Defining Effect Methods for Other Models

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The effects package in R is designed primarily to draw graphs that visualize a fitted response surface of a fitted model in problems with a linear predictor. Many modeling paradigms that can be fit with base R or contributed packages fit into this framework, including methods for linear, multivariate linear, and generalized linear models fit by the standard `lm` and `glm` functions and by the `svyglm` function in the survey package (Lumley 2004); linear models fit by generalized least squares using the `gls` function in the `nlme` package (Pinheiro et al. 2016); multinomial regression models fit by `multinom` in the `nnet` package (Venables and Ripley 2002); ordinal regression models using `polr` from the MASS package (Venables and Ripley 2002) and `clm` and `clm2` from the ordinal package (Christensen 2015); linear and generalized linear mixed models using the `lme` function in the `nlme` package (Pinheiro et al. 2016) and the `lmer` and `glmer` functions in the `lme4` package (Bates et al. 2015); and latent class models fit by `poLCA` in the `poLCA` package (Linzer and Lewis 2011). This is hardly an exhaustive list of fitting methods that are based on a linear predictor, and we have been asked from time to time to write functions to use effects with this other fitting methods. The mechanism for this is fairly simple. This vignette assumes you are familiar with R’s S3 methods.

The default `Effect.default` may work with some modeling functions, as would objects of the class `gls` that we describe below in Section [1] but as illustrated in later sections you may need to modify some of the arguments that are sent to `Effect.default`.

The `effect` package has five functions that create the information needed for drawing effects plots, `Effect`, `allEffects`, `effect` and `predictorEffect` and `predictorEffects`. To add new modeling to the package only a new `Effect` needs to be written; the package will take care of all the other functions.

1 Using effects with Other Modeling Methods, with Generalized Least Squares in the `nlme` package as an Example

Applying effects to other than `lm` and `glm` objects may require writing an method for the `Effect` generic function for that type of model object. For
example, the `gls` function in the `nlme` package [Pinheiro et al. 2018] fits linear models via generalized least squares. A call to `gls` creates an object of class `gls`. The following function `Effect.gls` provides a method for `gls` objects by finding the information needed to draw effects plots from `gls` objects:

```r
Effect.gls <- function(focal.predictors, mod, ...){
  cl <- mod$call
  cl$weights <- NULL
  args <- list(
    type = "glm",
    call = cl,
    formula = formula(mod),
    family = NULL,
    coefficients = coef(mod),
    vcov = as.matrix(vcov(mod)),
    method=NULL
  )
  Effect.default(focal.predictors, mod, ..., sources=args)
}
```

The `Effect.gls` function has three required arguments, `focal.predictors` and `mod` that match the first two arguments of `Effect.default`, and `...` that matches any other arguments you would like to pass to `Effect.default`; see `help(Effect)` for a list of these arguments.

The body of the function simply harvests the needed information from the `mod` object, and stores them in a list of named elements called `sources`. The `sources` list is then passed as a named argument to the default `Effect` method.

The named elements in `sources` include:

**type** The `effects` package has three basic modeling functions: `type = "glm"`, the default, is used for functions with a univariate response and a linear predictor and possibly a link function. This class includes linear models, generalized linear models, robust regression, generalized least squares fitting, linear and generalized linear mixed effects models, and many others. The `type = "polr"` is used for ordinal regression models, as in the `polr` function in the `MASS` package, and similar methods described below in Section 6. The The `type = "multinom"` for multinomial log-linear models as fit by the `multinom` function in `nnet`, and to polytomous latent class models created with the `polCA` function in the `polCA` package. The default is `type = "glm"`.

**call** The `Effect.default` method may use the call to set additional arguments that it needs. For `type="glm"`, for example, these arguments are `formula`, `data`, `contrasts`, `subset`, `family`, `weights`, and `offset`, although only the `formula` argument is required. The `gls` function includes an optional `weights` argument that is used differently from the `weights` argument for a generalized linear model and is not needed for computing effects or
predictor effects plots. In the function shown above the call is modified by setting weights=\texttt{NULL}.

The default for \texttt{call} is \texttt{mod\$call} for S3 objects and \texttt{mod@call} for S4 objects.

\texttt{formula} In most cases the formula for the linear predictor is returned by \texttt{formula(mod)}, the default, but if this is not the case the value of this argument should be the value of the formula for fixed effects.

\texttt{family} The default is \texttt{family=\texttt{NULL}}. This argument is required for GLM-like models that include a \texttt{family} that specifies both an error distribution and a link function only if \texttt{family=family(mod)} is not appropriate. See the \texttt{betareg} example in Section 5 below for an example that includes a user-selected link function, but a fixed error distribution.

