

A0B17MTB – Matlab

Part #11



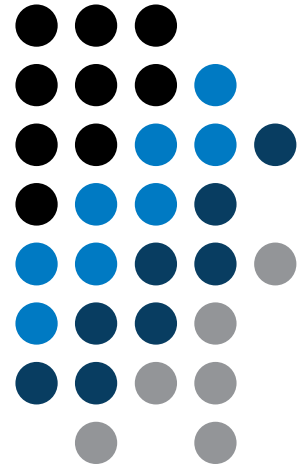
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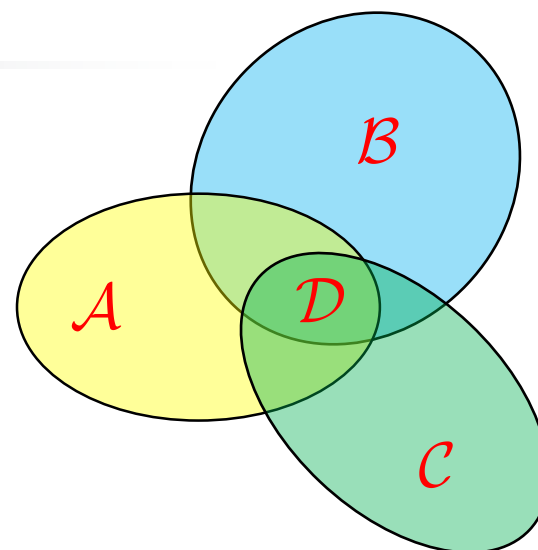


Learning how to ...

Set operations

Sorting

Searching



$$D = A \cap B \cap C$$

$$A \cap B = \{x : x \in A \wedge x \in B\}$$

Set operations

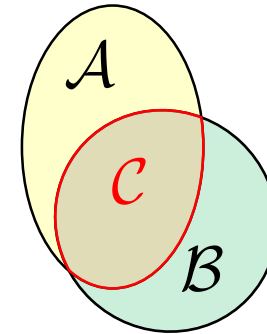
- there exist following operations (operators) in Matlab applicable to arrays or individual elements
 - arithmetic (part #1)
 - relational (part #4)
 - logical (part #4)
 - set (part #11)
 - bit-wise (help, >> doc)
- set operations are applicable to vectors matrices, arrays, cells, strings, tables, ...
 - mutual sizes of these structures are usually not important

intersection of two sets	intersect
union of two sets	union
difference of two sets	setdiff
exclusive OR of two sets	setxor
unique values in a set	unique
sorting, row sorting	sort, sortrows
is the element member of a set?	ismember
is the set sorted?	issorted

Set operations #1

- intersection of sets: `intersect`
 - example: intersection of a matrix and a vector:

```
>> A = [1 -1; 3 4; 0 2];
>> b = [0 3 -1 5 7];
>> c = intersect(A, b)
% c = [-1; 0; 3]
```



$$C = A \cap B$$

`intersect`

`union`

`setdiff`

`setxor`

`unique`

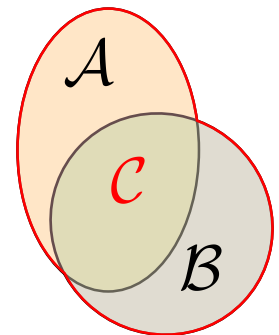
`sort,`
`sortrows`

`ismember`

`issorted`

- union of sets: `union`
 - all set operations can be carried out row-wise
(in that case the number of columns has to be observed)

```
>> A = [1 2 3; 4 5 1; 1 7 1];
>> b = [4 5 1];
>> C = union(A, b, 'rows')
% C = [1 2 3; 1 7 1; 4 5 1]
```

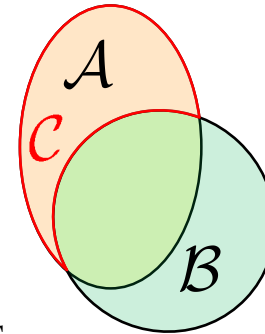


$$C = A \cup B$$

Set operations #2

- intersection of a set and complement of another set : `setdiff`
 - all set operations return more than one output parameter - we get the elements as well as the indexes

```
>> A = [1 1; 3 NaN];
>> B = [2 3; 0 1];
>> [C, ai] = setdiff(A,B)
% C = NaN, ai = 4
% i.e.: C = A(ai)
```

