Markdown Main code

1. Technological Spaces based on Technological field

1.1. Calculate Specializations for Different Time intervals

In this first part, we load the very large datasets containing patent data and inventor's location, and use them to calculate specialisations and ultimately create the Global technological space (GTS) and the AI-specific technological space (ATS). We calculate specialisations per interval.

We start by defining custom functions and loading the first part of the large patent dataset with inventors' location.

The patent file with inventors' location looks like this:

```
head(ipc_all_patents_part2_df)

##    appln_id ctry_code techn_field_nr weight priority_year
##       <int>    <char>          <int> <char>         <int>
## 1:   203438        JP              2      9          2000
## 2:   203438        JP              2      9          2000
## 3:   203438        JP              9      1          2000
## 4:   203438        JP              9      1          2000
## 5:   203521        US             15    375          1996
## 6:   203521        US             16    625          1996
```

The weight column was downloaded from patstat, but it it's totally irrelevant and it will be calculated again later. We load next the data on AI patents (file "other_files/IPCs_AI.csv"). It looks like this:

```
head(ai_patents_df)

##     appln_id appln_id2 patent_office priority_year ctry_code source  kinds
##        <int>     <int>        <char>         <int>    <char>  <int> <char>
## 1: 475222998 475222998            CN          2016    AI_pat      7 single
## 2: 475222998 475222998            CN          2016    AI_pat      7 single
## 3: 475222998 475222998            CN          2016    AI_pat      7 single
## 4: 475222998 475222998            CN          2016    AI_pat      7 single
## 5: 475222998 475222998            CN          2016    AI_pat      7 single
## 6: 475222998 475222998            CN          2016    AI_pat      7 single
##    appln_id3 ipc_class_symbol ipc_class_level ipc_version ipc_value
##        <int>           <char>          <char>      <char>    <char>
## 1: 475222998      G06F  17/22               A  01/01/2006         I
## 2: 475222998      G06F  17/24               A  01/01/2006         I
## 3: 475222998      G06F  17/27               A  01/01/2006         I
## 4: 475222998      G06F  17/30               A  01/01/2006         I
## 5: 475222998      G06F  19/00               A  01/01/2011         I
```

```
## 6: 475222998      G06N   3/08              A  01/01/2006         I
##    ipc_position ipc_gener_auth
##          <char>         <char>
## 1:            L             CN
## 2:            L             CN
## 3:            L             CN
## 4:            F             CN
## 5:            L             CN
## 6:            L             CN
```

We also load the IPC file with information about technological fields (file “other_files/ipc_technology.csv”), which after processing looks like this:

```
head(ipc_names_df)
```

```
##   field_nr                 sector                              field_name
## 1        1 Electrical engineering Electrical machinery, apparatus, energy
## 2        2 Electrical engineering                Audio-visual technology
## 3        3 Electrical engineering                     Telecommunications
## 4        4 Electrical engineering                  Digital communication
## 5        5 Electrical engineering          Basic communication processes
## 6        6 Electrical engineering                    Computer technology
##   techn_field_nr
## 1              1
## 2              2
## 3              3
## 4              4
## 5              5
## 6              6
```

Now we’ll start calculating the specialisations of countries and AI technologies per interval. We have three intervals, the first being from 1974 to 1988, the second from 1989 to 2003, and the third from 2004 to 2018. We start by breaking the large patent file into it’s corresponding interval, and applying the two custom functions over it (group_by_applnID and group_by_ctry_and_techn_field).

The first function (group_by_applnID) groups data by application ID, and within each group, calculates a field-specific weight equal to 1 divided by the number of technological fields in that group. After applying this function over our interval-specific patent data, it looks like this:

```
head(region_tech_fields_1_df)
```

```
## # A tibble: 6 × 4
##   appln_id ctry_code techn_field_nr field_weight
##      <int> <chr>              <int>        <dbl>
## 1   206163 DE                     1         0.5
## 2   206163 DE                     1         0.5
## 3   214019 FR                     9         0.25
## 4   214019 FR                     9         0.25
## 5   214019 FR                    29         0.25
## 6   214019 FR                    29         0.25
```

Next we apply the second function (group_by_ctry_and_techn_field), which aggregates the weighted fields at the country-technology field level. After applying it, the data looks like this:

```
head(region_tech_fields_1_df)
```

```
## # A tibble: 6 × 3
##   ctry_code techn_field_nr n_tech_reg
##   <chr>              <int>      <dbl>
## 1 AD                    20          1
## 2 AD                    24          1
## 3 AD                    28          3
## 4 AD                    32          1
## 5 AD                    33          1
## 6 AD                    34          3
```

This file is saved as a csv for being used later (for this first interval, the name and location of the file is "Files_created_with_the_code/data/files_code_Fields_analysis/reg_tech_FirstPeriod.csv"). We use this file in the next calculation, in which we create a matrix from this aggregated data. The matrix counts the name of registers of each country in which possible technological field. It looks like this:

```
print(as.matrix(mat_reg_tech1[1:20, 1:12]))
```

```
##       1    2    3   4   5   6  7   8    9   10  11   12
## AG    1    0    0   0   0   0  0   0    0    0   0    0
## AM    1    0    0   0   0   0  0   0    0    0   0    0
## AR   11    7    6   1   2   2  0   0    3   12   1    6
## AT  758  299  198  23 131  64  1  28  279  461  38  130
## AU 1403  606  409  48 178 272 10  81  509 1321 149  659
## BA    0    0    0   0   0   0  0   0    0    0   0    0
## BB    0    0    0   0   0   0  0   0    0    1   0    0
## BE  261   97  159  32  54  43  0  26  182  196  65   80
## BG  992  335  166  36 333 455  0 114  228 1284 137  340
## BI    1    0    0   0   0   0  0   0    0    0   0    0
## BM    2    2    0   0   0   0  0   0    0    0   0    0
## BO    2    0    0   0   0   0  0   0    0    1   0    1
## BR 1759  647  754  47 138 325 12  50  296  962  48  851
## BS    4    0    0   0   0   0  0   0    0    0   0    0
## BU    0    0    0   0   0   0  0   0    0    1   0    0
## CA 3827 1409 1474 254 553 784 14 372 1368 2915 252 1041
## CH 2194  788  372 108 299 242  4 225  841 2526 120  754
## CL    0    1    1   0   0   1  0   0    1    1   0    2
## CN  931  233  146  20 106 317  0 132  306  994  45  223
## CO    8    2    0   0   0   0  0   0    0    0   0    4
```

We finally use this matrix to calculate the general specialisations (RTA indexes, which stands for Revealed Technological Advantage) of countries in this first interval. The RTA is set to be non-binary, and the data looks like this after this calculation:

```
head(reg_RCA1_df)
```

```
## # A tibble: 6 × 3
##   ctry_code techn_field_nr    RCA
##   <chr>     <chr>           <dbl>
## 1 AG        1               6.41
## 2 AM        1              12.8
## 3 AR        1               0.421
## 4 AT        1               0.748
## 5 AU        1               0.479
## 6 BA        1               0
```

We do the same for the specialisations of countries in AI considering the AI patents in this interval. The steps are pretty much the same: we separate the AI data into this specific interval (ai_patents_df), apply the two custom functions (group_by_applnID and group_by_ctry_and_techn_field), save the file ("Files_created_with_the_code/data/files_code_Fields_analysis/Data1period_RCA_techn_field.csv"), create a matrix, and use it to calculate countries' specialisations in AI for this period. The AI-related specialisations data looks like this:

```
head(reg_RCA1_AI_df)

## # A tibble: 6 × 3
##   ctry_code techn_field_nr   RCA
##   <chr>     <chr>          <dbl>
## 1 AT        1                  0
## 2 AT        10                 0
## 3 AT        11                 0
## 4 AT        12                 0
## 5 AT        13                 0
## 6 AT        17                 0
```

We merge this data with the "general" specialisations calculated earlier. The resulting file and an additional example for the case of Japan look like this:

```
#Resulting file:
head(rca_data_period_1_df)

##   ctry_code techn_field_nr RCA_Gen RCA_AI    Period
## 1        AD              1       0     NA 1974-1988
## 2        AD             10       0     NA 1974-1988
## 3        AD             11       0     NA 1974-1988
## 4        AD             12       0     NA 1974-1988
## 5        AD             13       0     NA 1974-1988
## 6        AD             14       0     NA 1974-1988

#Example Japan:
head(rca_data_period_1_df[rca_data_period_1_df$ctry_code == "JP",])

##      ctry_code techn_field_nr   RCA_Gen    RCA_AI    Period
## 2731        JP              1 1.1268685 1.4025974 1974-1988
## 2732        JP             10 1.0109760 1.2022263 1974-1988
## 2733        JP             11 0.7067914 0.0000000 1974-1988
## 2734        JP             12 1.0644547 1.0957792 1974-1988
```

```
## 2735         JP              13 0.6104061 0.7012987 1974-1988
## 2736         JP              14 0.6177233        NA 1974-1988
```

We save this data for later usage ("Files_created_with_the_code/data/files_code_Fields_analysis/Data1period_RCA_techn_field.csv"). Next, we turn to the AI-specific specialisations of this interval. We pick our AI data for this interval and replace their country codes by a new "AI-specific" fake code named AI_pat. This allows us to calculate specialisations for AI as it were a country exploring distinct technologies. We apply the same two custom functions over it (group_by_applnID and group_by_ctry_and_techn_field), and get the following resulting file with the AI specialisations:

```
head(region_tech_ai_1_df[region_tech_ai_1_df$ctry_code == "AI_pat",])

## # A tibble: 6 × 3
##   ctry_code techn_field_nr n_tech_reg
##   <chr>              <int>      <dbl>
## 1 AI_pat                 1       1.75
## 2 AI_pat                 2       2.25
## 3 AI_pat                 3       3.53
## 4 AI_pat                 4       2.75
## 5 AI_pat                 5      12.9
## 6 AI_pat                 6     279.
```

