

Multiple logistic regression

INTERMEDIATE REGRESSION IN R



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Bank churn dataset

has_churned	time_since_first_purchase	time_since_last_purchase
0	0.3993247	-0.5158691
1	-0.4297957	0.6780654
0	3.7383122	0.4082544
0	0.6032289	-0.6990435
...
<i>response</i>	<i>length of relationship</i>	<i>recency of activity</i>

¹ <https://www.rdocumentation.org/packages/bayesQR/topics/Churn>

glm()

```
glm(response ~ explanatory, data = dataset, family = binomial)
```

```
glm(response ~ explanatory1 + explanatory2, data = dataset, family = binomial)
```

```
glm(response ~ explanatory1 * explanatory2, data = dataset, family = binomial)
```

Prediction flow

```
explanatory_data <- expand_grid(  
  explanatory1 = some_values,  
  explanatory2 = some_values  
)  
prediction_data <- explanatory_data %>%  
  mutate(  
    has_churned = predict(md1, explanatory_data, type = "response")  
  )
```

The four outcomes

	actual false	actual true
predicted false	correct	false negative
predicted true	false positive	correct

¹ <https://campus.datacamp.com/courses/introduction-to-regression-in-r/simple-logistic-regression?ex=10>

Confusion matrix

```
actual_response <- dataset$response  
predicted_response <- round(fitted(md1))
```

```
outcomes <- table(predicted_response, actual_response)
```

```
confusion <- conf_mat(outcomes)
```

```
autoplot(confusion)
```

```
summary(confusion, event_level = "second")
```

Visualization

- Use faceting for categorical variables.
- For 2 numeric explanatory variables, use color for response.
- Give responses below 0.5 one color; responses above 0.5 another color.

```
scale_color_gradient2(midpoint = 0.5)
```

Let's practice!

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The logistic distribution

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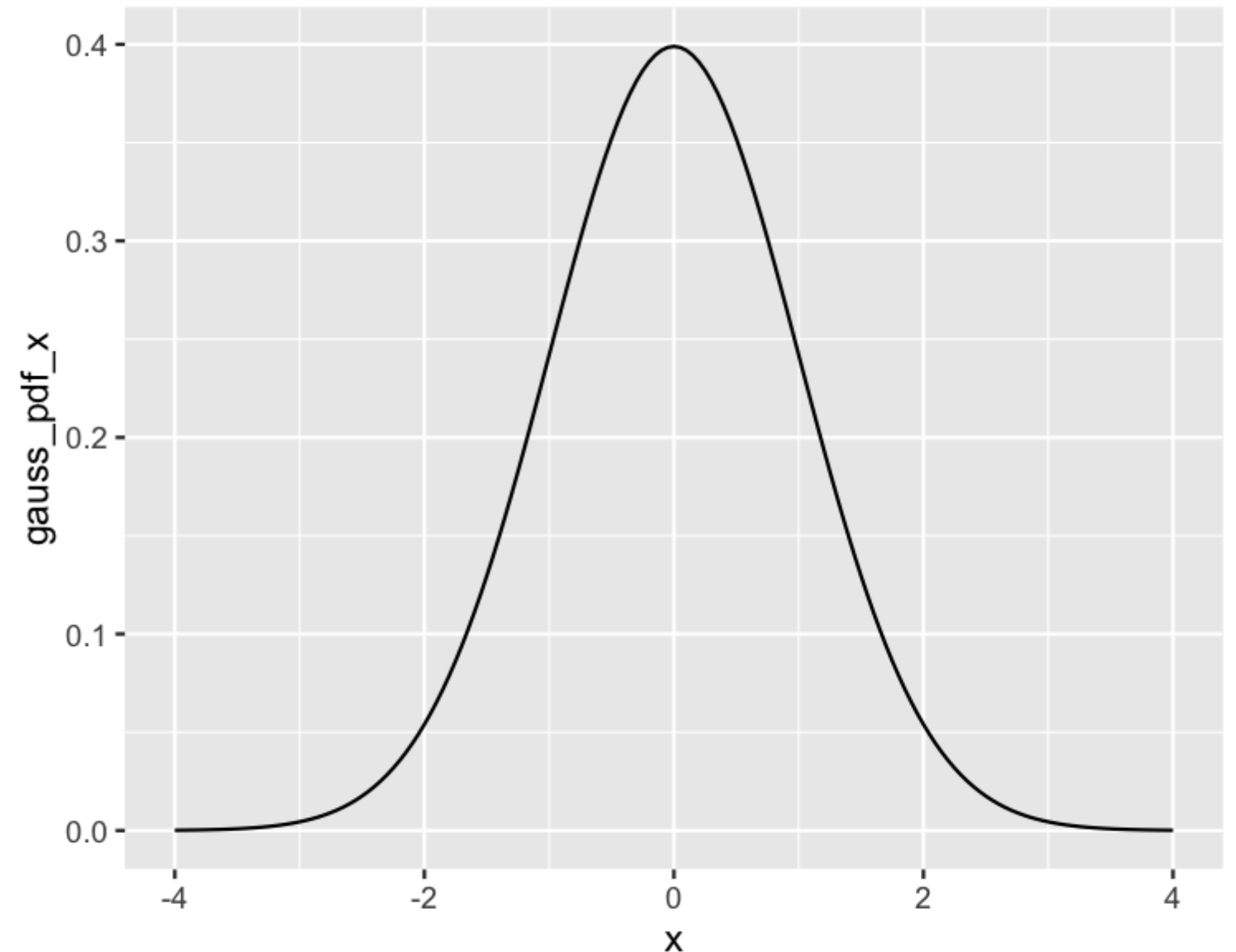
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Gaussian probability density function (PDF)

```
gaussian_distn <- tibble(  
  x = seq(-4, 4, 0.05),  
  gauss_pdf_x = dnorm(x)  
)
```

