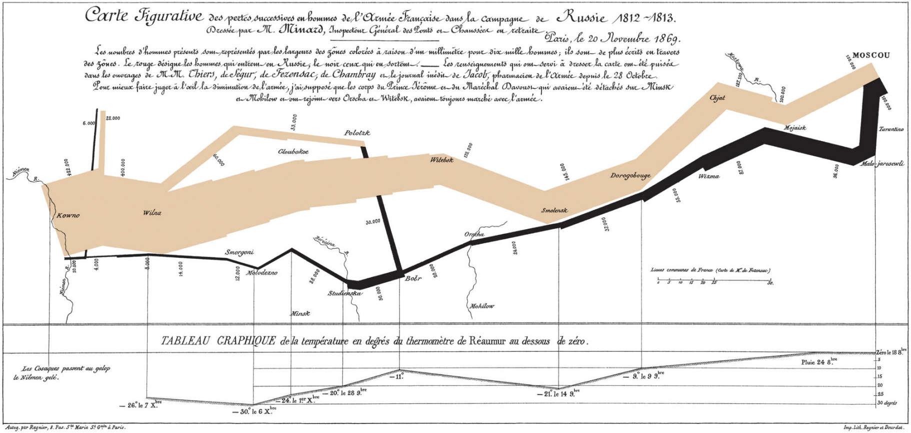
Sankey Plots for Visualising Bilateral Migration

Guy J. Abel

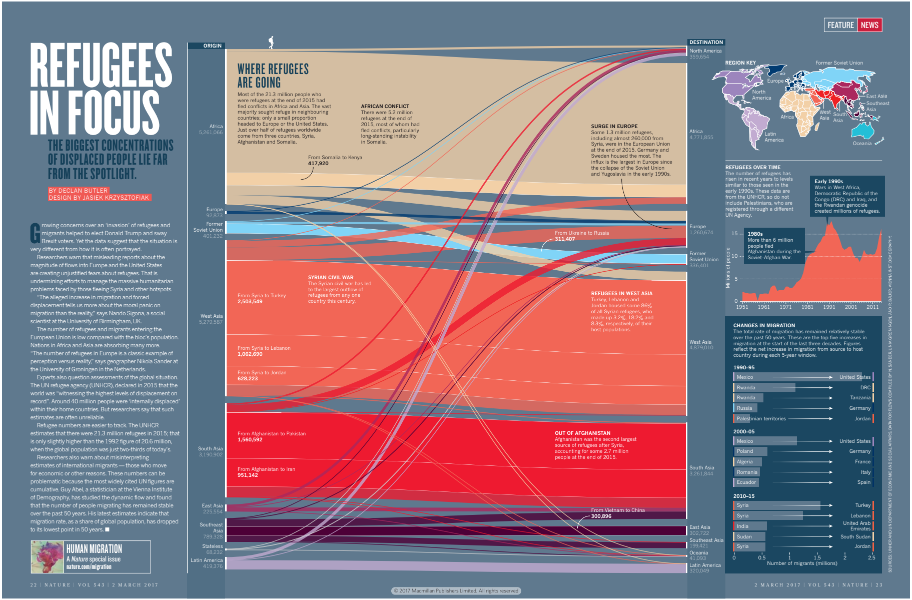
Background

- An alternative approach to visualize bilateral migration are Sankey or alluvial plots.
- Sankey plots feature arrows with width proportional to the flow quantity.
- Named after Irish Captain Sankey, who used to show the energy efficiency of a steam engine in 1898.
- Minard's plot of Napoleon's Russian Campaign of 1812 was made in 1869 - before Sankey
- Alluvial plots are a form of Sankey plot
  - Contain blocks at nodes (e.g. origin and destination of migraiton flows)
  - No space between blocks, implying a meaningful axis, unlike Sankey plots that do have spaces

Men in Napoleon’s 1812 Russian Campaign



Sankey plot of migration in Nature by Butler (2017)



FEATURE NEWS

REFUGEES IN FOCUS

THE BIGGEST CONCENTRATIONS OF DISPLACED PEOPLE LIE FAR FROM THE SPOTLIGHT.

BY DECLAN BUTLER
DESIGN BY JASIEK KRZYSZTOFIAK

Growing concerns over an 'invasion' of refugees and migrants helped to elect Donald Trump and sway Brexit voters. Yet the data suggest that the situation is very different from how it is often portrayed.

Researchers warn that misleading reports about the magnitude of flows into Europe and the United States are creating unjustified fears about refugees. That is undermining efforts to manage the massive humanitarian problems faced by those fleeing Syria and other hotspots.

"The alleged increase in migration and forced displacement tells us more about the moral panic on migration than the reality," says Nando Sigona, a social scientist at the University of Birmingham, UK.

The number of refugees and migrants entering the European Union is low compared with the bloc's population. Nations in Africa and Asia are absorbing many more. "The number of refugees in Europe is a classic example of perception versus reality," says geographer Nikola Sander at the University of Groningen in the Netherlands.

Experts also question assessments of the global situation. The UN refugee agency (UNHCR), declared in 2015 that the world was "witnessing the highest levels of displacement on record". Around 40 million people were 'internally displaced' within their home countries. But researchers say that such estimates are often unreliable.

Refugee numbers are easier to track. The UNHCR estimates that there were 21.3 million refugees in 2015; that is only slightly higher than the 1992 figure of 20.6 million, when the global population was just two-thirds of today's.

Researchers also warn about misinterpreting estimates of international migrants — those who move for economic or other reasons. These numbers can be problematic because the most widely cited UN figures are cumulative. Guy Abel, a statistician at the Vienna Institute of Demography, has studied the dynamic flow and found that the number of people migrating has remained stable over the past 50 years. His latest estimates indicate that migration rate, as a share of global population, has dropped to its lowest point in 50 years. ■

HUMAN MIGRATION
A *Nature* special issue
nature.com/migration

22 | NATURE | VOL 543 | 2 MARCH 2017

WHERE REFUGEES ARE GOING

Most of the 21.3 million people who were refugees at the end of 2015 had fled conflicts in Africa and Asia. The vast majority sought refuge in neighbouring countries; only a small proportion headed to Europe or the United States. Just over half of refugees worldwide come from three countries, Syria, Afghanistan and Somalia.

AFRICAN CONFLICT
There were 5.2 million refugees at the end of 2015, most of whom had fled conflicts, particularly long-standing instability in Somalia.

From Somalia to Kenya
417,920

SURGE IN EUROPE
Some 1.3 million refugees, including almost 260,000 from Syria, were in the European Union at the end of 2015. Germany and Sweden housed the most. The influx is the largest in Europe since the collapse of the Soviet Union and Yugoslavia in the early 1990s.

From Ukraine to Russia
311,407

SYRIAN CIVIL WAR
The Syrian civil war has led to the largest outflow of refugees from any one country this century.

