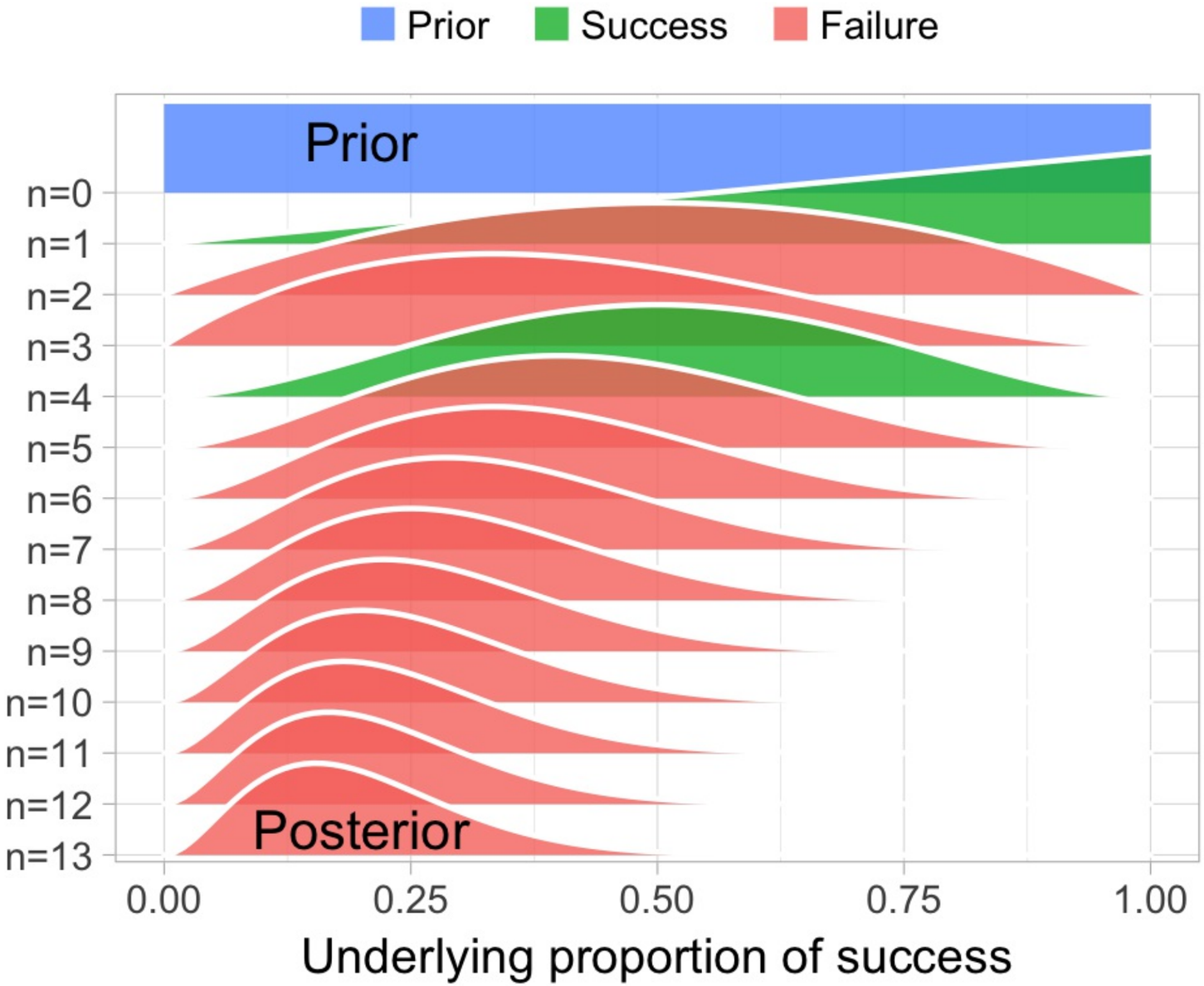
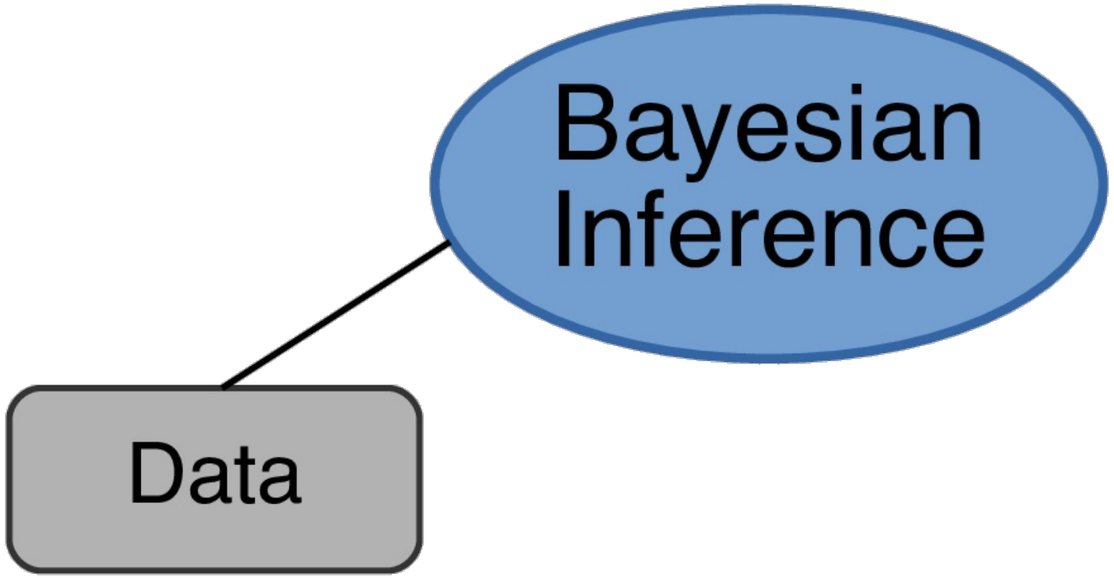
FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

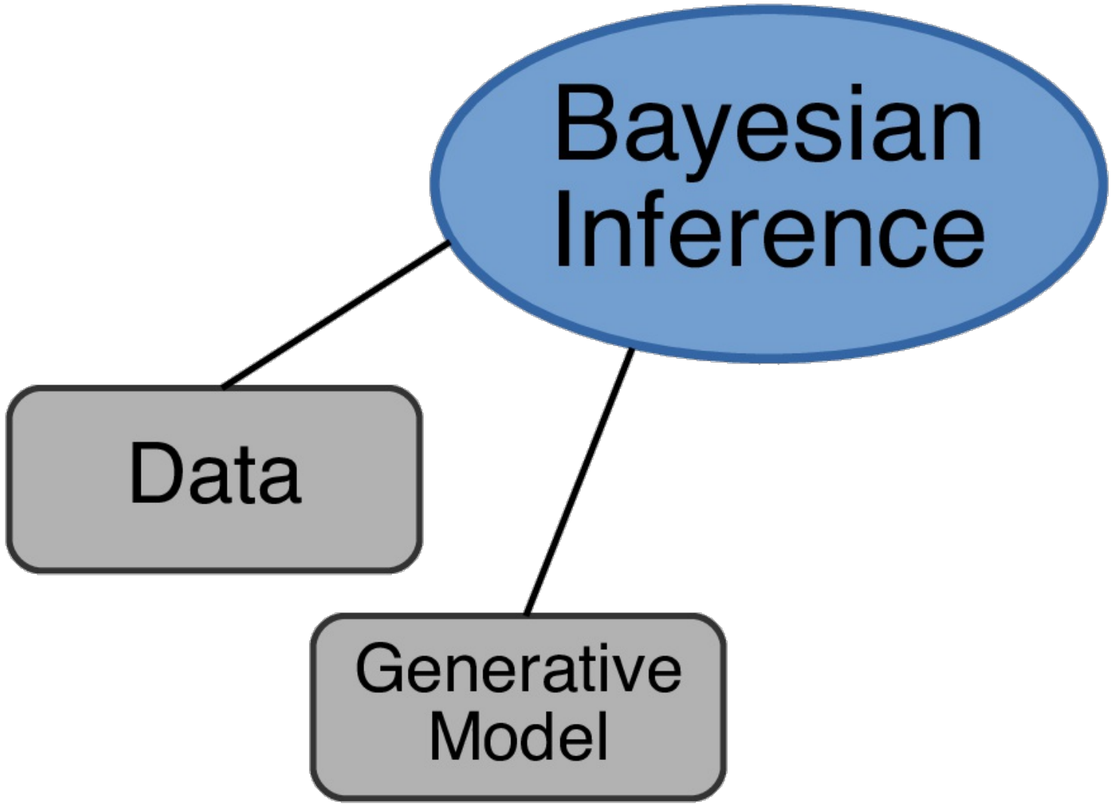
The parts needed for Bayesian inference

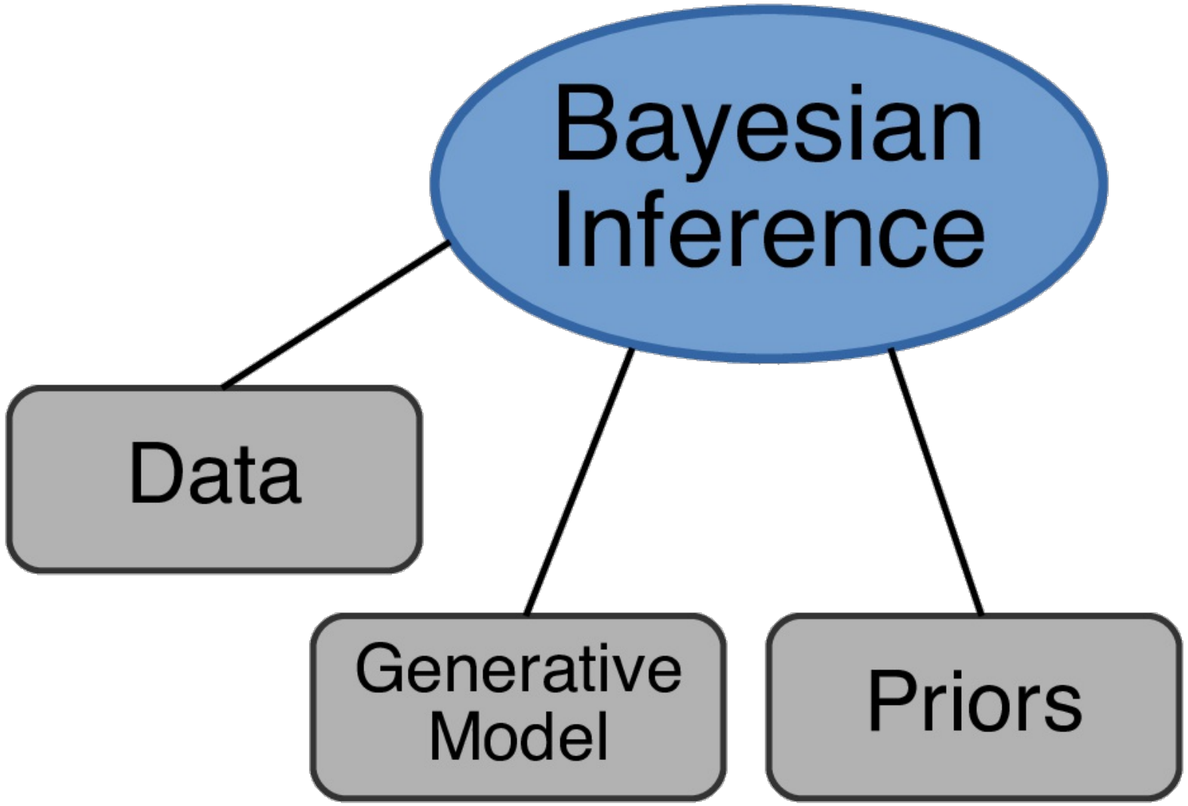
Rasmus Bååth
Data Scientist


Prior
Success
Failure
Prior
n=0
n=1
n=2
n=3
n=4
n=5
n=6
n=7
n=8
n=9
n=10
n=11
n=12
n=13
Posterior
0.00
0.25
0.50
0.75
1.00
Underlying proportion of success

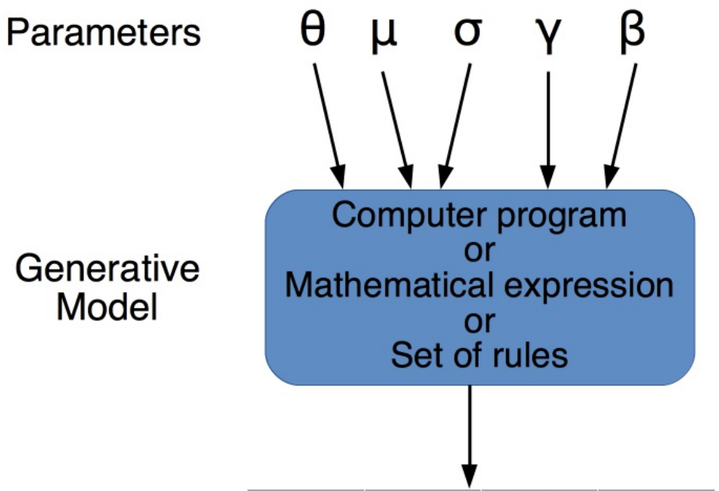

Bayesian
Inference


Bayesian
Inference
Data


Bayesian Inference
Data
Generative Model


Bayesian Inference
Data
Generative Model
Priors

What is a generative model?



x	y	animal	cuteness
4	0.34	Dog	13
1	0.63	Dog	12
-7	0.22	Cat	7
3	0.62	Dog	11
...	...	...	...

Generative zombie drug model

Generative zombie drug model

```
# Parameters
prop_success <- ???
n_zombies <- ???
```

Generative zombie drug model

```
# Parameters
prop_success <- 0.15
n_zombies <- 13
```

Generative zombie drug model

```
# Parameters
prop_success <- 0.15
n_zombies <- 13
# Simulating data
data <- c()
for(zombie in 1:n_zombies) {
  data[zombie] <- ???
}
```

Generative zombie drug model

```
# Parameters
prop_success <- 0.15
n_zombies <- 13
# Simulating data
data <- c()
for(zombie in 1:n_zombies) {
  data[zombie] <- runif(1, min = 0, max = 1) < prop_success
}
```

Generative zombie drug model

```
# Parameters
prop_success <- 0.15
n_zombies <- 13
# Simulating data
data <- c()
for(zombie in 1:n_zombies) {
  data[zombie] <- runif(1, min = 0, max = 1) < prop_success
}
```

```
data
# [1] FALSE FALSE FALSE TRUE FALSE FALSE FALSE FALSE TRUE FALSE TRUE FALSE FALSE
```

Generative zombie drug model

```
# Parameters
prop_success <- 0.15
n_zombies <- 13
# Simulating data
data <- c()
for(zombie in 1:n_zombies) {
  data[zombie] <- runif(1, min = 0, max = 1) < prop_success
}
data <- as.numeric(data)
```

Generative zombie drug model

```
# Parameters
prop_success <- 0.15
n_zombies <- 13
# Simulating data
data <- c()
for(zombie in 1:n_zombies) {
  data[zombie] <- runif(1, min = 0, max = 1) < prop_success
}
data <- as.numeric(data)
```

```
data
# [1] 0 0 0 1 0 0 0 0 1 0 1 0 0
```

Generative zombie drug model

```
# Parameters
prop_success <- 0.15
n_zombies <- 13
# Simulating data
data <- c()
for(zombie in 1:n_zombies) {
  data[zombie] <- runif(1, min = 0, max = 1) < prop_success
}
data <- as.numeric(data)
```

```
data
# [1] 0 0 1 0 0 0 0 0 0 0 0 0 0
```

Generative zombie drug model

```
# Parameters
prop_success <- 0.15
n_zombies <- 13
# Simulating data
data <- c()
for(zombie in 1:n_zombies) {
  data[zombie] <- runif(1, min = 0, max = 1) < prop_success
}
data <- as.numeric(data)
```

```
data
# [1] 0 1 0 1 1 0 0 1 0 1 0 0 0
```

Generative zombie drug model

```
# Parameters
prop_success <- 0.15
n_zombies <- 13
# Simulating data
data <- c()
for(zombie in 1:n_zombies) {
  data[zombie] <- runif(1, min = 0, max = 1) < prop_success
}
data <- as.numeric(data)
```

```
data
# [1] 0 0 0 0 0 0 0 1 0 0 0 0 0
```

Generative zombie drug model

```
# Parameters
prop_success <- 0.15
n_zombies <- 13
# Simulating data
data <- c()
for(zombie in 1:n_zombies) {
  data[zombie] <- runif(1, min = 0, max = 1) < prop_success
}
data <- as.numeric(data)
```

```
data
# [1] 0 0 0 0 1 0 0 0 0 1 0 1 0
```

FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

Take this model for a spin!

FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

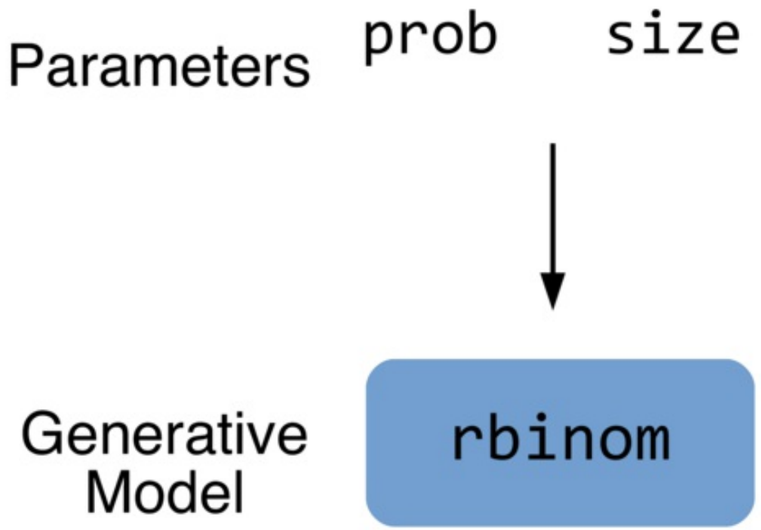
Using a generative model

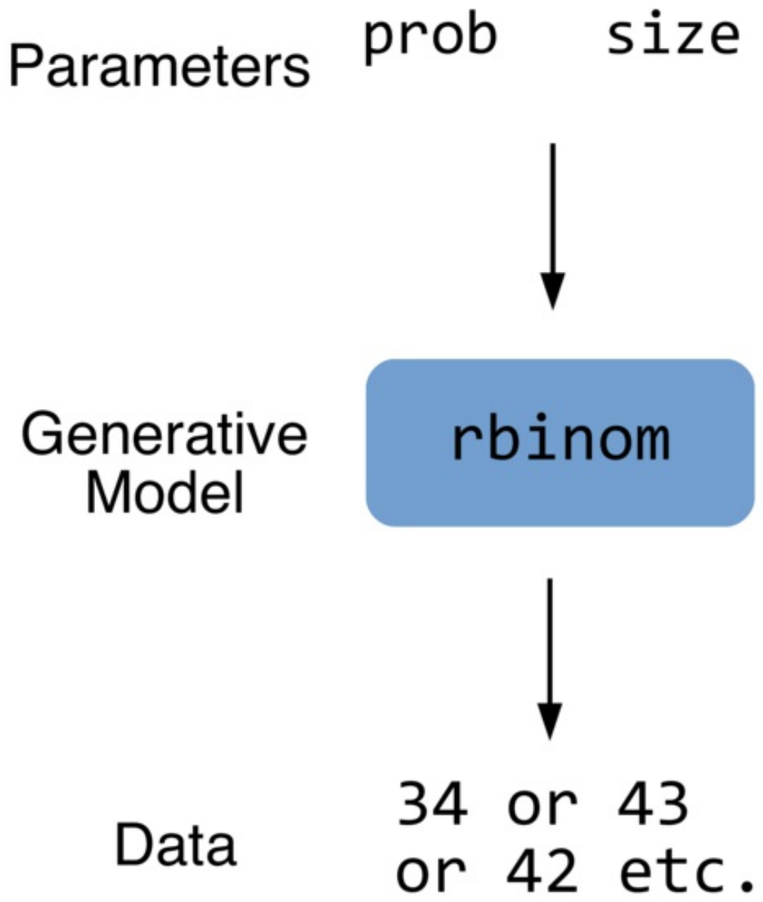
Rasmus Bååth
Data Scientist

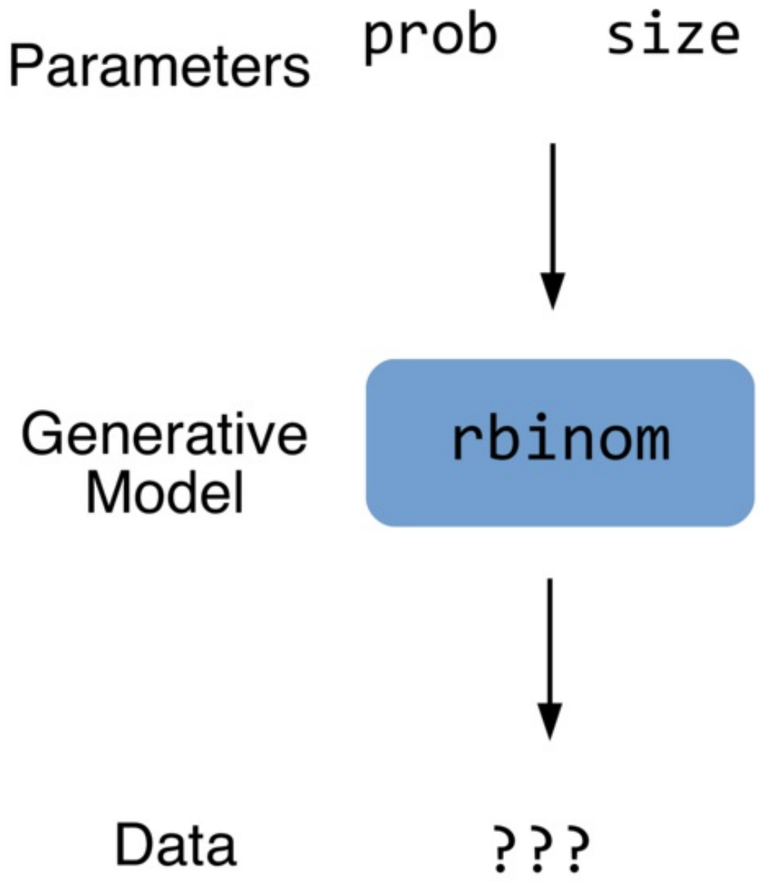
```
rbinom(n, size, prob)
```

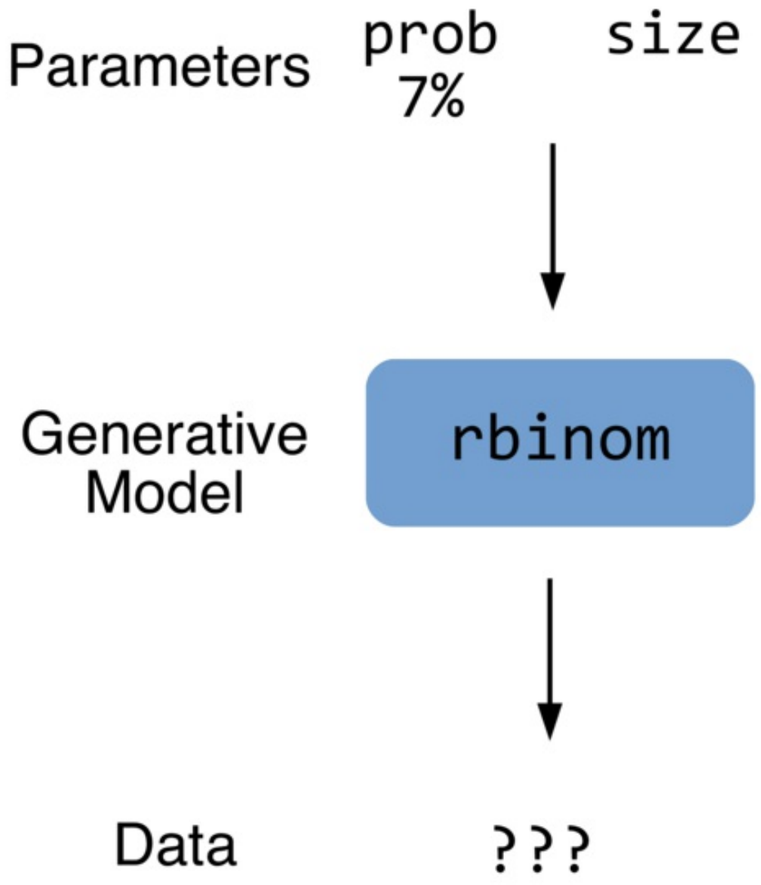
Generative Model

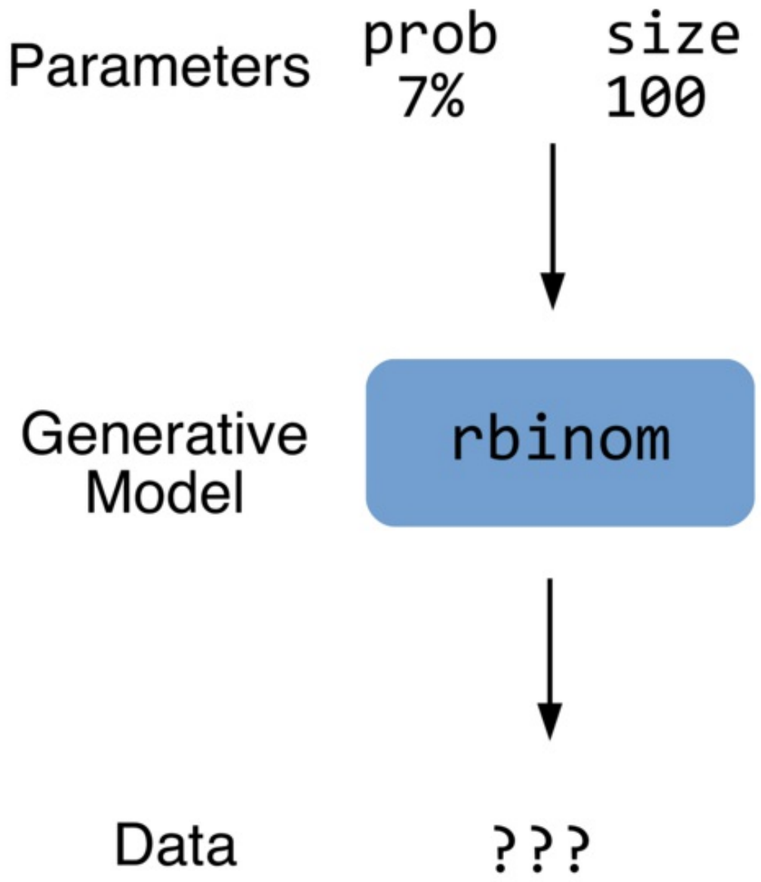
`rbinom`


Parameters
prob
size
Generative Model
rbinom


Parameters
prob
size
Generative Model
rbinom
Data
34 or 43
or 42 etc.


Parameters
prob
size
Generative Model
rbinom
Data
???


Parameters
prob
7%
size
Generative
Model
rbinom
Data
???



[1] https://commons.wikimedia.org/wiki/File:The_Hoard_III_-_Flickr_-_SoulStealer.co.uk.jpg

```
cured_zombies <- rbinom(n = 100000, size = 100, prob = 0.07)
```

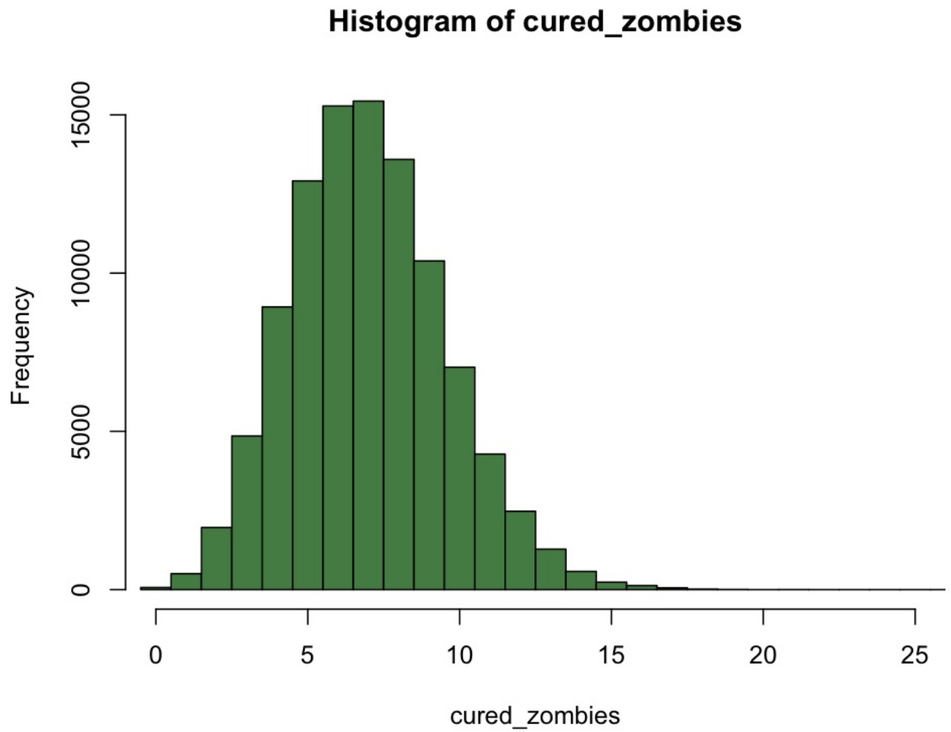
```
cured_zombies <- rbinom(n = 100000, size = 100, prob = 0.07)
```

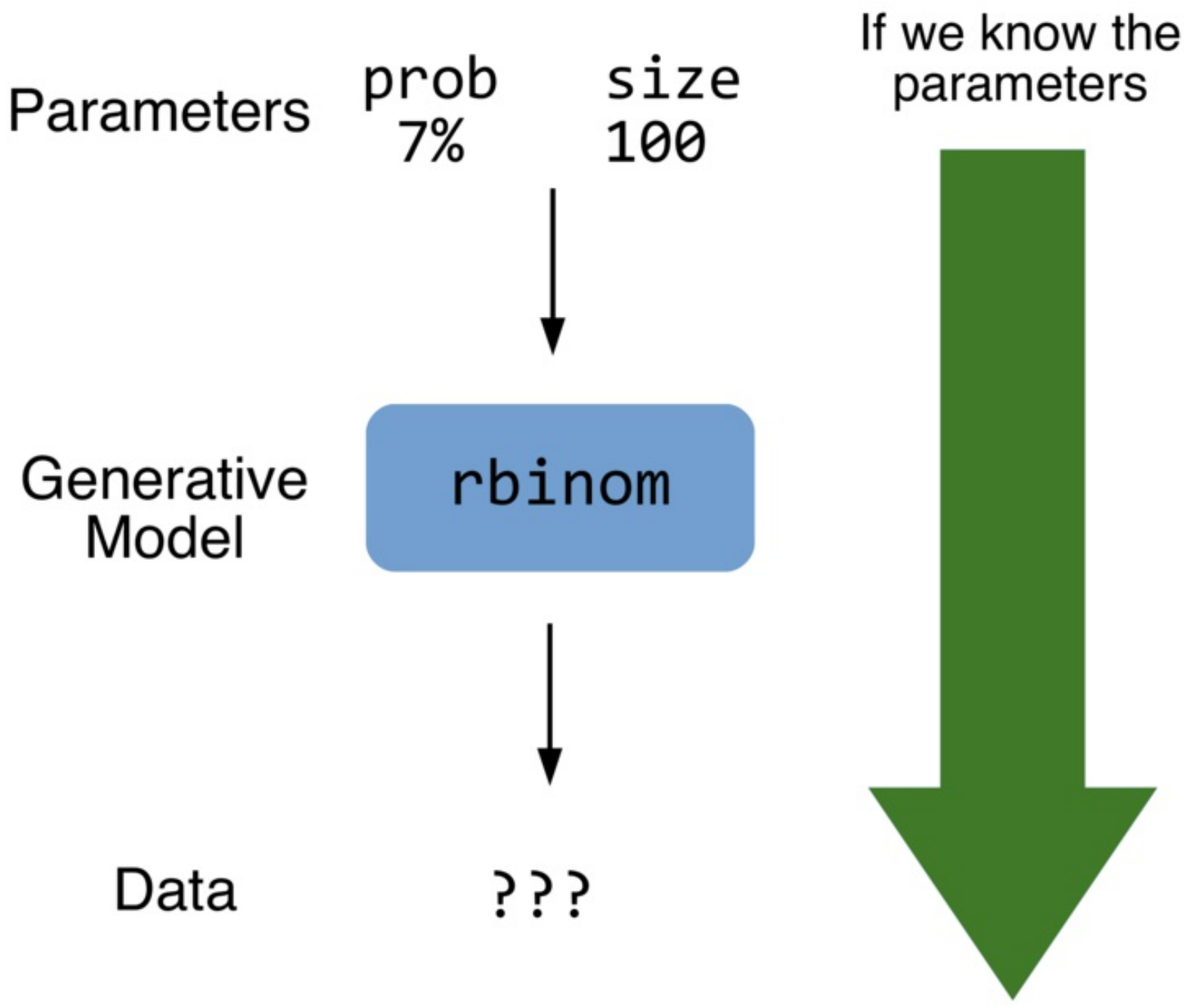
```
cured_zombies
```

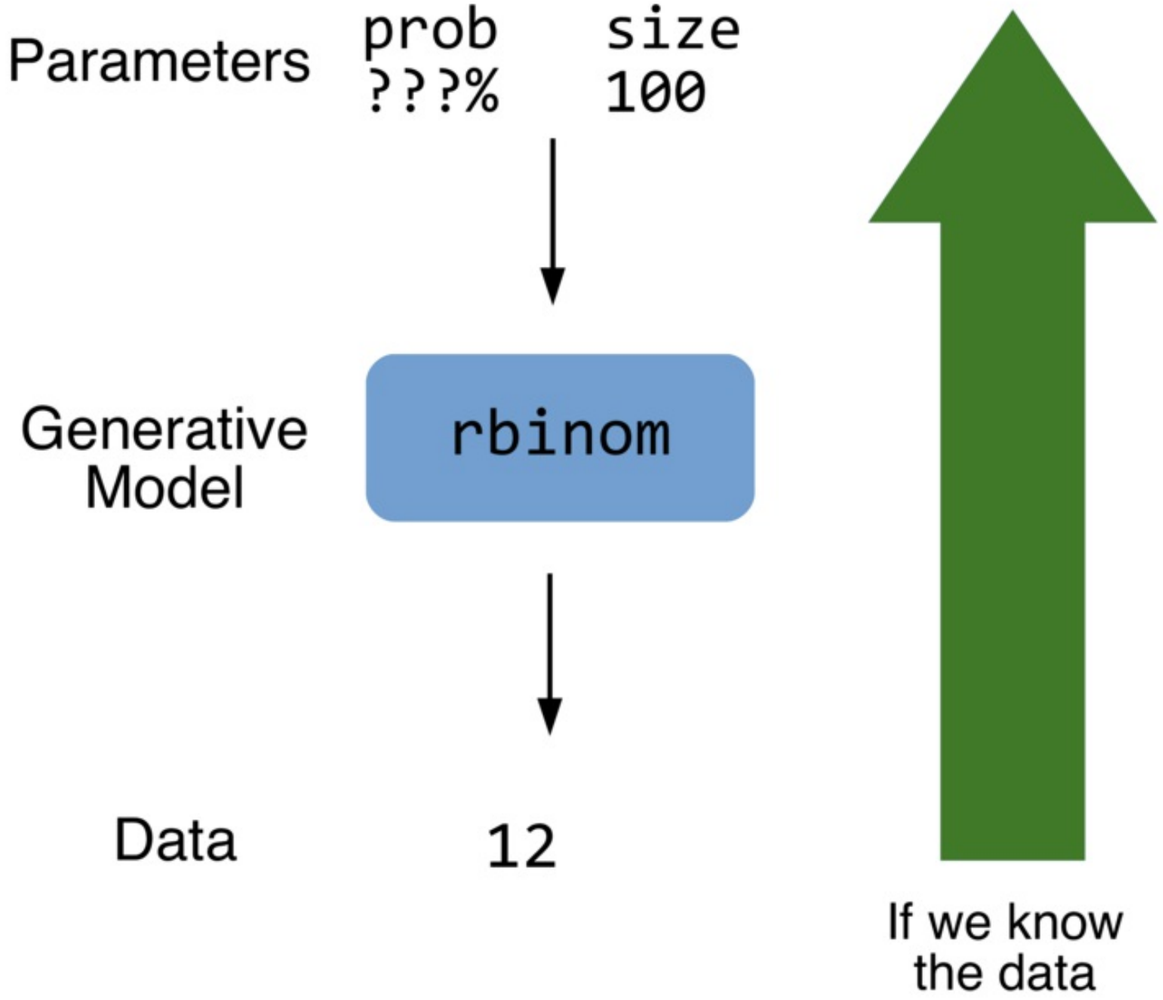
```
  [1]  8  6  5  8 11  5  7  7  5  8  7 11  6  8  8
 [16]  9  9  4  7  4  8  7  5  5  6  9 14  4  4  8
 ... and so on ...
```

