Lecture 17: Oct 12, 2018

Joins

- *Databases*
- *Keys and Relationships*
- *Joins*
    - *Naive*, *Inner*, *Full*, *Left*, *Right*, *Anti*, *Semi*

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STAT 385 @ UIUC

Announcements

- **hw06** is due **Friday, Oct 12th, 2018** at **6:00 PM**
- **Office Hour Changes**
  - **John Lee's** are now from **4 - 5 PM** on **WF**
  - **Hassan Kamil's** are now from **2:30 - 3:30 PM** on **TR**
- **Quiz 07** covers Week 6 contents @ CBTF.
  - Window: Oct 9th - 11th
  - Sign up: https://cbtf.engr.illinois.edu/sched
- Want to review your homework or quiz grades?
  Schedule an appointment.

Last Time

- **Grammar of Data**
  - Pose question about the data
  - Answer the questions through **five** verbs: select, filter, mutate, arrange, and summarise
- **Split-Apply-Combine**
  - **Split** Data into pieces
  - **Apply** function to each piece, and
  - **Combine** result

Lecture Objectives

- **Explain** the similarities that exist a table in a database and a data frame
- **Apply** the different kinds of join appropriately

Databases

Definition:
Database refers to a collection of different tabular pieces of data.

Students

id	firstname	lastname	age	instate
1	Billy	Joe	23	FALSE
2	Theodore	Squirrel	25	TRUE
3	Keeya	Nod	21	TRUE

Grades

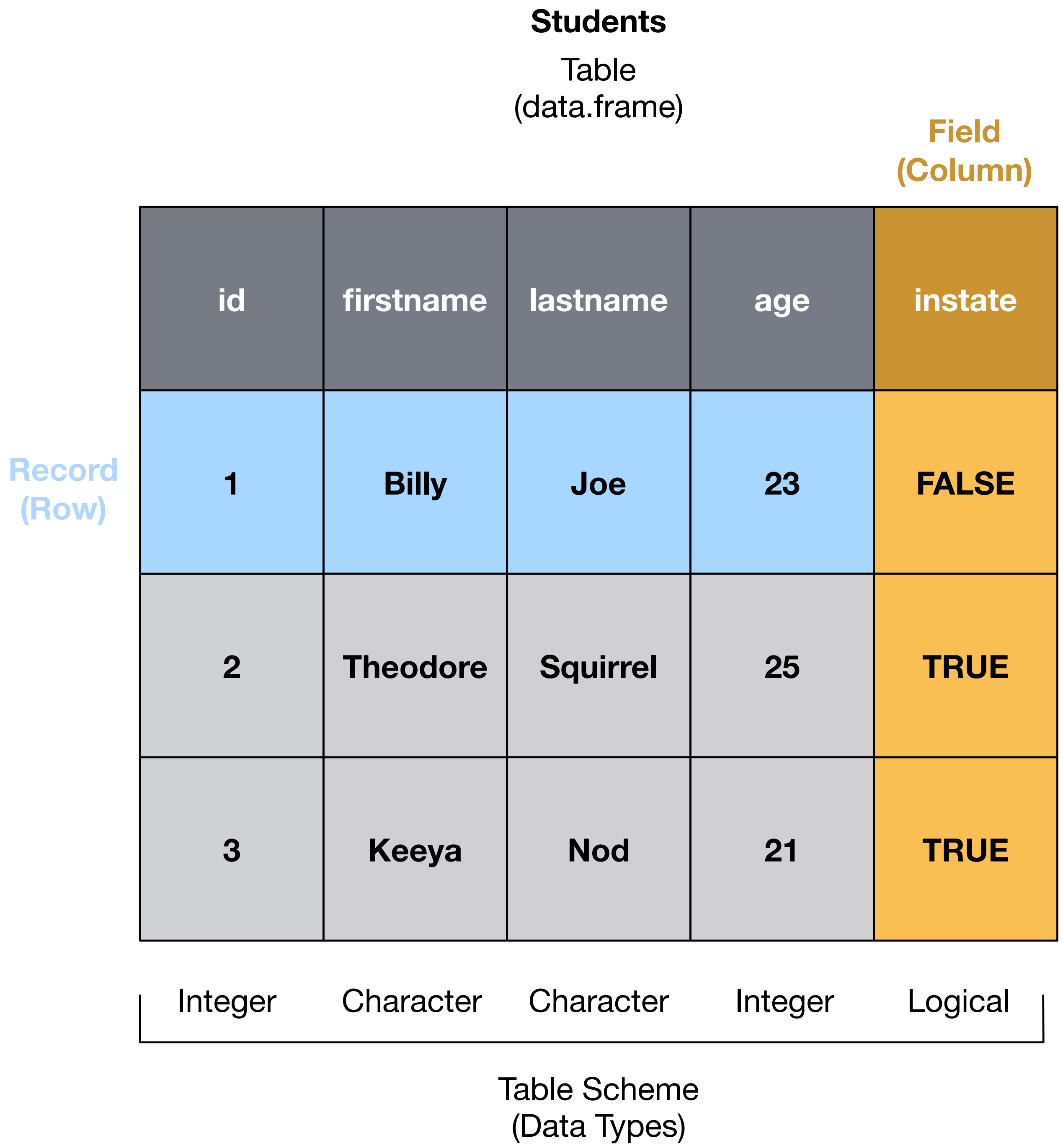
student_id	course_id	grade
1	STAT385	A+
2	STAT432	A-
1	HIST100	A
3	STAT385	B+

Courses

course_id	acronym
STAT385	SPM
STAT432	BSL
HIST100	GH

Table to Data Frame

… database logic vs *R's* data structures …



Students

Table
(data.frame)

**Field
(Column)**

id	firstname	lastname	age	instate
1	**Billy**	**Joe**	**23**	**FALSE**
2	**Theodore**	**Squirrel**	**25**	**TRUE**
3	**Keeya**	**Nod**	**21**	**TRUE**

**Record
(Row)**

Integer Character Character Integer Logical

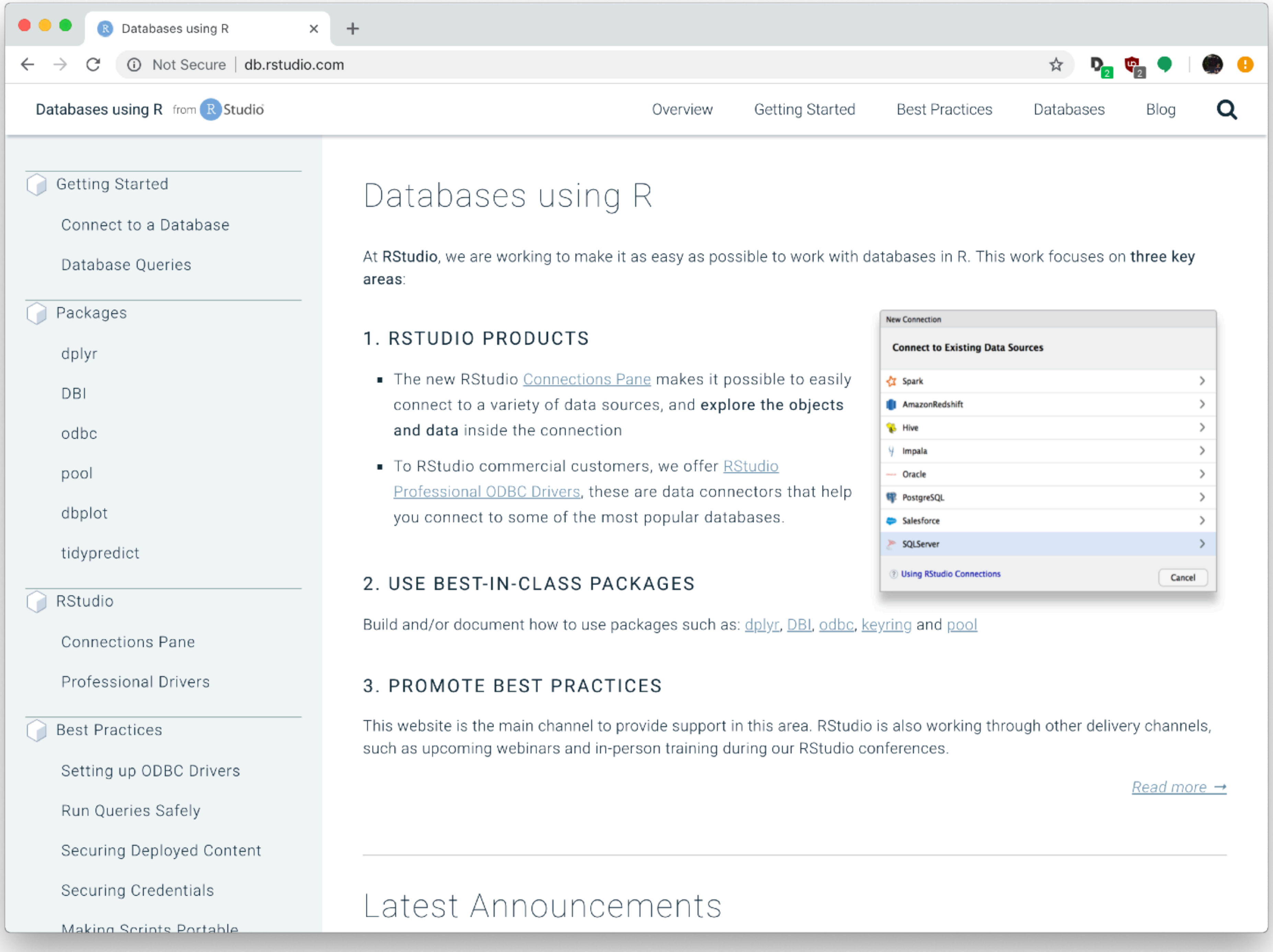
Table Scheme
(Data Types)

