FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

Why use Bayesian data analysis?

Rasmus Bååth
Data Scientist

Bayes is flexible

1. You can include information sources in addition to the data.
2. You can make any comparisons between groups or data sets.
3. You can use the result of a Bayesian analysis to do Decision Analysis.
4. You can change the underlying statistical model.

Including information in addition to data

- Background information
- Expert opinion
- Common knowledge

You

So what are really the range of proportion of clicks you see for ads?

You

So what are really the range of proportion of clicks you see for ads?

Social media company person

Hi You! Most ads gets clicked on 5% of the time, but for some ads it is as low as 2% and for others as high as 8%.

You

So what are really the range of proportion of clicks you see for ads?

Social media company person

Hi You! Most ads gets clicked on 5% of the time, but for some ads it is as low as 2% and for others as high as 8%.

You

Ah, but you've written 10% on your webpage!? 🤔

You

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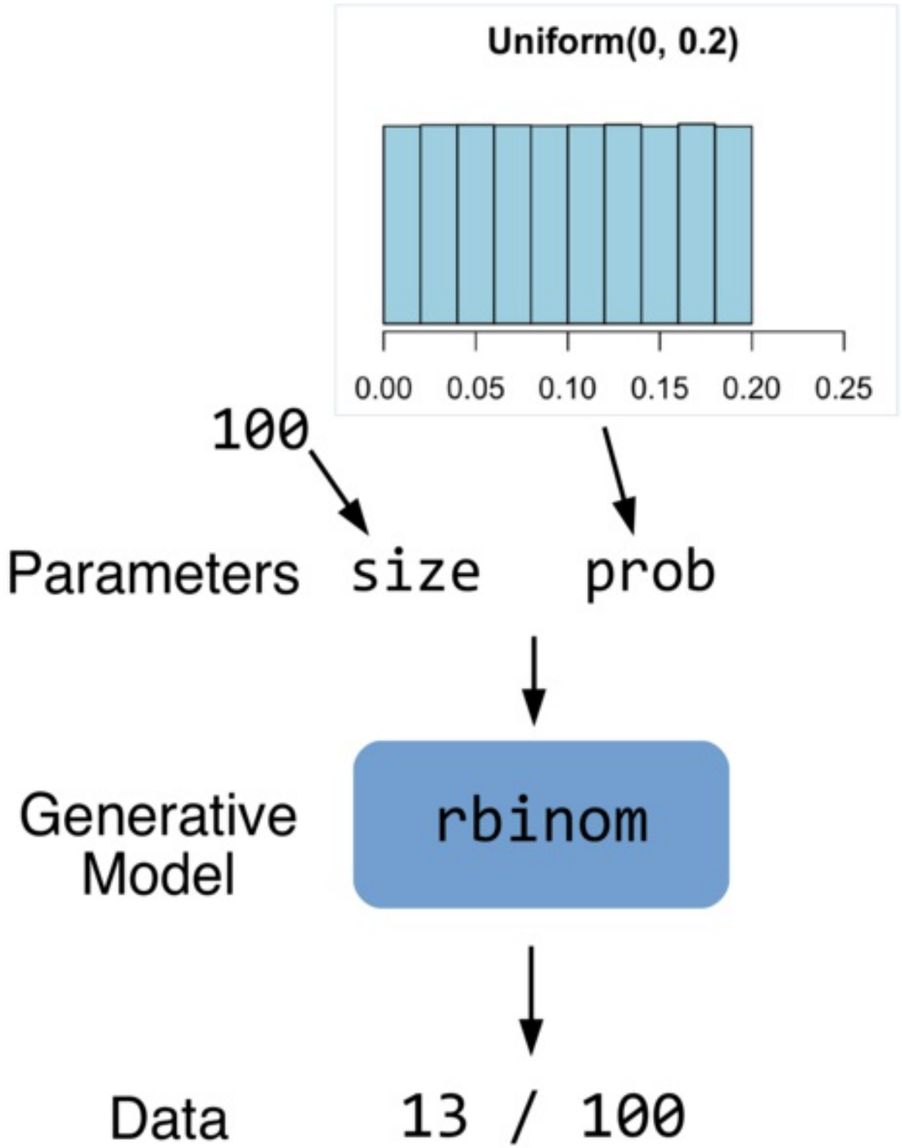
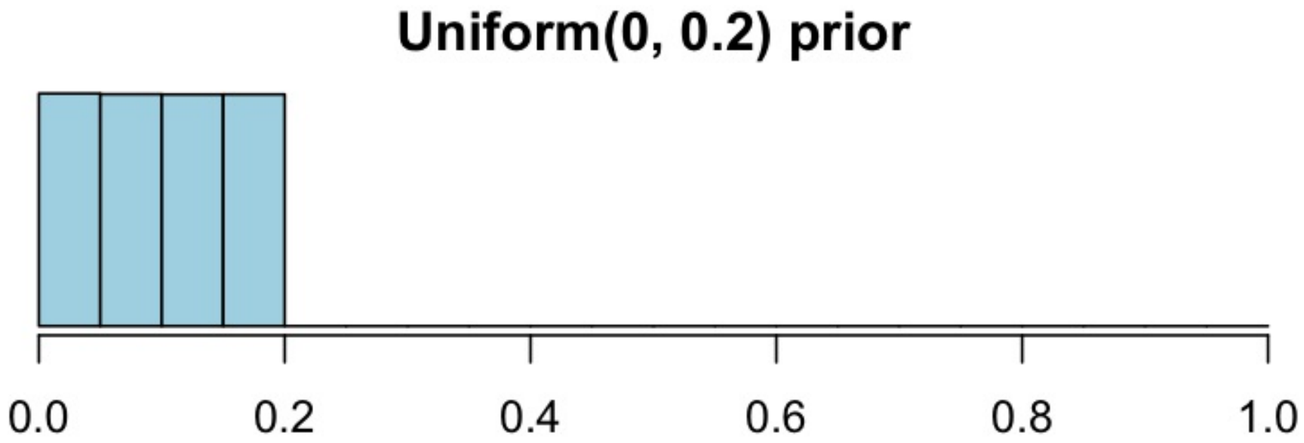
You

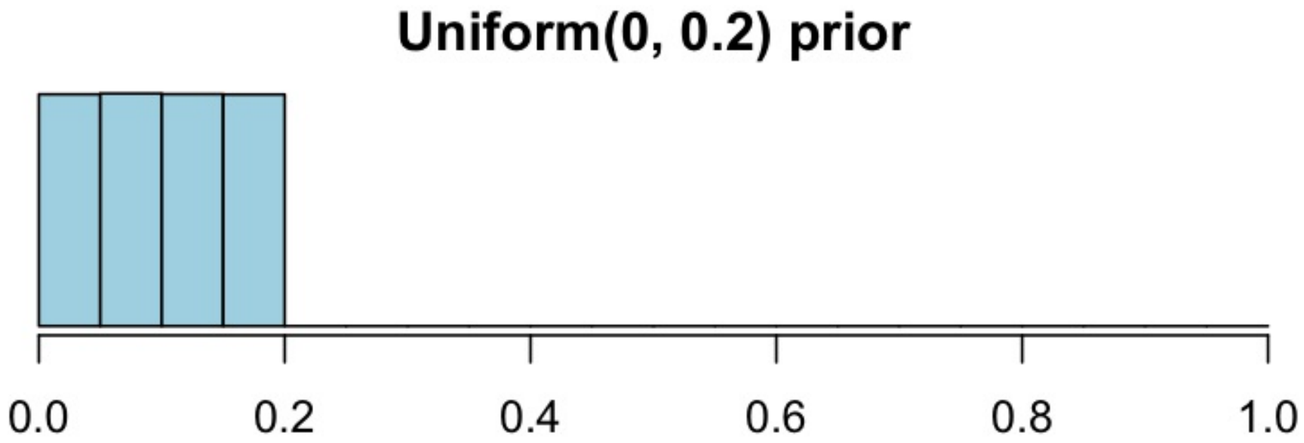
Ah, but you've written 10% on your webpage!? 🤔

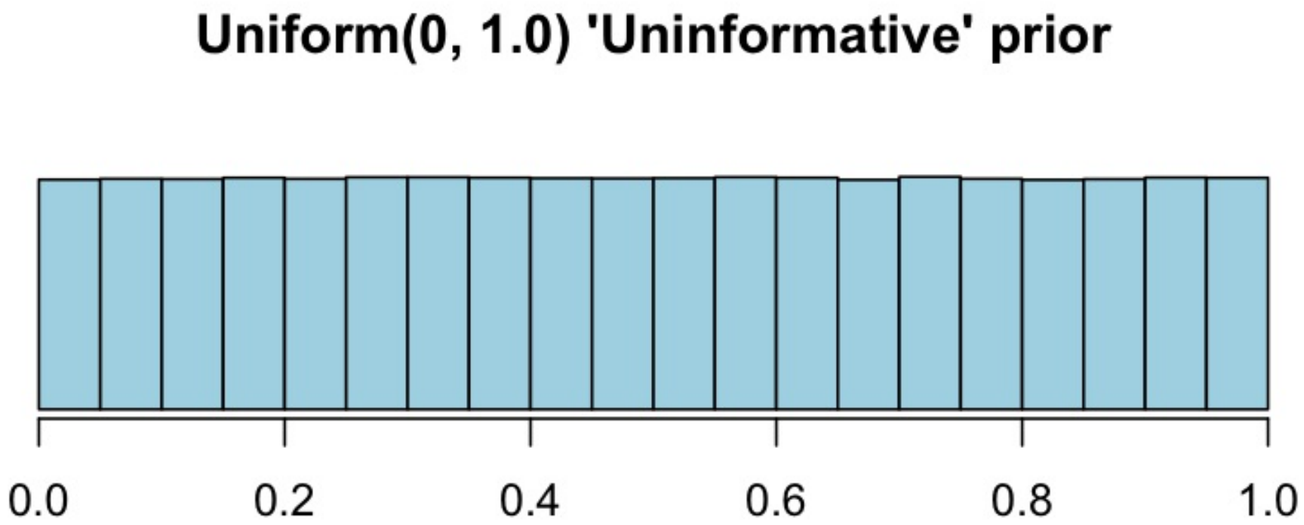
Social media company person

That's marketing, don't listen to them! 😜


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) prior
0.0
0.2
0.4
0.6
0.8
1.0


Uniform(0, 0.2) prior
0.0
0.2
0.4
0.6
0.8
1.0


Uniform(0, 1.0) 'Uninformative' prior
0.0
0.2
0.4
0.6
0.8
1.0

You

So what are really the range of proportion of clicks you see for ads?

