6.094 Introduction to MATLAB®
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6.094
Introduction to Programming in MATLAB®

Lecture 4: Advanced Methods

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IAP 2009

Outline

(1) Probability and Statistics
(2) Data Structures
(3) Images and Animation
(4) Debugging
(5) Symbolic Math
(6) Other Toolboxes

Statistics

- Whenever analyzing data, you have to compute statistics
  - » `scores = 100*rand(1,100);`

- Built-in functions
  - ➢ mean, median, mode

- To group data into a histogram
  - » `hist(scores,5:10:95);`
    - ➢ makes a histogram with bins centered at 5, 15, 25…95
  - » `N=histc(scores,0:10:100);`
    - ➢ returns the number of occurrences between the specified bin *edges* 0 to <10, 10 to <20…90 to <100.

Random Numbers

- Many probabilistic processes rely on random numbers

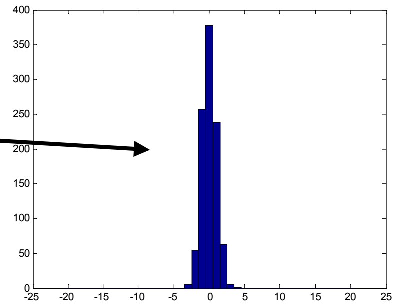
- MATLAB contains the common distributions built in
  » **rand**
    - draws from the uniform distribution from 0 to 1

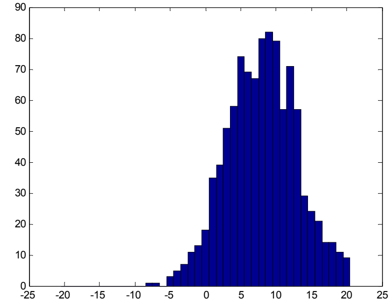
  » **randn**
    - draws from the standard normal distribution (Gaussian)

  » **random**
    - can give random numbers from many more distributions
    - see **doc random** for help
    - the docs also list other specific functions
- You can also seed the random number generators
  » **rand('state',0)**

Changing Mean and Variance

- We can alter the given distributions
  - » `y=rand(1,100)*10+5;`
    - ➢ gives 100 uniformly distributed numbers between 5 and 15
  - » `y=floor(rand(1,100)*10+6);`
    - ➢ gives 100 uniformly distributed integers between 10 and 15. floor or ceil is better to use here than round
  - » `y=randn(1,1000)`
  - » `y2=y*5+8`
    - ➢ increases std to 5 and makes the mean 8





Exercise: Probability

- We will simulate Brownian motion in 1 dimension. Call the script ‘brown’
- Make a 10,000 element vector of zeros
- Write a loop to keep track of the particle’s position at each time
- Start at 0. To get the new position, pick a random number, and if it’s <0.5, go left; if it’s >0.5, go right. Store each new position in the k^{th} position in the vector
- Plot a 50 bin histogram of the positions.

Exercise: Probability

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- Plot a 50 bin histogram of the positions.

```
» x=zeros(10000,1);
» for n=2:10000
»     if rand<0.5
»         x(n)=x(n-1)-1;
»     else
»         x(n)=x(n-1)+1;
»     end
» end
» figure;
» hist(x,50);
```

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Advanced Data Structures

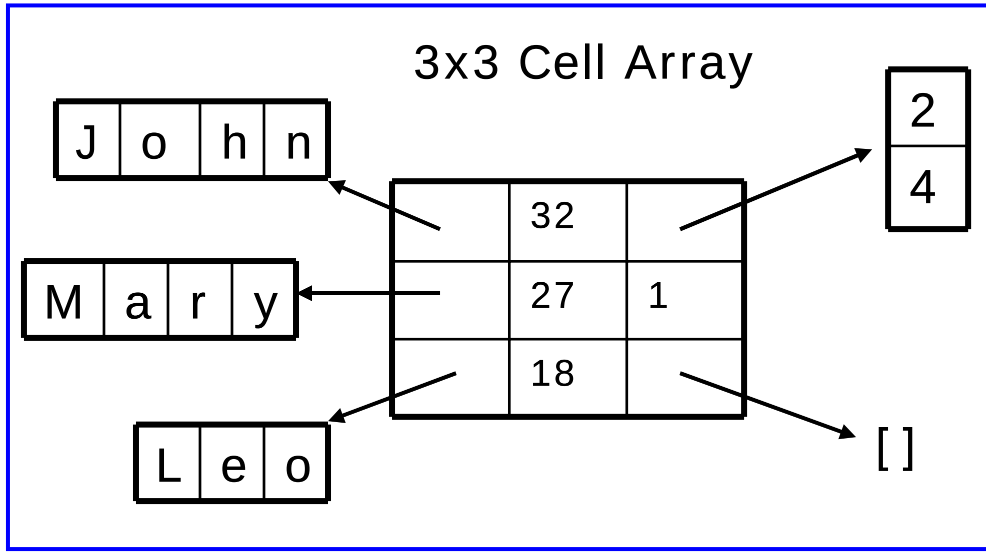
- We have used 2D matrices
  - Can have n-dimensions
  - Every element must be the same type (ex. integers, doubles, characters…)
  - Matrices are space-efficient and convenient for calculation
- Sometimes, more complex data structures are more appropriate
  - Cell array: it's like an array, but elements don't have to be the same type
  - Structs: can bundle variable names and values into one structure
    - Like object oriented programming in MATLAB

Cells: organization

- A cell is just like a matrix, but each field can contain anything (even other matrices):

3x3 Matrix

1.2	-3	5.5
-2.4	15	-10
7.8	-1.1	4



- One cell can contain people's names, ages, and the ages of their children
- To do the same with matrices, you would need 3 variables and padding

