Digital Signal Processing

Prof. Nizamettin AYDIN, PhD

naydin@yildiz.edu.tr
nizamettinaydin@gmail.com
nizamettinaydin@aydin.edu.tr
http://www3.yildiz.edu.tr/~naydin

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Course Details

- Course Code : SEN522
- Course Name: Digital Signal Processing
  (Sayısal İşaret İşleme)
- Instructor : Nizamettin AYDIN

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MATLAB Tutorial

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Content…

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MATLAB

- high-performance software
  - ***Computation***
  - ***Visualization***
  - ***Easy-to-use environment***.
- high-level language
  - ***Data types***
  - ***Functions***
  - ***Control flow statements***
  - ***Input/output***
  - ***Graphics***
  - ***Object-oriented*** programming capabilities

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MATLAB Parts

- Developed Environment
- Programming Language
- Graphics
- Toolboxes
- Application Program Interface

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Toolboxes

- Collections of functions to solve problems of several applications.
  - DSP Toolbox
  - Image Toolbox
  - Wavelet Toolbox
  - Neural Network Toolbox
  - Fuzzy Logic Toolbox
  - Control Toolbox
  - Communication Toolbox
  - ……

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MATLAB Desktop Tools

- Command Window
- Command History
- Help Browser
- Workspace Browser
- Editor/Debugger
- Launch Pad

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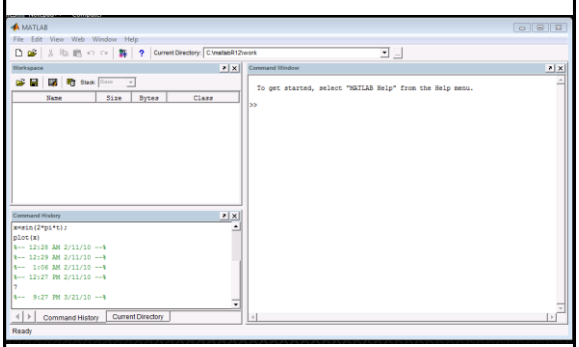

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Calculations at the Command Line

MATLAB as a calculator

```
» -5/(4.8+5.32)^2
ans =
   -0.0488
» (3+4i)*(3-4i)
ans =
    25
» cos(pi/2)
ans =
  6.1230e-017
» exp(acos(0.3))
ans =
    3.5470
```

Assigning Variables

```
» a = 2;
» b = 5;
» a^b
ans =
    32
» x = 5/2*pi;
» y = sin(x)
y =
     1
» z = asin(y)
z =
    1.5708
```

Semicolon suppresses screen output

Results assigned to "ans" if name not specified

() parentheses for function inputs

Numbers stored in double-precision floating point format

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General Functions

- whos: List current variables
- clear : Clear variables and functions from memory
- close: Closes last figures
- cd : Change current working directory
- dir : List files in directory
- echo : Echo commands in M-files
- format: Set output format

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Getting help

- *help* command (`>>help`)
- *lookfor* command (`>>lookfor`)
- Help Browser (`>>doc`)
- *helpwin* command (`>>helpwin`)
- Search Engine
- Printable Documents
  - "Matlabroot\help\pdf_doc\"
- Link to The MathWorks

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Matrices

- Entering and Generating Matrices
- Subscripts
- Scalar Expansion
- Concatenation
- Deleting Rows and Columns
- Array Extraction
- Matrix and Array Multiplication

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Entering Numeric Arrays

```
» a=[1 2;3 4]
a =
     1     2
     3     4
» b=[-2.8, sqrt(-7), (3+5+6)*3/4]
b =
   -2.8000   0 + 2.6458i   10.5000
» b(2,5) = 23
b =
   -2.8000   0 + 2.6458i   10.5000    0         0
         0             0         0    0   23.0000
```

Use square brackets [ ]

Row separator
- semicolon (;)

Column separator
- space / comma (,)

- Any MATLAB expression can be entered as a matrix element
- Matrices must be rectangular. (Set undefined elements to zero)