Social media company person

Hi You! Most ads gets clicked on 5% of the time, but for some ads it is as low as 2% and for others as high as 8%.

You

Ah, but you've written 10% on your webpage!? 🤔

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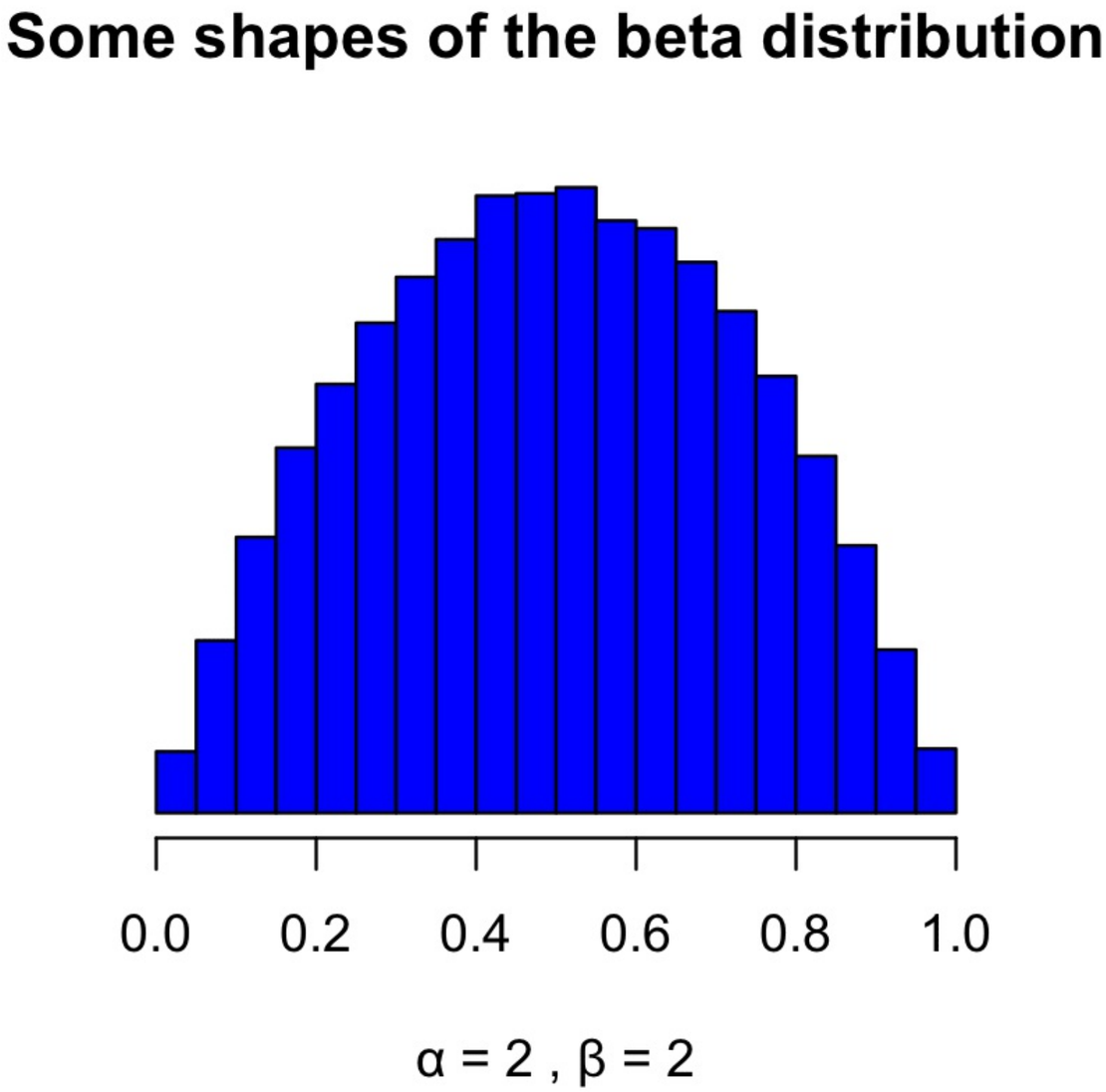
That's marketing, don't listen to them! 😜


Some shapes of the beta distribution
0.0
0.2
0.4
0.6
0.8
1.0
α = 2 , β = 2

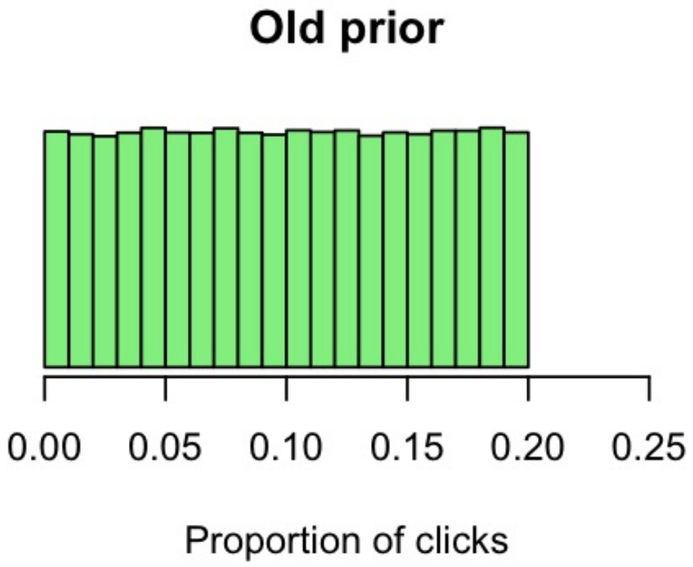
FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

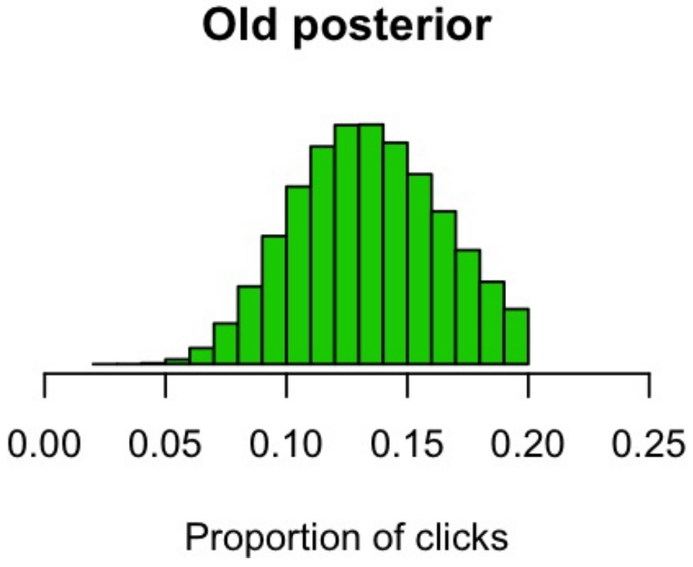
Define an informed prior!

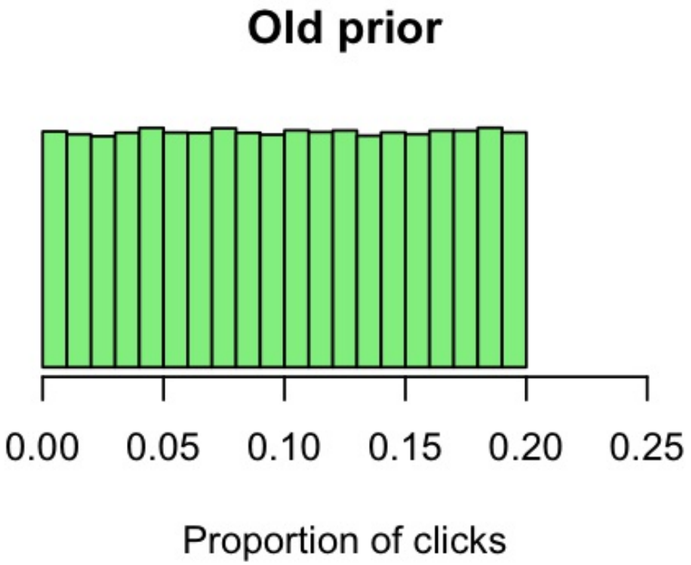
FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

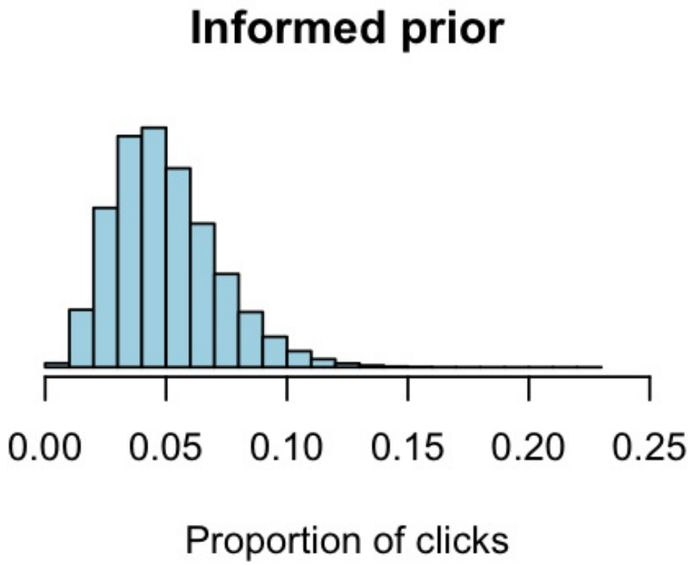
You've changed the prior!

