

Binding the independent layers into a single fabric:

Up to this point the layers have been completely independent; indeed, if woven that way they will come off the loom as separate fabrics (which, on a loom with a true shuttle, lets you weave fabric wider than the loom).

Usually a single fabric is desired so the weaves are modified to "bind" the layers together. This is done by violating the separation of the layers - either by passing a higher layer's warp under a lower layer's weft, of by raising a lower layer's warp over a higher layer's weft. In other words, by changing one of the between-layer crossings to change a cut in a higher layer to a miss, or to change a miss in a lower layer to a cut.

In most cases one wants to bind with minimum disturbance to the layers themselves. An exception would be to when desiring to produce a dimpled "mattress" appearance, in which case one would place binders which maximize the disturbance.

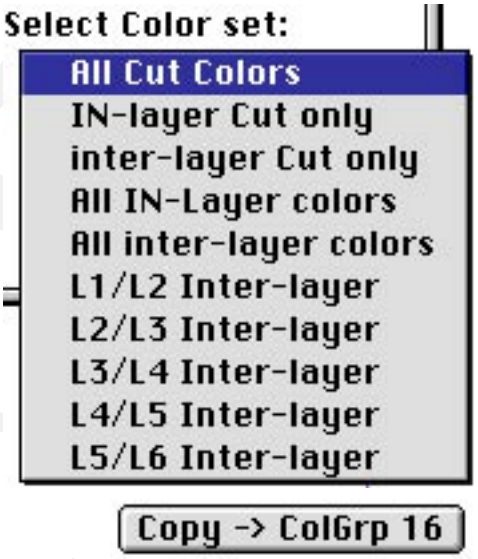
Minimizing disturbance means that the binding should occur between adjacent layers - e.g., between L1 and L2 or between L2 and L3, but not directly between L1 and L3.

The "context" is an important consideration- for example, if you intend to bind two layers by dropping an upper layer warp below a lower layer weft (i.e., changing a Cut into a Miss), the least disturbance will occur if that upper layer warp has been down (Miss) within the layer before and after the binding site. In other words, if that warp has been running along the underside of the upper layer around the spot at which you propose to lower it under the lower layer's weft.

Similarly, disturbance will be minized if the lower layer's weft has been running along the upper surface of that lower layer around the spot at which you propose to let the upper layer's warp pass under it.

The usual approach is to select the relevant layers, e.g., Layer 2, Layer 3 and their between-layer crossings, click Done to return to the weave template with all other crossings colors grayed out and then manually insert binders by using colors 0 and 255 to insert Miss and Cut marks in the selected inter-layer. Repeat the cycle to view and bind other layers...

The "***Select Color set:***" and "***Copy -> ColGrp 16***" functions provide an alternate approach by letting you load a set of colors into Color Group 16 which can then be used to create masks to protect all except the selected colors (or only the selected colors). The two techniques are complimentary - you might want to display L2, L3 and L2/L3 but also create a mask which protects all except the L2/L3 between layers colors you intend to edit for binding...



The color group can also be used in ***Change Colors*** or ***Convert Select to Weave*** for quick selection of the relevant colors.

Simply select the desired set of colors (Help Balloons are provided to give a more complete description of each set) and then click on "***Copy -> ColGrp 16***"

The ***ML Weave Template*** dialog creates a template in the Clipboard, ready for Pasting into some window, rather than creating a new window itself. Though this seems to require an extra step (File > New) to create a window, this approach was chosen to make it easier to Paste several templates into a single window. It is usually the case that the designer will be drafting a family of weaves rather than a single one - for example to bring different wefts to the visible surfaces for figuring. The design of binders for the entire family is best done in a single window which shows all the related weaves rather than in multiple windows each showing only a single weave.

Because the Clipboard is used, a New'ed window may not have the expected color table. This will be remedied the first time the ***ML Wve Colors*** dialog is called, so just Paste, Set into image (even if it doesn't look right) and then enter the ***ML Wve Colors*** dialog...