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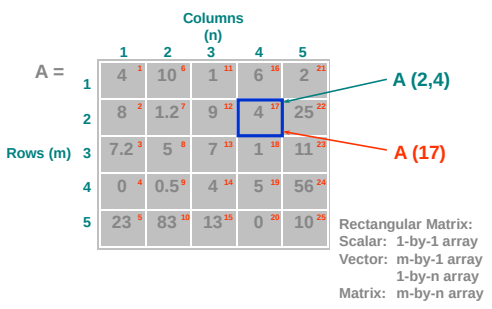
The Matrix in MATLAB



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Entering Numeric Arrays

Scalar expansion

Creating sequences:
- colon operator (:)

Utility functions for creating matrices.

```
» w=[1 2;3 4] + 5
w =
     6     7
     8     9
» x = 1:5
x =
     1     2     3     4     5
» y = 2:-0.5:0
y =
   2.0000   1.5000   1.0000   0.5000   0
» z = rand(2,4)
z =
   0.9501   0.6068   0.8913   0.4565
   0.2311   0.4860   0.7621   0.0185
```

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Numerical Array Concatenation

Use [ ] to combine existing arrays as matrix "elements"

Row separator:
- semicolon (;)

Column separator:
- space / comma (,)

- The resulting matrix must be rectangular

```
» a=[1 2;3 4]
a =
     1     2
     3     4
» cat_a=[a, 2*a; 3*a, 4*a; 5*a, 6*a]
cat_a =
     1     2     2     4
     3     4     6     8
     3     6     4     8
     9    12    12    16
     5    10     6    12
    15    20    18    24
```

Use square brackets [ ]

4*a

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Deleting Rows and Columns

```
» A=[1 5 9;4 3 2.5; 0.1 10 3i+1]
A =
    1.0000         5.0000         9.0000
    4.0000         3.0000         2.5000
    0.1000        10.0000    1.0000+3.0000i
» A(:,2)=[]
A =
    1.0000         9.0000
    4.0000         2.5000
    0.1000    1.0000 + 3.0000i
» A(2,2)=[]
???  Indexed empty matrix assignment is not allowed.
```

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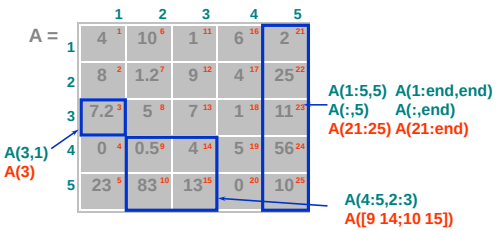
Array Subscripting / Indexing



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Matrix/Array Multiplication

Matrix Multiplication

```
» a = [1 2 3 4; 5 6 7 8];          [2x4]
» b = ones(4,3);                   [4x3]
» c = a*b          [2x4]*[4x3] → [2x3]
c =
    10    10    10
    26    26    26   ← a(2nd row).b(3rd column)
```

Array Multiplication

```
» a = [1 2 3 4; 5 6 7 8];
» b = [1:4; 1:4];
» c = a.*b
c =
     1     4     9    16
     5    12    21    32   ← c(2,4) = a(2,4)*b(2,4)
```

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Matrix Manipulation Functions…

- zeros : Create an array of all zeros
- ones : Create an array of all ones
- eye : Identity Matrix
- rand : Uniformly distributed random numbers
- diag : Diagonal matrices and diagonal of a matrix
- size : Return array dimensions
- fliplr : Flip matrices left-right
- flipud : Flip matrices up and down
- repmat : Replicate and tile a matrix

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…Matrix Manipulation Functions

- transpose (') : Transpose matrix
- rot90 : rotate matrix 90
- tril : Lower triangular part of a matrix
- triu : Upper triangular part of a matrix
- cross : Vector cross product
- dot : Vector dot product
- det : Matrix determinant
- inv : Matrix inverse
- eig : Evaluate eigenvalues and eigenvectors
- rank : Rank of matrix

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Character Arrays (Strings)

- Created using single quote delimiter (')

```
» str  = 'Hi there,'
str =
Hi there,
» str2 = 'Isn''t MATLAB great?'
str2 =
Isn't MATLAB great?
```