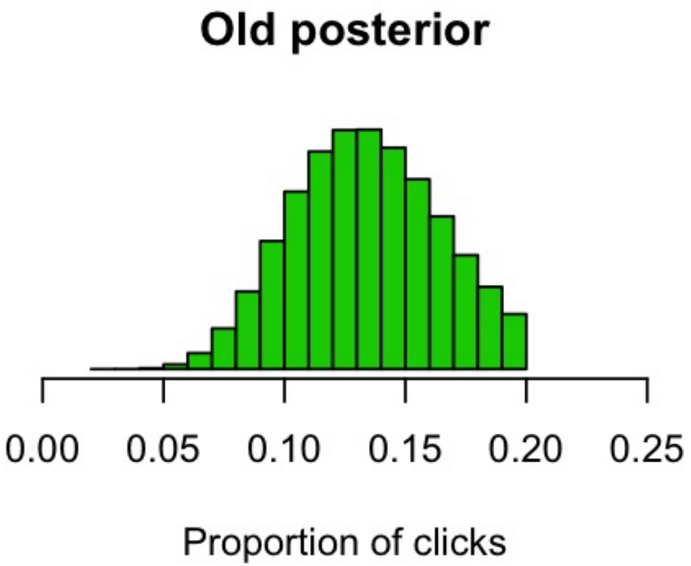
Rasmus Bååth
Data Scientist

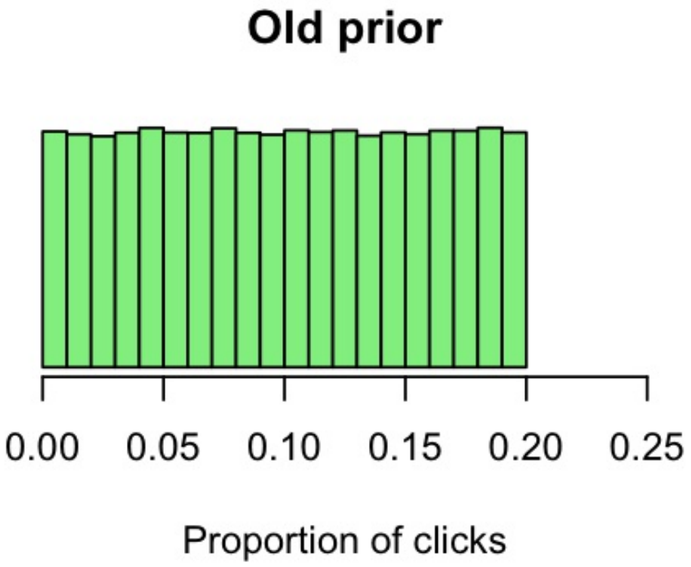

Old prior
0.00
0.05
0.10
0.15
0.20
0.25
Proportion of clicks

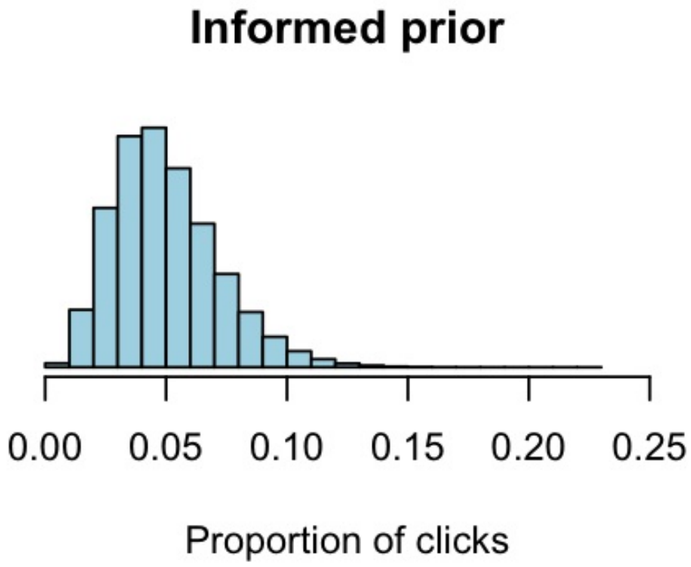

Old posterior
0.00
0.05
0.10
0.15
0.20
0.25
Proportion of clicks

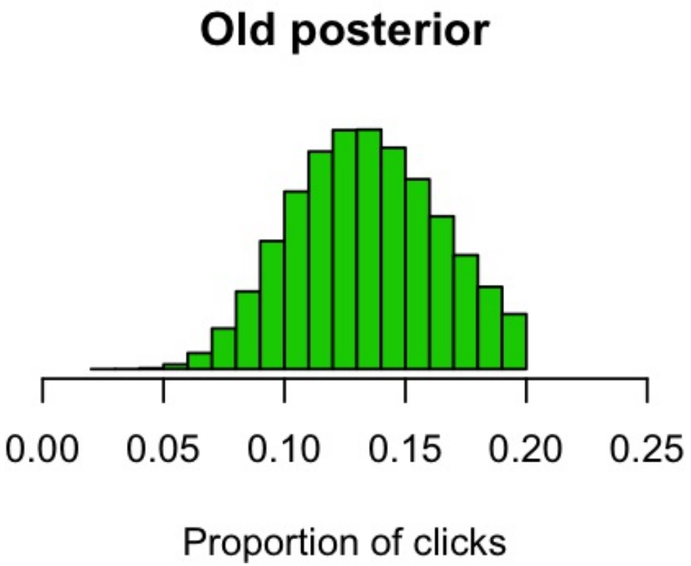

Old prior
0.00
0.05
0.10
0.15
0.20
0.25
Proportion of clicks

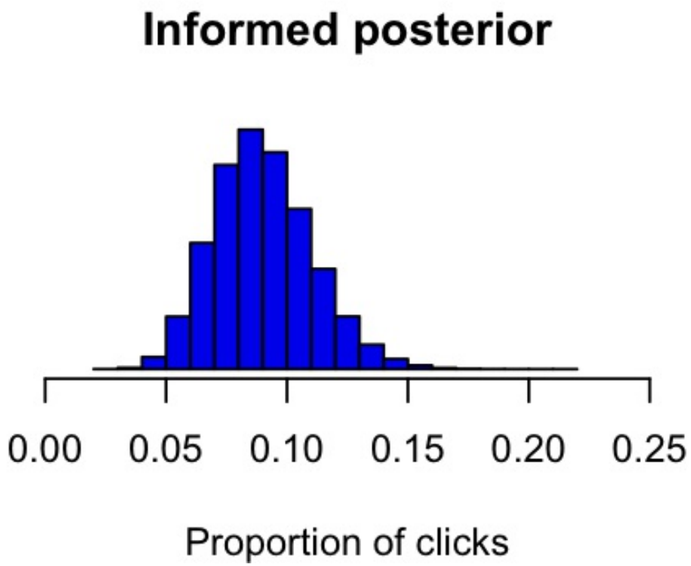

Informed prior
0.00
0.05
0.10
0.15
0.20
0.25
Proportion of clicks


Old posterior
0.00
0.05
0.10
0.15
0.20
0.25
Proportion of clicks


Old prior
0.00
0.05
0.10
0.15
0.20
0.25
Proportion of clicks


Informed prior
0.00
0.05
0.10
0.15
0.20
0.25
Proportion of clicks

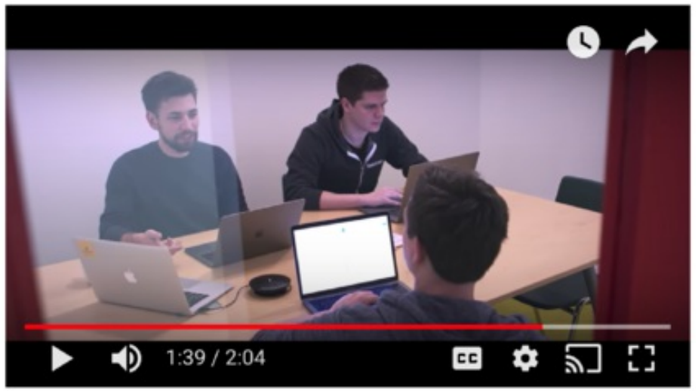

Old posterior
0.00
0.05
0.10
0.15
0.20
0.25
Proportion of clicks


Informed posterior
0.00
0.05
0.10
0.15
0.20
0.25
Proportion of clicks

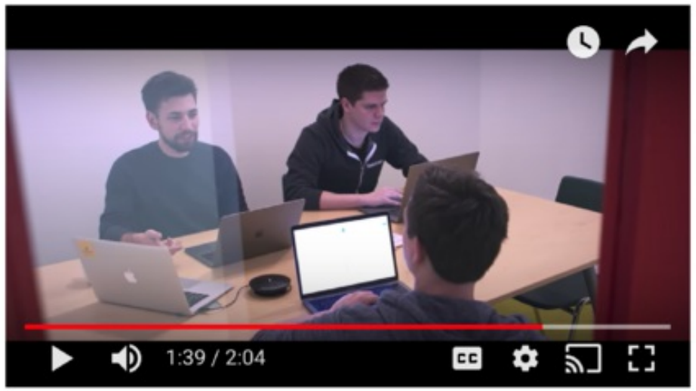
Next up on reasons to use Bayesian data analysis

1. You can include information sources in addition to the data.
2. **You can make any comparissons between groups or datasets.**
3. You can use the result of a Bayesian analysis to do Decision Analysis.
4. You can change the underlying statistical model.