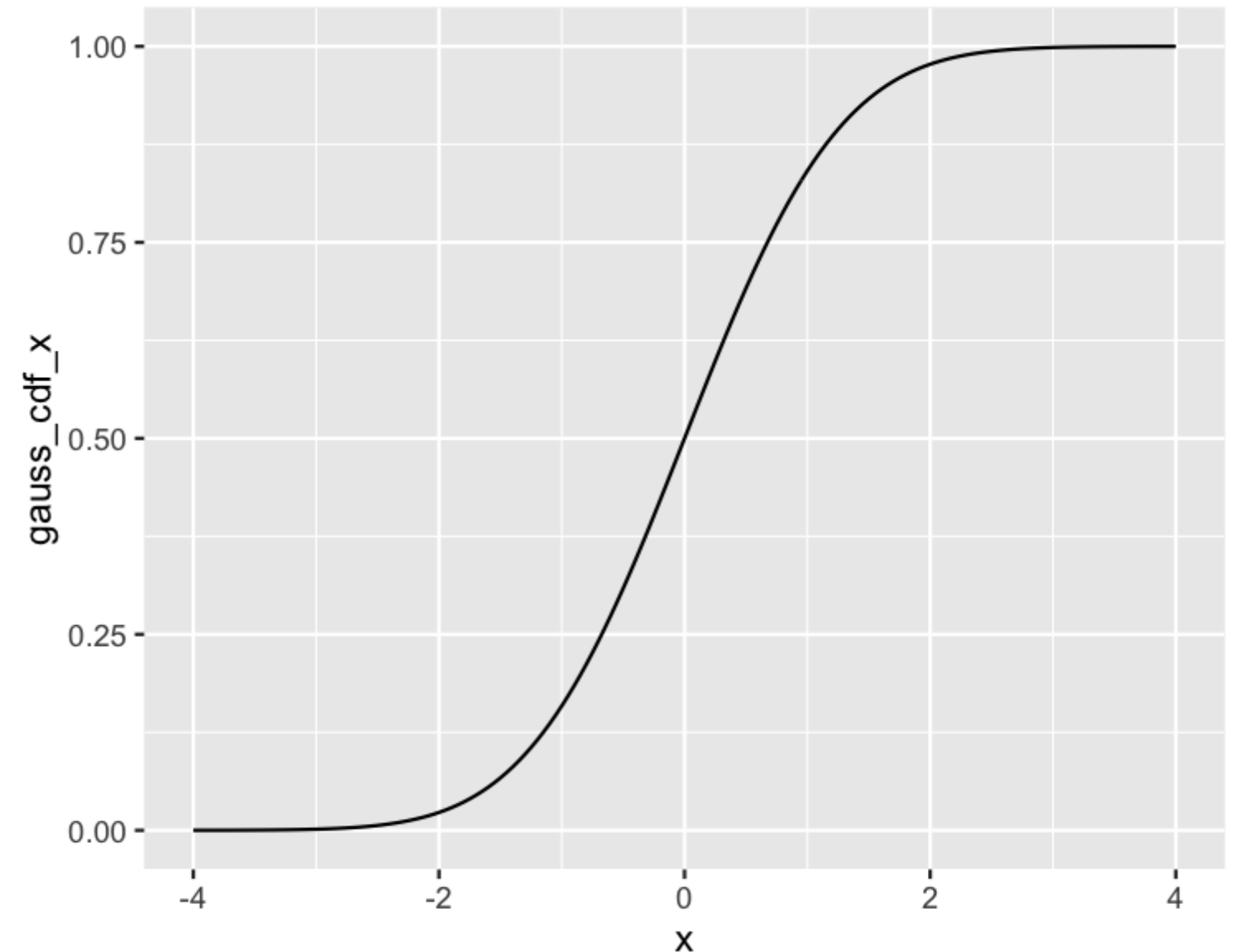
```
ggplot(gaussian_distn, aes(x, gauss_pdf_x)) +  
  geom_line()
```



