A gentle introduction to Matlab

The “Mat” in Matlab does not stand for “mathematics”, but for “matrix”..

$\Rightarrow$ all objects in matlab are matrices of some sort! Keep this in mind when using it.

Matlab is a high level *interpreted* programming language:

- a matlab program is typically a set of instructions that are evaluated iteratively;
- most of the work can be done directly from the command line.

Defining a function

We want to plot the iterates of some function f. First, we define the function.

```
>> f=inline('r.*x.*(1-x)','x','r')


f =


     Inline function:
     f(x,r) = r.*x.*(1-x)
```

This defines a function (here, with two arguments, x and r), that can then be used:

```
>> f(0.2,3.2)


ans =


    0.5120
```

";" hides the result on the command line

Remark that

```
>> f(0.2,3.2)

ans =

    0.5120
```

but

```
>> f(0.2,3.2);
```

produces no output.

Creating a vector

To create a vector, use the command

$$x = \text{first entry} : \text{step} : \text{last entry},$$

or, if entries are a subset of the integers,

$$x = \text{first entry} : \text{last entry}.$$

For example, we want to plot the iterates of the logistic map, so

```
x=0:0.01:1;
```

Note the ";": otherwise, we get the full 101 elements vector displayed.

What is the size of .. ?

As mentioned, in matlab everything is a matrix. For matrix operations, size is important, and it is frequent to make mistakes. To check, `whos` and `size`. `whos` gives a lot of information.

```
>> whos x
  Name       Size                    Bytes  Class

  x          1x101                     808  double array
Grand total is 101 elements using 808 bytes
```

Various variables can be listed on the line after `whos`:

```
>> whos x k
  Name       Size                     Bytes  Class

  k          1x1                          8  double array
  x          1x101                      808  double array
Grand total is 102 elements using 816 bytes
```

size

`size`, on the other hand, is "attributable". It can be used like this

```
>> size(x)


ans =
     1   101
```

but also like this, since the result is a vector

```
>> [r,c]=size(x)


r =
     1


c =
   101
```

in which case, *r* and *c* take the values of the numbers of rows and columns, respectively.

Vectorized functions versus nonvectorized functions

Recall that we wrote

```
>> f=inline('r.*x.*(1-x)','x','r')
```

that is, every multiplication sign took the form `.*` instead of `*`. Here, this is needed: we want to use the *vectorized* form of the function, and be able to pass to f a vector instead of a single value. The `.*` form means that the operation is applied to every entry in the vector/matrix. Same exists for `/` and `^`. Can also use the function `vectorize`.

The result of using this vectorized form is that f will be applied to every entry of x, and will produce a vector.

Vectorized operations have been optimized in matlab, and are extremely fast. When possible, they should be used instead of loops.

Vectorized vs nonvectorized

Define

```
>> f=inline('r.*x.*(1-x)','x','r')
>> g=inline('r*x*(1-x)','x','r')
```

and for simplicity, consider the vector

```
>> x=[1,2];
```

Then

```
>> f(x,3.5)
   g(x,3.5)
ans =
     0    -7

??? Error using ==> inlineeval
Error in inline expression ==> r*x*(1-x)
??? Error using ==> mtimes
Inner matrix dimensions must agree.
```