Video vs Text



Video vs Text



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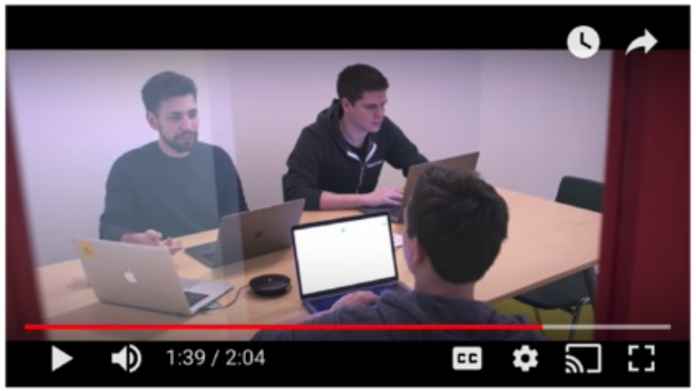
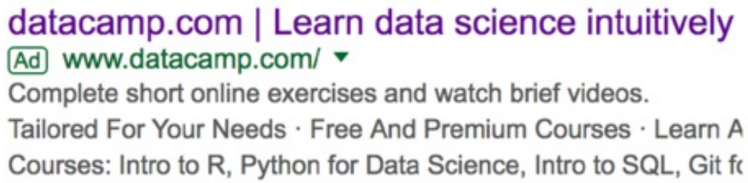
Courses: Intro to R, Python for Data Science, Intro to SQL, Git fo

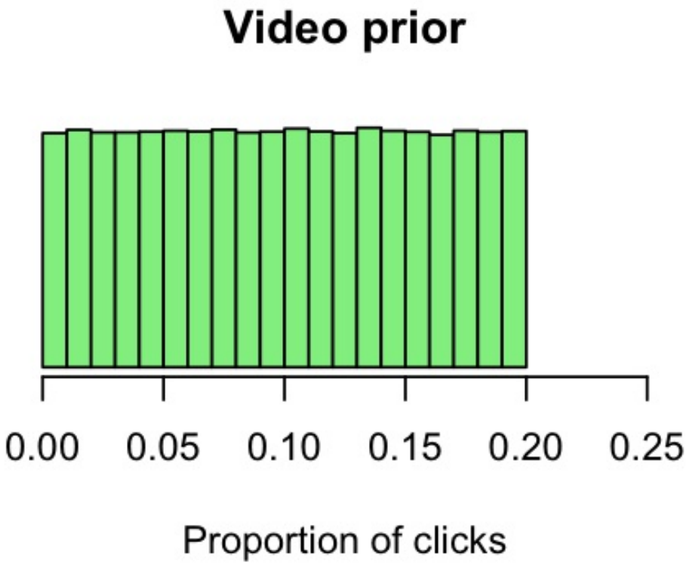
Video vs Text

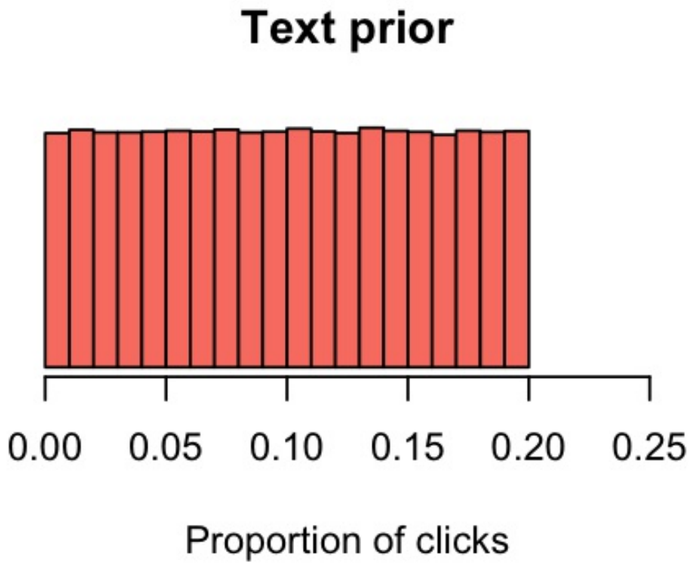


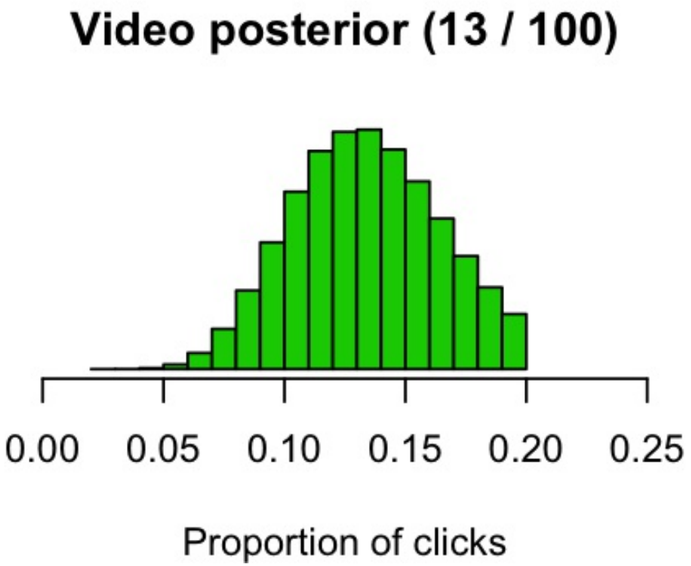


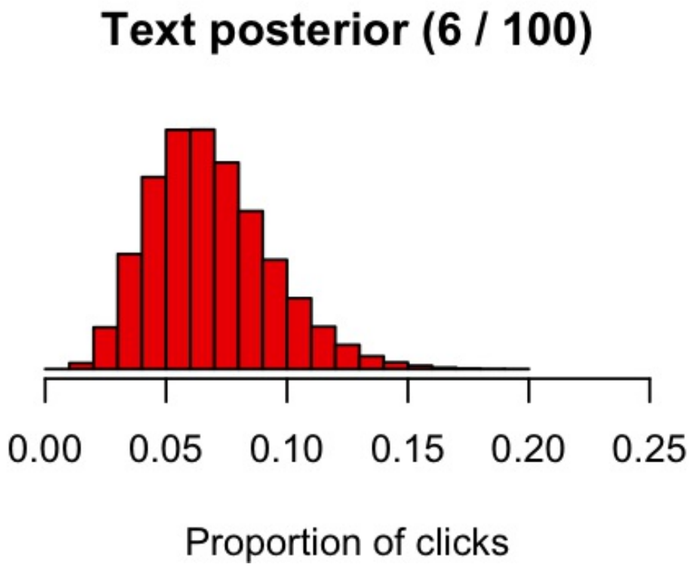
13 / 100

6 / 100


Video prior
0.00
0.05
0.10
0.15
0.20
0.25
Proportion of clicks


Text prior
0.00
0.05
0.10
0.15
0.20
0.25
Proportion of clicks


Video posterior (13 / 100)
0.00
0.05
0.10
0.15
0.20
0.25
Proportion of clicks


Text posterior (6 / 100)
0.00
0.05
0.10
0.15
0.20
0.25
Proportion of clicks

Comparing Video and Text ads

```
posterior
```

```
   video_prop text_prop
1        0.08      0.10
2        0.10      0.07
3        0.16      0.05
4        0.09      0.05
5        0.18      0.03
6        0.13      0.05
7        0.12      0.10
8        0.10      0.04
9        0.11      0.09
10       0.18      0.05
11       0.12      0.04
12       0.13      0.07
13       0.10      0.13
14       0.15      0.03
15       0.07      0.05
16       0.14      0.09
...       ...       ...
```

Comparing Video and Text ads

```
posterior$prop_diff <- posterior$video_prop - posterior$text_prop
posterior
```

```
   video_prop text_prop prop_diff
1        0.08      0.10     -0.02
2        0.10      0.07      0.03
3        0.16      0.05      0.11
4        0.09      0.05      0.04
5        0.18      0.03      0.15
6        0.13      0.05      0.08
7        0.12      0.10      0.02
8        0.10      0.04      0.06
9        0.11      0.09      0.02
10       0.18      0.05      0.13
11       0.12      0.04      0.08
12       0.13      0.07      0.06
13       0.10      0.13     -0.03
14       0.15      0.03      0.11
15       0.07      0.05      0.01
16       0.14      0.09      0.05
...       ...       ...
```

FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

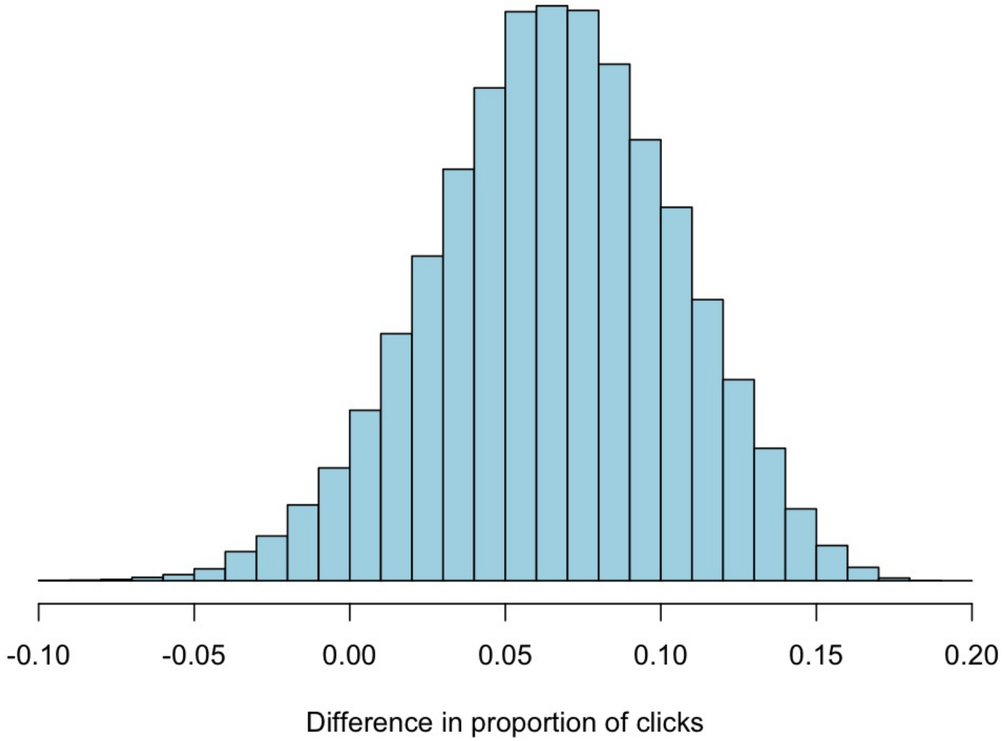
How does the prop_diff distribution look?

FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

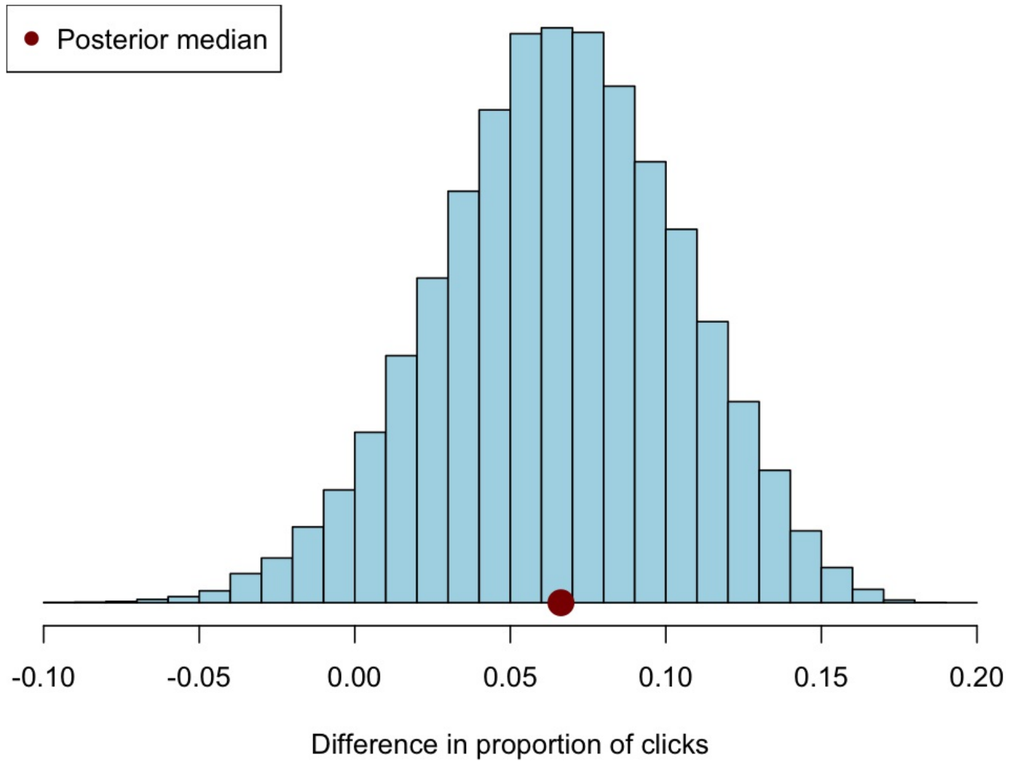
It's easy to compare and contrast!

Rasmus Bååth
Data Scientist

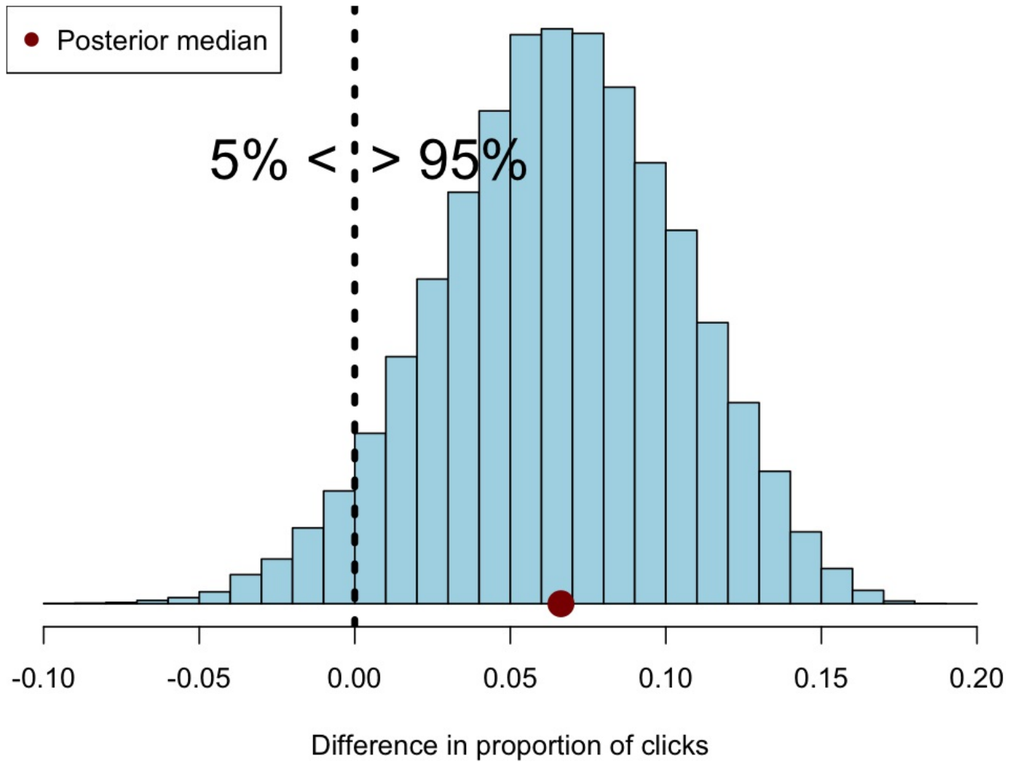
A probability distribution over an interesting parameter



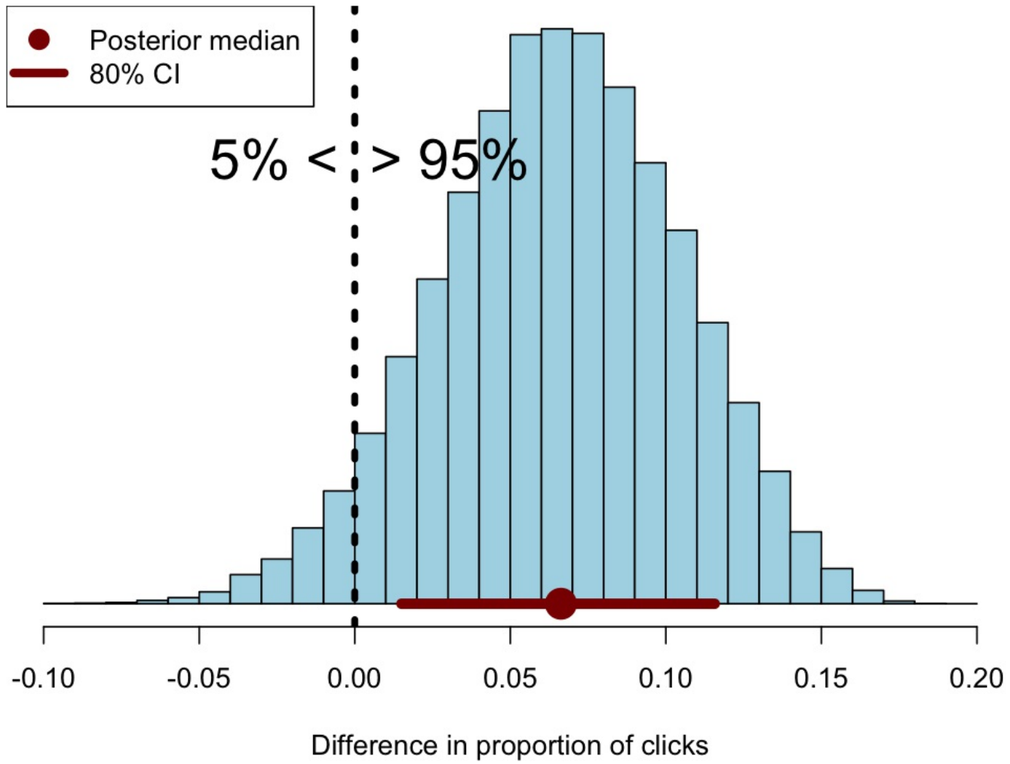
A probability distribution over an interesting parameter