\texttt{coefficients} In many cases the (fixed-effect) coefficient estimates are returned by \texttt{coef(mod)}, the default, but if this is not the case then the value of this argument should be the estimates of the coefficients in the linear predictor. The functions in the \texttt{effects} package do not use estimates of random effects.

\texttt{zeta} Ordinal regression models return both a set of regression coefficients and also a set of \textit{thresholds}. In the \texttt{polr} function the regression coefficients and the thresholds are stored in separate vectors, but in other ordinal regression programs, such as \texttt{clm} in the \texttt{ordinal} package they are stored as a single vector. See Section 5 for an example of the use of this argument for specifying the values of the thresholds.

\texttt{vcov} In many cases the estimated covariance matrix of the (fixed-effect) coefficient estimates is returned by \texttt{vcov(mod)}, the default, but if this is not the case then the value of this argument should be the estimated covariance matrix of the (fixed-effect) coefficient estimates in the linear predictor.

\texttt{method} This argument is used only for methods that use effects graphics based on the \texttt{polr} function, where the argument \texttt{method} is the name of a link function; see \texttt{help(polr)} for a list of the accepted links, and see Section 6.1 below for an example.

The only non-default argument in \texttt{sources} in \texttt{Effect.gls} is the modification of the \texttt{call} to omit weights in the call to \texttt{gls}. Had this change not been needed, there would be no need to have written the \texttt{Effect.gls} method, as the default method would have worked.

\texttt{library(effects)}

Loading required package: carData

\texttt{lattice theme set by effectsTheme()} See \texttt{?effectsTheme} for details.
require(nlme)

Loading required package: nlme

\[ g \leftarrow \text{gls}(\text{Employed} \sim \text{GNP} + \text{Population}, \right. \\
\text{correlation}=\text{corAR1}(\text{form} \sim \text{Year}), \text{data}=\text{longley}) \]

plot(predictorEffects(g))

2 Mixed Effects with lme (nlme package)

The \texttt{lme} function in the \texttt{nlme} package \cite{Pinheiro} fits linear mixed models. The required function for fitted objects from this function is included in the \texttt{effects} package. It is given by

\[
\text{print(Effect.lme)}
\]

function (focal.predictors, mod, ...)
{
  args <- list(call = mod$call, formula = mod$call$fixed, coefficients = mod$coefficients, 
                vcov = mod$varFixed)
  Effect.default(focal.predictors, mod, ..., sources = args)
}

<bytecode: 0x55b601d245a0>
<environment: namespace:effects>

The \texttt{formula}, \texttt{coefficients} and \texttt{vcov} arguments are set to non-default values. The other arguments are automatically set to default values, with \texttt{call} set explicitly and other arguments set implicitly.

\[
data(\text{Orthodont, package="nlme"})
\]
\[
m1 \leftarrow \text{nlme::lme} \left( \text{distance} \sim \text{age} + \text{Sex}, \text{data}=\text{Orthodont}, \right. \\
\text{random} = \sim 1 \mid \text{Subject}) 
\]

\[
as.data.frame(\text{Effect("age", m1)})
\]
age   fit   se  lower  upper
1  8.0  22.04259  0.4172841  21.21520  22.86999
2  9.5  23.03287  0.3853671  22.26876  23.79698
3 11.0  24.02315  0.3741236  23.28133  24.76497
4 12.0  24.68333  0.3791619  23.93153  25.43514
5 14.0  26.00370  0.4172841  25.17631  26.83110

3 Mixed Effects with the lmer (lme4 package)

The lme4 package \cite{Bates+2015} fits linear and generalized linear mixed effects models with the lmer and glmer functions, respectively. The same Effect function can be used for lmer and glmer models.

The following method is a little more complicated because it contains an additional argument KR to determine if the Kenward-Roger coefficient covariance matrix is to be used to compute effect standard errors. The default is FALSE because the computation is very slow. If KR = TRUE, the function also checks if the pbkrtest package is present.

\[
\text{print(Effect.merMod)}
\]

\[
\text{function (focal.predictors, mod, ..., KR = FALSE)}
\]

\[
\{
\text{if (KR && !requireNamespace("pbkrtest", quietly = TRUE))} \{
\text{KR <- FALSE}
\text{warning("pbkrtest is not available, KR set to FALSE")}
\}
\text{fam <- family(mod)}
\text{args <- list(call = mod@call, coefficients = lme4::fixef(mod),}
\text{family = fam, vcov = if (fam$family == "gaussian" && fam$link == "identity" && KR) as.matrix(pbkrtest::vcovAdj(mod)) else as.matrix(vcov(mod)))}
\text{Effect.default(focal.predictors, mod, ..., sources = args)}
\}
\]

