ISBA

INTERNATIONAL SOCIETY FOR BAYESIAN ANALYSIS

THE ISBA BULLETIN

OFFICIAL BULLETIN OF THE INTERNATIONAL SOCIETY FOR BAYESIAN ANALYSIS

MESSAGE FROM THE PRESIDENT

Sudipto Banerjee

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I am writing this message two weeks prior to the commencement of the 2022 ISBA World Meeting. By all accounts so far the World Meeting is expected to see about 600 attendees from all over the world gather at the conference site in the Hotel Bonaventure in Montreal, Canada. I, too, am eagerly looking forward to this event and greeting all of you in person. When I think about all the discussions and meetings over the uncertainties that pervaded throughout last year surrounding this event, I feel great happiness and deep gratitude. I am happy that we will be able to conduct this meeting in the way we have always wanted to. And I am deeply grateful to the Local Organizing Committee, led by the indefatigable Alexandra Schmidt, who surmounted so many challenges, compounded by the pandemic, to bring us to this juncture.

I want to take this opportunity to appreciate the members of the scientific committee, chaired by Botond Szabo, for their efforts in compiling a truly outstanding scientific program. Let me indulge myself with a few notable extractions. The program features a truly stellar lineup of plenary speakers: Foundational lectures by Subhashis Ghoshal, Steffen Lauritzen, Adrian Raftery and Nancy Reid; Keynote lectures by Francesca

Dominici, Antonio Lijoi, David Stephens and Richard Nikl; the Bruno de Finneti lecture by Mike West; and the Susie J. Bayarri lecture by Pierre Jacob. The opening day of the conference, Sunday, June 26th, 2022, features five short courses on Bayesian statistics and its applications in fields as diverse as clinical trials; epidemics; environmental science and neuroscience; spatial public health; and causal inference. I thank all the instructors for their time and efforts in administering these courses. The scientific sessions commence on Monday, June 27th and features parallel sessions that are interspersed with the plenary lectures. A quick glance at the scientific program reveals the spectacular and burgeoning reach of Bayesian statistics in the sciences and society today in conjunction with the amazing growth in scalable computational methods as Bayesian inference continues to embed itself within various aspects of machine learning.

I also hope that attendees will enjoy the social aspects of the program. The welcome cocktail on Monday will allow attendees, many of whom will be taking long international flights at a time when traveling in general, and by air in particular, is more cumbersome than usual, to relax and socialize. The carefully interspersed coffee breaks and lunch, each day, is expected to offer additional opportunities for attendees to meet and greet old friends, while also making new friends and acquaintances. The poster sessions, which comprise an integral part of these meetings, in the evenings provide another platform for attendees to mingle in a relaxed environment while discussing several exhilarating research projects on display. Finally, let us not forget the closing banquet on Friday to take stock of how the past few days went by.

Turning to a few matters of governance, I would like to remind all members that the meeting of the General ISBA Assembly will take place on Thursday, June 30th, 2022, at 5pm. The ISBA leadership will take this opportunity to provide members with an overview of the state of the Society and also bring to attention matters under current deliberations. All members are invited to attend. The meeting will also provide members an opportunity to meet the leadership face to face and raise issues they deem important.

The ISBA leadership takes ISBA's financial health with utmost seriousness. The organization of this conference has proceeded amid significant inflationary pressures and high expenses. In spite of such pressures, we were able to reduce the registration rates for most categories from the last onsite World Meeting in 2018 and significantly so for students. In addition, the 2022 World Meeting is likely to break ISBA's past record for the highest number of student travel awards. We have been able to accomplish these only through active engagement with our professional partners in successfully securing sponsorship and funds to help defray the costs of the World Meeting. Students and junior researchers are an integral and indispensable part of our society and it gives me no greater joy than to be able to offer support to them, albeit partially, for attending the World Meeting. Growing our membership and engaging with our sponsors will continue to occupy a major part of ISBA's future initiatives as we strive to further enhance the vibrancy of our society. Therefore, please remember to renew your memberships, including your Section memberships (see https://bayesian.org/ for a list of the Sections), and also encourage your students and colleagues to join ISBA. The link to join or renew ISBA membership, including Section memberships, is available at https://bayesian.org/membership/joinrenew.

