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THE ISBA BULLETIN

OFFICIAL BULLETIN OF THE INTERNATIONAL SOCIETY FOR BAYESIAN ANALYSIS

MESSAGE FROM THE PRESIDENT

Amy Herring
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December is my favorite month of the year – as a child because of my birthday and winter holidays, and now because of time with family, time by the fire, and time to refresh and reset for the coming year. This year I am particularly grateful for all the ISBA members who make our society such a productive and fulfilling one – whether they do so through stimulating research, fruitful discussions, or formal volunteer work. With that in mind, I'd like to extend my sincere thanks to those volunteers who are rotating off the Board of Directors. Sudipto Banerjee finishes his highly successful three-year term as President-Elect, President, and Past-President of ISBA. He has brought so much energy and positivity to the role, and I am very grateful for his leadership in many areas, including getting us back to in-person meetings, securing new sponsors, and planning outreach to members in all areas. We will certainly miss the care and wisdom he has put into this role. I also want to express my gratitude to our four "retiring" board members: Veronica Berrocal, Cathy W.S. Chen, David Dahl, and Mario Peruggia. We have all benefited from their thoughtful contributions, and while retiring from the Board, I hope to be able to work with them again in the future (in fact some have already taken on other roles for ISBA). We have great new Board members joining the leadership team, thanks in significant part to the excellent work our retiring officers have put forth to better our society. (If you are interested in serving ISBA, please feel free to reach out to me in 2024 as Past President, Aad van der Vaart as President, or Michele Guindani as President Elect, and we can make suggestions and pass along your name as appropriate.)

After a seamless three-year term, Gregor Kastner is wrapping up his work as ISBA Bulletin Editor and has graciously agreed to serve on the search committee for the next Editor, which is chaired by former editor Maria de Yoreo and also includes former editor Feng Liang. I hope you enjoy Gregor's last issue and look forward to spring and reading the work of the new editorial team.

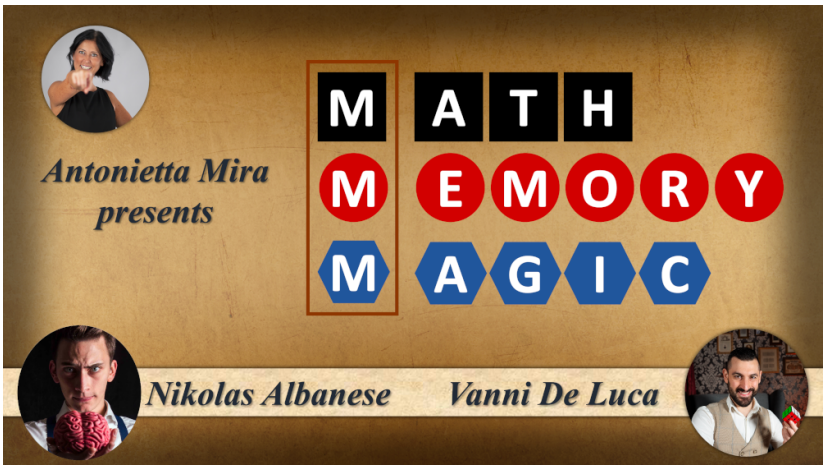
IN THIS ISSUE

While their terms do not end until January 2024, I'd like to express my most sincere gratitude to Ramses Mana and Sara Wade for their exemplary service on the ISBA Prize Committee. While you might think this committee is nothing but fun (and it is quite rewarding!), the committee must ensure awards committees for the various ISBA prizes run smoothly, and emotions can run high when one's work (or one's student's work) is being evaluated against outstanding competitors. I very much appreciate all the energy and care they put into the committee and wish them both a bit of well-earned tranquility in the new year!

Of course many other volunteers have contributed to our Committees, Sections, and Chapters, and I risk omitting someone if I attempt to name you all, but I do want to express my sincere gratitude to all who have served ISBA in any capacity this year, from reviewing papers for Bayesian analysis to submitting an abstract to a meeting to judging a best talk award at BAYSM:O and more. Thank you so much for your time!

Hard at work over the winter break are ISBA's Program Council and World Meeting Committees, and I am deeply grateful to them and to all who are working to make our next World Meeting a success. Past Program Council Chair Matthias Katzfuss would typically be rotating off the committee now, but he has generously agreed to be on call to the Council while our outgoing Chair and incoming Past Chair, Sinead Williamson, is on family leave this winter. The contributed program for the World Meeting is being finalized, and meeting registration, the application for travel support, and the sign-up for childcare will all appear in the coming months. Please make sure your membership is renewed by early January so that you get all the member announcements regarding the World Meeting and other opportunities!

Our local committee, chaired by Roberto Casarin at Ca' Foscari University of Venice, has been hard at work making arrangements for reasonably-priced childcare for children of members, which will take a variety of formats depending on age. Most likely this will involve use of a local kindergarten within walking distance of conference facilities for children aged 1-7, potential babysitting for children under 12 months (we hope to have good options but note this is the trickiest age to accommodate), and day camp options for older children. Final details should be available in early spring, and we will communicate information as soon as we are able, to assist you all with planning. We are also finalizing details of a (mathe-)magical show for children on Monday afternoon, hosted by our own magical mathematician, Antonietta Mira.



We are seeking sponsorships to help ISBA subsidize the cost of childcare, and the ISBA Board and Finance Committee have both expressed support for ISBA providing a subsidy in the event that is needed. If you have ideas about sponsorship for childcare or other aspects of the meeting, please reach out to Tony Canale and the Sponsorship Committee, who have made great progress so far but who are continuing to work to secure funding for junior researcher travel, childcare, and other

meeting components. Plans for multiple satellite and joint meetings, including the popular BAYSM meeting, a satellite workshop in Lugano, Switzerland, and a joint workshop with the International Conference on Information Fusion, are well underway and described in further detail in this issue.

I'd like to thank you for the opportunity to serve as ISBA President over the past year. Seeing all our members have accomplished throughout the year has been energizing and inspirational. I can't wait to catch up with you in person in Venice!

FROM THE EDITOR

Gregor Kastner
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2023 is coming to an end, and it is with pleasure to present to you the final Bulletin under my watch. The issue features Amy Herring's final piece as President, a brief note concerning the passing of Thomas Leonard, the founding editor of the Bulletin (then "Newsletter"), updates from the Program Council and from jISBA, and the traditional News from the World section with the latest about past and upcoming events.

This edition's specials are a Teaching Highlight about a newly developed course on data science and data-driven engineering by Luca Porta-Mana and Steffen Mæland who tackle this topic from a Bayesian viewpoint. To conclude, read about the new software package `bayesianVARs`, short for Bayesian Vectorautoregressions, authored by Luis Gruber. It brings together a multitude of recently developed "automatic" shrinkage priors with a long-standing tradition of carefully crafted subjective priors, all packaged neatly to be conveniently used by researchers and practitioners alike.