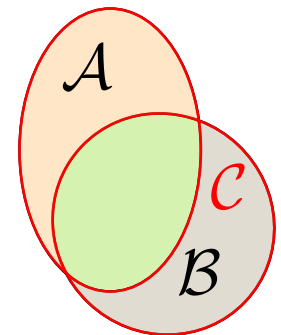


$$C = A \cap B^c = A \setminus B$$

intersect
union
setdiff
setxor
unique
sort, sortrows
ismember
issorted

- exclusive intersection (XOR): `setxor`
 - all set operations can be carried out either as '*stable*' (not changing the order of elements) or as '*sorted*' (elements are sorted)

```
>> A = [5 1 0 4];
>> B = [1 3 5];
>> [C, ia, ib] = setxor(A, B, 'stable')
% C = [0 4 3], ia = [3; 4], ib = [2]
```



$$C = A \oplus B$$

Set operations #3

- selection of unique elements of an array: `unique`
 - set operations are also applicable to arrays not (exclusively) containing numbers

$$\begin{pmatrix} c & b & a & c \\ a & c & b & a \\ c & c & d & b \end{pmatrix} \supseteq \begin{pmatrix} a \\ b \\ c \\ d \end{pmatrix}$$

intersect

union

setdiff

setxor

uniquesort,
sortrows

ismember

issorted

```
>> A = {'Joe', 'Tom', 'Sam'};
>> B = {'Tom', 'John', 'Karl', 'Joe'};
>> C = unique([A B])
% C = {'John', 'Karl', 'Joe', 'Sam', 'Tom'}
```

- it is possible to combine all above mentioned techniques
 - e.g. row-wise listing of unique elements of a matrix including indexes:

```
>> A = round(rand(10, 3)).*mod(10:-1:1, 3)
>> [C, ai, ci] = unique(sum(A, 2), 'rows', 'stable')
```

- **Interpret the meaning of the above code?** Is the `'rows'` parameter necessary?

Set operations #1

600 s ↑

- consider three vectors **a**, **b**, **c** containing natural numbers $x \in \mathbb{N}$ so that
 - vector **a** contains all primes up to (and including) 1000
 - vector **b** contains all even numbers up to (and including) 1000
 - vector **c** is complement of **b** in the same interval
- find vector **v** so that

$$\mathbf{v} = \mathbf{a} \cap (\mathbf{b} + \mathbf{c}), \quad \mathbf{b} + \mathbf{c} \equiv \{b_i + c_i\}, \quad i \in \{1, 500\}$$
 - what elements does **v** contain?

$$b_{i-1} < b_i < b_{i+1} \wedge c_{i-1} < c_i < c_{i+1}, \quad \forall i$$
- how many elements are there in **v**?

v =

Columns 1 through 24

3 7 11 19 23 31 43 47 59 67 71 79

Columns 25 through 48

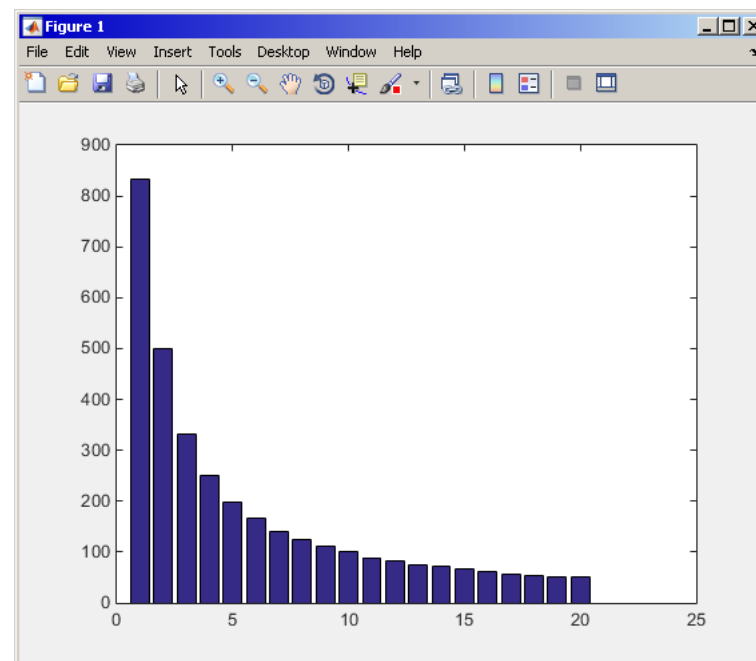
211 223 227 239 251 263 271 283 307 311 331 347