- Each character is a separate matrix element

(16 bits of memory per character)

str = | H | i | | t | h | e | r | e | , | ← 1x9 vector

- Indexing same as for numeric arrays

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String Array Concatenation

- **Using [ ] operator:**
  - Each row must be same length
- **Row separator:**
  - semicolon (;)
- **Column separator:**
  - space / comma (,)
- **For strings of different length:**
  - STRVCAT
  - char

```
» str ='Hi there,';
» str1='Everyone!';
» new_str=[str, ' ', str1]
new_str =
Hi there, Everyone!
» str2 = 'Isn''t MATLAB great?';
» new_str2=[new_str; str2]
new_str2 =
Hi there, Everyone!
Isn't MATLAB great?
```

1x9 vectors → 1x19 vector → 2x19 matrix

```
» new_str3 = strvcat(str, str2)
new_str3 =
Hi there,
Isn't MATLAB great?
```

2x19 matrix (zero padded)

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Working with String Arrays

- String Comparisons
  - strcmp : compare whole strings
  - strncmp : compare first 'N' characters
  - findstr : finds substring within a larger string
- Converting between numeric & string arrays:
  - num2str : convert from numeric to string array
  - str2num : convert from string to numeric array

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Elementary Math

- Logical Operators
- Math Functions
- Polynomial and Interpolation

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Logical Operations

= =	equal to
>	greater than
<	less than
>=	Greater or equal
<=	less or equal
~	not
&	and
|	or
isfinite(), etc. . . .	
all(), any()	
find	

```
» Mass = [-2 10 NaN 30 -11 Inf 31];
» each_pos = Mass>=0
each_pos =
     0     1     0     1     0     1     1
» all_pos = all(Mass>=0)
all_pos =
     0
» all_pos = any(Mass>=0)
all_pos =
     1
» pos_fin = (Mass>=0)&(isfinite(Mass))
pos_fin =
     0     1     0     1     0     0     1
```

Note: 1 = TRUE 0 = FALSE

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Elementary Math Function…

- abs : Absolute value
- sign : Signum Function
- sin, cos : Triangular functions (sinus, cosinus)
- asin, acos: Triangular functions (arcsinus,…)
- exp : Exponential
- log : Natural logarithm
- log10 : Common (base 10) logarithm
- ceil, floor: Round toward infinities
- fix : Round toward zero

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…Elementary Math Function…

- round : Round to the nearest integer
- gcd : Greatest common devisor
- lcm : Least common multiple
- sqrt : Square root function
- real, imag: Real and Image part of complex
- rem : Remainder after division

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…Elementary Math Function

- max, min: Maximum and Minimum of arrays
- mean, median: Average and Median of arrays
- std, var: Standard deviation and variance
- sort: Sort elements in ascending order
- sum, prod: Summation & Product of Elements
- trapz: Trapezoidal numerical integration
- cumsum, cumprod: Cumulative sum, product
- diff, gradient: Differences and Numerical Gradient

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Polynomials and Interpolation

- Polynomials
  - Representing
  - Roots (**>> roots**)
  - Evaluation (**>> polyval**)
  - Derivatives (**>> polyder**)
  - Curve Fitting (**>> polyfit**)
  - Partial Fraction Expansion (**residue**)
- Interpolation
  - One-Dimensional (**interp1**)
  - Two-Dimensional (**interp2**

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Example

```
polysam=[1 0 0 8];
roots(polysam)
ans =
  -2.0000
   1.0000 + 1.7321i
   1.0000 - 1.7321i
Polyval(polysam,[0 1 2.5 4 6.5])
ans =
    8.0000    9.0000   23.6250   72.0000  282.6250
polyder(polysam)
ans =
     3     0     0
[r p k]=residue(polysam,[1 2 1])
r =  3     7
p = -1    -1
k =  1    -2
```

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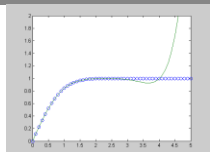
Example

```
x = [0: 0.1: 2.5];
y = erf(x);
p = polyfit(x,y,6)
p =
 0.0084  -0.0983   0.4217  -0.7435   0.1471   1.1064   0.0004
```



```
interp1(x,y,[0.45 0.95 2.2 3.0])
ans =
    0.4744    0.8198    0.9981       NaN
```

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Importing and Exporting Data

- Using the Import Wizard
- Using ***Save*** and ***Load*** command

```
save fname
save fname x y z
save fname -ascii
save fname -mat
```

```
load fname
load fname x y z
load fname -ascii
load fname -mat
```

