Enabling Analytics for Learning Applications with {learnrextra}

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MultiLA Project / HTW Berlin
https://ifafmultila.github.io/

UseR! Conference – July 9, 2024

Our goals

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    ✖ Not provided in the R ecosystem so far

What you can expect:

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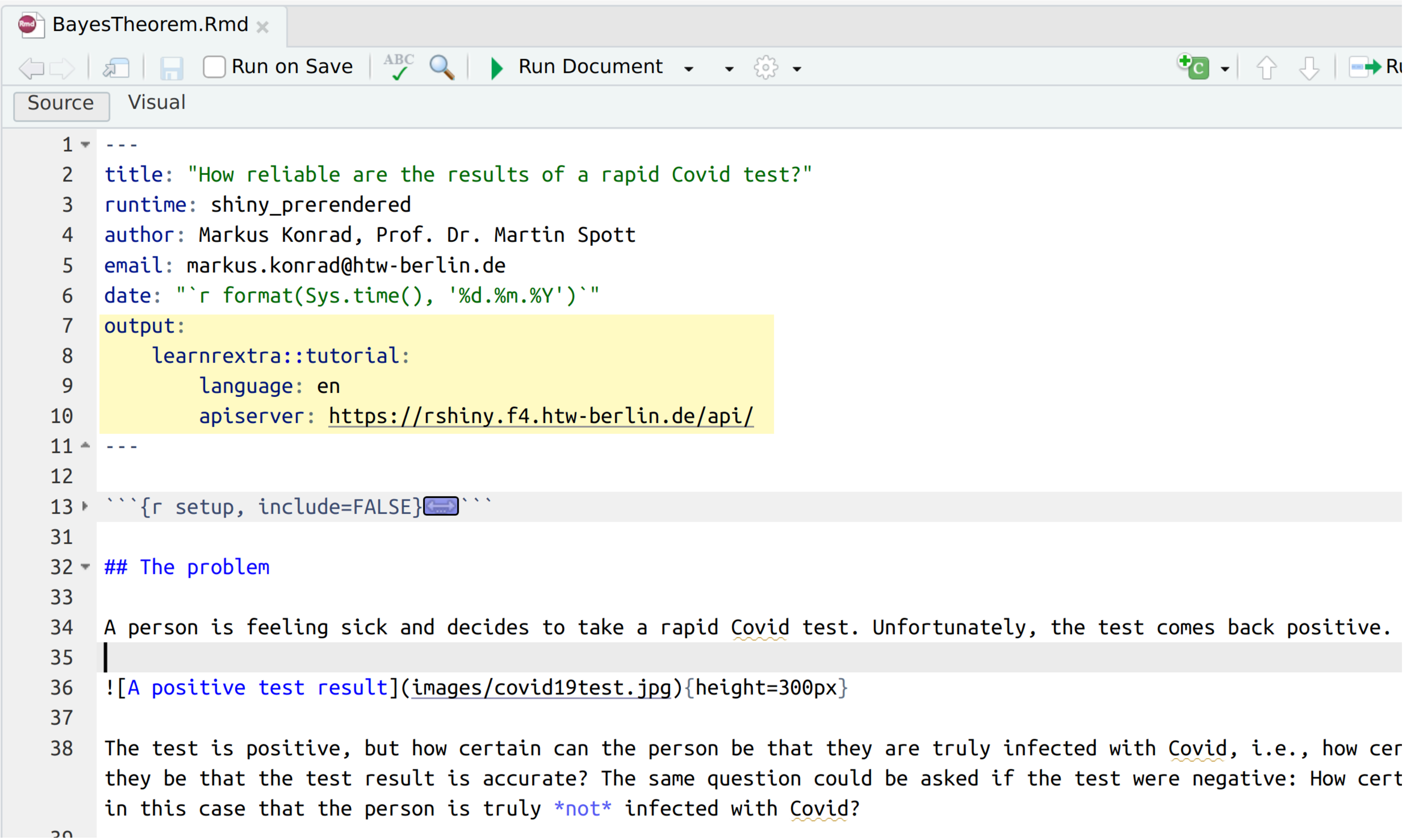
- Some technical background
- First observations from in-class experiments