From Syria to Turkey
2,503,549

From Syria to Lebanon
1,062,690

From Syria to Jordan
628,223

REFUGEES IN WEST ASIA
Turkey, Lebanon and Jordan housed some 86% of all Syrian refugees, who made up 3.2%, 18.2% and 8.3%, respectively, of their host populations.

From Afghanistan to Pakistan
1,560,592

From Afghanistan to Iran
951,142

OUT OF AFGHANISTAN
Afghanistan was the second largest source of refugees after Syria, accounting for some 2.7 million people at the end of 2015.

From Vietnam to China
300,896

REFUGEES OVER TIME
The number of refugees has risen in recent years to levels similar to those seen in the early 1990s. These data are from the UNHCR, so do not include Palestinians, who are registered through a different UN Agency.

Early 1990s
Wars in West Africa, Democratic Republic of the Congo (DRC) and Iraq, and the Rwandan genocide created millions of refugees.

1980s
More than 6 million people fled Afghanistan during the Soviet–Afghan War.

CHANGES IN MIGRATION
The total rate of migration has remained relatively stable over the past 50 years. These are the top five increases in migration at the start of the last three decades. Figures reflect the net increase in migration from source to host country during each 5-year window.

1990–95

Mexico	United States
Rwanda	DRC
Rwanda	Tanzania
Russia	Germany
Palestinian territories	Jordan

2000–05

Mexico	United States
Poland	Germany
Algeria	France
Romania	Italy
Ecuador	Spain

2010–15

Syria	Turkey
Syria	Lebanon
India	United Arab Emirates
Sudan	South Sudan
Syria	Jordan

SOURCES: UNHCR AND UN DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS. DATA FOR FLOWS COMPILED BY N. SANDER, UNIV. GRONINGEN, AND R. BAUER, VIENNA INST. DEMOGRAPHY.

2 MARCH 2017 | VOL 543 | NATURE | 23

Sankey plots in R

- As the number of regions or countries increases the plot become more cumbersome
    - Labels for the smaller areas get too small and the plotting area becomes a very long rectangle making it awkward to fit on paper or view on the screen.
    - In such cases I prefer chord diagrams
- There are a few packages in R that have functions for Sankey plots, such as *sankey*, *PantaRhei*, *networkD3*, *sankeywheel*, *plotly*, *ggsankey*.
    - Also *ggalluvial* which produces an allivual plot, but without any spaces between each sectors.
- I am going to use *ggforce* which I think is the most flexible
    - At the cost of a new layout for the data set
    - Good labels need a some work - as in *circlize* - because Sankey plots tend to have many set axis
    - Migration data tend to have only two set axis (origin and destinations)

Sankey plots in R

- For Sankey plots with *ggforce* the `gather_set_data()` function formats the data so that every migration corridor has two rows for the size of the migration at the origin and destination
- Can then use standard `ggplot()` function to set up the plot format. The mapping argument includes
  - `id` the id of the ribbons
  - `value` the size of the ribbons
  - `split` categories for splitting of the ribbons
- Add on layers for the ribbons themselves using `geom_parallel_sets()`
- Add blocks at the end of the ribbons to allow for clear identification of origin and destinations using `geom_parallel_sets_axes()`
- Add labels at the start and end of the ribbons using `geom_parallel_sets_axes()`

UN international migrant stock data 2020

- United Nations Department of Economic and Social Affairs Population Division (2020) stock data as before

```
> library(tidyverse)
> un <- read_csv(file = "../data/un_desa_ims_tidy.csv")
> un
# A tibble: 259,357 x 6
    year     stock dest  dest_code orig               orig_code
   <dbl>     <dbl> <chr>     <dbl> <chr>                  <dbl>
 1  1990 152986157 WORLD       900 WORLD                    900
 2  1995 161289976 WORLD       900 WORLD                    900
 3  2000 173230585 WORLD       900 WORLD                    900
 4  2005 191446828 WORLD       900 WORLD                    900
 5  2010 220983187 WORLD       900 WORLD                    900
 6  2015 247958644 WORLD       900 WORLD                    900
 7  2020 280598105 WORLD       900 WORLD                    900
 8  1990  15334807 WORLD       900 Sub-Saharan Africa       947
 9  1995  16488973 WORLD       900 Sub-Saharan Africa       947
10  2000  15638014 WORLD       900 Sub-Saharan Africa       947
# ... with 259,347 more rows
# i Use `print(n = ...)` to see more rows
```

UN international migrant stock data 2020

- Plot between World Bank income groups

```
> # codes for income groups
> cc <- c(1503:1500, 2003)
> d <- un %>%
+   filter(orig_code %in% cc,
+          dest_code %in% cc,
+          year == 2020) %>%
+   mutate(stock = stock/1e6)
> d
# A tibble: 16 x 6
    year  stock dest                          dest_code orig             orig_~1
   <dbl>  <dbl> <chr>                             <dbl> <chr>              <dbl>
 1  2020 45.8   High-income countries              1503 High-income cou~    1503
 2  2020 59.9   High-income countries              1503 Upper-middle-in~    1502
 3  2020 58.0   High-income countries              1503 Lower-middle-in~    1501
 4  2020 10.5   High-income countries              1503 Low-income coun~    1500
 5  2020  5.66  Upper-middle-income countries      1502 High-income cou~    1503
 6  2020 20.6   Upper-middle-income countries      1502 Upper-middle-in~    1502
 7  2020 18.3   Upper-middle-income countries      1502 Lower-middle-in~    1501
 8  2020 10.8   Upper-middle-income countries      1502 Low-income coun~    1500
 9  2020  0.961 Lower-middle-income countries      1501 High-income cou~    1503
10  2020  6.45  Lower-middle-income countries      1501 Upper-middle-in~    1502
11  2020 10.5   Lower-middle-income countries      1501 Lower-middle-in~    1501
12  2020  7.93  Lower-middle-income countries      1501 Low-income coun~    1500
```

Data format

- Format data for Sankey plot using `gather_set_data()` function in *ggforce*

```
> library(ggforce)
>
> s <- d %>%
+   select(orig, dest, stock) %>%
+   gather_set_data(x = 1:2)
> s
# A tibble: 32 x 6
   orig                          dest                    stock    id x     y
   <chr>                         <chr>                   <dbl> <int> <chr> <chr>
 1 High-income countries         High-income countries  45.8       1 orig  High~
 2 Upper-middle-income countries High-income countries  59.9       2 orig  Uppe~
 3 Lower-middle-income countries High-income countries  58.0       3 orig  Lowe~
 4 Low-income countries          High-income countries  10.5       4 orig  Low-~
 5 High-income countries         Upper-middle-income c~  5.66      5 orig  High~
 6 Upper-middle-income countries Upper-middle-income c~ 20.6       6 orig  Uppe~
 7 Lower-middle-income countries Upper-middle-income c~ 18.3       7 orig  Lowe~
 8 Low-income countries          Upper-middle-income c~ 10.8       8 orig  Low-~
 9 High-income countries         Lower-middle-income c~  0.961     9 orig  High~
10 Upper-middle-income countries Lower-middle-income c~  6.45     10 orig  Uppe~
# ... with 22 more rows
# i Use `print(n = ...)` to see more rows
```