Because \texttt{lmer} is an S4 object, the default for \texttt{call} is \texttt{mod@call}, and this argument would have been set automatically had we not included it in the above method. The fixed-effect estimates for an object created by a call to \texttt{lmer} or \texttt{glmer} are not returned by \texttt{coef(mod)}, so the value of \texttt{coefficients} is the value returned by \texttt{lme4::fixef(mod)}. The \texttt{vcov} estimate contains its estimated variance covariance matrix of the fixed effects. The Kenward-Roger method is used to estimate the covariance matrix for linear models if the additional argument \texttt{KR=TRUE}. The default is \texttt{KR=FALSE} because The Kenward-Roger estimate requires a long computation; see \texttt{help(Effect)}.

The formula for a mixed-effects model in the lme4 package specifies linear predictors for both the mean function and the variance functions, specified by,
for example (1 + age | Subject). The effects code will automatically remove any terms like these in any formula, as the effects package only displays the mean function.

\[
fm2 <- lme4::lmer(distance ~ age + Sex + (1 | Subject), data = Orthodont)
\]

\[
\text{plot(allEffects(fm2))}
\]

data(cbpp, package="lme4")
gm1 <- lme4::glmer(cbind(incidence, size - incidence) ~ period + (1 | herd),
                   data = cbpp, family = binomial)
as.data.frame(predictorEffect("period", gm1))

<table>
<thead>
<tr>
<th>period</th>
<th>fit</th>
<th>se</th>
<th>lower</th>
<th>upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.19807921</td>
<td>0.03672693</td>
<td>0.13569523</td>
<td>0.2798569</td>
</tr>
<tr>
<td>2</td>
<td>0.08391784</td>
<td>0.02363110</td>
<td>0.04775454</td>
<td>0.1433443</td>
</tr>
<tr>
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<td>0.02241761</td>
<td>0.04040242</td>
<td>0.1317591</td>
</tr>
<tr>
<td>4</td>
<td>0.04842565</td>
<td>0.01959184</td>
<td>0.02163870</td>
<td>0.1048199</td>
</tr>
</tbody>
</table>

4 Robust Linear Mixed Models (robustlmm package)

The rlmer function in the robustlmm package [Koller 2016] fits linear mixed models with a robust estimation method. As rlmer closely parallels the lmer function, an object created by rlmer is easily used with effects:

\[
\text{print(Effect.rlmerMod)}
\]

function (focal.predictors, mod, ...)
{
    args <- list(coefficients = lme4::fixef(mod), family = family(mod))
    Effect.default(focal.predictors, mod, ..., sources = args)
}

<bytecode: 0x55b600b81ab8>
<environment: namespace:effects>
require(lme4)

fm3 <- robustlmm::rlmer(distance ~ age * Sex + (1 |Subject),
                        data = Orthodont)

plot(predictorEffects(fm3))

5 Beta Regression

The \texttt{betareg} function in the \texttt{betareg} package (Grün et al. 2012) fits regressions with a link function but with Beta distributed errors.

\begin{verbatim}
print(Effect.betareg)
function (focal.predictors, mod, ...)
{
  coef <- mod$coefficients$mean
  vco <- vcov(mod)[1:length(coef), 1:length(coef)]
  fam <- binomial(link = mod$link$mean)
  fam$variance <- function(mu) {
    f0 <- function(mu, eta) (1 - mu) * mu/(1 + eta)
    do.call("f0", list(mu, mod$coefficient$precision))
  }
  fam$initialize <- expression({
    mustart <- y
  })
  args <- list(call = mod$call, formula = formula(mod), family = fam,
               coefficients = coef, vcov = vco)
  Effect.default(focal.predictors, mod, ..., sources = args)
}
\end{verbatim}

Beta regression has a response \( y \in [0, 1] \), with the connection between the mean \( \mu \) of the Beta and a set for predictors \( x \) through a link function \( x' \beta = g(\mu) \). The variance function for the beta is \( \text{var}(y) = \mu(1 - \mu)/(1 + \phi) \), for a precision parameter \( \phi \) estimated by \texttt{betareg}.