Gaussian cumulative distribution function (CDF)

```
gaussian_distn <- tibble(  
  x = seq(-4, 4, 0.05),  
  gauss_pdf_x = dnorm(x),  
  gauss_cdf_x = pnorm(x)  
)
```

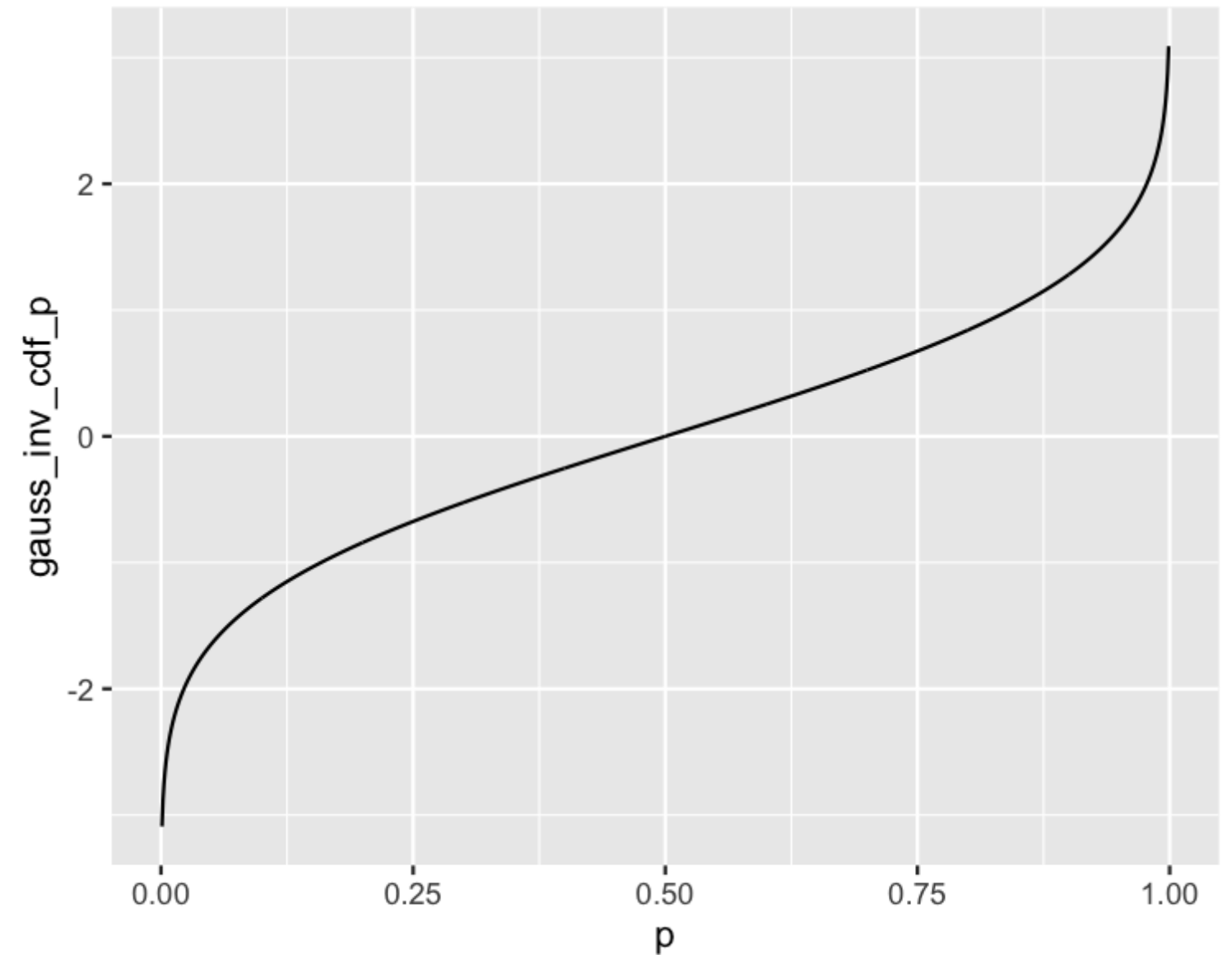
```
ggplot(gaussian_distn, aes(x, gauss_cdf_x)) +  
  geom_line()
```



