

EP16: Missing Values in Clinical Research: Multiple Imputation

10. Requirements for MICE to work (well)

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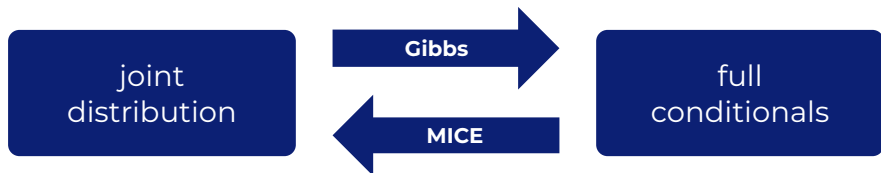
Joint and Conditional Distributions

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Gibbs sampling exploits the fact that a joint distribution is fully determined by its full conditional distributions.



In MICE, the full conditionals are not derived from the joint distribution: we directly specify the full conditionals and hope a joint distribution exists.

Joint and Conditional Distributions

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However, as we have seen in the examples on the previous slides, there are **settings where the direct specification** of the full conditionals/imputation models **may lead to problems**, causing biased results.

Some Conditions and Definitions

Two important definitions:

Compatibility:

A joint distribution exists, that has the full conditionals (imputation models) as its conditional distributions.

Congeniality:

The imputation model is compatible with the analysis model.

Some Conditions and Definitions

Important requirements for MICE to work well include:

- ▶ Compatibility
- ▶ Congeniality
- ▶ MAR or MCAR (in the standard implementations)
- ▶ **All relevant variables** need to be included. (Omission might result in MNAR.)
- ▶ **The outcome needs to be included** as predictor variable (but we usually do not impute missing outcome values).
- ▶ The imputation models (and analysis model) need to be **correctly specified** (which is a requirement in any standard analysis).

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Furthermore, **omission of variables** may lead to **mis-specified models**, however, models may also be mis-specified when all relevant covariates are included, but **distributional assumptions** or the specified **form of associations** are incorrect.

Alternatives to MICE

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- ▶ specify the joint distribution
- ▶ and derive full conditionals / imputation models from this joint distribution

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Problem: The joint distribution may not be of any known form:

$$\begin{matrix} x_1 \sim N(\mu_1, \sigma_1^2) \\ x_2 \sim N(\mu_2, \sigma_2^2) \end{matrix} \Rightarrow \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \sim N \left(\begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix}, \begin{bmatrix} \sigma_1^2 & \sigma_{12} \\ \sigma_{12} & \sigma_2^2 \end{bmatrix} \right)$$

but $\begin{matrix} x_1 \sim N(\mu_1, \sigma_1^2) \\ x_2 \sim \text{Bin}(\mu_2) \end{matrix} \Rightarrow \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \sim ???$

Alternatives to MICE

Possible approaches:

Approach 1: **Multivariate Normal Model** \ Approximate the joint distribution by a known multivariate distribution

(usually the normal distribution; this is the approach mentioned in Part I on slide~??).

Approach 2: **Sequential Factorization** \ Factorize the joint distribution into a (sequence of) conditional and a marginal distributions.

Multivariate Normal Model

Assumption: The outcome and incomplete variables follow a **joint multivariate normal distribution**, conditional on the completely observed covariates \mathbf{X}_c , parameters θ and, possibly, random effects, \mathbf{b} :

$$p(\mathbf{y}, \mathbf{x}_1, \dots, \mathbf{x}_p \mid \mathbf{X}_c, \theta, \mathbf{b}) \sim N(\mu, \Sigma)$$

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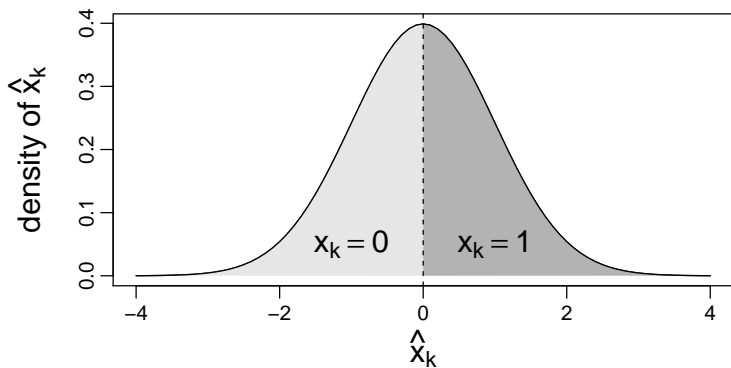
How do we get that multivariate normal distribution?

1. Assume **all** incomplete variables and the outcome are **(latent) normal**.
2. Specify linear (mixed) **models based on observed covariates**.
3. **Connect** using multivariate normal for **random effects & error terms**.

