

# Fast approximate Bayesian inference of HIV indicators

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## Fast-Track Targets

by 2020

**90-90-90**

Treatment

**500 000**

New infections among adults

**ZERO**

Discrimination

by 2030

**95-95-95**

Treatment

**200 000**

New infections among adults

**ZERO**

Discrimination

Figure 1: Ambitious targets required to end the AIDS epidemic as a public health threat by 2030.

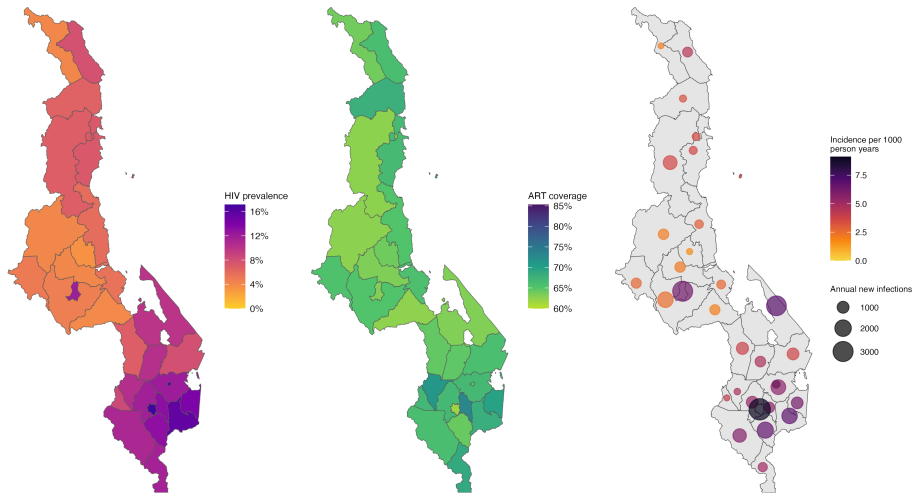


Figure 2: More effective intervention based on granular estimates of HIV indicators. One size does not fit all!

The interface displays a progress bar at the top with seven steps: 1. Upload inputs (highlighted in red), 2. Review inputs, 3. Model options, 4. Fit model, 5. Calibrate model, 6. Review output, and 7. Save results. Below the progress bar is a horizontal line with the text "BACK / CONTINUE" on the left. The main content area contains six file upload sections, each with a label, a "Select new file" input, and a "Browse" button. The labels are: "Spectrum file (required)", "Area boundary file (required)", "Population (required)", "Household Survey (required)", "ART", and "ANC Testing". Each section is separated by a horizontal line. At the bottom of the form is another horizontal line with the text "BACK / CONTINUE" on the left.

1 Upload inputs

2 Review inputs

3 Model options

4 Fit model

5 Calibrate model

6 Review output

7 Save results

BACK / CONTINUE

**Spectrum file** (required)

Select new file Browse

**Area boundary file** (required)

Select new file Browse

**Population** (required)

Select new file Browse

**Household Survey** (required)

Select new file Browse

**ART**

Select new file Browse

**ANC Testing**

Select new file Browse

BACK / CONTINUE

Figure 3: Generation of estimates by country teams strengthens data quality, use and ownership. User interface from <https://naomi.unaids.org/>.

## Want

Fast approximate Bayesian inference for a complex, spatiotemporal, evidence synthesis model