Gaussian inverse CDF

```
gaussian_distn_inv <- tibble(  
  p = seq(0.001, 0.999, 0.001),  
  gauss_inv_cdf_p = qnorm(p)  
)
```

```
ggplot(gaussian_distn_inv, aes(p, gauss_inv_cdf_p)) +  
  geom_line()
```



Distribution function names

curve	prefix	normal	logistic	nmemonic
PDF	d	<code>dnorm()</code>	<code>dlogis()</code>	"d" for differentiate - you differentiate the CDF to get the PDF
CDF	p	<code>pnorm()</code>	<code>plogis()</code>	"p" is backwards "q" so it's the inverse of the inverse CDF
Inv. CDF	q	<code>qnorm()</code>	<code>qlogis()</code>	"q" for quantile

glm()'s family argument

```
lm(response ~ explanatory, data = dataset)
```

```
glm(response ~ explanatory, data = dataset, family = gaussian)
```

```
glm(response ~ explanatory, data = dataset, family = binomial)
```

¹ <https://campus.datacamp.com/courses/introduction-to-regression-in-r/simple-logistic-regression?ex=1>

gaussian()

```
str(gaussian())
```

```
List of 11
```

```
$ family      : chr "gaussian"
$ link        : chr "identity"
$ linkfun     :function (mu)
$ linkinv     :function (eta)
$ variance    :function (mu)
$ dev.resids  :function (y, mu, wt)
$ aic         :function (y, n, mu, wt, dev)
$ mu.eta      :function (eta)
$ initialize:  expression({ n <- rep.int(1, nobs) if (is.null(etastart) && is.null(start) &&
               is.null(mustart) && ((family$lin| __truncated__
$ validmu     :function (mu)
$ valideta    :function (eta)
- attr(*, "class")= chr "family"
```

linkfun and linkinv

Link function is a transformation of the response variable

```
gaussian()$linkfun
```

```
function (mu)
mu
```