I will conclude on a somewhat somber note. By all accounts the COVID-19 pandemic is not over. The World Meeting will see a very large gathering of individuals from across the world. One cannot overemphasize the importance of conducting ourselves in a responsible manner at the meeting for one's own safety and the safety of others. Responsible behavior will include wearing masks while indoors and especially when in close proximity to others; self-monitoring for symptoms, testing and isolating if and as needed; and maintaining social distance during interactions. While this is easier said than done, especially when meeting old friends and colleagues after a long time, we should follow the guidance from public health experts at all times and take steps to ensure a very successful and healthy ISBA 2022 World Meeting. I look forward to seeing you all in Montreal soon!

FROM THE EDITOR

Gregor Kastner

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In an unprecedented effort involving all authors and editors of this Bulletin, we publish well before the end of the month; just in time when the Bayesian Young Statisticians Meeting (BAYSM) and the ISBA World Meeting are around the corner. I am absolutely convinced that both these events will be exciting for those who get to be there; for those who cannot: maybe this Bulletin, featuring the newest updates from BA, j-ISBA, the program council, alongside news from the world and a special

about the newest features of R-INLA, can serve as a tiny consolation. To be read from anywhere!

UPDATES FROM BA

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I am slowly finding my feet in my still rather new role as Editor-in-Chief of *Bayesian Analysis* (BA). I am very grateful for the continued support of the past Editor-in-Chief, Michele Guindani, and I want to extend my heartfelt thanks to the entire Editorial Board which is comprised of 10 Co-Editors and 50 Associate Editors, who are doing a tremendous job in dealing with the continuous stream of submissions in a very wide range of areas, both theoretical and applied.

The Prize Committee of ISBA has recently opened the call for submissions for the **2022 Lindley Prize**. The 2022 Lindley Prize will be awarded for innovative research in Bayesian statistics that is accepted for publication in BA and was presented at the ISBA 2022 World Meeting in Montreal, Canada. Please indicate that your paper is being submitted for consideration for the 2022 Lindley Prize. Papers from any presenter (invited or contributed, oral or poster) may be submitted. The prize includes a check for $ 1000 and a plaque and/or certificate with the winner(s) announced at the ISBA World Meeting in 2024. Submissions should be made electronically by 31 August 2022 at https://projecteuclid.org/authors/euclid.ba and should include the identification number of the session in which the work was presented. Authors should prepare their manuscripts using the BA macros. For further details on the Lindley Prize, including its background, names of past winners, eligibility, and submission information, just visit https://bayesian.org/project/lindley-prize/. Please direct any queries to the Lindley Prize Committee, at m.steel@warwick.ac.uk. The committee looks forward to seeing many interesting submissions for this prize.

Now that life is slowly returing to some form of normality, we can look forward to some exciting meetings which provide opportunities to hear first-hand about the latest research in our field, but also to interact with each other in person! I want to remind you that in the upcoming **ISBA2022 World Meeting** in Montreal, there is a BA invited session entitled *Highlights in Bayesian Analysis: Impact and Challenges in Applications*, with the following papers

- "Colombian Women's Life Patterns: A Multivariate Density Regression Approach" Sara Wade, University of Edinburgh

- "Bias Correction in Clustered Underreported Data: Model Features and Applications" Guilherme Lopes de Oliveira, CEFET-MG

- "A Bayesian Approach to Modeling Multivariate Multilevel Insurance Claims in the Presence of Unsettled Claims" Marie-Pier Côté, Université Laval

which is scheduled for Wednesday, June 29 at 10:30 am.

Thanks to the valuable support of the Section on Bayesian Statistical Science of the American Statistical Association, another invited BA session will take place in the **2022 Joint Statistical Meetings** in Washington, DC on August 9 at 2 pm, called *Highlights in Bayesian Analysis: Innovations in Bayesian Learning* and featuring the presentations

- "Informative Bayesian Neural Network Priors for Weak Signals" Tianyu Cui, Aalto University; Aki Havulinna, Finnish Institute for Health and Welfare (THL); Pekka Marttinen, Aalto University; Samuel Kaski, Aalto University and University of Manchester

- "Fast and Accurate Estimation of Non-Nested Binomial Hierarchical Models Using Variational Inference" Max Goplerud, University of Pittsburgh