Data format

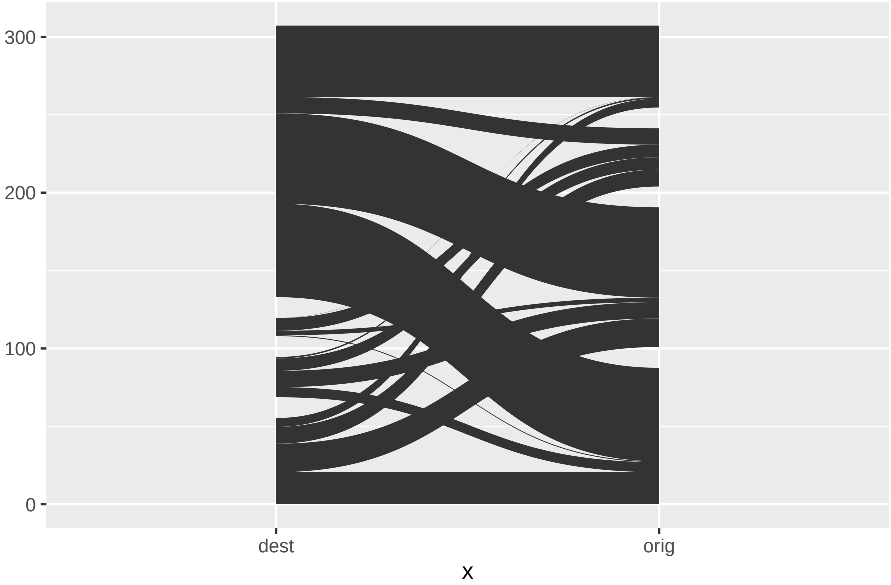
```
> tail(s)
# A tibble: 6 x 6
  orig                          dest                     stock    id x     y
  <chr>                         <chr>                    <dbl> <int> <chr> <chr>
1 Lower-middle-income countries Lower-middle-income co~ 10.5      11 dest  Lowe~
2 Low-income countries          Lower-middle-income co~  7.93     12 dest  Lowe~
3 High-income countries         Low-income countries     0.102    13 dest  Low-~
4 Upper-middle-income countries Low-income countries     0.579    14 dest  Low-~
5 Lower-middle-income countries Low-income countries     2.90     15 dest  Low-~
6 Low-income countries          Low-income countries     8.12     16 dest  Low-~
```

Default Plot

- Pass the different columns to `ggplot()` mappings
- The `geom_parallel_sets()` plots the ribbons

```
> ggplot(data = s,
+         mapping = aes(x = x, id = id, value = stock, split = y)) +
+   geom_parallel_sets()
```

Default Plot

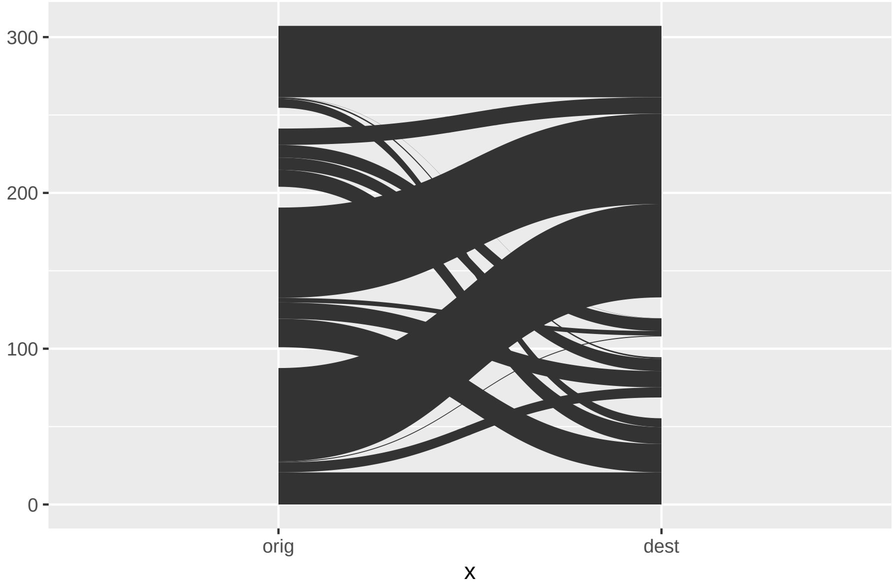


Default Plot

- By default the x-axis goes in alphabetical order
  - Use factors to set ordering of categorical variable

```
> levels(s$x)
NULL
> s <- mutate(s, x = fct_rev(x))
> levels(s$x)
[1] "orig" "dest"
>
> ggplot(data = s,
+        mapping = aes(x = x, id = id, value = stock, split = y)) +
+   geom_parallel_sets()
```

