In this paper we will describe some macros that we have written to generate contrasts for the GLM procedure. The CONTRAST statement is a powerful tool for analyzing experiments using planned contrasts. It is clear that it would be more powerful if it were possible to indicate certain common contrasts concisely instead of writing out the coefficients. In fact, this facility is provided in the REPEATED statement. With it one can request any of several sets of contrasts including orthogonal polynomial contrasts for trend analysis. It is easy to see most contrasts involve just 5 concepts which are:

1. One level compared to another (simple comparison).
2. The average of one set of levels compared to the average of another set of levels (complex comparison).
3. Orthogonal polynomial contrasts.
4. Comparisons restricted to a level of another factor (or factors).
5. Interactions of one or more comparisons with another.

It would dearly be useful to be able to specify contrasts based on these concepts for factors which are not repeated measures.

Another case of interest is that of what one might call modified factorial treatment structures. The most common example of this might be factorial plus control. Once again the CONTRAST statement can be used to analyze these experiments, but again a way to generate the coefficients automatically would make the CONTRAST statement a more effective tool.

The set of macros we have written is designed to allow one to use a concise syntax to request the desired contrasts. The macros generate the required CONTRAST statements and allow one to use more fully the power of the GLM procedure.

In this paper we will use examples to show how these macros may be applied. Figure 1. is a formal syntax description. In a final section we discuss programming considerations.

For the user there are four new statements added to those already in the GLM procedure, BEGIN, FACTOR, SUBFAC, and COMPARE. The BEGIN statement is technical and is needed to reset certain macro variables. The FACTOR statement declares the number and names of the levels for a given factor. The SUBFAC statement allows us to work with modified factorial structures. The COMPARE statement generates contrasts using information from the FACTOR and SUBFAC statements.

**Factorial Plus Control Example**

The first example is from Winer (1971), pp. 468-473. This study is a factorial experiment plus control. Two doses of radiation are applied to four age groups of subjects. In addition there is a control group receiving no radiation (for which ages are unclassified). The measurements are scores of learning ability. To see how this experiment might be analyzed, assume the data for the study is in a data set called WINER, that the response variable is called SCORE, and the nine treatment combinations are in a variable TRT with levels 1 to 9. Level 1 is the control, levels 2 to 5 are the four age groups at the low dose and levels 6 to 9 are the age groups at the high dose.

The data could be analyzed using the following set of statements.

```plaintext
BEGIN;
FACTOR TRT(9);
SUBFAC TRT DOSE(2)*AGE(4) 2 TO 9;
PROC GLM DATA=WNER ORDER=INTERNAL;
CLASSES TRT;
MODEL SCORE = TRT;
COMPARE DOSE;
COMPARE AGE;
COMPARE TRT(1 VS 2 TO 9 (CTRL VS. TRTMNT));
QUIT;
```

The levels defined by the FACTOR statement must agree with the levels in the variable TRT. (The statement prints a table of levels that can be checked with those in the GLM procedure output.)

The SUBFAC statement defines subfactors for dose and age. (Note: As with the GLM procedure the second factor changes most quickly.)

The first COMPARE statement tests the effect of DOSE by generating the contrast statement:

```plaintext
CONTRAST "DOSE" TRT 0 1 1 1 -1 -1 -1 -1 -1;
```

The next COMPARE statement tests the effect of AGE by creating the contrast
Syntax for Contrast Generating Macros

Statements used before the GLM procedure statement.

BEGIN: (Technical needed to reset global macro variables)

FACTOR variable( Number of levels or level names ) / <Short=short name for contrast labels>;

SUBFAC variable variable name(# levels or level names)< variable name ( # levels or level names), etc. > list of associated main factor levels ;

Statements used after the MODEL statement.

COMPARE variable «choice» < *variable«choice»>, etc. > < AT variable level <variable level, etc. > > < / options for contrast statement > ;

where the choices are

default
level1 VS level2
VS level
list of levels VS 2nd list of levels <(user supplied label)>
POLY deg
POLY
LR
LQR

effect
simple comparison
complex comparison
Orthogonal polynomial contrast of the given degree.
Orthogonal polynomial contrast (all degrees).
Linear and residual polynomial contrasts.
Linear, quadratic and residual contrasts.