- "Bayesian Survival Tree Ensembles with Submodel Shrinkage" Antonio R. Linero, University of Texas at Austin; Piyali Basak, Merck Pharmaceuticals; Yinpu Li, Florida State University; Debajyoti Sinha, Florida State University

- "Bayesian Hierarchical Stacking: All Models Are Wrong, but Some Are Somewhat Useful" Yuling Yao, Flatiron Institute; Gregor Pirš, University of Ljubljana; Aki Vehtari, Aalto University; Andrew Gelman, Columbia University

I do hope you will enjoy both of these sessions. Of course, there are other wonderful meetings out there that I would encourage you to attend. As examples, I can mention the 2022 Objective Bayes Methodology Conference (O'Bayes 2022) in Santa Cruz, California (September 6-10) and the 13th International Conference on Bayesian Nonparametrics (BNP13) to be held in Puerto Varas, Chile, from October 24 to October 28, 2022, but this is by no means an exhaustive list. I very much hope to see you in one of these meetings in person!

JUNIOR ISBA

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Dear ISBA community, we are very excited for the numerous events and initiatives coming up this summer!

BaYSM 2022 BaYSM, the official conference of j-ISBA, is coming up and will be held on June 22-23 in Montreal. We have an excellent lineup of keynote speakers (Tamara Broderick, Lorin Crawford, Sylvia Frühwirth Schnatter, Amy H. Herring, and Adrian E. Raftery) and of discussants (Raquel Prado, Bruno Remillard, Jason Roy, Alexandra Schmidt, and David Alan Stephens).

We are also very excited for our **new seminar series "Updating your (prior) beliefs"**. This is a mentoring event with the aim of providing a safe space for guidance and dialogue around the difficulties that encompass academia, such as work-life balance, career development, burnout, and mental well-being. Senior researchers will be invited to share their own experiences and show how they have overcome the setbacks of their academic careers.

Title: Updating your (prior) beliefs.

Subtitle: Update your prior on the struggles of junior academic life, with data from senior researchers sharing their experiences.

Abstract: The life of a researcher within an academic career path has a lot of advantages. An academic is often in the position to work on state-of-the-art interesting projects, to form collaborations of their own choice, have a flexible schedule, mentor and inspire junior future generations and more in general make a positive impact on the world. But in spite of all these appealing perks, life in academia can be challenging, especially for early career researchers. Junior researchers are often away from their families and support networks, and are subject to feel the pressure of competitive academic environments. Lack of self-confidence, impostor syndrome and mental health problems are very common

in research communities. In the last few years, several studies have shown that mental health problems, such as anxiety and depression, are higher in PhD students compared to other populations (Levecque et al 2017, Liu et al 2019). The j-ISBA section, committed to promote and support early career researchers, is launching the new seminar series "Updating your (prior) beliefs", with the aim of providing a space for dialogue and guidance. Senior researchers will be invited to share their own experiences and show how they have overcome the setbacks of their academic careers. This seminar series is seeking to remove the stigma against mental health difficulties and to openly talk about topics such as work-life balance, career development, burnout, and mental wellbeing. We aim to provide junior researchers with tools to endure hard times and build their resilience, while assuring them that they do not stand alone.

Levecque, K., Anseel, F., De Beuckelaer, A., Van der Heyden, J., & Gisle, L. (2017). Work organization and mental health problems in PhD students. *Research Policy, 46(4)*, 868-879.

Liu, C., Wang, L., Qi, R., Wang, W., Jia, S., Shang, D., Shao, Y., Yu, M., Zhu, X., Yan, S., Chang, Q., & Zhao, Y. (2019). Prevalence and associated factors of depression and anxiety among doctoral students: The mediating effect of mentoring relationships on the association between research self-efficacy and depression/anxiety. *Psychology Research and Behavior Management, 12*, 195-208.

The first event of this series will be a panel discussion held at BaYSM, with the participation of Amy Herring (Duke University), Sylvia Frühwirth-Schnatter (Vienna University of Economics and Business), and Adrian Raftery (University of Washington). A recording will be made available to j-ISBA members that are not able to attend in person.

j-ISBA organized sessions at ISBA 2022 and JSM 2022 j-ISBA will also be actively participating in the upcoming conferences! At ISBA 2022, don't miss the session "Advances in Bayesian methods for complex data", featuring Bora Jin (Duke University), Francesco Denti (Università Cattolica del Sacro Cuore, Milan), and Gabriel Hassler (University of California, Los Angeles), with a discussion led by Giovanni Parmigiani (Harvard University).

j-ISBA is also endorsing the ISBA 2022 session "Junior advances in Bayesian treed regression", that includes talks from Vittorio Orlandi (Duke University), Akira Horiguchi (Duke University), and Sameer Deshpande (University of Wisconsin–Madison), with discussion by Matthew Pratola (The Ohio State University).