In addition to the many contributors over the years (too numerous to list here), I want to thank my Associate Editors Francesco Denti and Anton Westveld for the continued dedication they put into making this publication possible.

REMEMBERING THOMAS LEONARD

Amy Herring | Gregor Kastner
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It is with sadness that we relay the news of the recent peaceful passing of one of ISBA's founders and its first newsletter editor, Thomas Leonard, on December 18th. An obituary with remembrances from colleagues will appear in the next issue of the Bulletin. If you would like to contribute a tribute or a remembrance, please reach out to ISBA secretary Donatello Telesca at dtelesca@ucla.edu.

In the meantime, the interview by Diego Andres Perez Ruiz on page 11 in the December 2016 Bulletin will give you a flavor of his extraordinary academic experiences and many accomplishments. Tom's funeral will be on Friday, January 12th, at 4:30pm. It will be held at Warriston Crematorium, Edinburgh EH7 4WH in the Cloister Chapel. There will be a collection for cancer research and a wake meal afterwards. All are welcome.

We express our deepest sympathies to his friends and family.

FROM THE PROGRAM COUNCIL

Sergios Agapiou
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The organization of the 2024 world meeting at Venice is continuing at full speed. The Program Council is working closely with the Executive Committee, the Local Organizing Committee and the Scientific Committee to this end.

Regarding the scientific program, we already have an outstanding line-up of Foundational, Keynote and Named lecturers, the entire invited sessions program, and the short courses; please refer to the website for details. Acceptance letters on contributed talks and posters will be sent within the next days, while a call for travel support will be sent immediately after that.

In addition to the core scientific program, several other ISBA-related events are scheduled to occur concurrently to the world meeting in Venice. These include BAYSM2024, a joint workshop between ISBA and the International Society of Information Fusion, a roundtable discussion on data protection, and an entertaining show involving magic and Statistics.

We are currently finalizing details for childcare, which will include a kindergarten for kids aged 1-7, baby sitting service for infants aged 0-1, as well as a list of available camps for children aged 7+. A call for financial assistance for childcare will be sent in due course.

Changes in the Program Council

First, I would like to thank Sinead Williamson for the excellent job she has done so far coordinating the organization of the world meeting. Sinead has just completed her tenure as chair and is currently on maternity leave; please join me in wishing her all the best. She has left everything in great shape

and I hope to successfully fill her shoes while she is away. I would also like to thank Matthias Katzfuss, who although completing his tenure as past-chair, agreed to extend his term to actively assist with the organization of the world meeting. The new vice-chair will be announced very soon.

(Co-)Sponsorship/Endorsement Requests

If you are planning a meeting in 2024 and would like to request financial sponsorship (or co-sponsorship) or non-financial endorsement from ISBA, please submit your requests 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 here.

The list of upcoming ISBA-sponsored/endorsed events can be found in the News section on page 11.

UPDATES FROM BA

Mark Steel
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I only have a very brief update, concerning the Lindley Prize. As you know, in order to be eligible for the Lindley Prize, papers have to be presented at the previous ISBA World Meeting and appear in the December issue of the journal the year before the next World Meeting takes place. The December issue of BA has just appeared, and it features a separate section with the eight contenders for the 2022 Lindley Prize. The papers can be viewed at https://projecteuclid.org/journals/bayesian-analysis/volume-18/issue-4. Judging which of these excellent papers merits the prize is going to be quite demanding. Fortunately, we have a very knowledgeable and dedicated Lindley Prize Committee to make that tough decision, which will be communicated during the 2024 World Meeting in Venice. I hope to see many of you there!

Some background on the Lindley Prize and a list of previous winners can be found at https://bayesian.org/project/lindley-prize/. Finally, I wish you all a wonderful Christmas break and a happy, healthy and productive New Year!

JUNIOR ISBA

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Blackwell-Rosenbluth Award

It is our great pleasure to announce the winners of the 2023 Blackwell-Rosenbluth Award. We made the official announcements in October 2023, and held two sessions dedicated to the awardees at BaYSM:O 2023 in November 2023. We would like to extend our heartfelt congratulations to the award winners for their achievements and overall contributions to the field.

Winners from the UTC+ regions are: François-Xavier Briol (University College London), Xenia Miscouridou (University of Cyprus), and Maria Skoularidou (The Broad Institute of MIT and Harvard). Winners from the UTC- regions are: Jonathan H. Huggins (Boston University), Georgia Papadogeorgou (University of Florida) and Guanyang Wang (Rutgers University).

Figure 1: 2023 Blackwell-Rosenbluth Award winners. Top row (left to right): François-Xavier Briol, Xenia Miscouridou, and Maria Skoularidou. Bottom row (left to right): Jonathan H. Huggins, Georgia Papadogeorgou, and Guanyang Wang.

We would like to thank all members of the scientific committee for the 2023 Blackwell-Rosenbluth Award, and all nominators who collectively contributed to an exceptionally outstanding candidate pool. Since its inauguration in 2021, this prestigious award would not have been achievable without the support and efforts from the entire ISBA community.

We are looking forward to reopening the call for award nominations in mid-2024. Please stay tuned for more information on the official webpage at https://j-isba.github.io/blackwell-rosenbluth.html.

BaYSM:O 2023

We successfully held the Bayesian Young Statisticians Meeting - Online (BaSYM:O 2023) in November 2023 as an entirely virtual conference. With more than 170 total participants, 99 speakers and 20 sessions that spanned five days across various time zones, BaSYM:O 2023 was a record-breaking effort by j-ISBA to provide an open, accessible and inclusive conference venue for early-stage researchers.

We would like to congratulate all BaYSM:O 2023 talk award winners again for their great presentations! The long talks awards winners were Alexander Dombowsky and Maria Fernanda Pintado, while the short talks awards by j-ISBA were shared between Peter Potaptchik and Xi Jiang, and the short talks awards sponsored by Springer were presented to Bao Anh Vu and Zach Horton.

We want to thank all senior discussants who provided constructive feedback during each long talks session, and all five plenary talk speakers who showcased the broad spectrum of cutting-edge Bayesian research.

You can find more details about the conference in the events section of this bulletin.

BaYSM 2024

BaYSM 2024 will be taking place on **June 29th - 30th, 2024 in Venice, Italy**, at a nearby location to ISBA and right before the ISBA 2024 World Meeting. An exciting program is lined up, with our great plenary speakers: Stephanie Van der Paas, Michele Guindani, Sonia Petrone and Sudipto Banerjee.

