Introduction to Matlab

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IFCAM Workshop on Control of PDE
22 July - 2 August, 2013

In the following slides, the symbol

```
>>
```

denotes the matlab command prompt.

Variables: Come into existence when you assign a value

```
>> x=1
```

To prevent the value from being printed to screen, end the line with a colon

```
>> x=1;
```

You can now use the variable `x` in other statements

```
>> y=sin(x)
```

A **row vector**

```
>> x = [1,2,3,4]
>> y=sin(x)
```

Note that Matlab computed `sin` on every element of the vector `x`

A **column vector**

```
>> x = [1; 2; 3; 4]
>> y = sin(x)
```

Output y inherits dimensions of input x

Matrix

```
>> x = [1, 2, 3, 4; 5, 6, 7, 8]
>> y=sin(x)
```

Line continuation

```
>> x = [1, 2, 3, 4; ...
          5, 6, 7, 8]
>> y=sin(x)
```

Adding vectors

```
>> x = [1, 2, 3, 4]
>> y = [5, 6, 7, 8]
>> z = x + y
```

x and y must have same dimensions. This is wrong

```
>> x = [1, 2, 3, 4]
>> y = [5; 6; 7; 8]
>> z = x + y
```

To find dimensions

```
>> size(x)
>> size(y)
```

Transpose a vector or matrix

```
>> z = x + y'
>> size(y')
```

Find all variables

```
>> who
```

Deleting all existing variables

```
>> clear all
>> who
```

Matrix-vector multiplication

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

```
>> A = [1, 2; 3, 4]
>> y = A*x
```

Matrix-matrix operations

```
>> B = [5, 6; 7, 8]
>> C = A + B
>> D = A*B
```

Elementwise operation

$$z = x \sin(y)$$

```
>> x = [1, 2, 3, 4]
>> y = [5, 6, 7, 8]
>> z = x .* sin(y)
```

A more complicated example

$$z = \frac{x^2 \sin(y)}{\cos(x + y)}$$

```
>> z = x.^2 .* sin(y) ./ cos(x+y)
```

Multiply matrices element-wise

```
>> E = A .* B
```

A and B must have same size

Zero vector/matrix

```
>> x = zeros(4,1)
>> A = zeros(3,3)
```

Ones vector/matrix

```
>> x = ones(4,1)
>> A = ones(3,3)
```

Identity matrix

```
>> A = eye(4)
```

Random vector/matrix

```
>> x = rand(1,3)
>> A = rand(3,2)
```

Documentation

```
>> help rand
```

Plotting

Making a uniform grid

```
>> x = linspace(0, 2*pi, 10)
>> y = sin(x)
```

Plot a line graph

```
>> plot(x, y, '-')
```

Plot a symbol graph

```
>> plot(x, y, 'o')
```

Plot a line and symbol graph

```
>> plot(x, y, 'o-')
```

Plotting

Multiple graphs

```
>> x = linspace(0, 2*pi, 100);
>> y = sin(x);
>> z = cos(x);
>> plot(x, y, 'b-', x, z, 'r--')
>> xlabel('x')
>> ylabel('y,z')
>> legend('x versus y', 'x versus z')
>> title('x versus y and z')
```

Plotting

Subplots

```
>> x = linspace(0, 2*pi, 100);
>> y = sin(x);
>> z = cos(x);
>> subplot(1,2,1)
>> plot(x, y, 'b-')
>> xlabel('x')
>> ylabel('y')
>> subplot(1,2,2)
>> plot(x, z, 'r--')
>> xlabel('x')
>> ylabel('z')
```

For more, use `help`

```
>> help plot
```

Sparse matrices

Suppose the matrix A has mostly zero entries

$$A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 2 \\ 3 & 0 & 0 \end{bmatrix}$$

Create a sparse matrix

```
>> A = sparse(3,3)
```

Fill in non-zero entries

```
>> A(1,2) = 1;
>> A(2,3) = 2;
>> A(3,1) = 3;
```

To get normal matrix

```
>> full(A)
```

To convert normal matrix to full matrix

```
>> sparse(A)
```

Sparse matrices

Sparse diagonal matrix

$$A = \text{diag}[1, -2, 1] \in \mathbb{R}^{n \times n}$$

```
>> n = 10;
>> e = ones(n,1);
>> A = spdiags([e, -2*e, e], -1:1, n, n);
```