Multivariate Normal Model

1. Latent normal assumption:

e.g.: \mathbf{x}_k binary \rightarrow latent \mathbf{z}_k is standard normal:
$$\begin{cases} \mathbf{x}_k = 1 & \text{if } \mathbf{z}_k \geq 0 \\ \mathbf{x}_k = 0 & \text{if } \mathbf{z}_k < 0 \end{cases}$$



Multivariate Normal Model

2. Specify models:

$$\mathbf{y} = \mathbf{X}_c \beta_y + \mathbf{Z}_y \mathbf{b}_y + \epsilon_y$$

$$\mathbf{w} = \mathbf{X}_c \beta_w + \mathbf{Z}_w \mathbf{b}_w + \epsilon_w$$

$$\begin{array}{l} \mathbf{x}_1 = \mathbf{X}_c \beta_{x_1} + \epsilon_{x_1} \\ \vdots \end{array}$$

$$\mathbf{x}_p = \mathbf{X}_c \beta_{x_p} + \epsilon_{x_p}$$

Multivariate Normal Model

2. Specify models / 3. Connect random effects & error terms:

$$\begin{aligned} \mathbf{y} &= \mathbf{X}_c \beta_y + \mathbf{Z}_y \mathbf{b}_y + \epsilon_y \\ \mathbf{w} &= \mathbf{X}_c \beta_w + \mathbf{Z}_w \mathbf{b}_w + \epsilon_w \\ \mathbf{x}_1 &= \mathbf{X}_c \beta_{x_1} + \epsilon_{x_1} \\ &\vdots \\ \mathbf{x}_p &= \mathbf{X}_c \beta_{x_p} + \epsilon_{x_p} \end{aligned}$$

multivariate normal (optional, but suggested)

multivariate normal

Multivariate Normal Model

Advantages:

- ▶ easy to specify
- ▶ relatively easy to implement
- ▶ relatively easy to sample from
- ▶ works for longitudinal outcomes

Disadvantages:

- ▶ assumes linear associations

Imputation with **non-linear associations** or **survival data** is possible with **extensions** of the multivariate normal approach.

Sequential Factorization

The **joint distribution** of two variables y and x can be written as the product of conditional distributions:

$$p(y, x) = p(y \mid x) p(x)$$

(or alternatively $p(y, x) = p(x \mid y) p(y)$)

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This can easily be **extended for more variables**:

$$p(y, x_1, \dots, x_p, X_c) = \underbrace{p(y \mid x_1, \dots, x_p, X_c)}_{\text{analysis model}} p(x_1 \mid x_2, \dots, x_p, X_c) \dots p(x_p \mid X_c)$$

where x_1, \dots, x_p denote incomplete covariates and X_c contains all completely observed covariates.

Sequential Factorization

The analysis model is part of the specification of the joint distribution.

➡ Advantages:

- ▶ The outcome is **automatically included in the imputation** procedure.
- ▶ The outcome does not appear in any of the predictors of the imputation models:
 - ▶ **no need to approximate** complex outcomes,
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Since the joint distribution usually does not have a known form, Gibbs sampling is used to estimate parameters and sample imputed values.

Sequential Factorization

Advantages:

- ▶ **flexible** with regards to outcome type
- ▶ univariate conditional distributions of incomplete covariates can be chosen according to **type of variable**
- ▶ **non-linear associations** and interactions can be taken into account
- ▶ assures **congeniality and compatible imputation models**

Disadvantages:

- ▶ separate models need to be specified per incomplete variable: **takes more time and consideration**
- ▶ the joint distribution is of unknown form and sampling may be more **computationally intensive**

Some Relevant R Packages

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For example the R packages **JointAI**, **smcfcs** and **jomo**.

- ▶ they use **Bayesian methodology** to impute values
- ▶ **jomo** and **smcfcs** perform **multiple imputation**;
the imputed datasets that can then be analysed the same way data imputed by **mice** would be analysed.
- ▶ **JointAI** works **fully Bayesian**
 - ▶ performs analysis and imputation simultaneously
 - ▶ ➡ results from the analysis model of interest are obtained directly

R package smcfcs

Substantive Model Compatible Fully Conditional Specification, a hybrid approach between FCS and sequential factorization [?]

smcfcs (version 1.4.0) can impute incomplete covariates in

- ▶ linear regression
- ▶ logistic regression
- ▶ poisson regression
- ▶ Weibull survival models
- ▶ Cox proportional hazard models
- ▶ competing risk survival models
- ▶ nested case control studies
- ▶ case cohort studies

while ensuring compatibility between analysis model and imputation models.

For more information see the help files and the [vignette](#).

R Package jomo

JOint MOdel imputation using the multivariate normal approach, with **extensions to assure compatibility** between analysis and imputation models. [?]

jomo (version 2.6-7) can handle

- ▶ linear regression
- ▶ generalized linear regression
- ▶ proportional odds (ordinal) probit regression
- ▶ linear mixed models
- ▶ generalized linear mixed models
- ▶ (ordinal) cumulative link mixed models
- ▶ Cox proportional hazards models.

For more info see the [help file](#).

R Package JointAI

Joint Analysis and Imputation, \ uses the **sequential factorization approach** to perform simultaneous analysis and imputation. [?, ?]

JointAI (version 0.5.1) can analyse incomplete data using

- ▶ linear regression
- ▶ generalized linear regression
- ▶ linear mixed models
- ▶ generalized linear mixed models
- ▶ (ordinal) cumulative logit regression
- ▶ (ordinal) cumulative logit mixed models
- ▶ parametric (Weibull) survival models
- ▶ Cox proportional hazards models

while assuring compatibility between analysis model and imputation models when non-linear functions or interactions are included.

R Package JointAI

The necessary **Gibbs sampling** is performed using **JAGS** (an external program), which is free, but needs to be installed from <https://sourceforge.net/projects/mcmc-jags/files/>.

JointAI can be installed from CRAN or [GitHub](#) (development version containing bug fixes and other improvements)

```
install.packages("devtools")  
devtools::install_github("NErler/JointAI")
```

JointAI has its own web page (<https://nerler.github.io/JointAI/>) with several vignettes on [Visualization of Incomplete Data](#), a [Minimal Example](#), details on [Model Specification](#), etc.