

# A Graphical User Interface to Generalized Linear Models in MATLAB

Peter K Dunn

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## Abstract

Generalized linear models unite a wide variety of statistical models in a common theoretical framework. This paper discusses GLMLAB—software that enables such models to be fitted in the popular mathematical package MATLAB. It provides a graphical user interface to the powerful MATLAB computational engine to produce a program that is easy to use but with many features, including offsets, prior weights and user-defined distributions and link functions. MATLAB's graphical capacities are also utilized in providing a number of simple residual diagnostic plots.

## 1 Introduction

Generalized linear models (or glm's) were introduced by Nelder and Wedderburn [8] in 1972 as a means of unifying a diverse range of statistical models, including multiple regression, log-linear analysis and probit analysis. The subsequent release of the GLIM software (Francis *et. al.* [4]) enabled the theory to be applied easily to practical problems. Since that time, other popular statistical software packages, including S-Plus (Statistical Sciences [10]) and SPSS (Norusis [9]), have incorporated glm's.

This paper explores the use of MATLAB (The MathWorks Inc. [5]) to implement glm's using a graphical interface in the program GLMLAB. The motivation for the development of the program comes from the need to teach a short course in statistical models, with a section on glm's, to a wide cross-section of students: different students may be familiar with different packages, and perhaps some students not familiar with any statistical package at all. All have a firm grounding in MATLAB, however. There are many advantages with this approach: the rich variety of mathematical and graphical functions of MATLAB are readily available; there is no need to purchase or learn a specialist statistics package (such as GLIM); the same code can be used for all the different MATLAB platforms; the graphical environment makes glm's quickly available to students in a short course. The software is not intended to take the place of commercial packages, but rather to bring the world of glm's to users of MATLAB.

Section 2 provides a theoretical background to glm's. Section 3 discusses some of the methods used in the software. The program itself is discussed in Section 4, and two examples are discussed in Section 5. Section 6 briefly concludes with a short discussion.

## 2 Background Theory

Generalized linear models are based around distributions in the exponential family, such that

$$f_Y(y_i; \theta_i, \phi) = a(y_i, \phi) \exp \{[y_i \theta_i - \kappa(\theta_i)] / \phi\} \quad (1)$$

for known functions  $a(\cdot)$  and  $\kappa(\cdot)$ . In such models,  $\mu_i = \kappa'(\theta_i)$  and  $\text{Var}(y_i) = \phi V(\mu_i)$ , where  $V(\mu_i) = \kappa''(\theta_i)$  is known as the *variance function* and  $\phi$  is the *dispersion parameter*. The linear predictor, usually referred to as  $\boldsymbol{\eta}$ , is given by  $\boldsymbol{\eta} = \mathbf{X}^T \boldsymbol{\beta}$ .

The mean parameter,  $\boldsymbol{\mu}$ , is related to the linear predictor,  $\boldsymbol{\eta}$  through a monotonic, differentiable link function so that  $g_i(\boldsymbol{\mu}_i) = \boldsymbol{\eta}_i$ . (Usually, the link function is the same for all points  $i = 1, \dots, n$ .) The link function can be chosen independently of the distribution, but a popular link function (called the *canonical link function*) is found by setting  $\boldsymbol{\theta}_i = \boldsymbol{\eta}_i$ . The standard multiple linear regression technique sets the link function at  $\boldsymbol{\eta} = \boldsymbol{\mu}$ . Distributions of the form (1) include the normal (Gaussian), inverse Gaussian, gamma, Poisson and binomial distributions.

The deviance of a model (a measure of the distance between  $\mathbf{y}$  and  $\boldsymbol{\mu}$ ) is given by

$$D(y_i, \mu_i) = \sum_{i=1}^n w_i d(y_i, \mu_i)$$

where  $d(y_i, \mu_i)$  is the unit deviance defined as

$$d_i(y_i, \mu_i) = 2 \int_{\mu_i}^{y_i} \frac{y_i - u}{V(u)} du,$$

and  $w_i$  are prior weights.

The  $\mathbf{X}$  matrix can contain quantitative variables and also qualitative variables (also called *categorical* variables, or *factors*). Each level of the factor is identified with a variable. However, there are usually dependencies between the variables. This overparameterization introduces a singular design matrix which must be removed prior to the fitting of any model. There are many different methods available for doing so, including Helmert contrasts (as favoured by S-Plus), orthogonal polynomials, sum-to-zero constraints and corner-point parameterizations (as in GLIM). All are different methods of introducing qualitative variables by having  $k - 1$  independent variables for a variables with  $k$  levels.

The theory of glm's has been documented by Nelder and Wedderburn [8], McCullagh and Nelder [6] and more briefly by Dobson [2] among others.

### 3 Methods

The algorithms for fitting glm's to data are well established and robust (see McCullagh and Nelder [6] and Nelder and Wedderburn [8]). The maximum likelihood estimates of  $\boldsymbol{\beta}$  can be found using iterative least squares: set  $\boldsymbol{\eta}_0 = \mathbf{X}^T \boldsymbol{\beta}_0$  to be the initial value of the linear predictor, and  $\boldsymbol{\mu}_0$  the corresponding value of the fitted value (recall that  $\boldsymbol{\eta} = g(\boldsymbol{\mu})$ ). The link function is linearized so that

$$\mathbf{z}_0 = \hat{\boldsymbol{\eta}}_0 + (\mathbf{y} - \hat{\boldsymbol{\mu}}_0) \left( \frac{d\boldsymbol{\eta}}{d\boldsymbol{\mu}} \right)_0$$

and is then regressed onto the covariates  $\mathbf{X}$  with quadratic weights defined as

$$W_0^{-1} = \left( \frac{d\boldsymbol{\eta}}{d\boldsymbol{\mu}} \right) V(\boldsymbol{\mu}_0)$$

to produce a new estimate of  $\boldsymbol{\beta}$ . The algorithm is repeated until convergence.

Starting values for the algorithm are easily obtained from the data. Setting  $\boldsymbol{\mu}_0 = \mathbf{y}$ ,  $\hat{\boldsymbol{\eta}}_0$  is then obtained from the link function. In some cases, the method needs some refining (for example, to avoid calculating  $\log 0$  when fitting a log-linear model with zero counts).

The program itself—called GLMLAB—consists of numerous m-files (MATLAB functions and scripts) for fitting generalized linear models. Large portions of the code involve setting up the graphical interface, parsing the input strings and subsequent checks of the inputs, and executing menu commands. The example pieces of code included in the Appendices concern the actual fitting of the model (the code probably of most interest to readers of this paper). The actual fitting algorithm is implemented in the file `irls.m` as shown in Appendix A.

Each distribution used in the program has an associated file that contains the information relevant to GLMLAB; namely the variance function and the deviance (see Appendix C for an example of the gamma distribution). Similarly, each link function has an associated file containing information about the link; namely finding  $\boldsymbol{\eta}$  given  $\boldsymbol{\mu}$ ; finding  $\boldsymbol{\mu}$  given  $\boldsymbol{\eta}$ ; and finding  $d\boldsymbol{\eta}/d\boldsymbol{\mu}$  given  $\boldsymbol{\mu}$ . An example using the probit link function is given in Appendix D. This idea of placing relevant information about distribution and links in files enables the user to create new distributions and link functions with a minimum of knowledge of MATLAB programming.