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Input/Output for Text File

- Read formatted data, reusing the format string N times.

```
»[A1…An]=textread(filename,format,N)
```

- Import and Exporting **Numeric** Data with General ASCII delimited files

```
» M = dlmread(filename,delimiter,range)
```

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Input/Output for Binary File

- fopen : Open a file for input/output
- fclose : Close one or more open files
- fread : Read binary data from file
- fwrite : Write binary data to a file
- fseek : Set file position indicator

```
» fid = fopen('mydata.bin', 'wb');
» fwrite (fid,eye(5) , 'int32');
» fclose (fid);
» fid = fopen('mydata.bin', 'rb');
» M = fread(fid, [5 5], 'int32')
» fclose (fid);
```

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Graphics

- Basic Plotting
  plot, title, xlabel, grid, legend, hold, axis
- Editing Plots
  Property Editor
- Mesh and Surface Plots
  meshgrid, mesh, surf, colorbar, patch, hidden
- Handle Graphics

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2-D Plotting

- Syntax:

```
plot(x1, y1, 'clm1', x2, y2, 'clm2', ...)
```

```
x=[0:0.1:2*pi];
y=sin(x);
z=cos(x);
plot(x,y,x,z,'linewidth',2)
title('Sample Plot','fontsize',14);
xlabel('X values','fontsize',14);
ylabel('Y values','fontsize',14);
legend('Y data','Z data')
grid on
```

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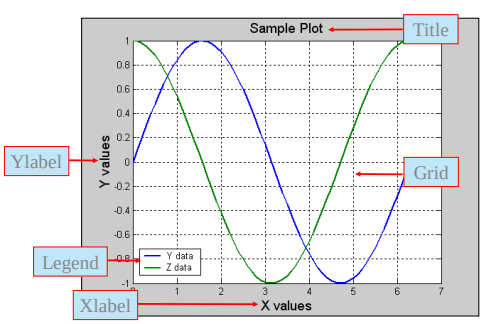
Sample Plot



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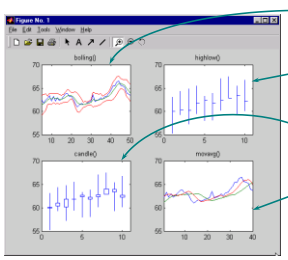
Subplots

```
subplot(rows,cols,index)
```



```
»subplot(2,2,1);
» ...
»subplot(2,2,2)
» ...
»subplot(2,2,3)
» ...
»subplot(2,2,4)
» ...
```

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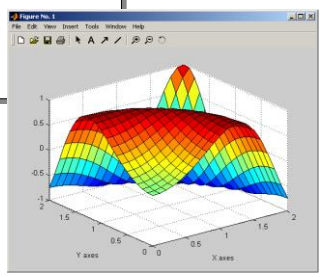
Surface Plot Example

```
x = 0:0.1:2;
y = 0:0.1:2;
[xx, yy] = meshgrid(x,y);
zz=sin(xx.^2+yy.^2);
surf(xx,yy,zz)
xlabel('X axes')
ylabel('Y axes')
```



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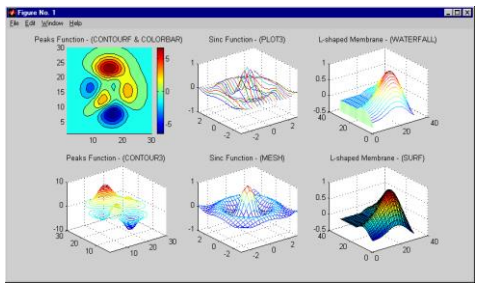
3-D Surface Plotting

contourf-colorbar-plot3-waterfall-contour3-mesh-surf



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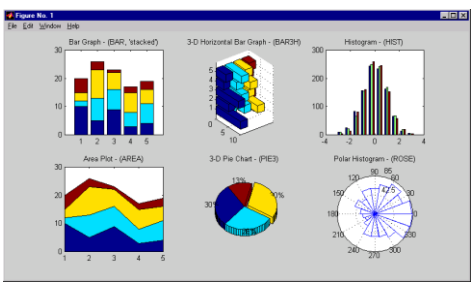
Specialized Plotting Routines

bar-bar3h-hist-area-pie3-rose



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Editing and Debugging M-Files