Default Plot

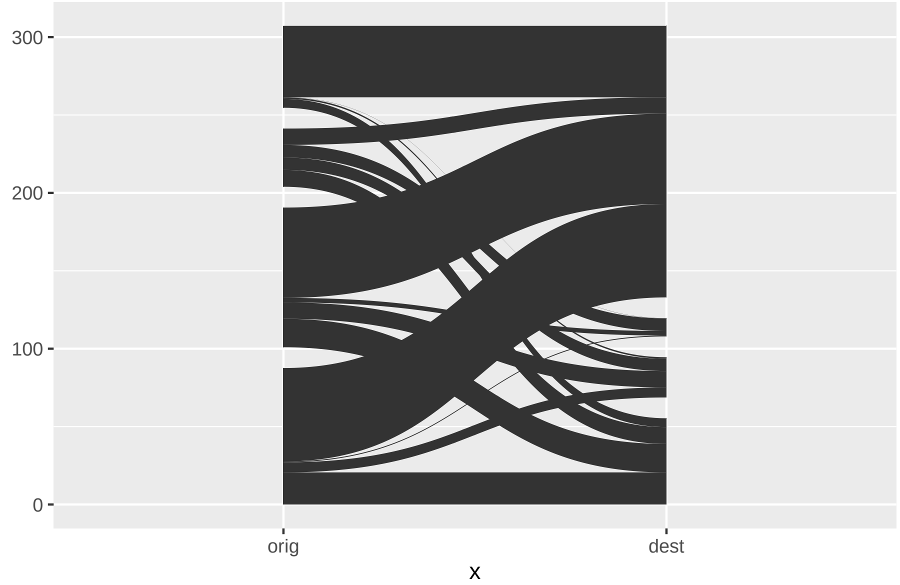


Set Axes

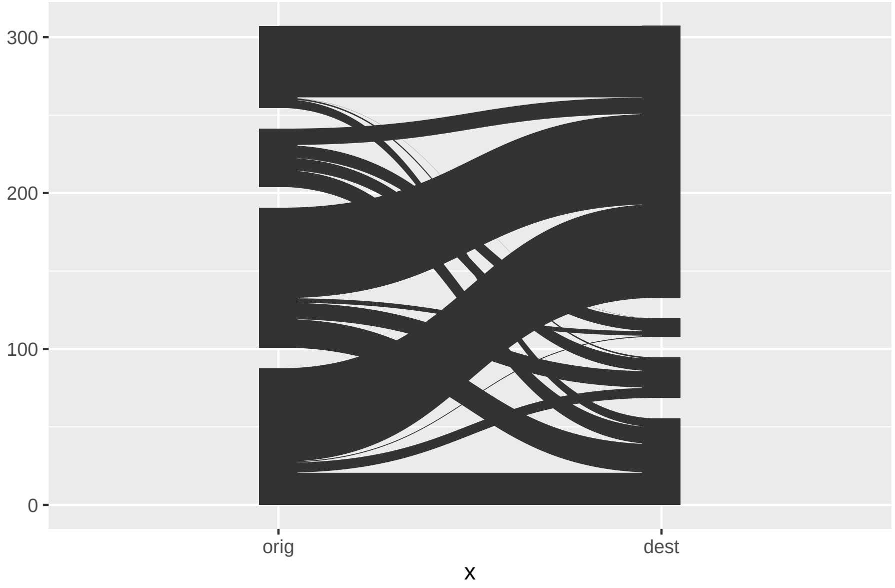
- The `geom_parallel_sets_axes()` function adds blocks besides the start and end of the ribbons
    - Set the width (as a proportion) using `axis.width`

```
> # default axis.width
> ggplot(data = s,
+        mapping = aes(x = x, id = id, value = stock, split = y)) +
+   geom_parallel_sets() +
+   geom_parallel_sets_axes()
>
> # wider axis.width
> ggplot(data = s,
+       mapping = aes(x = x, id = id, value = stock, split = y)) +
+   geom_parallel_sets() +
+   geom_parallel_sets_axes(axis.width = 0.1)
```

Set Axes



Set Axes

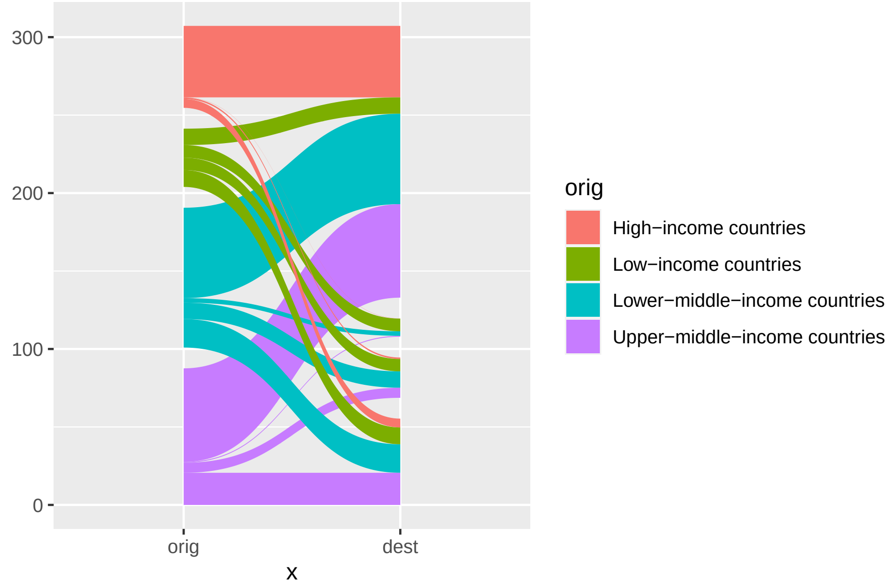


Colour

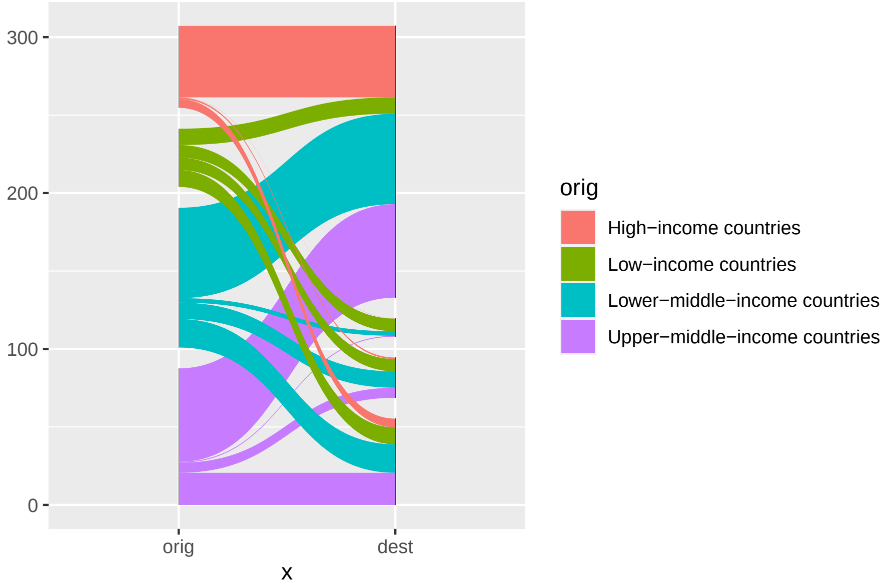
- Use mapping in geom_parallel_sets() to set the colours
  - Fill the colours following the origin regions, as was the case in the chord diagrams
- The geom_parallel_sets_axes() cannot take a fill colour from the data frame

```
> # geom_parallel_sets_axes cannot take fill colours from data
> ggplot(data = s, mapping = aes(x = x, id = id, value = stock, split = y, fill = o
+   geom_parallel_sets() +
+   geom_parallel_sets_axes()
Warning: Computation failed in `stat_parallel_sets_axes()`:
Axis aesthetics must be constant in each split
>
> # set fill colour for parallel_sets only
> ggplot(data = s, mapping = aes(x = x, id = id, value = stock, split = y)) +
+   geom_parallel_sets(mapping = aes(fill = orig)) +
+   geom_parallel_sets_axes()
```

