

Bayesian MNLFA

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Load Packages

```
library(tidyr)
library(ggplot2)
library(cmdstanr)
```

This is cmdstanr version 0.8.1

- CmdStanR documentation and vignettes: mc-stan.org/cmdstanr
- CmdStan path: `/home/markl/.cmdstan/cmdstan-2.35.0`
- CmdStan version: 2.35.0

Import Data

Data can be downloaded from <https://github.com/jmk7cj/SEM-mnlfa>.

```
data <- read.csv(here::here("SEM-mnlfa", "data.csv"))
# Define grouping variable
data$group <- data$study_id
# Sort data by group
data <- data[order(data$group), ]
head(data)
```

	id	study_id	sex	race	T_TOCA_breakrule	T_TOCA_harmpro	T_TOCA_breakthg
1	FT001	FAST	male	black	0	NA	0
2	FT002	FAST	male	white	1	NA	0
3	FT003	FAST	female	white	0	NA	0
4	FT004	FAST	female	white	1	NA	0
5	FT005	FAST	male	black	1	NA	0
6	FT006	FAST	male	black	1	NA	1

	T_TOCA_takeprop	T_TOCA_fight	T_TOCA_lies	T_TOCA_yell	T_TOCA_stub	T_TOCA_teas
1	0	0	0	0	0	0
2	1	1	0	1	1	1
3	0	0	0	1	0	0
4	0	1	1	0	1	0
5	0	1	0	1	1	1
6	1	1	1	1	1	1

	hs	group
1	1	FAST
2	1	FAST
3	1	FAST
4	0	FAST
5	1	FAST
6	1	FAST

```
# Sample sizes
# Study 1 = FAST; Study 2 = LIFT; Study 3 = PIRC1;
# Study 4 = PIRC2; Study 5 = SAFE
table(data$study_id)
```

```
FAST  LIFT  PIRC1  PIRC2  SAFE
817   451  1884   639   157
```

```
item_names <- names(data)[5:13] # save item names
```

Convert to long-format data

This is needed for handling missing data. See <https://mc-stan.org/docs/stan-users-guide/regression.html#item-response-models.section>.

```
data_long <- data[c("id", "study_id", "sex", "race", item_names)] |>
  tidyr::pivot_longer(cols = -(id:race), names_to = "item", values_to = "y")
# Exclude missing observations
data_long_lw <- data_long[complete.cases(data_long[, "y"]), ]
```

Bayesian MNLFA

The model is coded in the Stan language (see <https://mc-stan.org/docs/stan-users-guide/>). It uses regularization (hierarchical shrinkage prior; see <https://projecteuclid.org/journals/electronic-journal-of-statistics/volume-11/issue-2/Sparsity-information-and-regularization-in-the-horseshoe-and-other-shrinkage/10.1214/17-EJS1337SI.full>) to allow covariates to moderate loadings, intercepts, latent means, and the logarithm of latent SDs.

```
//
// From https://mc-stan.org/docs/stan-users-guide/regression.html#item-response-models.section
//

// The input data is an array of integers.
data {
  int<lower=1> J;           // number of students
  int<lower=1> K;           // number of questions
  int<lower=1> N;           // number of observations
  array[N] int<lower=1, upper=J> jj; // student for observation n
  array[N] int<lower=1, upper=K> kk; // question for observation n
  array[N] int<lower=0, upper=1> y;  // correctness for observation n
  int<lower=1> p;           // number of covariates
  matrix[N, p] X;          // covariate predicting latent variance
}

parameters {
  vector[J] alpha_star;    // ability of student j - mean ability
  vector[K] gamma0_star;   // discrimination of question k (before rotation)
  vector[K] beta0;         // difficulty of question k
  vector[p] g_star;        // effect of x on latent mean
  vector[p] h;             // effect of x on log(latent SD)
  // Horseshoe prior for paths on intercepts
  matrix[p, K] zb;         // unregularized effect of x on intercepts
}
```

```

    real<lower=0> taub;          // global shrinkage
    matrix<lower=0>[p, K] lb;   // local shrinkage
    // Horseshoe prior for paths on loadings
    matrix[p, K] zc_star;      // unregularized effect of x on loadings/discrimination
    real<lower=0> tauc;          // global shrinkage
    matrix<lower=0>[p, K] lc;   // local shrinkage
}
transformed parameters {
    matrix[p, K] b = zb .* lb * taub;
    matrix[p, K] c_star = zc_star .* lc * tauc;
}
// The model to be estimated.
model {
    // alpha_star ~ std_normal();          // informative true prior
    h ~ std_normal();
    g_star ~ std_normal();
    alpha_star ~ std_normal();
    beta0 ~ normal(0, 2.5);                // informative true prior
    gamma0_star ~ normal(1, 2.5);          // informative true prior
    to_vector(zb) ~ std_normal();
    to_vector(lb) ~ student_t(3, 0, 1);
    taub ~ std_normal();
    to_vector(zc_star) ~ std_normal();
    to_vector(lc) ~ student_t(3, 0, 1);
    tauc ~ std_normal();
    {
        vector[N] dbeta; // deviation from reference intercepts
        vector[N] dgamma; // deviation from reference intercepts
        for (n in 1:N) {
            dbeta[n] = X[n, ] * b[, kk[n]]; // choose the right item for observation n;
            dgamma[n] = X[n, ] * c_star[, kk[n]];
        }
        y ~ bernoulli_logit((gamma0_star[kk] + dgamma) .*
                            (exp(X * h) .* (alpha_star[jj] + X * g_star)) +
                            beta0[kk] + dbeta);
    }
}
generated quantities {
    vector[K] gamma0;
    vector[J] alpha;
    vector[p] g;
    matrix[p, K] c;
}