Demonstration

Integrating {learnrextra} in your RMarkdown document



~~~
---
title: "How reliable are the results of a rapid Covid test?"
runtime: shiny_prerendered
author: Markus Konrad, Prof. Dr. Martin Spott
email: markus.konrad@htw-berlin.de
date: "`r format(Sys.time(), '%d.%m.%Y')`"
output:
    learnrextra::tutorial:
        language: en
        apiserver: https://rshiny.f4.htw-berlin.de/api/
---

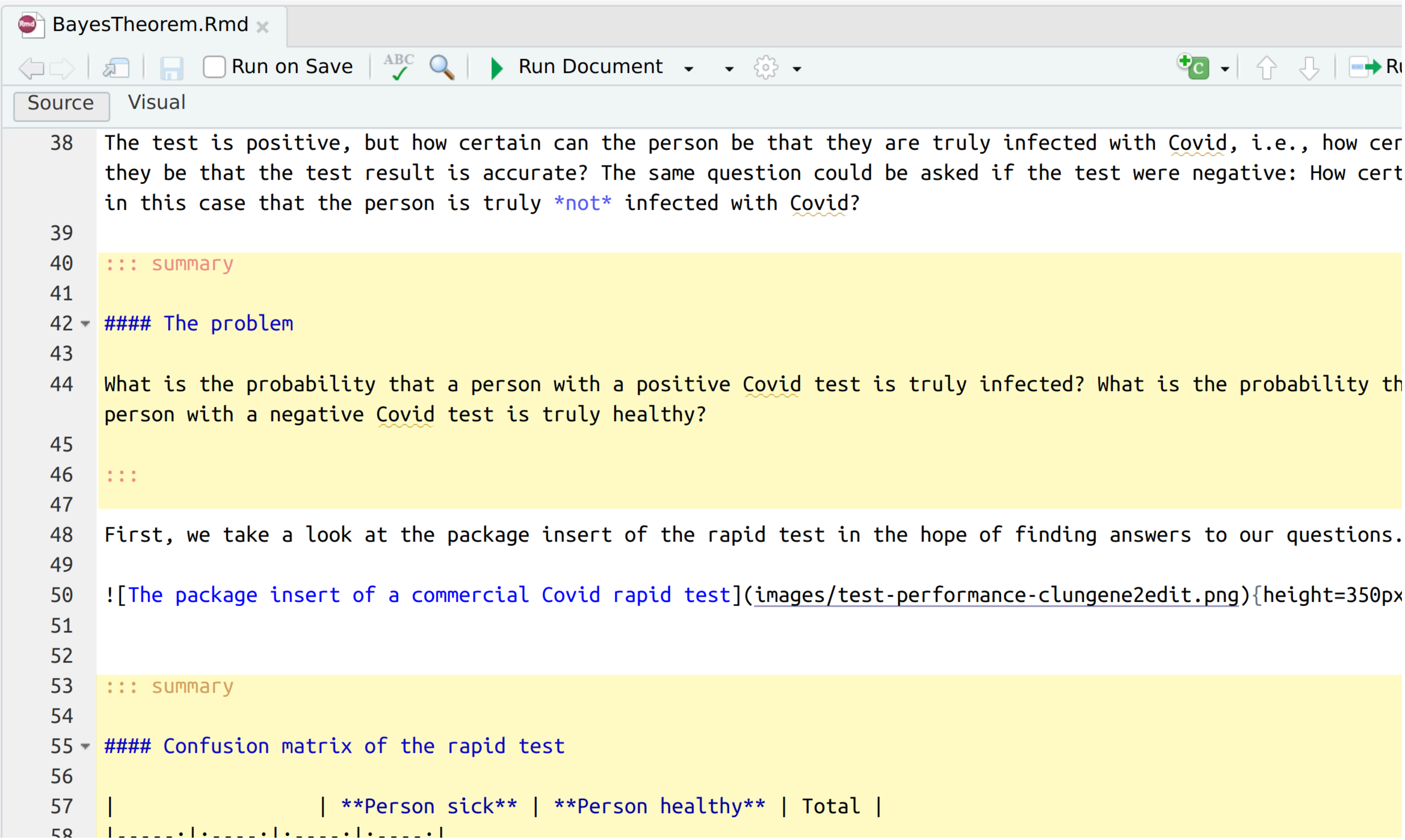
```{r setup, include=FALSE}```

## The problem

A person is feeling sick and decides to take a rapid Covid test. Unfortunately, the test comes back positive.