## Strategy

1. Marginal Laplace approximation
2. Adaptive Gauss-Hermite quadrature
3. Principal components analysis

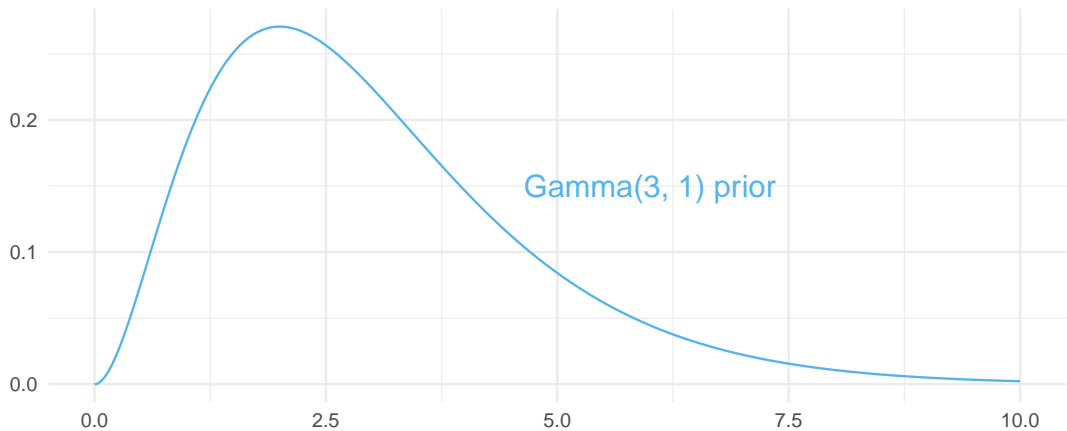


Figure 4: A Gamma prior with  $a = 3$  and  $b = 1$ .

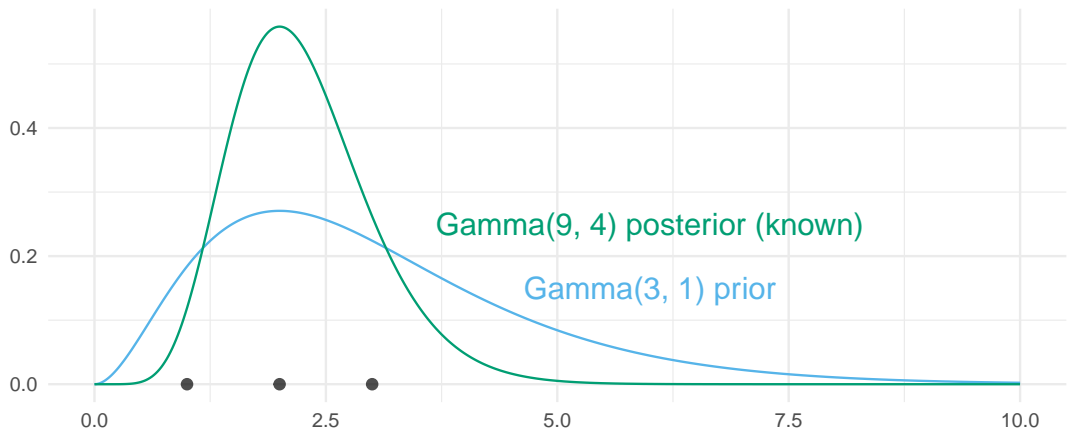


Figure 5: Draw 3 points from  $\text{Poisson}(3)$ , then compute the posterior.

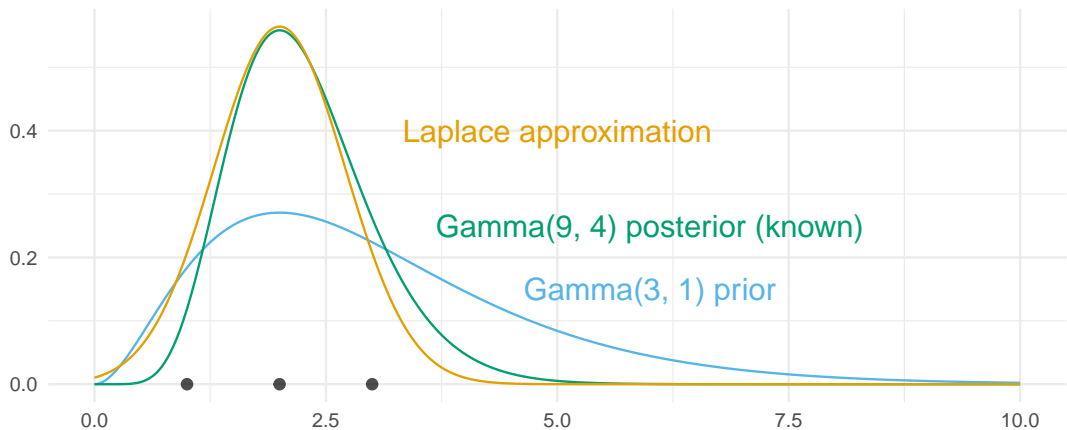


Figure 6: The Laplace approximation in this case is good near the mode but not in the tails.