Columns 49 through 72

491 499 503 523 547 563 571 587 599 607 619 631

Columns 73 through 87

823 827 839 859 863 883 887 907 911 919 947 967



Set operations #5

600 s



- Radio relay link operates at frequency of 80 GHz at 20 km distance with 64-QAM modulation
 - phase stability of $\pm 0.5^\circ$ is required for sufficiently low bit error rate without using synchronization and coding
 - that corresponds to the change of distance between antennas equal to $\pm 5 \mu\text{m}$
 - the statistics of link distance with normal distribution containing $1 \cdot 10^6$ elements can be generated as:

```
L = 20e3; % length of path
deviation = 5e-6; % standard deviation
N = 1e6; % number of trials
% random distances
distances = L + randn(1, N)*deviation;
```

- How many times is the distance L contained in the vector `distances`?
- How many unique elements are there in `distances`?
- Can the distribution be considered continuous?

Array sorting #1

- sort array elements

- column-wise, in ascending order:

```
>> sort(A)
```

- row-wise, in ascending order :

```
>> sort(A, 2)
```

- in descending order:

```
>> sort(A, 'descend')
```

- in descending order, row-wise:

```
>> sort(A, 2, 'descend')
```

- apply the sorting function, to following matrices (for instance):

```
>> A = reshape([magic(3) magic(3)'], [3 3 2])
>> B = 'for that purpose';
```

intersect

union

setdiff

setxor

unique

sort,
sortrows

ismember

issorted

Array sorting #2

- function `sortrows` sorts rows of a matrix
 - elements of the rows are not swapped - rows are sorted as blocks

$$\begin{pmatrix} 8 & 1 & 6 \\ 3 & 5 & 7 \\ 4 & 9 & 2 \end{pmatrix}$$

SORT:

$$\begin{pmatrix} 3 & 1 & 2 \\ 4 & 5 & 6 \\ 8 & 9 & 7 \end{pmatrix}$$

SORTROWS:

$$\begin{pmatrix} 3 & 5 & 7 \\ 4 & 9 & 2 \\ 8 & 1 & 6 \end{pmatrix}$$

intersect

union

setdiff

setxor

unique

sort,
sortrows

ismember

issorted

is* functions related to sets

- function `issorted` returns true if array is sorted
- function `ismember(A, B)` tests whether an element of array B is also an element of array A

intersect

union

setdiff

setxor

unique

sort,
sortrows**ismember****issorted**

```
>> ismember([1 2 3; 4 5 6; 7 8 9], [0 0 1; 2 1 4])
```

```
>> ismember([1 2 3; 4 5 6; 7 8 9], [0 0 1; 2 1 4])
```

```
ans =
```

```

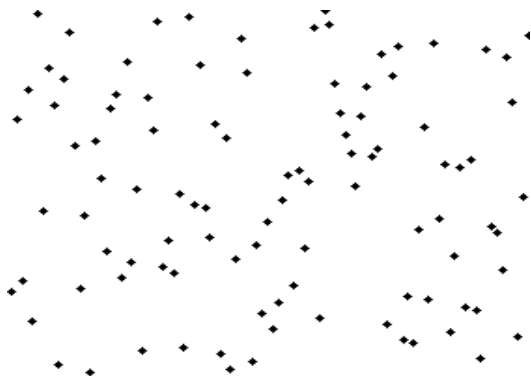
     1     1     0
     1     0     0
     0     0     0

```

Array sorting

600 s ↑

- try to write your own sorting algorithm `bubbleSort.m`
 - use the *bubble sort* algorithm
 - use the function `issorted` to test whether the resulting array is sorted



wikipedia.org

if you wish, you can use the following code inside loops :