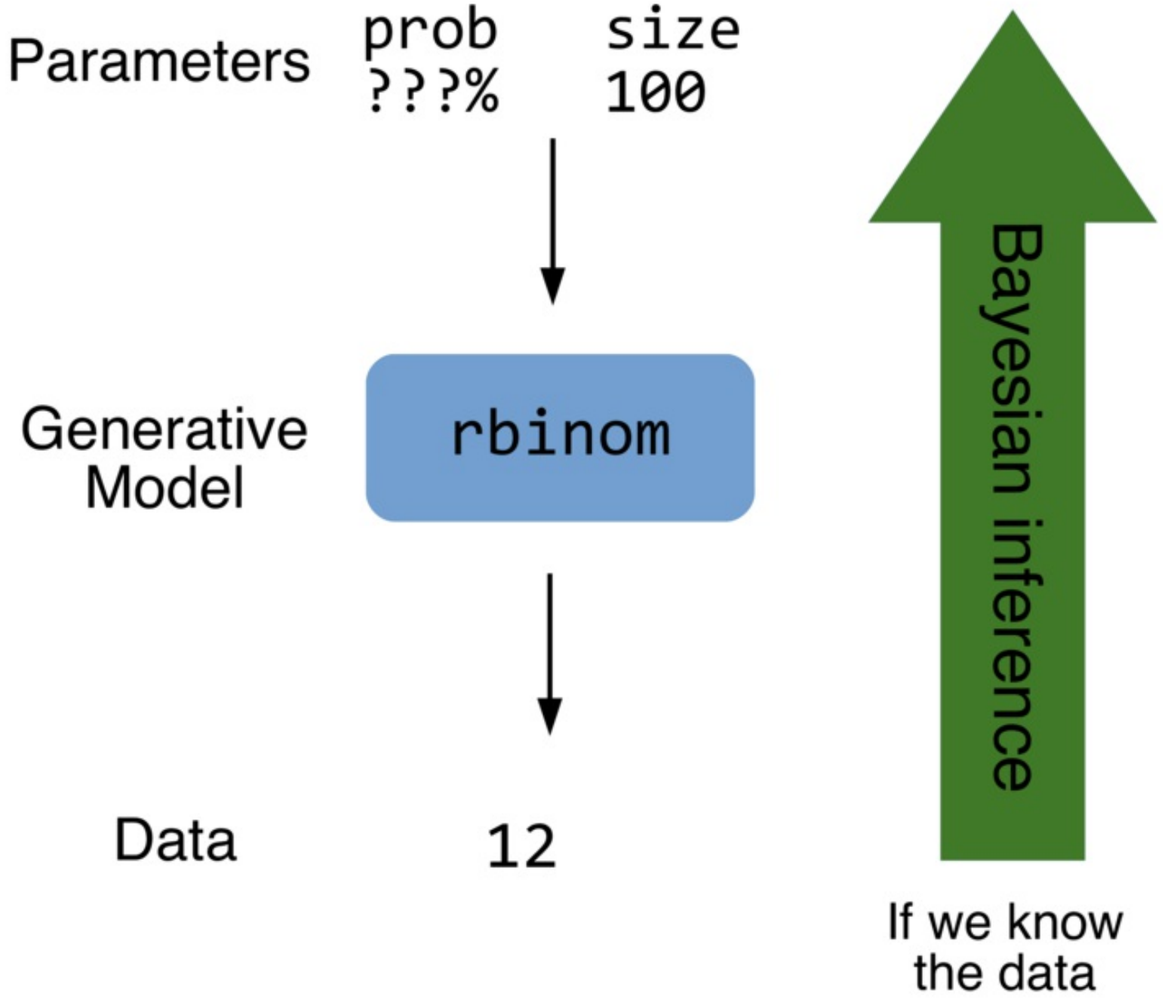
```
cured_zombies <- rbinom(n = 100000, size = 100, prob = 0.07)
```

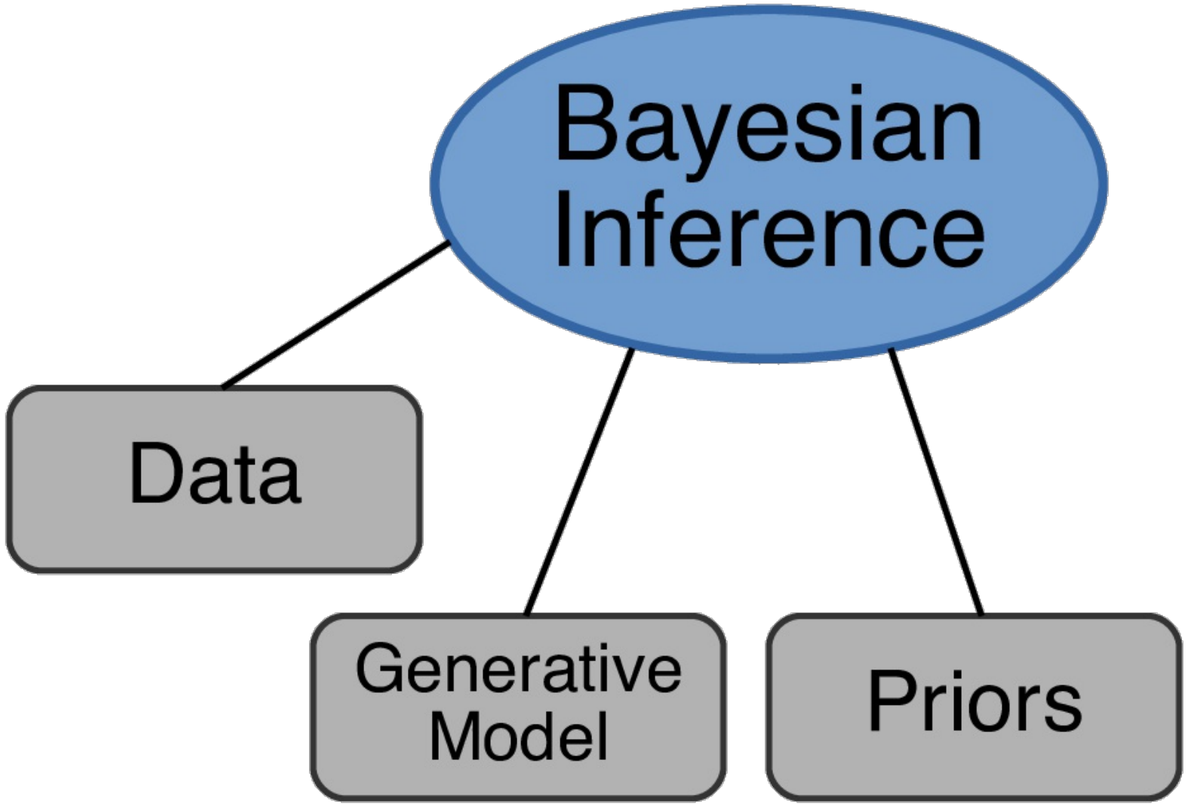
```
hist(cured_zombies)
```

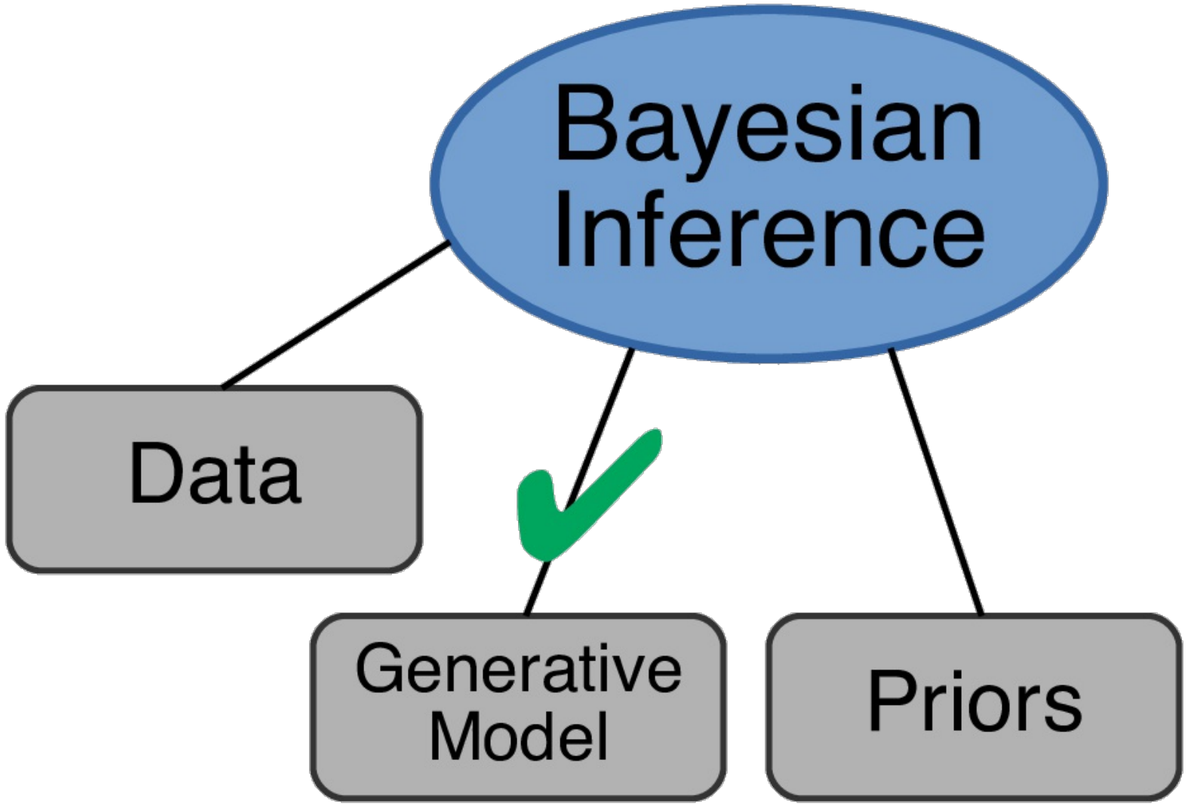



If we know the parameters
Parameters
prob
7%
size
100
Generative Model
rbinom
Data
???


Parameters
prob
???%
size
100
Generative Model
rbinom
Data
12
If we know the data


Parameters
prob
???%
size
100
Generative Model
rbinom
Data
12
Bayesian inference
If we know the data


Bayesian Inference
Data
Generative Model
Priors


Bayesian Inference
Data
Generative Model
Priors

[1] https://commons.wikimedia.org/wiki/File:The_Hoard_III_-_Flickr_-_SoulStealer.co.uk.jpg


dmoz
Google
YAHOO!
Ask Jeeves
AOL
S
E
O

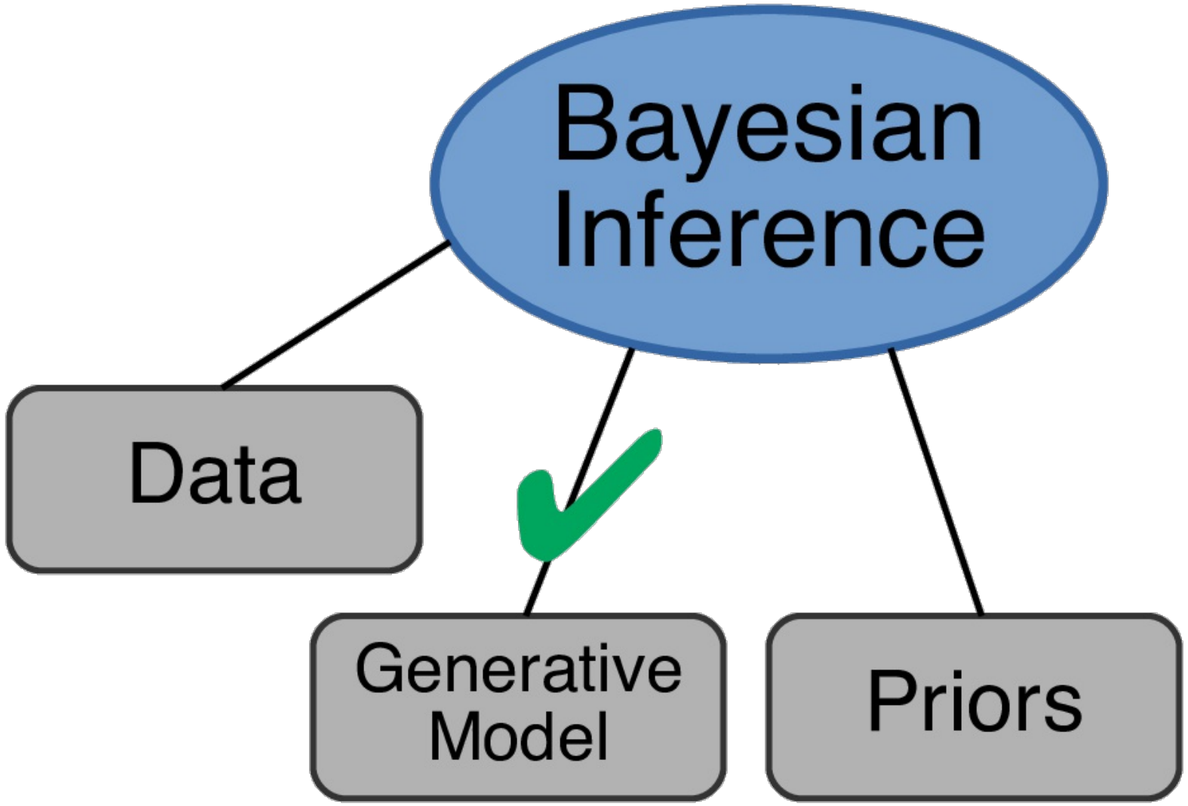
FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

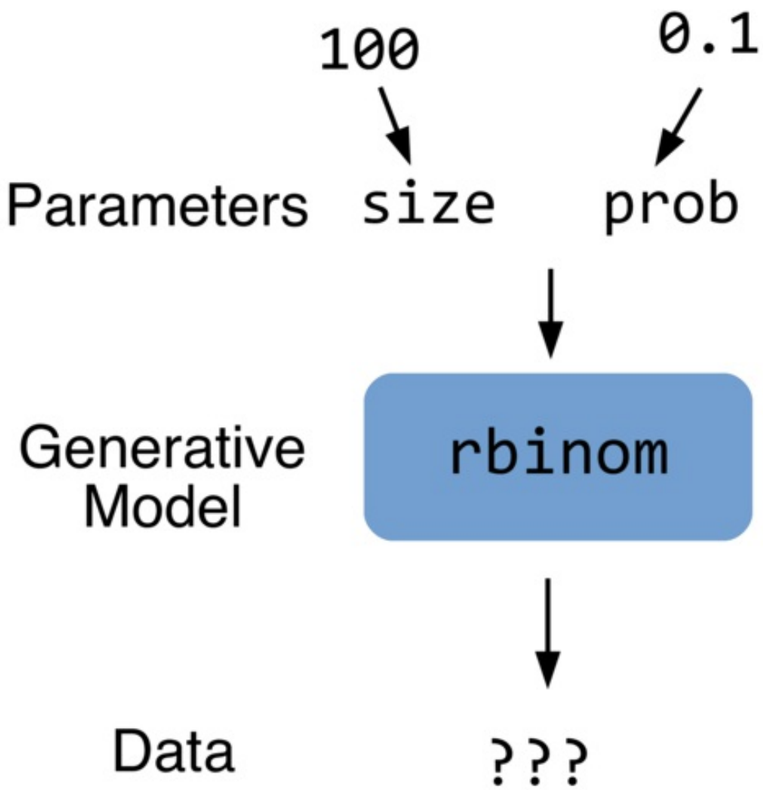
How many visitors?

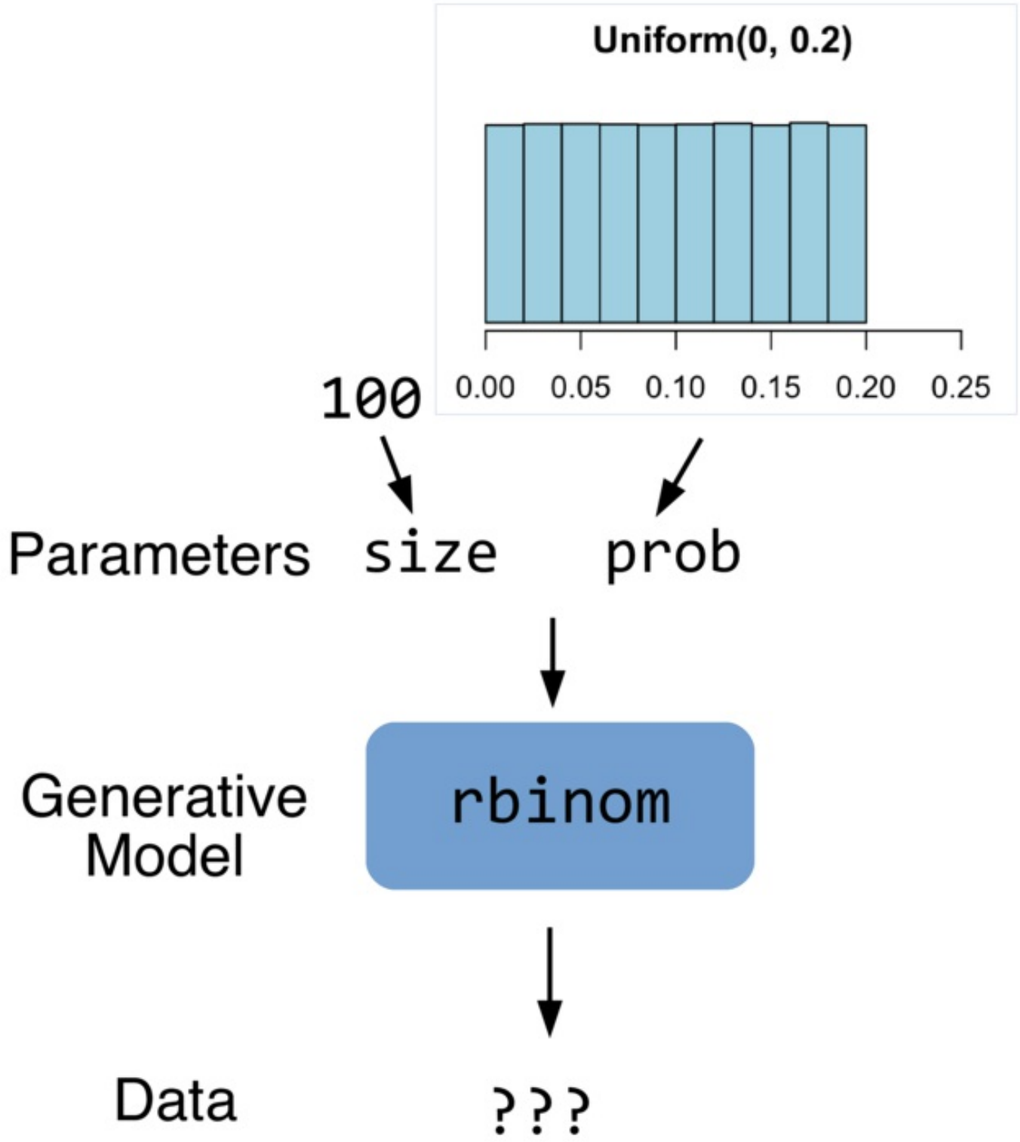
FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

One more part

Rasmus Bååth
Data Scientist


Bayesian Inference
Data
Generative Model
Priors


100
0.1
Parameters
size
prob
Generative Model
rbinom
Data
???