- For Malawi, the model has 491 parameters
- 467 have a joint Gaussian prior: call them the latent field  $x$
- 24 are not Gaussian: call them hyperparameters  $\theta$
- Use the Laplace approximation only for the latent field marginal posterior!

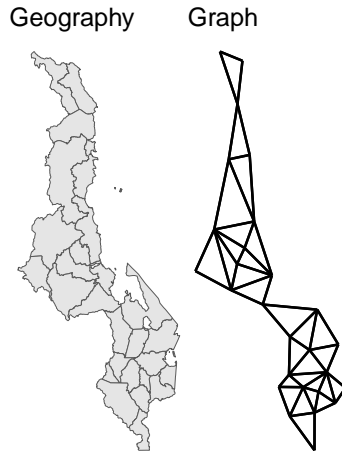


Figure 7: Spatial random effects  $\phi_i | \phi_{-i} \sim \mathcal{N}\left(\frac{1}{n_{\delta i}} \sum_{j:j \sim i} \phi_j, \frac{1}{n_{\delta i} \tau_\phi}\right)$  are included in the latent field. We assume that neighbouring districts are similar: first law of geography.

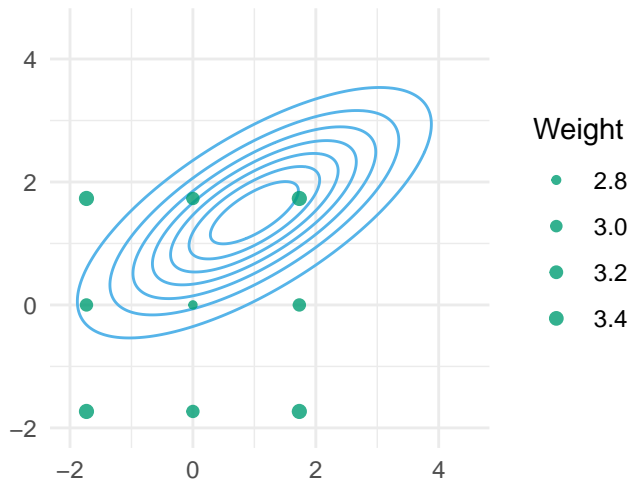


Figure 8: Unadapted Gauss-Hermite points in two dimensions with  $k = 3$ .

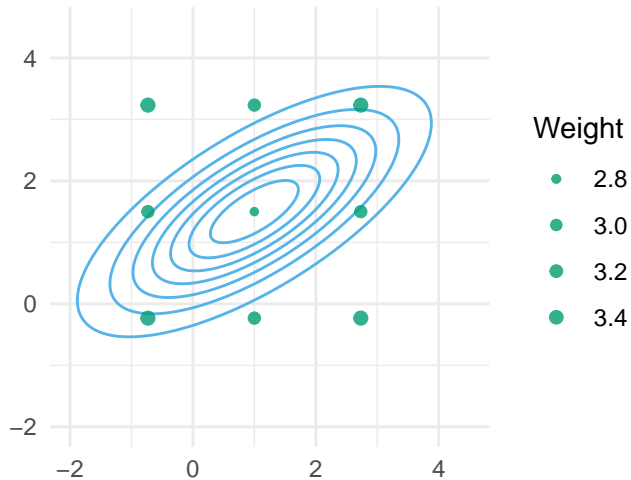


Figure 9: Add the mean  $z + \hat{\theta}$ .

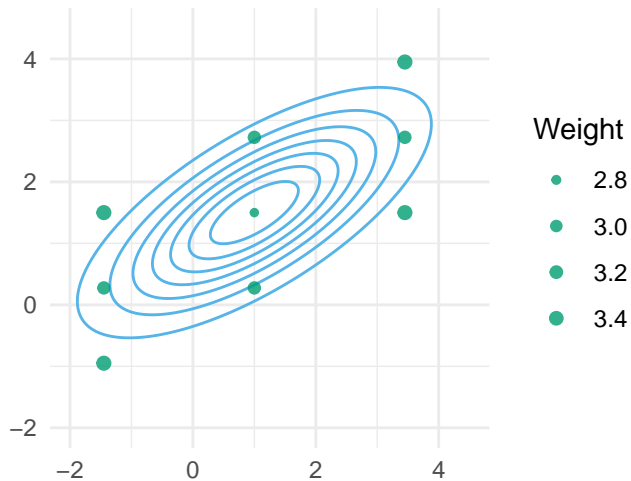


Figure 10: First option: rotate by the lower Cholesky  $Lz + \hat{\theta}$ .