And for those attending JSM 2022, you certainly will want to check out the topic contributed session "Advances in Scalable Bayesian Methods for Spatial Data" with talks by Lu Zhang (Columbia University), and Isabelle Grenier (University of California, Santa Cruz), Michele Peruzzi (Duke University), and discussion by Alexandra M. Schmidt (McGill University).

2022 Call for Blackwell-Rosenbluth Award The 2022 Call for the Blackwell-Rosenbluth Award is now open! The recently established award aims at recognizing outstanding junior Bayesian researchers based on their overall contribution to the field and to the community. The deadline for submission is July 25, 2022.

Three prizes will be awarded to researchers based in time zones UTC+0 to UTC+13 [e.g. Africa + Asia + Europe + Oceania] and three to those based in UTC-12 to UTC-1 [e.g. North America + South America]. The six winners, who will be announced in October, will be invited to present their work in two special events of the Junior Bayes Beyond the Borders (JBˆ3) webinar series and will receive three years of free ISBA and j-ISBA membership. We welcome nominations of junior researchers working in the broad spectrum of topics in Bayesian statistics, including but not limited to methods, theory, computation, machine learning, data science, biostatistics, econometrics, industrial statistics, environmental science, and software.

You can find more details on the call and timeline at j-isba.github.io/blackwell-rosenbluth.html.

j-ISBA is looking for officers! In the upcoming ISBA elections, the j-ISBA board will need two new board members, to fill in the positions of Chair-Elect and Treasurer for the years 2023-2024. Senior PhD students, postdocs, and early career researchers are encouraged to apply. Those interested in being nominated for the elections are invited to contact the j-ISBA board by July 17 2022 at jisba.section@gmail.com. Please include your CV and a short motivation letter.

FROM THE PROGRAM COUNCIL

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ISBA World Meeting 2022 In his message at the beginning of this Bulletin, Sudipto has already provided a very nice overview of the The ISBA 2022 World Meeting (https://bayesian.org/isba2022/). I would just like to emphasize the outstanding program, with well over 200 speakers and hundreds of poster presentations, and the large number (around 200) of travel awards to junior researchers. We are looking forward to seeing many of you there!

(Co-)Sponsorship/Endorsement Requests If you are planning a meeting and would like to request financial sponsorship (or co-sponsorship) or non-financial endorsement from ISBA, please submit your request to the program council at program-council@bayesian.org. Detailed information on how to submit a request for either sponsorship or endorsement can be found at https://bayesian.org/events/request-sponsorshipendorsement/.

Upcoming ISBA-Sponsored/Endorsed Events

1. Bayesian Young Statisticians Meeting (BAYSM), June 22-23, 2022, Montreal, Canada.

2. ISBA 2022 World Meeting, June 26-July 1, 2022, Montreal, Canada.

3. NSF-CBMS Conference on Bayesian Forecasting and Dynamic Models at University of California, Santa Cruz, CA, USA. Summer 2022.

4. O'Bayes 2022, September 7-10, 2022, University of California, Santa Cruz, CA, USA.

5. Bayesian Biostatistics conference, October 12-14, 2022, Bethesda, MD, USA.

6. BNP 13, October 24-28, 2022, Puerto Varas, Chile.

NEWS FROM THE WORLD

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Reports from Important Events and Conferences

The BNP 2022 networking event
by Sergios Agapiou and Mario Beraha

Figure 1: Pictures taken at the Bayesian Nonparametrics Networking workshop in Nicosia.

The inaugural Bayesian Nonparametrics Networking workshop took place at the University of Cyprus, Nicosia, and was a success. With a strong focus on junior researchers, the workshop's program was built around three tutorials delivered by David Dunson (Duke University), Yanxun Xu (Johns Hopkins University), and Aad van der Vaart (TU Delft), 15 invited talks by a blend of both established and junior researchers, as well as 23 contributed talks and a small poster session. It also included a mentoring session moderated by Amy Herring with two main discussion topics "Help my paper! Navigating journal revisions with former journal Editors" and "How to succeed in academia", which were particularly appreciated among young (and not-so-young) researchers.