A probability distribution over an interesting parameter



A probability distribution over an interesting parameter



Next up on reasons to use Bayesian data analysis

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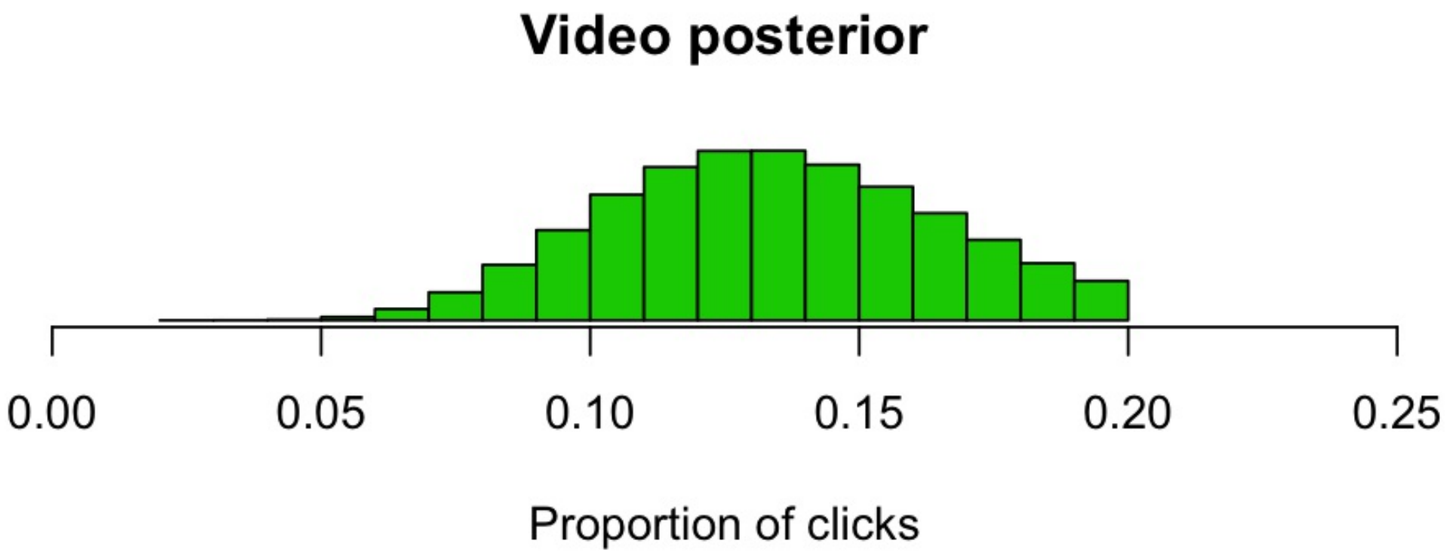
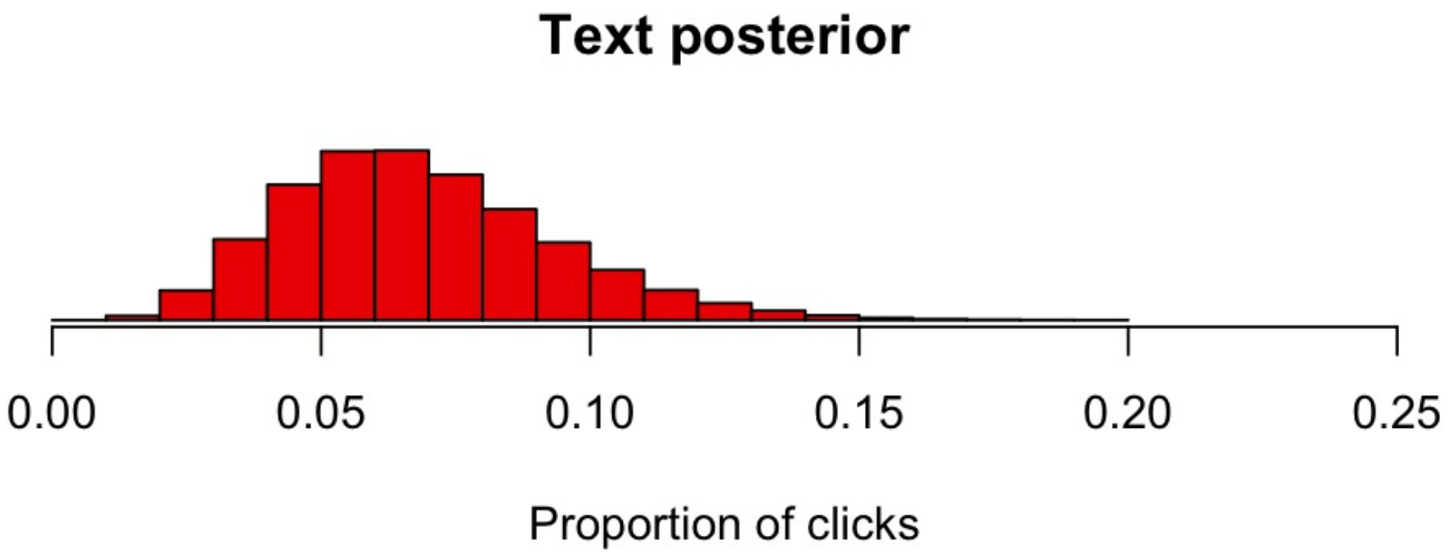
4. You can change the underlying statistical model.


Video posterior
0.00
0.05
0.10
0.15
0.20
0.25
Proportion of clicks


Text posterior
0.00
0.05
0.10
0.15
0.20
0.25
Proportion of clicks

A small decision analysis

```
video_cost <- 0.25
text_cost <- 0.05
visitor_spend <- 2.53




.
```

A small decision analysis

```
video_cost <- 0.25
text_cost <- 0.05
visitor_spend <- 2.53
posterior




.
```

```
   video_prop text_prop
1        0.08      0.10
2        0.10      0.07
3        0.16      0.05
4        0.09      0.05
5        0.18      0.03
6        0.13      0.05
7        0.12      0.10
8        0.10      0.04
9        0.11      0.09
10       0.18      0.05
11       0.12      0.04
12       0.13      0.07
13       0.10      0.13
...       ...       ...
```

A small decision analysis

```
video_cost <- 0.25
text_cost <- 0.05
visitor_spend <- 2.53
posterior
posterior$video_profit <-
  posterior$video_prop * visitor_spend - video_cost



.
```

```
   video_prop text_prop video_profit
1        0.08      0.10        -0.04
2        0.10      0.07         0.00
3        0.16      0.05         0.15
4        0.09      0.05        -0.02
5        0.18      0.03         0.21
6        0.13      0.05         0.08
7        0.12      0.10         0.06
8        0.10      0.04         0.01
9        0.11      0.09         0.02
10       0.18      0.05         0.21
11       0.12      0.04         0.06
12       0.13      0.07         0.08
13       0.10      0.13        -0.01
...       ...       ...          ...
```

A small decision analysis

```
video_cost <- 0.25
text_cost <- 0.05
visitor_spend <- 2.53
posterior
posterior$video_profit <-
  posterior$video_prop * visitor_spend - video_cost
posterior$text_profit <-
  posterior$text_prop * visitor_spend - text_cost
.
```

```
   video_prop text_prop video_profit text_profit
1        0.08      0.10        -0.04        0.21
2        0.10      0.07         0.00        0.12
3        0.16      0.05         0.15        0.09
4        0.09      0.05        -0.02        0.08
5        0.18      0.03         0.21        0.02
6        0.13      0.05         0.08        0.09
7        0.12      0.10         0.06        0.20
8        0.10      0.04         0.01        0.05
9        0.11      0.09         0.02        0.17
10       0.18      0.05         0.21        0.09
11       0.12      0.04         0.06        0.05
12       0.13      0.07         0.08        0.12
13       0.10      0.13        -0.01        0.27
...       ...       ...          ...         ...
```

A small decision analysis

```
video_cost <- 0.25
text_cost <- 0.05
visitor_spend <- 2.53
posterior
posterior$video_profit <-
  posterior$video_prop * visitor_spend - video_cost
posterior$text_profit <-
  posterior$text_prop * visitor_spend - text_cost
posterior$profit_diff <- posterior$video_profit - posterior$text_profit
```

```
   video_prop text_prop video_profit text_profit profit_diff
1        0.08      0.10        -0.04        0.21       -0.26
2        0.10      0.07         0.00        0.12       -0.12
3        0.16      0.05         0.15        0.09        0.07
4        0.09      0.05        -0.02        0.08       -0.10
5        0.18      0.03         0.21        0.02        0.18
6        0.13      0.05         0.08        0.09        0.00
7        0.12      0.10         0.06        0.20       -0.14
8        0.10      0.04         0.01        0.05       -0.04
9        0.11      0.09         0.02        0.17       -0.15
10       0.18      0.05         0.21        0.09        0.12
11       0.12      0.04         0.06        0.05        0.00
12       0.13      0.07         0.08        0.12       -0.04
13       0.10      0.13        -0.01        0.27       -0.28
...       ...       ...          ...         ...         ...
```

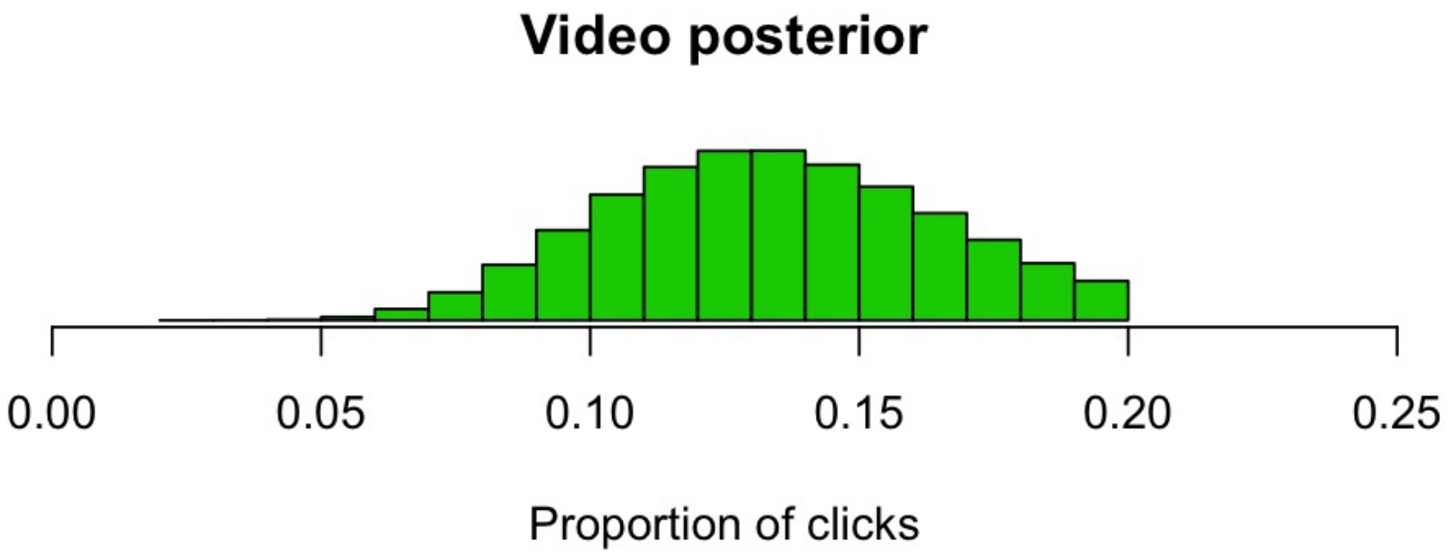
FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