![A positive test result](images/covid19test.jpg){height=300px}

The test is positive, but how certain can the person be that they are truly infected with Covid, i.e., how cer
they be that the test result is accurate? The same question could be asked if the test were negative: How cert
in this case that the person is truly *not* infected with Covid?
~~~



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::: summary

#### The problem

What is the probability that a person with a positive Covid test is truly infected? What is the probability th
person with a negative Covid test is truly healthy?

:::

First, we take a look at the package insert of the rapid test in the hope of finding answers to our questions.

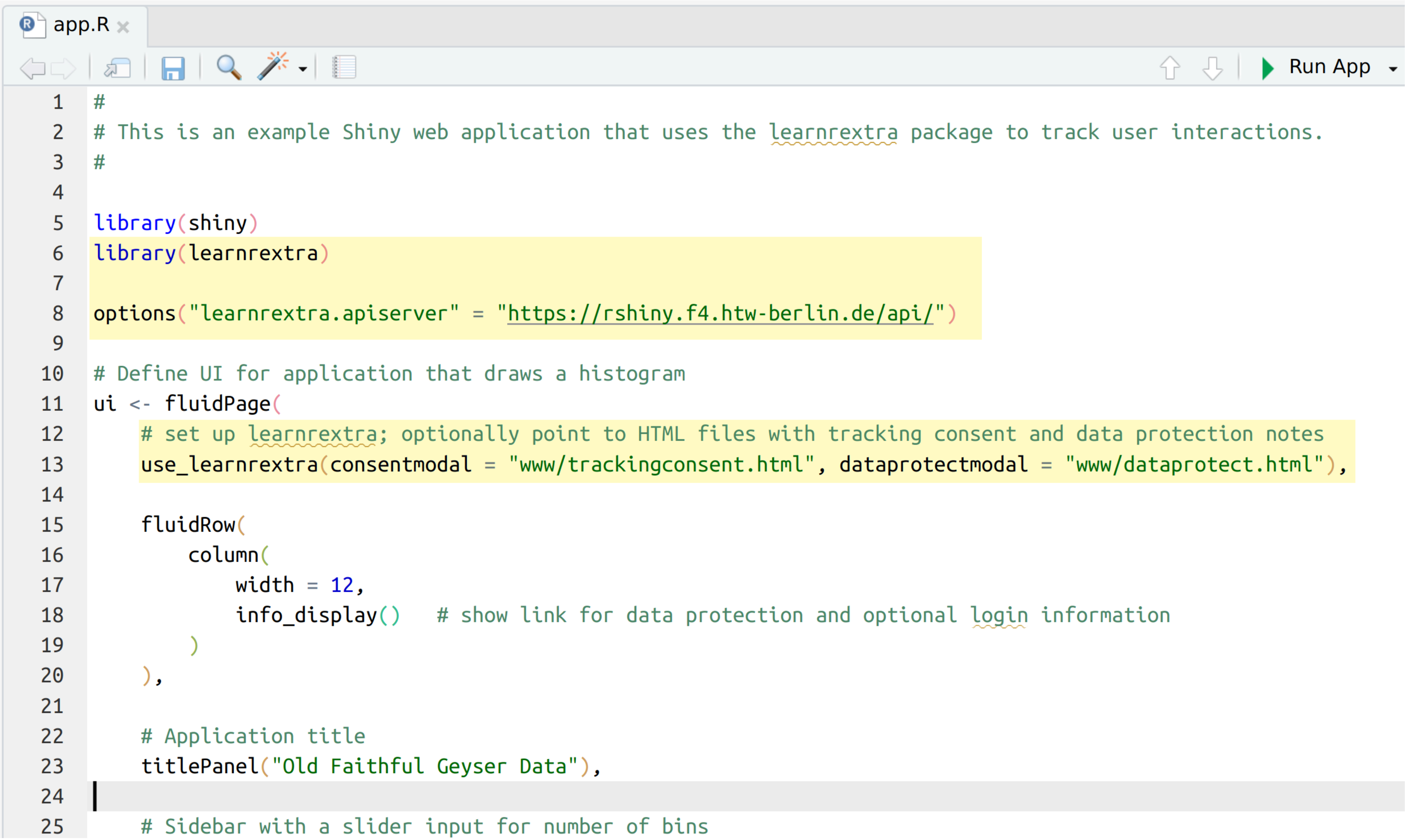
![The package insert of a commercial Covid rapid test](images/test-performance-clungene2edit.png){height=350px


::: summary

#### Confusion matrix of the rapid test

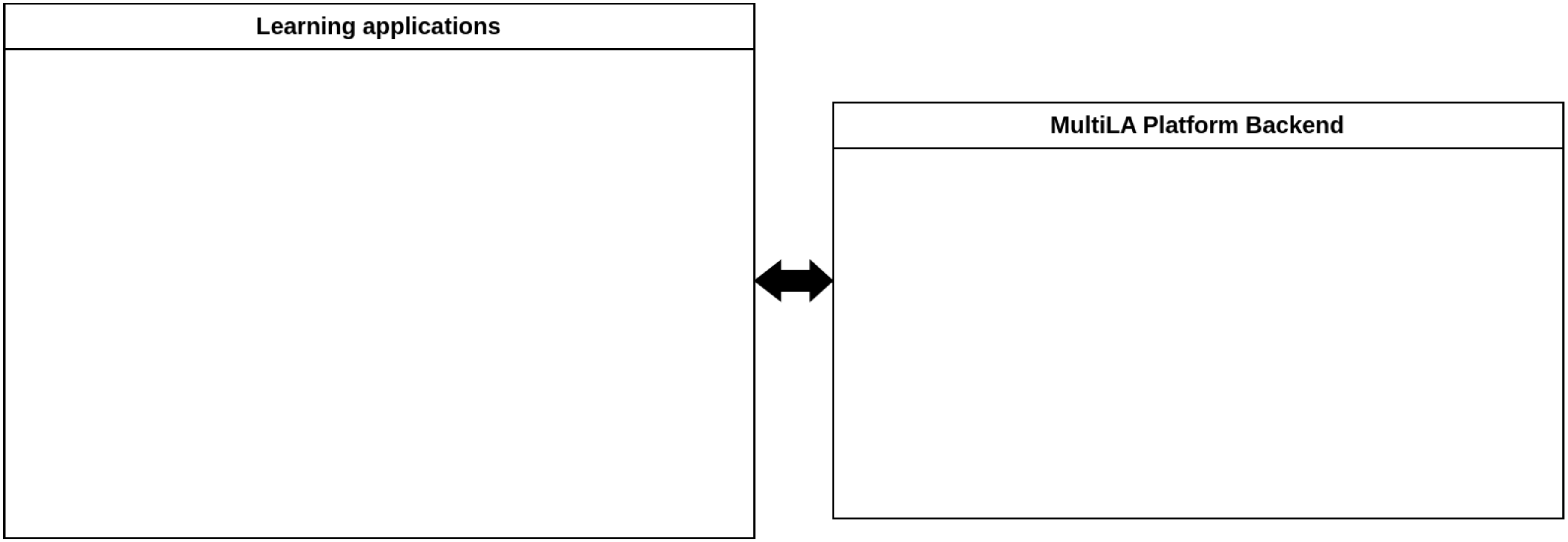
|                  | **Person sick** | **Person healthy** | Total |
|-----:|:-----:|:-----:|:-----:|
```