The workshop was generously sponsored by ISBA, the BNP-section of ISBA, and the Cypriot Deputy Ministry of Tourism. The sponsorships had a high impact on junior participation. Out of 60 participants, more than half were graduate students (mainly from the US and Europe), while a quarter were postdocs and junior faculty. The female participation was also notable and reached almost 40%.

The organizers are particularly happy about the quality of the talks and, most importantly, about the audience's engagement throughout the program. The audience asked many questions after each talk, with discussions continuing during the breaks. For most of the student attendees, this was the first in-person conference; for the more senior attendees, the event felt like a return to the pre-pandemic era.

Overall, the environment was fantastic: we shared several dinners and got to know both young and seniors alike, having a beer or sharing some mezes. Cyprus's warm climate helped too!

Upcoming Meetings, Conferences, and Workshops

- The **Bayesian Biostatistics 2022** will be held in Bethesda, Maryland, on October 12-14, 2022. The call for abstracts is open; please send your abstract to bayes2022@lsacademy.com. The deadline for submission is set for June 30, 2022. Speakers will be informed by the end of July if their abstract has been selected. One can find more details at this link.

- The Department of Statistics at the University of **Warwick** is organizing a conference to celebrate its **50th anniversary**! The conference is open to everyone and will take place at the University of Warwick on September 7-9, 2022. The conference will feature talks from past and present members of the department on a wide range of topics within Statistics and Probability (including, of course, Bayes!). One can find more information including a draft program at this link.

And don't forget:

- The **13th International Conference on Bayesian Nonparametrics (BNP13)** will be held in Puerto Varas, Chile, from October 24 to October 28, 2022.

  Important information about the conference is available at this link.

- The **Joint Statistical Meetings** (JSM) is the largest gathering of statisticians and data scientists held in North America. The 2022 JSM will be held in Washington, DC. The conference is scheduled for August 6-11, 2022.

  The early-bird fee offer is over, but registration is still open! More info at this link.

- The **12th European Seminar on Bayesian Econometrics (ESOBE)** will be hosted by the University of Salzburg, Austria on 8-9 September 2022.

  Registrations are open and will close on July 15, 2022, without exemptions. One can find more info at this link.

- The **24th International Conference on Computational Statistics (COMPSTAT 2022)** will take place at the University of Bologna, Italy, 23-26 August 2022. Due to the COVID-19 pandemic, the conference will be hybrid.

  See all the details at this link.

- The **biennial meeting of the Objective Bayes section (O'Bayes 2022)** of the International Society for Bayesian Analysis will take place at the University of California - Santa Cruz on September 6-10, 2022.

  The registration is open, and poster submission has been extended to 6/15. More details can be found at this link.

- Don't miss the **series of monthly webinars** organized by the Bayesian nonparametric section of ISBA (**BNP-ISBA**). Check this link for more details.

SOFTWARE HIGHLIGHT

Denis Rustand, Janet van Niekerk, Elias Teixeira Krainski and Håvard Rue

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NEW FEATURES OF R-INLA: DATA-RICH APPLICATIONS AND JOINT MODELING

Integrated Nested Laplace Approximations is a deterministic alternative to the MCMC sampling methods for Bayesian inference of latent Gaussian models (Rue et al., 2009; Martins et al., 2013; Lindgren and Rue, 2015; Rue et al., 2017; Bakka et al., 2018). This computationally efficient and

accurate methodology is implemented in the freely available open-source R package **INLA** (see https://github.com/hrue/r-inla). The interest in INLA to perform Bayesian inference has been constantly growing, with applications in various fields such as health research (HIV and associated risk factors, evaluation of treatment effect in cancer clinical trials, more than 250 studies on COVID-19) and environmental statistics (health effect of air pollution, water and soil pollution, analysis of forest fires), to name but a few. There has been a constant evolution in the methodology behind INLA in order to make it more accurate and efficient, with enhanced applicability to new modelling challenges. Recent advances include the development of parallel computations strategies for INLA based on nested OpenMP parallelism and the sparse linear solver PARDISO (van Niekerk et al., 2019; Gaedke-Merzhäuser et al., 2022) as well improvements in the optimization algorithm (Fattah et al., 2022).