- What is an M-File?
- The Editor/Debugger
- Search Path
- Debugging M-Files
  - Types of Errors (*Syntax Error* and *Runtime Error*)
  - Using ***keyboard*** and " **;** " statement
  - Setting Breakpoints
  - Stepping Through
    - Continue, Go Until Cursor, Step, Step In, Step Out
  - Examining Values
    - Selecting the Workspace
    - Viewing ***Datatips*** in the Editor/Debugger
    - Evaluating a Selection

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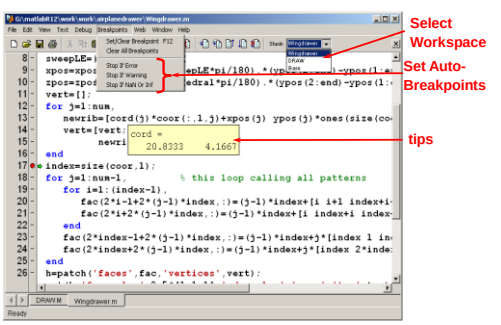
Debugging



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Script and Function Files

- Script Files
  - Work as though you typed commands into MATLAB prompt
  - Variable are stored in MATLAB workspace
- Function Files
  - Let you make your own MATLAB Functions
  - All variables within a function are **local**
  - All information must be passed to functions as parameters
  - Subfunctions are supported

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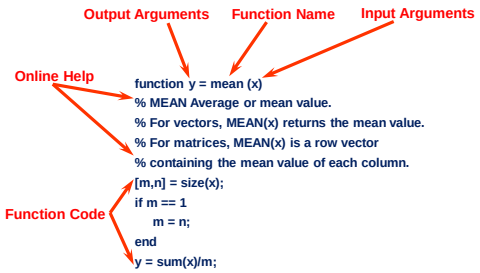
Basic Parts of a Function M-File



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Flow Control Statements…

- *if* Statement

```
if ((attendance >= 0.90) & (grade_average >= 60))
   pass = 1;
end;
```

- *while* Loops

```
eps = 1;
while (1+eps) > 1
    eps = eps/2;
end
eps = eps*2
```

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…Flow Control Statements

- *for* Loop

```
a = zeros(k,k)  % Preallocate matrix
for m = 1:k
    for n = 1:k
        a(m,n) = 1/(m+n -1);
    end
end
```

- *switch* Statement

```
method = 'Bilinear';
switch lower(method)
   case {'linear','bilinear'}
      disp('Method is linear')
   case 'cubic'
      disp('Method is cubic')
otherwise
      disp('Unknown method.')
end
Method is linear
```

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M-file Programming Features

- SubFunctions
- Varying number of input/output arguments
- ***Local*** and ***Global*** Variables
- Obtaining User Input
  - Prompting for Keyboard *Input*
  - Pausing During Execution
- Errors and Warnings
  - Displaying *error* and *warning* Messages
- Shell Escape Functions (*! Operator*)
- Optimizing MATLAB Code
  - Vectorizing loops
  - Preallocating Arrays

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Function M-file

```
function r = ourrank(X,tol)
% rank of a matrix
s = svd(X);
if (nargin == 1)
   tol = max(size(X)) * s(1)* eps;
end
r = sum(s > tol);
```

Multiple Input Arguments use ( )

Multiple Output Arguments, use [ ]

```
»[m std]=ourstat(1:9);
```

```
function [mean,stdev] = ourstat(x)
[m,n] = size(x);
if m == 1
   m = n;
end
mean = sum(x)/m;
stdev = sqrt(sum(x.^2)/m - mean.^2);
```

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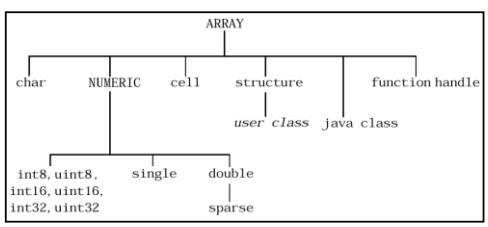
Data Types