We also save this file for later usage ("Files_created_with_the_code/data/files_code_Fields_analysis/reg_techAI_FirstPeriod.csv") . We do the exact same thing for the two remaining intervals (namely Interval 2 [1989-2003], and Interval 3 [2004-2018]), saving corresponding interval-specific files throughout the process. At the end, we combine the three interval-specific files with countries' general and AI-specific specialisations (namely rca_data_period_1_df, rca_data_period_2_df, rca_data_period_3_df) into a single file named ipc_rcas_df, which we also save ("Files_created_with_the_code/data/files_code_Fields_analysis/IPC_RCAs.csv"). Using again the case of Japan as an example and considering each of the three intervals, the combined and saved ipc_rcas_df file looks like this:

```
head(IPC_RCAs[IPC_RCAs$ctry_code == "JP" & IPC_RCAs$Period == "1974-1988",])

##      ctry_code techn_field_nr   RCA_Gen    RCA_AI    Period
## 2731        JP              1 1.1268685 1.4025974 1974-1988
## 2732        JP             10 1.0109760 1.2022263 1974-1988
## 2733        JP             11 0.7067914 0.0000000 1974-1988
## 2734        JP             12 1.0644547 1.0957792 1974-1988
## 2735        JP             13 0.6104061 0.7012987 1974-1988
## 2736        JP             14 0.6177233        NA 1974-1988

head(IPC_RCAs[IPC_RCAs$ctry_code == "JP" & IPC_RCAs$Period == "1989-2003",])

##      ctry_code techn_field_nr   RCA_Gen    RCA_AI    Period
## 9486        JP              1 1.1395992 0.9834465 1989-2003
## 9487        JP             10 1.0147327 0.8904603 1989-2003
## 9488        JP             11 0.6029495 0.6173858 1989-2003
```

```
## 9489        JP              12 1.0394907 0.9396071 1989-2003
## 9490        JP              13 0.5833007 0.5805270 1989-2003
## 9491        JP              14 0.6666774 1.8521575 1989-2003
```

```
head(IPC_RCAs[IPC_RCAs$ctry_code == "JP" & IPC_RCAs$Period == "2004-2018",])
```

```
##       ctry_code techn_field_nr   RCA_Gen    RCA_AI    Period
## 18341        JP              1 1.2953810 1.3244132 2004-2018
## 18342        JP             10 0.8728225 0.9737969 2004-2018
## 18343        JP             11 0.5286471 0.9540950 2004-2018
## 18344        JP             12 0.8957888 1.1166269 2004-2018
## 18345        JP             13 0.8071723 1.3124353 2004-2018
## 18346        JP             14 0.5785004 3.3393324 2004-2018
```

Next, we create additional interval-specific files that combine the specialisations of the four considered countries with the specialisations of AI in a more user-friendly format. One file is created and saved per interval. For the first interval, the file created is named "First_period", and it is saved as "Files_created_with_the_code/data/files_code_Fields_analysis/Metrics_First_period.csv". The file looks like this:

```
head(First_period)
```

```
##   techn_field_nr                 sector
field_name
## 1              1 Electrical engineering Electrical machinery, apparatus,
energy
## 2              2 Electrical engineering                Audio-visual
technology
## 3              3 Electrical engineering
Telecommunications
## 4              4 Electrical engineering                  Digital
communication
## 5              5 Electrical engineering         Basic communication
processes
## 6              6 Electrical engineering                   Computer
technology
##      RCA_US    RCA_CN    RCA_KR   RCA_JP      RCA_AI
## 1 0.8061303 0.7812853 0.8859104 1.126869  0.05934926
## 2 0.5290351 0.2812052 1.5817366 1.341886  0.08535377
## 3 0.6577273 0.3468912 1.4004752 1.230989  0.33606440
## 4 0.7356689 0.2069789 1.3043447 1.244439  1.09784935
## 5 0.8740121 0.3793871 1.0785703 1.191508  1.64528254
## 6 0.6008344 0.5349367 0.9466936 1.371771 16.64849577
```

The same is done for the remaining two intervals. Finally, we combine these 3 interval-specific files into a single file, adding some additional labels to the technological fields considering their visual location around the GTS. These additional labels are just information for analysis, which is not really used or mentioned in the paper. The file is named "All_periods" and saved at

"Files_created_with_the_code/data/files_code_Fields_analysis/Specializations_All_periods_IPC.csv". It looks like this:

```
head(IPC_names)

##   techn_field_nr                 sector
field_name
## 1              1 Electrical engineering Electrical machinery, apparatus,
energy
## 2              2 Electrical engineering                 Audio-visual
technology
## 3              3 Electrical engineering
Telecommunications
## 4              4 Electrical engineering                    Digital
communication
## 5              5 Electrical engineering          Basic communication
processes
## 6              6 Electrical engineering                     Computer
technology
##                RCA_US            RCA_CN            RCA_KR           RCA_JP
## 1 0,806130295464133 0,781285306548244 0,885910356664018  1,1268685164478
## 2  0,52903509458199 0,281205160490934  1,58173657700963 1,34188556343943
## 3 0,657727334104245 0,346891200617381  1,40047520647904 1,23098888970641
## 4 0,735668946649889 0,206978925416903  1,30434472270759  1,2444394102031
## 5 0,874012134211958 0,379387109049058  1,07857025021714 1,19150764942163
## 6 0,600834418175826 0,534936673226541 0,946693574054904 1,37177058622865
##                RCA_AI              Period          Category Category2
## 1 0,0593492634039308 Period 1 (1974-1988) Surrounding fields         3
## 2 0,0853537728458771 Period 1 (1974-1988) Surrounding fields         3
## 3  0,336064398912961 Period 1 (1974-1988) Surrounding fields         3
## 4   1,09784934911933 Period 1 (1974-1988)  AI-related fields         2
## 5   1,64528253859531 Period 1 (1974-1988)  AI-related fields         2
## 6   16,6484957668701 Period 1 (1974-1988)     AI-core fields         1
```

In the last step, we use the previously saved file named "Files_created_with_the_code/data/files_code_Fields_analysis/IPC_RCAs.csv" to create a file summarizing the number of general (column Round_general), AI-specific (column Round_AI), and coinciding specialisations (column Total_RCA) of each country over each interval. The previously calculated general and AI-specific specialisations are made binary, and their sum composes the number of coinciding specialisations. The resulting file IPC_RCAs_Top4 is saved at "Files_created_with_the_code/data/files_code_Fields_analysis/RCA_4countries_detailed.csv" and looks like this:

```
head(IPC_RCAs_Top4)

##   ctry_code techn_field_nr   RCA_Gen RCA_AI    Period
## 1        CN              1 0.7812853      0 1974-1988
## 2        CN             10 1.2306427      0 1974-1988
## 3        CN             11 0.9483087      0 1974-1988
## 4        CN             12 0.7424070      0 1974-1988
```

```
## 5        CN              13 1.3542371      0 1974-1988
## 6        CN              14 0.9327427      0 1974-1988
##                                     Label Round_general Round_AI Total_RCA
## 1 Electrical machinery, apparatus, energy             0        0         0
## 2                             Measurement             1        0         1
## 3        Analysis of biological materials             0        0         0
## 4                                 Control             0        0         0
## 5                      Medical technology             1        0         1
## 6                  Organic fine chemistry             0        0         0
```

1.2. Create Sparse Matrix of relatedness between technological fields

This section creates a large sparse matrix from patent-techn_field data and computes their co-occurrence (cross-product). Finally, it saves the resulting technology-relatedness matrix. We start again by reading the very large files containing patent and inventors' location data. But this time, we apply the function "create_sparse_matrix", which creates a sparse matrix of co-occurences of technological fields in patents. The result of applying the function is a matrix that shows in lines each unique application id of patents, and in columns all of the 35 possible technological fields containing information about the respective technological field being used in the respective patent or not (0s for not, above this value for the number of times that the code appears in each individual patent). Because the files are too big and a bit problematic computational-wise, they are split into smaller files that are summed up after everything is calculated. The first file resulting from applying the create_sparse_matrix function, named mat_tech_AI1, looks like this:

```
print(as.matrix(mat_tech_AI1[1:20, 1:12]))
```

```
##     1 2 3 4 5 6 7 8 9 10 11 12
## 58  0 0 0 0 0 2 0 0 0  0  0  0
## 76  0 0 0 0 0 0 0 0 0  0  0  0
## 111 0 0 0 0 0 0 0 0 0  0  0  0
## 139 0 0 0 0 0 0 0 0 0  0  0  4
## 151 0 0 0 0 0 0 0 0 0  0  0  0
## 159 0 0 0 0 0 0 0 0 0  0  0  0
## 183 0 0 0 0 0 0 0 0 0  0  0  0
## 193 0 0 0 0 0 0 0 0 0  0  0  0
## 200 0 0 0 0 0 0 0 0 0  0  0  0
## 206 0 0 0 0 0 0 0 0 0  0  0  0
## 217 0 0 0 0 0 0 0 0 0  0  0  0
## 218 0 0 0 0 0 0 0 0 0  0  0  0
## 220 0 0 0 0 1 0 0 0 0  0  0  0
## 231 1 0 0 0 0 0 0 0 0  0  0  0
## 243 3 0 0 0 0 0 0 0 0  0  0  0
## 246 0 0 0 0 0 0 0 0 0  0  0  0
## 261 0 0 0 0 0 0 0 0 0  0  0  0
## 266 0 0 0 0 0 0 0 0 0  0  0  0
## 280 0 0 0 0 0 0 0 0 0  0  0  0
## 283 0 0 0 0 0 0 0 0 0  0  0  0
```