Plotting

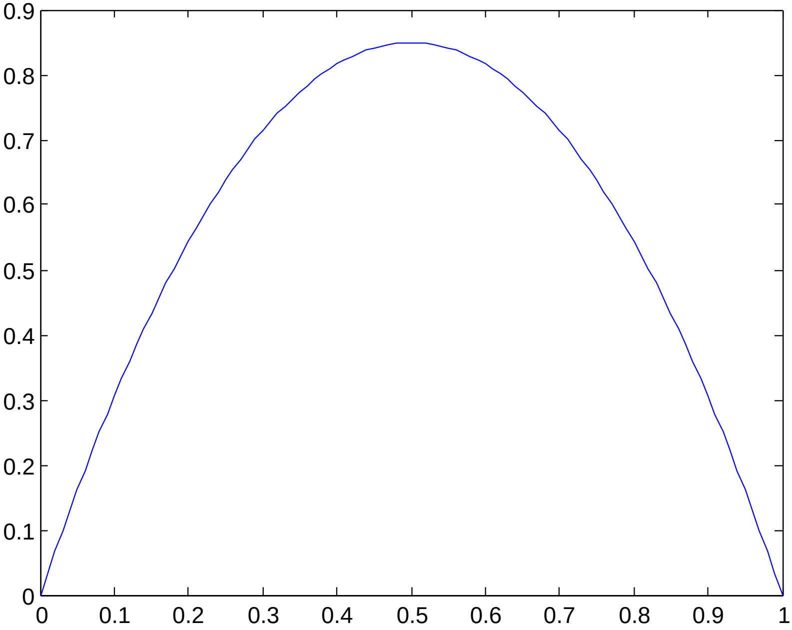
Basic plotting is very easy. The format is

```
plot(x_axis,y_value)
```

so, for example (with f as defined above),

```
plot(x,f(x,3.4))
```

(here, ";" or not does not matter, as the figure appears in a new window and all that ";" changes is the output in the command window).



0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Making things a bit more fancy

This is a very basic plot.

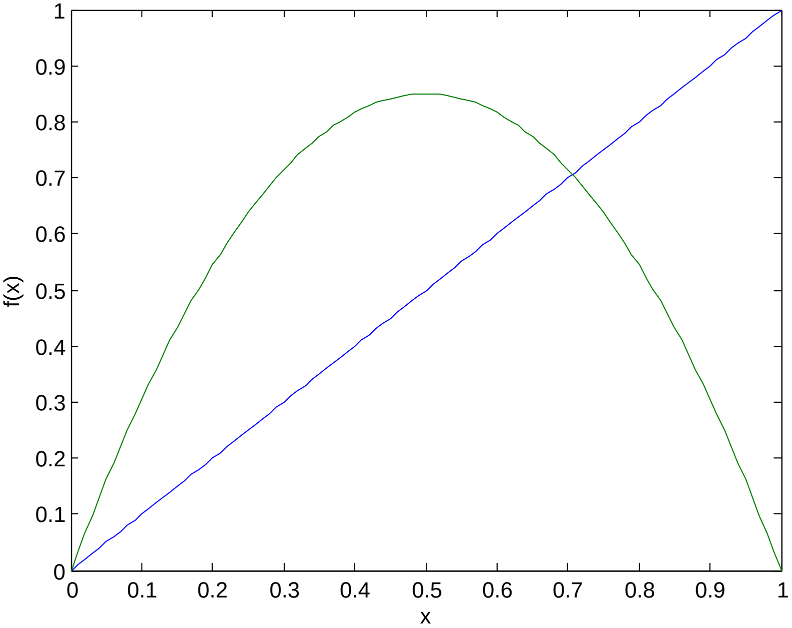
- We could want to plot more than one object (for example, the line $y = x$ would be nice)..

  ```
  plot(x,x,x,f(x,3.4));
  ```

  Ordering is by pairs: $x_1, f_1(x_1), x_2, f_2(x_2)$. Two elements in a pair **must have** the same number of columns. Different pairs **can have** different numbers of columns. Each element in a given pair can be a point, a vector, a matrix.

- We could want to label the axes..

  ```
  xlabel('x');
  ylabel('f(x)');
  ```


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
f(x)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
x

Computing several iterates

For the moment, we only have $f(x)$. We want $f^n(x)$, for a given n. Several ways.

- Taking for example $r = 3.5$, use

  ```
  f(f(x,3.5),3.5)
  ```

- The downside to this method is that matlab does not allow to formally define f^n, so tricks have to be used for larger values of n, for example, produce a string containing the command

  ```
  f(f(f(f(f(x,3.5),3.5),3.5),3.5),3.5)
  ```

  and evaluate it. Complicated..
- Another method consists in using the result found at the previous step to evaluate the next. We do that..