Parameters such as the maximum number of iterations, the parameter accuracy and the ill-conditioning tolerance, can be altered from one of the drop-down menus on the main screen.

The program produces an output file called `DETAILS.m` that contains information about the variables fitted, and deviance from each model; see Section 5. Screen output gives information such as parameter estimates and residual deviance. This information is easily captured using the MATLAB `diary` command.

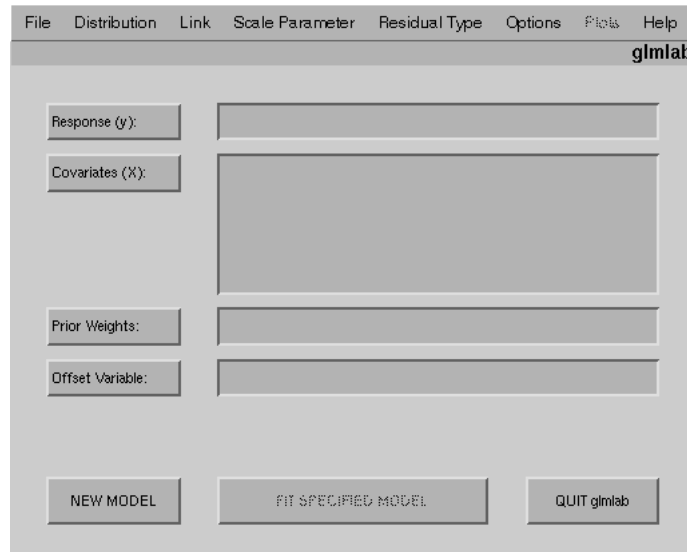


Figure 1: The Main GLMLAB Window

## 4 The Program

There are many functions written for the analysis of particular statistical problems in MATLAB, including a subset of problems in the generalized linear models framework. However, even with the *Statistics Toolbox*, MATLAB lacks a procedure for analysing the full range of generalized linear models.

This section discusses the program GLMLAB that has been written to allow MATLAB to analyse such situations. GLMLAB uses a graphical interface and so is easy to learn and use. Among other features, it allows the user to add distributions and link functions that are not included, and save and load work between sessions. It does not require the user to have access to the *Statistics Toolbox*.

Some aspects of the program are listed below.

### 4.1 Data Entry Windows

There are four areas in the main screen (see Figure 1) for the entry of data or variable names:

- **Response ( $y$ ):** The response (or  $y$ ) variable is entered here (but see Sections 4.6 and 5.2 also).
- **Covariates ( $X$ ):** The covariates, or  $\mathbf{X}$ -matrix, is entered here. The constant (or intercept) is automatically fitted, but this can be altered by the user in the **Options** menu.
- **Prior Weights:** Any prior weights can be entered here (for example, in a weighted regression, to omit structural zeros, or optionally with the binomial distribution as in Section 5.2).
- **Offset:** Any offset variables are entered here. An offset is a variable with a known coefficient (see Section 5.1).

Valid MATLAB workspace variables can be entered, as well as most valid MATLAB commands that produce matrices of the correct type and size. For example, the user could enter `magic(4)` as the covariates, and `[1.0, 3.2, -1.2, 0.5]'` as the response. Some commands, especially if complex, will not work. Using *vector* variables defined in the MATLAB workspace is recommended.

### 4.2 Menu Items

There are eight menu items in the main GLMLAB window (see Figure 1):

- **File:** The file menu opens data files (`*.mat` files); loads and saves models (`*.glg` files); exits from GLMLAB; quits MATLAB.

Error Distribution	Default Link Function	Default Scale Parameter
Normal	Identity $\eta = \mu$	Mean Deviance
Inverse Gaussian	Inverse Quadratic $\eta = 1/\mu^2$	Mean Deviance
Poisson	Logarithm $\eta = \log \mu$	Fixed (at 1)
Binomial	Logit $\eta = \log[\pi/(1 - \pi)]$	Fixed (at 1)
Gamma	Reciprocal $\eta = 1/\mu$	Mean Deviance

Table 1: Default Settings for Chosen Distributions  
*In the table,  $\eta$  is the linear predictor and  $\mu$  is the mean (or  $\pi$  in the binomial case).*

- **Distributions:** In the distributions menu, the user selects the distribution of choice. There are five built-in distributions (normal, inverse Gaussian, gamma, Poisson, binomial). Users can also add their own distributions which will appear in the menu. Distributions have default link functions and scale parameters as shown in Table 1.
- **Link:** In the link menu, the user selects the link function of choice. There are eight built-in link functions (identity, log, square root, power, reciprocal, complementary log-log, probit and logit (or logistic)). Users can also add their own links which will appear in the menu. For each distribution, the default link function is the canonical link (see Table 1).
- **Scale Parameter:** The scale parameter can be set to a fixed (positive) value, or to be estimated by the mean deviance.
- **Residual Type:** Three types of (standardized) residuals can be chosen: deviance, Pearson and quantile. (See Dunn and Smyth [3] for a description of quantile residuals.)
- **Options:** Many options can be set, including recycling fitted values, restoring default options, declaring new models, including the constant term (intercept) in the fit, and changing the fitting parameters.
- **Plots:** After fitting a model, six different plots are available directly from GLMLAB:
  - Residuals vs Response;
  - Residuals vs Covariates (X);
  - Normal Probability Plot;
  - Residuals vs Fitted Values;
  - Residuals vs Transformed Fitted Values: The transformation is to the constant information scale of the distribution; see Nelder [7] and McCullagh and Nelder [6];
  - Fitted Values vs Quantile Equivalents.

Of course, using MATLAB's facilities and the variables returned by GLMLAB into the MATLAB workspace (see Section 4.5), numerous plots can be constructed.

- **Help:** Contains help screens, plus links to the GLMLAB Home Page and on-line manual, and a simple demonstration. By having a quick link to the on-line manual, users have timely help at their disposal. The manual can be found at <http://www.sci.usq.edu.au/staff/dunn/glmlab/glhtml/html/gli.html>. The GLMLAB Home Page can be found at <http://www.sci.usq.edu.au/staff/dunn/glmlab/glmlab.html>

### 4.3 Buttons

There are seven buttons in the main GLMLAB window (see Figure 1); three of these along the bottom are of the most interest.

- **New Model:** Pressing this button prepares GLMLAB for fitting a new model by restoring default settings and clearing variables.
- **Fit Specified Model:** Pressing this button fits the model as currently specified.
- **Quit glmlab:** Quits GLMLAB.

The remaining four buttons on the left of the main window (for example, one is labelled **Response (y):**) open windows for selecting numeric variables from the workspace.