Integrating {learnrextra} in your Shiny app



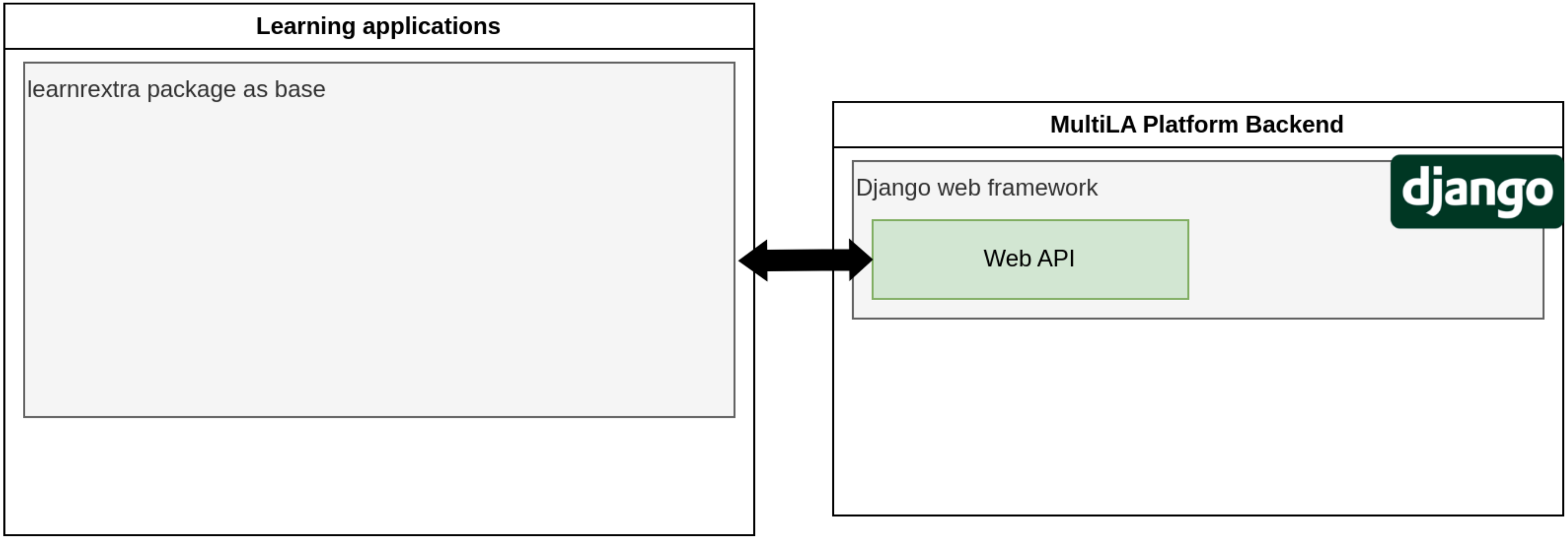
```r
#
# This is an example Shiny web application that uses the learnrextra package to track user interactions.
#

library(shiny)
library(learnrextra)

options("learnrextra.apiserver" = "https://rshiny.f4.htw-berlin.de/api/")

# Define UI for application that draws a histogram
ui <- fluidPage(
    # set up learnrextra; optionally point to HTML files with tracking consent and data protection notes
    use_learnrextra(consentmodal = "www/trackingconsent.html", dataprotectmodal = "www/dataprotect.html"),

    fluidRow(
        column(
            width = 12,
            info_display()   # show link for data protection and optional login information
        )
    ),

    # Application title
    titlePanel("Old Faithful Geyser Data"),

    # Sidebar with a slider input for number of bins
```