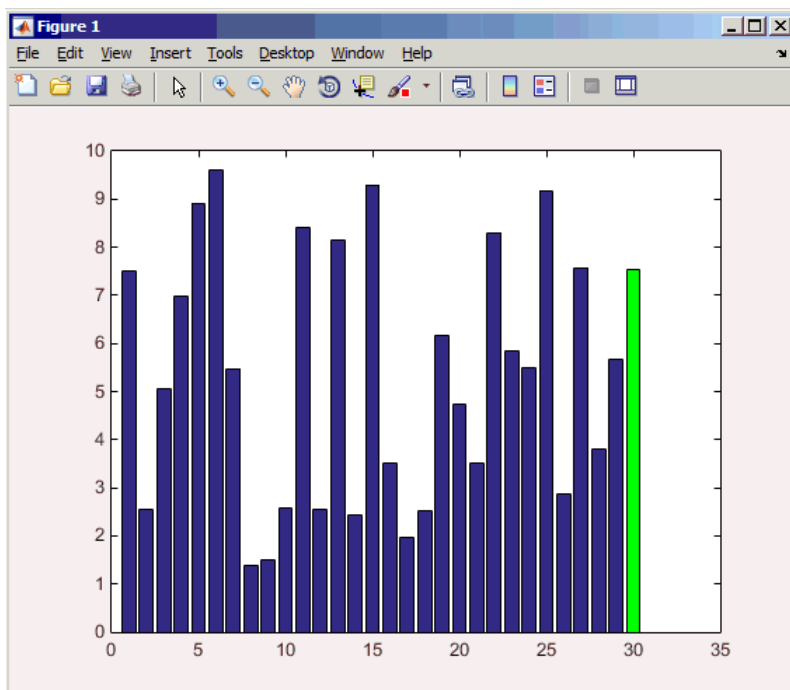
```
figure(1);  
plot(R, '*', 'LineWidth', 2);  
pause(0.01);
```

```
sort(R)
```

Array sorting

600 s ↑

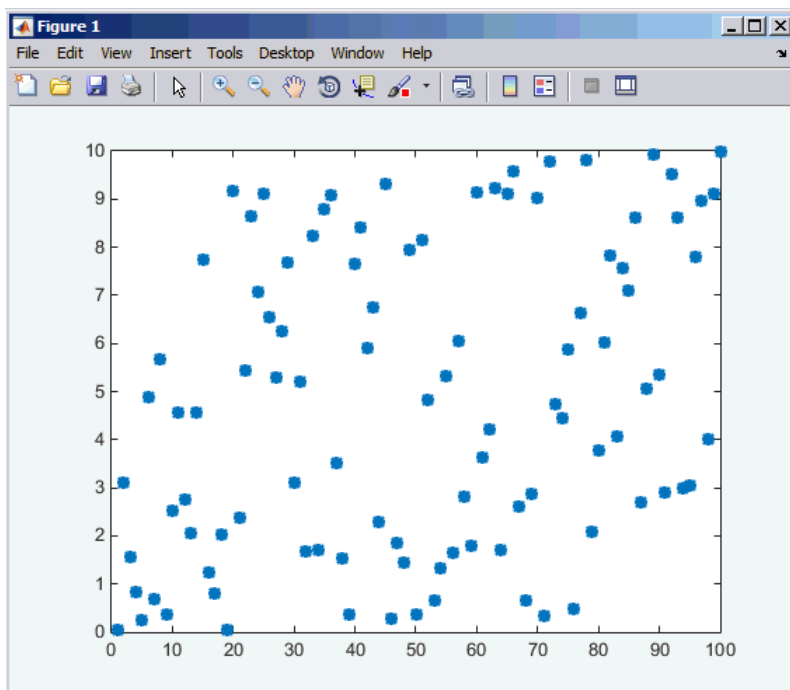
- try to get plot as in the figure using `bar` function:



Array sorting – shaker sort

600 s ↑

- try to write your own sorting algorithm `shakerSort.m`
 - use the *shaker sort* algorithm