This file is transformed in a square matrix of co-occurrences, which captures all possible combinations between two distinct technological fields. This square matrix looks like this:

```r
print(as.matrix(mat_tech_AI1[1:35, 1:35]))
```

```
##          1       2       3       4      5       6       7       8       9
## 1  5768289  180008   72869   35505  31634  105672   48931  293699  162448
## 2   180008 2531644  182176  197948  36765  435699   37718  187833  317265
## 3    72869  182176 2229334  679000  58436  355831   48692   13799  109871
## 4    35505  197948  679000 3345610  45697  596334  160911    2506    4448
## 5    31634   36765   58436   45697 506310   70807     435   34596    4931
## 6   105672  435699  355831  596334  70807 6260090  553534   95310  109728
## 7    48931   37718   48692  160911    435  553534 1701101     926    3984
## 8   293699  187833   13799    2506  34596   95310     926 2907011  220961
## 9   162448  317265  109871    4448   4931  109728    3984  220961 2596916
## 10  224446   91013  138039   81955  26343  269221   40824  114839  106349
## 11    6043    2012    4223    2157    380   26784    3310    2712    2321
## 12   98397   90671   95899  110688  12005  283610  142899   10402   22262
## 13   35221   33259   24034   12585   2645  127652   27438   12349   45652
## 14   26284    5530     622     912    672    6859     840  102013   25607
## 15    5711    1220     435     776    189   21330    1781    2263    3488
## 16    2489     688     139      93     39    4725     836     495    1208
## 17  110241   28068    1132     117     25    2902      20   78495  103336
## 18    2856     155      61      77      9    1485    1255     128      28
## 19   77403   28650    1243     108    222    5442     640  184747   86394
## 20  250123   18549    2934      95   1357   10175     518   59457   25865
## 21  124491   67392    4601     731   1170   14978     466  199001   88924
## 22   58683    7150    2666     166   2069    3842      50   53804   25285
## 23   82108   10257    2396     688   1471   10562    2764   45908   18939
## 24   29344    9675    1464     973    442    7448    2572   14057    5130
## 25   44158   19330   12865    4228    393   33521   15140   22677   47088
## 26   57741   25924    2658     596    448   12340     988   62331   21196
## 27   95078    5935    1948    1913    914   19023    2243   10748    8940
## 28   21109   26245   76191    1919    819   80353    4467   16159   82423
## 29   81035   28330    7767    3500    399   24244    6398   34466   75161
## 30   73388   22945    6641    3584    535   12310    2500   19714    5256
## 31   75597   20173    7014     913    583   15613    1003    5928   24813
## 32  213765   54606   28756   21166   2988   70014   15738    6698   19059
## 33   29184   20783    6655    8249    754   52055   14459    1232    4992
## 34   26222   33300   13681    4925   1838   38240    5927    8552   13602
## 35   59692   14997   14208    7775    743   35601    9893    7164    5614
##         10      11      12      13     14      15      16      17      18
## 1   224446    6043   98397   35221  26284    5711    2489  110241    2856
## 2    91013    2012   90671   33259   5530    1220     688   28068     155
## 3   138039    4223   95899   24034    622     435     139    1132      61
## 4    81955    2157  110688   12585    912     776      93     117      77
## 5    26343     380   12005    2645    672     189      39      25       9
## 6   269221   26784  283610  127652   6859   21330    4725    2902    1485
## 7    40824    3310  142899   27438    840    1781     836      20    1255
## 8   114839    2712   10402   12349 102013    2263     495   78495     128
## 9   106349    2321   22262   45652  25607    3488    1208  103336      28
## 10 5893276  237979  213472  103998  43521  104810   29536   16762    5190
## 11  237979  810267    8274   27172  48107  261182   96945    5074    7045
## 12  213472    8274 2064137   43797   1902    1012    7803    1243    2340
```

```
## 13  103998   27172   43797 2429739   16945   35668  125523   31251    7933
## 14   43521   48107    1902   16945 2867623  218485  880680  142222   72141
## 15  104810  261182    1012   35668  218485 2548809  536552   39796  301160
## 16   29536   96945    7803  125523  880680  536552 3083488   65679  234071
## 17   16762    5074    1243   31251  142222   39796   65679 2049722   20411
## 18    5190    7045    2340    7933   72141  301160  234071   20411 1898838
## 19   47689   10954    5778   25452  366020  132050   85334  343204   59224
## 20   31626    5843    5974   19786   46278    8297   13210   68382    3902
## 21   33031    4142    3131   31515   19938    5668    6219  104006    1959
## 22   50026    9304     680    8844    9300   10986   17217   14426     774
## 23   95527   24371   13263   59686  345426   43438   24794   94806   26817
## 24   35712    6285   16084   46015   30433   67992    3463   28112    9471
## 25   45455    2166   44920   48773    2091    2818    2974   20540   15336
## 26   40922    1909   20787   14450    4094   10729    1429    9678    2731
## 27   53426    2287   17820   20017    1825    2211    1446    4330     264
## 28   18286    2120    8993   22087   14666   11092    4794   88256    2880
## 29   43759   15562   26462   52776   19353   67652   34654  501786  128187
## 30   27833    1142   23917   21157    2021    1160     355    2040    4135
## 31   56718    1111   18569   14402    1537    1394     181   23407    2318
## 32  138519    2364  132219   19788    1447     659     425   36789     268
## 33   17664     730   46615   54425    1383     404    2645    6147   11201
## 34   22110    1079   26491   44840   10727    5087    4469   22655    7095
## 35   80910    8314   49748   10065    1578    1955     240   24444     750
##           19      20      21      22      23      24      25      26      27
## 1    77403  250123  124491   58683   82108   29344   44158   57741   95078
## 2    28650   18549   67392    7150   10257    9675   19330   25924    5935
## 3     1243    2934    4601    2666    2396    1464   12865    2658    1948
## 4      108      95     731     166     688     973    4228     596    1913
## 5      222    1357    1170    2069    1471     442     393     448     914
## 6     5442   10175   14978    3842   10562    7448   33521   12340   19023
## 7      640     518     466      50    2764    2572   15140     988    2243
## 8   184747   59457  199001   53804   45908   14057   22677   62331   10748
## 9    86394   25865   88924   25285   18939    5130   47088   21196    8940
## 10   47689   31626   33031   50026   95527   35712   45455   40922   53426
## 11   10954    5843    4142    9304   24371    6285    2166    1909    2287
## 12    5778    5974    3131     680   13263   16084   44920   20787   17820
## 13   25452   19786   31515    8844   59686   46015   48773   14450   20017
## 14  366020   46278   19938    9300  345426   30433    2091    4094    1825
## 15  132050    8297    5668   10986   43438   67992    2818   10729    2211
## 16   85334   13210    6219   17217   24794    3463    2974    1429    1446
## 17  343204   68382  104006   14426   94806   28112   20540    9678    4330
## 18   59224    3902    1959     774   26817    9471   15336    2731     264
## 19 3281112  126796  133673   28416  223167  106935   15567   32978   13952
## 20  126796 3478542  211364  137164  225615  137648    8314  183631   36572
## 21  133673  211364 1789373   35420   95519   27346   49898   77804   25745
## 22   28416  137164   35420  405306   39145    5423    1106    4918    2601
## 23  223167  225615   95519   39145 2731402  479200   47416   48496   45189
## 24  106935  137648   27346    5423  479200 2069291   14231   24015   83658
## 25   15567    8314   49898    1106   47416   14231 1786154   54803   10446
## 26   32978  183631   77804    4918   48496   24015   54803 2329323   32652
## 27   13952   36572   25745    2601   45189   83658   10446   32652 1816529
```

```
## 28  101627   20432   67269  10598   78191    8483   51364   15113    2404
## 29  217172  114726  135262  11263   90207   46258   57020   61081   17697
## 30   28914   66431   13007   1510   51070   84902    9815   22827   74745
## 31   20605   32638   32746   2071   31742   14969   60074   74156  123929
## 32    9411   11411   24564    616   18160   28141   63146   34357  100390
## 33    7559    2704    9689    149   23655    7024   39448    9904    5100
## 34   37134    9178   43825   1395   36675    8805   41268   14452    7191
## 35   77863   81833   44971    368   39360   52309   47536   31784   39369
##         28      29      30      31      32      33      34      35
## 1    21109   81035   73388   75597  213765   29184   26222   59692
## 2    26245   28330   22945   20173   54606   20783   33300   14997
## 3    76191    7767    6641    7014   28756    6655   13681   14208
## 4     1919    3500    3584     913   21166    8249    4925    7775
## 5      819     399     535     583    2988     754    1838     743
## 6    80353   24244   12310   15613   70014   52055   38240   35601
## 7     4467    6398    2500    1003   15738   14459    5927    9893
## 8    16159   34466   19714    5928    6698    1232    8552    7164
## 9    82423   75161    5256   24813   19059    4992   13602    5614
## 10   18286   43759   27833   56718  138519   17664   22110   80910
## 11    2120   15562    1142    1111    2364     730    1079    8314
## 12    8993   26462   23917   18569  132219   46615   26491   49748
## 13   22087   52776   21157   14402   19788   54425   44840   10065
## 14   14666   19353    2021    1537    1447    1383   10727    1578
## 15   11092   67652    1160    1394     659     404    5087    1955
## 16    4794   34654     355     181     425    2645    4469     240
## 17   88256  501786    2040   23407   36789    6147   22655   24444
## 18    2880  128187    4135    2318     268   11201    7095     750
## 19  101627  217172   28914   20605    9411    7559   37134   77863
## 20   20432  114726   66431   32638   11411    2704    9178   81833
## 21   67269  135262   13007   32746   24564    9689   43825   44971
## 22   10598   11263    1510    2071     616     149    1395     368
## 23   78191   90207   51070   31742   18160   23655   36675   39360
## 24    8483   46258   84902   14969   28141    7024    8805   52309
## 25   51364   57020    9815   60074   63146   39448   41268   47536
## 26   15113   61081   22827   74156   34357    9904   14452   31784
## 27    2404   17697   74745  123929  100390    5100    7191   39369
## 28 1308730   42673    1881    8205    6575   13946   59257    7957
## 29   42673 3126645   15300   49310   69364   18062   29144   90968
## 30    1881   15300 1463621   30728   33966   23370   41410   31058
## 31    8205   49310   30728 1831696  212337   19557   16086  103204
## 32    6575   69364   33966  212337 2772775   40099   19890  113411
## 33   13946   18062   23370   19557   40099 1236189   41595   36894
## 34   59257   29144   41410   16086   19890   41595 1084525   19702
## 35    7957   90968   31058  103204  113411   36894   19702 3560637
```