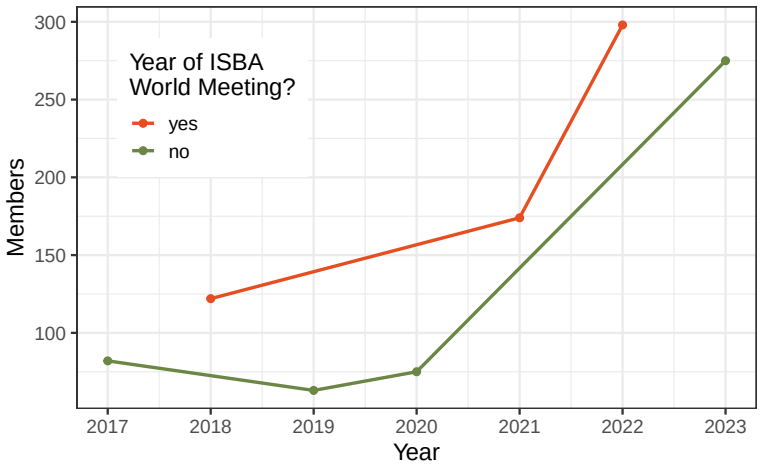

Figure 2: j-ISBA year-end member counts by year. We now have 275 total members, a historical high in years without an ISBA World Meeting. The all-time highest members count (298) was achieved last year.

Early-career researchers interested in giving a talk or presenting a poster are invited to submit an extended abstract by **January 14, 2024**. The extended abstract should be approximately 4 pages (with a maximum of 9 pages) using this template. The submission link is now live at https://forms.gle/SdQKcFEsbwGdt7PJ6. Note that there is no minimum length and it is equally acceptable to submit a 2 or 3 pages extended abstract. While the meeting is organized for and by junior Bayesians, **anyone who is interested is welcome to attend**.

Please visit the official website (https://events.stat.uconn.edu/BAYSM2024/) for more details on the program and abstract submission.

j-ISBA Events and Announcements

- We held a special session titled "Junior Advances in Bayesian Methods for Complex Data" (organized by our own Cecilia Balocchi) at the 2023 International Day of Women in Statistics and Data Science (IDWSDS 2023) on October 10, 2023. We look forward to organizing more sessions highlighting early-career Bayesians in the upcoming year.
- The ISBA Elections have concluded and we are thrilled to share the names of three new j-ISBA board members beginning January 2024. They are: Matteo Giordano as Chair-Elect, Filippo Ascolani as Program Chair, and Jordan Bryan as Secretary.
- Proceedings for BaYSM 2022 are officially published and available at https://link.springer.com/book/10.1007/978-3-031-42413-7. We would like to thank our editors, Alejandra Avalos-Pacheco, Roberta De Vito and Florian Maire for their editorial work. Please keep an eye out for the BaYSM 2023 proceedings open call!
- We are excited to announce that j-ISBA has now reached a membership of 275 following the successful conclusion of BaYSM:O 2023! This marks the highest number of members in years without an ISBA World Meeting (see Figure 2). We are delighted to witness the consistent growth of the j-ISBA community and remain committed to expanding our community-engagement events and activities in the coming year. Don't forget to renew your membership to stay connected with us!

NEWS FROM THE WORLD

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Reports from Important Events and Conferences

BNP Networking Workshop - conference report

by Catherine Forbes

Sixty researchers from twenty-one universities and institutes located in Australia, France, Hong Kong, Indonesia, Spain, the UK, and the USA participated in the Bayesian Nonparametric Networking Workshop held on 4-7 December 2023 at Monash University in Melbourne, Australia. Held in the beautiful Pavilion event space at Monash University's Caulfield campus, participants enjoyed spectacular views across Melbourne, spanning Port Philip Bay, the Central Business District (CBD), and Mount Dandenong.

Figure 3: Top: Participants of the BNP Networking Workshop at Monash University, 4-7 December 2023. Center: the Keynote Speakers Jim Griffin (UCL), Maria Kalli, and Athanasios Kottas. Bottom: The Monash BNP Networking Workshop Dinner on Thursday 7 December 2023.

The scientific program, coordinated by the scientific committee chaired by Francois Caron (Oxford University) featured excellent keynote talks and tutorial sessions from Keynote Speakers Jim Griffin (University College London), Athanasios Kottas (University of California Santa Cruz), and Maria

Kalli (King's College London). The workshop experience was open and friendly, with many wonderful discussions taking place in response to the fantastic keynote talks, tutorials, and the many enlightened contributed talks and posters presented during the workshop.

New friendships and collaborative relationships have surely resulted from this workshop. In addition to having plenty of time for discussion, debate, and new ideas, participants enjoyed a welcome reception at The Pavilion, a social excursion to the Healesville Animal Sanctuary located in a rural area just outside of Melbourne, and a festive conference dinner held in the Docklands area of the Melbourne CBD.

The Monash BNP Networking workshop is the second in a series of smaller informal events initiated and supported by the BNP Section of ISBA. These workshops aim to provide presentation opportunities for early career researchers, establish and strengthen local networks, broaden the appeal of BNP methods, and foster brainstorming and innovation. The first of these events took place in 2022 in Cyprus, and the next one looks set to be in Singapore in mid-2024.

More detailed information from the workshop can be found at this link.

BaYSM:O 2023 - conference report

by Alejandra Avalos-Pacheco

The BaYSM:O 2023 successfully took place from November 13 to 17, totally online. This conference wasn't your average Zoom call; it was an outstanding event, showcasing the brilliance and innovation of the rising stars in Bayesian statistics from every part of the world.

BAYSM:O 2023's digital platform turned out to be a game-changer, reaching the historical maximum of registrations for a BaYSM conference with more than 170 participants. The advantages of the online conference became evident as attendees revealed the convenience of participating from the comfort of their own countries. The online format amplified networking opportunities and fostered a dynamic exchange of ideas. Attendees could attend the conference without the hassle of visas or jet lag – a true win-win in the ever-evolving landscape of academic conferences.

The conference featured an impressive line-up of five plenary talks addressed by Giacomo Zanella, Catherine Forbes, David Rossell, Marc Suchard, and Alexandra Schmidt. The members of the Scientific Committee (SC) were Cecilia Balocchi, Beatrice Franzolini, Akira Horiguchi, Arman Oganisian, Augusto Fasano, Dootika Vats, Filippo Ascolani, Jeremias Knoblauch, Laura Bondi, Sameer Deshpande, Veronica Ballerini and Willem van den Boom. The SC was happily impressed by the quality of the work presented by the participants in the forty-nine long and thirty-nine short talks. The SC is particularly thankful for all the work and great comments of the discussants: Judith Rousseau, Fabrizia Mealli, Chris Oates, Peter Mueller, Jim Griffin, Botond Szabo, Raffaele Argiento, Mark Steel, Michele Guindani, David B. Dahl, Yuansi Chen, Paul Kirk, Sara Wade, Edward I. George and Trevor Cambell.