Why Databases?

… Relational Database Management Systems (RDBMS) …

- **Speed**
  - High level of optimization around data requests
- **Size**
  - Data in *R* is limited by the amount of system memory
- **Scale**
  - Add additional resources to meet computational demand
- **Concurrent**
  - Work on the same data with multiple users without corrupting data

Databases in R



Databases using R

At **RStudio**, we are working to make it as easy as possible to work with databases in R. This work focuses on **three key areas**:

1. RSTUDIO PRODUCTS

- The new RStudio Connections Pane makes it possible to easily connect to a variety of data sources, and **explore the objects and data** inside the connection
- To RStudio commercial customers, we offer RStudio Professional ODBC Drivers, these are data connectors that help you connect to some of the most popular databases.

2. USE BEST-IN-CLASS PACKAGES

Build and/or document how to use packages such as: dplyr, DBI, odbc, keyring and pool

3. PROMOTE BEST PRACTICES

This website is the main channel to provide support in this area. RStudio is also working through other delivery channels, such as upcoming webinars and in-person training during our RStudio conferences.

Read more →

Latest Announcements

https://db.rstudio.com/

Keys and Relationships

Definition:
Primary Key refers to a unique set of values in one or more columns that is used to identify the rows of a table.

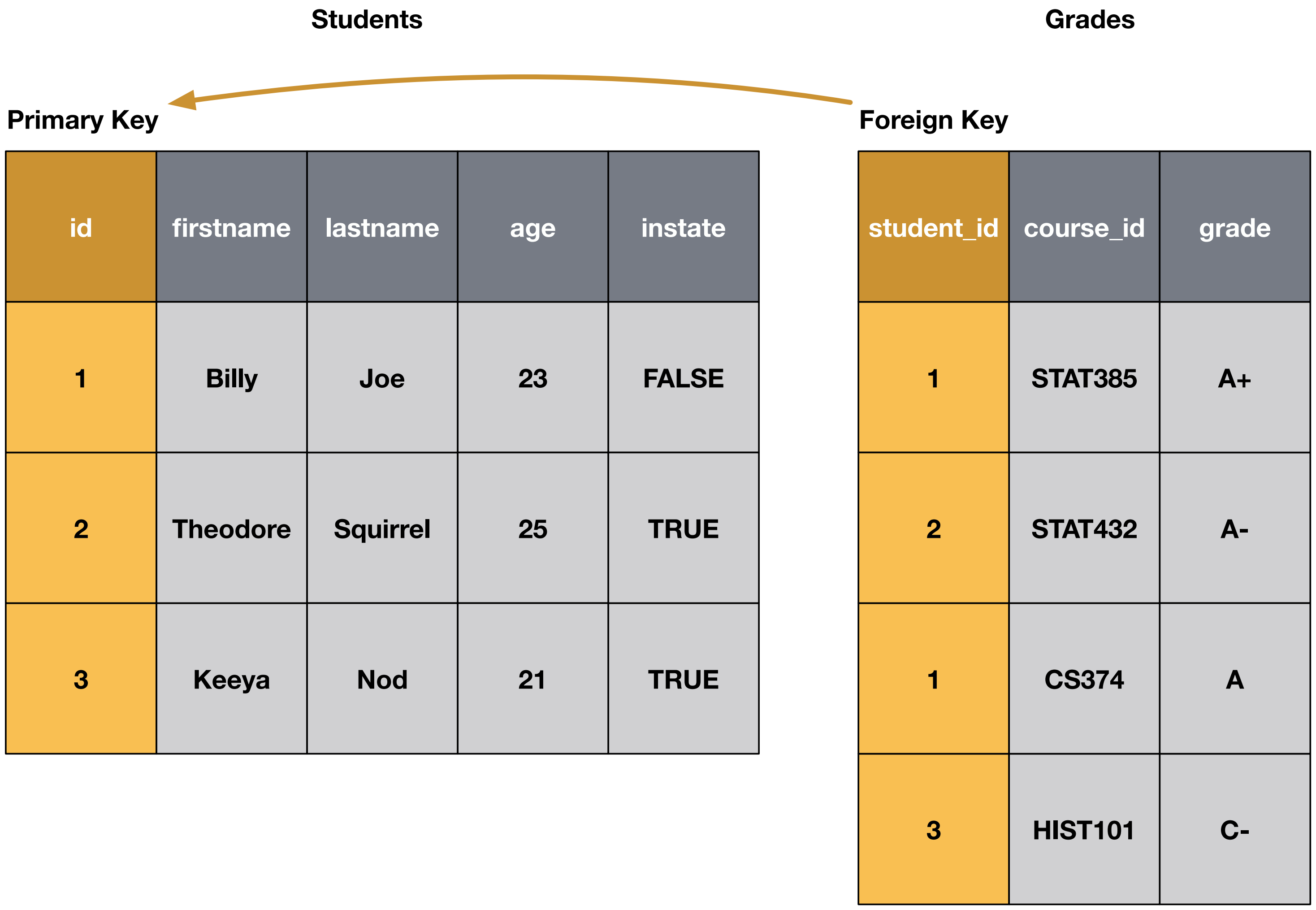
Students

id	firstname	lastname	age	instate
1	Billy	Joe	23	FALSE
2	Theodore	Squirrel	25	TRUE
3	Keeya	Nod	21	TRUE

Primary Key →

Source

Definition:
Foreign Keys refer to a set of one or more columns that is a primary key in another table.