Technical background & software components



Learning applications

MultiLA Platform Backend



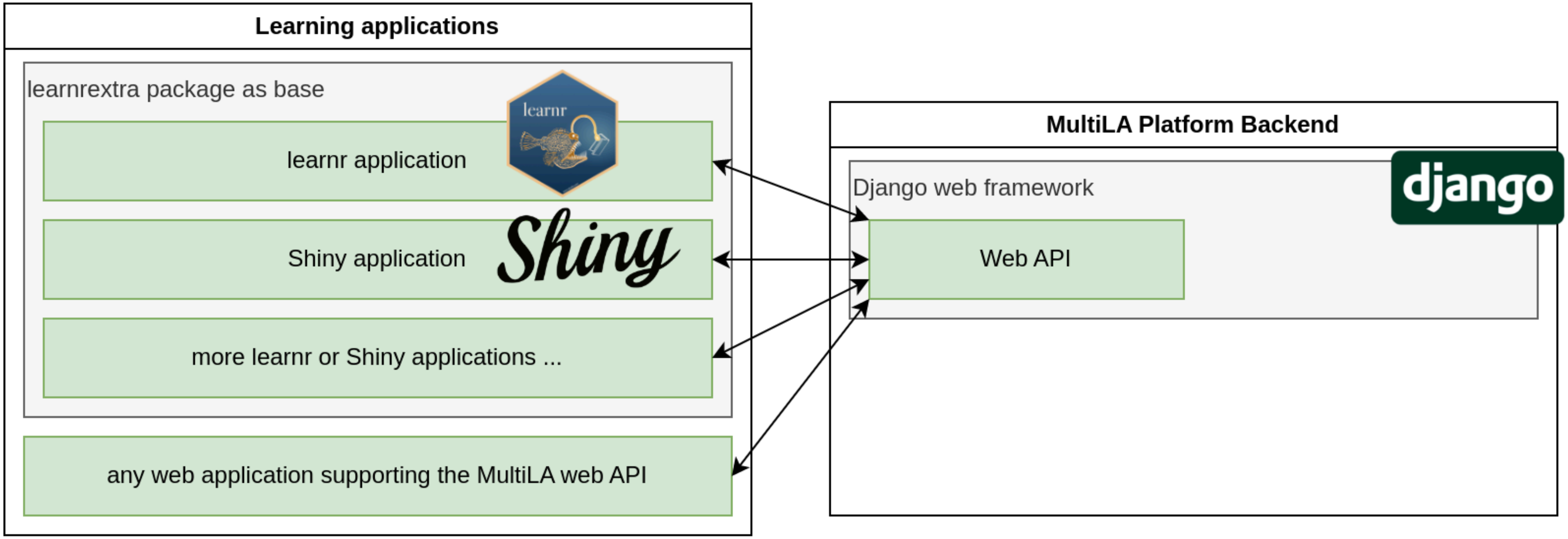
Learning applications

learnrextra package as base

MultiLA Platform Backend

Django web framework

Web API


Learning applications
learnrextra package as base
learnr
learnr application
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more learnr or Shiny applications ...
any web application supporting the MultiLA web API
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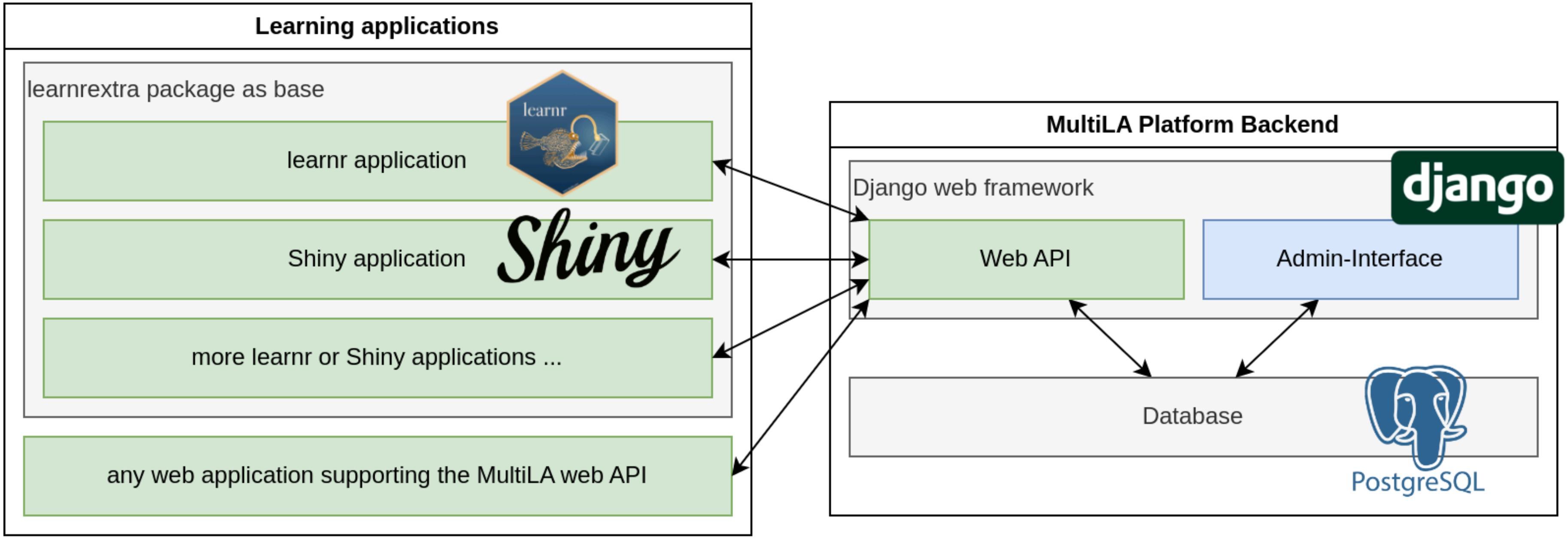
Learning applications
learnrextra package as base
learnr
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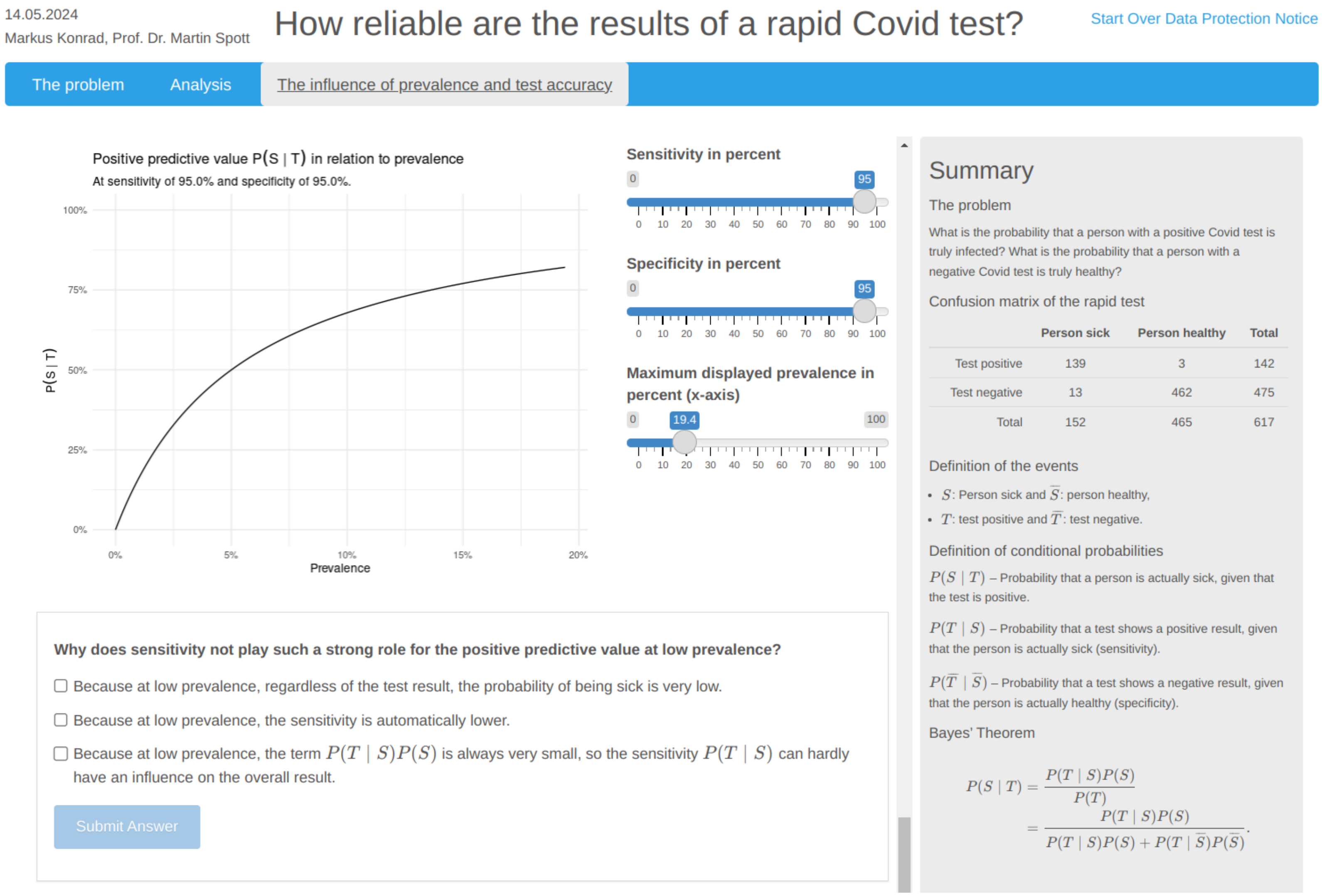
more learnr or Shiny applications ...
any web application supporting the MultiLA web API
MultiLA Platform Backend
Django web framework
django
Web API
Admin-Interface
Database
PostgreSQL