The call to \texttt{betareg} does not have a family argument, although it does have a link stored in \texttt{mod$link$mean}. For use with \texttt{Effect.default}, the method above creates a family from the binomial family generator. It then adjusts this family by changing from binomial variance to the variance for the beta distribution. Since the \texttt{glm} function expects a variance that is a function of only one parameter, we fix the value of the precision \( \phi \) at its estimator from the \texttt{betareg} fit. We need to replace the \texttt{initialize} method in the family to one appropriate for \( y \in [0, 1] \).

\begin{verbatim}
require(betareg)
\end{verbatim}

Loading required package: betareg
require(lme4)
data("GasolineYield", package = "betareg")
gy_logit <- betareg(yield ~ batch + temp, data = GasolineYield)
summary(gy_logit)

Call:
betareg(formula = yield ~ batch + temp, data = GasolineYield)

Standardized weighted residuals 2:

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>1Q</td>
<td>Median</td>
<td>3Q</td>
<td>Max</td>
</tr>
<tr>
<td>-2.8750</td>
<td>-0.8149</td>
<td>0.1601</td>
<td>0.8384</td>
<td>2.0483</td>
</tr>
</tbody>
</table>

Coefficients (mean model with logit link):

|        | Estimate | Std. Error | z value | Pr(>|z|) |
|--------|----------|------------|---------|--------|
| (Intercept) | -6.1595710 | 0.1823247 | -33.784 | < 2e-16 |
| batch1  | 1.7277289  | 0.1012294 | 17.067  | < 2e-16 |
| batch2  | 1.3225969  | 0.1179020 | 11.218  | < 2e-16 |
| batch3  | 1.5723099  | 0.1161045 | 13.542  | < 2e-16 |
| batch4  | 1.0597141  | 0.1023598 | 10.353  | < 2e-16 |
| batch5  | 1.1337518  | 0.1035232 | 10.952  | < 2e-16 |
| batch6  | 1.0401618  | 0.1060365 | 9.809   | < 2e-16 |
| batch7  | 0.5436922  | 0.1091275 | 4.982   | 0.000000629 |
| batch8  | 0.4959007  | 0.1089257 | 4.553   | 0.000005297 |
| batch9  | 0.3857930  | 0.1185933 | 3.253   | 0.00114 |
| temp    | 0.0109669  | 0.0004126 | 26.577  | < 2e-16 |

Phi coefficients (precision model with identity link):

|        | Estimate | Std. Error | z value | Pr(>|z|) |
|--------|----------|------------|---------|--------|
| (phi)  | 440.3    | 110.0      | 4.002   | 0.0000629 |

Type of estimator: ML (maximum likelihood)
Log-likelihood:  84.8 on 12 Df
Pseudo R-squared: 0.9617
Number of iterations: 51 (BFGS) + 3 (Fisher scoring)

plot(predictorEffects(gy_logit))
6 Ordinal Models (ordinal package)

Proportional odds logit and probit regression models fit with the `polr` function in the MASS package ([Venables and Ripley](2002)) are supported in the effects package. The ordinal package, ([Christensen](2015)) contains three functions that are very similar to polr. The `clm` and `clm2` functions allow more link functions and a number of other generalizations. The `clmm` function allows including random effects.

6.1 clm

```r
print(Effect.clm)

function (focal.predictors, mod, ...)
{
  if (requireNamespace("MASS", quietly = TRUE)) {
    polr <- MASS::polr
  }
  else stop("MASS package is required")
  polr.methods <- c("logistic", "probit", "loglog", "cloglog", "cauchit")
  method <- mod$link
  if (method == "logit")
    method <- "logistic"
  if (!(method %in% polr.methods))
    stop("link must be a 'method' supported by polr; see help(polr)"
  if (mod$threshold != "flexible")
    stop("Effects only supports the 'flexible' threshold")
  numTheta <- length(mod$Theta)
  numBeta <- length(mod$beta)
  or <- c((numTheta + 1):(numTheta + numBeta), 1:(numTheta))
  args <- list(type = "polr", coefficients = mod$beta, zeta = mod$alpha, method = method, vcov = as.matrix(vcov(mod)[or, or]))
```

9
Effect.default(focal.predictors, mod, ..., sources = args)
}
<bytecode: 0x55b608deef00>
<environment: namespace:effects>

This method first checks that the MASS package is available. The clm function orders the parameters in the order (threshold parameters, linear predictor parameters), so the next few lines identify the elements of vcov that are needed by Effects. Since the polr function does not allow thresholds other than flexible, we don’t allow them either. The zeta argument supplies the estimated thresholds, which are called zeta in polr, and Alpha in clm. The polr argument method is equivalent to the clm argument link, except that the clm link "logit" is equivalent to the polr method "logistic".

```r
require(ordinal)
require(MASS)
mod.wvs1 <- clm(poverty ~ gender + religion + degree + country*poly(age,3),
data=WVS)
plot(Effect(c("country", "age"), mod.wvs1),
     lines=list(multiline=TRUE), layout=c(2, 2))
```