### 4.4 Commands

There are only a few commands that need to be learnt to use GLMLAB:

- **glmlab:** Once in MATLAB, the user starts the program by typing `glmlab` at the MATLAB prompt.
- **fac:** The `fac` command is used to flag a variable as qualitative (see Section 5.1). `fac` uses a corner-point parameterization (as in GLIM) that includes each level of the factor as a dummy variable, and excludes the first column to preserve full-rank.
- **@:** The `@` symbol is used to flag interactions between variables (see Section 5.1).
- **makefac:** The `makefac` command is similar to the GLIM command `%g1`. It allows for easier creation of factors. To create a factor of length 36 that has twelve levels ( $A, B, C, \dots, L$  say), occurring in groups of three (that is,  $A, A, A, B, B, B, C, \dots, K, L, L, L$ ), the variable can be generated using  

```
Newvar = makefac( 36, 12, 3 );
```

in the MATLAB workspace.

### 4.5 Returned Variables

After the fitting of a model, ten variables are made available in the MATLAB workspace:

- **BETA:** The parameter estimates;
- **SERRORS:** The standard errors of the parameter estimates;
- **FITS:** The fitted values;
- **RESIDS:** The residuals;
- **COVB:** The covariance matrix of the parameters;
- **COVD:** The covariance matrix of the differences between parameters;
- **DEVLIST:** The deviance at each iteration of the fit;
- **LINPRED:** The linear predictor,  $\boldsymbol{\eta}$ ;
- **XMATRIX:** The  $\mathbf{X}$  matrix used in fitting the model;
- **XVARNAMES:** The names of the  $\mathbf{X}$ -variables.

### 4.6 Binomial Responses

Binomial responses variables require some special handling. Three link function are unique to the binomial distribution (and are unavailable otherwise from the **Link** menu): the logit (or logistic), probit and complementary log-log link functions. In addition, the response variable must reflect the binomial situation of counts and sample size. In this situation, response variable consists of two columns: the first for the counts, and the second for the sample sizes. (Note that this is different than the convention adopted in S-Plus, where the response has the two columns as the number of successes and the number of failures.) When the data to be analysed is in the form of probabilities, only one column is needed. See Section 5.2 for an example using the binomial distribution.

<code>/glmLAB</code>	Contains general information and files used in starting glmLAB.
<code>/glmLAB/fit</code>	Contains numerous files for fitting the model and parsing the input.
<code>/glmLAB/fit/dist</code>	Contains information about the distributions that can be used.
<code>/glmLAB/fit/link</code>	Contains information about the link functions that can be used.
<code>/glmLAB/plotting</code>	Contains plotting routines.
<code>/glmLAB/misc</code>	Contains other miscellaneous files used in GLMLAB, including formatting and tricks.
<code>/glmLAB/glmhelp</code>	Contains the GLMLAB help menu information.
<code>/glmLAB/glmlog</code>	Contains log files, fitting parameters, and data files that come with GLMLAB.

Table 2: The Structure of GLMLAB

## 4.7 Directory Structure

GLMLAB consists of over 70 MATLAB files in a number of directories (or folders). They are structured as shown in Table 2.

## 5 Examples

### 5.1 Ship Damage Data

McCullagh and Nelder [6, §6.3] give some data concerning wave damage done to cargo carrying ships, available in the file `shipdam.txt`. The data consists of five variables:

- *Ship Type*: Five types of ship are considered (MATLAB variable `Shiptype`);
- *Year of Construction*: 1960–1964, 1965–1969, 1970–1974, 1975–1979 (MATLAB variable `Yearmade`);
- *Period of Operation*: 1960–1974; 1975–1979 (MATLAB variable `Operation`);
- *Aggregate Months of Service* (MATLAB variable `Service`);
- *Number of Damage Incidents* (MATLAB variable `Damage`).

The first three variable are qualitative factors.

The data contains many interesting features that serve to demonstrate features of the GLMLAB software. For example, there are many structural zeros, since (for example) ships made after 1975 cannot have periods of operation before 1975. There is also an observational zero in the data. The authors consider an initial model of the form

$$\begin{aligned}
 & \log(\text{expected number of damage incidents}) \\
 &= \beta_0 + \log(\text{aggregate months of service}) + (\text{effect due to ship type}) \\
 & \quad + (\text{effect due to year of construction}) + (\text{effect due to service period}). \tag{2}
 \end{aligned}$$

The first term after the intercept is a quantitative variable with a known coefficient of 1. Such a variable is known as an *offset*. As is usual with count data, the authors decide to use the Poisson distribution with the logarithm link function. They expect overdispersion due to expected inter-ship variability and so we over-ride the default fixed scale parameter option in GLMLAB and estimate with the mean dispersion.

To fit the model discussed in McCullagh and Nelder [6], variables are entered as shown in Figure 2. Note that the offset variable is entered as `log(Service)`; this shows that GLMLAB can happily accept transformations being entered as variable names. `log(Service)` has been used as the offset because of the model in Equation 2 proposed by McCullagh and Nelder. The variable `Weights` is a vector of prior weights that omits the structural zeros (it is zero for the structural zeros, and one elsewhere). The following options are also set:

- To declare the distribution, choose `Poisson` from the `Distribution` menu.

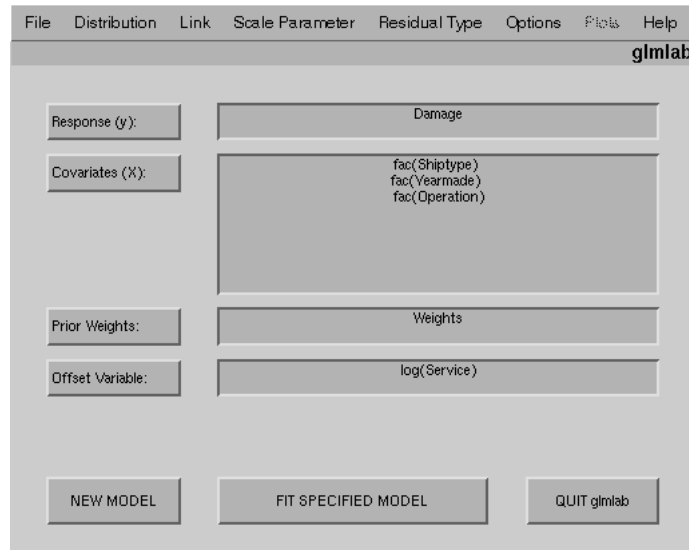


Figure 2: Variables Entered for the Ship Damage Example

- The logarithm link function is the default for the Poisson distribution (it is the canonical link), so no changes need to be made using the Link menu.
- To alter the scale parameter, choose Mean Deviance from the Scale Parameter menu. (For the Poisson distribution, the Scale Parameter, by default, is set to a Fixed Value of 1.)