First observations from user trials

Learning app for Bayes’ theorem



14.05.2024

Markus Konrad, Prof. Dr. Martin Spott

How reliable are the results of a rapid Covid test?

Positive predictive value P(S | T) in relation to prevalence

At sensitivity of 95.0% and specificity of 95.0%.

Sensitivity in percent: 95

Specificity in percent: 95

Maximum displayed prevalence in percent (x-axis): 19.4

Why does sensitivity not play such a strong role for the positive predictive value at low prevalence?

☐ Because at low prevalence, regardless of the test result, the probability of being sick is very low.

☐ Because at low prevalence, the sensitivity is automatically lower.

☐ Because at low prevalence, the term $P(T \mid S)P(S)$ is always very small, so the sensitivity $P(T \mid S)$ can hardly have an influence on the overall result.

Summary

The problem

What is the probability that a person with a positive Covid test is truly infected? What is the probability that a person with a negative Covid test is truly healthy?

Confusion matrix of the rapid test

	Person sick	Person healthy	Total
Test positive	139	3	142
Test negative	13	462	475
Total	152	465	617

Definition of the events

- S: Person sick and $\overline{S}$: person healthy,
- T: test positive and $\overline{T}$: test negative.

Definition of conditional probabilities

$P(S \mid T)$ – Probability that a person is actually sick, given that the test is positive.

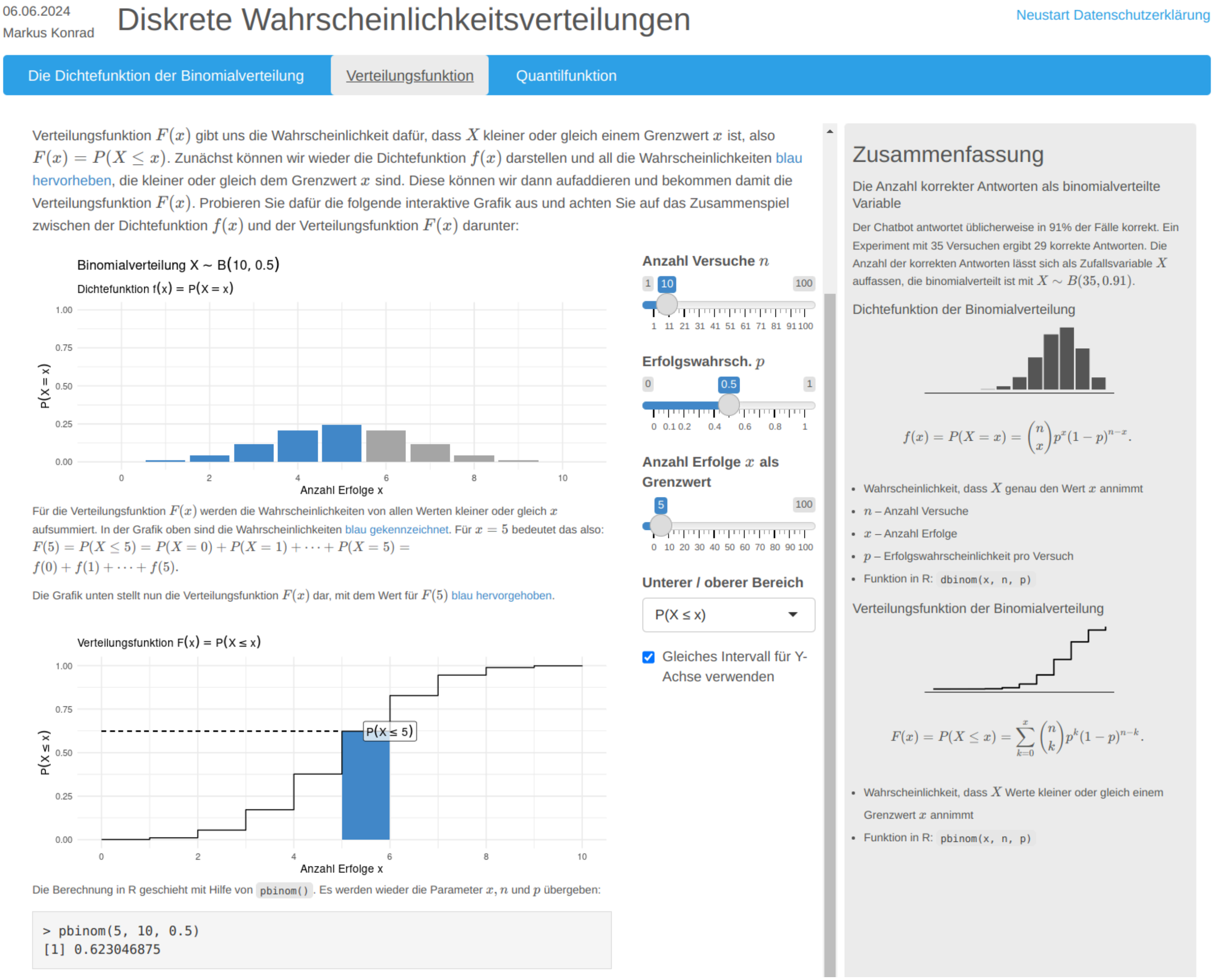
$P(T \mid S)$ – Probability that a test shows a positive result, given that the person is actually sick (sensitivity).