One of the highlights of the conference was the Blackwell-Rosenbluth Award sessions, which recognize the outstanding contributions of junior researchers in Bayesian statistics. The presenters were: Jonathan H. Huggins, Georgia Papadogeorgou, Guanyang Wang, Maria Skoularidou, Xenia Miscouridou and François-Xavier Briol. We thank Ramsés H. Mena and Sylvia Frühwirth-Schnatter for all their efforts and for chairing these sessions.

All presenters (long or short talks) at BaYSM:O 2023 will be invited to extend and submit their contribution as a chapter for the Proceedings of BaYSM:O 2023, published by Springer. This initiative not only provides a platform for participants to disseminate their research findings but also contributes to the advancement of Bayesian statistics by showcasing the latest developments in the field. More information will be given soon!

The conference granted four j-ISBA and two Springer awards to talk presentations. The long talks j-ISBA award winners were Alexander Dombowsky and Maria Fernanda Pintado, while the short

Figure 4: BaYSM:O 2023

talks were shared between Peter Potaptchik and Xi Jiang. The Springer awardees were Bao Anh Vu and Zach Horton. Congratulations!

We also want to thank our great webmaster Daeyoung Lim; the ISBA board, for all the help, in particular thanks to Donatello Telesca and Amy Herring; and the organizing committees: Fan Bu, Dr. Beniamino Hadj-Amar, Alejandra Avalos-Pacheco, and Cecilia Balocchi, with a big shoutout to Beatrice Franzolini, the true hero behind leading all the online organization.

And above all, thanks to the more than 170 participants, who injected the conference with an infectious blend of energy, passion, and unwavering positivity, they were key to the success of this conference. See you at BaYSM 2024 in Italy!

Upcoming Meetings, Conferences, and Workshops

ISBA Sponsored Events

- **International Society for Bayesian Analysis World Meeting (ISBA 2024)** Venice, Italy, July 1-7, 2024, at the Department of Economics - Ca' Foscari University of Venice, in San Giobbe Economics Campus.

  The scope of the ISBA world meetings is to bring together the international statistical community of researchers and professionals who develop Bayesian methods and apply them to challenging problems in different fields, ranging from economics and finance to business, industry, biostatistics, pharmaceutical statistics, environmental statistics, etc.

  If you are considering traveling with children, you are encouraged to fill out this childcare survey. ISBA is considering several options for childcare, and your input will be very helpful in gauging levels of interest and helping us tailor our options. The survey is non-binding. Details about childcare options will be sent out in early 2024. Monitor the official ISBA 2024 website for news at this link.

- A **Satellite workshop to International Society for Bayesian Analysis (ISBA) world meeting** will take place on June 25-28, 2024, in Lugano, Switzerland.

  This workshop brings together world experts in Bayesian methodology to disseminate state-of-the-art work in the field and explore the application of novel Bayesian methods across various scientific domains. The presented work will reflect the ongoing efforts within the academic community to refine and expand Bayesian techniques to address complex scientific challenges. The proposed format, combining focused lectures with networking breaks, is designed to meet the aims and objectives of knowledge dissemination and community building in Bayesian statistics. More details about the workshop can be found at this link.

- **BAYSM 2024** will occur in Venice, Italy, on June 29-30, 2024.

  The Bayesian Young Statisticians Meeting is the official conference of j-ISBA, the junior section of the International Society for Bayesian Analysis (ISBA). Please use this form to submit an approximately 4-page (at most nine pages) abstract for BAYSM 2024. You may use this template for your abstract. The deadline for submission is January 14, 2024 (end of day anywhere around the world).

  If you are interested in participating in BAYSM 2024 and are considering traveling with children, please complete the childcare survey on the conference website by January 14, 2024. The organizing committee is exploring various childcare possibilities, and we are trying to assess the extent of interest. The survey is non-binding, so we encourage you to participate even if your plans for next June still need to be determined.

  Please visit the BaYSM 2024 website for more information. Check the **JUNIOR ISBA** section of the Bulletin and this link for more details.

- The **27th International Conference on Information Fusion 2024**, dedicated to Machine Learning methods and their applications, will occur on July 7-11, 2024, in Venice, Italy. Check this webpage for more information.

  As the conference will take place right after ISBA 2024, given the interdisciplinarity of the two initiatives and to strengthen the scientific collaboration between the two communities, the opportunity was taken to promote a joint ISBA-Fusion 2024 Joint Workshop between the two events. It will take place on July 7, 2024, in Venice.

Also, be sure to save the date for the following events!

- **VII Latin America Congress on Bayesian Statistics and 17th Brazilian Meeting of Bayesian Statistics**, Belo Horizonte, Minas Gerais, Brazil, December 2-6, 2024
- **BayesComp**, National University of Singapore, 26-30 May, 2025

More details will be available soon.

Other Events

- An **Applied Bayesian Statistics (ABS)** summer school will take place in Villa del Grumello, located in Como, Italy, on August 26-30, 2024. The topic chosen for the 2024 school is *Bayesian phylogenetics and infectious diseases*.

  The Applied Bayesian Statistics summer school has been running since 2004. It is organized by IMATI CNR Istituto di Matematica Applicata e Tecnologie Informatiche, Consiglio Nazionale delle Ricerche, Milano. The school aims to present state-of-the-art Bayesian applications, inviting leading experts in their field. Registration is now open, but payments will be possible (by bank transfer or credit card) only after February 1, 2024. Visit this link for more information.

And Don't Forget:

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

TEACHING HIGHLIGHT

Luca Porta-Mana | Steffen Mæland
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Foundations of Data science and data-driven engineering

Machine Learning and Artificial Intelligence are developing extremely fast. They are increasingly used in ethically sensitive domains such as medicine. Additionally, we expect to see many technological improvements in the near future. When factors such as these converge, one rediscovers the importance of the scientific foundations of a field. Bayesian foundations in this case.

This is the goal of a new course at the Western Norway University of Applied Sciences, endorsed by the Artificial Intelligence Engineering group. The course's name is "foundations of data science and data-driven engineering", but more precisely it is about *Bayesian nonparametric density inference* and

Bayesian decision theory: most present-day machine-learning algorithms are indeed essentially doing an approximate form of nonparametric density inference.