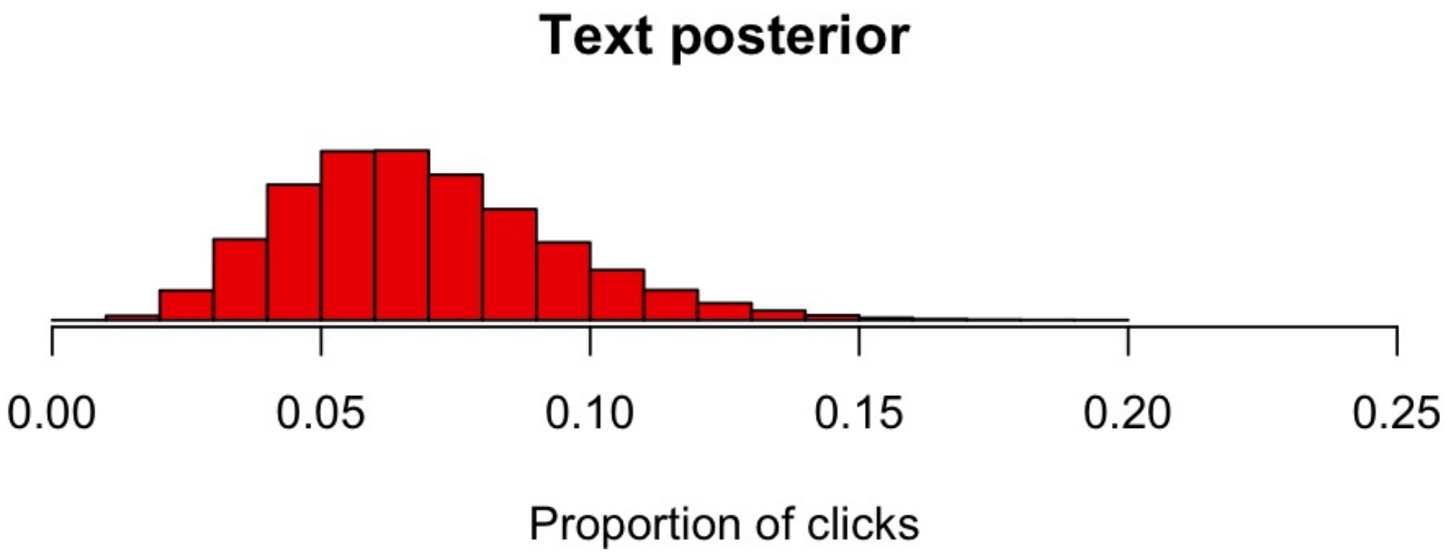
Make a data informed decision!

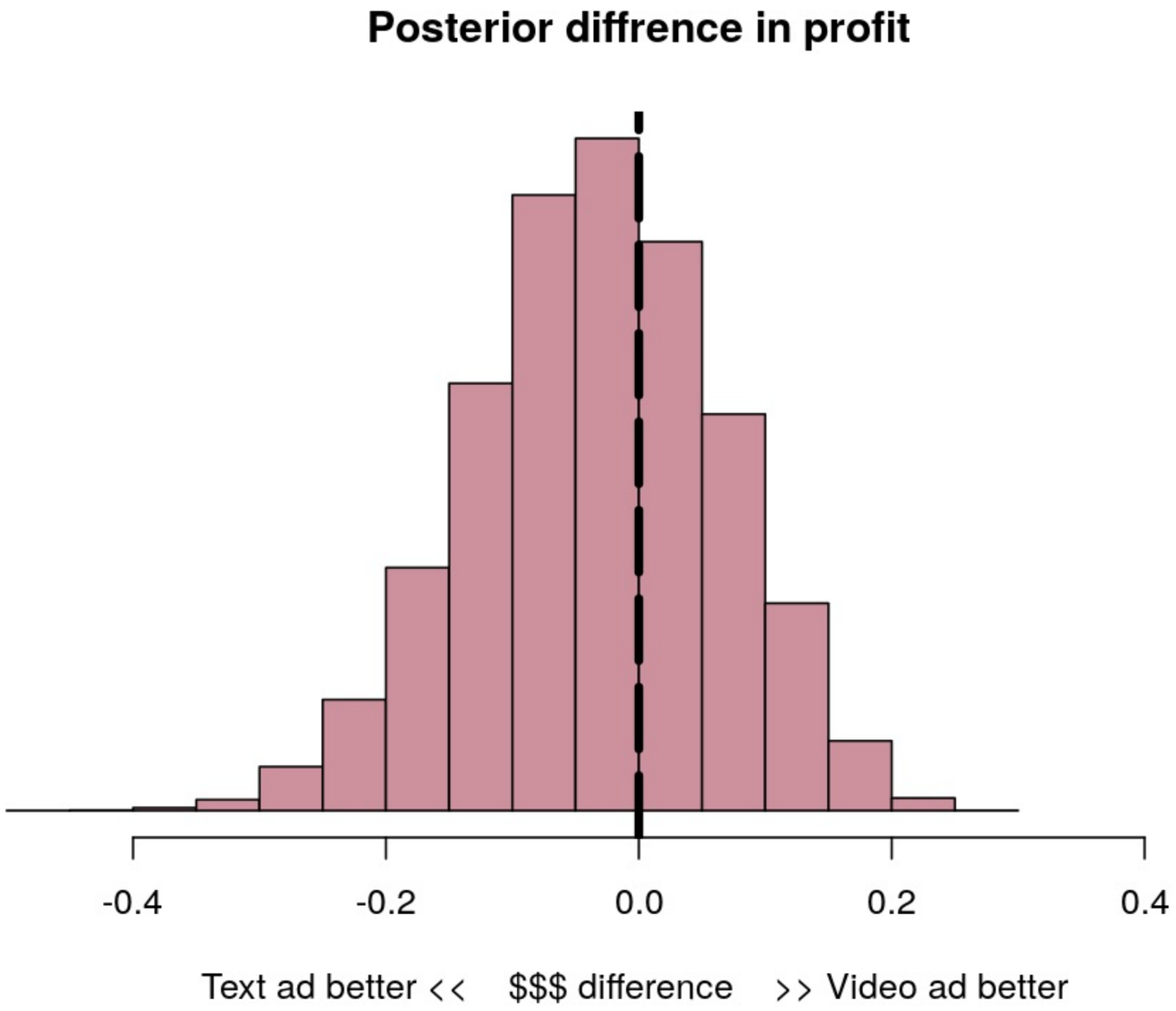
FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

Change anything and everything

Rasmus Bååth
Data Scientist


Video posterior
0.00
0.05
0.10
0.15
0.20
0.25
Proportion of clicks


Text posterior
0.00
0.05
0.10
0.15
0.20
0.25
Proportion of clicks


Posterior diffrence in profit
-0.4
-0.2
0.0
0.2
0.4
Text ad better <<
$$$ difference
>> Video ad better

Next up on reasons to use Bayesian data analysis

1. You can include information sources in addition to the data.
2. You can make any comparisons between groups or data sets.
3. You can use the result of a Bayesian analysis to do Decision Analysis.
4. **You can change the underlying statistical model.**

Completely switch out the binomial model

- Why? Well, you have some new data...
- A *banner ad* for your site.
- You **don't** pay per view, you pay **per day**.
- A trial resulted in 19 clicks in a day
- *How many daily site visits, should we expect, on average, if we pay for this banner?*

A model for counts per day

- Split the day into 1440 minutes.
- What proportion of minutes results in a click on the ad?

A model for counts per day

- ~~Split the day into 1440 minutes.~~
- ~~What proportion of minutes results in a click on the ad?~~
- Split the day into 86400 seconds.
- What proportion of seconds results in a click on the ad?

A model for counts per day

- ~~Split the day into 1440 minutes.~~
- ~~What proportion of minutes results in a click on the ad?~~
- ~~Split the day into 86400 seconds.~~
- ~~What proportion of seconds results in a click on the ad?~~
- Split the day into 86400000 milliseconds.
- What proportion of milliseconds results in a click on the ad?

A model for counts per day

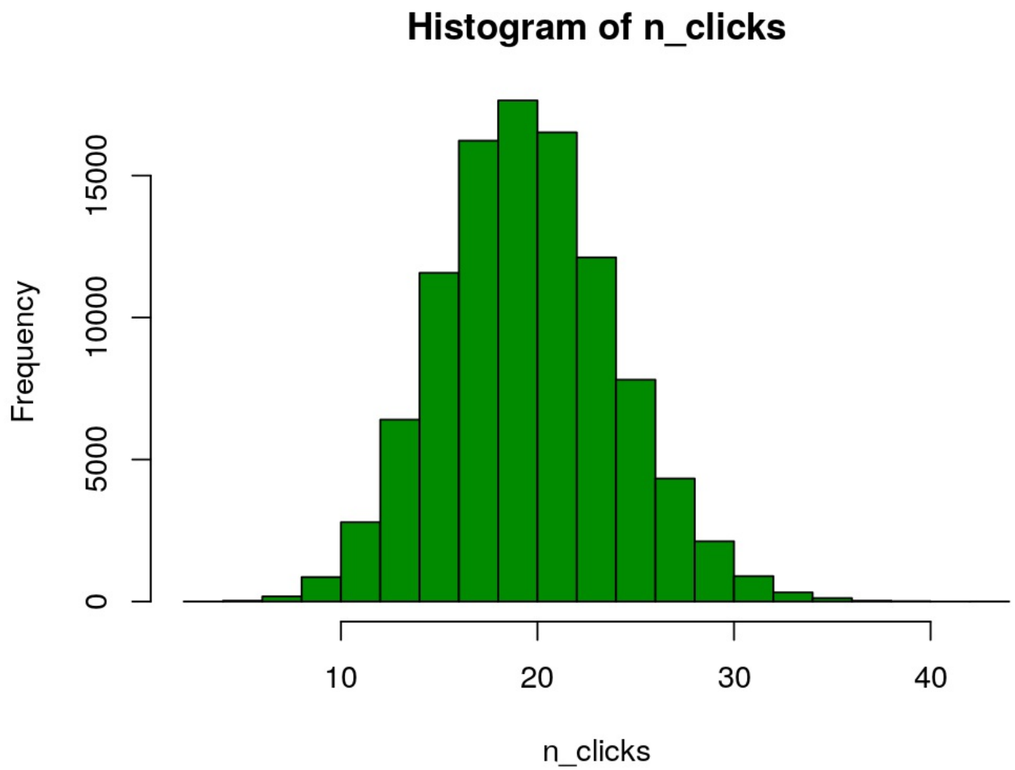
- ~~Split the day into 1440 minutes.~~
- ~~What proportion of minutes results in a click on the ad?~~
- ~~Split the day into 86400 seconds.~~
- ~~What proportion of seconds results in a click on the ad?~~
- ~~Split the day into 86400000 milliseconds.~~
- ~~What proportion of milliseconds results in a click on the ad?~~
- Split the day into ∞ parts...
- ???