Last but not least, the recent `cgeneric` model interface allows the user to define a (new) latent model in `C`-code (see one of the available vignettes for details). Such an implementation will run at about the same speed as those already available. This new feature makes it possible to write a new package on top of **R-INLA** providing a set of new latent models and new functionality. We are currently working on a such package to provide new non-separable space-time models, but it is still "in-progress" at the time of writing.

New avenue for INLA

A low-rank Variational Bayes approach introduced by Van Niekerk and Rue (2021), imposes a joint correction to the mean of the latent field conditional posteriors obtained from a Gaussian approximation with the Laplace method. This approach results in the accuracy of a nested Laplace approximation at the cost of a single Gaussian approximation at the mode. This joint correction ensures a more accurate joint posterior meanwhile the low-rank approach propagates changes from each element to the rest of the latent means. The immediate benefit of this new strategy of computing latent posteriors is fast and accurate posteriors, with excellent scalability in model complexity and data size.

The low-rank Variational Bayes approach affords the opportunity of a modern formulation of the latent Gaussian model structure to improve numerical stability and enable broader applications, particularly for big data and high dimensions like the analysis of fMRI data (Mejia et al., 2020). The standard INLA formulation augments the latent field by including the linear predictor in order to compute Laplace approximations for all components. The modern formulation computes approximate Bayesian inference without the linear predictor in the latent field formulation, after which the posteriors are computed using the efficient and accurate low-rank Variational Bayes approach (Van Niekerk et al., 2022). Without the VB approach, the modern formulation is not feasible since no computational gains are possible in the necessary posterior computations in the case of non-Gaussian assumptions or inaccurate Gaussian approximations. We illustrate the performance of this new formulation based on the Tokyo rainfall data example described in Rue and Held (2005). It involves a simple binomial time series to estimate the daily probability p_i of rainfall at calendar day $i = 1, ..., 366$, which is assumed to be gradually changing with time. Figure 2 illustrates the difference between the "classic" INLA that uses nested Laplace approximations for the marginal posteriors of the linear predictors, the simple Gaussian approximation and the new approach of a simple Gaussian approximation with the low-rank Variational Bayes correction.

This new avenue of research within the INLA methodology, forms the basis for future developments in approximate Bayesian inference for latent Gaussian models and manifest INLA as a viable and efficient approach for various statistical modelling challenges. Now, INLA can scale better to complex models and huge data sizes without compromising on the accuracy of the posterior approximations.
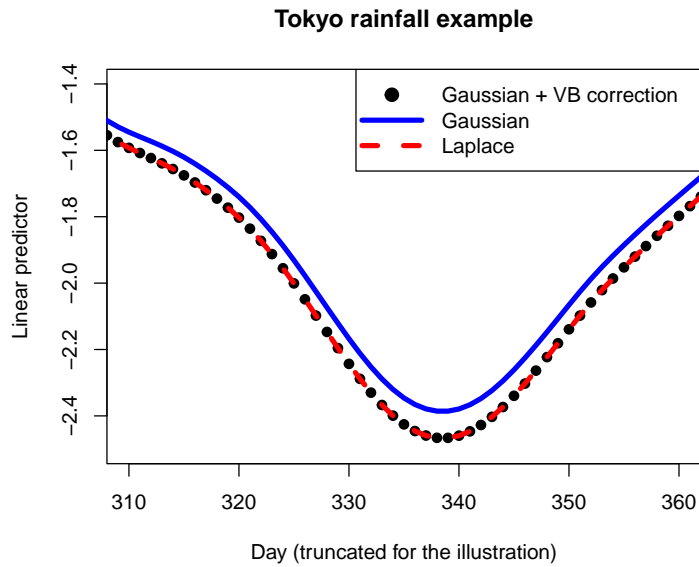
Tokyo rainfall example

Figure 2: Illustration of the difference between the different methods available in INLA on the Tokyo rainfall data example.