Figure 1.

Another Example

The next example comes from a study of Wallace Pill at the University of Delaware (personal communication). Tomato seeds are germinated in commercial-peat-lite and gel and dry weight is measured at intervals after germination. The design is a randomized complete block design
with 3 blocks and with 2 factors medium and day. The levels of medium are commercial peat-lite and gel with 0.5, 1.0, 2.0, and 3.0 fold Hoagland solution. Plants are harvested 8, 12, 16, 20 and 24 days after germination...

Notice that MEDIUM is an interesting factor in that it is both qualitative and quantitative. In an analysis it is useful to separate it into Peat-Lite and a GEL factor. The SUBFAC statement is a convenient tool for doing this as we will see below.

We wish to test the following hypotheses.

1. Gel by Day Interaction.
2. Day by Peat-Lite vs Gel.
3. Linear Trend and Residual for Gel within Day 24.
4. Linear Trend and Residual for Day within Media.
5. Linear Trend of Day by Peat-lite vs Gels.

The set of commands using the contrast generating macros are

```
BEGIN;
FACTOR MEDIUM(PL .5H 1H 2H 3H) / S= ;
SUBFAC MEDIUM GEL(.5 2 3) .5H TO 3H
FACTOR DAY(8 12 16 20 24) / S=D;
PROC GLM DATA=GEL ORDER=INTERNAL ;
CLASSES R MEDIUM DAY ;
MODEL DRYWT = R MEDIUM DAY MEDIUM-DAY
COMPARE DAY-GEL ;
COMPARE DAY'MEDIUM (PL VS .5H TO 3H (PL vs. GEL))
COMPARE DAY(LR) AT MEDIUM PL ;
COMPARE DAY(LR) AT MEDIUM .5H;
COMPARE DAY(LR) AT MEDIUM 1H;
COMPARE DAY(LR) AT MEDIUM 2H;
COMPARE DAY(LR) AT MEDIUM 3H;
COMPARE DAY(LR)-MEDIUM
QUIT;
```

In Figure 2 we show the output of the FACTOR and SUBFAC statements along with the class level information from the GLM procedure. We can also check that the levels of the subfactor correspond properly to levels of the main factor. Notice that the names of the levels in the FACTOR statement do not need to be the same as in the data set as long as they correspond correctly. This allows some freedom in creating labels for contrasts. In particular, long names can be replaced with short ones.

Looking at Figure 2b we see the output from the generated contrasts. Here another way to control labels is illustrated for both MEDIUM and DAY. The SHORT (5) option was used to give a shorter name for each of these variables so that labels can stay within the 20 characters allowed. In fact, MEDIUM is replaced by empty text since this factor is implied by context.

It is not possible to list all the CONTRAST statements generated. We have selected the ones from

```
COMPARE DAY(LR) AT MEDIUM PL ;
```

The contrasts are displayed in Figure 2b. The LR choice is a convenient way to use polynomial contrasts since it makes it easy to test linear trend and deviation from linear trend. (The LQR choice extends this to quadratic trend). The spacing is determined by the levels in the FACTOR or SUBFAC statement. The coefficients of the trend analysis are carried to high precision to ensure the estimability of the contrasts.

Note: The orthogonal polynomial contrasts generated here are for balanced data.

A Final Example

We conclude with an example on the tissue culture of petunias (Personal communication, R. McCordell and J. Frett, University of Delaware). This experiment is notable in that it has two factorials plus a control. Plant material is to be cultured in an agar medium containing either 0 or 10 units of BA, a growth hormone. All plant material is subjected to one of 13 pretreatments. One is a control. In the next six a vacuum treatment is used to expose the plant material to BA at either 0, 500 or 1000 units for 5 or 10 minutes. In a final six the material is soaked in a solution of 0, 500 or 1000 units of BA for either 10 to 20 minutes. (The experiment is a randomized complete block design.) The variable tested is the index of productivity IP which measures how efficiently shoots are produced.

In this study it is desired to analyze factorial structures at each level of the medium. It is also desired to compare the control to the average of the soak and the vacuum pretreatments within each medium and to compare soak to vacuum.