Students

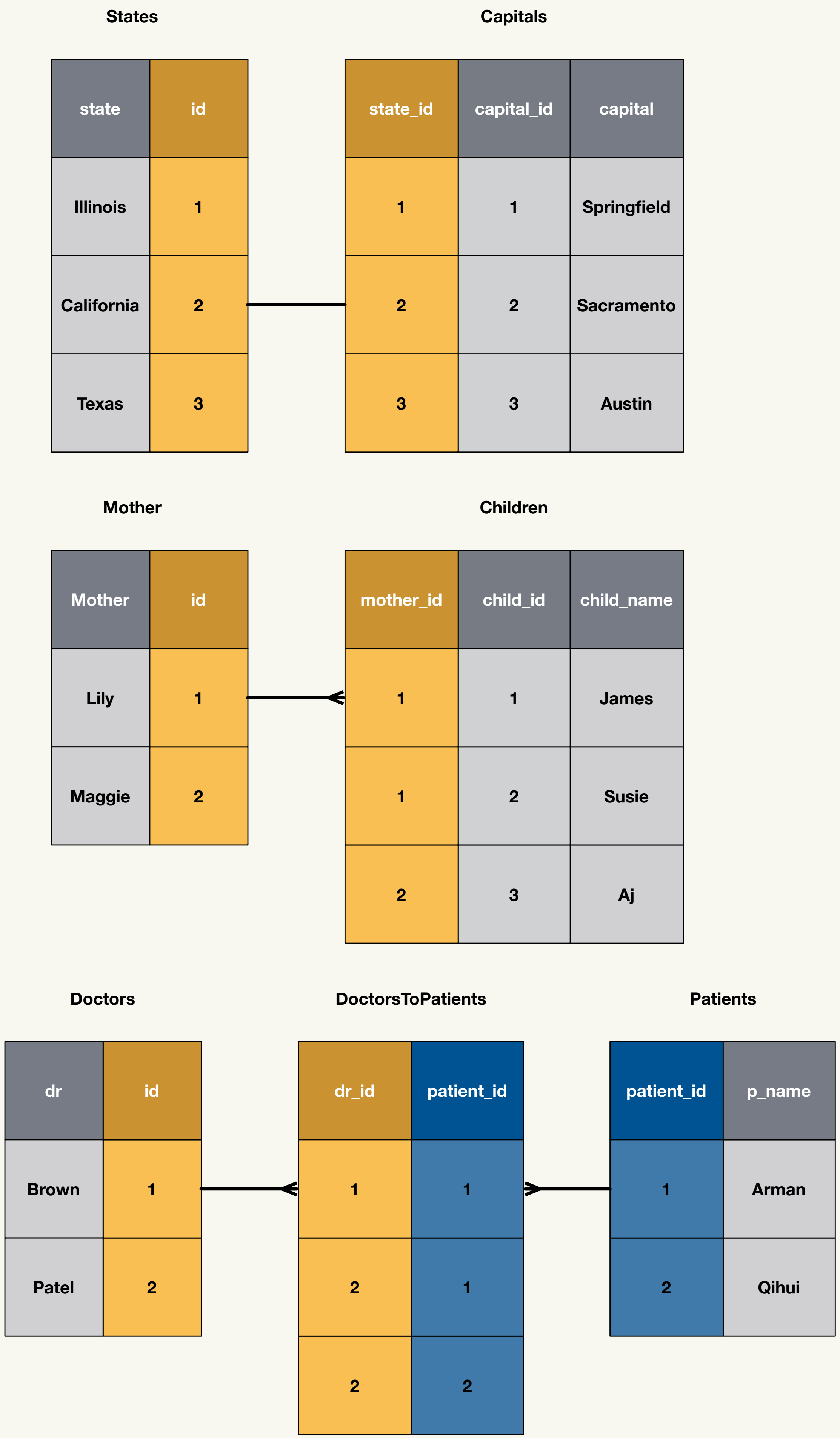
Primary Key

id	firstname	lastname	age	instate
1	Billy	Joe	23	FALSE
2	Theodore	Squirrel	25	TRUE
3	Keeya	Nod	21	TRUE

Grades

Foreign Key

student_id	course_id	grade
1	STAT385	A+
2	STAT432	A-
1	CS374	A
3	HIST101	C-



States

state	id
Illinois	1
California	2
Texas	3

Capitals

state_id	capital_id	capital
1	1	Springfield
2	2	Sacramento
3	3	Austin

Mother

Mother	id
Lily	1
Maggie	2

Children

mother_id	child_id	child_name
1	1	James
1	2	Susie
2	3	Aj

Doctors

dr	id
Brown	1
Patel	2

DoctorsToPatients

dr_id	patient_id
1	1
2	1
2	2

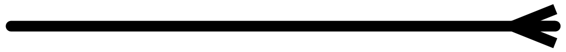
Patients

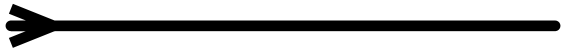
patient_id	p_name
1	Arman
2	Qihui

Types of Relationships

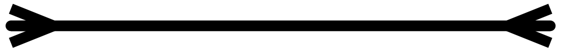
- **One-to-one**: *one row* in a table matches exactly with only *one row* in another table

- **One-to-many (Many-to-one)**: *one row* of a table matches *multiple rows* in a another table.





- **Many-to-many**: *multiple rows* in one table can be mapped to *multiple rows* in another table and vice versa.



Your Turn

1. Identify the different keys for each database table.
2. What kinds of relationships exist between tables?

Students

id	firstname	lastname	age	instate
1	Billy	Joe	23	FALSE
2	Theodore	Squirrel	25	TRUE
3	Keeya	Nod	21	TRUE

Grades

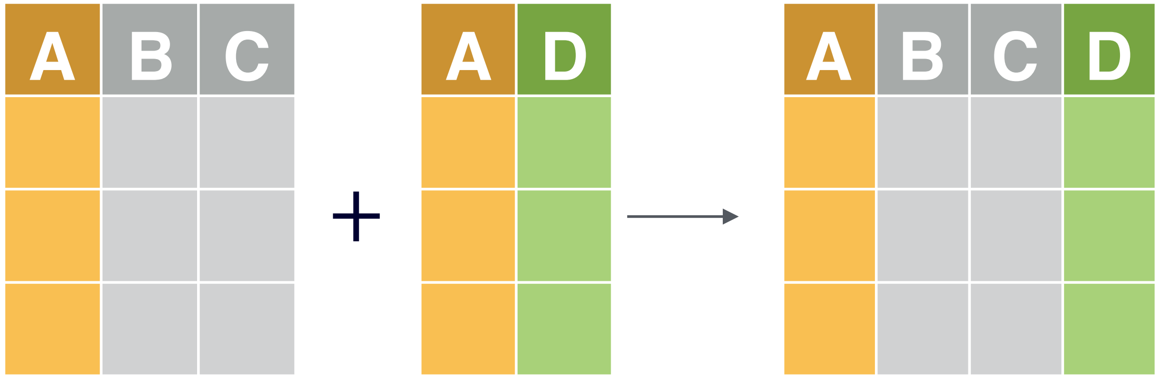
student_id	course_id	grade
1	STAT385	A+
2	STAT432	A-
1	HIST100	A
3	STAT385	B+

Courses

course_id	acronym
STAT385	SPM
STAT432	BSL
HIST100	GH

Joins

Definition:
Joining or *merging* refers to combining two different pieces of data together to form a larger data set that contains more observations, variables, or both.



Ordered Naive Joins

… merging data naively …

```
# Same number of rows, exact ordering, no repeated columns.
first_df = data.frame(A = c(1, 2, 3, 4),
                      B = c("A", "B", "C", "A"))
sec_df = data.frame(D = c(38.4, 39.9, 40, 20.5))

# Merge the data together
merged_df = data.frame(first_df, sec_df)
# Or, bind by column
merged_df_cols = cbind(first_df, sec_df)

# Retrieve specific columns with the same order
selected_df = data.frame(first_df$A, sec_df$D)
```

