




BGmisc: An R Package for Extended Behavior Genetics Analysis

S. Mason Garrison ¹✉, Michael D. Hunter ², Xuanyu Lyu ^{1,3,4}, Jonathan D. Trattner ¹, and S. Alexandra Burt ⁵

¹ Department of Psychology, Wake Forest University, North Carolina, USA ² Department of Human Development and Family Studies, Pennsylvania State University, Pennsylvania, USA ³ Institute for Behavioral Genetics, University of Colorado at Boulder, Boulder, USA ⁴ Department of Psychology & Neuroscience, University of Colorado at Boulder, Boulder, USA ⁵ Department of Psychology, Michigan State University, Michigan, USA ✉ Corresponding author

DOI: [10.xxxxxx/draft](https://doi.org/10.xxxxxx/draft)

Software

- [Review](#) 
- [Repository](#) 
- [Archive](#) 

Editor: [Open Journals](#) 

Reviewers:

- [@openjournals](#)

Submitted: 01 January 1970

Published: unpublished

License

Authors of papers retain copyright and release the work under a Creative Commons Attribution 4.0 International License ([CC BY 4.0](#)).

Summary

The field of behavior genetics focuses on illuminating genetic and environmental influences on individual differences. Traditionally, twin studies have been at the forefront of this discipline. However, research has moved beyond the classical twin design to embrace more complex family structures such as children of twins (CoT) (D'Onofrio et al., 2003), mother-daughter-aunt-niece (MDAN) (Rodgers, Bard, Johnson, D'Onofrio, & Miller, 2008), and other extended family designs. These expansions allow for a deeper, more nuanced exploration of genetic and environmental influences, but it also introduces challenges, particularly in data structuring and modeling. In particular, the data structures inherent in these more complicated family designs are orders of magnitude larger than traditional designs. In the classical twin study, for example, a family will consist of a single pair of twins (i.e., two people), whereas in the MDAN design, a family consists of two mother-daughter pairs (i.e., four people). This problem quickly becomes intractable when applied to very extended family pedigrees, where a single family can be of any size. The BGmisc package addresses this gap by offering a comprehensive suite of functions for structuring and modeling extended family pedigree data.

Statement of need

As behavior genetics delves into more complex data structures like extended pedigrees, the limitations of current tools become evident. Understandably, packages like OpenMx (Neale et al., 2016), EasyMx (Hunter, 2023), and kinship2 (J. P. Sinnwell, Therneau, & Schaid, 2014; J. Sinnwell & Therneau, 2022) were built for smaller families and classical designs. In contrast, the BGmisc R package was specifically developed to structure and model extended family pedigree data.

Two widely-used R packages in genetic modeling are OpenMx (Neale et al., 2016) and kinship2 (J. P. Sinnwell et al., 2014; J. Sinnwell & Therneau, 2022). The OpenMx (Neale et al., 2016) package is a general-purpose software for structural equation modeling that is popular among behavior geneticists (Garrison, 2018) for its unique features, like the `mxCheckIdentification()` function. This function checks whether a model is identified, determining if there is a unique solution to estimate the model's parameters based on the observed data. In addition, EasyMx (Hunter, 2023) is a more user-friendly package that streamlines the process of building and estimating structural equation models. It seamlessly integrates with OpenMx's infrastructure. Its functionalities range from foundational matrix builders like `emxCholeskyVariance` and `emxGeneticFactorVariance` to more specialized functions like `emxTwinModel` designed for classical twin models. Despite their strengths, EasyMx and OpenMx have limitations when

43 handling extended family data. Notably, they lack functions for handling modern molecular
44 designs (Kirkpatrick, Pritikin, Hunter, & Neale, 2021), modeling complex genetic relationships,
45 inferring relatedness, and simulating pedigrees.

46 Although not a staple in behavior genetics, the kinship2 (J. P. Sinnwell et al., 2014) package
47 provides core features to the broader statistical genetics scientific community, such as plotting
48 pedigrees and computing genetic relatedness matrices. It uses the Lange algorithm (Lange,
49 2002) to compute relatedness coefficients. This recursive algorithm is discussed in great detail
50 elsewhere, laying out several boundary conditions and recurrence rules. The BGmisc package
51 extends the capabilities of kinship2 by introducing an alternative algorithm to calculate the
52 relatedness coefficient based on network models. By applying classic path-tracing rules to the
53 entire network, this new method is computationally more efficient by eliminating the need for
54 a multi-step recursive approach.

55 Features

56 The BGmisc package offers features tailored for extended behavior genetics analysis. These
57 features are grouped under two main categories, mirroring the structure presented in our
58 vignettes.

59 Modeling and Relatedness:

- 60 ■ Model Identification: BGmisc evaluates whether a variance components model is identified
61 and fits the model's estimated variance components to observed covariance data. The
62 technical aspects related to model identification have been described by Hunter, Garrison,
63 Burt, & Rodgers (2021).
- 64 ■ Relatedness Coefficient Calculation: Using path tracing rules first described by Wright
65 (1922) and formalized by McArdle & McDonald (1984), BGmisc calculates the (sparse)
66 relatedness coefficients between all pairs of individuals in extended pedigrees based solely
67 on mother and father identifiers.
- 68 ■ Relatedness Inference: BGmisc infers the relatedness between two groups based on their
69 observed total correlation, given additive genetic and shared environmental parameters.

70 Pedigree Analysis and Simulation:

- 71 ■ Pedigree Conversion: BGmisc converts pedigrees into various relatedness matrices, in-
72 cluding additive genetics, mitochondrial, common nuclear, and extended environmental
73 relatedness matrices.
- 74 ■ Pedigree Simulation: BGmisc simulates pedigrees based on parameters including the
75 number of children per mate, generations, sex ratio of newborns, and mating rate.