$P(\overline{T} \mid \overline{S})$ – Probability that a test shows a negative result, given that the person is actually healthy (specificity).

Bayes’ Theorem

$$P(S \mid T) = \frac{P(T \mid S)P(S)}{P(T)} = \frac{P(T \mid S)P(S)}{P(T \mid S)P(S) + P(T \mid \overline{S})P(\overline{S})}.$$

Discrete probability distributions (German)



06.06.2024
Markus Konrad

Diskrete Wahrscheinlichkeitsverteilungen

Neustart Datenschutzerklärung

Die Dichtefunktion der Binomialverteilung | Verteilungsfunktion | Quantilfunktion

Verteilungsfunktion $F(x)$ gibt uns die Wahrscheinlichkeit dafür, dass X kleiner oder gleich einem Grenzwert x ist, also $F(x) = P(X \leq x)$. Zunächst können wir wieder die Dichtefunktion $f(x)$ darstellen und all die Wahrscheinlichkeiten blau hervorheben, die kleiner oder gleich dem Grenzwert x sind. Diese können wir dann aufaddieren und bekommen damit die Verteilungsfunktion $F(x)$. Probieren Sie dafür die folgende interaktive Grafik aus und achten Sie auf das Zusammenspiel zwischen der Dichtefunktion $f(x)$ und der Verteilungsfunktion $F(x)$ darunter:

Für die Verteilungsfunktion $F(x)$ werden die Wahrscheinlichkeiten von allen Werten kleiner oder gleich x aufsummiert. In der Grafik oben sind die Wahrscheinlichkeiten blau gekennzeichnet. Für $x = 5$ bedeutet das also: $F(5) = P(X \leq 5) = P(X = 0) + P(X = 1) + \cdots + P(X = 5) = f(0) + f(1) + \cdots + f(5)$.

Die Grafik unten stellt nun die Verteilungsfunktion $F(x)$ dar, mit dem Wert für $F(5)$ blau hervorgehoben.

Die Berechnung in R geschieht mit Hilfe von `pbinom()`. Es werden wieder die Parameter x, n und p übergeben:

```
> pbinom(5, 10, 0.5)
[1] 0.623046875
```

Anzahl Versuche n

Erfolgswahrsch. p

Anzahl Erfolge x als Grenzwert

Unterer / oberer Bereich

P(X ≤ x)

☑ Gleiches Intervall für Y-Achse verwenden

Zusammenfassung

Die Anzahl korrekter Antworten als binomialverteilte Variable

Der Chatbot antwortet üblicherweise in 91% der Fälle korrekt. Ein Experiment mit 35 Versuchen ergibt 29 korrekte Antworten. Die Anzahl der korrekten Antworten lässt sich als Zufallsvariable X auffassen, die binomialverteilt ist mit $X \sim B(35, 0.91)$.

Dichtefunktion der Binomialverteilung

$$f(x) = P(X = x) = \binom{n}{x} p^x (1-p)^{n-x}.$$

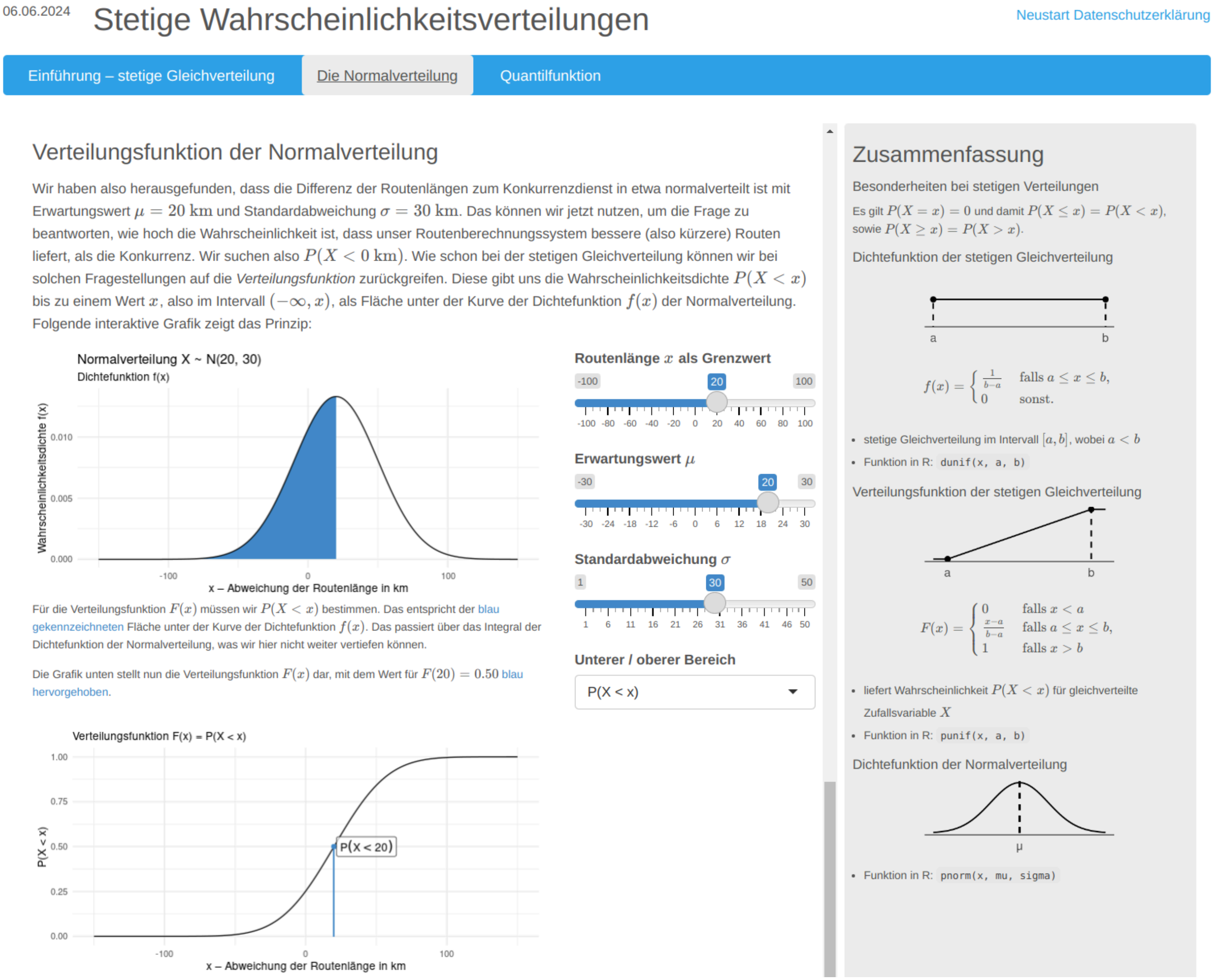
- Wahrscheinlichkeit, dass X genau den Wert x annimmt
- n – Anzahl Versuche
- x – Anzahl Erfolge
- p – Erfolgswahrscheinlichkeit pro Versuch
- Funktion in R: `dbinom(x, n, p)`