Ordering for Naive Joins

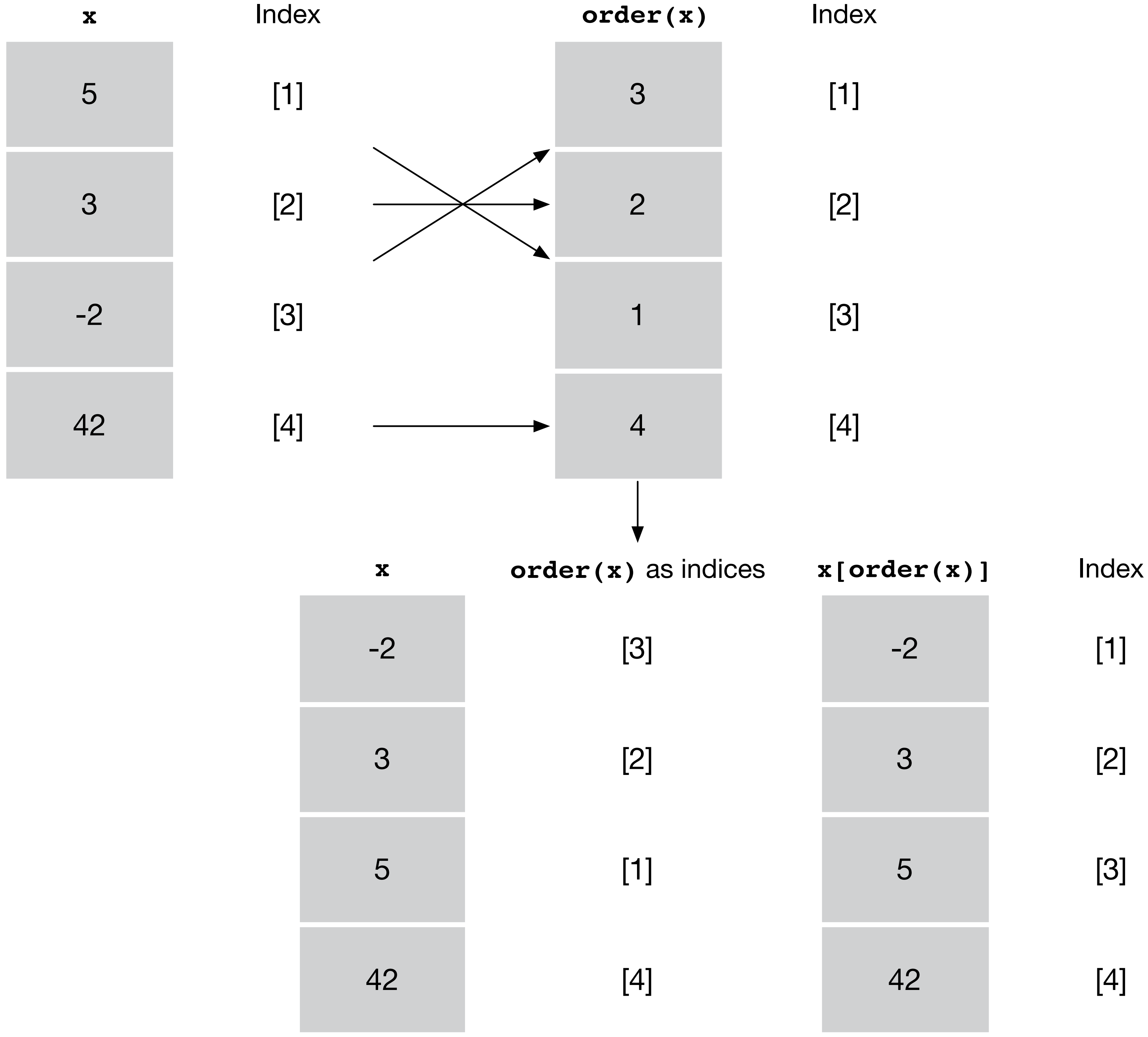
… when data isn't ordered right …

```
# Same number of rows, exact ordering, no repeated columns.
bad_first_df = data.frame(A = c(4, 3, 2, 1),
                          B = c("A", "C", "B", "A"))
bad_sec_df = data.frame(A = c(2, 1, 4, 3),
                        D = c(39.9, 38.4, 20.5, 40))
# Order data frames
ordered_first_df = bad_first_df[order(bad_first_df$A), ]
ordered_sec_df = bad_sec_df[order(bad_sec_df$A), ]

# Combine the ordered data frames
ordered_merged_df = data.frame(ordered_first_df$A,
                               ordered_first_df$B,
                               ordered_sec_df$D)
```

Behind order()

… using sorted positional indices we can rearrange the data …

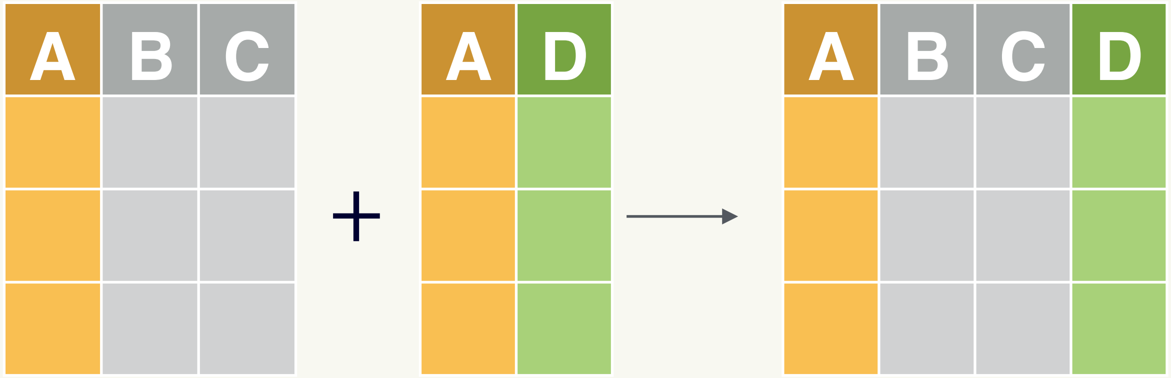


`x`	Index	`order(x)`	Index
5	[1]	3	[1]
3	[2]	2	[2]
-2	[3]	1	[3]
42	[4]	4	[4]

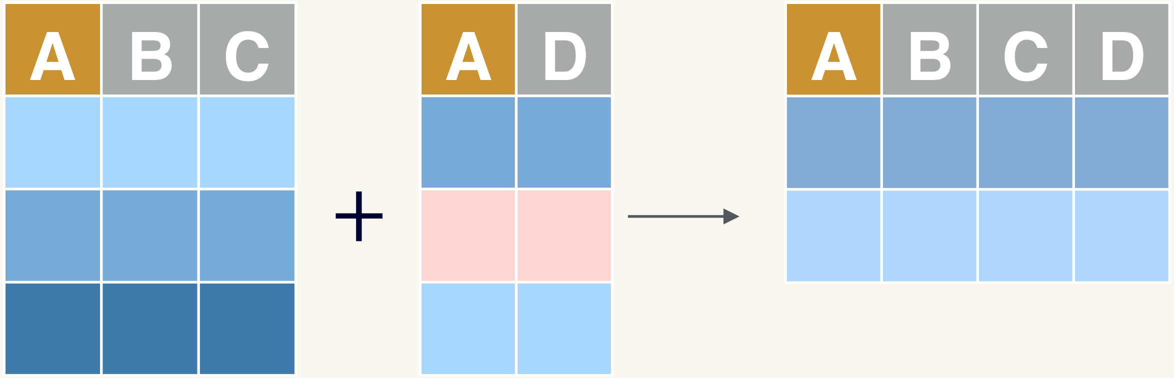
`x`	`order(x)` as indices	`x[order(x)]`	Index
-2	[3]	-2	[1]
3	[2]	3	[2]
5	[1]	5	[3]
42	[4]	42	[4]

Naive Joining
Fails with Uneven Rows

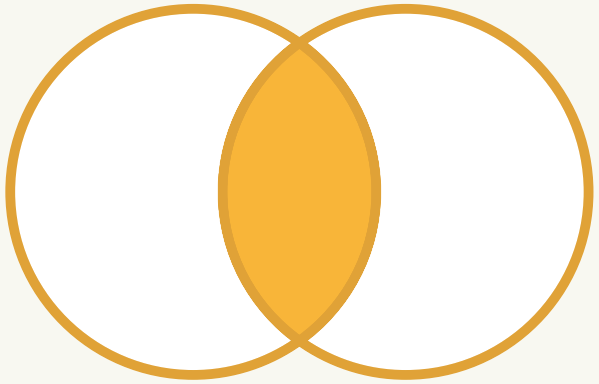
Types of Joins



- **Mutating joins** will add new variables to one table from matching observations in another.



- **Filtering joins** will filter observations from one table based on whether or not they match an observation in the other table.



- **Set operations** will treat observations as if they were elements in a set.