Six small co-occurrence matrices are calculated, and then they are summed up in a file named mat_tech_AI_Final, which is saved at "Files_created_with_the_code/data/files_code_Fields_analysis/Matrix_IPC.csv". This final file of co-occurrences between technological fields looks like this:

```
print(mat_tech_AI_Final[1:35, 1:35])
```

```
##            1       10      11      12       13       14       15       16
## 1   26242833  1105050   36467  460300   170587   113955    20807    10445
## 10   1105050 24682955 1084761 1050741   563614   204173   409432   106582
## 11     36467  1084761 3525353   34621   131313   253957  1242197   563632
## 12    460300  1050741   34621 8999453   164516     8290     6446    22004
## 13    170587   563614  131313  164516 10467208    97468   155323   563556
## 14    113955   204173  253957    8290    97468 15116843  1152360  4615828
## 15     20807   409432 1242197    6446   155323  1152360 10401074  2707298
## 16     10445   106582  563632   22004   563556  4615828  2707298 13025114
## 17    533998    77728   30836    7817   179377   854888   181385   316366
## 18     13709    22386   30137   10141    44737   337538  1089819   896097
## 19    443392   201039   52245   23760   152775  2235446   541154   390863
## 2    1119478   563726    8619  438005   198152    47780     6197     4455
## 20   1469546   174826   26056   38608   100743   231642    35052    67891
## 21    724137   157456   18887   22339   153392   104417    22737    24447
## 22    219144   173075   27249    3116    27220    31400    33307    56329
## 23    419139   524854  149002   76178   325463  1755442   221998   152120
## 24    145875   184676   37931   72363   213020   130941   260273    17747
## 25    237008   244039   12659  304054   217590    15050    11041    15281
## 26    327159   229919    7065  176239    74190    32237    36376     8564
## 27    460192   330778   16227  119692    94111    13592    11044     7183
## 28    142474   114862   13331   64315   127019   121893    50116    22389
## 29    432784   238130   91847  145060   252392   105799   273218   160764
## 3     362362   613474   16588  454421    86787     4913     2593     2314
## 30    386632   135633    7282  131213    92050    13022     6068     2210
## 31    400546   274385    7332  126129    71485     8727     5164     3323
## 32    915437   662630   10983  612923    88497     7206     3185     3009
## 33    146905    82825    3331  219052   261890     9877     1754    11232
## 34    128408   127036    6630  145379   209610    61408    20616    18056
## 35    278714   366014   36342  230550    43541     8633    10697     1797
## 4     143077   325019    8870  479100    46635     4488     3065     1814
## 5     202650   169190    1162   71090    15821     2653      992      290
## 6     445672  1223744  111402 1314660   492137    32031    93726    20856
## 7     189070   160542   16033  735780   120184     3834     7143     3661
## 8    1432517   686541   12597   73831    50575   365327     9801     3727
## 9     832079   615023   15757  123855   349238   252442    17505    11026
##           17      18      19       2       20      21      22       23
24
## 1     533998   13709  443392  1119478  1469546  724137  219144   419139
145875
## 10     77728   22386  201039   563726   174826  157456  173075   524854
184676
## 11     30836   30137   52245     8619    26056   18887   27249   149002
37931
## 12      7817   10141   23760   438005    38608   22339    3116    76178
72363
## 13    179377   44737  152775   198152   100743  153392   27220   325463
213020
## 14    854888  337538 2235446    47780   231642  104417   31400  1755442
130941
## 15    181385 1089819  541154     6197    35052   22737   33307   221998
```

```
260273
## 16   316366  896097   390863     4455    67891   24447   56329   152120
17747
## 17 10676610   93923  1944663   240044   362392  579773   46352   527703
125750
## 18    93923 7317728   265045     1573    21057   15419    2554   153172
47742
## 19  1944663  265045 15422287   356341   685512  733594  101637  1108478
494356
## 2    240044    1573   356341 14335959   199276  506317   30510    68765
45202
## 20   362392   21057   685512   199276 16386118 1158401  438789  1165654
675668
## 21   579773   15419   733594   506317  1158401 9278629  112480   555537
145430
## 22    46352    2554   101637    30510   438789  112480 1324026   133465
21055
## 23   527703  153172  1108478    68765  1165654  555537  133465 13214230
2323343
## 24   125750   47742   494356    45202   675668  145430   21055  2323343
9199630
## 25   125085   85630    87337   147285    57671  295880    5819   276808
75744
## 26    56172   14007   184865   248275   922532  425365   16226   263347
138952
## 27    24044    2876    88232    31077   232388  135681   12957   265500
460881
## 28   488151   16674   601362   296926   145835  373035   36658   430127
58240
## 29  2274295  531516  1012771   232699   662971  890035   36419   548439
222304
## 3      6304     725     9616   993581    24974   21894   10691    15323
13785
## 30    11193   19936   146983    90727   463218   90091    4051   302186
446346
## 31   125667    5232   126105   115040   200267  209204    9998   168414
85347
## 32   157364    2287    59265   239762    71269  139276    3684    92185
133339
## 33    37219   52233    42519    99615    19752   62699     315   126170
49967
## 34   102186   39290   179676   210021    51377  239564    4544   174306
59730
## 35   119196    2513   364466    88928   386575  262458    1693   215646
271865
## 4      1398     458     1428   798019      895    1899     584     4346
5944
## 5       869     190     1584   300865     7543    8101    6949     8945
5790
## 6     11786    7036    31035  2073525    39318   55552   12485    52088
35730
```

```
## 7      1054    4409     2739   166538     5415    1756     156    10773
19378
## 8    379736    1018   703190  1132716   384304 1171768  184721   282961
73581
## 9    640378    1250   591978  1778205   204091  496639   90594   135042
39531
##          25        26       27       28        29         3      30      31
32
## 1   237008   327159  460192  142474   432784   362362  386632  400546
915437
## 10  244039   229919  330778  114862   238130   613474  135633  274385
662630
## 11   12659     7065   16227   13331    91847    16588    7282    7332
10983
## 12  304054   176239  119692   64315   145060   454421  131213  126129
612923
## 13  217590    74190   94111  127019   252392    86787   92050   71485
88497
## 14   15050    32237   13592  121893   105799     4913   13022    8727
7206
## 15   11041    36376   11044   50116   273218     2593    6068    5164
3185
## 16   15281     8564    7183   22389   160764     2314    2210    3323
3009
## 17  125085    56172   24044  488151  2274295     6304   11193  125667
157364
## 18   85630    14007    2876   16674   531516      725   19936    5232
2287
## 19   87337   184865   88232  601362  1012771     9616  146983  126105
59265
## 2   147285   248275   31077  296926   232699   993581   90727  115040
239762
## 20   57671   922532  232388  145835   662971    24974  463218  200267
71269
## 21  295880   425365  135681  373035   890035    21894   90091  209204
139276
## 22    5819    16226   12957   36658    36419    10691    4051    9998
3684
## 23  276808   263347  265500  430127   548439    15323  302186  168414
92185
## 24   75744   138952  460881   58240   222304    13785  446346   85347
133339
## 25 9267812   360892   62498  397629   374961    93698   55575  293059
316170
## 26  360892 11407587  174310  109204   347920    16900  127266  387707
170519
## 27   62498   174310 9032042   15843    88766    13427  374929  659505
542172
## 28  397629   109204   15843 8187901   299707   477030   14857   59083
41079
## 29  374961   347920   88766  299707 15132833    39136   87262  321723
```

```
405485
## 3    93698    16900   13427  477030    39136 10554590   37350   34597
153809
## 30   55575   127266  374929   14857    87262    37350 7500577  170350
167141
## 31  293059   387707  659505   59083   321723    34597  170350 8975847
1094346
## 32  316170   170519  542172   41079   405485   153809  167141 1094346
12649692
## 33  190775    52267   27189   76670   114989    31671  134233   95790
175913
## 34  221657    84352   35329  340332   184052    79752  209624   86359
120849
## 35  262033   187657  178042   45916   470602    71338  166601  577745
544994
## 4    15775     2672    6855   15540    13139  2820312   13797    3925
93460
## 5     2484     4826    7045    6822     3479   406133    4839    5318
18938
## 6   174082    64361   81588  501207   104021  1706302   53130   73536
275421
## 7   109065    21471   11568   28035    33017   220822   12660    3825
64206
## 8   139063   348827   64121   93685   168451   112782  101086   34116
32146
## 9   447847   140327   60694  702628   462908   760568   24403  156239
92514
##         33      34      35       4       5        6       7        8
9
## 1   146905  128408   278714   143077  202650   445672  189070  1432517
832079
## 10   82825  127036   366014   325019  169190  1223744  160542   686541
615023
## 11    3331    6630    36342     8870    1162   111402   16033    12597
15757
## 12  219052  145379   230550   479100    71090  1314660  735780    73831
123855
## 13  261890  209610    43541    46635    15821   492137  120184    50575
349238
## 14    9877   61408     8633     4488     2653    32031    3834   365327
252442
## 15    1754   20616    10697     3065      992    93726    7143     9801
17505
## 16   11232   18056     1797     1814      290    20856    3661     3727
11026
## 17   37219  102186   119196     1398      869    11786    1054   379736
640378
## 18   52233   39290     2513      458      190     7036    4409     1018
1250
## 19   42519  179676   364466     1428     1584    31035    2739   703190
591978
```

```
## 2    99615  210021    88928   798019  300865  2073525  166538  1132716
1778205
## 20   19752   51377   386575      895    7543    39318    5415   384304
204091
## 21   62699  239564   262458     1899    8101    55552    1756  1171768
496639
## 22     315    4544     1693      584    6949    12485     156   184721
90594
## 23  126170  174306   215646     4346    8945    52088   10773   282961
135042
## 24   49967   59730   271865     5944    5790    35730   19378    73581
39531
## 25  190775  221657   262033    15775    2484   174082  109065   139063
447847
## 26   52267   84352   187657     2672    4826    64361   21471   348827
140327
## 27   27189   35329   178042     6855    7045    81588   11568    64121
60694
## 28   76670  340332    45916    15540    6822   501207   28035    93685
702628
## 29  114989  184052   470602    13139    3479   104021   33017   168451
462908
## 3    31671   79752    71338  2820312  406133  1706302  220822   112782
760568
## 30  134233  209624   166601    13797    4839    53130   12660   101086
24403
## 31   95790   86359   577745     3925    5318    73536    3825    34116
156239
## 32  175913  120849   544994    93460   18938   275421   64206    32146
92514
## 33 5758204  219012   209748    38328    3621   208961   55401     5833
22884
## 34  219012 5290424   120742    30035   22367   242998   39460    45044
97315
## 35  209748  120742 15805378    29060    4422   155283   59391    40477
32646
## 4    38328   30035    29060 12132499  261134  2358962  648691    11314
27124
## 5     3621   22367     4422   261134 2871031   435879    3267   212314
34443
## 6   208961  242998   155283  2358962  435879 25287889 2302961   544407
544095
## 7    55401   39460    59391   648691    3267  2302961 6633202     7694
19252
## 8     5833   45044    40477    11314  212314   544407    7694 13624917
1366521
## 9    22884   97315    32646    27124   34443   544095   19252  1366521
15211979
```