Uniform(0, 0.2)
0.00
0.05
0.10
0.15
0.20
0.25
100
Parameters
size
prob
Generative Model
rbinom
Data
???

```
n_samples <- 100000
n_ads_shown <- 100
proportion_clicks <- 0.1
n_visitors <- rbinom(n_samples, size = n_ads_shown,
                     prob = proportion_clicks)
```

runif - Random Uniform samples

runif - Random Uniform samples

```
proportion_clicks <- runif(n = 6, min = 0.0, max = 1.0)
```

```
proportion_clicks
# [1] 0.05  0.58  0.21  0.61  0.69  0.39
```

runif - Random Uniform samples

```
proportion_clicks <- runif(n = 6, min = 0.0, max = 1.0)
n_clicks <- rbinom(n = 6, size = 100, proportion_clicks)
```

```
proportion_clicks
# [1] 0.05  0.58  0.21  0.61  0.69  0.39
```

runif - Random Uniform samples

```
proportion_clicks <- runif(n = 6, min = 0.0, max = 1.0)
n_clicks <- rbinom(n = 6, size = 100, proportion_clicks)
```

```
proportion_clicks
# [1] 0.05  0.58  0.21  0.61  0.69  0.39
n_clicks
# [1]  7    59    13    63    67    29
```

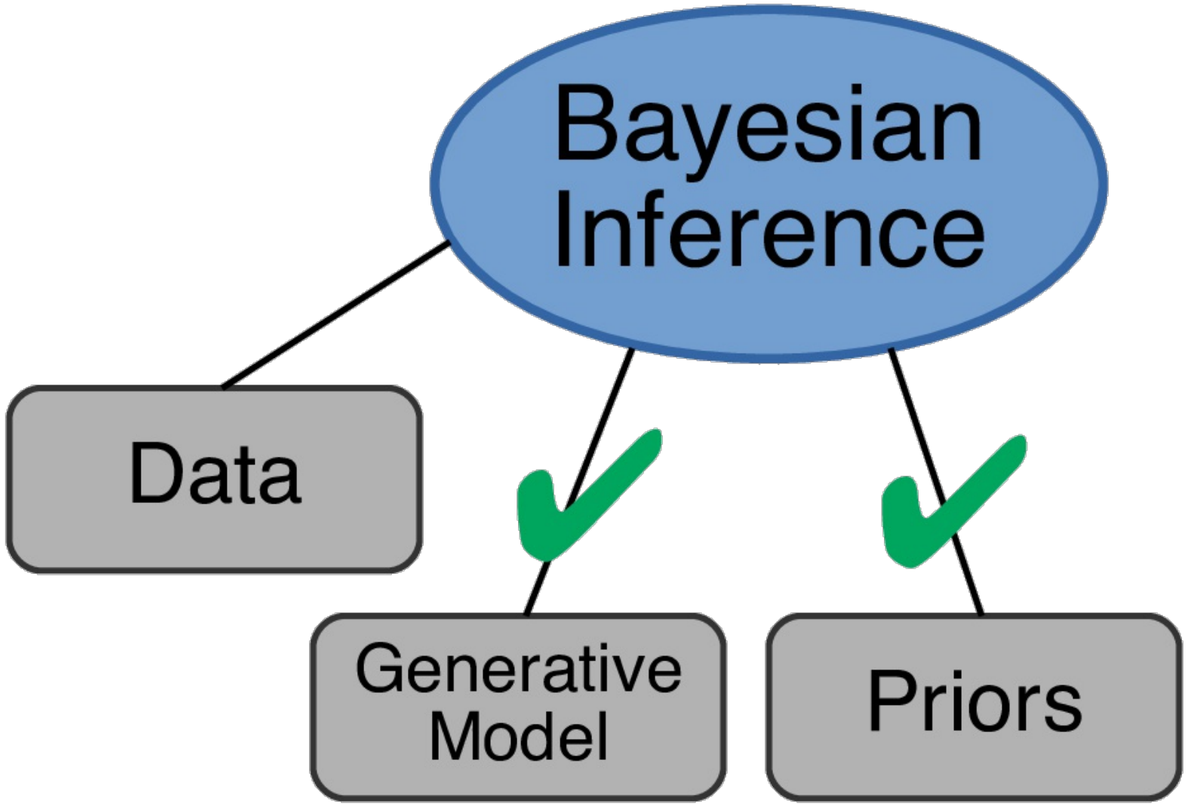
FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

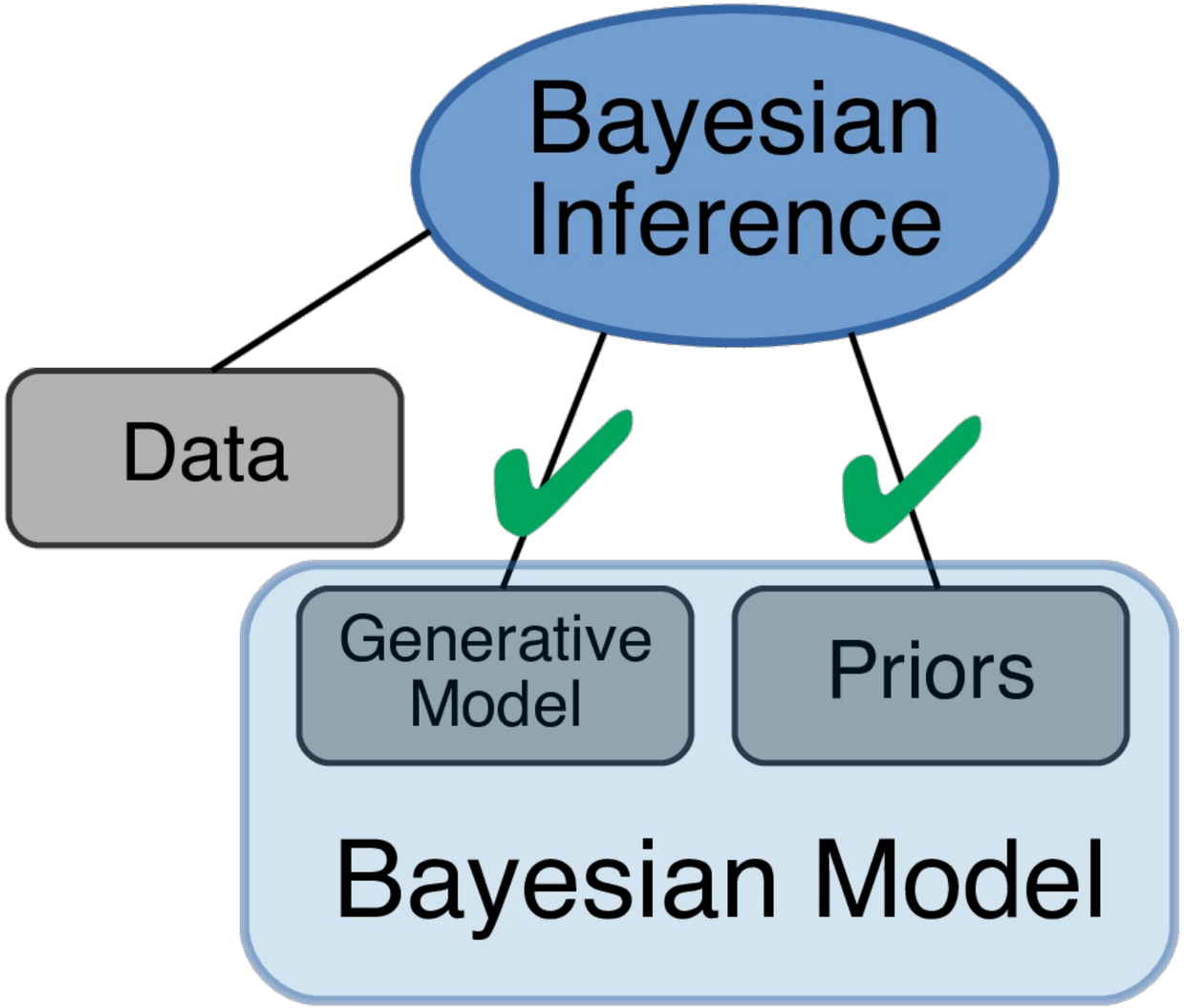
Try this in practice!

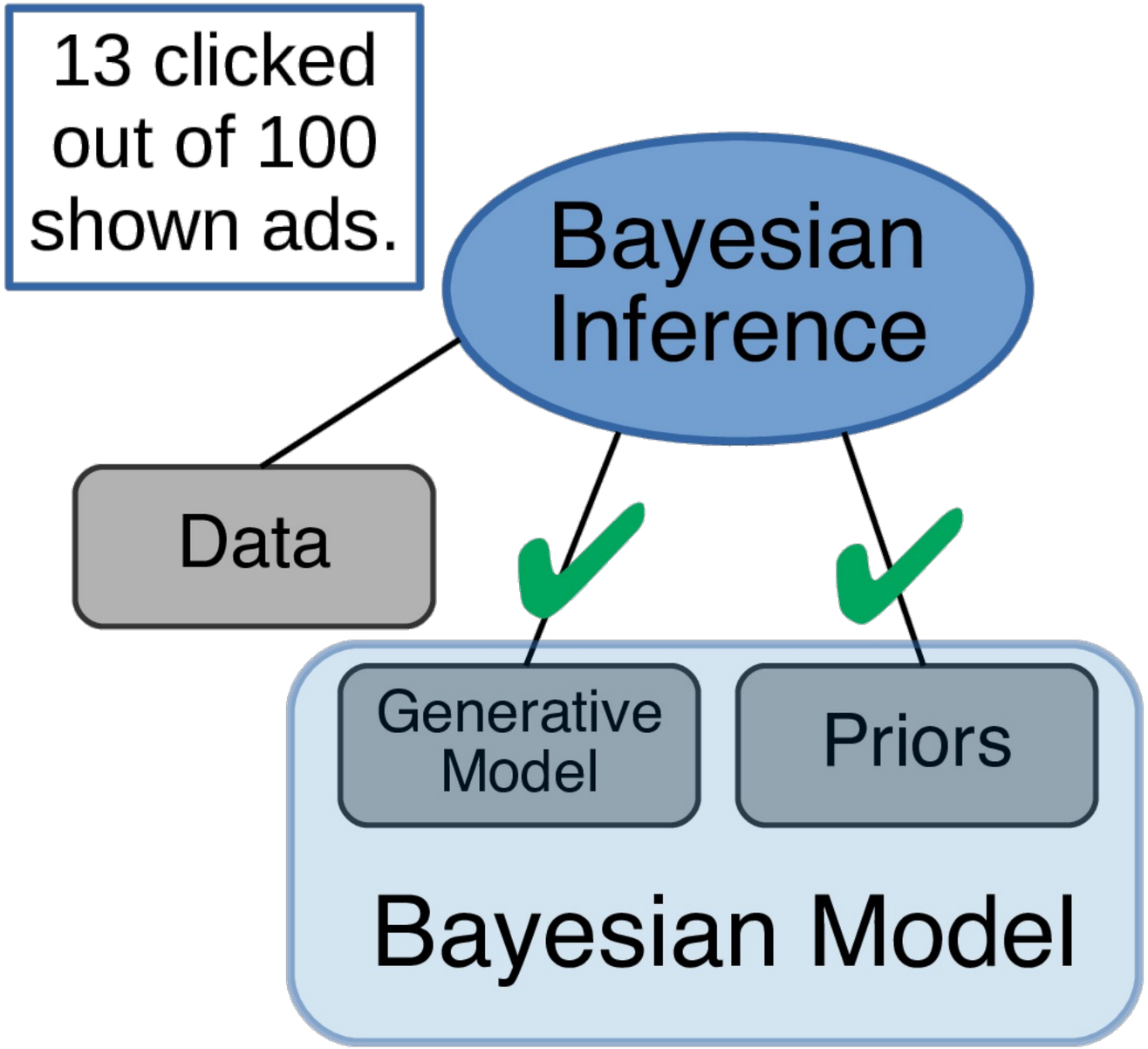
FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

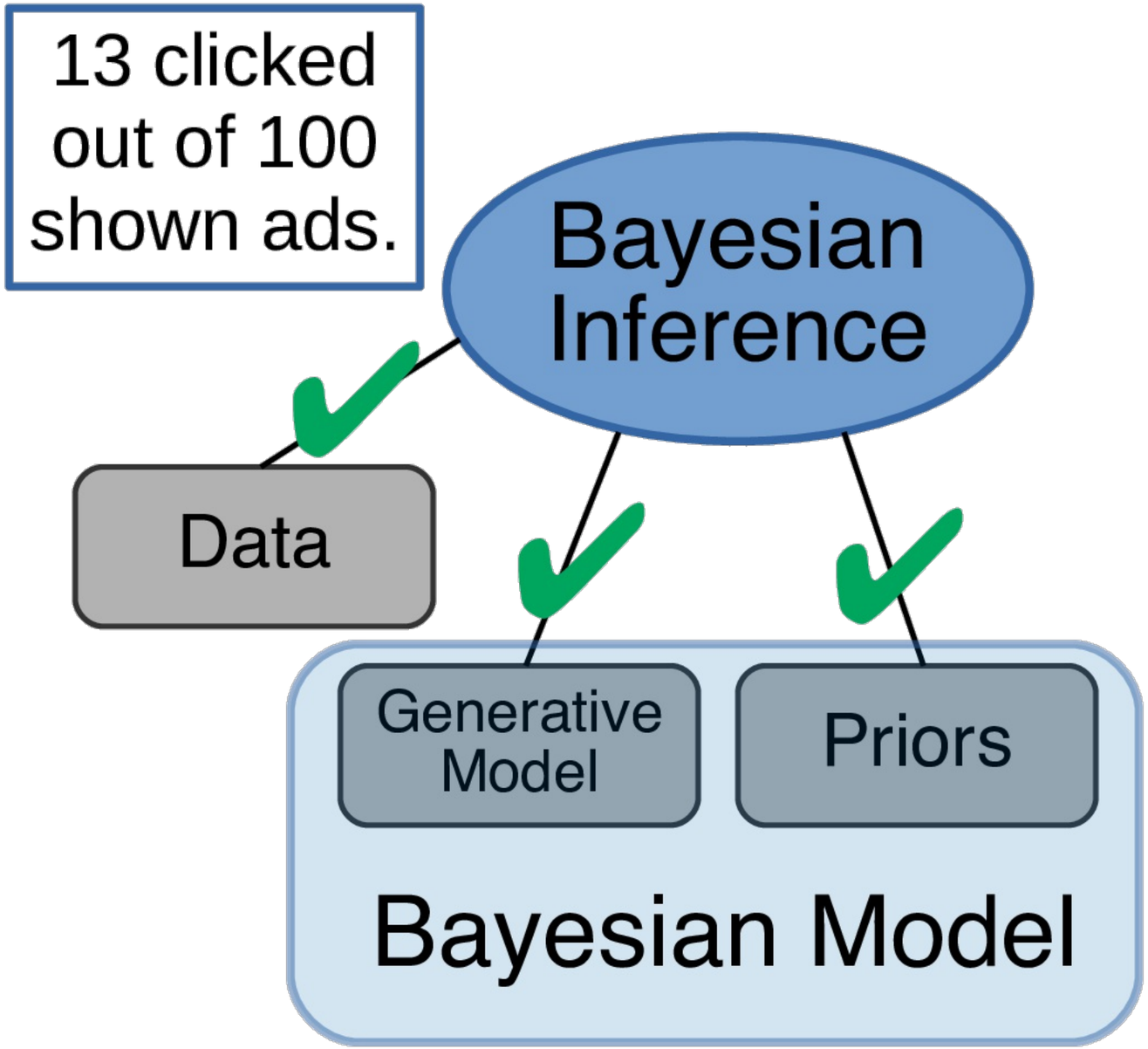
Bayesian models and conditioning

Rasmus Bååth
Data Scientist


Bayesian Inference
Data
Generative Model
Priors


Bayesian Inference
Data
Generative Model
Priors
Bayesian Model


13 clicked out of 100 shown ads.
Bayesian Inference
Data
Generative Model
Priors
Bayesian Model

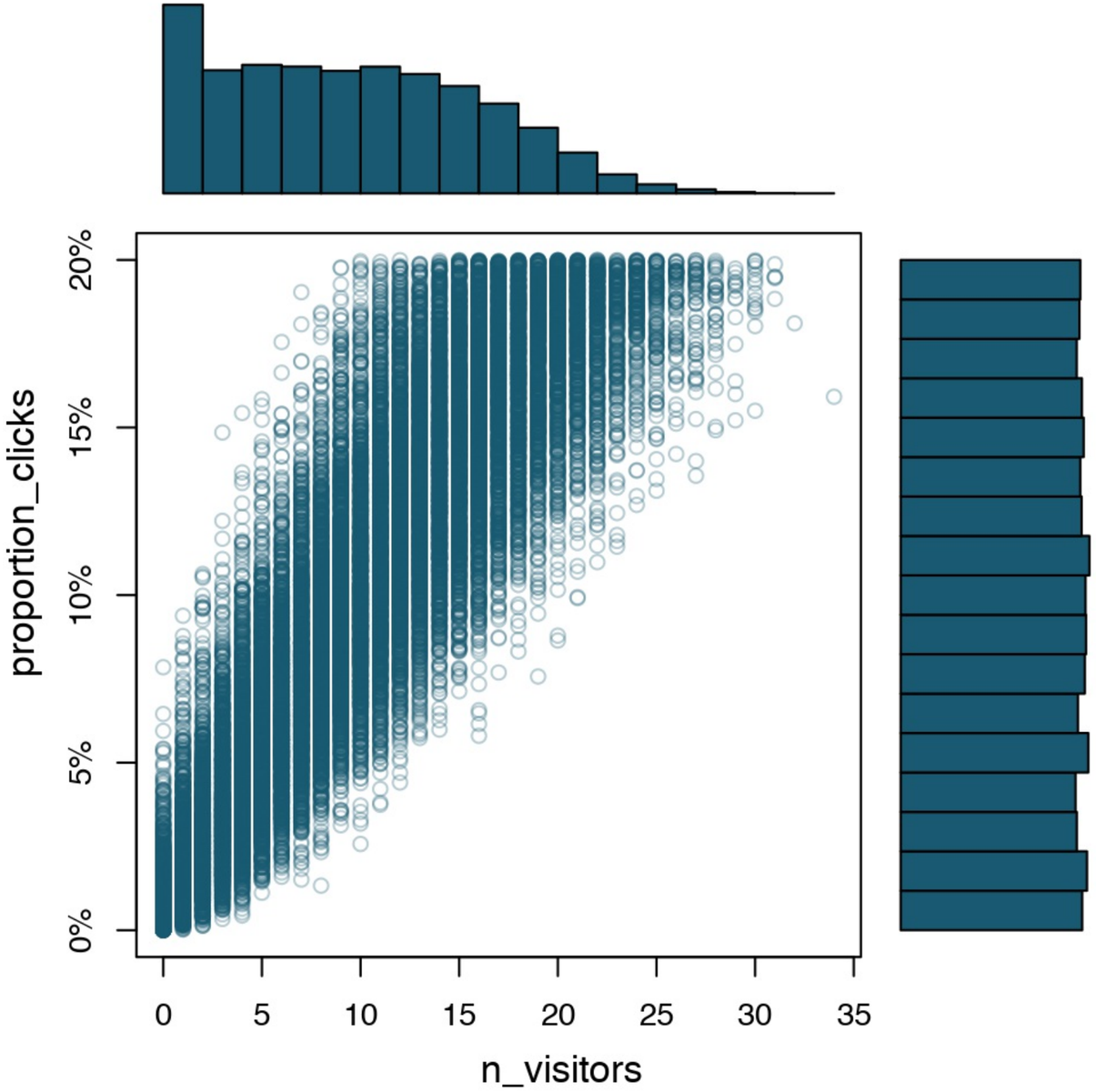

13 clicked out of 100 shown ads.
Bayesian Inference
Data
Generative Model
Priors
Bayesian Model