```

```

{
  int sign_l1 = gamma0_star[1] > 0 ? 1 : -1;
  gamma0 = sign_l1 * gamma0_star;
  alpha = sign_l1 * alpha_star;
  g = sign_l1 * g_star;
  c = sign_l1 * c_star;
}
}

```

```

# Compile the model
mnlfa_mod <- cmdstan_model("twopl_rev_mnlfa.stan")

```

```

# Prepare data
stan_data <- list(
  J = length(unique(data_long_lw$id)),
  K = length(unique(data_long_lw$item)),
  N = nrow(data_long_lw),
  jj = as.numeric(factor(data_long_lw$id, levels = unique(data_long_lw$id))),
  kk = as.numeric(factor(data_long_lw$item)),
  y = data_long_lw$y,
  p = 4,
  # Predictors: LIFT, PIRC1, PIRC2, SAFE
  X = model.matrix(~ factor(study_id),
                    data = data_long_lw)[, -1]
)

```

```

# Sampling (this takes a long time)
mnlfa_fit <- mnlfa_mod$sample(
  data = stan_data,
  # chains = 4,
  # parallel_chains = 4,
  # adapt_delta = 0.99,
  # max_treedepth = 12,
  # iter_warmup = 1000,
  # iter_sampling = 1000
  chains = 2,
  parallel_chains = 2,
  iter_warmup = 100,
  iter_sampling = 100
)
mnlfa_fit$save_object("mnlfa_fit.RDS")

```

Extract harmonized scores

Using posterior means and SDs

```
mnlfa_fit <- readRDS("mnlf_fit.RDS")  
# Extract factor scores  
fs_draws <- mnlfa_fit$summary("alpha")[c("mean", "sd")]
```