This matrix is used for calculating the relatedness between all technological fields, which is at the core of the GTS. The matrix is normalised to prevent overestimating knowledge links associated with ubiquitously used technological fields through the cosine index. This normalised matrix is then used as an input for calculating relatedness. Both relatedness and the normalisation are made using the function “relatedness” provided by the EconGeo package. The resulting matrix of relatedness looks like this:

```
print(mat_tech_rel_AI[1:35, 1:35])
```

```
##               1          10           11           12          13
14
## 1  0.0000000000 0.079946743 0.0047211202 0.0428721050 0.018407944
0.0082334420
## 10 0.0799467434 0.000000000 0.1470137330 0.1024491448 0.063667816
0.0154427693
## 11 0.0047211202 0.147013733 0.0000000000 0.0060405771 0.026544349
0.0343726668
## 12 0.0428721050 0.102449145 0.0060405771 0.0000000000 0.023925516
0.0008072283
## 13 0.0184079442 0.063667816 0.0265443487 0.0239255157 0.000000000
0.0109958659
## 14 0.0082334420 0.015442769 0.0343726668 0.0008072283 0.010995866
0.0000000000
## 15 0.0018598341 0.038311165 0.2079985053 0.0007765132 0.021678032
0.1076864208
## 16 0.0008350303 0.008919828 0.0844100996 0.0023707689 0.070347746
0.3857904013
## 17 0.0429860301 0.006550041 0.0046499763 0.0008480503 0.022546223
0.0719457183
## 18 0.0018409602 0.003146980 0.0075812991 0.0018353260 0.009380475
0.0473881020
## 19 0.0311910778 0.014804770 0.0068848147 0.0022525932 0.016780858
0.1644048918
## 2  0.0820081944 0.043230333 0.0011827789 0.0432428754 0.022665196
0.0036592818
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## 23 0.0305215958 0.040009811 0.0203257348 0.0074760559 0.037005828
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## 24 0.0331238548 2.020067e-03 0.0144126126 9.128223e-03 0.0495141523
## 25 0.0015681178 1.941114e-03 0.0159992079 1.827133e-02 0.0097621694
## 26 0.0051521271 1.084869e-03 0.0071649717 2.980510e-03 0.0206064941
## 27 0.0017301955 1.006477e-03 0.0033923330 6.769110e-04 0.0108785922
## 28 0.0067735255 2.706463e-03 0.0594176564 3.385728e-03 0.0639664334
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## 34 0.0035237878 2.760298e-03 0.0157296734 1.008930e-02 0.0241698078
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## 4  0.0003635501 1.924421e-04 0.0001493358 8.161560e-05 0.0001333030
## 5  0.0002252616 5.889827e-05 0.0001777126 6.481909e-05 0.0002830795
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## 5  6.083916e-02 0.000000e+00 0.0730502580 9.671703e-04 0.0442313905
## 6  2.065071e-01 7.305026e-02 0.0000000000 2.561738e-01 0.0426157350
## 7  1.003113e-01 9.671703e-04 0.2561738018 0.000000e+00 0.0010638894
## 8  1.231194e-03 4.423139e-02 0.0426157350 1.063889e-03 0.0000000000
## 9  2.829015e-03 6.877397e-03 0.0408218033 2.551475e-03 0.1274470866
##               9
## 1  0.0653998810
## 10 0.0506037358
## 11 0.0023200157
## 12 0.0131195745
## 13 0.0428601043
## 14 0.0207434998
## 15 0.0017795051
## 16 0.0010024994
## 17 0.0586268399
## 18 0.0001909066
## 19 0.0473609570
## 2  0.1481480323
## 20 0.0186266975
## 21 0.0471544184
## 22 0.0196696563
## 23 0.0111838259
## 24 0.0044238176
## 25 0.0559303588
## 26 0.0174767439
## 27 0.0083610766
## 28 0.0835048067
## 29 0.0405814354
## 3  0.0729520175
## 30 0.0036015122
## 31 0.0190708971
## 32 0.0100922402
## 33 0.0040241793
## 34 0.0146262429
## 35 0.0040367410
## 4  0.0028290146
## 5  0.0068773971
## 6  0.0408218033
## 7  0.0025514749
## 8  0.1274470866
## 9  0.0000000000
```

Next, the matrix is turned into a network (file g_tech_AI). The degree of centrality of nodes is calculated using the Eigenvector centrality of vertices (centrality_eigen), which also calculates the width of the links between nodes (i.e., technological fields). Links that have below average width are excluded for better visualisation. Then, a network layout is calculated based on this network (coords_tech_AI). The resulting coordinates look like this for the top 10 technological fields:

```
coords_tech_AI[1:10,]
```

```
##            x        y
## 1  135.6454 65.62816
## 2  134.0933 64.22519
## 3  135.2521 58.81728
## 4  131.3472 67.12986
## 5  135.1214 62.67884
## 6  138.8334 59.25243
## 7  137.6120 58.32931
## 8  138.0070 57.48352
## 9  136.7269 61.15738
## 10 139.9433 57.74551
```

Then, the previously file with general, AI-specific and coinciding country specialisations (from the file "RCA_4countries_detailed.csv") and the file with AI-specific specialisations (file "Specializations_All_periods_IPC.csv") are loaded. The resulting file is processed for facilitating the plotting later. A new category is created, reflecting the types of specialisations used in the paper (Var1, which goes from 0 to 3; 0 stands for no specialisation, 1 for general specialisation, 2 for AI-specific specialization, and 3 for coinciding specialization). This new dataset named Newtable is saved at "Files_created_with_the_code/data/files_code_Fields_analysis/Table_appendix.xlsx" and looks like this:

```
Newtable[1:10,]
```

```
##                           Var1 Var2      Var3 Freq
## 1            No specialization   CN 1974-1988   19
## 2       General specialization   CN 1974-1988   16
## 3   AI-specific specialization   CN 1974-1988    0
## 4    Coinciding specialization   CN 1974-1988    0
## 5            No specialization   JP 1974-1988   12
## 6       General specialization   JP 1974-1988    7
## 7   AI-specific specialization   JP 1974-1988    6
## 8    Coinciding specialization   JP 1974-1988   10
## 9            No specialization   KR 1974-1988   21
## 10      General specialization   KR 1974-1988   14
```

1.3. Plotting technological spaces

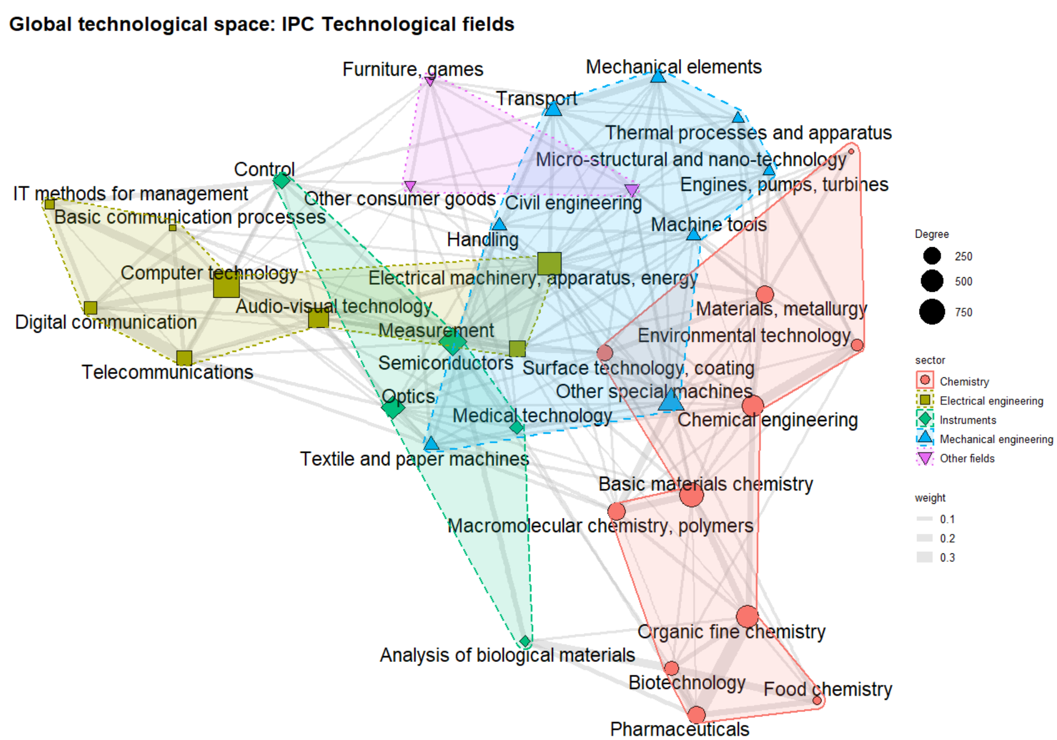
Next, we use the loaded information to plot technological spaces. For now, we have only calculated the coordinates and network for the GTS and not yet for the ATS, so we'll start with this one.