On pressing the Fit Specified Model button, results are presented on the screen as shown below:

```
>> === INFO :-| =====
Response Variable:      [Damage]
Covariates:            fac(Shiptype),fac(Yearmade),fac(Operation)
- fitting a constant term/intercept
Offset Variable:      log(Service)
Prior Weights Variable: Weights
-----
Estimate      S.E.      Variable
-----
-6.405902    0.270524  Constant
-0.543344    0.220941  Shiptype(2)
-0.687402    0.409369  Shiptype(3)
-0.075961    0.361511  Shiptype(4)
 0.325579    0.293459  Shiptype(5)
 0.697140    0.186170  Yearmade(2)
 0.818427    0.211217  Yearmade(3)
 0.453427    0.290089  Yearmade(4)
 0.384467    0.147143  Operation(2)
-----
Deviance:      38.695052  (change:   -39.883544)
Residual df:   25      (change:     -5)
Scale parameter (dispersion parameter): 1.547802
Output variables: BETA ERRORS FITS RESIDS COVB COVD
                  DEVLIST LINPRED XMATRIX XVARNAMES
```

The results, naturally, agree with those given in McCullagh and Nelder [6]. Variables with numbers following are qualitative variables; the numbers refer to the levels of the variable. They are understood to be in reference to the first level of the variable, the same way in which GLIM treats qualitative variables.

After a model has been fitted, the Plots menu becomes available, and residual plots can be generated to informally examine the residuals. For example, if deviance residuals were chosen from the Residual Type menu, the Residuals vs Transformed Fitted Values plot is displayed on the screen; see Figure 3.

To include an interaction term between (say) Year of Operation and Year of Construction as a covariate, enter the variables into the main window as shown in Figure 4. Pushing the Fit Specified Model button produces the following output:

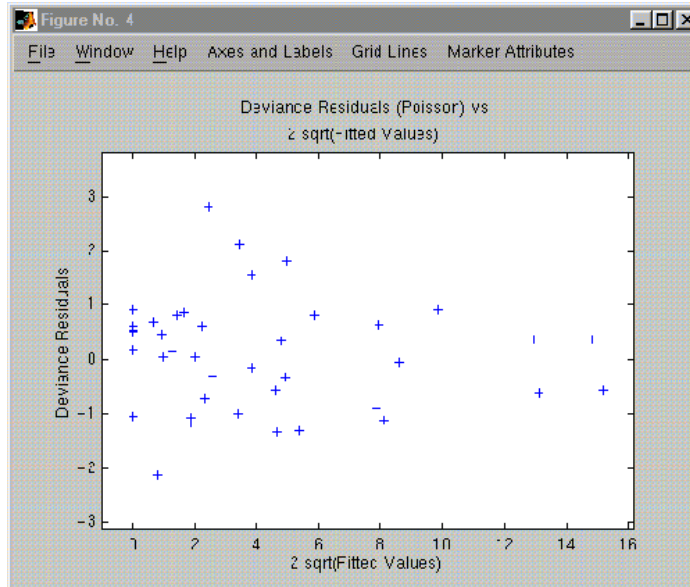


Figure 3: The Deviance Residuals vs the Transformed Fitted Values for the Ship Damage Data

```

INFO :-| =====
Response Variable:      [Damage]
Covariates:            fac(Shiptype),fac(Yearmade),fac(Operation),fac(Yearmade)@fac(Operation)
  - fitting a constant term/intercept
Offset Variable:       log(Service)
Prior Weights Variable: Weights
-----
      Estimate      S.E.      Variable
-----
      -6.515032     0.299392   Constant
      -0.546126     0.225026   Shiptype(2)
      -0.689259     0.416861   Shiptype(3)
      -0.076216     0.368217   Shiptype(4)
       0.321635     0.298830   Shiptype(5)
       0.860880     0.253208   Yearmade(2)
       0.972409     0.312793   Yearmade(3)
       0.280620     0.330341   Yearmade(4)
       0.668061     0.305957   Operation(2)
      -0.387270     0.376715   Yearmade(2)@Operation(2)
      -0.340986     0.404893   Yearmade(3)@Operation(2)
       0.000000     aliased    Yearmade(4)@Operation(2)
-----
Deviance:              36.907591   (change:    -1.787460)
Residual df:           23        (change:     -2)
Scale parameter (dispersion parameter): 1.604678
Output variables:      BETA SERRORS FITS RESIDS COVB COVD
                       DEVLIST LINPRED XMATRIX XVARNames

```

The final parameter is *aliased*, in that it contains no information that is not already contained in the other variables.

## 5.2 Example: Binomial Data

Because of the particular nature of the binomial distribution, a simple example is considered here. The data comes from Bliss [1] (cited in Dobson [2]) and is shown in Table 3. The data involves counting the number of beetles killed after five hours of exposure to various concentrations of gaseous carbon disulphide ( $CS_2$ ). The analysis concerns estimating the proportion  $r_i/n_i$  of beetles that are killed by the gas.

The variables in MATLAB were named *Dose*, *Number* and *Killed* for the obvious variables. Dobson analyses the data using a logit link function. The data is entered into GLMLAB as shown in Figure 5. In particular, take note of the entry for the response variable, which is entered as two columns. After choosing



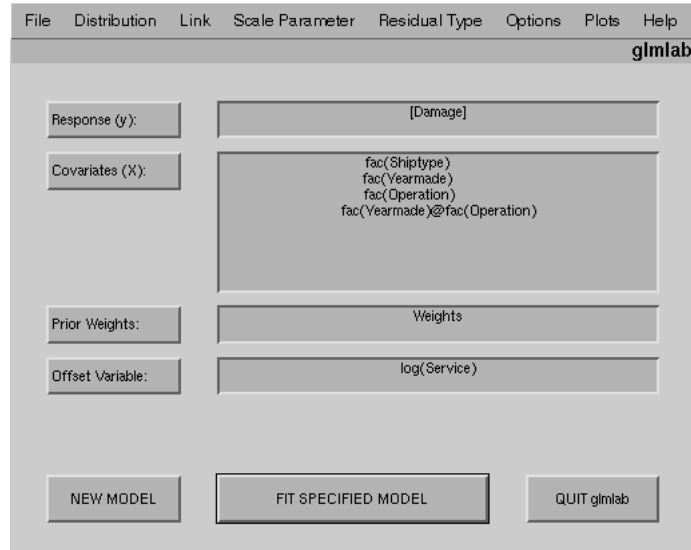


Figure 4: Fitting Interaction Terms

Dose ( $\log_{10} \text{CS}_2 \text{mg l}^{-1}$ )	Number of Beetles ( $n_i$ )	Number of Beetles Killed ( $r_i$ )
1.6907	59	6
1.7242	60	13
1.7552	62	18
1.7842	56	28
1.8113	63	52
1.8369	59	53
1.8610	62	61
1.8839	60	60