Searching in an array – find

- `find` function is a very useful one!!
- returns positions of non-zero (logical true) elements of a matrix
 - useful for searching in an array of logical values
 - example: find positions of those elements of vector $\mathbf{A} = \left(\frac{\pi}{2} \quad \pi \quad \frac{3}{2}\pi \quad 2\pi \right)$ fulfilling the condition $\mathbf{A} > \pi$

```
>> A = pi/2*(1:4)
>> find(A > pi)
```

- **compare the above command** with `A > pi`. What is the difference?
- function `find` can also search a square matrix etc.
- to find first / last k non-zero elements of X :

```
>> ind = find(X, k, 'first')
>> ind = find(X, k, 'last')
```

- for more see `>> doc find`

Array searching #1

420 s ↑

- sort the vector $\mathbf{v} = (16 \ 2 \ 3 \ 13 \ 5 \ 11 \ 10 \ 8 \ 9 \ 7 \ 6 \ 12 \ 4 \ 14 \ 15 \ 1)$ in descending order and find the elements of the vector (and their respective positions within the vector) that are divisible by three and at the same time are greater than 10

```
>> v = reshape(magic(4)', [1 numel(magic(4))])
```

```
v =
    16     2     3    13     5    11    10     8     9     7     6    12     4    14    15     1

v1 =
     0     1     0     0     1     0     0     0     0     0     0     0     0     0     0     0

ans =
    15    12

ans =
     2     5
```

Array searching #2

300 s ↑

- in matrix **w**

```
>> w = (8:-1:2)'*(1:1/2:4).*magic(7)
```

find last 3 values that are smaller than 50

- find out the column and row positions of the values

w =

240.0000	468.0000	768.0000	20.0000	240.0000	532.0000	896.0000
266.0000	493.5000	98.0000	157.5000	378.0000	661.5000	812.0000
276.0000	54.0000	96.0000	255.0000	468.0000	735.0000	888.0000
25.0000	105.0000	160.0000	312.5000	510.0000	630.0000	900.0000
52.0000	90.0000	192.0000	330.0000	504.0000	616.0000	64.0000
63.0000	103.5000	192.0000	307.5000	387.0000	31.5000	144.0000
44.0000	93.0000	160.0000	245.0000	12.0000	77.0000	160.0000

Application of the `find` function

600 s ↑

- Samples of demodulated signal of a radio receiver can be approximated as :

```
w = 0.6833; t = 1:10; % time
samples = 2.7 + 0.5*(cos(w*t) - sin(w*t) - cos(2*w*t) + sin(2*w*t) ...
    - cos(3*w*t) + 3*sin(3*w*t) + 2*cos(4*w*t) + 4*sin(4*w*t));
plot(samples, '*')
```

- Voltage corresponding to characters are within ± 0.5 V tolerance
- Decipher the message!

```
chars = 'acdgmrs'; volts = 1:7;
message = blanks(length(samples));
for iVolt = volts
    logCondition = samples > (iVolt - 0.5) & ...
        samples < (iVolt + 0.5);
    indices = find(logCondition);
    message(indices) = chars(iVolt);
end
disp(message)
```