Ribbon colour - failed axis colour



Ribbon colour

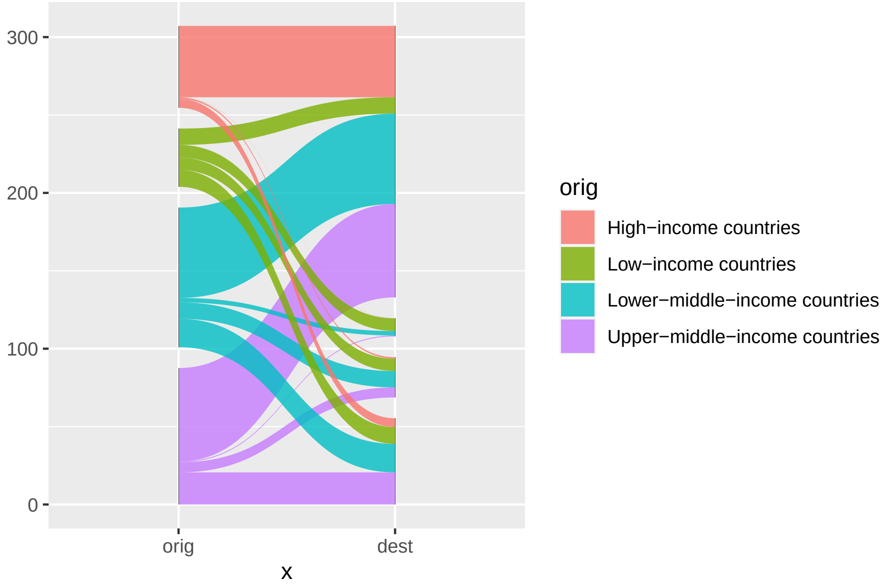


Ribbon transparency

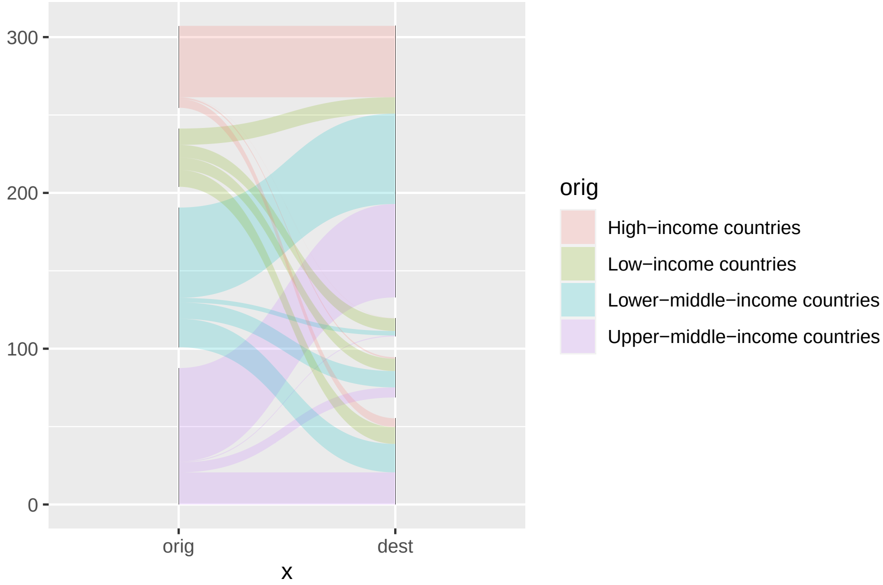
- Add some transparency in the ribbons using the `alpha` argument in `geom_parallel_sets()`

```
> # transparency of 0.8
> ggplot(data = s, mapping = aes(x = x, id = id, value = stock, split = y)) +
+   geom_parallel_sets(mapping = aes(fill = orig), alpha = 0.8) +
+   geom_parallel_sets_axes()
>
> # transparency of 0.2
> ggplot(data = s, mapping = aes(x = x, id = id, value = stock, split = y)) +
+   geom_parallel_sets(mapping = aes(fill = orig), alpha = 0.2) +
+   geom_parallel_sets_axes()
```

Ribbon colour



Ribbon colour

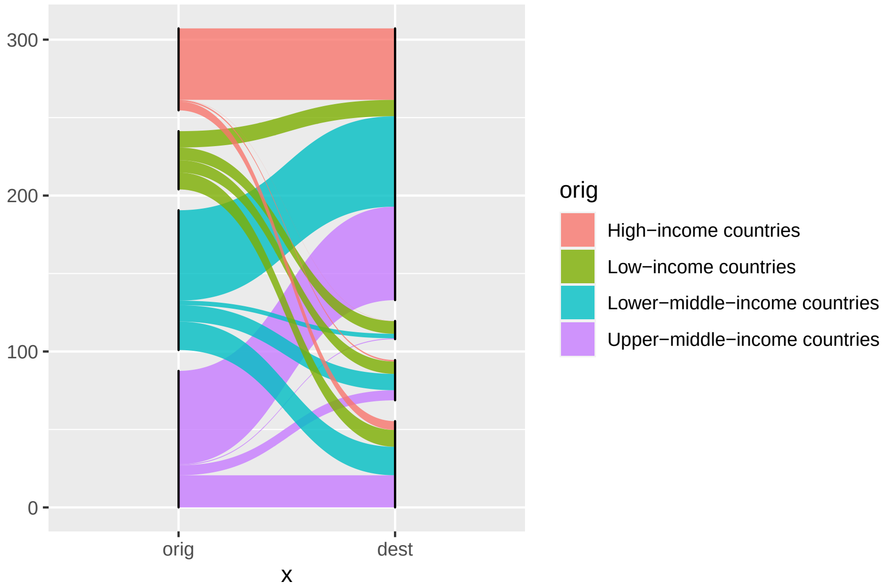


Axis colour

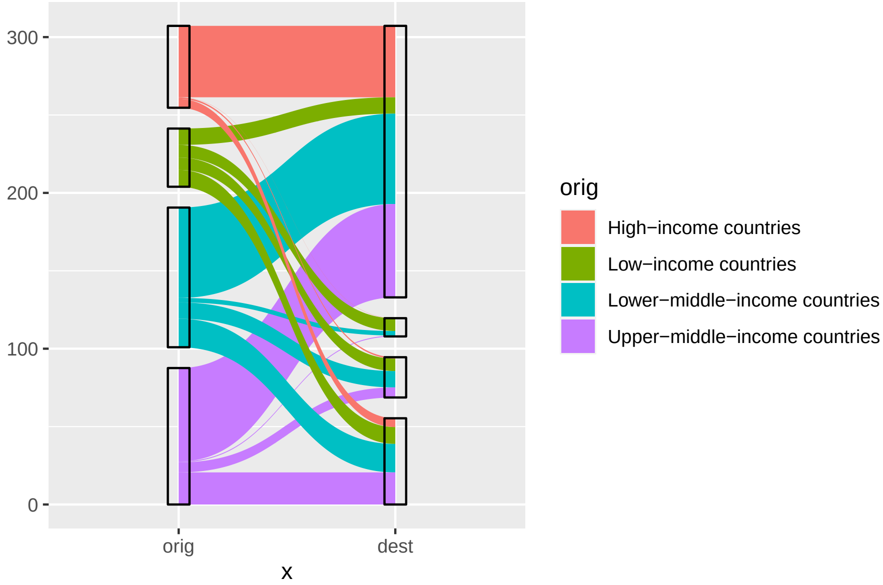
- To see the set axis colours we can draw an outline using the `colour` argument.
  - Also set `fill = "transparent"` in order to view the underlying ribbons

```
> # geom_parallel_sets_axes is an axis, can provide outline colour only
> ggplot(data = s, mapping = aes(x = x, id = id, value = stock, split = y)) +
+   geom_parallel_sets(mapping = aes(fill = orig), alpha = 0.8) +
+   geom_parallel_sets_axes(colour = "black")
>
> # geom_parallel_sets_axes is an axis, can provide outline colour only
> ggplot(data = s, mapping = aes(x = x, id = id, value = stock, split = y)) +
+   geom_parallel_sets(mapping = aes(fill = orig)) +
+   geom_parallel_sets_axes(fill = "transparent", colour = "black",
+                           axis.width = 0.1)
```