Table 3: Beetles Mortality Data

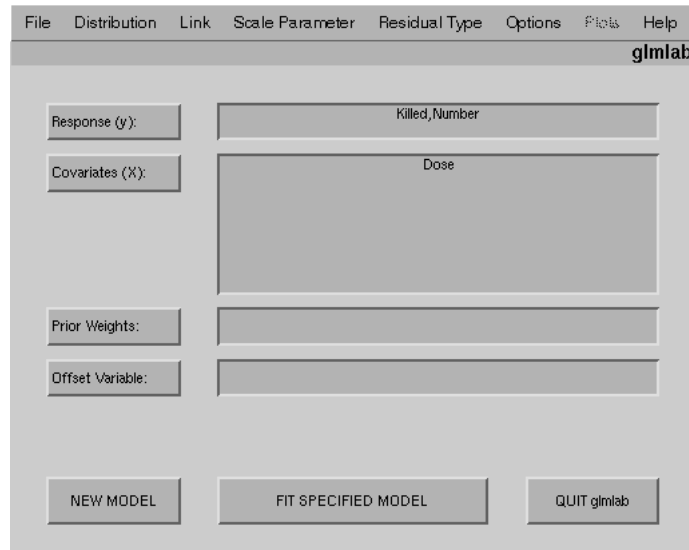


Figure 5: Variables Entered for the Beetle Mortality Example

the binomial distribution and the logit link function from the menus, the results are given below:

```

=== INFO :-| =====
Response Variable:      [Killed,Number]
Covariates:            Dose
- fitting a constant term/intercept
-----
      Estimate      S.E.      Variable
-----
      -60.717455    5.180701  Constant
       34.270326    2.912134  Dose
-----
Scaled deviance:      11.232231      Link: LOGIT
Residual df:         6      Distribution: BINOML
Scale parameter (dispersion parameter): 1.000000
Output variables:    BETA SERRORS FITS RESIDS COVB COVD
                    DEVLIST LINPRED XMATRIX XVARNAMES

```

The results agree with those given in Dobson. An alternative method is to fit the model using the probabilities  $r_i/n_i$  as the response (that is, one column of probabilities), and use  $n_i$  as the prior weights. The parameter estimates are identical. The residual plotted against the fitted values (produced using the Plot, Residual vs Fitted Value option) in Figure 6 shows a possible curvature.

## 6 Discussion

The program GLMLAB has been discussed for using MATLAB to fit the wide class of statistical models known as generalized linear models. The software is not meant to replace commercial packages, but to provide MATLAB with facilities for dealing with such a class of models. While GLMLAB may not be as powerful as programs like GLIM and S-Plus, it offers an easy to use introduction to generalized linear models in a user-friendly and powerful environment. It allows many different types of models to be fitted, including common models such as logit models, ANOVA, and multiple regression.

## References

- [1] C. I. Bliss. The calculation of the dosage-mortality curve. *The Annals of Applied Biology*, 22:134–167, 1935.
- [2] Annette J. Dobson. *An Introduction to Statistical Modelling*. Chapman and Hall, 1983.

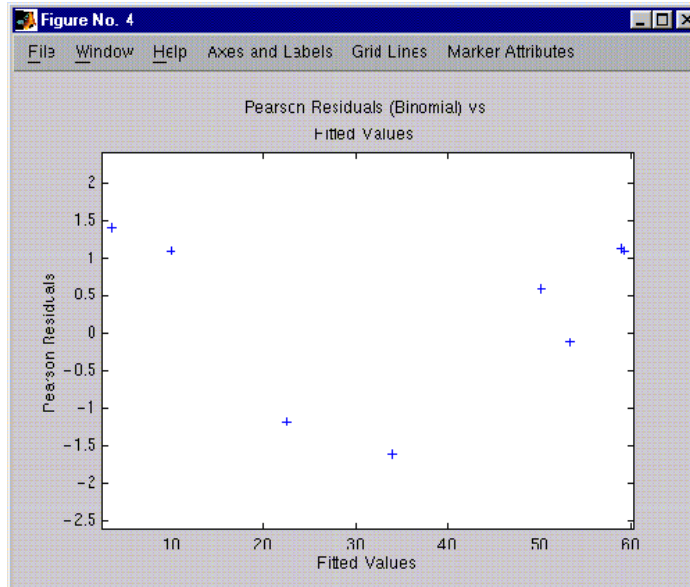


Figure 6: Residuals Versus Fitted Values for the Beetle Mortality Example

- [3] Peter K. Dunn and Gordon K. Smyth. Randomized quantile residuals. *The Journal of Computational and Graphical Statistics*, 5:1–10, September 1996.
- [4] Brian Francis, Mick Green, and Clive Payne. *The GLIM System: generalised linear interactive modelling. Release 4 Manual*. Clarendon Press, 1993.
- [5] The MathWorks Inc. *MATLAB Reference Guide*, August 1992.
- [6] P. McCullagh and J. A. Nelder. *Generalized Linear Models*. Number 37 in Monographs on Statistics and Applied Probability. Chapman and Hall, second edition, 1994.
- [7] J. A. Nelder. Nearly parallel lines in residual plots. *The American Statistician*, 44(3):221–222, August 1990.
- [8] J. A. Nelder and R. W. M. Wedderburn. Generalized linear models. *Journal of the Royal Statistical Society, A*, 135:370–384, 1972.
- [9] M. J. Norusis. *SPSS for Windows: base system user's guide, release 6*. SPSS Inc., 1993.
- [10] Statistical Sciences, Inc. *S-PLUS User's Manual, Version 3.3 for Windows*, 1995.