![country*age effect plot](image)
6.2 clm2

Although the fitted models are similar, syntax for clm2 is not the same as clm, so a separate method is required.

```r
print(Effect.clm2)

function (focal.predictors, mod, ...) {
  if (requireNamespace("MASS", quietly = TRUE)) {
    polr <- MASS::polr
  }
  polr.methods <- c("logistic", "probit", "loglog", "cloglog", "cauchit")
  method <- mod$link
  if (!method %in% polr.methods)
    stop("'link' must be a 'method' supported by polr; see help(polr)"
  if (is.null(mod$Hessian)) {
    message("Re-fitting to get Hessian")
    mod <- update(mod, Hess = TRUE)
  }
  if (mod$threshold != "flexible")
    stop("Effects only supports the flexible threshold")
  numTheta <- length(mod$Theta)
  numBeta <- length(mod$beta)
  or <- c((numTheta + 1):(numTheta + numBeta), 1:(numTheta))
  args <- list(type = "polr", formula = mod$call$location,
               coefficients = mod$beta, zeta = mod$Theta, method = method,
               vcov = as.matrix(vcov(mod)[or, or]))
  Effect.default(focal.predictors, mod, ..., sources = args)
}
```

```r
v2 <- clm2(poverty ~ gender + religion + degree + country*poly(age,3), data=WVS)
plot(emod2 <- Effect(c("country", "age"), v2),
     lines=list(multiline=TRUE), layout=c(2,2))
```
6.3 clmm

This function allows for random effects in an ordinal model.

\[
\text{print(Effect.clmm)}
\]

\[
\text{function (focal.predictors, mod, \ldots)}
\{
\text{if (requireNamespace("MASS", quietly = TRUE))} \{
  \text{polr} \leftarrow \text{MASS::polr}
\}
\text{else stop("The MASS package must be installed")}
\text{polr.methods } \leftarrow \text{c("logistic", "probit", "loglog", "cloglog", "cauchit")}
\text{method } \leftarrow \text{mod$link}
\text{if (method == "logit")}
  \text{method } \leftarrow \text{"logistic"}
\text{if (!method %in% polr.methods))}
  \text{stop("'link' must be a 'method' supported by polr; see help(polr)")}
\text{if (is.null(mod$Hessian))} \{
  \text{message("\nRe-fitting to get Hessian\n")}
  \text{mod } \leftarrow \text{update(mod, Hess = TRUE)}
\}
\text{if (mod$threshold != "flexible")}
  \text{stop("Only threshold='flexible supported by Effects")}
\text{numTheta } \leftarrow \text{length(mod$Theta)}
\text{numBeta } \leftarrow \text{length(mod$beta)}
\text{or } \leftarrow \text{c((numTheta + 1):(numTheta + numBeta), 1:(numTheta))}
Vcov <- as.matrix(vcov(mod)[or, or])
args <- list(type = "polr", formula = formula(mod), coefficients = mod$beta,
             zeta = mod$alpha, method = method, vcov = as.matrix(Vcov))
Effect.default(focal.predictors, mod, ..., sources = args)

The first few lines of the method check for the presence of the MASS package that is needed to use polr, makes sure the link used is supported by polr, and requires that the argument threshold has its default value. The polr and clmm functions store the fixed effects estimates of regression and threshold coefficients in different orders, so the next few lines rearrange the variance matrix to match the order that polr uses.

require(ordinal)
require(MASS)
mm1 <- clmm(SURENESS ~ PROD + (1|RESP) + (1|RESP:PROD), 
             data = soup, link = "logit", threshold = "flexible")
plot(Effect("PROD", mm1), lines=list(multiline=TRUE))
6.4 Others

The `poLCA` function in the `poLCA` package (Linzer and Lewis, 2011) fits polytomous variable latent class models, which uses the multinomial effects plots.


The `lm` function can also be used to create a multivariate linear model. The `Effect.mlm` function, with slightly different syntax, will draw effects plots for these models, with separate plots of each response.

```r
data(Baumann, package="carData")
b1 <- lm(cbind(post.test.1, post.test.2, post.test.3) ~ group + pretest.1 + pretest.2, data = Baumann)
plot(Effect("group", b1))
```

References