Below VACUUM is the name for the 13 pretreatments and MEDIUM stands for medium. In the vacuum pretreatments BAV is the subfactor for BA and V is the subfactor for time in the soak pretreatments BAS is the factor for BA and SK is the factor for time. The following commands will do the analysis.

```
BEGIN ;
FACTOR VACUUM(13) / S=;
FACTOR MEDIUM(O 10) /S=M
SUBFAC VACUUM V(5M 10M)
*BAV(O 500 1000) 2 TO 7;
SUBFAC VACUUM SK(10M 20M)
*BAS(O 500 1000) 8 TO 13;
PROC GLM DATA=VACUUM ORDER=INTERNAL ;
CLASSES BLOCK VACUUM MEDIUM ;
MODEL IP = BLOCK
```
VACUUM MEDIUM VACUUM MEDIUM;
COMPARE VACUUM(1 VS 2 TO 7 (C VS. VAC.))
AT MEDIUM 0;
COMPARE VACUUM(1 VS 2 TO 7 (C VS. VAC.))
AT MEDIUM 10;
COMPARE VACUUM(1 VS 8 TO 13(C VS. SOAK))
AT MEDIUM 0;
COMPARE VACUUM(1 VS 8 TO 13(C VS. SOAK))
AT MEDIUM 10;
COMPARE VACUUM(2 TO 7 VS 8 TO 13
(VAC. VS SOAK)) AT MEDIUM 0;
COMPARE VACUUM(2 TO 7 VS 8 TO 13
(VAC. VS SOAK)) AT MEDIUM 10;
COMPARE V AT MEDIUM 0;
COMPARE V AT MEDIUM 10;
COMPARE BAV AT MEDIUM 0;
COMPARE BAV AT MEDIUM 10;
COMPARE SK AT MEDIUM 0;
COMPARE SK AT MEDIUM 10;
COMPARE V+BAV AT MEDIUM 0;
COMPARE V+BAV AT MEDIUM 10;
COMPARE SK+BAS AT MEDIUM 0;
COMPARE SK+BAS AT MEDIUM 10;
QUIT;

Of course, other contrasts such as orthogonal polynomial contrasts might be performed. We think this example gives an illustration of the possibilities of this system.

Programming Considerations

In addition to the BEGIN, FACTOR, SUBFAC and COMPARE statement macros, there is a statement macro with the same name as every GLM subcommand CLASSES, MODEL, etc. As each statement is encountered, its text is stored in a macro variable. When a QUIT command is encountered, all these statements are expressed as well as the contrasts generated by the COMPARE statements and the analysis is done. (This is accomplished by turning the IMPLMAC option on and off at the appropriate times.) Because of this arrangement some restrictions in the operation of GLM are made. It is not possible to use the program interactively when using the contrast generating macros. Most of the work is done by data steps and the IML procedure which are invoked by the macros.

The programs were written on VM/CMS but use no features specific to this operating system. The programs will be adapted to other systems as we find assistance in making them run on other systems.

References:


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Output for GEL example
Correspondence of levels defined by FACTOR and SUBFAC with class level information

Contrast generating macros eg. W. Pill 16:37 Wednesday, February 6, 1991 1
FACTOR LEVELS OF MEDIUM
1 2 3 4 5
PL .5H 1H 2H 3H
FACTOR LEVELS OF GEL
1 2 3 4
.5 1 2 3
GEL MEDIUM
.5 .5H
1 1H
2 2H
3 3H
Contrast generating macros eg. W. Pill 16:37 Wednesday, February 6, 1991 3
FACTOR LEVELS OF DAY
1 2 3 4 5
8 12 16 20 24
Contrast generating macros eg. W. Pill 16:37 Wednesday, February 6, 1991 4

General Linear Models Procedure

Class Level Information

Class Levels Values
R 3 1 2 3
MEDIUM 5 1 2 3 4 5
DAY 5 8 12 16 20 24

Figure 2

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### Gel Example Contrast Output