1.3.1. Global technological space (GTS)

The first figure from the GTS doesn't have any information linked to specialisations. The command below uses the general network created before to plot this geography-agnostic

GTS. The figure produced is saved at "Files_created_with_the_code/figures/Figure_3_GTS_for_IPC_fields.jpg"

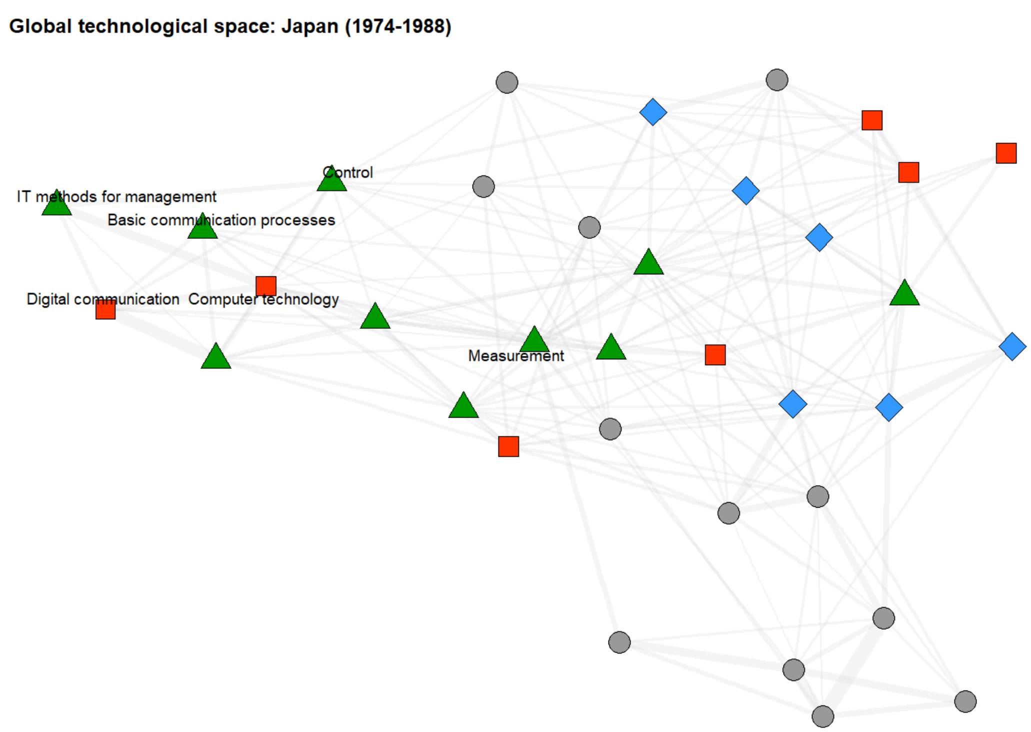
```
g_tech_AI %>%  ggraph(layout =  coords_tech_AI) +
  geom_edge_link(aes(width = weight), alpha = 0.4, colour = "grey") +
  geom_node_point(aes(fill = sector, size = 1000^dgr, shape= sector))+
  scale_shape_manual(values=c(21, 22, 23, 24, 25)) + scale_size("Degree",
range = c(2, 12)) +
  geom_node_text(aes(label = field_name), size = 6, repel = TRUE) +
  theme_graph(base_family = "sans")+
  ggtitle("Global technological space: IPC Technological fields") +
  theme(legend.title = element_text(size = 10), legend.text =
element_text(size = 10)) +
  guides(colour = guide_legend(override.aes = list(size=4)))+
  geom_mark_hull(aes(x = x, y=y, colour = sector, fill= sector,
                     linetype = sector), alpha = 0.15, expand = unit(2.5,
"mm"), size = .8)
```



Next, this very same technological space is used to plot the technological trajectories of the selected countries, through plotting their specialisations information. Thus, the commands for color and size of the nodes are adapted to reflected the previously calculated 3 types of specialisations. Three technological spaces are plotted for each country (one for each interval). Using again the case of Japan as an example, in the first interval:

```
#GTS with specialisations per country
country_select <- c("CN", "US", "JP", "KR")
### 1.2.3.3. Third Country
```

```
i=3
p=1
  g_tech_AI %N>%
  left_join(IPC_RCAs_Top4 %>% filter(ctry_code == country_select[i] &
IPC_RCAs_Top4$Period_sim == p) %>%
            select(-ctry_code), by = c("name" = "techn_field_nr")) %>%
ggraph(layout = coords_tech_AI) +
  geom_edge_link(aes(width = weight), alpha = 0.2, colour = "#CCCCCC") +
  geom_node_point(aes(fill = factor(Total_RCA_2), size = 7, shape=
factor(Total_RCA_2))) +
  scale_shape_manual(values=c(21, 22, 23, 24)) + labs(color   = "RCA") +
scale_size("Degree", range = c(2, 12))+
  geom_node_text(aes(filter=RCA_AI_Period > .99, label = field_name), size =
5, repel = TRUE) +
  scale_fill_manual(values=c("#999999", "#FF3300", "#3399FF", "#009900"))+
  theme_graph(base_family = "sans") + theme(legend.position = "none")+
  ggtitle("Global technological space: Japan (1974-1988)")
```



The code is the basically the same for the remaining countries in interval. The countries and intervals are selected by varying the variables i (for countries), and p (for intervals). The figures are generated and combined by country using the custom function "multiplot". The files are saved at "Files_created_with_the_code/figures/Figure_5_Specialisations_techn_space_4_countries_d_China.jpg", "Files_created_with_the_code/figures/Figure_5_Specialisations_techn_space_4_countries_b_USA.jpg", "Files_created_with_the_code/figures/Figure_5_Specialisations_techn_space_4_countries_a_J apan.jpg", and "Files_created_with_the_code/figures/Figure_5_Specialisations_techn_space_4_countries_c_SouthKorea.jpg".

1.3.2. AI-specific technological space (ATS)

Next, we create the ATS. We follow very similar steps: load the AI data, separate the patents that are specific to each interval, calculate the network and it's coordinates, and plot one technological space per interval. The difference now is that the ATS is dynamic, meaning that we calculate the network every time for each interval. Starting with the first interval, the calculated degree for the top 10 most connected codes is:

```
g_tech_AI %N>%  arrange(desc(dgr)) %>%  as_tibble() %>%  slice(1:10)
```

```
## # A tibble: 10 × 5
##    name  sector                 field_name                Category
dgr
##    <chr> <chr>                  <chr>                     <chr>
<dbl>
##  1 12    Instruments            Control                   AI-core fields
1
##  2 6     Electrical engineering Computer technology       AI-core fields
0.987
##  3 7     Electrical engineering IT methods for management AI-core fields
0.861
##  4 10    Instruments            Measurement               AI-core fields
0.731
##  5 25    Mechanical engineering Handling                  Surrounding fie…
0.534
##  6 26    Mechanical engineering Machine tools             Other
0.523
##  7 8     Electrical engineering Semiconductors            Other
0.473
##  8 32    Mechanical engineering Transport                 Other
0.447
##  9 27    Mechanical engineering Engines, pumps, turbines  Other
0.419
## 10 29    Mechanical engineering Other special machines    Other
0.417
```

The dataset with the AI-specific specialisations (named AI_RCA), saved previously in the file "Specializations_All_periods_IPC.csv" (together with the specialisations of countries), looks like this:

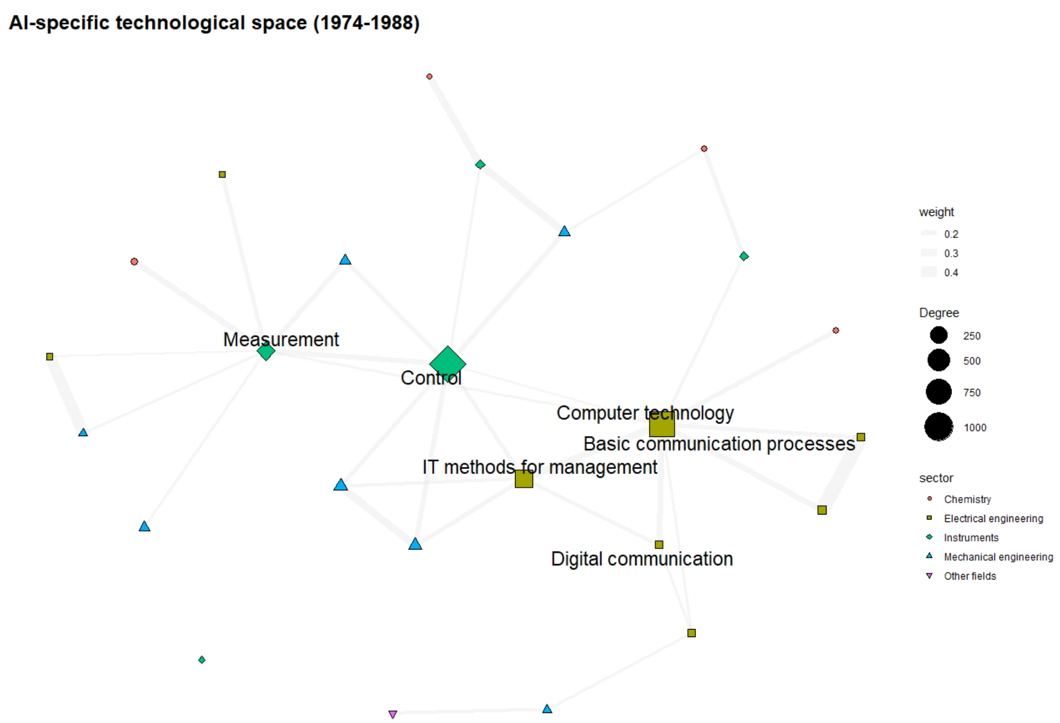
```
head(AI_RCA)
```

```
##   techn_field_nr RCA_AI_Period Period_sim Binary
## 1              1    0.05934926          1      0
## 2              2    0.08535377          1      0
## 3              3    0.33606440          1      0
## 4              4    1.09784935          1      1
```

```
## 5                 5     1.64528254           1       1
## 6                 6    16.64849577           1       1
```