## A The Function `irls.m`

The function `irls` implements the iterative reweighted least squares algorithm that finds estimates of  $\beta$ .

```
function [b,mu,xtwx,devlist,l,eta]=irls(y,x,m)
%IRLS Iteratively reweighted least squares for use with glmlab
%USE: [b,mu,xtwx,devlist,l,eta]=irls(y,x,m)
% where y is the vector of y-variables;
%       x is the matrix of x-variables;
%       m is the vector of sample sizes for a binomial distribution.
%       For other distributions, it is not needed (or use a dummy).
%       b is the vector of parameter estimates
%       mu is the fitted values
%       xtwx is the matrix X'*W*X
%       devlist is the deviance for each iteration of the fit.
%       l is the labels for linearly independent columns of x.
%       eta is the linear predictor.

%Copyright 1996, 1997 Peter Dunn
%Last revision: 20 October 1997

%Extract info:
extractgl; %extract GLMLAB_INFO_

%load default parameter settings
clear paramtrs; %to ensure reloading of parameters
[toler,maxits,illctol]=paramtrs; %reload parameters

%obtain information about the model to fit
distn=GLMLAB_INFO_{1}; %distribution
link=GLMLAB_INFO_{2}; %link function
format=GLMLAB_INFO_{7}; %output display
fitvals=GLMLAB_INFO_{19}; %fitted values
weights=GLMLAB_INFO_{16}; %prior weights
offset=GLMLAB_INFO_{17}; %offsets

%determine files that contain distribution and link information
if isstr(link),
    linkinfo=['l',link]; %the file containing link info
else
    linkinfo='lpower'; %link info if a power link
end;
distinfo=['d',distn]; %the file containing distribution info

%remove aliased variables from the fit
xx=x; %make other copies
oo=offset;
mm=m;
l=alias(x); %determine aliased variables
x=x(:,l); %only use unaliased variables

%remove points with zero weights from the fit
if any(weights==0), %removes weights==0 from fitting

    zeroind=find(weights==0);
    allmat=[y,m,weights,offset,x,fitvals];
    allmat(zeroind,:)=[];

    if size(allmat,2)==6, %if new fit, fitvals is empty
        fitvals=allmat(:,6);
    end;

    x=allmat(:,5:size(allmat,2)-1);
    y=allmat(:,1);
    m=allmat(:,2);
    weights=allmat(:,3);
    offset=allmat(:,4);
```

```

%check again for aliasing
l=alias(x);
x=x(:,l);

end;

%Starting values
if GLMLAB_INFO_{5}&&(~isempty(fitvals)),

    %If 'Recycle fitted values' option is selected, use fitted values
    %as starting point:
    mu=fitvals;

else

    %else usually use the actual observations and the starting point for the
    %fitted values; in some cases we must fiddle to avoid problems with zeros.
    if strcmp(link,'logit')|strcmp(link,'complg')|strcmp(link,'probit'),

        mu= m.*(y+0.5)./(m+1); %over m+1 in the general case; McC and Nelder p 117

    elseif strcmp(link,'log')|strcmp(link,'recip'),

        mu=y+(y==0);          %remove 0's that may be there

    else

        mu=y;

    end;

end;

%initialise
its=-1;          %number of iterations
devlist=[];     %list of deviances after fits
clear allmat

rdev=sqrt(sum( y.^2)); %residual deviance
rdev2=0;        %dummy to enter loop

b=zeros(size(x,2),1); %initial beta
b2=100*ones(size(x,2),1); %dummy to enter loop
b(1)=-10;       %extra precaution to enter loop

eta=feval(linkinfo,mu,m,'eta'); %eta=Xb + offset

%iterate!
while ( ( abs(rdev-rdev2) > toler) )&(its<maxits),

    %while: (rdev is changing;or max its not reached) and b still changing

    detadmu=feval(linkinfo,mu,m,'detadmu'); %d(eta)/d(mu)
    vfun=feval(distinfo,1,y,mu,m,weights); %variance function
    fwts=( 1./((detadmu).^2) ./ vfun).*weights; %fitting weights
    z=(eta-offset+(y-mu).*detadmu); %adjusted dependent var
    xtwx=x'*diag(fwts,x); %X'WX

    b2=b;
    b=(xtwx)\( x'*diag(fwts,z) ); %next beta

    eta=(x*b)+offset; %linear predictor, eta
    mu=feval(linkinfo,eta,m,'mu'); %means, mu
    rdev2=rdev; %last residual deviance
    rdev=feval(distinfo,2,y,mu,m,weights); %residual deviance
    its=its+1; %update iterations
    devlist=[devlist;rdev]; %list of deviances for fits

end;

```

```

devlist(1)=[]; %remove initial empty entry

%Issue warnings where appropriate
if its>=maxits,
    disp(' ');disp(' * MAXIMUM ITERATIONS REACHED WITHOUT CONVERGENCE');
    disp([' (This is currently set at ',num2str(maxits),')']);
end;

if (rcond(xtwx)<illctol),
    disp(' * ILL-CONDITIONED COVARIATE MATRIX');
end;

if (rcond(xtwx)<illctol)|(its==maxits),
    disp(' -----');
    disp(' PLEASE NOTE: INACCURACIES MAY EXIST IN THE SOLUTION:');
end;

%Message about the fit
if format(1),
    if (its<maxits),
        tag='';
        if its~=1,
            tag='s';
        end;
        disp([blanks(14),'Convergence in: ',num2str(its),' iteration',tag]);
    end;
end;

x=xx(:,1);
eta=(x*b)+oo;
mu=feval(linkinfo,eta,mm,'mu');

%%%SUBFUNCTION DIAGM
function A=diagm(D,B)
%DIAGM Multiplies D, a diagonal matrix as a row of diag elements with matrix B
%USE: A=diagm(D,B)
% where D is the diagonal elements of a diagonal matrix;
%       B is a matrix of suitable size;
%       A is the result of the multiplication.

%Copyright 1996 Peter Dunn
%11 Nov 1996

%error checks
if length(D)~=size(B,1),
    error('Matrix sizes are not compatible.');
```

```

end;
%end error checks

A=zeros(length(D),size(B,2));
for i=1:length(D),
    A(i,:)=D(i)*B(i,:);
end;

%%%SUBFUNCTION ALIAS
function label=alias(X)
%ALIAS Finds aliased columns of matrix X
%USE: labels=alias(X)
% where labels is a vector of the linearly independent columns
%       X is the original data matrix.
%X(:,label) is the matrix with aliased variables removed
%For use within glmlab

%Copyright 1996 Peter Dunn
%Last revision: 11 Nov 1996

toler=paramtrs;
```

```
XX=X(:,1);
i=1;label=[1];
for j=1:size(X,2);
    i=i+1;
    XX=[XX X(:,j)];
    if det(XX'*XX)<toler,
        XX=[ XX(:,1:size(XX,2)-1) ];
    else
        label=[label j];
    end;
end;
end;
```

## B The Function glmfit.m

The function `glmfit` organises the fitting of the model, checks the inputs, deals with the results and looks for errors.

```
function [beta,serrors,mu,res,covarbeta,covdiff,devlist,linpred,xnames]=glmfit(y,x)
%GLMFIT Fits a generalised linear model (glm)
% USE: [beta,serrors,fits,res,covarbeta,covdiff,devlist,linpred]=glmfit(y,x)
% where y is the response variable;
% (For a binomial response, y has two columns:
% the first contains y, the second has the sample sizes)
% x is the covariate matrix
% (the number of columns of x is the number of variables.
% beta contains the parameters estimates;
% serrors are the standard errors;
% fits are the fitted values;
% covarbeta covariance matrix of the parameter estimates;
% res are the standardised residuals:
% (y-fits)*sqrt(prior wt / (scale parameter*variance function))
% covdiff is the var/covariance matrix of standard error of parameter
% differences.
% devlist is a vector of residual deviance for iterations of the fit.
% linpred is the linear predictor.
% xnames is a string array of the names of the variables (as in the output).
%
% Both vectors y, x, should be the same length: the number of observations.
%
% Only y is needed. If x is not supplied, only the constant term is fitted.
%
%ALSO SEE: glmLAB (fitting glm's using glmfit) where glmfit is used.

%Copyright 1996--1998 Peter Dunn
%02 March 1998

%Setup
beta=[];
serrors=[];
mu=[];
res=[];
covarbeta=[];
covdiff=[];
devlist=[];
linpred=[];
xnames=[];

%Extract info:
extractgl; %extract GLMLAB_INFO_
DFORMAT=GLMLAB_INFO_{7};
DETAILSFILE=GLMLAB_INFO_{8};
DEVIANCE=GLMLAB_INFO_{20};
y=yvar;

%A check on links/distns:
if(editerrs),
    return;
end;

%Some necessary fiddling
[yrows,ycols]=size(y);

%Make each row an observation
%(can't use y=y(:) since the binomial case has two columns)
if yrows<ycols,
    y=y';
end;

ylen=length(y);

if ycols==2,%Binomial case: extract responses and sample sizes
```



```

    m=y(:,2);
    y=y(:,1);

else

    m=ones(size(y));

end;
m=m(:);

if exist('rownamev')==1, %rownamev = GLMLAB_INFO_{13}
    namelist=rownamev;
end;

%X variables names
if inc_const, %if include_constant, tag such on

    x=[ones(yrows,1),xvar];
    namexv=[' [Const, ',cel2lstr(namexv),']'];
    namelist=str2mat('Constant',rownamev);

else

    x=xvar;
    namexv=cel2lstr(namexv);

end;

%end of that bit of fiddling

if isempty(pwvar),
    GLMLAB_INFO_{16}=ones(yrows,1);
    pwvar=GLMLAB_INFO_{16};
end;

if isempty(osvar),
    GLMLAB_INFO_{17}=zeros(yrows,1);
    osvar=GLMLAB_INFO_{17};
end;

zerowts=sum(pwvar==0); %Number of points with zero wight
effpts=ylen-zerowts; %Effective number of points
line=' -----';

%DISPLAY FITTING INFORMATION
if DFORMAT(1),

    disp(line);

    if isstr(link),
        l=upper(link);
    else
        l=['TO POWER OF ',num2str(link)];
    end;

    disp([' INFORMATION: Distribution/Link: ',upper(errdis),'/',l]);

    if zerowts>0,
        add='s';
        if effpts==1,
            add='';
        end;

        disp([blanks(14),'Fitting based on: ',...
            num2str(effpts),' observation',add]);
    end;

    if (sum((pwvar/max(pwvar))==1))~=ylen, %Only enter if weights not all one