Automatic resizing of vectors and matrices

We are going to use a very nice feature of matlab: adding elements to a vector, or rows/columns to a matrix, is automatic. Suppose for example that we had defined x as

```
x=0:0.01:0.5;
```

Then

```
x=[x,0.51:0.01:1];
```

would produce the vector x as we had earlier.

Be careful! Note that the command was

```
x=[x,0.51:0.01:1];
```

that is, the old and new entries were separated by a ",". This is *horizontal concatenation*. The command with a ";" tries to add a new row. In our case, we get

```
>> z=[z;0.51:0.01:1]
??? Error using ==> vertcat
All rows in the bracketed expression must have the same
number of columns.
```

because we are trying to add a row of 50 elements to a row of 51 elements. But

```
>> z=[z;0.51:0.01:1.01]
```

works, and gives a 2×51 matrix.

Here, we are going to use the latter form of the command, and add each successive iterate to a solution matrix M.
First, define an empty matrix,

```
M=[];
```

Then we need to loop from 1 to n, where n is the iterate that we want.

Loops

The command uses the same type of syntax as the creation of a vector: to loop from 4 to 12 by steps of 1,

```
for i=4:12,
   command(s) to be repeated, maybe using the value i
end;
```

whereas to loop by non-unit or non-integer steps, say from 4 to 12 by steps of 1.35,

```
for i=4:1.35:12,
   command(s) to be repeated, maybe using the value i
end;
```

Note that in that case, the last i is equal to 10.75, not 12, since $10.75 + 1.35 = 12.1 > 12$. The same is true when using non-unit steps to create vectors.

Accessing matrix elements

Suppose that M is an $m \times n$-matrix. Then

- `M(i,j)` is the element on the ith row and jth column.
- `M(i,:)` is the ith row.
- `M(:,j)` is the jth column.
- `M(end,:)` is the last row of M (`end` is a reserved word which always points to the last valid index in a given matrix dimension).
- `M(:,end)` is the last column of M.
- `M(end,1:10)` are the first 10 entries in the last row of M.
- `M(1:2,3:5)` is the submatrix of M consisting of rows 1 and 2 and columns 3 to 5 of M.

Back to the iterates

After some thought, we realize that we will need to go back one iterate. So instead of starting with empty matrix M, fill the first row of M with first iterate, and start at iterate 2.

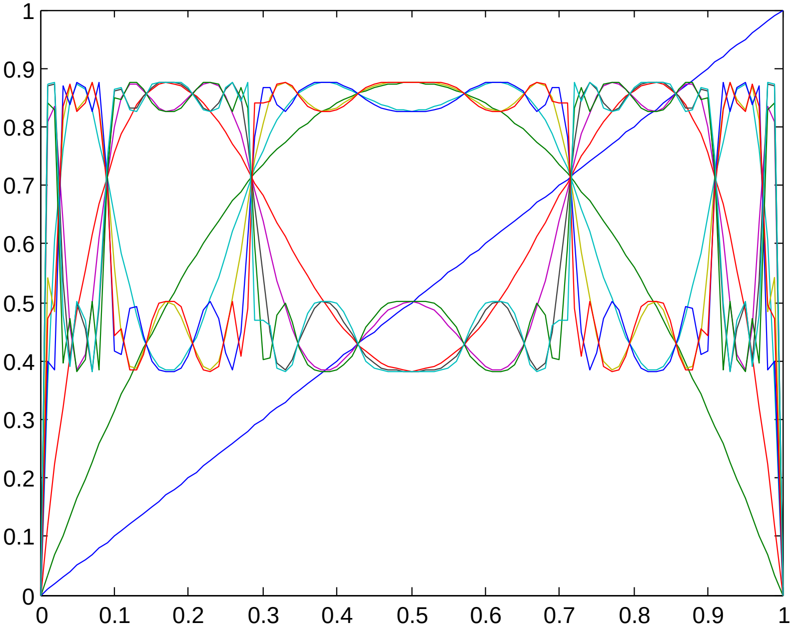
```
n=10;
r=3.5;

M=f(x,r);

for i=2:n,
    M=[M;f(M(end,:),r)];
end;

plot(x,M);
```

This plots all the iterates to n. A bit crowded..


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1