The Poisson distribution

- One parameter: The mean number of events per time unit.
- `rpois` samples from the Poisson distribution.

The Poisson distribution

```
n_clicks <- rpois(n = 100000, lambda = 20)
hist(n_clicks)
```



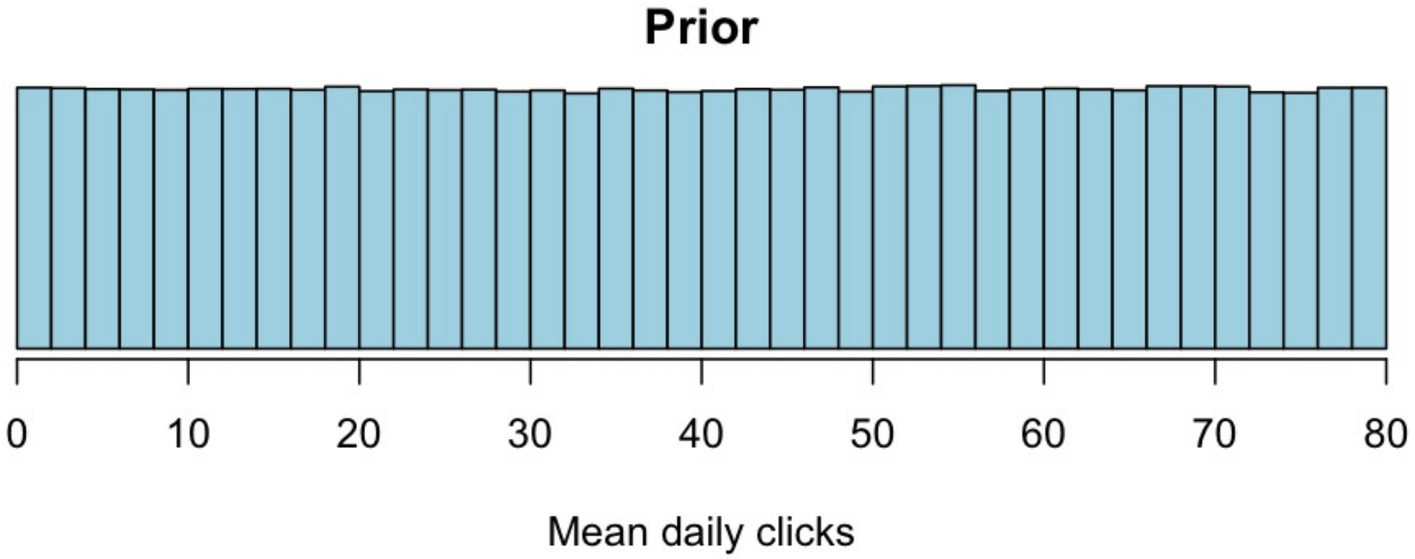
FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

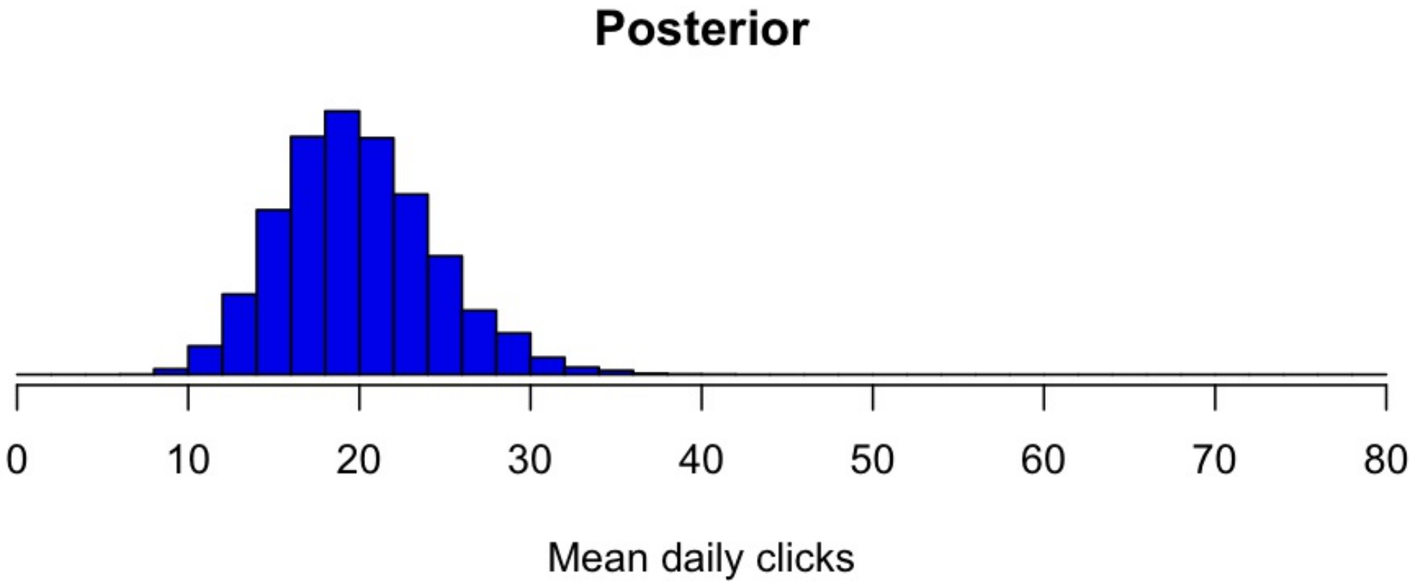
Let's find out in the exercises!

FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

You just replaced the whole model!

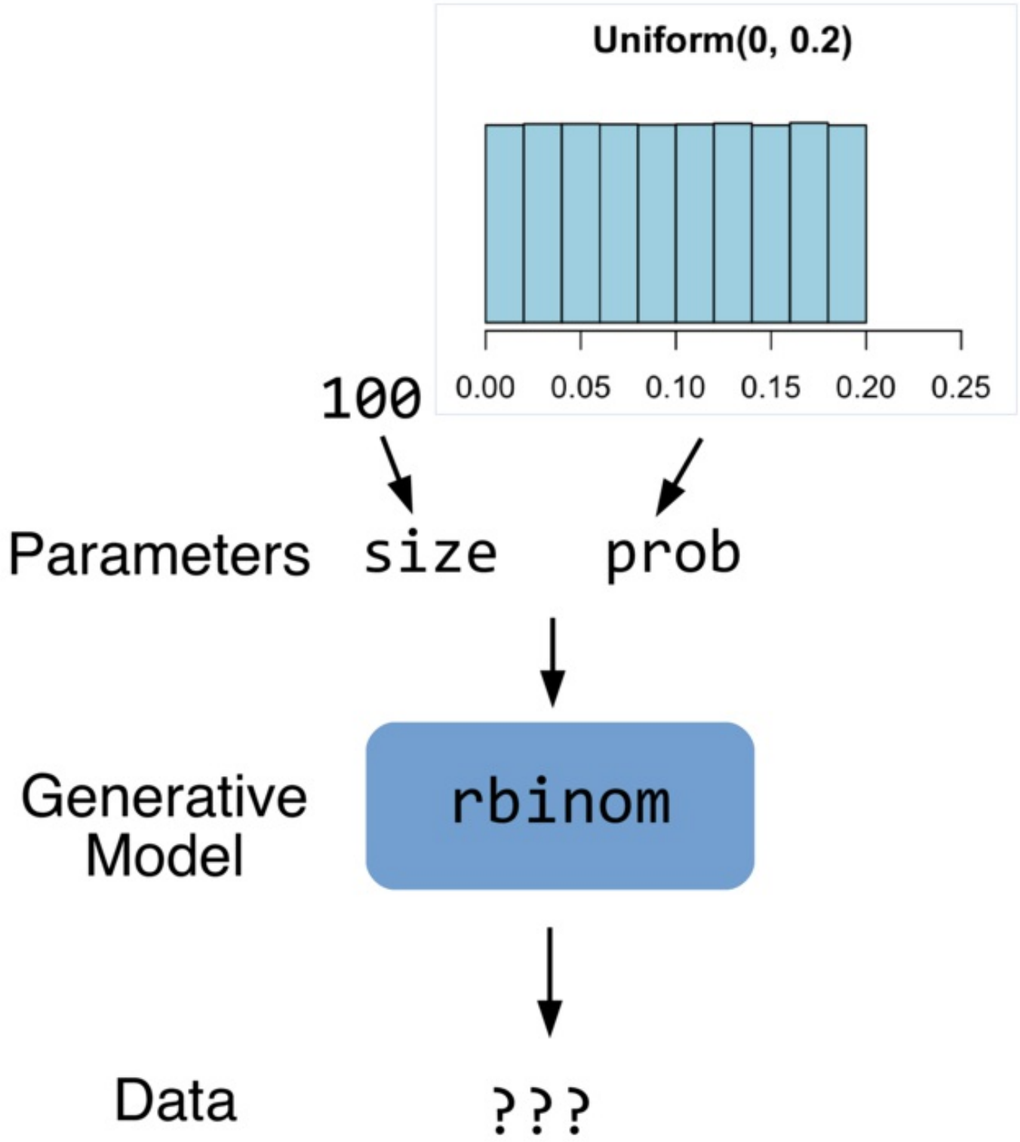
Rasmus Bååth
Data Scientist


Prior
0
10
20
30
40
50
60
70
80
Mean daily clicks


Posterior
0
10
20
30
40
50
60
70
80
Mean daily clicks

Some ways Bayesian data analysis can be useful

1. You can include information sources in addition to the data.
2. You can make any comparisons between groups or data sets.
3. You can use the result of a Bayesian analysis to do Decision Analysis.
4. You can change the underlying statistical model.
5. **Bayesian inference is optimal, kind of.**


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

Nice properties of Bayes

- *Bayes is optimal, in the small world of the model.*
- *In Bayesian data analysis there is a separation between model and computation.*

FUNDAMENTALS OF BAYESIAN DATA ANALYSIS IN R

Next up: How to fit Bayesian models more efficiently!