Axis colour


300
200
100
0
orig
dest
x
orig
High−income countries
Low−income countries
Lower−middle−income countries
Upper−middle−income countries

Axis colour

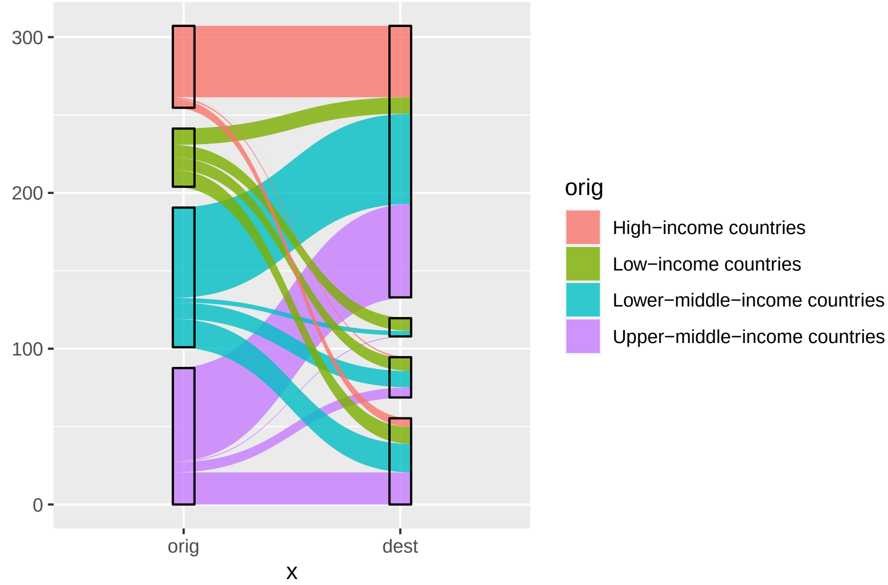

300
200
100
0
orig
dest
x
orig
🟥 High−income countries
🟩 Low−income countries
🟦 Lower−middle−income countries
🟪 Upper−middle−income countries

Axis colour

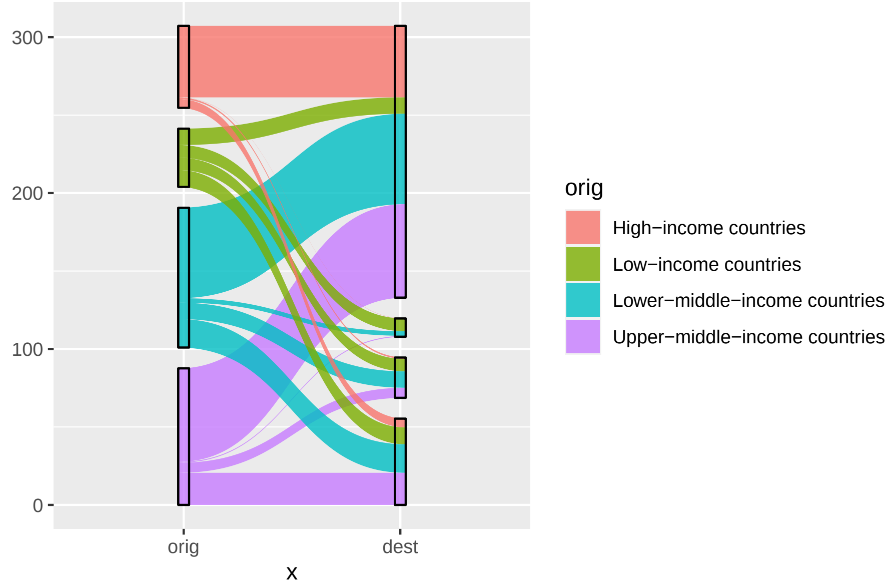
- Tweak the width in `geom_parallel_sets()` so that it fills into the axis box
  - Need to set `fill = "transparent"`

```
> ggplot(data = s, mapping = aes(x = x, id = id, value = stock, split = y)) +
+   geom_parallel_sets(mapping = aes(fill = orig), alpha = 0.8, axis.width = -0.1) +
+   geom_parallel_sets_axes(fill = "transparent", colour = "black",
+                           axis.width = 0.1)
>
> # narrower set axes
> ggplot(data = s,mapping = aes(x = x, id = id, value = stock, split = y)) +
+   geom_parallel_sets(mapping = aes(fill = orig), alpha = 0.8, axis.width = -0.05) +
+   geom_parallel_sets_axes(fill = "transparent", colour = "black",
+                           axis.width = 0.05)
```

Axis colour


300
200
100
0
orig
dest
x
orig
High−income countries
Low−income countries
Lower−middle−income countries
Upper−middle−income countries

Axis colour

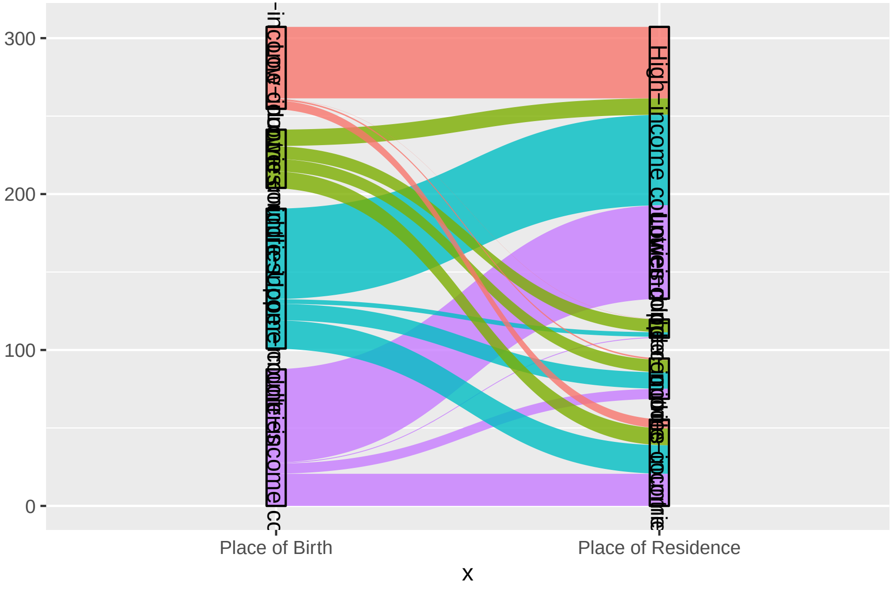

300
200
100
0
orig
dest
x
orig
High−income countries
Low−income countries
Lower−middle−income countries
Upper−middle−income countries