The course is part of the master's program in Applied Computer Science, and is designed to cater for students with very diverse backgrounds within computer science and data science, including those who were never exposed to Bayesian notions before. The introduction of Bayesian probability & decision theory turned out to be very natural from an artificial-intelligence perspective. The students want to build an *AI agent* capable of drawing inferences and making decisions under uncertainty, at least in specific applications.

We adopted an approach à la Johnson, Jeffreys, Cox, Jaynes, Hailperin, taking *propositions* as the basic objects for the probability calculus. They are particularly suited to an artificial-intelligence approach, as they can flexibly represent information, hypotheses, and decisions. Their use moreover connects with much of the AI literature on knowledge-base representation.

Probability emerges as an inevitable notion to quantify the agent's uncertainty or degree of belief. The four basic axioms of coherence (or Cox's axioms) and the principle of maximal expected utility also enter quite naturally, as the rules by which the AI agent can calculate any needed degrees of belief in a self-consistent way, update those beliefs according to new training data entering its knowledge base, and make optimal decisions.

The students found such a framework sensible, and readily grasped the difference between probability and frequency, as well as the necessity of initial degrees of belief (priors) and utilities to "jump-start" the agent.

We gradually focused this framework on the construction of an AI agent capable of solving specific tasks where an assumption of *exchangeability* can be made.

The students easily understood the idea of exchangeability and how it applies to specific machine-learning tasks. De Finetti's representation theorem was introduced in an intuitive way. The integration parameter was presented as the "future and past frequencies" of a task's outcomes. From a principled point of view, we are not completely satisfied with such an interpretation; however, it seems that the students grasped it easily and it also helped them not to conflate probability and frequency.

An exciting part of the course was the final design and building of a simple but concrete "AI agent" that operates exactly according to the coherence rules and the exchangeability assumption, learns from data, draws inferences, and makes decisions. Essentially it is a suite of R functions that calculates conditional and marginal probabilities according to de Finetti's formula, as well as expected utilities of decisions. The students became increasingly eager to build it and their enthusiasm was very contagious! Their common mathematical denominator didn't allow for the development of nonparametric models with continuous variates, possibly needing Monte Carlo methods. We focused instead on inference and decision tasks involving variates of a nominal type, and built an AI agent based on the Dirichlet distribution – a nonparametric model on a finite dimensional space.

Students with prior machine-learning education were positively surprised, not to say amazed, by the flexibility and features of their AI agent. In particular that: (1) it does not have a hard-coded distinction between "features" (predictors) and "labels" (predictands): given any known variate, it can calculate the probability of any unknown variate as desired; (2) it can tell how the calculated probability could change if more training data were available – one of the beautiful features of de Finetti's theorem; (3) it outputs probabilities, and can thus make decisions based on utilities that can change from one task instance to the next.

These observations also made the students realize the intrinsic assumptions, approximations, and limitations of many present-day machine-learning algorithms such as neural networks (for instance the maximum-likelihood approximation underlying most machine-learning models, or the fact that utilities are intrinsically hard-coded). Indeed, the most fulfilling outcome of the course is that many students concluded it with ambitions about modifying complex machine-learning models or build

completely new ones that could better approximate the "perfect (Bayesian) AI agent". Some of them will probably continue on working with Bayesian neural networks or fully nonparametric Bayesian models.

Our and our students' experience during this course shows that Bayesian theory can be fully integrated with Artificial Intelligence and Machine Learning, at their very foundations. Maybe a good strategy is not to insist on particular terminology or vernacular. Bayesian is as Bayesian does. We used the adjective "Bayesian" only once or twice in the whole course, yet it is undeniable that the students learned the basics and some important applications of Bayesian theory.

The course did not have a textbook, rather we created our own (see below). We drew from Parts III–IV of Russell & Norvig's *Artificial Intelligence: A Modern Approach* (Pearson 2022) – an excellent text for Bayesian inference and decision theory – as well as some parts of Lindley's *Making Decisions* (Wiley 1988), O'Hagan's *Probability: Methods and measurement* (Chapman & Hall 1988), Fenton & Neil's *Risk Assessment and Decision Analysis with Bayesian Networks* (CRC 2019), and other texts and articles. The course's general perspective was greatly inspired by Jaynes' *Probability Theory: The Logic of Science*.

We will be extremely happy if other teachers find the course or any of its parts useful. It is freely accessible on GitHub at `https://hvl-ml.github.io/ADA511/`, and can be freely forked from `https://github.com/pglpm/ADA511`. Any comments, corrections, criticisms, suggestions for improvements are heartily welcome.

SOFTWARE HIGHLIGHT

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BAYESIANVARS – SHRINKAGE PRIORS FOR BAYESIAN VECTORAUTOREGRESSIONS IN R

1 Introduction

In multivariate time series analysis, vectorautoregressions (VARs) are widely applied in fields such as brain connectivity modeling (e.g., Goebel et al., 2003; Chiang et al., 2017; Wegmann et al., 2021) and the modeling of macroeconomic and financial time series (e.g., Sims, 1980; Karlsson, 2013; Crump et al., 2021). Especially in macroeconomic applications, VARs have probably become the workhorse model for forecasting. The VAR model of order p, VAR(p), can be formulated as follows:[1]

$$y_t' = \sum_{l=1}^{p} y_{t-l}' A_l + \varepsilon_t', \quad \varepsilon_t \sim \mathcal{N}(0, \Sigma_t), \quad t = 1, \dots, T, \tag{1}$$

where y_t is the M-dimensional vector of interest, A_l, for $l = 1, \dots, p$, an unknown $M \times M$ matrix of regression coefficients, ε_t an M-dimensional vector of errors, and Σ_t the corresponding $M \times M$ variance-covariance matrix. For ease of notation, let $\Phi \coloneqq (A_1, \dots, A_p)'$ denote the $(K = pM) \times M$ matrix containing all VAR coefficients and let $\phi \coloneqq \text{vec}(\Phi)$ denote the vectorization thereof with length $n = pM^2$.

[1] For simplicity of exposition we omit the intercept in the following (which nonetheless `bayesianVARs` implements by default).

To facilitate efficient and reliable estimation when M gets large, we consider two different decompositions of the variance-covariance matrix Σ_t explained in the following paragraphs.