Joins for Uneven Data

… how to handle different numbers of observations …

`inner_join(x, y)`

1	x1	y1
2	x2	y2

Original

x

1	x1
2	x2
3	x3

y

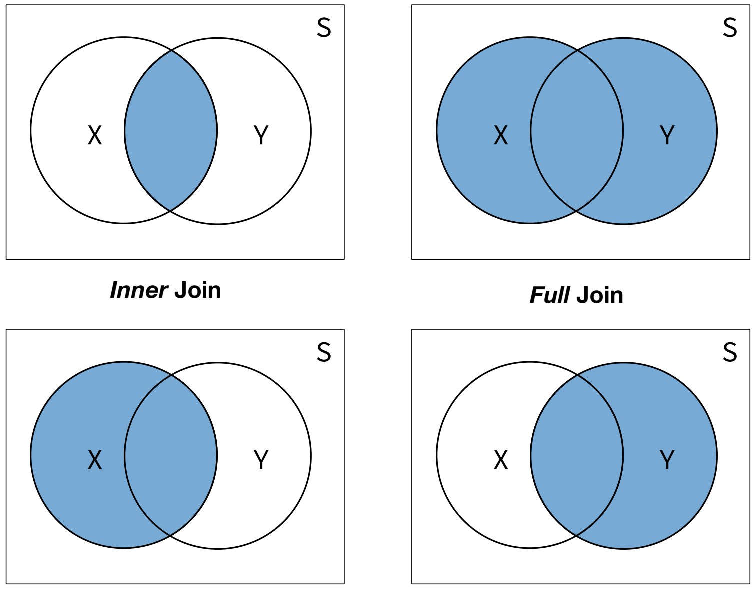
1	y1
2	y2
4	y4

Source

`full_join(x, y)`

1	x1	y1
2	x2	y2
3	x3	
4		y4

JOIN Venn Diagrams



Inner **Join**

Full **Join**

Left **Join**

Right **Join**

`left_join(x, y)`

1	x1	y1
2	x2	y2
3	x3	

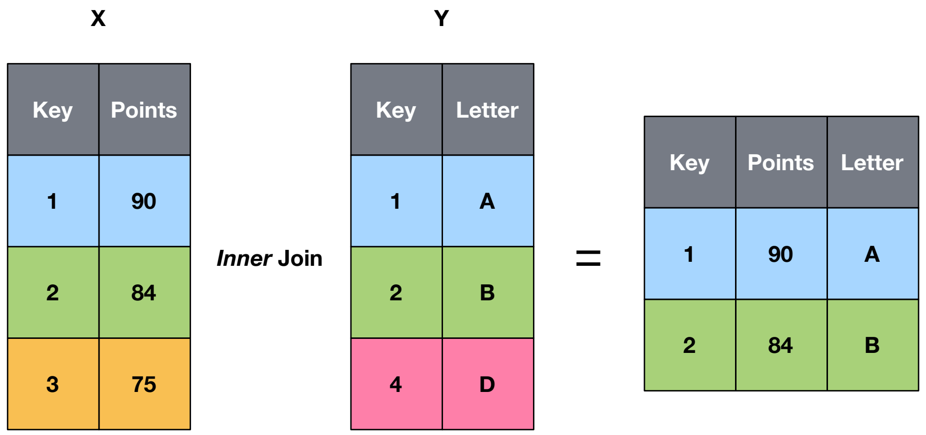
`right_join(x, y)`

1	x1	y1
2	x2	y2
4		y4

Inner Join

acquires the set of values that are in both **Table *X*** and **Table *Y***.

Join Operation



X

Key	Points
1	90
2	84
3	75

Inner Join

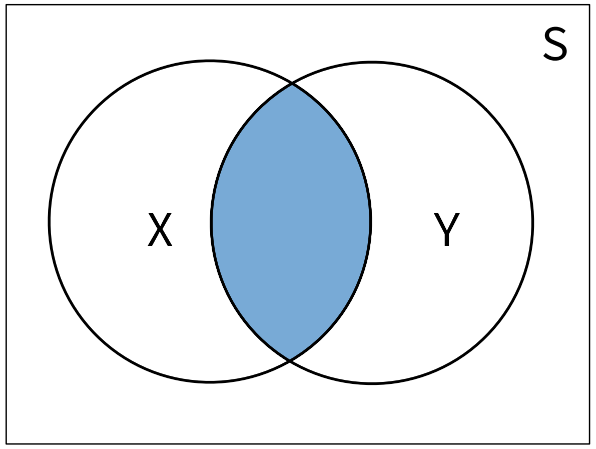
Y

Key	Letter
1	A
2	B
4	D

=

Key	Points	Letter
1	90	A
2	84	B

Venn Diagram



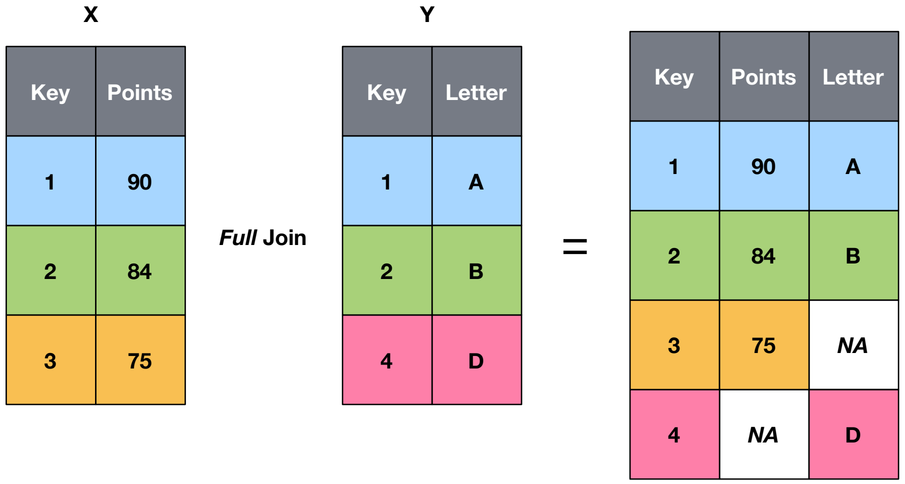
```
# Using inner_join in dplyr
dplyr::inner_join(X, Y, by = "Key")

# Using Base R's merge()
# function to perform an inner
# join
merge(X, Y, by = "Key")
```

Full (Outer) Join

acquires the set of all values in **Table X** and **Table Y**, regardless of whether they have values that exist in both tables. If the values do not exist, the missing side will have ***NA*** values substituted.

Join Operation



X

Key	Points
1	90
2	84
3	75

Full Join

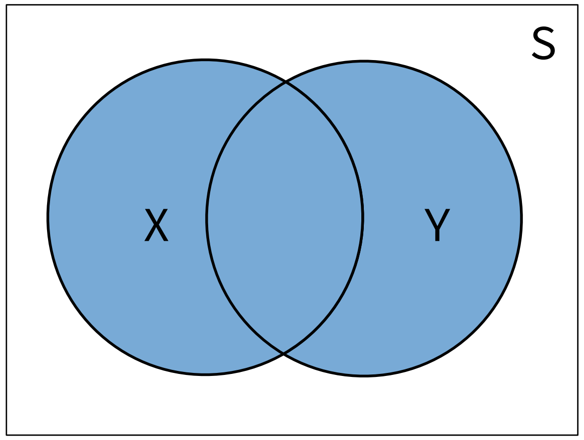
Y

Key	Letter
1	A
2	B
4	D

=

Key	Points	Letter
1	90	A
2	84	B
3	75	*NA*
4	*NA*	D

Venn Diagram



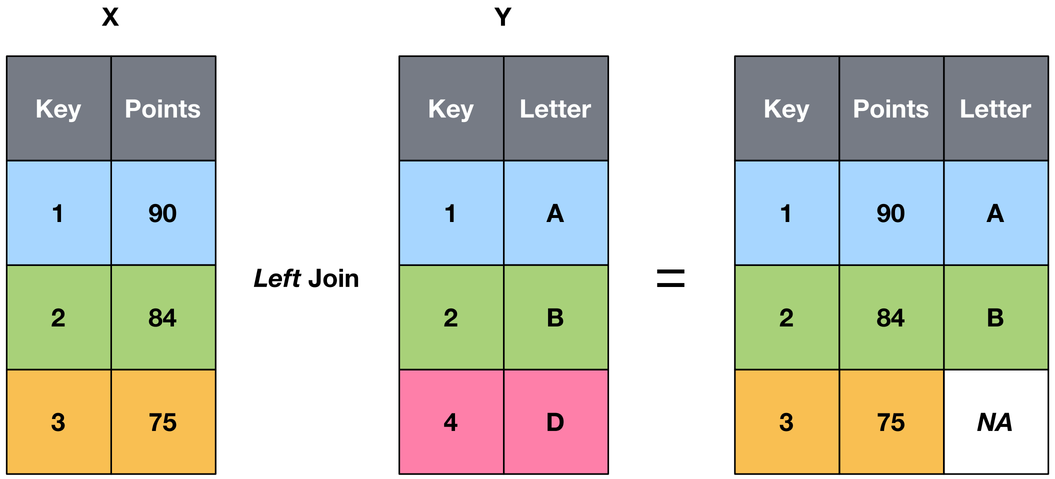
```
# Using full_join in dplyr
dplyr::full_join(X, Y, by = "Key")

# Using Base R's merge()
# function to perform a full
# join
merge(X, Y, by = "Key",
          all.x = TRUE,
          all.y = TRUE)
```

Left (Outer) Join

acquires the set of complete values in **Table X** paired with the values in **Table Y** if available. If the values do not exist, the left side will have ***NA*** values substituted.