Labels

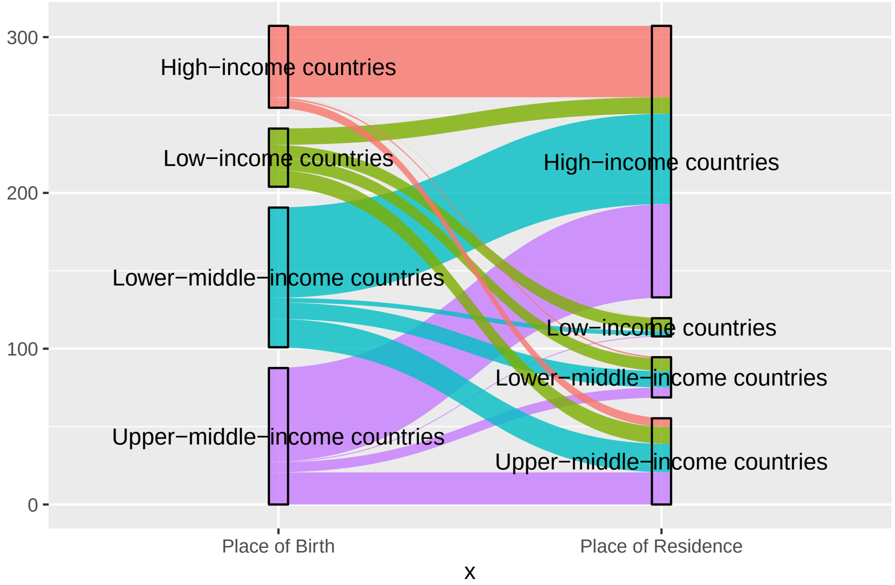
- Add labels on the x-axis using `scale_x_discrete()` from *ggplot2*
- Add labels to the sets using `geom_parallel_sets_labels()` from *ggforce*
  - Terrible default positions and angles if labels are not very short.

```
> ggplot(data = s, mapping = aes(x = x, id = id, value = stock, split = y)) +
+   geom_parallel_sets(mapping = aes(fill = orig), alpha = 0.8, axis.width = -0.05)
+   geom_parallel_sets_axes(fill = "transparent", colour = "black",
+                           axis.width = 0.05) +
+   guides(fill = "none") +
+   geom_parallel_sets_labels() +
+   scale_x_discrete(labels = c(orig = "Place of Birth",
+                               dest = "Place of Residence"))
>
> ggplot(data = s, mapping = aes(x = x, id = id, value = stock, split = y)) +
+   geom_parallel_sets(mapping = aes(fill = orig), alpha = 0.8, axis.width = -0.05)
+   geom_parallel_sets_axes(fill = "transparent", colour = "black",
+                           axis.width = 0.05) +
+   guides(fill = "none") +
+   geom_parallel_sets_labels(angle = 0) +
+   scale_x_discrete(labels = c(orig = "Place of Birth",
+                               dest = "Place of Residence"))
```

Defualt labels



Labels with `angle = 0`



Labels

- Change order of origin and destinations by modifying the levels of the factors
  - Set levels to order they appear in the y column using `fct_inorder()` in the *forcats* package
  - Remove unnecessary parts in the label

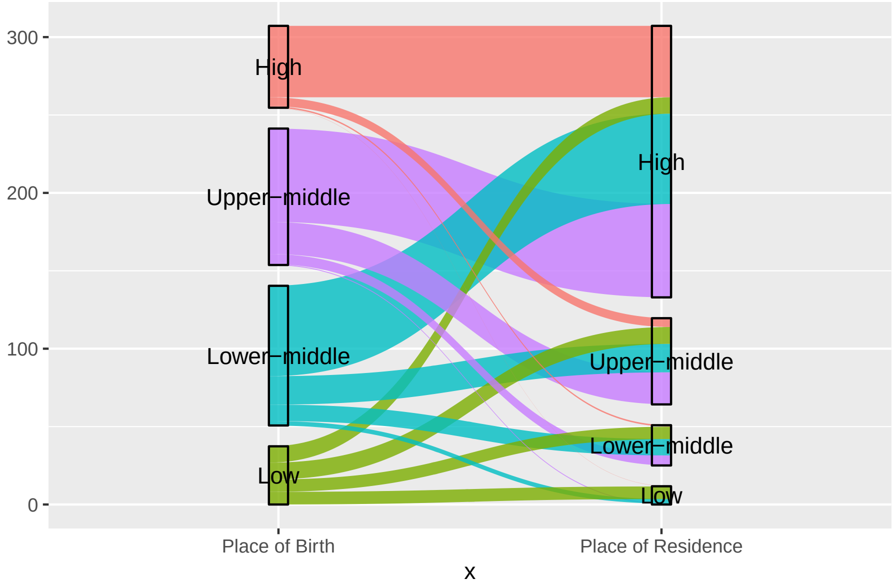
```
> levels(s$y)
NULL
> s <- s %>%
+   mutate(y = str_remove(string = y, pattern = "-income countries"),
+          y = fct_inorder(y))
> levels(s$y)
[1] "High"         "Upper-middle" "Lower-middle" "Low"
> s
# A tibble: 32 x 6
   orig                          dest                    stock    id x     y
   <chr>                         <chr>                   <dbl> <int> <fct> <fct>
 1 High-income countries         High-income countries  45.8        1 orig  High
 2 Upper-middle-income countries High-income countries  59.9        2 orig  Uppe~
 3 Lower-middle-income countries High-income countries  58.0        3 orig  Lowe~
 4 Low-income countries          High-income countries  10.5        4 orig  Low
 5 High-income countries         Upper-middle-income c~  5.66       5 orig  High
 6 Upper-middle-income countries Upper-middle-income c~ 20.6        6 orig  Uppe~
 7 Lower-middle-income countries Upper-middle-income c~ 18.3        7 orig  Lowe~
 8 Low-income countries          Upper-middle-income c~ 10.8        8 orig  Low
 9 High-income countries         Lower-middle-income c~  0.961      9 orig  High
```

Labels

- Run same code as before, with updates s,. . .

```
> ggplot(data = s,
+        mapping = aes(x = x, id = id, value = stock, split = y)) +
+   geom_parallel_sets(mapping = aes(fill = orig), alpha = 0.8, axis.width = -0.05)
+   geom_parallel_sets_axes(fill = "transparent", colour = "black",
+                           axis.width = 0.05) +
+   guides(fill = "none") +
+   geom_parallel_sets_labels(angle = 0) +
+   scale_x_discrete(labels = c(orig = "Place of Birth",
+                               dest = "Place of Residence"))
```