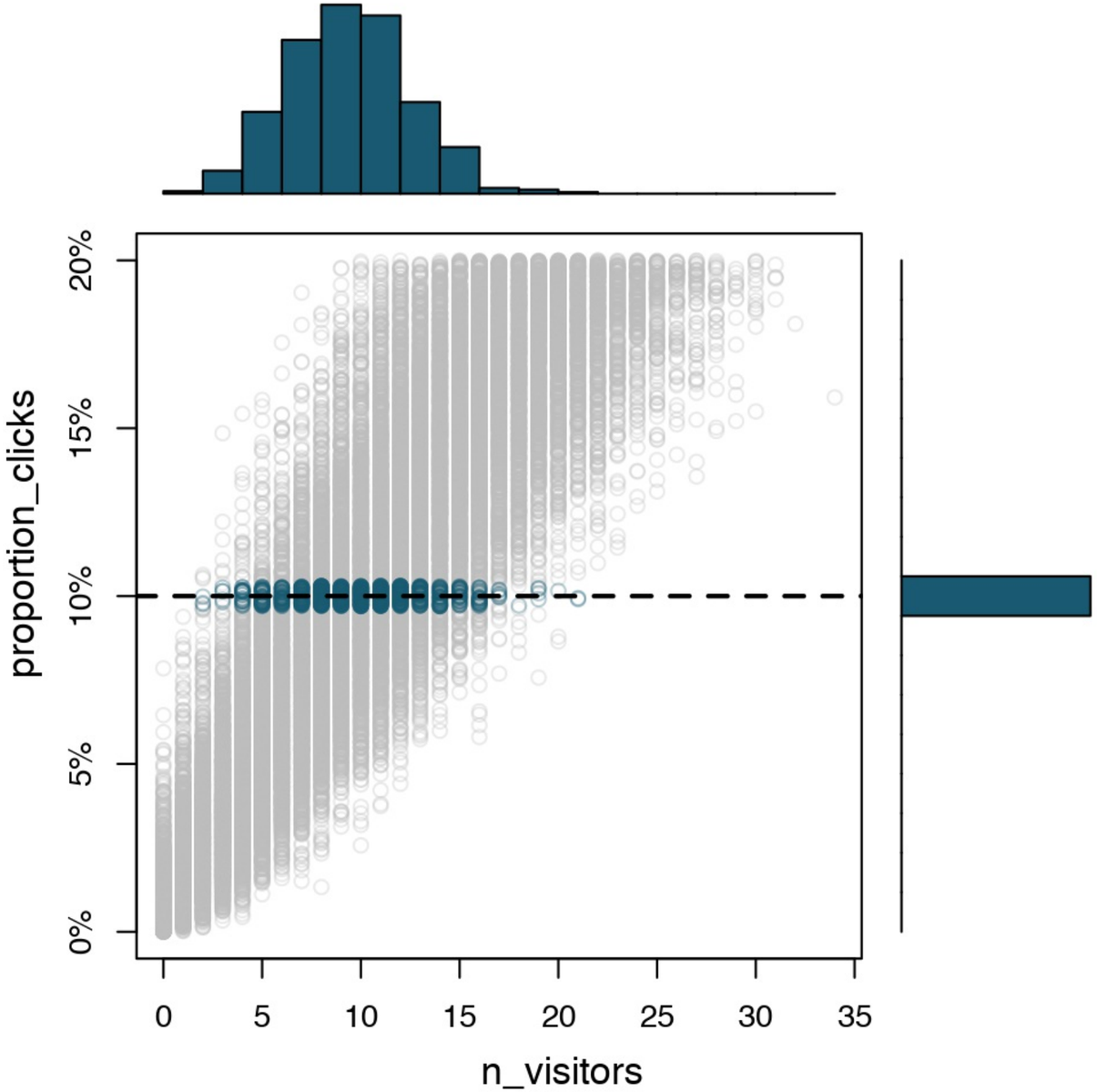
```
n_samples <- 100000
n_ads_shown <- 100
proportion_clicks <- runif(n_samples, min = 0.0, max = 0.2)
n_visitors <- rbinom(n = n_samples, size = n_ads_shown,
                     prob = proportion_clicks)
```

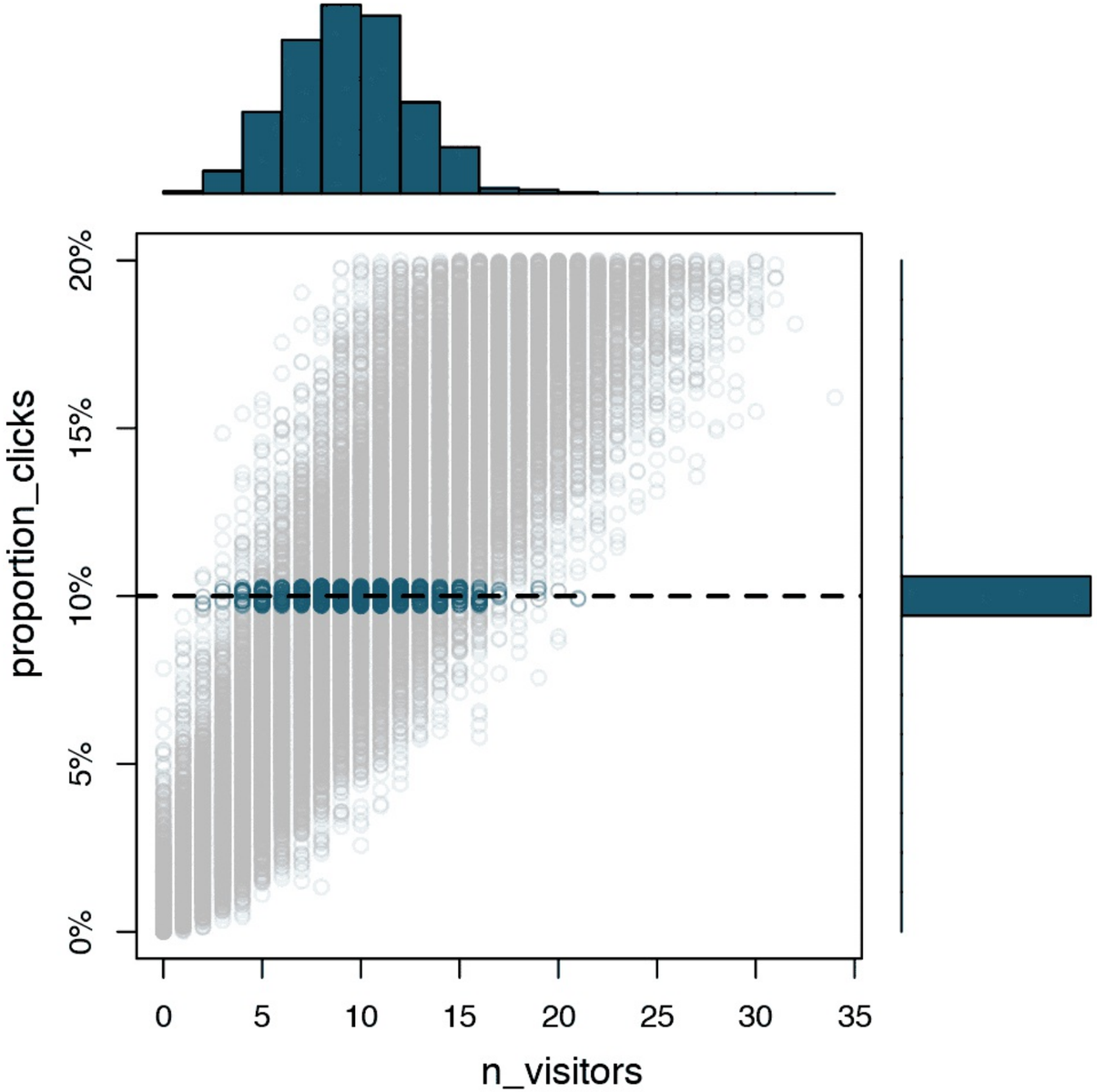
```
n_samples <- 100000
n_ads_shown <- 100
proportion_clicks <- runif(n_samples, min = 0.0, max = 0.2)
n_visitors <- rbinom(n = n_samples, size = n_ads_shown,
                     prob = proportion_clicks)
prior <- data.frame(proportion_clicks, n_visitors)
```

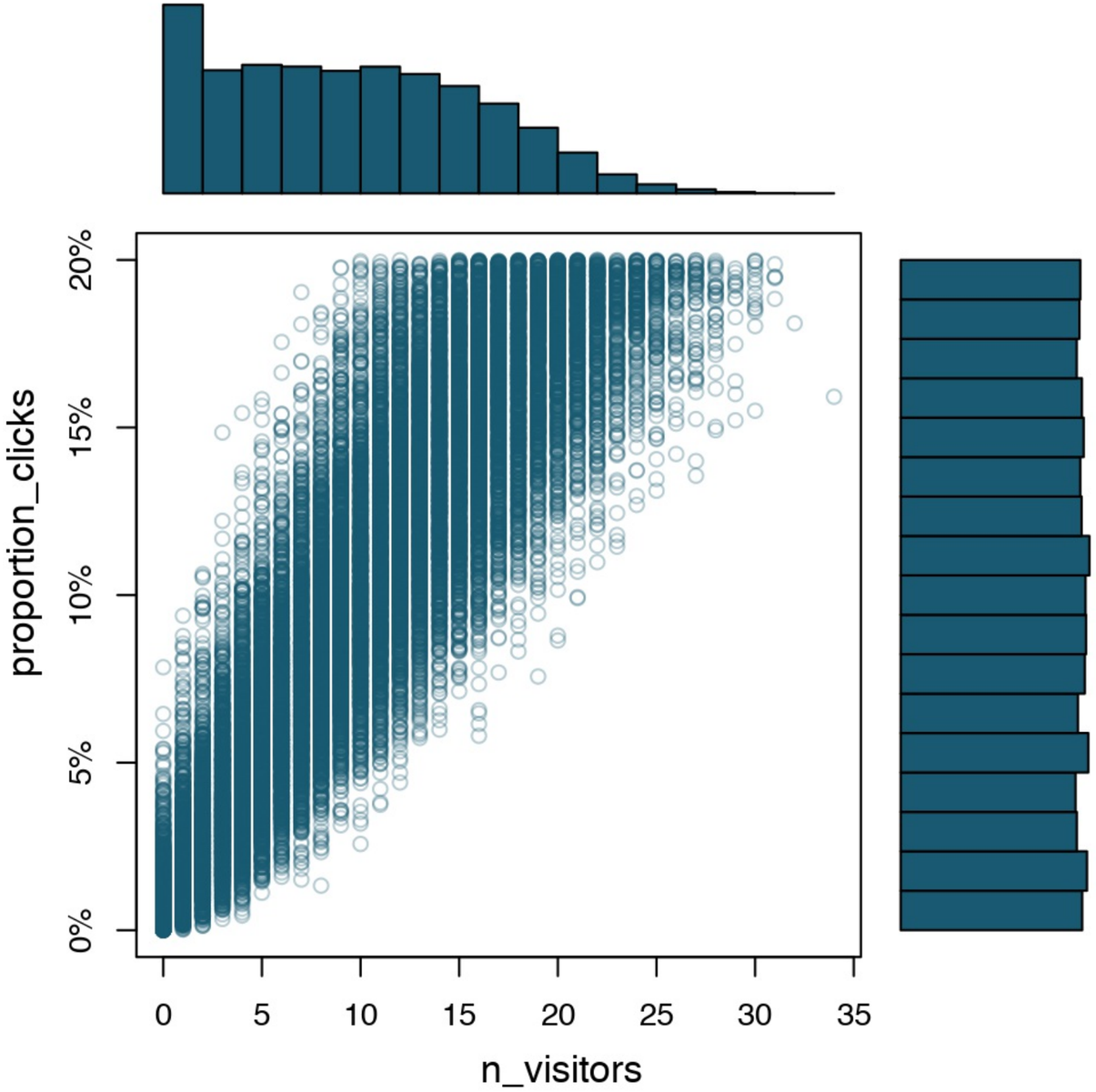
```
prior
```

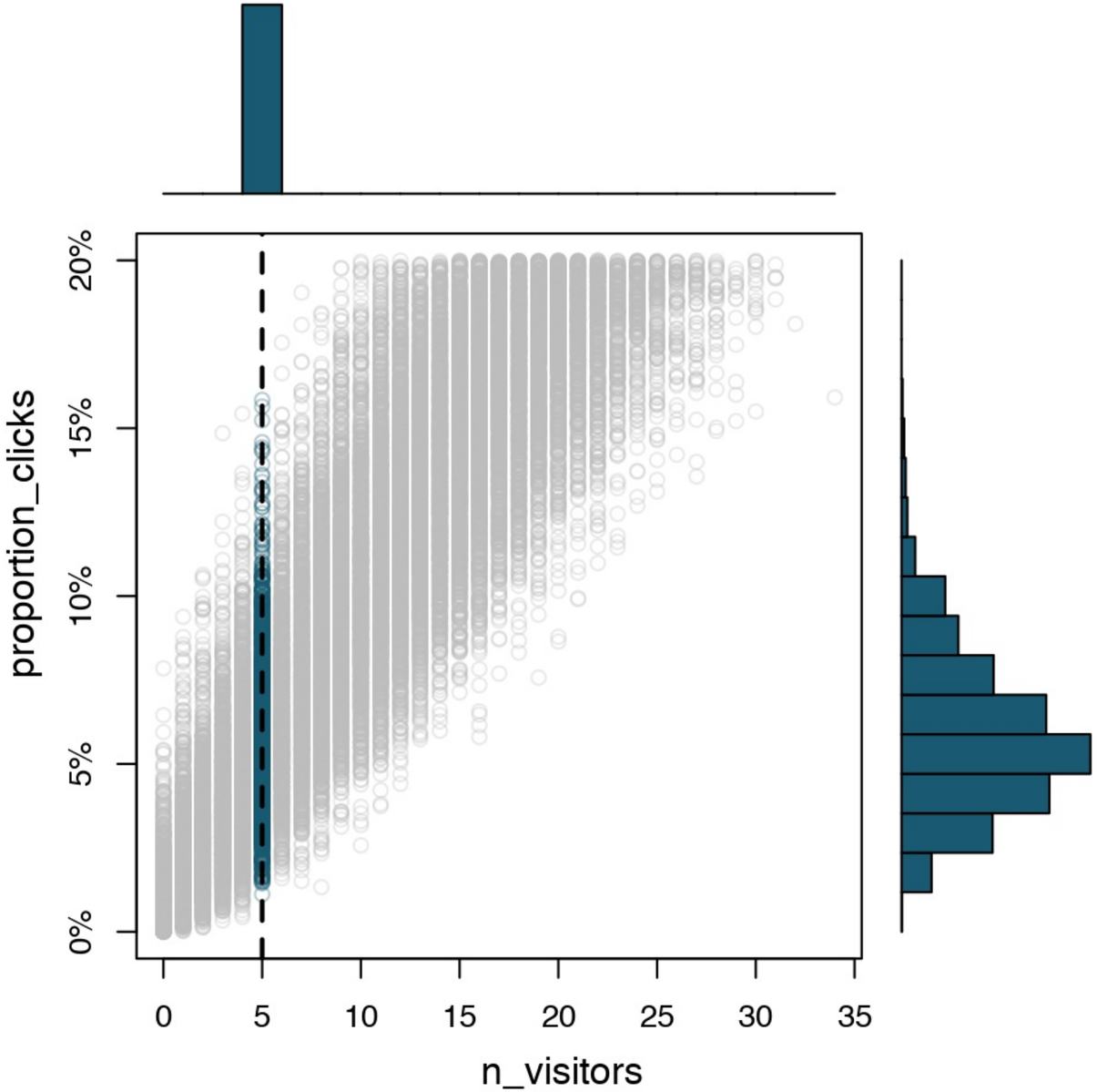
```
   proportion_clicks n_visitors
1               0.12         10
2               0.04          3
3               0.11         14
4               0.15         14
5               0.15         12
6               0.16         13
7               0.04          6
8               0.04          3
9               0.09         10
10              0.04          3
11              0.08          8
12              0.13         12
13              0.02          3
14              0.18         19
15              0.04          5
16              0.10         10
...              ...        ...
```

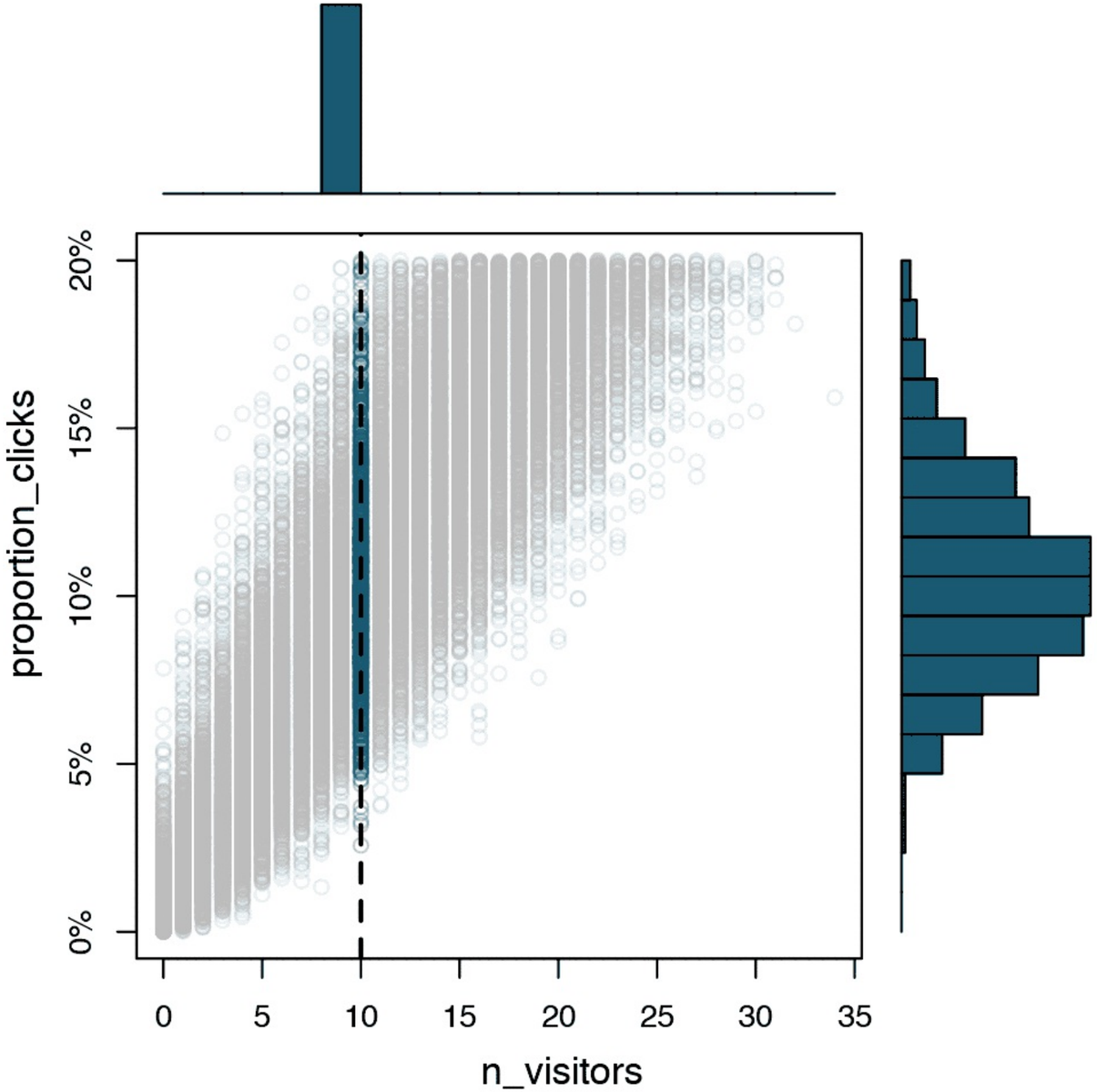

proportion_clicks
0%
5%
10%
15%
20%
0
5
10
15
20
25
30
35
n_visitors


proportion_clicks
0%
5%
10%
15%
20%
0
5
10
15
20
25
30
35
n_visitors


proportion_clicks
0%
5%
10%
15%
20%
0
5
10
15
20
25
30
35
n_visitors


proportion_clicks
0%
5%
10%
15%
20%
0
5
10
15
20
25
30
35
n_visitors


proportion_clicks
0%
5%
10%
15%
20%
0
5
10
15
20
25
30
35
n_visitors


proportion_clicks
0%
5%
10%
15%
20%
0
5
10
15
20
25
30
35
n_visitors

The essence of Bayesian inference

Bayesian inference is conditioning on data, in order to learn about parameter values.

FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

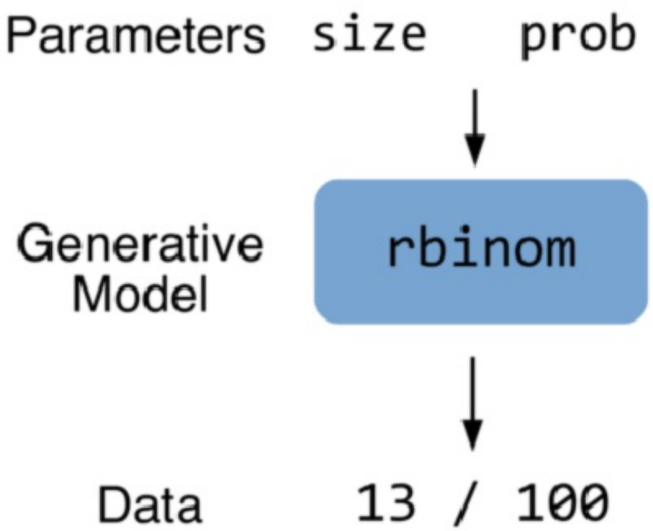
Try some Bayesian inference yourself!

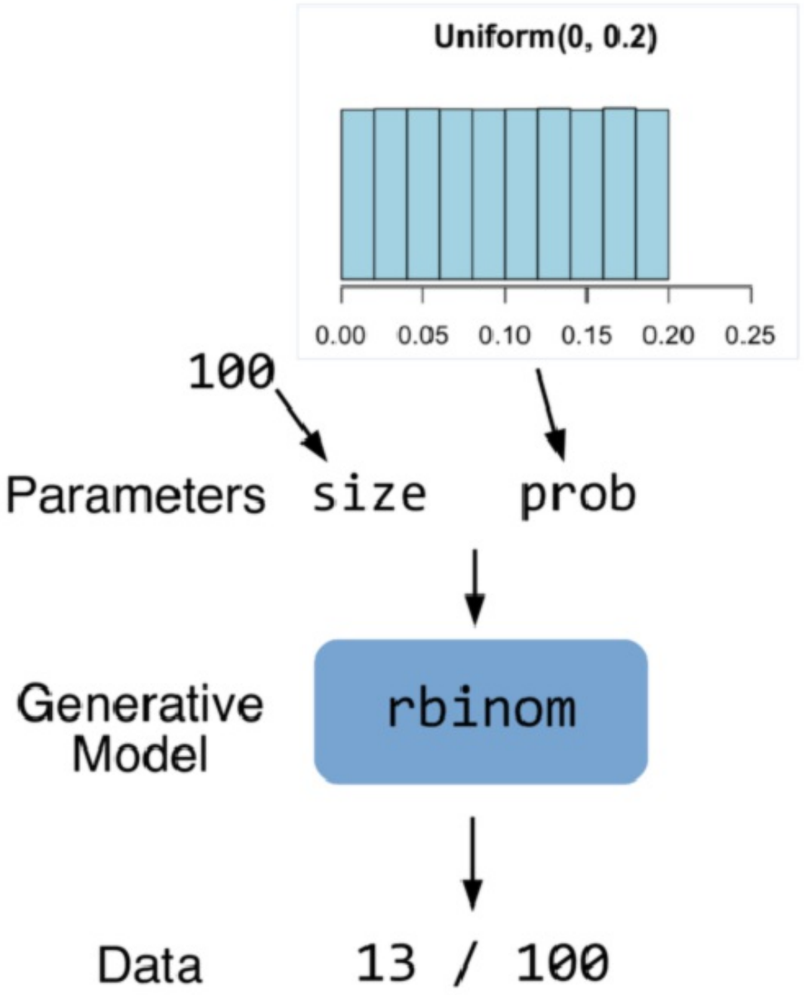
FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

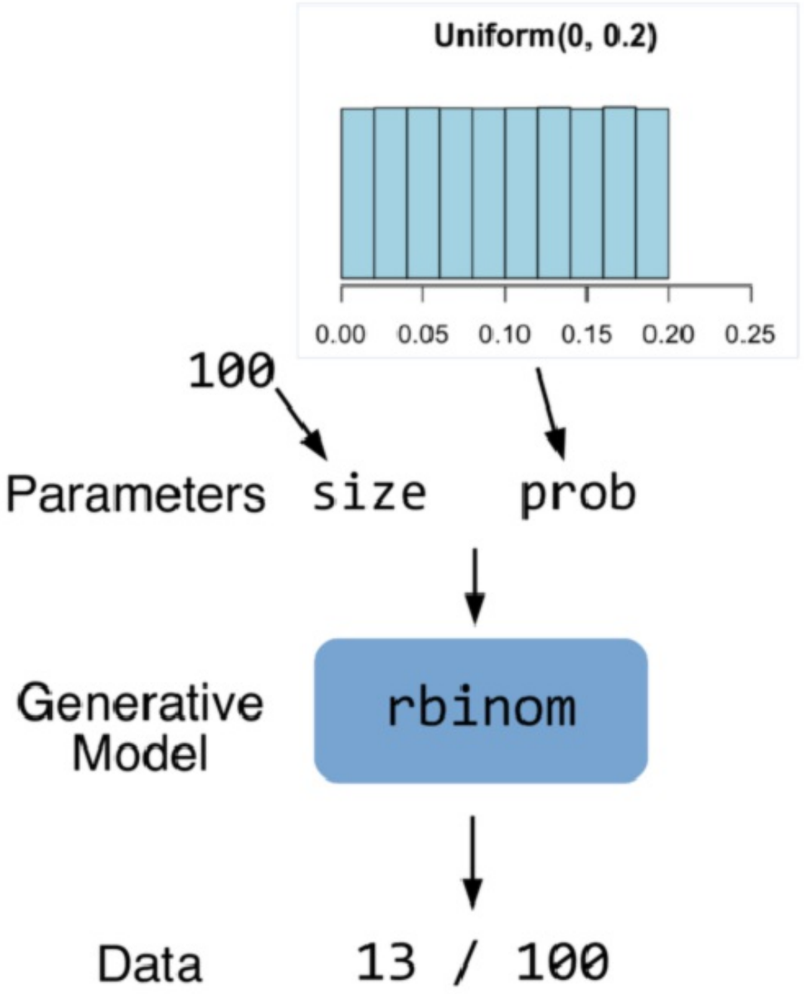
Bayesian inference, again!

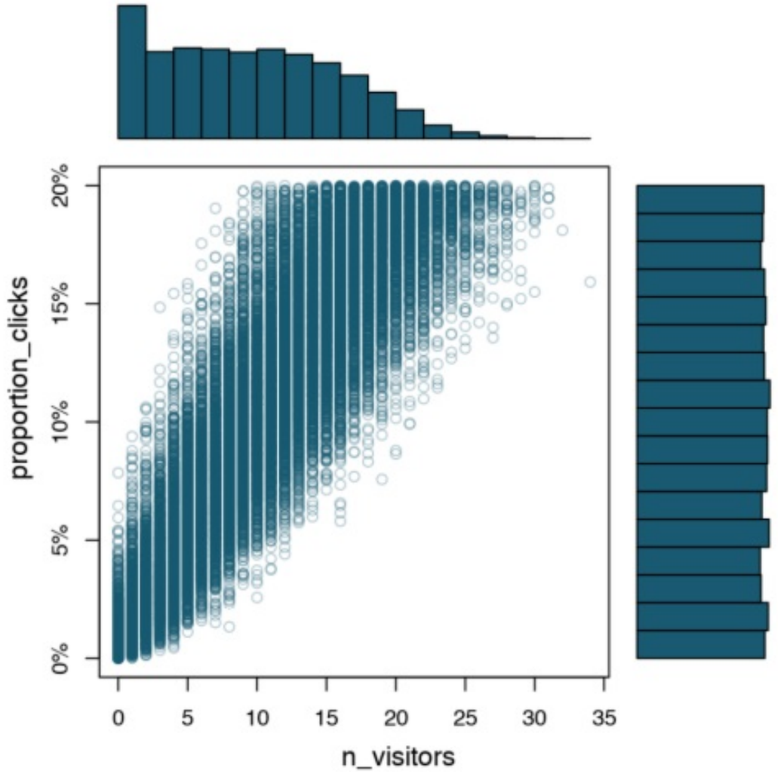
Rasmus Bååth
Data Scientist

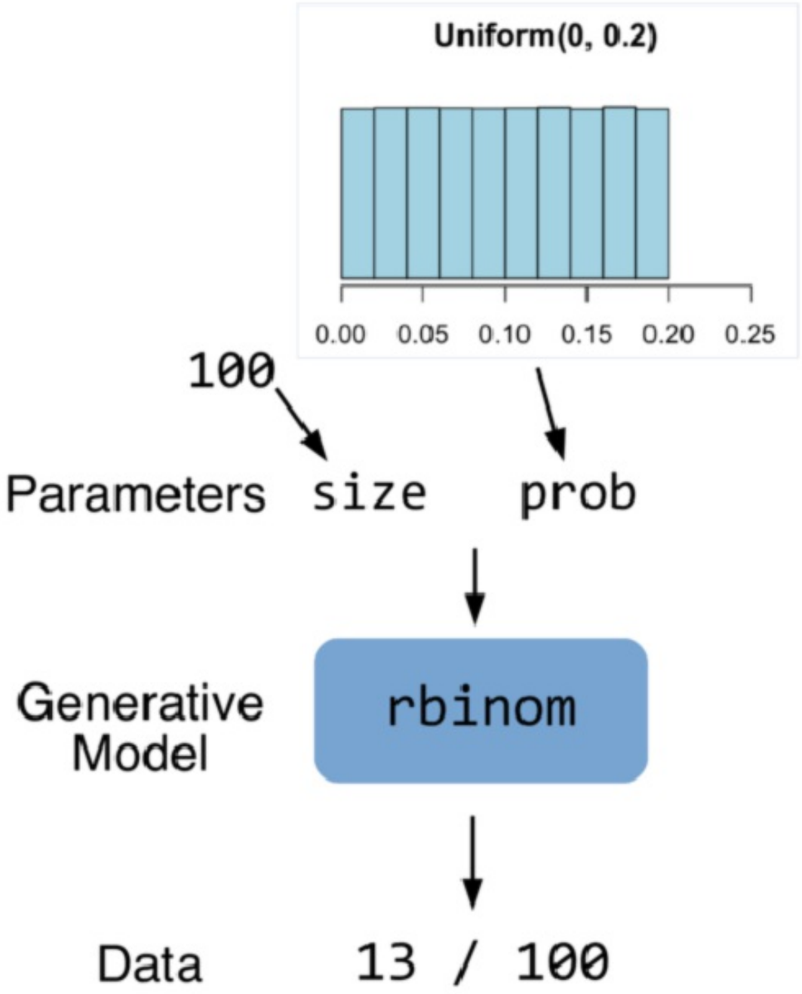
```
prop_success <- 0.1
size <- 100
# Simulating data
data <- c()
for(i in 1:size) {
  data[i] <-
    runif(1, min = 0, max = 1) <
      prop_success
}
data <- as.numeric(data)
```

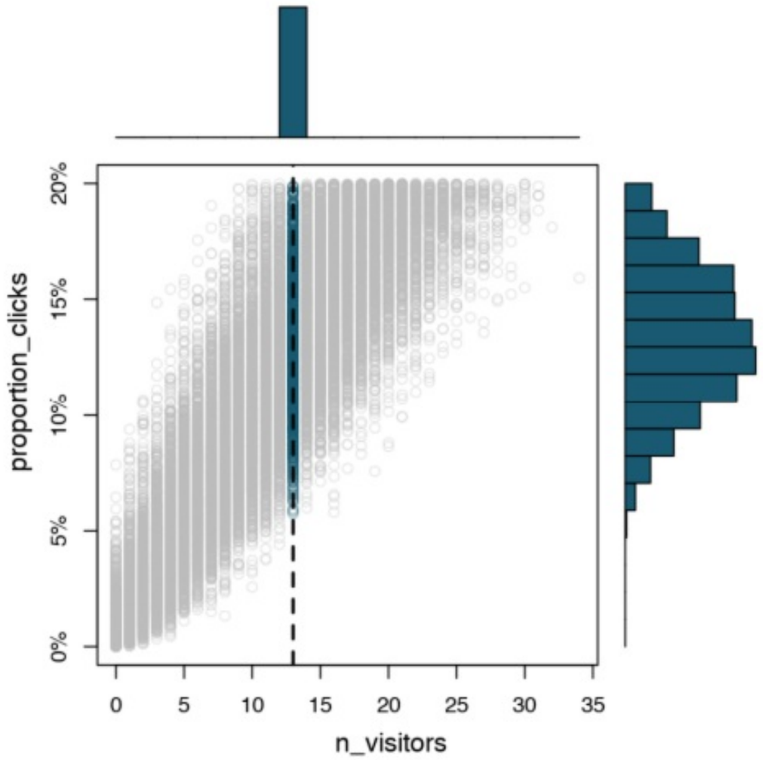

Parameters
size
prob
Generative Model
rbinom
Data
13 / 100

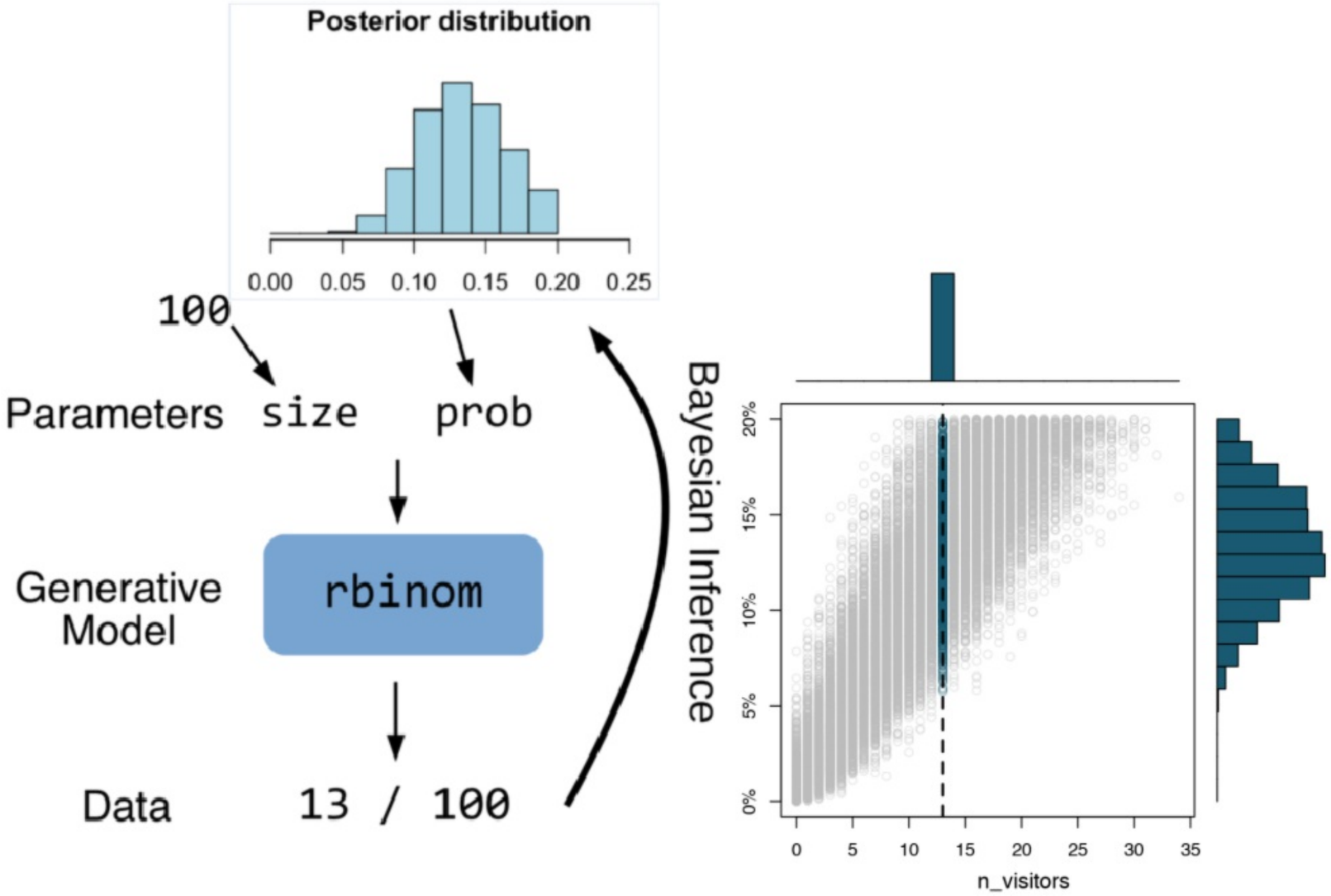

Uniform(0, 0.2)
0.00
0.05
0.10
0.15
0.20
0.25
100
Parameters
size
prob
Generative Model
rbinom
Data
13 / 100

