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REJOINDER

Rejoinder to commentaries on 'The BUGS project: Evolution, critique and future directions'

We are very grateful to the discussants for their contributions, which express the mixture of gratitude and frustration that seems to characterize many BUGS users.

Some common themes can be identified. Both Andrew Gelman and Martyn Plummer suggest that the program could be made more 'intelligent', both in automatically spotting when more efficient sampling algorithms could be used, such as block updating in hierarchical models, and in trying to help users in their modelling. The latter aim could require the development of a basic 'expert system' that, in Plummer's words, puts out 'red flags' when, for example, an apparently innocuous prior is being very influential, or there is clear conflict between one part of the data and either the prior or another part of the data. In both cases the key idea is probably refining the design of the VGM to provide more contextual information. This has already been identified as a long-term strategy for recognizing larger design motifs (in Plummer's words), as well as for facilitating the operation of alternative inference engines on the BUGS VGM.

Martyn Plummer and Kate Cowles both comment on the need to exploit parallel processing opportunities. Indeed, this seems an obvious step given that multi-chain Gibbs samplers represent examples of *embarrassingly parallel* problems (where there is no need for communication between processors), although there is great scope for implementing more efficient parallelization schemes. As mentioned in the paper, some of the infrastructure required for parallelizing BUGS has been incorporated into the design of OpenBUGS, but it is unlikely that this will fully come to fruition before issues with the Linux version (see below) have been addressed. Actually, it may interest readers to know that a parallel version of WinBUGS apparently already exists in the form of *GridBUGS* [1], developed by a team at Johnson and Johnson for distributing applications across their computer grid.

One of the main sources of frustration, as pointed out by both Kate Cowles and Teixeira-Pinto and Normand, is the error reporting system. We are sure we could do better here, but it is difficult to say by how much. The problem might be due in part to the modular nature of BUGS. Each modelling component can perform basic checks on itself and its neighbours when initialized, but such checks are context-independent and localized, as well as potentially not comprehensive enough. Hence, context-driven and long-range conflicts between modelling components may always be difficult to catch. As noted above, extracting more contextual information from the virtual graph is a long-term objective. Perhaps this contextual information can also be used to improve error handling.

Both Andrew Gelman and Teixeira-Pinto and Normand suggest the use of predictive distributions in order to carry out model checking—this is not difficult to do within BUGS but does currently require special effort. Progress towards a flexible and stable open-source version will, we hope, make it much easier for such features to be automated.

Andrew Gelman rightly makes comparisons with the R-function *lmer*, and his excellent book with Jennifer Hill shows the relative strengths of each package. We have found a common practice is to use BUGS as a 'gold standard', but to then seek faster non-MCMC implementations as approximations that allow rapid exploratory analysis.

Jon Wakefield focuses on some tricky modelling issues within Bayesian analysis. Our own preference is to avoid inverse-gamma priors altogether for variances of random effects, and follow Gelman [2] in using half-normal or half-Cauchy priors for random-effect standard deviations, since these place finite but non-zero weight on the variance component being precisely zero, but decline steadily in order to down-weight the possibility of complete independence. His suggestion regarding the partial use of non-model-based likelihoods is intriguing, and follows our use of the 'cut' function [3] to allow inferences that are not based on a full probability model: however, each case threatens nocturnal visits from the Bayesian thought-police.

We fully support Kate Cowles' and Teixeira-Pinto and Normand's pleas for less Windows-dependence, and again point to the opportunities that the formation of a 'BUGS Foundation' offers to support such developments in the future. In particular, at the time of writing, we were gearing up towards a major new release of OpenBUGS, which we hope will attract much of the existing WinBUGS community. One of our fundamental prerequisites for release is a fully functioning and comprehensively documented (including compilation instructions) Linux implementation.

Finally, Teixeira-Pinto and Normand allude to the possibility of learning about the structure of the graph as part of the analysis. We have experimented to some extent with such ideas in implementing the *Jump* interface [4]. A more general approach might make use of a dynamic VGM, one in which links between nodes can easily be switched on and off. We are not sure if the data structures currently used for representing graphs are well suited to such endeavours, however. Perhaps this is an area for the next generation of graphical modelling software, which the 'BUGS Foundation' will aim to support.

DAVID LUNN
MRC Biostatistics Unit, *Institute of Public Health*
University Forvie Site, *Robinson Way*, *Cambridge CB2 0SR*, *U.K.*
E-mail: david.lunn@mrc-bsu.cam.ac.uk

DAVID SPIEGELHALTER
Institute of Public Health, *University of Forvie Site*
Robinson Way, *Cambridge CB2 0SR*, *U.K.*
E-mail: david.spiegelhalter@mrc-bsu.cam.ac.uk

ANDREW THOMAS
School of Mathematics and Statistics
University of St Andrews, *St Andrews*, *U.K.*
E-mail: andrewt@mcs.st-andrews.ac.uk

NICKY BEST
Division of Epidemiology, *Public Health and Primary Care*
Imperial College, *South Kensington Campus*, *London SW7 2AZ*, *U.K.*
E-mail: n.best@imperial.ac.uk

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