New, shorter labels



Labels

- Set up a label data frame to adjust position and alignment

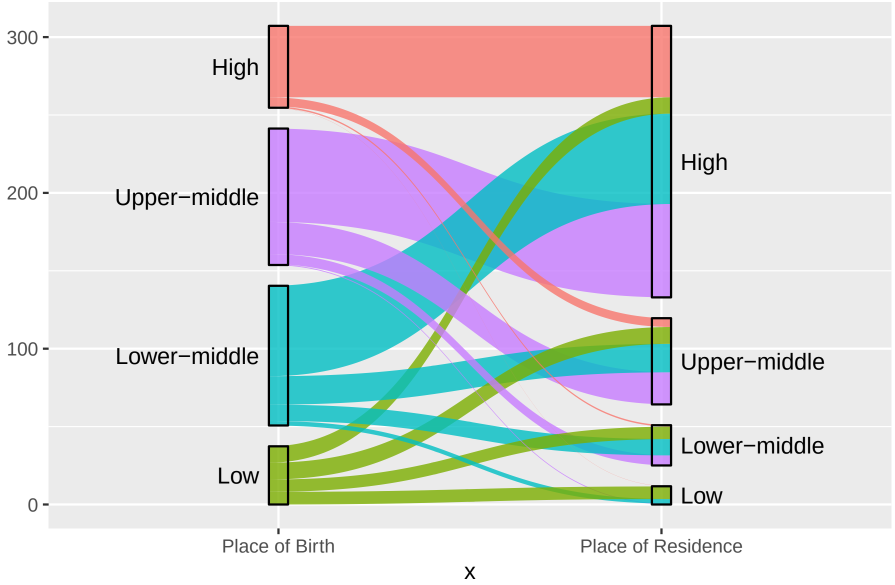
```
> p <- s %>%
+   distinct(x, y) %>%
+   mutate(h = as.numeric(x == "orig"),
+          n = h * -0.1 + 0.05)
> p
# A tibble: 8 x 4
  x     y                h     n
  <fct> <fct>        <dbl> <dbl>
1 orig  High             1 -0.05
2 orig  Upper-middle     1 -0.05
3 orig  Lower-middle     1 -0.05
4 orig  Low              1 -0.05
5 dest  High             0  0.05
6 dest  Upper-middle     0  0.05
7 dest  Lower-middle     0  0.05
8 dest  Low              0  0.05
```

Labels

- Pass the position coordinates to the ggplot code

```
> ggplot(data = s,
+        mapping = aes(x = x, id = id, value = stock, split = y)) +
+   geom_parallel_sets(mapping = aes(fill = orig), alpha = 0.8,
+                      axis.width = -0.05) +
+   geom_parallel_sets_axes(fill = "transparent", colour = "black",
+                           axis.width = 0.05) +
+   guides(fill = "none") +
+   geom_parallel_sets_labels(angle = 0, hjust = p$h,
+                             position = position_nudge(x = p$n)) +
+   scale_x_discrete(labels = c(orig = "Place of Birth",
+                               dest = "Place of Residence"))
```

Looking good

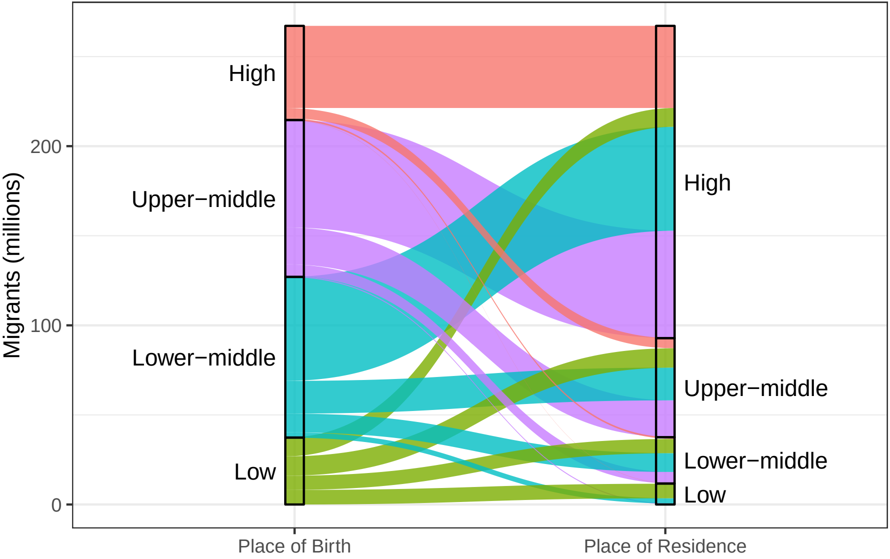


Spacing

- We convert the Sankey plot to an alluvial plot by reducing the space separating the parallel sets to zero via the sep argument
  - Need to set sep in all the geom functions for alignment.
  - Default is sep = 0.05 (5%)
  - Might need to reduce when have many regions
- In alluvial plots the y-axis are more meaningful
  - Add y-axis labels via labs() function
- Set background to white using theme_bw() function

```
> ggplot(data = s,
+        mapping = aes(x = x, id = id, value = stock, split = y)) +
+   geom_parallel_sets(mapping = aes(fill = orig), alpha = 0.8,
+                      axis.width = -0.05, sep = 0) +
+   geom_parallel_sets_axes(fill = "transparent", colour = "black",
+                           axis.width = 0.05, sep = 0) +
+   guides(fill = "none") +
+   geom_parallel_sets_labels(angle = 0, hjust = p$h,
+                             position = position_nudge(x = p$n, ), sep = 0) +
+   scale_x_discrete(labels = c(orig = "Place of Birth",
+                               dest = "Place of Residence")) +
+   labs(y = "Migrants (millions)", x = "") +
+   theme_bw()
```

Alluvial plot



Exercise (ex9.R)

```
# 0.  a) Load the KOSTAT2022.Rproj file.
#     Run the getwd() below. It should print the directory where the
#     KOSTAT2022.Rproj file is located.
getwd()
#     b) Load the packages used in this exercise
library(tidyverse)
library(ggforce)
##
##
##
##
# 1. Run the code below to read in the migrant stock data from Gabon taken
#    from Table 21-6 in Shryock & Siegel (1979)
ga <- read_csv("./data/gabon_1961_tidy.csv")
ga
# 2. Run the code below to remove the totals groups and migrants from abroad
d <- ga %>%
  rename(orig = place_of_birth,
         dest = place_of_enumeration) %>%
  filter(sex == "total",
         !orig %in% c("Grand total", "Abroad", "Total Gabon"),
         dest != "Total") %>%
  select(-sex)
d
# 3. Create a data frame s1 using the gather_set_data() function to organise the
```

References

Butler, Declan. 2017. "What the numbers say about refugees." *Nature* 543 (7643): 22–23. https://doi.org/10.1038/543022a.

United Nations Department of Economic and Social Affairs Population Division. 2020. "International Migrant Stock 2020 (United Nations database, POP/DB/MIG/Stock/Rev.2020)." New York, New York, USA: United Nations Department of Economic; Social Affairs/Population Division. https://doi.org/10.18356/b4899381-en.