

# **brms: An R Package for Bayesian Multilevel Models using Stan**

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# Agenda

## 1 Short introduction to Stan

## 2 The brms package

- Model Specification
- Model Fitting
- Post-Processing

## 3 Discussion



## Stan Overview

- Probabilistic programming language...
- ... to fit open-ended Bayesian Models
- Powerful sampling algorithms: HMC and NUTS
- Automatic differentiation library
- Runs on all major platforms (Windows, OS X, Linux)
- Can be called from R, Python, Julia, Stata, and Matlab



## Stan code for simple linear regression

```
1 data {
2   int<lower=1> N; // number of observations
3   vector[N] Y; // response variable
4   int<lower=1> K; // number of fixed effects
5   matrix[N, K] X; // FE design matrix
6 }
7 parameters {
8   vector[K] b; // fixed effects
9   real<lower=0> sigma; // residual SD
10 }
11 transformed parameters {
12   vector[N] eta; // linear predictor
13   eta <- X * b;
14 }
15 model {
16   // prior specifications
17   sigma ~ student_t(3, 0, 100);
18   // likelihood contribution
19   Y ~ normal(eta, sigma);
20 }
```



## The idea of brms

Make Stan usable for a wider range of audience

- use R formula syntax
- internally write Stan code that is readable yet fast
- provide an easy interface for defining priors
- facilitate post-processing



## Some features of brms

### Basic model types:

- (Robust multivariate) linear models
- Count data models
- Categorical and ordinal models
- Survival models
- Zero-inflated and hurdle models
- Non-linear models

### Other modeling options:

- Group specific terms (random effects) using **lme4** syntax
- Residual autocorrelation
- censored / truncated data



## Example: Censored survival regression

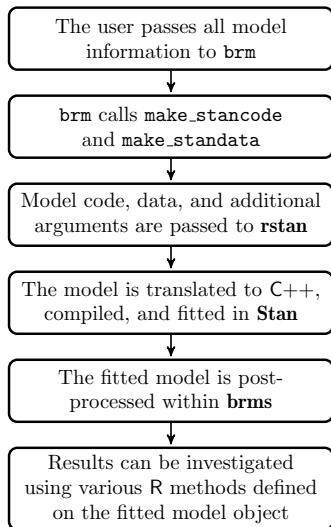
```
1 | brm(time | cens(censored) ~ age * sex + (1 + age|patient),  
2 |     data = kidney, family = exponential())
```

Let's add some priors:

```
1 | brm(time | cens(censored) ~ age * sex + (1 + age|patient),  
2 |     data = kidney, family = exponential(),  
3 |     prior = c(set_prior("normal(0,5)", class = "b"),  
4 |               set_prior("cauchy(0,2)", class = "sd"),  
5 |               set_prior("lkj(2)", class = "cor")))
```



## Flow chart of the model fitting procedure







## Example: Summary

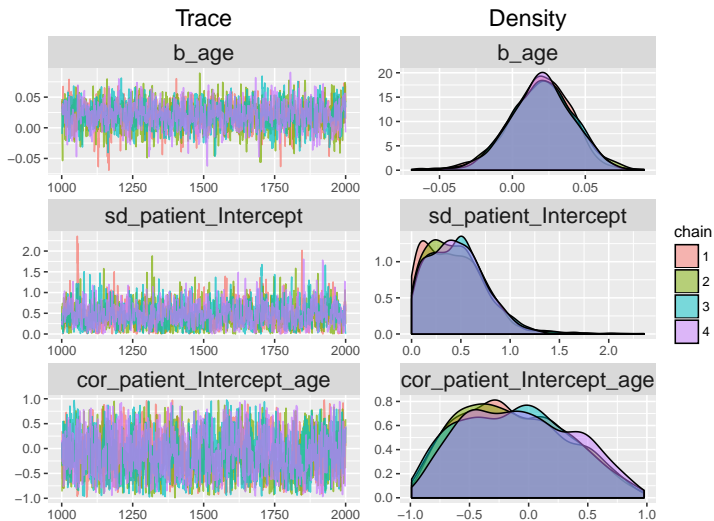
```

1 Family: exponential (log)
2 Formula: time | cens(censored) ~ age * sex + (1 + age | patient)
3 Data: kidney (Number of observations: 76)
4 Samples: 4 chains, each with iter = 2000; warmup = 1000; thin = 1;
5         total post-warmup samples = 4000
6 WAIC: 668.22
7
8 Random Effects:
9 ~patient (Number of levels: 38)
10
11      Estimate Est.Error l-95% CI u-95% CI Eff.Sample Rhat
12 sd(Intercept)      0.45     0.30    0.02    1.07      1172 1.00
13 sd(age)            0.01     0.01    0.00    0.03       450 1.01
14 cor(Intercept,age) -0.12     0.45   -0.87    0.77      1133 1.00
15
16 Fixed Effects:
17      Estimate Est.Error l-95% CI u-95% CI Eff.Sample Rhat
18 Intercept        2.91     0.93    1.22    4.85      1636 1
19 age              0.02     0.02   -0.02    0.06      1527 1
20 sexfemale        2.76     1.07    0.59    4.77      1578 1
21 age:sexfemale    -0.03     0.02   -0.08    0.02      1478 1

```

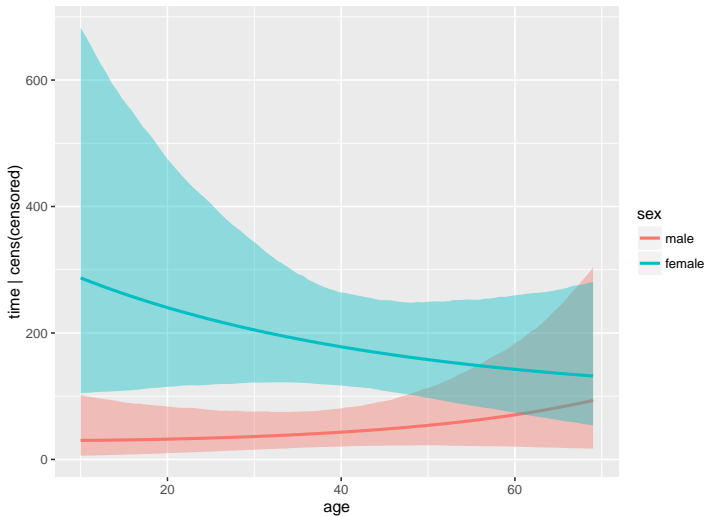


## Example: Trace and density plots





## Example: Marginal plots





## Example: Hypothesis Testing

```
1 > hypothesis(fit, "Intercept - age > 0", class = "sd", group = "patient")
2 Hypothesis Tests for class sd_patient:
3           Estimate Est.Error l-95% CI u-95% CI Evid.Ratio
4 Intercept-age > 0      0.44      0.3     0.03      Inf      62.49 *
```





## Plans for the future

- Full support for multivariate models
- Spatial correlation structures
- Generalized additive multilevel models
- Mixture distributions

Your ideas are always welcome!



## Learn more about brms and Stan

- Help within R: `vignette("brms")` or `help("brms")`
- List of all applicable methods: `methods(class = "brmsfit")`
- Website of brms: <https://github.com/paul-buerkner/brms>
- Website of Stan: <http://mc-stan.org/>
- Contact me: [paul.buerkner@gmail.com](mailto:paul.buerkner@gmail.com)



Thank you for your attention!  
Questions?