Verteilungsfunktion der Binomialverteilung

$$F(x) = P(X \leq x) = \sum_{k=0}^{x} \binom{n}{k} p^k (1-p)^{n-k}.$$

- Wahrscheinlichkeit, dass X Werte kleiner oder gleich einem Grenzwert x annimmt
- Funktion in R: `pbinom(x, n, p)`

Continuous probability distributions (German)



Stetige Wahrscheinlichkeitsverteilungen

Verteilungsfunktion der Normalverteilung

Wir haben also herausgefunden, dass die Differenz der Routenlängen zum Konkurrenzdienst in etwa normalverteilt ist mit Erwartungswert $\mu = 20 \text{ km}$ und Standardabweichung $\sigma = 30 \text{ km}$. Das können wir jetzt nutzen, um die Frage zu beantworten, wie hoch die Wahrscheinlichkeit ist, dass unser Routenberechnungssystem bessere (also kürzere) Routen liefert, als die Konkurrenz. Wir suchen also $P(X < 0 \text{ km})$. Wie schon bei der stetigen Gleichverteilung können wir bei solchen Fragestellungen auf die *Verteilungsfunktion* zurückgreifen. Diese gibt uns die Wahrscheinlichkeitsdichte $P(X < x)$ bis zu einem Wert x, also im Intervall $(-\infty, x)$, als Fläche unter der Kurve der Dichtefunktion $f(x)$ der Normalverteilung. Folgende interaktive Grafik zeigt das Prinzip:

Für die Verteilungsfunktion $F(x)$ müssen wir $P(X < x)$ bestimmen. Das entspricht der blau gekennzeichneten Fläche unter der Kurve der Dichtefunktion $f(x)$. Das passiert über das Integral der Dichtefunktion der Normalverteilung, was wir hier nicht weiter vertiefen können.

Die Grafik unten stellt nun die Verteilungsfunktion $F(x)$ dar, mit dem Wert für $F(20) = 0.50$ blau hervorgehoben.

Routenlänge x als Grenzwert: -100 – 20 – 100

Erwartungswert μ: -30 – 20 – 30

Standardabweichung σ: 1 – 30 – 50

Unterer / oberer Bereich: P(X < x)

Zusammenfassung

Besonderheiten bei stetigen Verteilungen

Es gilt $P(X = x) = 0$ und damit $P(X \leq x) = P(X < x)$, sowie $P(X \geq x) = P(X > x)$.

Dichtefunktion der stetigen Gleichverteilung

$$f(x) = \begin{cases} \frac{1}{b-a} & \text{falls } a \leq x \leq b, \\ 0 & \text{sonst.} \end{cases}$$

- stetige Gleichverteilung im Intervall $[a, b]$, wobei $a < b$
- Funktion in R: `dunif(x, a, b)`

Verteilungsfunktion der stetigen Gleichverteilung

$$F(x) = \begin{cases} 0 & \text{falls } x < a \\ \frac{x-a}{b-a} & \text{falls } a \leq x \leq b, \\ 1 & \text{falls } x > b \end{cases}$$

- liefert Wahrscheinlichkeit $P(X < x)$ für gleichverteilte Zufallsvariable X
- Funktion in R: `punif(x, a, b)`

Dichtefunktion der Normalverteilung

- Funktion in R: `pnorm(x, mu, sigma)`

Evaluation of the results

- Small survey (used {learnr} questions for that)
- 29 students participated in statistics class
- Analysis still work-in-progress (see https://github.com/IFAFMultiLA/TrackingDataScripts)

Gave us many insights, including:

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→ Directly helped to improve the apps

Summary and outlook

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- Define variants of an app via configurations
- Monitor & collect user interactions, survey and feedback data for learning analytics
- User tracking is highly granular, configurable and anonymous
- Prepare raw data for data analysis

Plus: employ A/B testing, use a dynamic summary panel, etc.

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Thank you!

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