Join Operation



X

Key	Points
1	90
2	84
3	75

Left Join

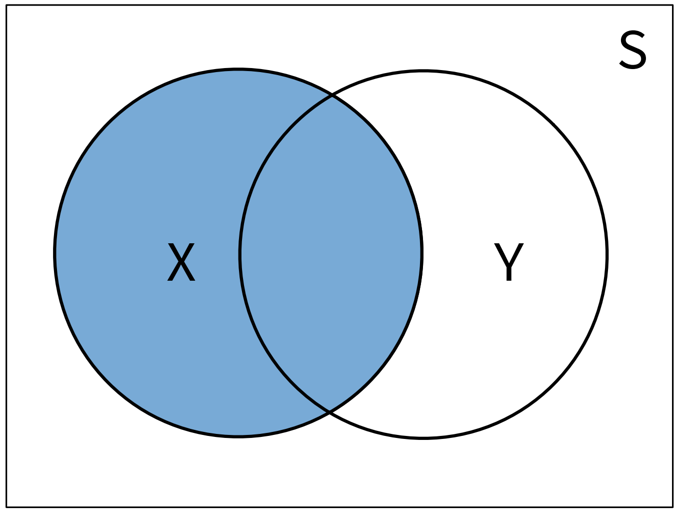
Y

Key	Letter
1	A
2	B
4	D

=

Key	Points	Letter
1	90	A
2	84	B
3	75	*NA*

Venn Diagram



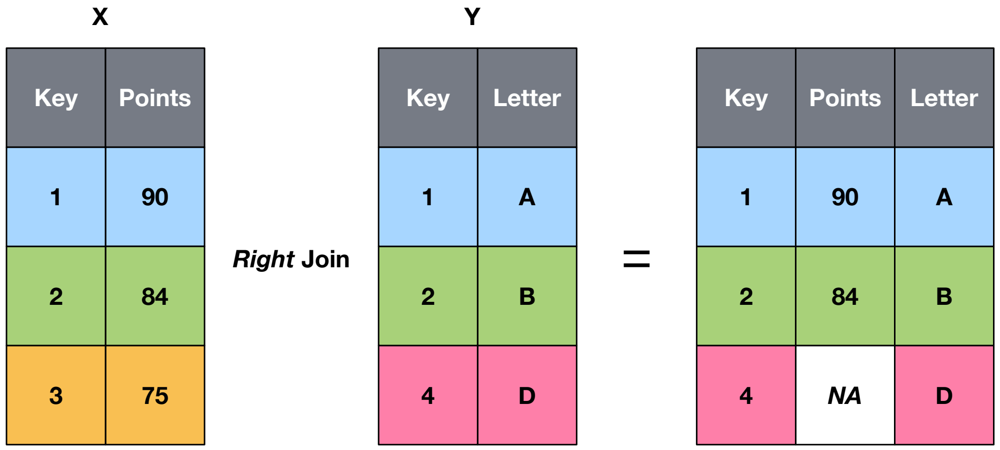
```
# Using left_join in dplyr
dplyr::left_join(X, Y, by = "Key")

# Using Base R's merge()
# function to perform a left
# join
merge(X, Y, by = "Key",
          all.x = TRUE)
```

Right (Outer) Join

acquires the set of complete values in **Table Y** paired with the values in **Table X** if available. If the values do not exist, the right side will have ***NA*** values substituted.

Join Operation



X

Key	Points
1	90
2	84
3	75

Right **Join**

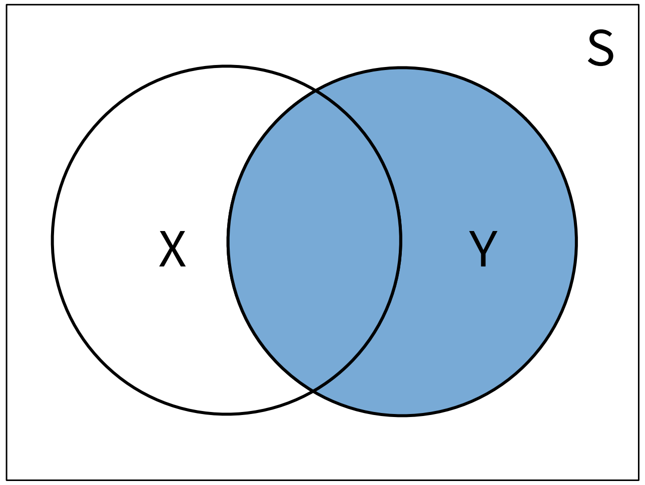
Y

Key	Letter
1	A
2	B
4	D

=

Key	Points	Letter
1	90	A
2	84	B
4	*NA*	D

Venn Diagram



```
# Using right_join in dplyr
dplyr::right_join(X, Y, by = "Key")

# Using Base R's merge()
# function to perform a left
# join
merge(X, Y, by = "Key",
          all.y = TRUE)
```

Your Turn

Join together the different tables in the **student database**.

Students

id	firstname	lastname	age	instate
1	Billy	Joe	23	FALSE
2	Theodore	Squirrel	25	TRUE
3	Keeya	Nod	21	TRUE

Grades

student_id	course_id	grade
1	STAT385	A+
2	STAT432	A-
1	HIST100	A
3	STAT385	B+

Courses

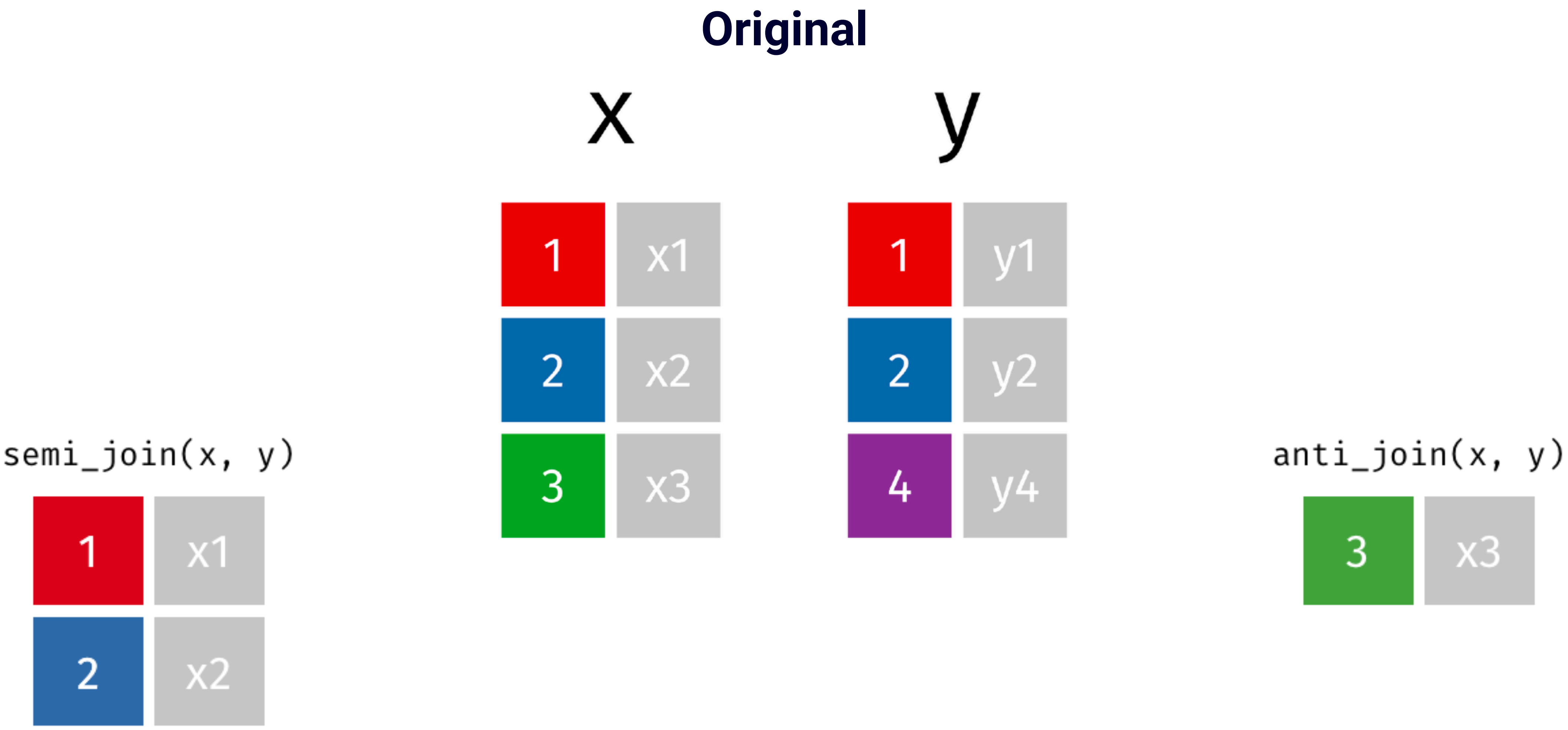
course_id	acronym
STAT385	SPM
STAT432	BSL
HIST100	GH