```

```

        disp([blanks(14),'Prior Weights:      ',namepw]);

end;

if (sum(osvar==0)~=ylen, %Enter if offsets is not all zeros
    disp([blanks(14),'Offset Variable:      ',nameos]);
end;

if isstr(scalepar),
    disp([blanks(14),'Scale parameter estimated from mean deviance.']);
else
    disp([blanks(14),'Scale parameter set to ',num2str(scalepar),'.']);
end

disp([blanks(14),'Residual Type:          ',upper(restype)]);

end;

resetgl;

%Obtain link and distribution file names
if isstr(link),
    linkinfo=['l',link];
else
    linkinfo='lpower';
end;

distinfo=['d',errdis];

%Check they exist (user-defined case)
if ~exist(linkinfo),
    opterr(8,linkinfo(2:length(linkinfo)));
    return;
end;

if ~exist(distinfo),
    opterr(9,distinfo(2:length(distinfo)));
    return;
end;

%%%DO THE NUMBER CRUNCHING:
[beta,mu,xtwx,devlist,l,linpred]=irls(y,x,m);
%%%DONE THE NUMBER CRUNCHING

%DISPLAY RESULTS
disp(line);
GLMLAB_INFO_{22}=0;

if ~isempty(devlist),                %if empty, an error

    curdev = devlist(end);            %deviance for current model
    curdf=effpts-length(beta);        %df for current model

    if (curdf<0),                    %if more estimates that points
        curdf=0;
    end;

    if ( strcmp(errdis,'normal')|strcmp(errdis,'gamma') ) & (curdf==0),

        dispers=Inf;                %Otherwise gives warning: Divide by zero

    else

        if ~isstr(scalepar),
            dispers=scalepar;
        else
            dispers=curdev/curdf;
        end;
    end;
end;

```

```

end;

covarbeta=real(pinv(xtwx)*dispers);

%Determine variable names
varno=1;
estno=1;
xnames=[];

while estno<=size(x,2)

    vn=namelist(varno,:);
    varno=varno+1;

    if strcmp(deblank(vn),'Constant'),
        numcols=1;
    else
        if isempty(findstr(deblank(vn),'@')), %no interactions
            if strcmp(vn(1:4), 'Var ') %then a glmlab Var ?
                numcols = 1;
            else
                evstr=['size(',deblank(vn),',2);'];
                evalin('base', ['numcols=',evstr],'numcols = 1;');
            end;
        end
    end

    if numcols==1,

        xnames=str2mat(xnames,deblank(vn));
        estno=estno+1;
    else

        for j=1:numcols
            xnames=str2mat(xnames,[deblank(vn),':',num2str(j),']);
            estno=estno+1;
        end

    end

end

xnames(1,:)=[];

%Display results
if DFORMAT(2)|nargout>0, %display the parameter estimates

    if DFORMAT(2),
        disp(' Estimate      S.E.      Variable');
        disp(line);
    end;

    jj=0;
    bb=zeros(size(x,2),1);
    errors = bb;
    estno=1;
    varno=1;

    for varno=1:size(x,2);

        vn=xnames(varno,:);
        varno=varno+1;

        if any(l==estno), %unaliased variables
            jj=jj+1;
            se=sqrt(covarbeta(jj,jj));

            if isinf(se)&DFORMAT(2),
                fprintf(' %12.6f      %s      %s\n',beta(jj),'??????',vn);
            end;
        end;
    end;
end;

```

```

elseif DFORMAT(2),
    fprintf(' %12.6f %12.6f %s\n',beta(jj),se,vn);
end;

serrors(estno) = se;
bb(estno) = beta(jj);

else %aliased variables

    if DFORMAT(2),
        fprintf(' %12.6f %s %s\n',0.0,' aliased',vn);
    end;

end;

estno=estno+1;

end;

end;

beta=bb;
disp(line);

if ~isempty(DEVIANCE), %deviance already exists so we print changes

    deldev=curdev-DEVIANCE; %defined as in GLIM
    deldf=curdf-GLMLAB_INFO_{21};

    if ~isstr(scalepar),

        sdev=curdev/scalepar;
        sdeldev=deldev/scalepar;
        fprintf('Scaled Deviance: %13.6f (change: %+13.6f)\n',sdev,sdeldev);

    else

        fprintf('Deviance: %20.6f (change: %+13.6f)\n',curdev,deldev);

    end;

    %Write to DETAILS file
    FID=fopen(DETAILSFILE,'a');
    fprintf('Residual df: %17.0f (change: %+13.0f)\n',curdf,deldf);
    fprintf(FID,'%12.6f %13.6f %3.0f %5.0f %s\n',...
        curdev,deldev,curdf,deldf,[nameyv,',' ,nameyv]);

else %deviance doesn't exist, so this is the first fit

    if ~isempty(scalepar),

        if isstr(scalepar),
            sdev=curdev;
        else
            sdev=curdev/scalepar;
        end;

        if isstr(link),
            fprintf('Scaled deviance: %13.6f Link: %s\n',curdev,upper(link));
        else
            fprintf('Scaled deviance: %13.6f Link: Power of %8.5f\n',curdev,link);
        end;

    else

        if isstr(link),
            fprintf('Deviance: %19.6f Link: %s\n',curdev,upper(link));
        else
            fprintf('Deviance: %19.6f Link: Power of %8.5f\n',curdev,link);
        end
    end
end