INLAjoint: User-friendly R package for multivariate joint modelling longitudinal and time-to-event outcomes with INLA

Joint modelling for longitudinal and time-to-event outcomes consists in modelling simultaneously multiple mixed-effects and survival regression models linked through correlated or shared random effects. They are gaining a lot of interest in various fields, particularly in health research where longitudinal marker trajectory and the risk of event(s) are often of interest. Joint modelling allows the simultaneous analysis of multiple outcomes sharing some feedback. A few examples include the joint analysis of CD4 lymphocytes counts and AIDS survival, prostate-specific antigen dynamics and the risk of cancer recurrence, cancer tumour dynamics and the risk of death, dynamics of aortic gradient and aortic regurgitations and their relationship with the competing risks of death or re-operation, cognitive markers's relationship with the the time to onset of Alzheimer's disease or the analysis of treatment effect on multiple longitudinal markers and competing risks of transplantation and death in a clinical trial for primary biliary cholangitis (Rustand et al., 2022).

The applicability of joint modelling has been limited by the available statistical software (Hickey et al., 2016). Indeed, the implementation of joint models involves complex calculations, particularly because of the random effects that require a numerical approximation. Most joint models can be expressed as latent Gaussian models and therefore belongs to the class of models that INLA can fit. Recent work has proven the benefits from using INLA over alternative algorithms (i.e., MCMC, MCEM, Newton-like) in terms of inference properties, computation time and convergence rates. Moreover, the good frequentist properties of the Bayesian inference with INLA has been assessed through a complete set of simulation studies, showing that INLA outperforms all the available software (i.e., frequentist and Bayesian) that can fit multivariate joint models (Rustand et al., 2021, 2022), with overall more flexibility in the model formulation. However, since INLA is developed to fit a wide variety of statistical models, fitting joint models requires to set up properly the call of the *inla()* function, which can be cumbersome. To facilitate the usage of INLA to fit joint models, we introduce **INLA-joint**, an user-friendly R package to facilitate the usage of R-INLA for joint modelling of multivariate longitudinal markers and time-to-events.

This package can easily be installed from Github using

```
install_github("DenisRustand/INLAjoint")
```

Model specification

The **INLAjoint** package allows the user to build various models with a lot of flexibility, using its main function *joint()*:

- Univariate and multivariate longitudinal outcomes

- Univariate and multivariate survival outcomes (i.e., competing risks, multi-state models)

- Multivariate longitudinal and survival outcomes

A vignette is included in the package to give details on the usage of the package and illustrate the variety of models that can be fitted, see:

```
vignette("INLAjoint")
```

Mixed effects models are used to fit longitudinal outcomes with several distributions available, including linear and lognormal models, generalized linear models (i.e., exponential family), proportional odds models for an ordinal outcome, zero-inflated models (Poisson, Binomial, negative Binomial and BetaBinomial) and two-part models for a semicontinuous outcome. Proportional hazards models are used to fit time-to-event outcomes with flexible non-parametric baseline risk functions.

Longitudinal markers can be assumed independent or correlated through their random effects. The association between longitudinal and survival outcomes can be specified as any linear combination of the linear predictors's components from the longitudinal submodels (therefore including commonly used shared random effects, current value and current slope parameterization).

Example

We propose an example including three longitudinal markers with continuous, counts and binary distributions, respectively, and three competing risks of events. The model has the following structure:

$$
\begin{cases}
\begin{aligned}
Y_{ij1} \quad &= \eta_{i1}(t_{ij}) + \varepsilon_{ij1} & \text{(L1)}\\
&= \beta_{10} + b_{i10} + (\beta_{11} + b_{i11})year_{ij} + \\
&\quad (\beta_{12} + b_{i12})year_{ij}^2 + \beta_{13}ctsX_i + \\
&\quad \beta_{14}binX_i + \varepsilon_{ij1} \\
\log(E[Y_{ij2}]) &= \eta_{i2}(t_{ij}) & \text{(L2)}\\
&= \beta_{20} + b_{i20} + \beta_{21}year_{ij} + \\
&\quad \beta_{22}NS(year_{ij})_1 + \beta_{23}NS(year_{ij})_2 + \\
&\quad \beta_{24}ctsX_i + \beta_{25}binX_i \\
\text{logit}(E[Y_{ij3}]) &= \eta_{i3}(t_{ij}) & \text{(L3)}\\
&= \beta_{30} + b_{i30} + \beta_{31}year_{ij} + \\
&\quad \beta_{32}ctsX_i + \beta_{33}binX_i \\
\lambda_{i1}(t) \quad &= \lambda_{01}(t)\exp\left(\gamma_{11}binX_i + \gamma_{12}ctsX_i + \right. & \text{(S1)}\\
&\qquad \left. \varphi_{11}\eta_{i1}(t) + \varphi_{12}\eta_{i2}(t)\right) \\
\lambda_{i2}(t) \quad &= \lambda_{02}(t)\exp\left(\gamma_{21}binX_i + \varphi_{21}\eta_{i1}'(t) + \right. & \text{(S2)}\\
&\qquad \left. \varphi_{22}\eta_{i3}(t) + \varphi_{23}\eta_{i3}'(t)\right) \\
\lambda_{i3}(t) \quad &= \lambda_{03}(t)\exp\left(\gamma_{31}ctsX_i + \varphi_{31}\eta_{i2}(t)\right) & \text{(S3)}
\end{aligned}
\end{cases}
$$