VAR with factor stochastic volatility Assuming that the errors feature a factor stochastic volatility structure, following Kastner and Huber (2020), we decompose the variance-covariance matrix into

$$\Sigma_t = \Lambda V_t \Lambda' + Q_t. \tag{2}$$

Both $Q_t = \text{diag}(e^{h_{1t}}, \ldots, e^{h_{Mt}})$ and $V_t = \text{diag}(e^{h_{M+1,t}}, \ldots, e^{h_{M+r,t}})$ are diagonal matrices of dimension M and r, respectively, and Λ is the $M \times r$ matrix of factor loadings. This is obviously equivalent to introducing r conditionally independent latent factors $f \sim \mathcal{N}_r(0, V_t)$ and rewriting the error term in (1) as

$$\varepsilon_t' = f' \Lambda' + \eta_t', \tag{3}$$

where $\eta_t \sim \mathcal{N}_M(0, Q_t)$. The matrix Q_t contains the idiosyncratic, series specific, variances. The matrix V_t contains the factor specific variances governing the contemporaneous dependencies. The logarithms of the elements in Q_t and V_t follow a priori independent autoregressive processes of order one (AR(1)). More specifically, the evolution of the idiosyncratic log-variance $h_{it} \sim \mathcal{N}(\mu_i + \phi_i(h_{i,t-1} - \mu_i), \sigma_i^2)$, for $i = 1, \ldots, M$, is described by the parameters μ_i, the level, ϕ_i, the persistence and σ_i^2, the variance. The factor-specific log-variance $h_{jt} \sim \mathcal{N}(\phi_j h_{j,t-1}, \sigma_j^2)$, for $j = M+1, \ldots, M+r$, is assumed to have mean zero to identify the scaling of the elements of Λ. Without imposing restrictions on the factor loadings, the VAR with factor stochastic volatility is invariant to the way the variables are ordered.

VAR with Cholesky stochastic volatility Assuming that the errors feature a Cholesky stochastic volatility structure, following Cogley and Sargent (2005), we decompose the variance-covariance matrix into

$$\Sigma_t = U'^{-1} D_t U^{-1}, \tag{4}$$

where U is an $M \times M$ upper triangular matrix with ones on the diagonal. The logarithms of the elements of the M-dimensional diagonal matrix $D_t = \text{diag}(e^{h_{1t}}, \ldots, e^{h_{Mt}})$ are assumed to follow a priori independent AR(1) processes, i.e. $h_{it} \sim \mathcal{N}(\mu_i + \phi_i(h_{i,t-1} - \mu_i), \sigma_i^2)$, for $i = 1, \ldots, M$. Since U_t is a triangular matrix, the VAR with Cholesky stochastic volatility depends on the way the variables are ordered.

2 Prior Distributions

While flexible, VARs are known to be overparameterized: In macroeconomic applications the number of available observations T can be relatively small compared to the number of VAR coefficients n, since the data is usually reported on a quarterly or yearly basis. Bayesian shrinkage priors can be used to alleviate this issue. In the following paragraphs, we discuss several prior options for the VAR coefficients before briefly discussing prior choices for the variance-covariance matrix. In general, we assume that the joint prior distribution has a product form $p(\phi, \Sigma_t) = p(\phi)p(\Sigma_t)$, i.e. we assume that a priori ϕ and Σ_t are independent. The generic prior for the VAR coefficients is conditionally normal $\phi | \underline{V} \sim \mathcal{N}_n(0, \underline{V})$, where $\underline{V} = \text{diag}(v_1, \ldots, v_n)$ is an n-dimensional diagonal matrix. The priors distinguish themselves in their treatment of $\underline{V}$.

Hierarchical Minnesota prior The *original* Minnesota prior proposed in Litterman (1986) is mainly characterized by two assumptions: First, the own past of a given variable is more important in predicting its current value than the past of other variables. Second, the most recent past is assumed to be more important in predicting current values than the more distant past. Hence, $\underline{V}$ is structured

in a way, such that the sub-diagonal elements of Φ (the own-lag coefficients) are shrunken less than the off-diagonal elements (the cross-lag coefficients). And, coefficients associated with more recent lags are shrunken less than the ones associated with more distant lags. Denote $\underline{\mathrm{V}}_i$ the block of $\underline{\mathrm{V}}$ that corresponds to the K coefficients in the ith equation, and let $\underline{\mathrm{V}}_{i,jj}$ be its diagonal elements. The diagonal elements are set to

$$\underline{\mathrm{V}}_{i,jj} = \begin{cases} \frac{\lambda_1}{l^2} & \text{for coefficients on own lag } l \text{ for } l = 1, \ldots, p, \\ \frac{\lambda_2 \hat{\sigma}_i^2}{l^2 \hat{\sigma}_j^2} & \text{for coefficients on lag } l \text{ of variable } j \neq i, \end{cases} \tag{5}$$

where $\hat{\sigma}_i^2$ is the OLS variance of a univariate AR(6) model of the ith variable. The term l^2 in the denominator automatically imposes more shrinkage on the coefficients towards their prior mean as lag length increases. The term $\frac{\hat{\sigma}_i^2}{\hat{\sigma}_j^2}$ adjusts not only for different scales in the data, it is also intended to account for different scales of the responses of one economic variable to another. To shrink own-lag coefficients less than cross-lag coefficients, one could set $\lambda_1 > \lambda_2$. The hierarchical Minnesota prior, however, treats both shrinkage parameters as unknown. Following Huber and Feldkircher (2019), we place independent gamma priors on λ_1 and λ_2,

$$\lambda_i \sim \mathcal{G}(c_i, d_i), \quad \text{for } i = 1, 2. \tag{6}$$

Semi-global local shrinkage Global local shrinkage priors in the fashion of Polson and Scott (2011) are also used in the VAR literature (e.g., Follett and Yu, 2019; Huber and Feldkircher, 2019; Kastner and Huber, 2020). In order to combine the merits of tailor-made priors, such as the Minnesota prior, with the flexibility of off-the-shelf global local shrinkage priors, Gruber and Kastner (2023) propose the class of semi-global local priors. Other than global local priors, which shrink globally, semi-global local priors shrink semi-globally, meaning that semi-global shrinkage is imposed on k pre-specified subgroups of the parameter space. Let $\mathcal{A}_j$, for $j = 1, \ldots, k$, denote the generic index set that labels the coefficients of the jth group in ϕ (e.g., the first group could be the own-lag coefficients associated with the first lag, the second group could be the cross-lag coefficients associated with the first lag, etc.). Then, a semi-global local prior with k groups has the following hierarchical representation:

$$\phi_i \sim K(\vartheta_i \zeta_j), \quad \vartheta_i \sim f, \quad \zeta_j \sim g, \quad i \in \mathcal{A}_j, \quad j = 1, \ldots, k, \tag{7}$$