Voltage [V]	Character
1	a
2	c
3	d
4	g
5	m
6	r
7	s

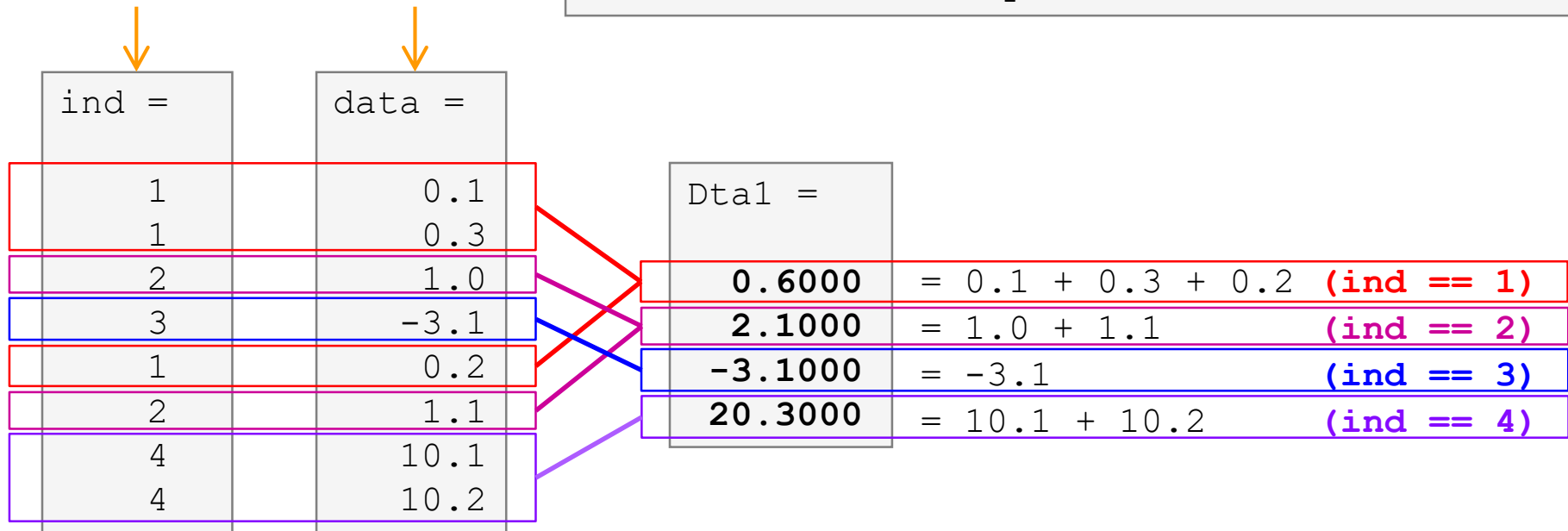
Function accumarray #1

- the function `accumarray` is able to group data with the same index
 - not a very well known function, but an exceptionally useful one
- quite often we deal with a dataset that is organised in the following way:

indexes (e.g. measurement number)

values (measured)

```
>> ind = [1 1 2 3 1 2 4 4].';
>> data = [.1 .3 1 -3.1 .2 1.1 10.1 10.2].';
>> Dta1 = accumarray(ind, data)
```



Function `accumarray` #2

- basic operation applicable to data from one 'box' (data with the same index) is summation
- any other function can be applied, however
 - e.g. maximum of a set of elements with the same index
 - we use the `max` function

```
>> Dta2 = accumarray(ind, data, [], @max)
```

```
Dta2 =
    0.3000
    1.1000
   -3.1000
   10.2000
```

- e.g. listing of all elements with the same index
- we use so called handle function and `cell` data type

```
>> Dta3 = accumarray(ind, data, [], @(x) {x})
```

```
Dta3 =
 [3x1 double]
 [2x1 double]
 [   -3.1000]
 [2x1 double]
```

Function accumarray #3

- the function has a wide variety of other features
- it is possible, for instance, to use 2D indexation of results
 - the results are not put in a 1D set of 'boxes' but to a 2D array instead

```
>> ind = [1 1;2 2;1 2;1 3;1 1;3 1];
>> data = [10 22 12 13 1 pi];
>> Dta4 = accumarray(ind, data)
```

ind =

```
1 1
2 2
1 2
1 3
1 1
3 1
```

data =

```
10
22
12
13
1
pi
```

ind == [1 1] 10 + 1 = 11	ind == [1 2] 12	ind == [1 3] 13
ind == [2 1] 0	ind == [2 2] 22	ind == [2 3] 0
ind == [3 1] pi	ind == [3 2] 0	ind == [3 3] 0

Function accumarray

300 s ↑

- account transfers in CZK, EUR a USD are as follows
 - (CZK ~ 1, EUR ~ 2, USD ~ 3)
- find out account balance in each currency
 - the exchange rate is 26 CZK = 1€, 25 CZK = 1\$, find out total balance

$$\begin{pmatrix} 1 & -110 \\ 1 & -140 \\ 2 & -22 \\ 3 & -2 \\ 2 & -34 \\ 1 & -1300 \\ 2 & -15 \\ 1 & -730 \\ 3 & 24 \end{pmatrix}$$

```
>> dta = [1 -110; 1 -140; 2 -22; 3 -2; ...
          2 -34; 1 -1300; 2 -15; 1 -730; 3 24]
>> K    = [1 26 25]
```