The evolution of the linear predictors's value over time for each marker is defined as either quadratic (marker 1), defined by two natural cubic splines (marker 2) or linear (marker 3). The association of these k ($k = 1, 2, 3$) markers with the proportional hazards submodels for each competing risk of event are defined based on either the current value ($\eta_{ik}(t)$), the current slope of the linear predictor ($\eta'_{ik}(t)$), or both.

```
data(Long)
data(Surv)
# Set up the three event outcomes
S1 <- inla.surv(time = Surv$deathTimes,
                event = Surv$Event1)
S2 <- inla.surv(time = Surv$deathTimes,
                event = Surv$Event2)
S3 <- inla.surv(time = Surv$deathTimes,
                event = Surv$Event3)
# Any function of time can be included as follows:
# Quadratic function of time for first marker
f1 <- function(x) x^2
# 2 natural cubic splines for second marker
Nsplines <- ns(Long$time, knots=2)
f2 <- function(x) predict(Nsplines, x)[,1]
f3 <- function(x) predict(Nsplines, x)[,2]
# Model fit
JMINLA <- joint(
  formLong = list(
   Y1 ~ time + f1(time) + ctsX + binX +
        (1 + time + f1(time) | Id),
   Y2 ~ time + f2(time) + f3(time) + ctsX +
        binX + (1 | Id),
   Y3 ~ time + ctsX + binX + (1 | Id)),
  formSurv = list(S1 ~ binX + ctsX,
                  S2 ~ binX,
                  S3 ~ ctsX),
  dataLong = Long, dataSurv = Surv,
  id = "Id", timeVar = "time", corLong=TRUE,
  family = c("gaussian", "poisson", "binomial"),
  basRisk = c("rw1", "rw1", "rw1"),
  assoc = list(c("CV", "CS", ""),
               c("CV", "", "CV"),
               c("", "CV_CS", "")))
```

The longitudinal markers are assumed correlated but it is also possible to set "corLong" to FALSE to have independent random effects accross markers and reduce the number of covariance parameters. A complete and intuitive summary of the results is available with the standard *summary()* method. Moreover, many plots are available using the standard *plot()* method on an **INLAjoint** object, including the posterior densities of all the model parameters (i.e., fixed and random effects) as well as the baseline risk functions for survival outcomes. Figure 3 gives an example with the plots of the posterior densities for all the association parameters between the longitudinal and survival components of the joint model given in the example.

```
p <- plot(JMINLA)
p$Associations
```

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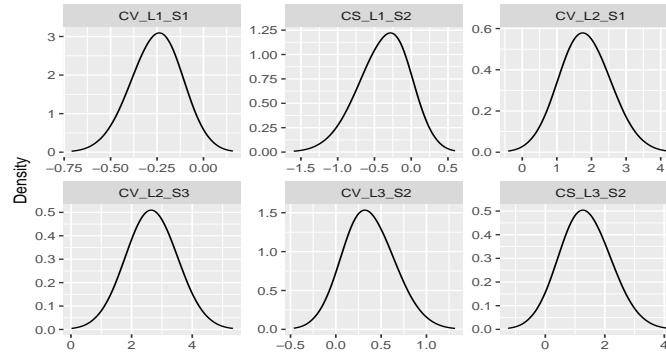
Figure 3: Marginal posterior densities for the association parameters.

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