<table>
<thead>
<tr>
<th>Contrast</th>
<th>DF</th>
<th>Contrast SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEL-D</td>
<td>12</td>
<td>10.51474218</td>
<td>0.87622852</td>
<td>0.82</td>
<td>0.6252</td>
</tr>
<tr>
<td>PL vs. GEL-D</td>
<td>4</td>
<td>0.50224395</td>
<td>0.12556099</td>
<td>0.12</td>
<td>0.9754</td>
</tr>
<tr>
<td>GEL Ln AT D 24</td>
<td>1</td>
<td>0.57465387</td>
<td>0.57465387</td>
<td>0.54</td>
<td>0.4658</td>
</tr>
<tr>
<td>GEL Rs AT D 24</td>
<td>2</td>
<td>0.63648895</td>
<td>0.31824447</td>
<td>0.30</td>
<td>0.7427</td>
</tr>
<tr>
<td>D Ln AT PL</td>
<td>1</td>
<td>0.34593055</td>
<td>0.34593055</td>
<td>0.33</td>
<td>0.5710</td>
</tr>
<tr>
<td>D Rs AT PL</td>
<td>3</td>
<td>1.38424492</td>
<td>0.46141497</td>
<td>0.43</td>
<td>0.7296</td>
</tr>
<tr>
<td>D Ln AT .5H</td>
<td>1</td>
<td>5.59463444</td>
<td>5.59463444</td>
<td>5.26</td>
<td>0.0262</td>
</tr>
<tr>
<td>D Rs AT .5H</td>
<td>3</td>
<td>0.60883357</td>
<td>0.20294452</td>
<td>0.19</td>
<td>0.9021</td>
</tr>
<tr>
<td>D Ln AT 1H</td>
<td>1</td>
<td>0.18738864</td>
<td>0.18738864</td>
<td>0.18</td>
<td>0.6765</td>
</tr>
<tr>
<td>D Rs AT 1H</td>
<td>3</td>
<td>1.91796952</td>
<td>0.63932317</td>
<td>0.60</td>
<td>0.6173</td>
</tr>
<tr>
<td>D Ln AT 2H</td>
<td>1</td>
<td>1.00628375</td>
<td>1.00628375</td>
<td>0.95</td>
<td>0.3355</td>
</tr>
<tr>
<td>D Rs AT 2H</td>
<td>3</td>
<td>0.25617200</td>
<td>0.08539067</td>
<td>0.08</td>
<td>0.9704</td>
</tr>
<tr>
<td>D Ln AT 3H</td>
<td>1</td>
<td>1.36448339</td>
<td>1.36448339</td>
<td>1.28</td>
<td>0.2629</td>
</tr>
<tr>
<td>D Rs AT 3H</td>
<td>3</td>
<td>2.04889681</td>
<td>0.68296560</td>
<td>0.64</td>
<td>0.5915</td>
</tr>
<tr>
<td>PL vs. GEL-D Ln</td>
<td>1</td>
<td>0.33578547</td>
<td>0.33578547</td>
<td>0.32</td>
<td>0.5767</td>
</tr>
<tr>
<td>PL vs. GEL-D Rs</td>
<td>3</td>
<td>0.16645848</td>
<td>0.05648616</td>
<td>0.05</td>
<td>0.9841</td>
</tr>
</tbody>
</table>

*Original data were unavailable so normal random deviates were used.*

**Figure 2a.**

### GEL example—Some Generated Contrasts

**Contrast "D Ln AT PL"**

<table>
<thead>
<tr>
<th>Contrast</th>
<th>DAY</th>
<th>MEDIUM</th>
<th>DAY</th>
<th>MEDIUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1195228609335</td>
<td>0.47809144373392</td>
<td>0.71713716560078</td>
<td>0.47809144373392</td>
<td>0.1195228609335</td>
</tr>
</tbody>
</table>

**Contrast "D Rs AT PL"**

<table>
<thead>
<tr>
<th>Contrast</th>
<th>DAY</th>
<th>MEDIUM</th>
<th>DAY</th>
<th>MEDIUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1195228609335</td>
<td>0.47809144373392</td>
<td>0.71713716560078</td>
<td>0.47809144373392</td>
<td>0.1195228609335</td>
</tr>
</tbody>
</table>

**Figure 2b**