Where “RCA_AI_Period” refers to the specific RTA of each code for each interval (which in turn is shown in the column Period_sim). We then plot the ATS for the first interval:

```
AI_RCA1 <- AI_RCA[AI_RCA$Period_sim == 1,]
p=1
  g_tech_AI %N>%
  left_join(AI_RCA1 %>% filter(Period_sim == p), by = c("name" =
"techn_field_nr")) %>%
  ggraph(layout = coords_tech_AI) +
  geom_edge_link(aes(width = weight), alpha = 0.2, colour = "#CCCCCC") +
  geom_node_point(aes(fill = sector, size = 1000^dgr, shape= sector)) +
  scale_shape_manual(values=c(21, 22, 23, 24, 25)) + labs(color   = "RCA")+
scale_size("Degree", range = c(2, 12)) +
  geom_node_text(aes(filter=Binary > .99, label = field_name), size = 6,
repel = TRUE) +
  theme_graph(base_family = "sans") + guides(colour =
guide_legend(override.aes = list(size=5)))+
  ggtitle("AI-specific technological space (1974-1988)") #
```



We do the same for the 2 other intervals, and combine the three figures again using the multiplot custom function. The resulting figure is saved at “Files_created_with_the_code/figures/Figure_2_ATS_and_AI_core_technologies_3_intervals.jpg”

2. Specialisations based on subclasses (4-digits)

Next, we calculate the specialisations of countries and AI, but now based on subclasses instead of technological fields. The calculations are exactly the same, with the only difference that the function “group_by_ctry_and_subclass” is used (instead of “group_by_ctry_and_techn_field”). As the name suggests,tThis function aggregates the weighted fields at the subclass (4-digit IPC codes) level (instead of technology field, as done before). The specialisations are again calculated and saved by interval, which are then aggregated and saved at “Files_created_with_the_code/data/files_code_4-digits_analysis/IPC_RCAs_subclass.csv”. This file looks like this for the already mentioned Japanese case:

```
head(IPC_RCAs[IPC_RCAs$ctry_code == "JP",])

##       ctry_code Subclass   RCA_Gen RCA_AI    Period
## 49843        JP     A01B 0.7431930     NA 1974-1988
## 49844        JP     A01C 0.9595211     NA 1974-1988
## 49845        JP     A01D 0.6680463     NA 1974-1988
## 49846        JP     A01F 0.9183123     NA 1974-1988
## 49847        JP     A01G 0.7969855     NA 1974-1988
## 49848        JP     A01H 0.2681154     NA 1974-1988
```

3. Remaining figures

Next, we create 5 remaining figures shown in the paper (namely Figures 1, 4, 6, 7, and 8).

3.1. Overlapping specializations (Fig 6 and 8)

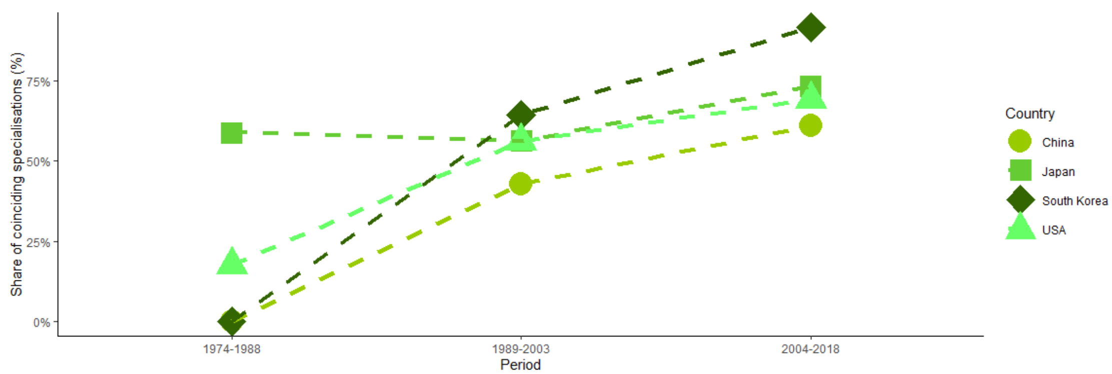
We create this figure by reading all the summary files we already separated before. We start by reading and combining files RCA_4countries_detailed.csv and Specializations_All_periods_IPC.csv into a new file named IPC_RCAs. Then, we summarize its main results, in the following way:

```
SummaryAllData<-distinct(IPC_RCAs, ctry_code, Period, .keep_all = TRUE)
colnames(SummaryAllData)[1] <- "Country"
head(SummaryAllData)

## # A tibble: 6 × 20
##   Country     techn_field_nr RCA_Gen RCA_AI Period  Label Round_general
Round_AI
##   <chr>       <chr>            <dbl>  <dbl> <chr>   <chr>         <int>
<int>
## 1 China       1                0.781  0     1974-1… Elec…             0
0
## 2 Japan       1                1.13   1.40  1974-1… Elec…             1
1
## 3 South Korea 1                0.886  0     1974-1… Elec…             0
0
## 4 USA         1                0.806  0     1974-1… Elec…             0
0
```

```
## 5 China       1               0.686   2.09   1989-2… Elec…             0
1
## 6 Japan       1               1.14    0.983 1989-2… Elec…             1
0
## # ℹ 12 more variables: Total_RCA <fct>, Period_sim <dbl>, RCA_AI_Period
<dbl>,
## #   Total_RCA_2 <dbl>, Coiciding <dbl>, justGeneral <dbl>, OnlyAI <dbl>,
## #   Share_coinciding <dbl>, Share_OnlyAI <dbl>, sum_coinciding <dbl>,
## #   sum_justGeneral <dbl>, sum_OnlyAI <dbl>
```

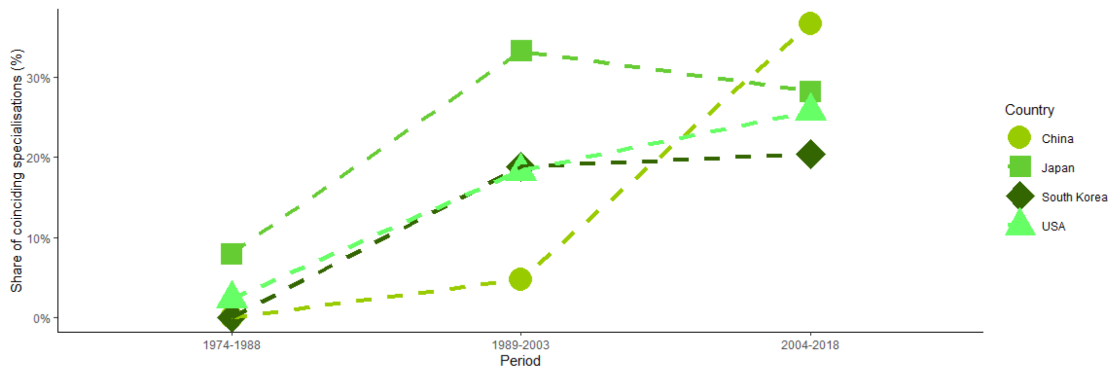
This file is all we need to create Figure 6, shown below (and saved in file "Files_created_with_the_code/figures/Figure_6_Share_coinciding_specialisations_techn_field.jpg")

```
  ggplot(data=SummaryAllData, aes(x=Period, y=Share_coinciding,
group=Country, shape = Country, color=Country)) +
  geom_point(aes(fill = Country), size=8) +   scale_shape_manual(values=c(21,
22, 23, 24)) +
  xlab("Period") +  ylab("Share of coinciding specialisations (%)") +
  theme_classic() +  geom_line(aes(color=Country), linetype = "dashed",
size=1.5)+
  scale_y_continuous(labels = scales::percent) +
  scale_fill_manual(values = c("#99CC00", "#66CC33", "#336600", "#66FF66")) +
  scale_color_manual(values = c("#99CC00", "#66CC33", "#336600", "#66FF66"))
```



Next, we do the same for the subclass-based Figure 8, which is shown belown and saved as "Files_created_with_the_code/figures/Figure_8_Share_coinciding_specialisations_subclass.jpg".

```
  ggplot(data=SummaryAllData4dig, aes(x=Period, y=Share_coinciding,
group=Country, shape = Country, color=Country)) +
  geom_point(aes(fill = Country), size=8) +
  scale_shape_manual(values=c(21, 22, 23, 24)) +
  xlab("Period") +
  ylab("Share of coinciding specialisations (%)") +
  theme_classic() +
  geom_line(aes(color=Country), linetype = "dashed", size=1.5)+
  scale_y_continuous(labels = scales::percent) +
  scale_fill_manual(values = c("#99CC00", "#66CC33", "#336600", "#66FF66")) +
  scale_color_manual(values = c("#99CC00", "#66CC33", "#336600", "#66FF66"))
```