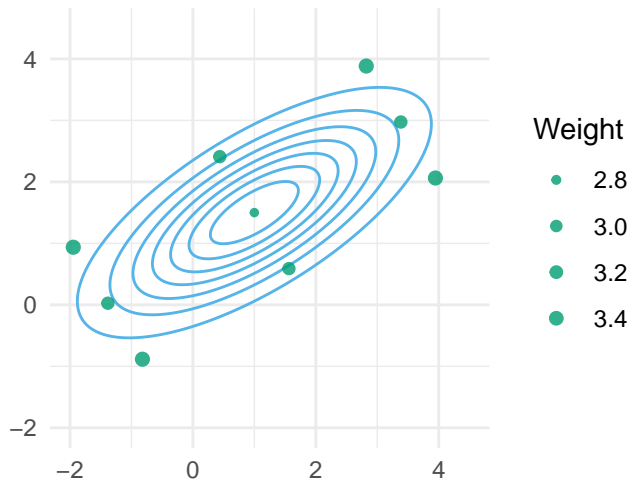


Figure 11: Second option: rotate using the eigendecomposition  $E\Lambda^{1/2}z + \hat{\theta}$ .

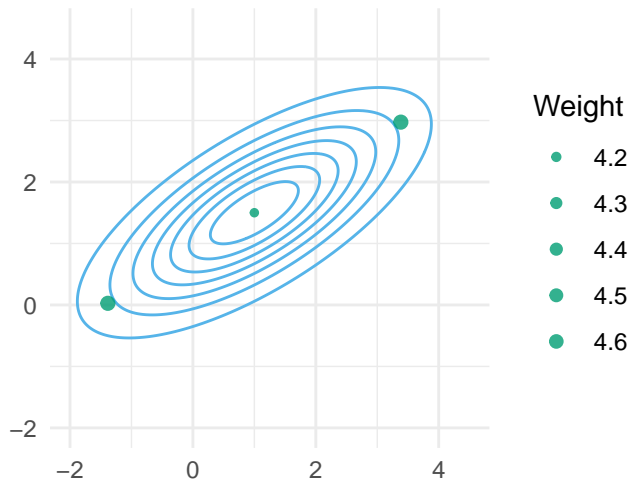


Figure 12: Now keeping only the first principal component,  $s = 1$ .

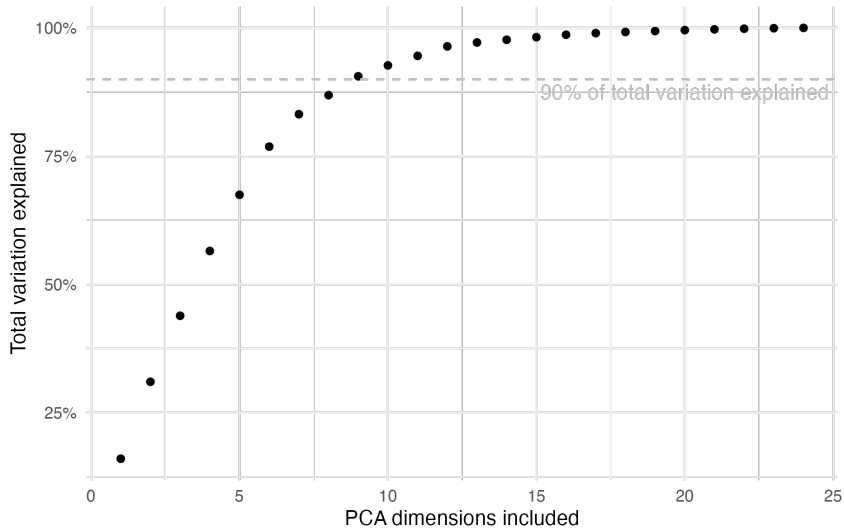
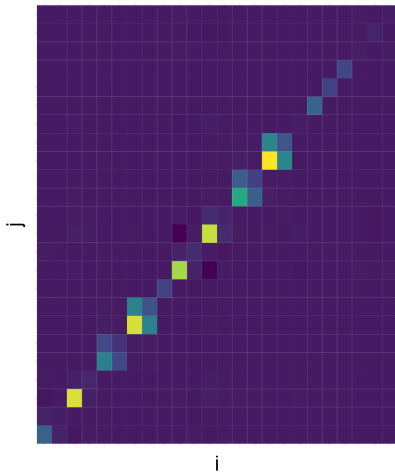