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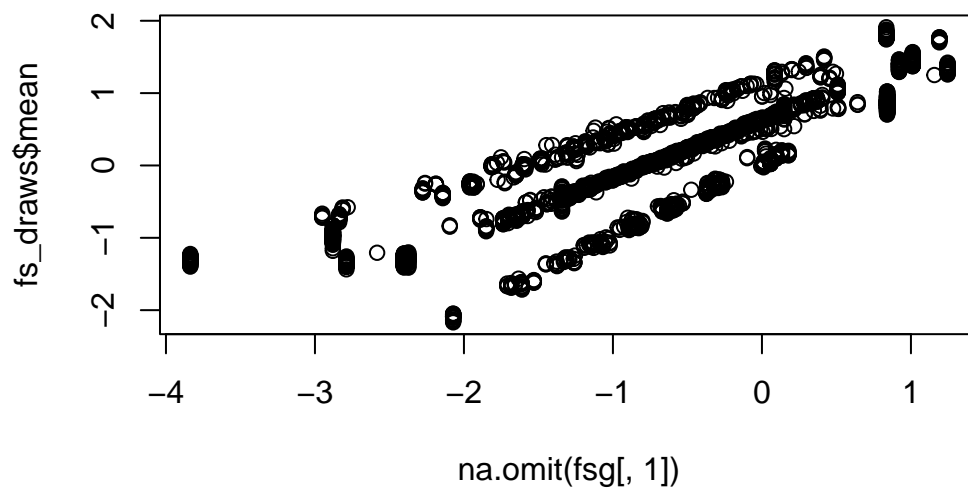
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Compare to aligned factor scores

```
fsg <- readRDS("fsg.RDS")  
plot(na.omit(fsg[, 1]), fs_draws$mean)
```



```
cor(na.omit(fsg[, 1]), fs_draws$mean)
```

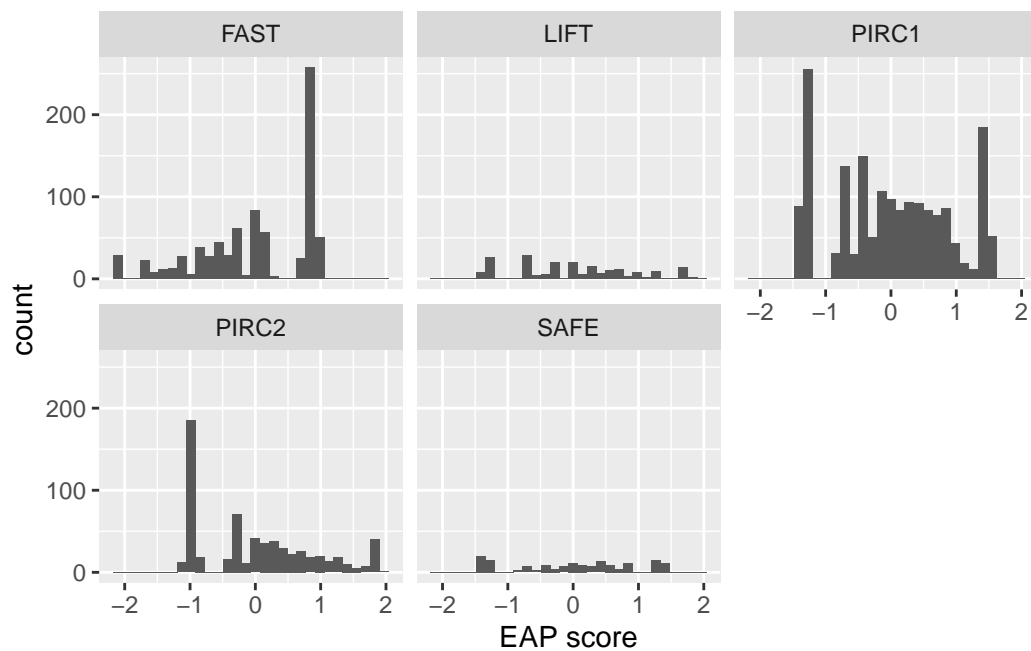
```
[1] 0.8930109
```

Descriptives

Add back Study ID

```
fs_draws$study_id <- data$study_id[data$id %in% unique(data_long_lw$id)]
ggplot(fs_draws, aes(x = mean)) +
  geom_histogram() +
  facet_wrap(~ study_id) +
  labs(x = "EAP score")
```

`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.



Reliability

```
# Average reliability
rel_avg <- var(fs_draws$mean) /
  (var(fs_draws$mean) + mean(fs_draws$sd^2))
rel_avg
```

```
[1] 0.7980037
```

```
# Group-specific reliability
relg <- tapply(fs_draws, INDEX = fs_draws$study_id,
  FUN = \(x) var(x$mean) /
    (var(x$mean) + mean(x$sd^2)))
relg
```

```
      FAST      LIFT      PIRC1      PIRC2      SAFE
0.7468280 0.8301663 0.8153685 0.7957242 0.8356492
```