where $K(\delta)$ denotes a symmetric unimodal density with variance δ, ζ_j represents the semi-global shrinkage, and ϑ_i the local shrinkage. The only additional input required is the partitioning of ϕ into k subgroups. Several options for grouping the coefficients are ready-made in `bayesianVARs`, though any custom grouping could be specified as well. The *equation-specific* grouping indicates that the covariates of each equation form M separate groups (column-wise shrinkage w.r.t. Φ). The *covariate-specific* partitioning implies that the K covariates across all equations form separate groups (row-wise shrinkage w.r.t. Φ). The *own-lag-cross-lag-lagwise* (olcl-lagwise) partitioning mimics some features of the Minnesota prior: In each lag, the diagonal elements (the own-lags) and the off-diagonal elements (the cross-lags) constitute separate groups, which makes $2p$ groups in total. The following list of hierarchical shrinkage priors, which can be cast in the form of semi-global (local) priors, are implemented in `bayesianVARs` (in alphabetical order): Dirichlet-Laplace (DL) prior (Bhattacharya et al., 2015), Horseshoe prior (Carvalho et al., 2010), normal-gamma (NG) prior (Brown and Griffin, 2010), R^2-induced Dirichlet decomposition (R2D2) prior (Zhang et al., 2022) and stochastic-search-variable-selection (SSVS) prior (George et al., 2008). Fore more detailed characteristics and comparisons of those priors we refer to Gruber and Kastner (2023).

Priors for the variance-covariance matrix In the case that the variance-covariance is modeled via the factor decomposition, the priors from Kastner et al. (2017) and Kastner (2019) are used. In the case that the errors are assumed to feature the Cholesky stochastic volatility structure, `bayesianVARs` implements the DL prior, the HS prior, the NG prior, the R2D2 prior, and the SSVS prior for the free off-diagonal elements in U. Concerning the latent variables and their associated parameters in D_t, the priors from Kastner and Frühwirth-Schnatter (2014) are used.

Homoscedastic VARs It should be noted that `bayesianVARs` also implements homoskedastic VARs where $\Sigma_t = \Sigma$ for all t. In case of the VAR with factor structure on the errors it holds that $V_t = V = I_r$ and $Q_t = Q = \text{diag}(q_1, \ldots, q_M)$ for all t. A priori, the ith diagonal element $q_i \sim \mathcal{IG}(a_f, b_f)$ is assumed to follow an inverse gamma distribution for $i = 1, \ldots, M$, independently. In case of the VAR with Cholesky structure on the errors, it holds that $D_t = D = \text{diag}(d_1, \ldots, d_M)$ for all t. The prior distribution of the ith diagonal element is inverse gamma, i.e. $d_i \sim \mathcal{IG}(a_c, b_c)$ for $i = 1, \ldots, M$, independently.

3 Algorithm

In a nutshell, `bayesianVARs` implements a Markov chain Monte Carlo (MCMC) algorithm which alternately samples from the full conditional posterior distribution of the VAR coefficients $p(\phi|\bullet)$ and from the full conditional posterior distribution of the paths of the variance-covariance matrix $p(\Sigma_t|\bullet)$ for $t = 1, \ldots, T$, with $\bullet$ indicating that we condition on the remaining parameters and latent quantities of the model. To render computation of the necessary steps required for sampling from $p(\phi|\bullet)$ feasible, `bayesianVARs` implements the equation-per-equation algorithm proposed in Kastner and Huber (2020) for the VAR with factor stochastic volatility and the correct triangular algorithm from Carriero et al. (2022) for the VAR with Cholesky stochastic volatility. The hyperparameters of the hierarchical shrinkage priors are sampled from the respective full conditional posterior distributions outlined in Gruber and Kastner (2023). To sample from $p(\Sigma_t|\bullet)$ for $t = 1, \ldots, T$, for the VAR with factor stochastic volatility, `bayesianVARs` accesses the package `factorstochvol` (Hosszejni and Kastner, 2021). For the VAR with Cholesky stochastic volatility, the latent variables and associated parameters in D_t are sampled using the package `stochvol` (Kastner, 2016). The free off-diagonal elements in U are sampled equation-per-equation as proposed in Cogley and Sargent (2005). Last but not least, all computationally intensive tasks are written in C++ and interfaced with R via `Rcpp` (Eddelbuettel and François, 2011) and `RcppArmadillo` (Eddelbuettel and Sanderson, 2014) for increased computational efficiency.

4 Case Study

We demonstrate the main functionality of `bayesianVARs` using the `usmacro_growth` dataset included in the package. The dataset – obtained from FRED-QD, a quarterly database for macroeconomic research (McCracken and Ng, 2021) – contains the time-series of 21 variables transformed to growth rates through taking log-differences (except for interest rates).

```
library(bayesianVARs)
variables <- c("GDPC1", "GDPCTPI",  "FEDFUNDS", "EXUSUKx", "S&P 500")
train_data <- 100 * usmacro_growth[1:230, variables]
test_data <- 100 * usmacro_growth[231:234, variables]
```

The workhorse function of `bayesianVARs` for conducting MCMC inference is the function `bvar`. Though it offers a low barrier to entry for users (in case only data is supplied without any further sampler and or prior configurations, default values are used), we encourage the user to specify the model to be estimated in more detail using the helper functions `specify_prior_phi` (prior configuration concerning the VAR coefficients) and `specify_prior_sigma` (prior configuration concerning the variance-covariance of the VAR). In our demonstration, we specify a VAR with $p = 2$ lags with factor stochastic volatility and $r = 4$ factors and a semi-global local HS prior with olcl-lagwise partitioning for the VAR coefficients. It is possible to impose standard global local priors by specifying `specify_prior_phi`'s argument `global_grouping = "global"`. An arbitrary grouping for semi-global local priors can be achieved by supplying an indicator matrix to `global_grouping`.