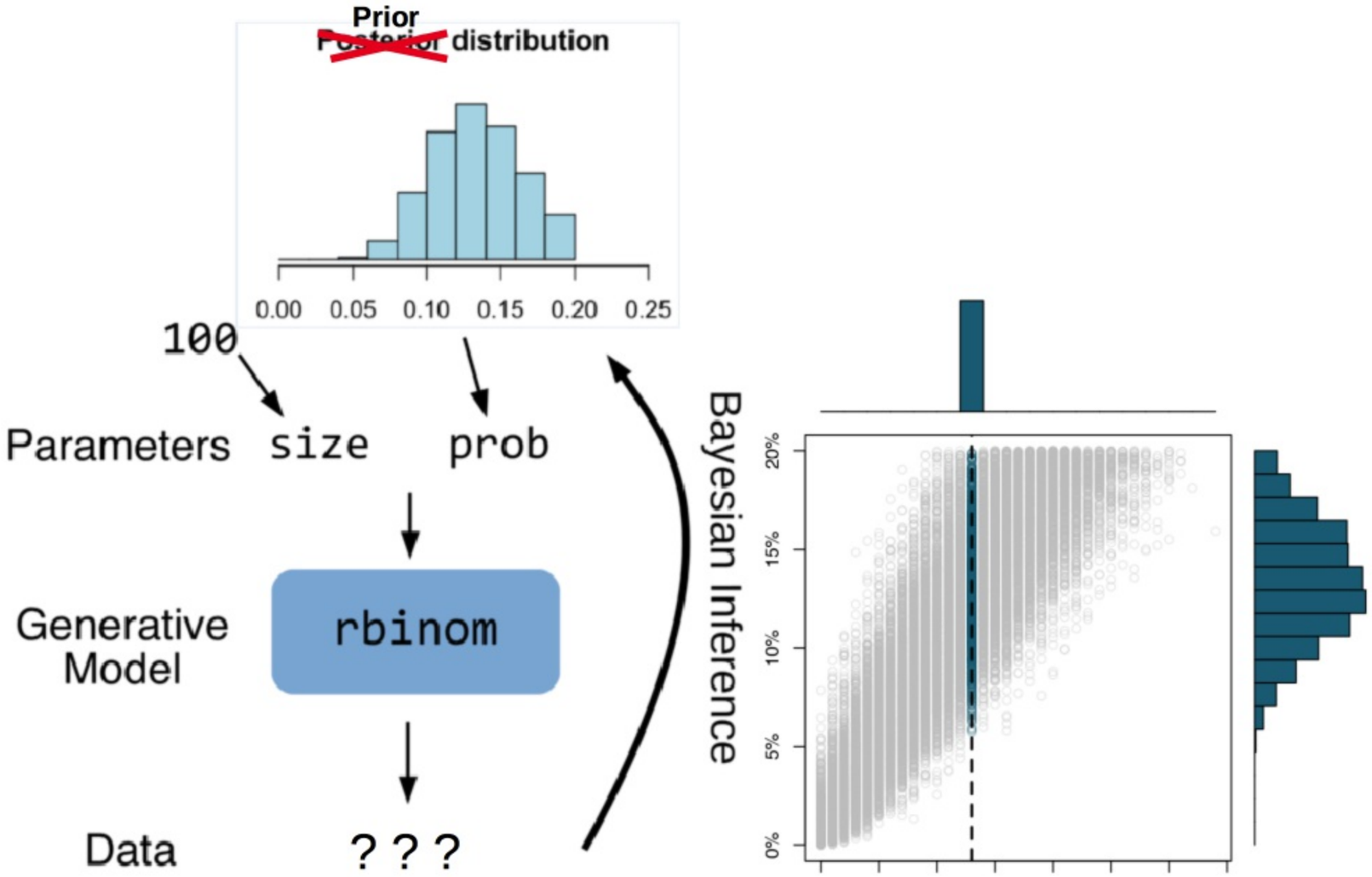

Uniform(0, 0.2)
0.00
0.05
0.10
0.15
0.20
0.25
100
Parameters
size
prob
Generative Model
rbinom
Data
13 / 100

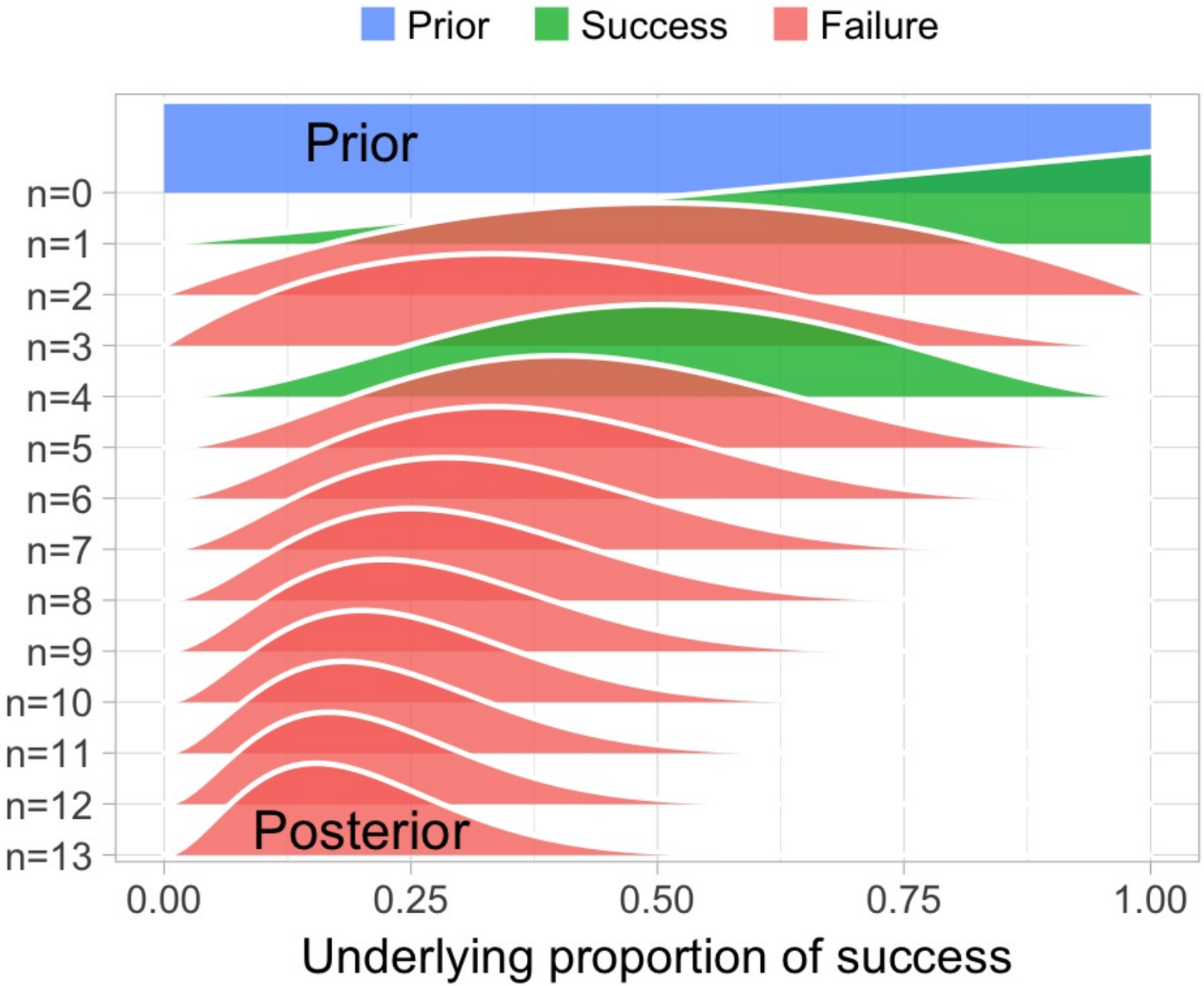

proportion_clicks
0%
5%
10%
15%
20%
0
5
10
15
20
25
30
35
n_visitors

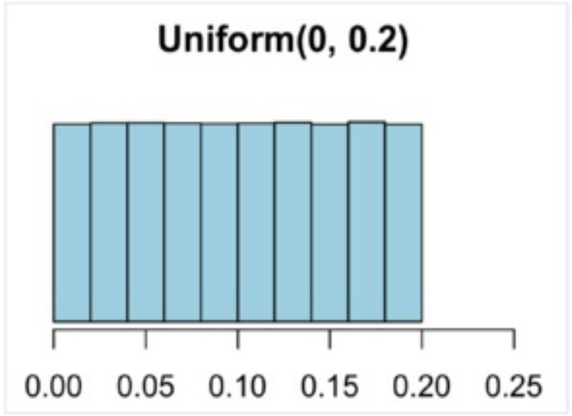

Uniform(0, 0.2)
0.00
0.05
0.10
0.15
0.20
0.25
100
Parameters
size
prob
Generative Model
rbinom
Data
13 / 100


proportion_clicks
0%
5%
10%
15%
20%
0
5
10
15
20
25
30
35
n_visitors


Posterior distribution
0.00
0.05
0.10
0.15
0.20
0.25
100
Parameters
size
prob
Generative Model
rbinom
Data
13 / 100
Bayesian Inference
0%
5%
10%
15%
20%
0
5
10
15
20
25
30
35
n_visitors

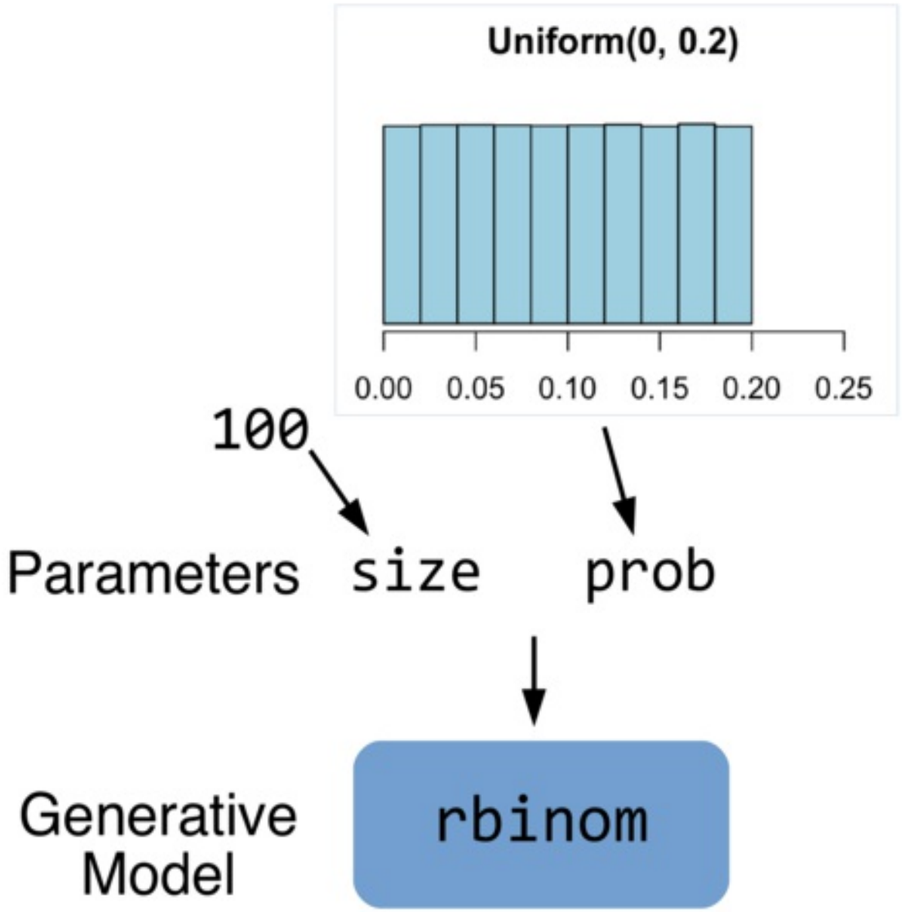

Prior
distribution
0.00
0.05
0.10
0.15
0.20
0.25
100
Parameters
size
prob
Generative Model
rbinom
Data
? ? ?
Bayesian Inference
0%
5%
10%
15%
20%
0
5
10
15
20
25
30
35
n_visitors

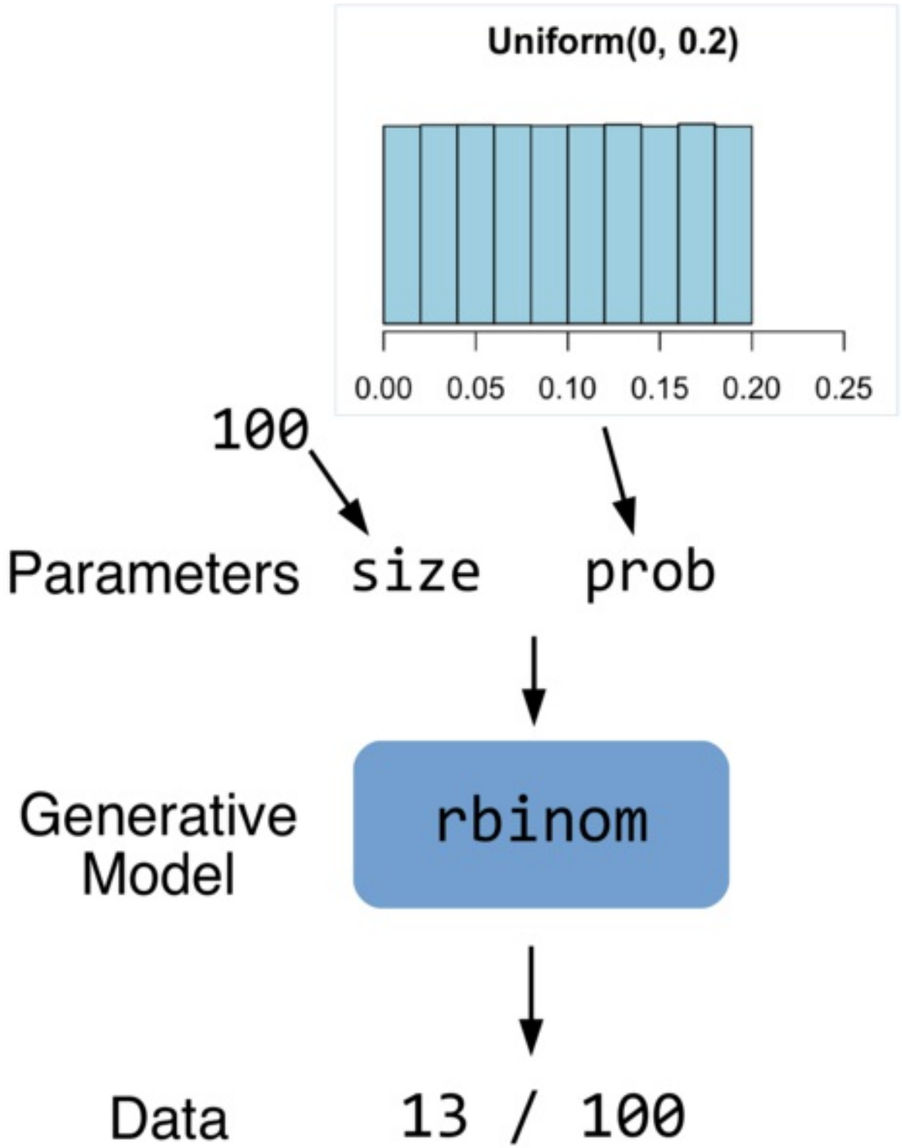

Prior
Success
Failure
Prior
n=0
n=1
n=2
n=3
n=4
n=5
n=6
n=7
n=8
n=9
n=10
n=11
n=12
n=13
Posterior
0.00
0.25
0.50
0.75
1.00
Underlying proportion of success



100

Parameters size prob


Uniform(0, 0.2)
0.00
0.05
0.10
0.15
0.20
0.25
100
Parameters
size
prob
Generative Model
rbinom