- Numeric Arrays
- Multidimensional Arrays
- Structures and Cell Arrays

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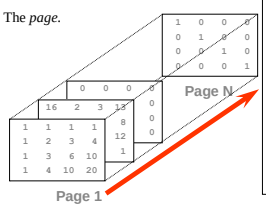
Multidimensional Arrays

The first references array dimension 1,
the row.
The second references dimension 2,
the column.
The third references dimension 3,
The *page*.




```
» A = pascal(4);
» A(:,:,2) = magic(4)
A(:,:,1) =
     1     1     1     1
     1     2     3     4
     1     3     6    10
     1     4    10    20
A(:,:,2) =
    16     2     3    13
     5    11    10     8
     9     7     6    12
     4    14    15     1
» A(:,:,9) =
  diag(ones(1,4));
```

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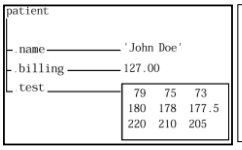
Structures

- Arrays with named data containers called ***fields***.




```
» patient.name='John Doe';
» patient.billing = 127.00;
» patient.test= [79 75 73;
180 178 177.5;
220 210 205];
```

- Also, Build structure arrays using the ***struct*** function.
- Array of *structures*

```
» patient(2).name='Katty Thomson';
» Patient(2).billing = 100.00;
» Patient(2).test= [69 25 33; 120 128 177.5; 220
  210 205];
```

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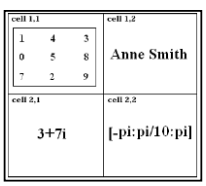
Cell Arrays

- Array for which the elements are *cells* and can hold other MATLAB arrays of different types.

```
» A(1,1) = {[1 4 3;
0 5 8;
7 2 9]};
» A(1,2) = {'Anne Smith'};
» A(2,1) = {3+7i};
» A(2,2) = {-pi:pi/10:pi};
```



- Using braces {} to point to elements of cell array
- Using *celldisp* function to display cell array

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Nonlinear Numerical Functions

- ***inline*** function
  - Use ***char*** function to convert *inline* object to *string*

```
» f = inline('3*sin(2*x.^2)','x')
f =
     Inline function:
     f(x) = 3*sin(2*x.^2)
» f(2)
ans =
    2.9681
```

- Numerical Integration using ***quad***

```
» Q = quad('1./(x.^3-2*x-5)',0,2);
» F = inline('1./(x.^3-2*x-5)');
» Q = quad(F,0,2);
» Q = quad('myfun',0,2)
```

- Note: ***quad*** function use adaptive Simpson quadrature

```
function y = myfun(x)
y = 1./(x.^3-2*x-5);
```

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Nonlinear Numerical Functions

- ***fzero*** finds a zero of a single variable function

```
[x,fval]= fzero(fun,x0,options)
```

  - fun is inline function or m-function
- ***fminbnd*** minimize a single variable function on a fixed interval. $x_1<x<x_2$

```
[x,fval]= fminbnd(fun,x1,x2,options)
```

- ***fminsearch*** minimize a several variable function

```
[x,fval]= fminsearch(fun,x0,options)
```

- Use ***optimset*** to determine *options* parameter.

```
options = optimset('param1',value1,...)
```

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Ordinary Differential Equations

- An explicit ODE with initial value:

$$y' = f(t, y)$$
$$y(t_0) = y_0$$

- Using ***ode45*** for non-stiff functions and ***ode23t*** for stiff functions.

```
[t,y] = solver(odefun,tspan,y0,options)
```

```
function dydt = odefun(t,y)
```

```
Initialvalue
```

```
[initialtime  finaltime]
```

- Use ***odeset*** to define options parameter

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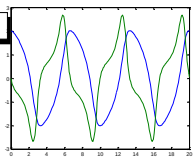
ODE Example

$$y_1'' - (1 - y_1^2)\,y_1' + y_1 = 0$$

$$y_1' = y_2$$
$$y_2' = (1 - y_1^2)\,y_2 - y_1$$

```
function dydt=myfunc(t,y)
dydt=zeros(2,1);
dydt(1)=y(2);
dydt(2)=(1-y(1)^2)*y(2)-y(1);
```

```
» [t,y]=ode45('myfunc',[0 20],[2;0])
```



Note:

Help on ***odeset*** to set options for more **accuracy** and other useful utilities like drawing results during solving.