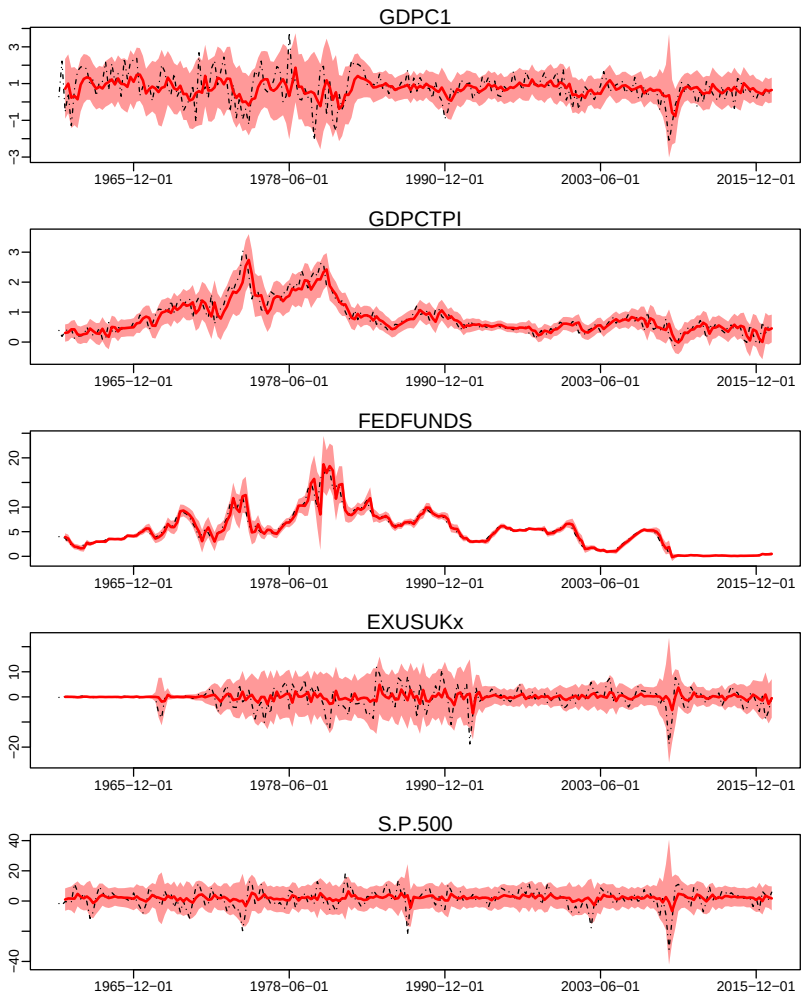

Figure 5: Visualization of estimated in-sample prediction intervals. The red solid line depicts the median, the red shaded region the 90% credible interval and the black dotted line the observed data used for estimation.

```
prior_phi <- specify_prior_phi(data = train_data,
                               lags = 2L,
                               prior = "HS",
                               global_grouping = "olcl-lagwise")
prior_sigma <- specify_prior_sigma(data = train_data,
                                   type = "factor",
                                   factor_factors = 4L)

mod <- bvar(train_data, lags = 2L, draws = 10000, burnin = 2000,
            prior_phi = prior_phi, prior_sigma = prior_sigma,
            sv_keep = "all")
```

The plot methods shows the model fit via 90% in-sample prediction intervals by default, see Figure 5.

```
plot(mod, quantiles = c(0.05,0.5,0.95), dates = rownames(mod$Yraw))
```

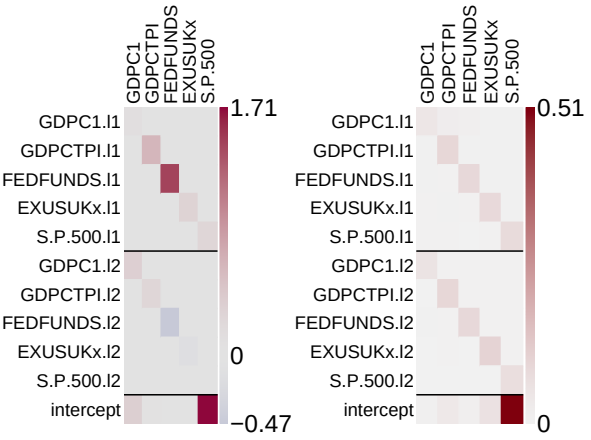

Figure 6: Posterior summary of the VAR coefficients. Left: Heatmap of the posterior median. Right: Heatmap of the posterior interquartile range.

The object output by `bvar` contains the posterior draws. The extractors `coef` and `vcov` come in handy to access the posterior draws of Φ and Σ_t, respectively. The function `posterior_heatmap` visualizes posterior summaries, such as the posterior median or posterior interquartile-range, as heatmaps, see Figure 6.

```
phi <- coef(mod)
par(mfrow=c(1,2))
posterior_heatmap(phi, median)
posterior_heatmap(phi, IQR)
```

The `predict` method simulates from the posterior predictive distribution. Log-predictive likelihoods will be computed if the ex-post observed data is supplied.

```
pred <- predict(mod, ahead = 1:4, LPL = TRUE, Y_obs = test_data)
```

The `plot` method for draws of the posterior predictive distribution defaults to displaying fan-charts by joining line charts for the observed data of the estimation sample with credible intervals of the posterior predictive distribution, see Figure 7.

```
plot(pred, first_obs = 216,
     dates = c(rownames(train_data[-c(1:215),]), rownames(test_data)))
```

The calculated log-predictive likelihoods could be used to comparing forecasting performances of different models.

```
pred$LPL
#>       t+1       t+2       t+3       t+4
#> -4.377206 -4.847919 -5.650827 -7.030685
```

More Information

The latest development version of the `bayesianARs` package is available at https://github.com/luisgruber/bayesianVARs. Within the first two weeks of 2024, the package should be available on the Comprehensive R Archive Network (CRAN).

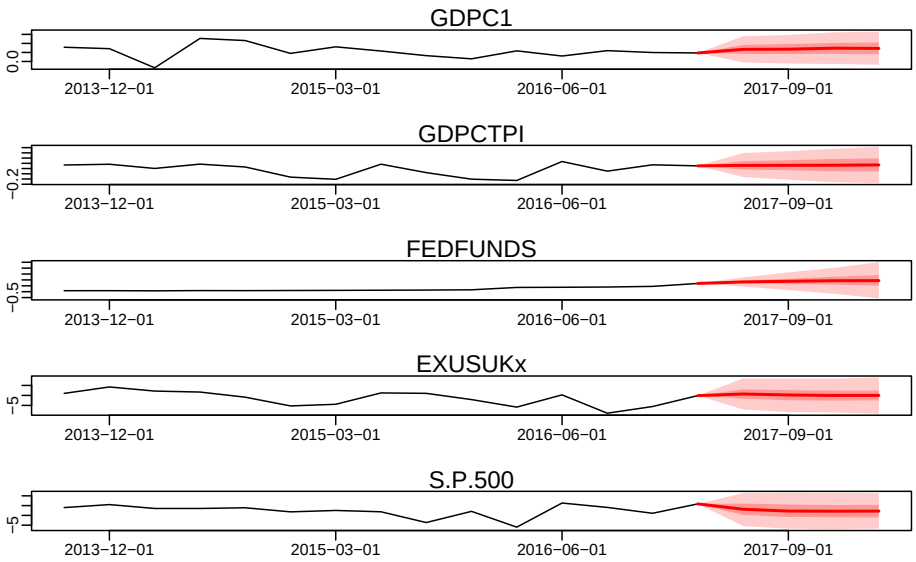

Figure 7: Fan-charts visualizing the last 15 out of 230 observations used for estimation through black solid lines, the median of the h-step ahead predictive distribution through red solid lines and the 50%/90% credible intervals of the h-step ahead predictive distribution through red shaded regions for $h = 1, \ldots, 4$.

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