Would the following joins be equivalent? If so, why?

```
dplyr::left_join(X, Y, by = "Key")
dplyr::right_join(Y, X, by = "Key")
```

Filtering Joins

… match vs. no match …



Original

x

1	x1
2	x2
3	x3

y

1	y1
2	y2
4	y4

`semi_join(x, y)`

1	x1
2	x2

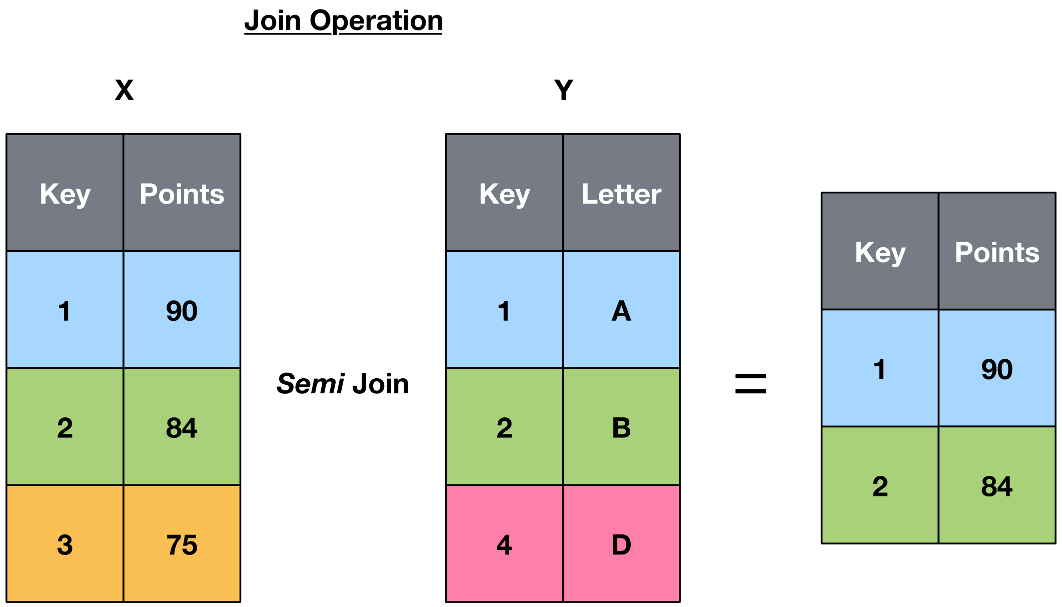
`anti_join(x, y)`

3	x3

Source

Semi joins

acquires the set of complete values in ***Table X*** that have a matching key in ***Table Y***.



Join Operation

X

Key	Points
1	90
2	84
3	75

Semi Join

Y

Key	Letter
1	A
2	B
4	D

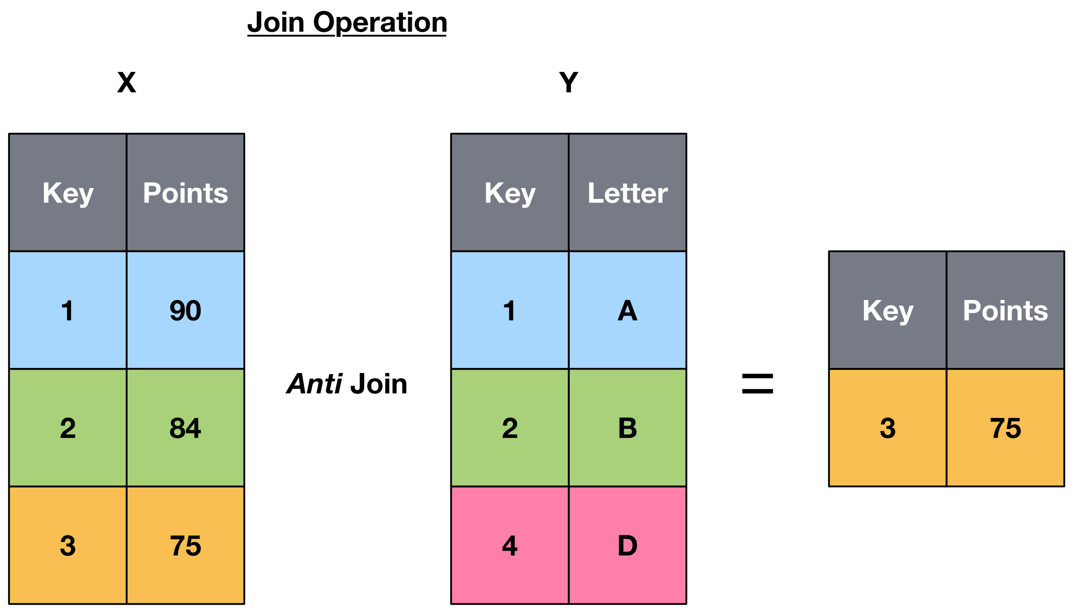
=

Key	Points
1	90
2	84

```
# Using semi_join in dplyr
dplyr::semi_join(X, Y, by = "Key")
```

Anti joins

purges the set of complete values in ***Table X*** that have a matching key in ***Table Y***.