```

```

end;

fprintf('Residual df: %17.0f  Distribution: %s\n',curdf,upper(errdis));
FID=fopen(DETAILSFILE,'a');
fprintf(FID,'(Created at %s on %s.)\n',mytime,date);
fprintf(FID,'  Deviance      Change  df Change  Variables\n');
fprintf(FID,'%12.6f      %12.0f      %s\n',...
        curdev,curdf,[nameyv,',';',name xv]);

end;

devlist=[devlist;curdev];

if (~isempty(namepw))|(~isempty(nameos)),
    fprintf(FID,'  The above fit includes the following:\n');
end;

if (~isempty(namepw))&(~isempty(nameos)),
    fprintf(FID,'      Prior weights: %s; Offset: %s\n',namepw,nameos);
else
    if ~isempty(namepw), fprintf(FID,'      Prior weights: %s\n',namepw);end;
    if ~isempty(nameos), fprintf(FID,'      Offset: %s\n',nameos);end;
end;

fclose(FID);

if ~finite(dispers),
    fprintf('Dispersion parameter cannot be found: 0 degrees of freedom.\n');
else
    fprintf('Scale parameter (dispersion parameter): %16.6f\n', dispers);
end;

disp(' Output variables:  BETA ERRORS FITS RESIDS COVB COVD');
disp('                    DEVLIST LINPRED XMATRIX XVARNames');
disp(' ');

%Update parameters
GLMLAB_INFO_{20}=curdev;
DEVIANCE=curdev;
GLMLAB_INFO_{21}=curdf;

scalepar
k=1; %scale parameter used
if ~isempty(scalepar),
    if ~isstr(scalepar),
        k=scalepar;
    end;
end;

%calculate the RESIDUALS
res=findres(y,m,mu,k);

if ~isfinite(dispers)
    disp(' WARNING:  Non-finite dispersion. ');
end;

%calculate other OUTPUT VARIABLES
if nargout>4,
    covdiff=zeros(size(covarbata));
    for ii=1:length(covarbata),
        for jj=ii+1:length(covarbata),

```

```

        cvd=real( sqrt( covarbeta(ii,ii)+covarbeta(jj,jj)-2*covarbeta(ii,jj) ) );
        covdiff(ii,jj)=cvd;
        covdiff(jj,ii)=cvd;

    end;

end;

end;

%Allow the proper residual plots to be available
if strcmp(GLMLAB_INFO_{1}, 'binoml') | strcmp(GLMLAB_INFO_{1}, 'poisson') | ...
    strcmp(GLMLAB_INFO_{1}, 'gamma') | strcmp(GLMLAB_INFO_{1}, 'inv_gsn'),
    set(findobj('tag', 'resvxf'), 'Enable', 'on');
end;

if strcmp(lower(GLMLAB_INFO_{4}), 'quantile'),
    set(findobj('tag', 'qequiv'), 'Enable', 'off');
end;

if isempty(GLMLAB_INFO_{10}),
    set(findobj('tag', 'resvc'), 'Enable', 'off');
else
    set(findobj('tag', 'resvc'), 'Enable', 'on');
end;

else

    errordlg('The model cannot be fitted sensibly; check the inputs and settings.',...
        'Model not fitted.')
```

```

    res = [];

    %Disallow residual plots
    set(findobj('tag', 'rplots'), 'Enable', 'off');

end

%fix up some things for use elsewhere
GLMLAB_INFO_{19}=mu;
GLMLAB_INFO_{18}=res;
M=m;

%enable residual plots
if isempty(GLMLAB_INFO_{18}),
    set(findobj('tag', 'rplots'), 'Enable', 'off');
else
    set(findobj('tag', 'rplots'), 'Enable', 'on');
end;

%Reset variables
resetgl;

return;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%SUBFUNCTION mytime
function time=mytime
%%MYTIME Return the current time in the format hh:mm:ss(am or pm)
%USE: mytime

%Copyright 1996 Peter Dunn
%11 November 1996

ss=fix(clock);
if ss(4)>12,%HOUR
    time=[num2str(ss(4)-12),':'];
    tag='pm';
else
    time=[num2str(ss(4)),':'];
    tag='am';

```

```
end;

if ss(5)<10, %MINUTES
    time=[time,'0',num2str(ss(5)),':'];
else
    time=[time,num2str(ss(5)),':'];
end;

if ss(6)<10,%SECONDS
    time=[time,'0',num2str(ss(6)),tag];
else
    time=[time,num2str(ss(6)),tag];
end;
```

## C The File dgamma.m

The function dgamma.m contains the information required by GLMLAB about the gamma distribution.

```
function answ=dgamma(what,y,mu,m,weights)
%DGAMMA Calculates all kinds of things for gamma distributions.
%USE:  answ=dgamma(what,y,mu,m,weights)
%  where y, mu, m and weights are the obvious;
%      what returns what is asked:
%          what== 1 returns the variance function;
%          what== 2 returns the deviance/scaled deviance;
%      answ is the answer asked for.
%Called by irls, glmfit.

%Copyright 1996, 1997 Peter Dunn
%Last revision: 15 May 1997

if what==1,
    answ=(mu.^2)+0.00000001*(mu==0);      %in case mu=0
    answ=answ.*(answ>0)+(answ<=0);      %removes negative mu's
elseif what==2,
    mu=mu+0.00000001*(mu==0);          %in case mu=0
    yy=y+(y==0).*mu;                  %in case y=0
    answ=2*sum( weights.*(-log(yy./mu) + (y-mu)./mu ) );
end;
```



## D The Function `lprobit.m`

The function `lprobit.m` contains the information required by `GLMLAB` about the probit link function.

```
function ans=lprobit(input1,input2,what)
%LPROBIT Calculates all kinds of things for probit link functions:
%USE: ans=lprobit(input1, input2, what)
% where y is the observed y vector;
% input1 is the input1 needed, determined by what you want out!
% what returns what is asked:
% what=='eta' returns the linear predictor, eta; (input1 is mu)
% what=='mu' returns the mean, mu; (input1 is eta)
% what=='detadmu' returns the deriv. d(eta)/d(mu) (input1 is mu);
% ans is the answer asked for.
%Called by glmfit and irls.

%Copyright 1996 Peter Dunn
%Last revision: 11 November 1996

% input2 is only used for binomial (logit/complg/probit) cases, when input2=m.
% for finding eta, input1 = mu
% for finding mu, input1 = eta
% for finding d(eta)/d(mu), input1 = mu

m=input2;
if strcmp(what,'mu'),
    eta=input1;
else
    mu=input1;
end;

if strcmp(what,'eta'),
    ans=sqrt(2)*erfinv(2*(mu./m)-1);
elseif strcmp(what,'mu'),
    ans=m.*(1+erf(eta/sqrt(2)))/2;
else
    ans=(sqrt(2*pi)./m).*exp((erfinv((2*mu./m)-1)).^2);
end;
```