Discussed functions

<code>intersect</code>	intersection of sets (vectors / matrices)	
<code>union</code>	intersection of sets (vectors / matrices)	
<code>setdiff</code>	Subtraction of sets (intersection of a set and complement of another set)	
<code>setxor</code>	exclusive intersection	
<code>unique</code>	selection of unique elements of an array	
<code>sort</code>	sort vector/matrix elements	
<code>sortrows</code>	sorts rows of a matrix as a whole	
<code>accumarray</code>	group data	•
<code>ismember</code>	is given element is member of array?	
<code>issorted</code>	is array sorted?	
<code>find</code>	find elements fulfilling given condition	•

Exercise #1

- measurement of temperature was carried out in the course of 5 days every second clock hour. Data was measured at 3 different sites (A, B, C)
- find out average daily temperature in given week for all 3 sites
 - i.e., get mean value of measurement at the same hour on the same site
- generate the data using `temperature_measurement.m`
 - see the script on the following slide
 - see the variables required

Exercise #2

script for data generation

```
clear; close all; clc;
%% allocation
days = 5; hours = 12;
TimeA = zeros(days*hours,1);
TimeB = TimeA;
TimeC = TimeA;
%% creation of time data-set
for kDay = 1:days
    TimeA((hours*(kDay-1)+1):(hours*(kDay-1)+12),1) = 2*(randperm(12)-1)';
    TimeB((hours*(kDay-1)+1):(hours*(kDay-1)+12),1) = 2*(randperm(12)-1)';
    TimeC((hours*(kDay-1)+1):(hours*(kDay-1)+12),1) = 2*(randperm(12)-1)';
end
%% place and temperture data-sets
PlaceA = abs(abs(TimeA - 11) - 10) + 10 + 5.0*rand(size(TimeA,1),1);
PlaceB = abs(abs(TimeB - 12) - 10) + 5 + 10.0*rand(size(TimeB,1),1);
PlaceC = abs(abs(TimeC - 11) - 11) + 5 + 7.5*rand(size(TimeC,1),1);

%% generating final variables for the example
TimeAndPlace = [TimeA/2+1 ones(size(TimeA,1),1);...
                TimeB/2+1 2*ones(size(TimeA,1),1);...
                TimeC/2+1 3*ones(size(TimeA,1),1)];
MeasuredData = [PlaceA; PlaceB; PlaceC];

%% plot final data-set
plot(TimeA,PlaceA,'LineWidth',1,'LineStyle','none','Marker','x',...
      'MarkerSize',15); hold on;
plot(TimeB,PlaceB,'LineWidth',1,'LineStyle','none','Marker','*',...
      'MarkerSize',15,'Color','r');
plot(TimeC,PlaceC,'LineWidth',2,'LineStyle','none','Marker','o',...
      'MarkerSize',10,'Color','g');
set(gcf,'Color','w','pos',[50 50 1000 600]); set(gca,'FontSize',15);
xlabel('time','FontSize',15); ylabel('Temperature','FontSize',15);
title('Measured Data'); grid on; legend('Place A','Place B','Place C');
```

and the results ...

Exercise #3

- all the data are contained in 2 matrices:
 - TimeAndPlace $(5 \times 3 \times 12, 2) = (180, 2)$
 - MeasuredData $(5 \times 3 \times 12, 1) = (180, 1)$



- unfortunately, data in TimeAndPlace are intentionally unsorted

INDEXES:

TimeAndPlace =

MeasuredData =

DATA:

tindex = 10, Place = 1

10 1

15.0797

T(10,1) = 15.0797 °C

4 1

18.9739

7 1

19.3836

... ...

...

12 2

9.9506

tindex = 6, Place = 2

6 2

19.7588

T(6,2) = 19.7588 °C

... ...

...