Join Operation

X

Key	Points
1	90
2	84
3	75

Anti Join

Y

Key	Letter
1	A
2	B
4	D

=

Key	Points
3	75

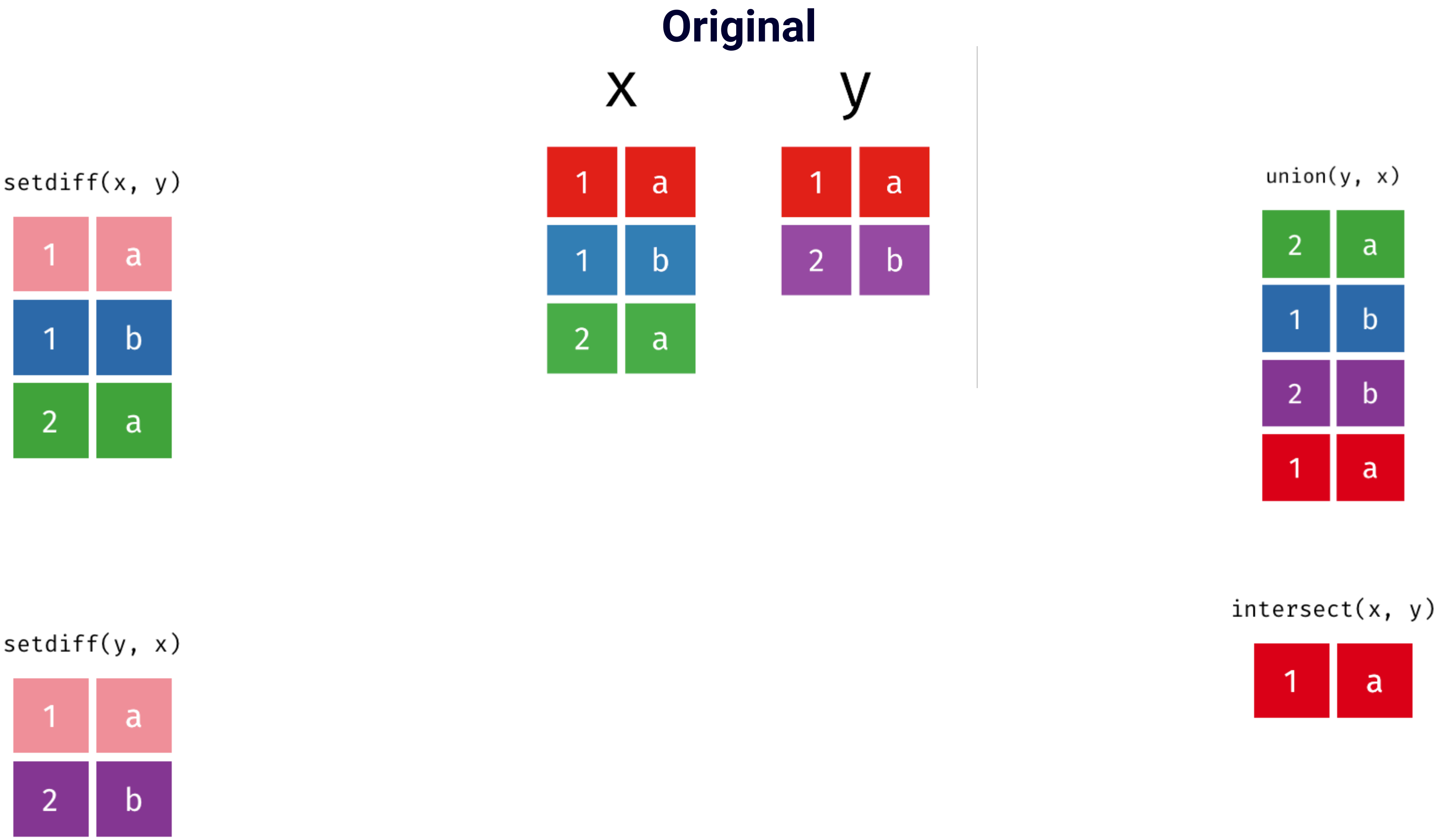
```
# Using anti_join in dplyr
dplyr::anti_join(X, Y, by = "Key")
```

Your Turn

1. Install the **fueleconomy** package.
2. Determine the appropriate keys between **common** and **vehicles** tables.
3. Perform a semi join

Set Manipulations

… operating on data …



Original

x

1	a
1	b
2	a

y

1	a
2	b

`setdiff(x, y)`

1	a
1	b
2	a

`setdiff(y, x)`

1	a
2	b

`union(y, x)`

2	a
1	b
2	b
1	a

`intersect(x, y)`

1	a

Source

Set Operations

```
x = c(-8, 0, 2, 1, 23, NA)
y = c(-8, 3, 1, NA, 2, 10)

union(x, y)          # X or Y (Full)
# [1] -8  0  2  1 23 NA  3 10

intersect(x, y)    # X and Y (Intersect)
# [1] -8  2  1 NA

setdiff(x, y)        # Y - X  (Anti-join)
# [1]  0 23

setdiff(y, x)        # X - Y  (Anti-join)
# [1]  3 10

setequal(x, y)    # X = Y
# [1] FALSE

is.element(x, y) # X in Y (Intersect)
# [1]  TRUE FALSE  TRUE  TRUE FALSE  TRUE

x %in% y            # equivalent
# [1]  TRUE FALSE  TRUE  TRUE FALSE  TRUE
```

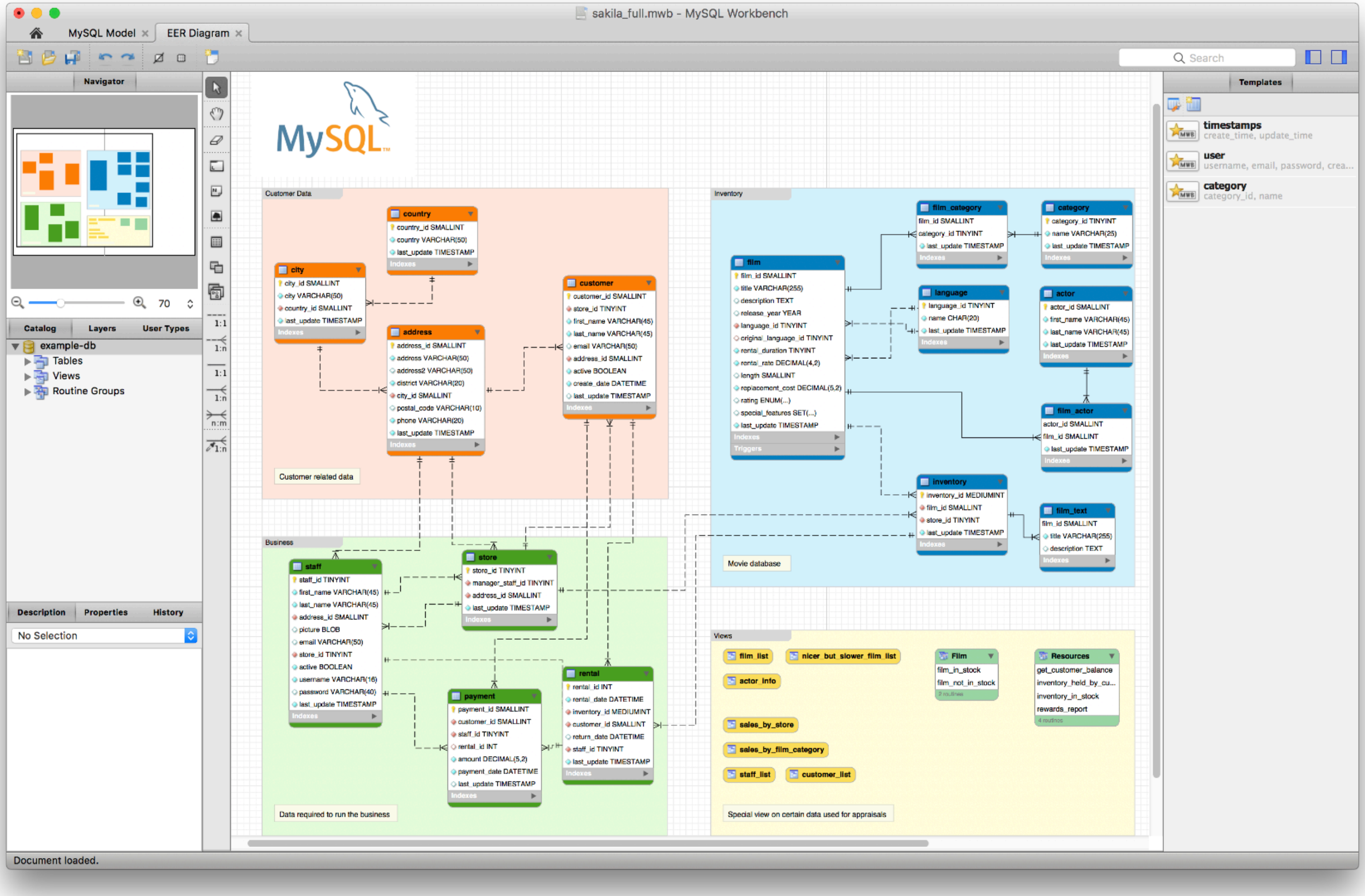
Recap

- **Databases**
    - Collection of data
    - Data tables mirror *R*'s data frame
- **Keys and Relationships**
    - Keys are unique field(s) to identify rows in data.
    - Relationships show how data is connected between tables
- **Joins**
    - Naively merging data is rarely a good idea.
    - Mutating, Filtering, and Set Joins are better for a varying number of rows between data sets.

Resources

MySQL Workbench

… GUI for Designing Databases …



https://www.mysql.com/products/workbench/