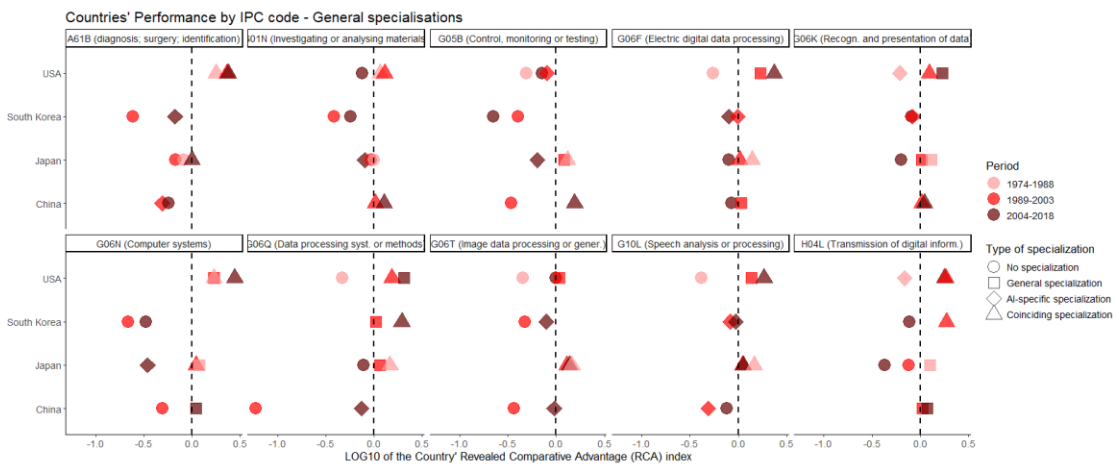
We now turn to the figure contrasting general and AI-specific specialisations for selected subclasses (Figure 7). We read again file "IPC_RCAs_subclass.csv" to get the specialisations, and use the function ddply (from the package plyr) to split the dataframe into two separate files, one of them containing the general specialisations of countries, and the other containing countries AI-specific specialisations. Please note that the package plyr can conflict with the already loaded packages. So, if you run it, make sure to restart R completely if you come back to the previous parts of the code (the problem doesn't appear with you keep running the code until the end without coming back to the start, though). The log10 is used to summarize the RCA values into the ones shown below:

```
Gen <- ddply(IPC_RCAs_Top4, c("Period", "Label"), summarise,
Value.mean=log10(mean(RCA_Gen)))
head(Gen)

##      Period                                    Label  Value.mean
## 1 1974-1988   A61B (diagnosis; surgery; identification)  0.11411362
## 2 1974-1988 G01N (Investigating or analysing materials)  0.03074913
## 3 1974-1988       G05B (Control, monitoring or testing) -0.04578035
## 4 1974-1988     G06F (Electric digital data processing) -0.01182467
## 5 1974-1988     G06K (Recogn. and presentation of data) -0.01827508
## 6 1974-1988                  G06N (Computer systems)  0.15801307

#Figure AI:
Ais <- ddply(IPC_RCAs_Top4, c("Period", "Label"), summarise,
Value.mean=log10(mean(RCA_AI)))
head(Ais)

##      Period                                    Label  Value.mean
## 1 1974-1988   A61B (diagnosis; surgery; identification)  0.21349102
## 2 1974-1988 G01N (Investigating or analysing materials)  0.14685611
## 3 1974-1988       G05B (Control, monitoring or testing) -0.08567104
## 4 1974-1988     G06F (Electric digital data processing) -0.06209186
## 5 1974-1988     G06K (Recogn. and presentation of data)  0.18805035
## 6 1974-1988                  G06N (Computer systems)  0.11218492
```

These two datasets are used to create two distinct figures, which are combined to produce Figure 7. The firt figure is produced through:

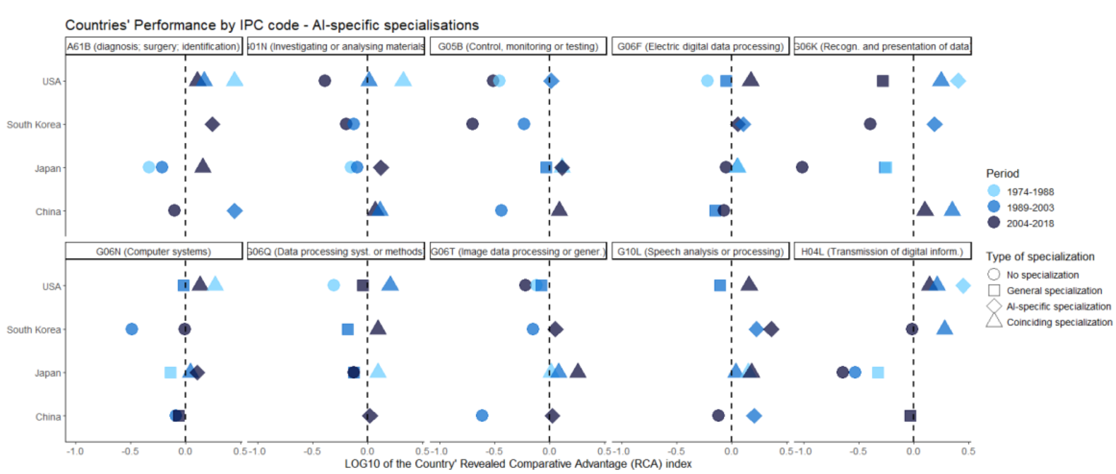
```
ggplot(IPC_RCAs_Top4,aes(x = log10(RCA_Gen), y=ctry_code, color=Period, shape
=`Type of specialization`, fill = Period)) + geom_count(alpha=0.7, size=6) +
```

```
  facet_wrap(~Label, ncol = 5)  +  theme_classic() +
  scale_fill_manual(values = c("#FF9999", "#FF0000", "#660000")) +
  scale_color_manual(values = c("#FF9999", "#FF0000", "#660000")) +
  scale_shape_manual(values=c(21, 22, 23, 24, 25))+
  geom_vline(data=Gen, aes(xintercept=0), linetype="dashed", size=1) +
  ggtitle("Countries' Performance by IPC code - General specialisations") +
  xlab("LOG10 of the Country' Revealed Comparative Advantage (RCA) index") +
  ylab(NULL) + theme(text = element_text(size = 13))
```



The second figure is:

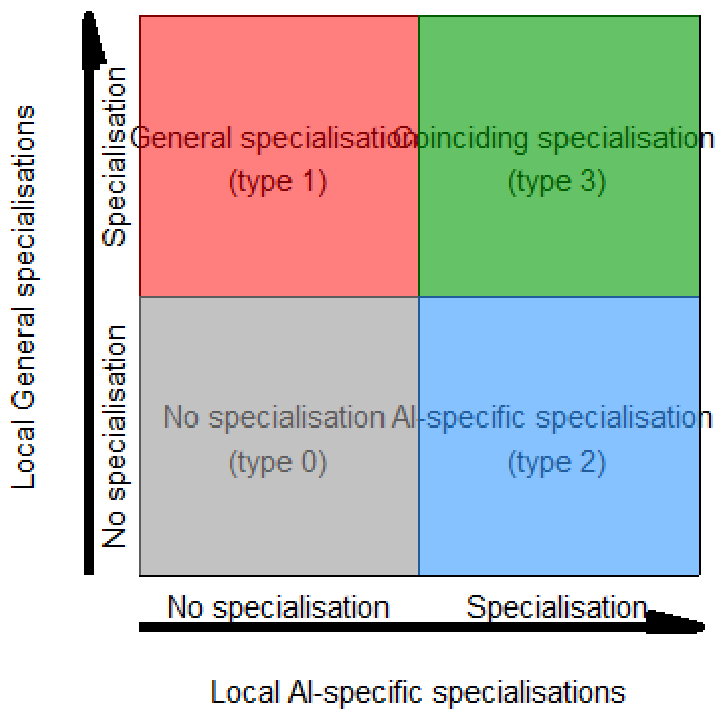
```
  ggplot(IPC_RCAs_Top4,aes(x = log10(RCA_AI), y=ctry_code, color=Period,
shape =`Type of specialization`, fill = Period)) + geom_count(alpha=0.7,
size=6) +
  facet_wrap(~Label, ncol = 5)  +  theme_classic() +
  scale_fill_manual(values = c("#66CCFF", "#0066CC", "#000033")) +
  scale_color_manual(values = c("#66CCFF", "#0066CC", "#000033")) +
  scale_shape_manual(values=c(21, 22, 23, 24, 25))+
  geom_vline(data=Ais, aes(xintercept=0), linetype="dashed", size=1) +
  ggtitle("Countries' Performance by IPC code - AI-specific specialisations")
+
  xlab("LOG10 of the Country' Revealed Comparative Advantage (RCA) index") +
  ylab(NULL) + theme(text = element_text(size = 13))
```



Both figures are combined using the custom multiplot function, and saved at Files_created_with_the_code/figures/Figure_7_General_and_AI-specific_specialisations_subclass_by_country.jpeg.

Next, we build Figure 4. This figure is very straightforward, it doesn't need any specific data. It's produced basically using custom annotation commands, with the resulting figure shown below and saved as "Files_created_with_the_code/figures/Figure_4_Three_types_of_country_specialisations.jpg".

```
plot
```



Finally, we create Figure 1 in a somewhat similar way: not much data needed (the only dataset needed is other_files/IPCs_AI.csv), and just simple commands used to process this data to get a summarized number. The produced figure is saved as "Files_created_with_the_code/figures/Figure_1_Log_10_AI_patents_per_country.jpg", and also shown below.

```
  ggplot(data=test, aes(x=Year, y=log10(Number_of_AI_patents), group=Country,
colour=Country, shape=Country)) +
  geom_line(size=1.2, aes(linetype=Country)) +
  geom_point(size=4) +  xlab("Year") +  ylab("Number of new AI registers
[Log10]") + theme_classic() +
  scale_linetype_manual(values=c("twodash", "longdash", "solid", "solid")) +
  scale_shape_manual(values=c(16, 15, 17, 18)) +
theme(legend.position="bottom") +
  theme(text = element_text(size = 15)) +  scale_y_continuous(limits=c(0,4))
+
```

```
  geom_vline(data=test, aes(xintercept=c(1988),  colour=Period),
linetype="dashed", size=1, color = "grey") +
  geom_vline(data=test, aes(xintercept=c(2003),  colour=Period),
linetype="dashed", size=1, color = "grey") +
  scale_x_continuous(breaks = c(1974, 1988, 2003, 2018), limits=c(1974,
2018)) + scale_color_brewer(palette="Dark2") +
  annotate("rect", xmin = 1974, xmax=1988, ymin = 3.6, ymax = 4, alpha = .01,
color = "black") +
  annotate("text", x = 1981, y = 3.8, label = c("First Period \n(1974-
1988)"), size=4)+
  annotate("rect", xmin = 1988, xmax=2003, ymin = 3.6, ymax = 4, alpha = .01,
color = "black") +
  annotate("text", x = 1996, y = 3.8, label = c("Second Period \n(1989-
2003)"), size=4) +
  annotate("rect", xmin = 2003, xmax=2018, ymin = 3.6, ymax = 4, alpha = .01,
color = "black") +
  annotate("text", x = 2011, y = 3.8, label = c("Third Period \n(2004-
2018)"), size=4)
```