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Handle Graphics

- Graphics in MATLAB consist of *objects:*
  - *root, figure, axes, image, line, patch, rectangle, surface, text, light*
- Creating Objects
- Setting Object Properties Upon Creation
- Obtaining an Object's Handles
- Knowing Object Properties
- Modifying Object Properties
  - Using *Command Line*
  - Using *Property Editor*

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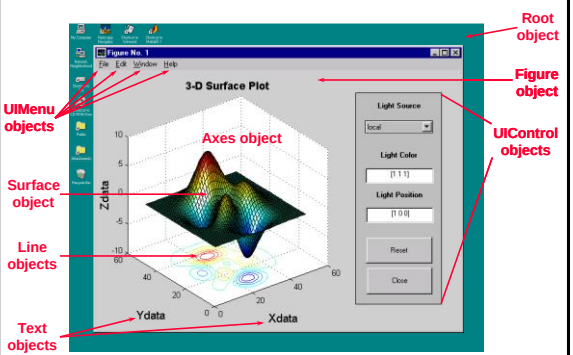
Graphics Objects



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Obtaining an Object's Handle

1. Upon Creation

```
h_line = plot(x_data, y_data, ...)
```

2. Utility Functions

   0 - root object handle
   gcf - current figure handle
   gca - current axis handle
   gco - current object handle

   What is the current object?
   - Last object created
   - OR
   - Last object clicked

3. FINDOBJ

```
h_obj = findobj(h_parent, 'Property', 'Value', ...)
```

Default = 0 (root object)

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Modifying Object Properties

- Obtaining a list of current properties:

```
get(h_object)
```

- Obtaining a list of settable properties:

```
set(h_object)
```

- Modifying an object's properties
  - Using Command Line

```
set(h_object,'PropertyName','New_Value',...)
```

  - Using Property Editor

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Graphical User Interface

- What is GUI?
- What is *figure* and *.fig file?
- Using *guide* command
- GUI controls
- GUI menus

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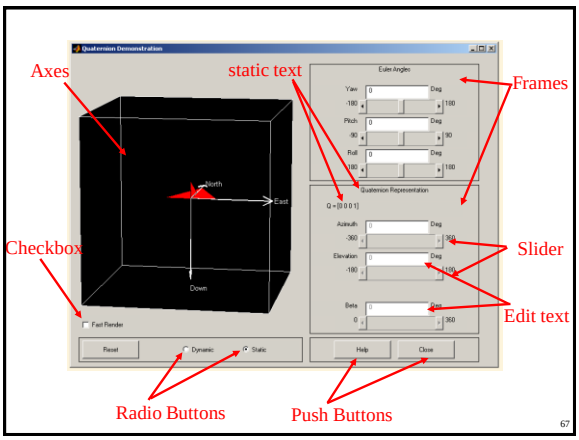

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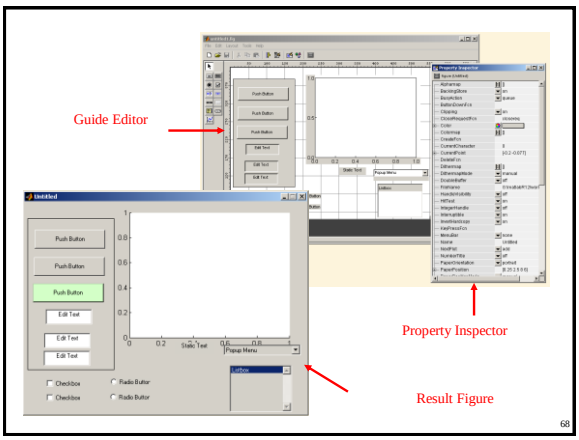

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Conclusion

- Matlab is a language of technical computing.
- Matlab, a high performance software, a high-level language
- Matlab supports GUI, API, and …
- Matlab Toolboxes best fits different applications
- Matlab …

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Getting more help

- Contact http://www.mathworks.com/support
  - You can find more help and FAQ about mathworks products on this page.
- Contact comp.soft-sys.matlab Newsgroup
  - Using Google Groups Page to Access this page
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