Exercise #4

600 s ↑

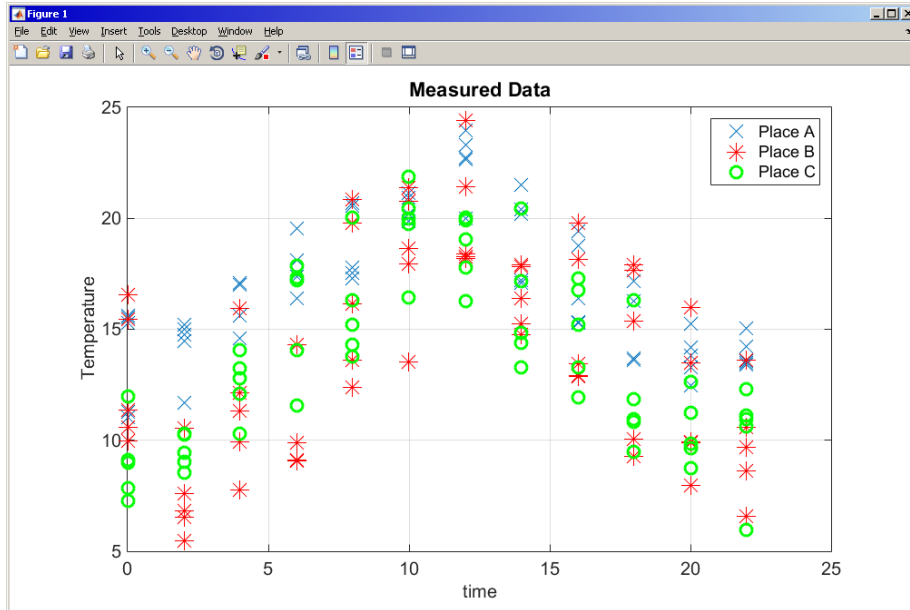
- following holds true
 - Place1 ~ measurement site A
 - Place2 ~ measurement site B
 - Place3 ~ measurement site C
 - measurement hour = $2*(tindex-1)$
- now try to place your code in the script to carry out the averaging and plot the data in the existing figure

```
%% PLACE YOUR CODE HERE
%=====

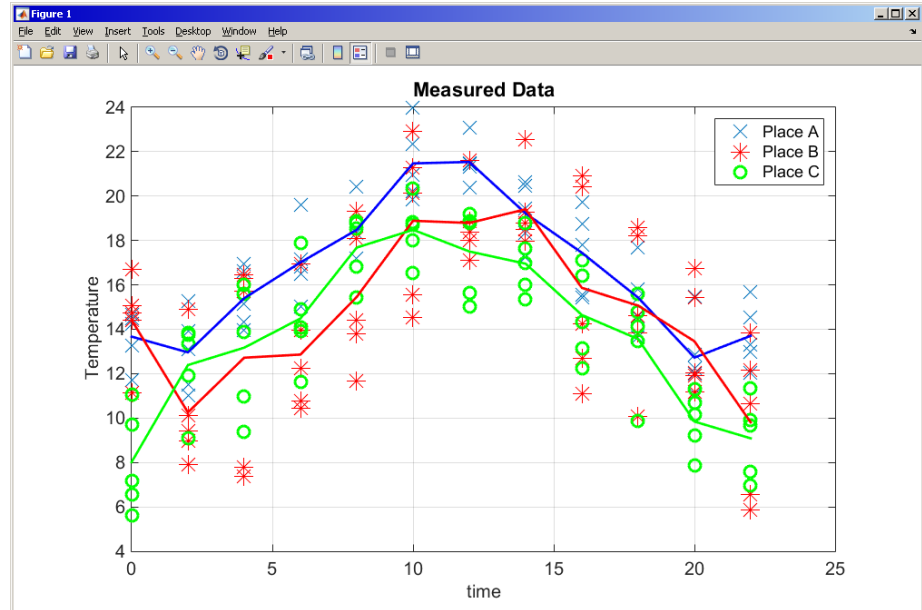
% ...
% dataA = ...
% dataB = ...
% dataC = ...
%=====

%% plot the averaged data
plot(0:2:22,dataA,'LineWidth',2,'Color','b','LineStyle','-');
plot(0:2:22,dataB,'LineWidth',2,'Color','r','LineStyle','-');
plot(0:2:22,dataC,'LineWidth',2,'Color','g','LineStyle','-');
```

Exercise #5



measured data



measured and averaged data

Thank you!



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