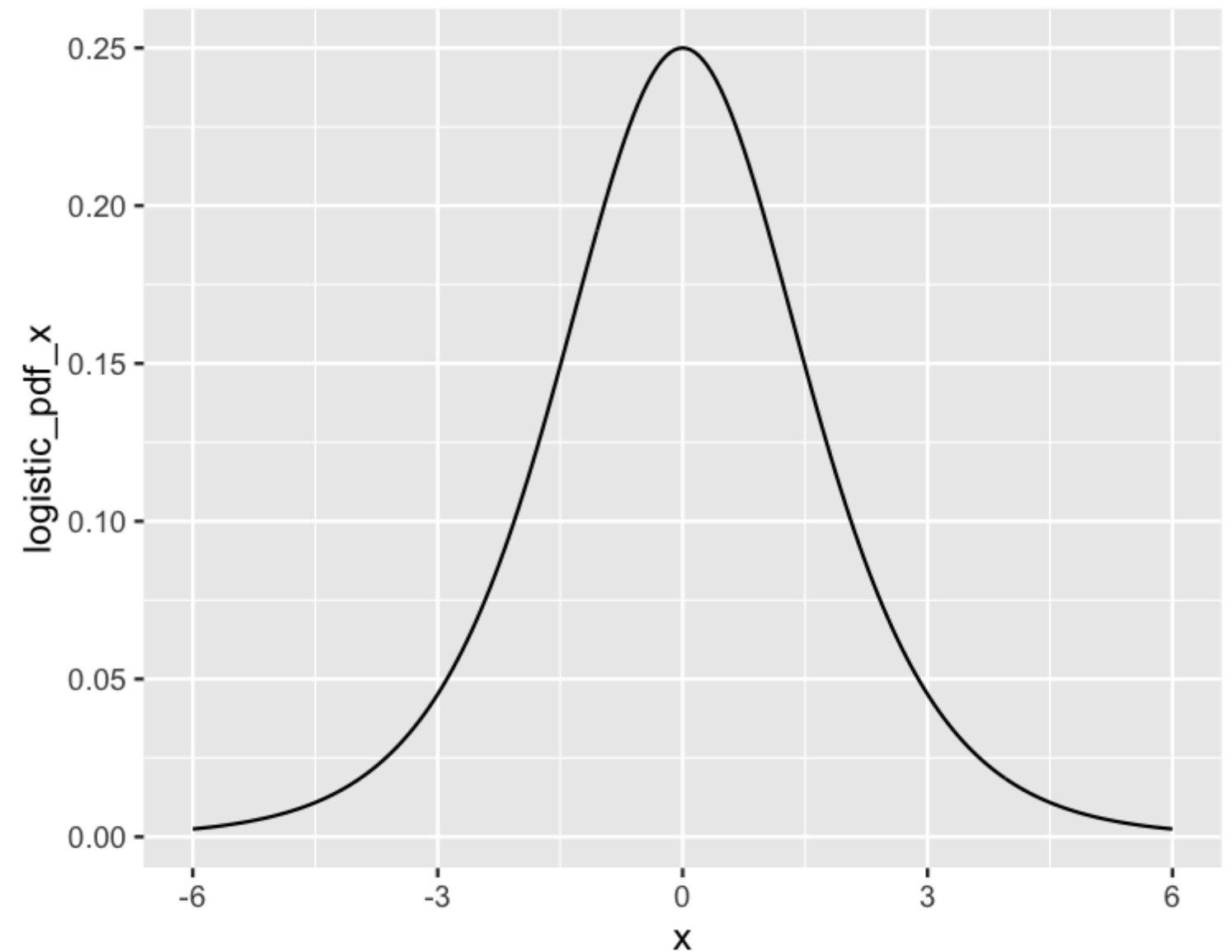
```
gaussian()$linkinv
```

```
function (eta)
eta
```


Logistic PDF

```
logistic_distn <- tibble(  
  x = seq(-6, 6, 0.05),  
  logistic_pdf_x = dlogis(x)  
)
```

```
ggplot(logistic_distn, aes(x, logistic_pdf_x)) +  
  geom_line()
```



Logistic distribution

- Logistic distribution CDF is also called the *logistic function*.
- $\text{cdf}(x) = \frac{1}{(1 + \exp(-x))}$
- Logistic distribution inverse CDF is also called the *logit function*.
- $\text{inverse_cdf}(p) = \log\left(\frac{1}{(1-p)}\right)$

Let's practice!

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How logistic regression works

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Sum of squares doesn't work

```
sum((y_pred - y_actual) ^ 2)
```

`y_actual` is always `0` or `1`.

`y_pred` is between `0` and `1`.