76 Collectively, these tools provide a valuable resource for behavior geneticists and others who
77 work with extended family data. They were developed as part of a grant and have been used
78 in several ongoing projects (Burt, 2023; Garrison et al., 2023; Hunter et al., 2023; Lyu et al.,
79 2023) and theses (Lyu, 2023).

80 Availability

81 The BGmisc package is open-source and available on both GitHub at <https://github.com/R-Computing-Lab/BGmisc> and the Comprehensive R Archive Network (CRAN) at <https://cran.r-project.org/package=BGmisc>. It is licensed under the GNU General Public License.

Acknowledgments

The current research is supported by the National Institute on Aging (NIA), RF1-AG073189. We want to acknowledge assistance from Carlos Santos.

References

- Burt, S. A. (2023). Mom genes: Leveraging maternal lineage to estimate the contributions of mitochondrial DNA. *Behavior Genetics*.
- D'Onofrio, B. M., Turkheimer, E. N., Eaves, L. J., Corey, L. A., Berg, K., Solaas, M. H., & Emery, R. E. (2003). The role of the children of twins design in elucidating causal relations between parent characteristics and child outcomes. *Journal of Child Psychology and Psychiatry*, 44(8), 1130–1144. doi:[ff3dbm](https://doi.org/10.1111/j.1469-7610.2003.02585.x)
- Garrison, S. M. (2018). Popular Structural Equation Modeling Programs for Behavior Genetics. *Structural Equation Modeling: A Multidisciplinary Journal*, 25(6), 972–977. doi:[10.1080/10705511.2018.1493385](https://doi.org/10.1080/10705511.2018.1493385)
- Garrison, S. M., Lyu, X., Hunter, M. D., Rodgers, J. L., Smith, K. R., Coon, H., & Burt, S. A. (2023). Analyzing extended cousin similarity to unravel the mystery of mtDNA and longevity. *Behavior Genetics*.
- Hunter, M. D. (2023). *EasyMx: Easy model-builder functions for 'OpenMx'*. Retrieved from <https://CRAN.R-project.org/package=EasyMx>
- Hunter, M. D., Garrison, S. M., Burt, S. A., & Rodgers, J. L. (2021). The Analytic Identification of Variance Component Models Common to Behavior Genetics. *Behavior Genetics*, 51(4), 425–437. doi:[10.1007/s10519-021-10055-x](https://doi.org/10.1007/s10519-021-10055-x)
- Hunter, M. D., Lyu, X., Garrison, S. M., Rodgers, J. L., Smith, K., Coon, H., & Burt, S. A. (2023). Modeling mtDNA effects from extended pedigrees in the utah population database. *Behavior Genetics*.
- Kirkpatrick, R. M., Pritikin, J. N., Hunter, M. D., & Neale, M. C. (2021). Combining Structural-Equation Modeling with Genomic-Relatedness-Matrix Restricted Maximum Likelihood in OpenMx. *Behavior Genetics*, 51(3), 331–342. doi:[10.1007/s10519-020-10037-5](https://doi.org/10.1007/s10519-020-10037-5)
- Lange, K. (2002). Genetic Identity Coefficients. In K. Lange (Ed.), *Mathematical and Statistical Methods for Genetic Analysis*, Statistics for Biology and Health (pp. 81–96). New York, NY: Springer. doi:[10.1007/978-0-387-21750-5_5](https://doi.org/10.1007/978-0-387-21750-5_5)
- Lyu, X. (2023, May). *Statistical power analysis on mtDNA effects estimation* (Master's thesis). Wake Forest University.
- Lyu, X., Hunter, M. D., Rodgers, J. L., Smith, K. R., Coon, H., Burt, S. A., & Garrison, S. M. (2023). Statistical power analysis on mtDNA effects estimation. *Behavior Genetics*.
- McArdle, J. J., & McDonald, R. P. (1984). Some algebraic properties of the reticular action model for moment structures. *British Journal of Mathematical and Statistical Psychology*, 37, 234–251. doi:[10.1111/j.2044-8317.1984.tb00802.x](https://doi.org/10.1111/j.2044-8317.1984.tb00802.x)
- Neale, M. C., Hunter, M. D., Pritikin, J. N., Zahery, M., Brick, T. R., Kirkpatrick, R. M., Estabrook, R., et al. (2016). OpenMx 2.0: Extended Structural Equation and Statistical Modeling. *Psychometrika*, 81(2), 535–549. doi:[f8rfrg](https://doi.org/10.1007/s11336-016-9588-8)
- Rodgers, J. L., Bard, D. E., Johnson, A., D'Onofrio, B., & Miller, W. B. (2008). The Cross-Generational Mother–Daughter–Aunt–Niece Design: Establishing Validity of the MDAN Design with NLSY Fertility Variables. *Behavior Genetics*, 38(6), 567–578. doi:[10.1007/s10519-008-9225-0](https://doi.org/10.1007/s10519-008-9225-0)

- 128 Sinnwell, J. P., Therneau, T. M., & Schaid, D. J. (2014). The kinship2 r package for pedigree
129 data. *Human Heredity*, 78, 91–93. doi:[10.1159/000363105](https://doi.org/10.1159/000363105)
- 130 Sinnwell, J., & Therneau, T. (2022). *kinship2: Pedigree functions*. Retrieved from [https:](https://CRAN.R-project.org/package=kinship2)
131 [//CRAN.R-project.org/package=kinship2](https://CRAN.R-project.org/package=kinship2)
- 132 Wright, S. (1922). Coefficients of inbreeding and relationship. *The American Naturalist*,
133 56(645), 330–338. doi:[10.1086/279872](https://doi.org/10.1086/279872)

DRAFT