Uniform(0, 0.2)
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0.10
0.15
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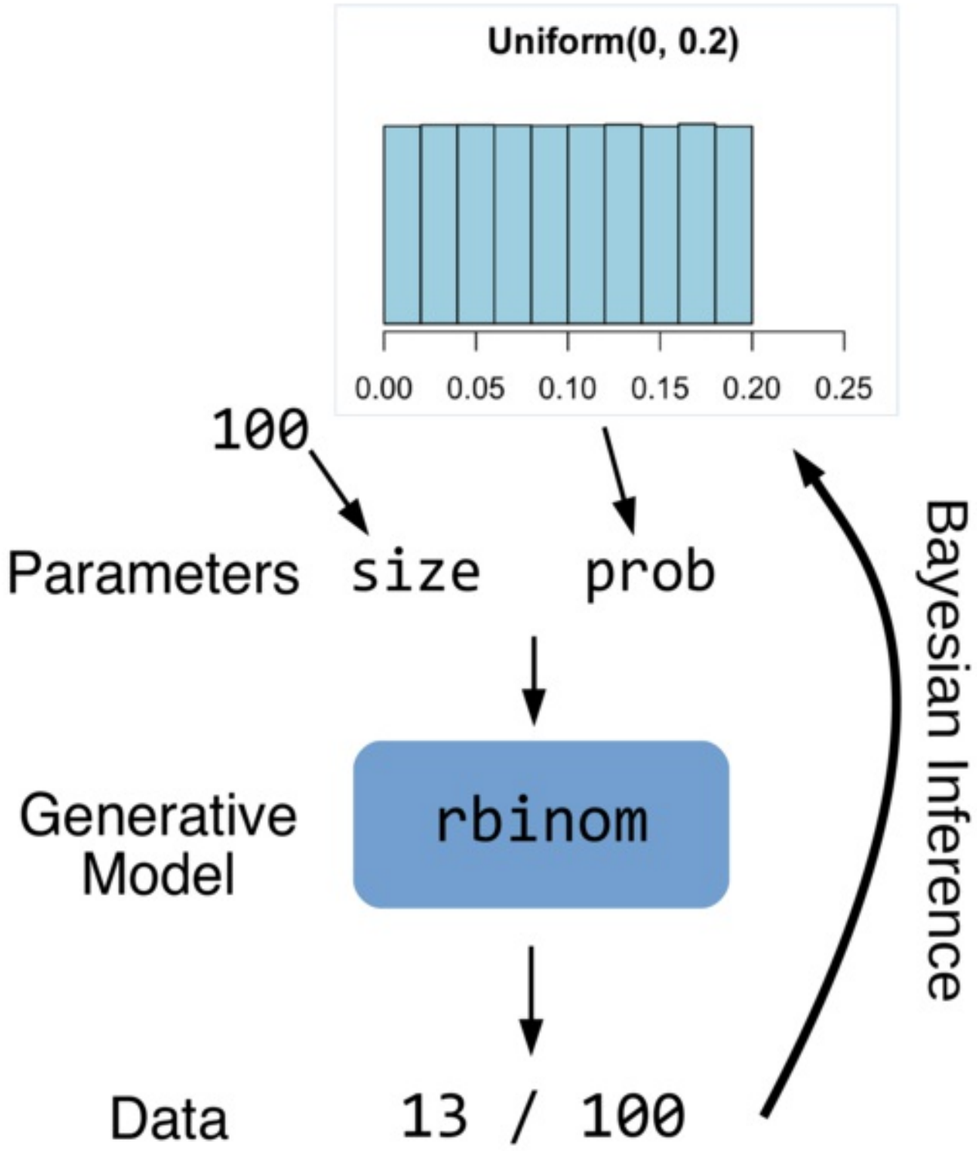
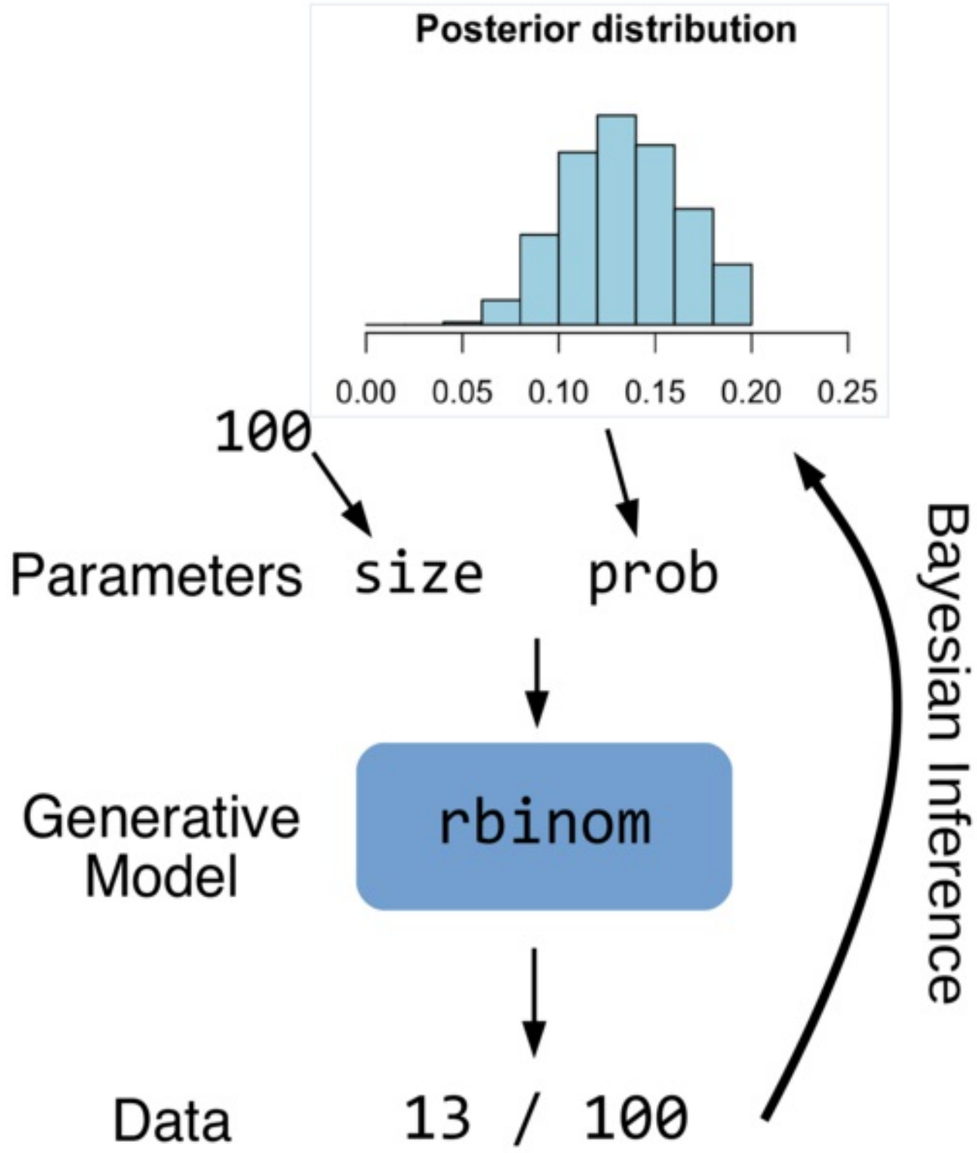
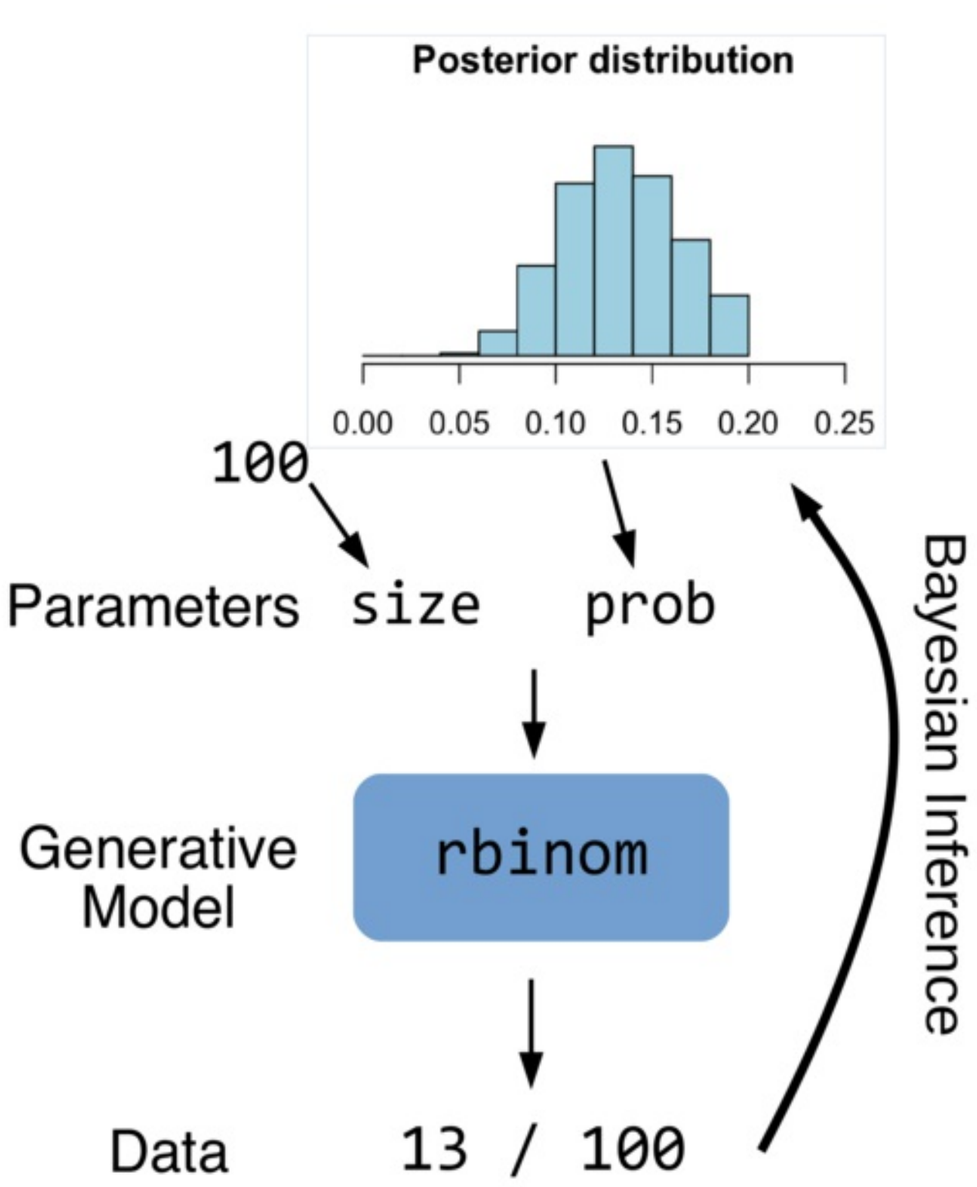
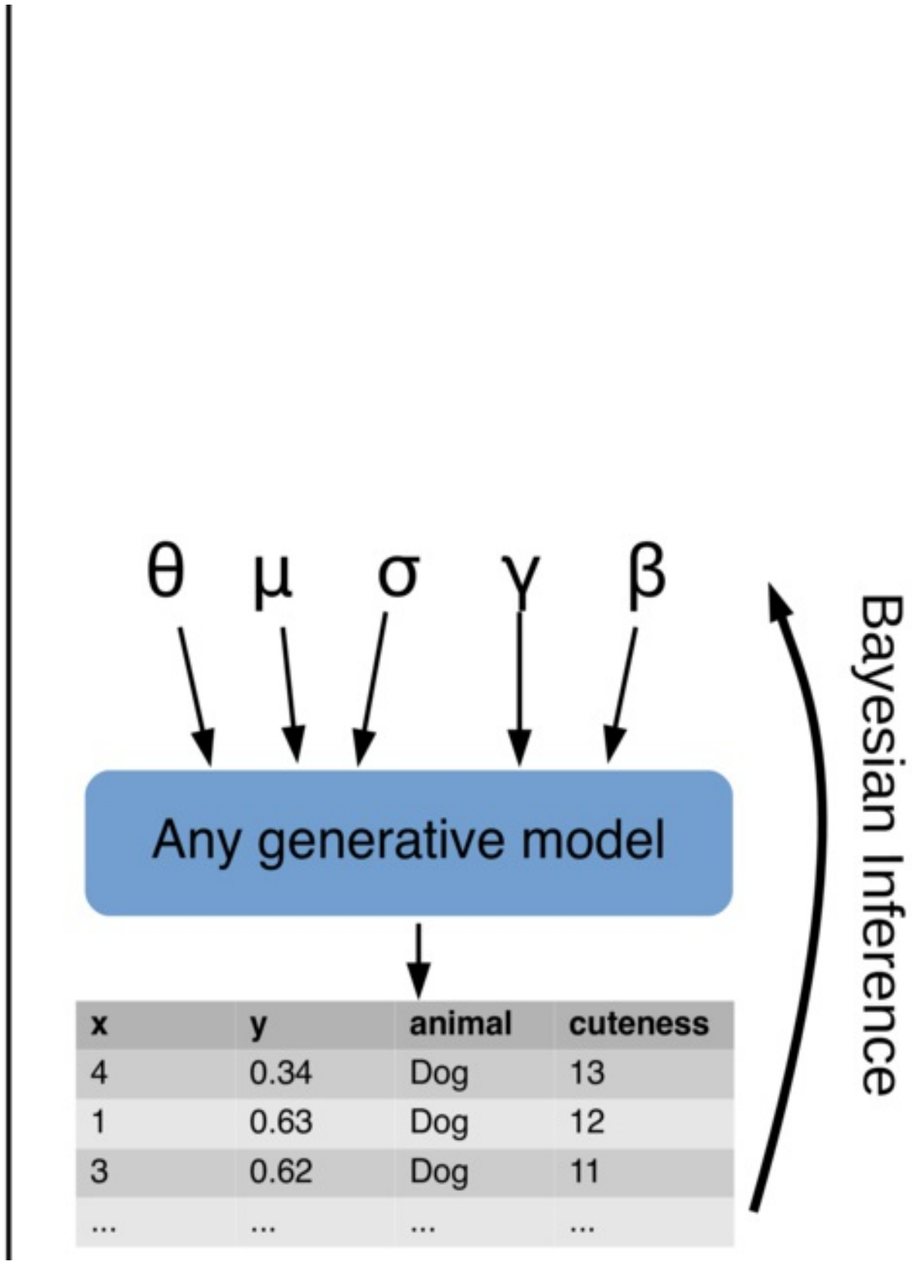
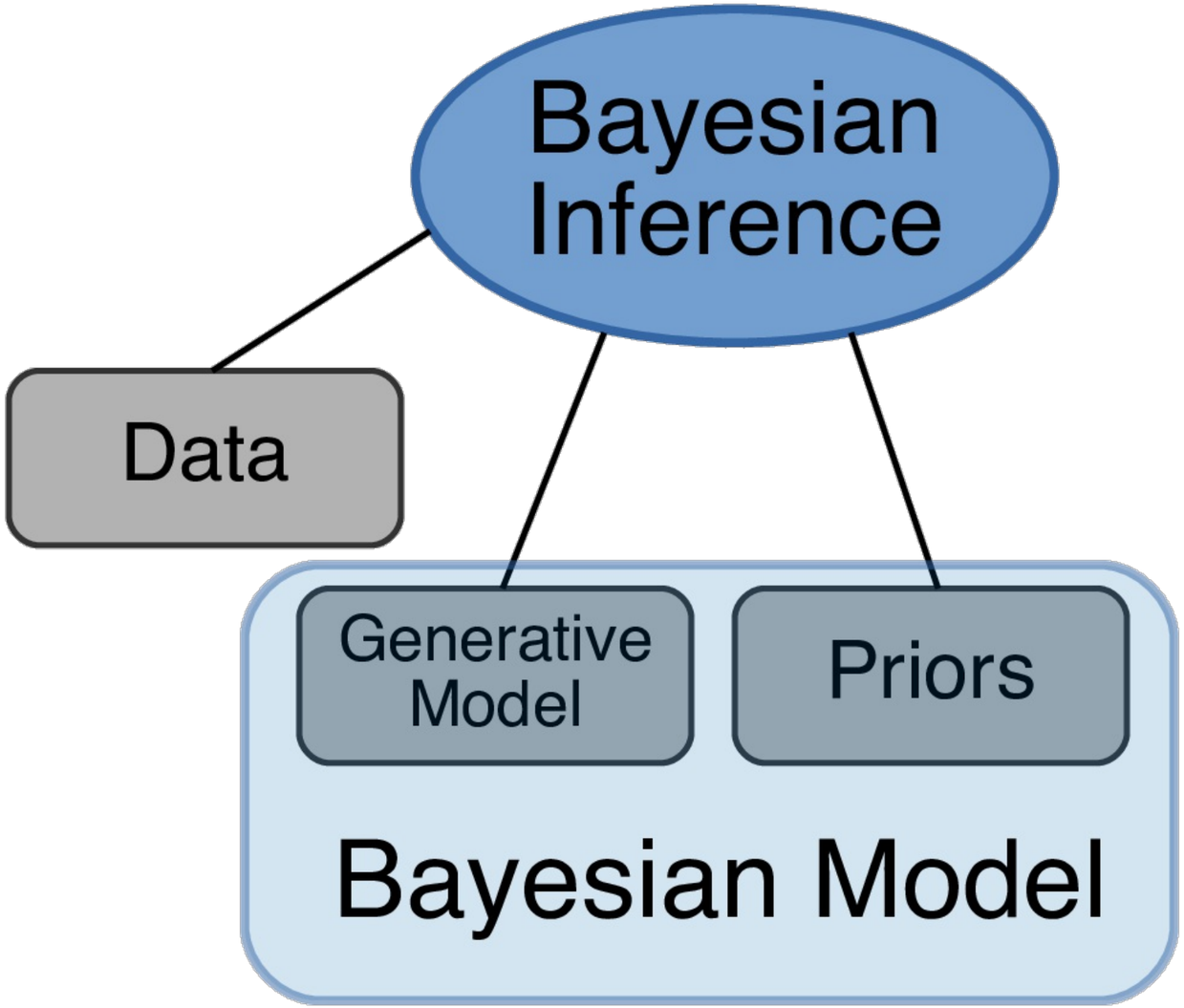
0.25
100
Parameters
size
prob
Generative Model
rbinom
Data
13 / 100

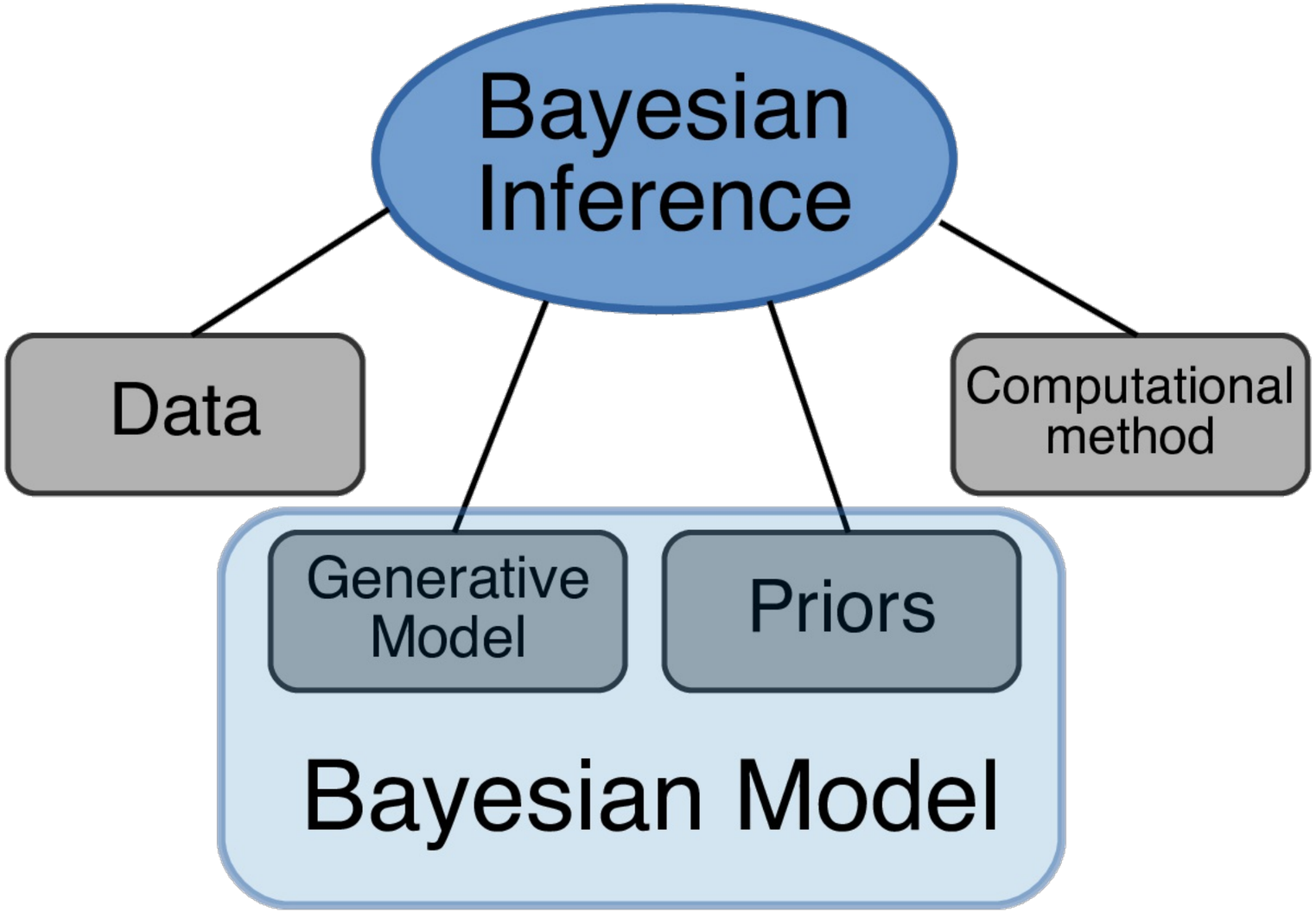

Uniform(0, 0.2)
0.00
0.05
0.10
0.15
0.20
0.25
100
Parameters
size
prob
Generative Model
rbinom
Data
13 / 100
Bayesian Inference


Posterior distribution
0.00
0.05
0.10
0.15
0.20
0.25
100
Parameters
size
prob
Generative Model
rbinom
Data
13 / 100
Bayesian Inference


Posterior distribution
0.00
0.05
0.10
0.15
0.20
0.25
100
Parameters
size
prob
Generative Model
rbinom
Data
13 / 100
Bayesian Inference


θ
μ
σ
γ
β
Any generative model
x
y
animal
cuteness
4
0.34
Dog
13
1
0.63
Dog
12
3
0.62
Dog
11
...
...
...
...
Bayesian Inference


Bayesian Inference
Data
Generative Model
Priors
Bayesian Model


Bayesian Inference
Data
Computational method
Generative Model
Priors
Bayesian Model

FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

Next up: Why use Bayes?