Sparse identity matrix

```
>> A = speye(5)
```

Eigenvalues and eigenvectors

$$Ax = \lambda x$$

```
>> A = rand(100,100);
>> lambda = eig(A);
>> plot(real(lambda), imag(lambda), 'o')
```

To get eigenvectors

```
>> [V,D] = eig(A);
```

Columns of `V` contain eigenvectors,

$$V = [e_1, e_2, \ldots, e_n] \in \mathbb{R}^{n\times n}, \qquad e_j \in \mathbb{R}^n$$

`D` is diagonal matrix with eigenvalues on the diagonal

$$D = \text{diag}[\lambda_1, \lambda_2, \ldots, \lambda_n]$$

$$Ae_j = \lambda_j e_j \qquad \Longrightarrow \qquad AV = VD$$

Eigenvalues and eigenvectors

Generalized eigenvalues/vectors

$$Ax = \lambda Bx$$

```
>> A = rand(10,10);
>> B = rand(10,10);
>> lambda = eig(A,B);
>> [V,D] = eig(A,B);
```

Sparse matrices

For large, sparse matrices, we may want to find only few eigenvalues, e.g., those with largest magnitude.

```
>> A = rand(10,10);
>> lambda = eigs(A,2)
```

To get eigenvectors and eigenvalues

```
>> [V,D] = eigs(A,2)
```

Similarly, to get generalized eigenvectors/values

Eigenvalues and eigenvectors

```
>> A = rand(10,10);
>> B = rand(10,10);
>> lambda = eigs(A,B,2)
>> [V,D] = eigs(A,B,2)
```

If matrix is **non-symmetric**, then we may want to compute eigenvalues with **largest real part**

```
>> lambda = eigs(A,B,2,'LR')
>> [V,D] = eigs(A,B,2,'LR')
```

Numerical example: `eigtest.m`

Compute eigenvalues and eigenfunctions

$$-u''(x) = \lambda u(x), \qquad x \in (0,1)$$

$$u(0) = u(1) = 0$$

Exact eigenvalues and eigenfunctions

$$u_n(x) = \sin(n\pi x), \qquad \lambda_n = \pi^2 n^2, \qquad n = 1, 2, \ldots$$

Use finite difference method: form a grid

$$0 = x_0 < x_1 < x_2 < \ldots < x_{N+1} = 1, \qquad x_j - x_{j-1} = h = \frac{1}{N+1}$$

$$-\frac{u_{j-1} - 2u_j + u_{j+1}}{h^2} = \lambda u_j, \qquad j = 1, 2, \ldots, N$$

$$u_0 = u_{N+1} = 0$$

Numerical example: `eigtest.m`

Define

$$U = [u_1, u_2, \ldots, u_N]^\top, \qquad A = \text{diag}[-1, 2, -1] \in \mathbb{R}^{N \times N}$$

then the finite difference approximation is

$$AU = \lambda U$$

Excercises

1. Run `eigtest.m`
2. Compare numerical and exact eigenvalues/eigenfunctions (Eigenfunctions are exact at the grid points. Can you explain why ?)
3. Replace the function `eig` with `eigs`; compute the 5 largest eigenvalues

Solving an ODE using ode15s

$$\frac{\mathrm{d}y}{\mathrm{d}t} = \mathsf{fun}(t, y, a, b, c, \ldots)$$

Write a matlab program `fun.m` which computes right hand side

```
function f = fun(t, y, a, b, c, ...)
```

`tspan`	`[T0, TFINAL]` or `[T0, T1, ..., TFINAL]`
`y0`	Initial condition y(`T0`)

Solve ode

```
[t, Y] = ode15s(@fun, tspan, y0, a, b, c, ...)
```

`Y(:,i)` = Solution at time `t(i)`

Numerical example: `odetest.m`

This program solves the inverted pendulum problem which we will study in next lecture.

Excercises

1. Study the programs
   `fbo.m, odetest.m`
2. Run `odetest.m`
3. Implement a program to solve the linearized pendulum

   $$z = [z_1, z_2, z_3, z_4]^\top, \qquad \frac{\mathrm{d}z}{\mathrm{d}t} = Az$$

   where

   $$A =$$

   The values of parameters in A are already set in program
   `parameters.m`
   Use the same initial conditions as in `odetest.m`