There is a better metric than sum of squares

Likelihood

```
y_pred * y_actual
```

Likelihood

```
y_pred * y_actual + (1 - y_pred) * (1 - y_actual)
```

Likelihood

```
sum(y_pred * y_actual + (1 - y_pred) * (1 - y_actual))
```

When `y_actual = 1`

```
y_pred * 1 + (1 - y_pred) * (1 - 1) = y_pred
```

When `y_actual = 0`

```
y_pred * 0 + (1 - y_pred) * (1 - 0) = 1 - y_pred
```


Log-likelihood

- Computing likelihood involves adding many very small numbers, leading to numerical error.
- Log-likelihood is easier to compute.

```
log(y_pred) * y_actual + log(1 - y_pred) * (1 - y_actual)
```

Both equations give the same answer.

Negative log-likelihood

Maximizing log-likelihood is the same as minimizing negative log-likelihood.

```
-sum(log_likelihoods)
```

Logistic regression algorithm

```
calc_neg_log_likelihood <- function(coeffs) {  
  intercept <- coeffs[1]  
  slope <- coeffs[2]  
  # More calculation!  
}
```

```
optim(  
  par = ???,  
  fn = ???  
)
```

Let's practice!

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Congratulations

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You learned things

Chapter 1

- Fit/visualize/predict/assess parallel slopes

Chapter 2

- Interactions between explanatory variables
- Simpson's Paradox

Chapter 3

- Extend to many explanatory variables
- Implement linear regression algorithm

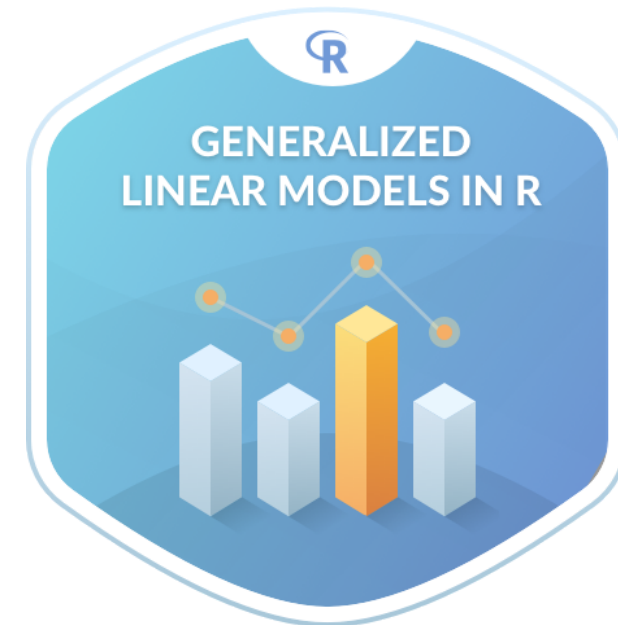
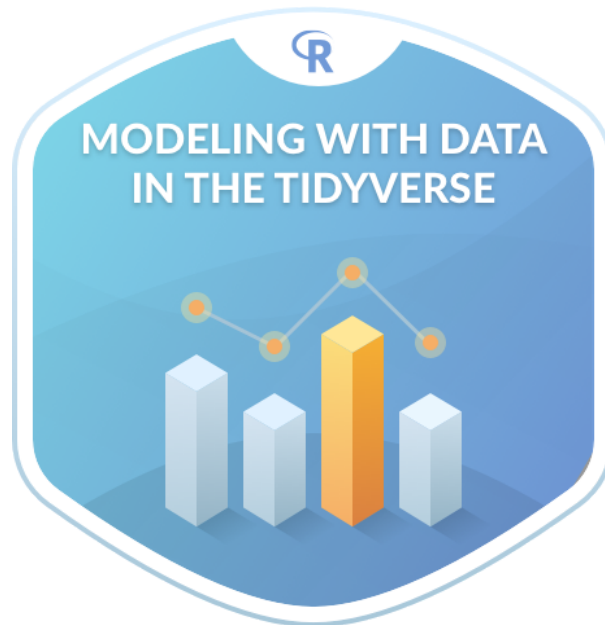
Chapter 4

- Logistic regression with multiple explanatory variables
- Logistic distribution
- Implement logistic regression algorithm

There is more to learn

- Training and testing sets
- Cross validation
- P-values and significance

Advanced regression



Let's practice!

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