Figure 13: Scree plot suggests 10 or so dimensions is enough. We use  $s = 8$  to avoid long computation times.



Full rank



Reduced rank

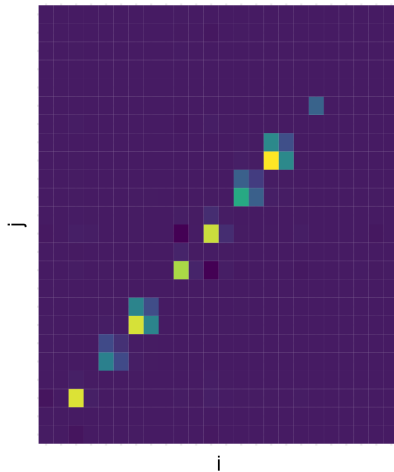
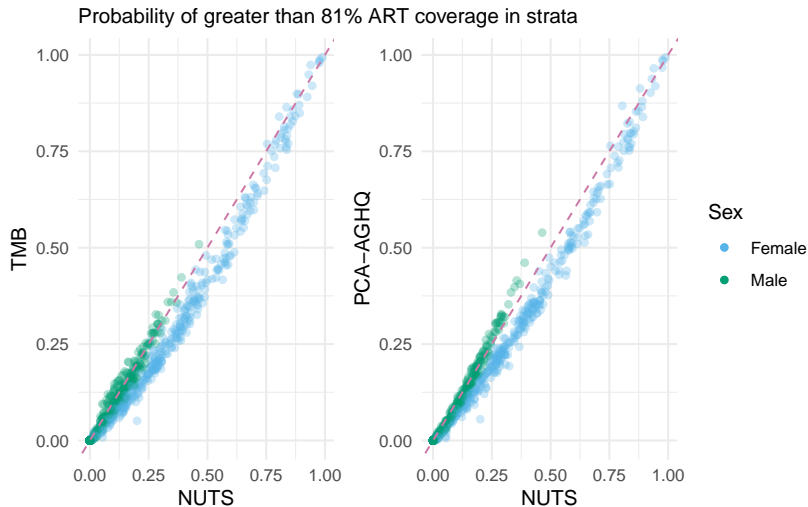


Figure 14: With 8 dimensions, the hyperparameter covariance matrix is accurately reproduced.



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\begin{figure}
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\caption{Reduced RMSE by 10%, but still a work in progress! Also using  
Kolmogorov-Smirnov tests, Pareto-smoothed importance sampling, maximum  
mean discrepancy...} \end{figure}
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# Thanks for listening!

- For more about Naomi, see Eaton et al. (2021)
- Joint work with Alex Stringer (Waterloo), Seth Flaxman (Oxford), and Jeff Eaton (Harvard, Imperial)
- For more about me, see [athowes.github.io/about](https://athowes.github.io/about)



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MACHINE LEARNING  
& GLOBAL HEALTH NETWORK

## References I

Eaton, Jeffrey W., Laura Dwyer-Lindgren, Steve Gutreuter, Megan O'Driscoll, Oliver Stevens, Sumali Bajaj, Rob Ashton, et al. 2021. "Naomi: A New Modelling Tool for Estimating HIV Epidemic Indicators at the District Level in Sub-Saharan Africa." *Journal of the International AIDS Society* 24 (S5): e25788.