Cells: initialization

- To initialize a cell, specify the size
  » **a=cell(3,10);**
    - a will be a cell with 3 rows and 10 columns
- or do it manually, with curly braces {}
  » **c={'hello world',[1 5 6 2],rand(3,2)};**
    - c is a cell with 1 row and 3 columns
- Each element of a cell can be anything
- To access a cell element, use curly braces {}
  » **a{1,1}=[1 3 4 -10];**
  » **a{2,1}='hello world 2';**
  » **a{1,2}=c{3};**

Structs

- Structs allow you to name and bundle relevant variables
  - ➢ Like C-structs, which are objects with fields

- To initialize an empty struct:

```
» s=struct([]);
```

  - ➢ size(s) will be 1x1
  - ➢ initialization is optional but is recommended when using large structs

- To add fields

```
» s.name = 'Jack Bauer';
» s.scores = [95 98 67];
» s.year = 'G3';
```

  - ➢ Fields can be anything: matrix, cell, even struct
  - ➢ Useful for keeping variables together

- For more information, see **doc struct**

Struct Arrays

- To initialize a struct array, give field, values pairs

  » `ppl=struct('name',{'John','Mary','Leo'},...`
  `'age',{32,27,18},'childAge',{[2;4],1,[]});`

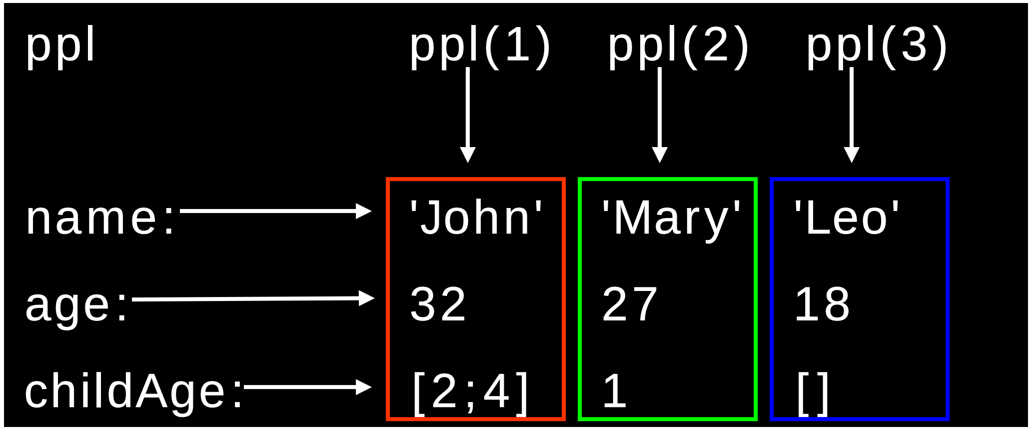
  - size(s2)=1x3
  - every cell must have the same size

  » `person=ppl(2);`

  - person is now a struct with fields name, age, children
  - the values of the fields are the second index into each cell

  » `person.name`

  - returns 'Mary'



Structs: access

- To access 1x1 struct fields, give name of the field
  - » **stu=s.name;**
  - » **scor=s.scores;**
    - ➢ 1x1 structs are useful when passing many variables to a function. put them all in a struct, and pass the struct

- To access nx1 struct arrays, use indices
  - » **person=ppl(2);**
    - ➢ person is a struct with name, age, and child age
  - » **personName=ppl(2).name;**
    - ➢ personName is 'Mary'
  - » **a=[ppl.age];**
    - ➢ a is a 1x3 vector of the ages

Exercise: Cells

- Write a script called sentGen
- Make a 3x2 cell, and put people's names into the first column, and adjectives into the second column
- Pick two random integers (values 1 to 3)
- Display a sentence of the form '[name] is [adjective].'
- Run the script a few times

Exercise: Cells

- Write a script called sentGen
- Make a 3x2 cell, and put people's names into the first column, and adjectives into the second column
- Pick two random integers (values 1 to 3)
- Display a sentence of the form '[name] is [adjective].'
- Run the script a few times

```
» c=cell(3,2);
» c{1,1}='John';c{2,1}='Mary-Sue';c{3,1}='Gomer';
» c{1,2}='smart';c{2,2}='blonde';c{3,2}='hot'
» r1=ceil(rand*3);r2=ceil(rand*3);
» disp([ c{r1,1}, ' is ', c{r2,2}, '.' ]);
```

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Importing/Exporting Images

- Images can be imported into matlab
  - » **`im=imread('myPic.jpg');`**

- MATLAB supports almost all image formats
  - jpeg, tiff, gif, bmp, png, hdf, pcx, xwd, ico, cur, ras, pbm, pgm, ppm
  - see **help imread** for a full list and details

- To write an image, give an rgb matrix or indices and colormap
  - » **`imwrite(mat,jet(256),'test.jpg','jpg');`**
  - see help imwrite for more options

Animations

- MATLAB makes it easy to capture movie frames and play them back automatically

- The most common movie formats are:
  - avi
  - animated gif

- Avi
  - good when you have ‘natural’ frames with lots of colors and few clearly defined edges
- Animated gif
  - Good for making movies of plots or text where only a few colors exist (limited to 256) and there are well-defined lines

Making Animations

- Plot frame by frame, and pause in between

```
» close all
» for t=1:30
»     imagesc(rand(200));
»     colormap(gray);
»     pause(.5);
» end
```

Saving Animations as Movies

- A movie is a series of captured frames
  - » **close all**
  - » **for n=1:30**
  - » **imagesc(rand(200));**
  - » **colormap(gray);**
  - » **M(n)=getframe;**
  - » **end**
- To play a movie in a figure window
  - » **movie(M,2,30);**
    - Loops the movie 2 times at 30 frames per second
- To save as an .avi file on your hard drive
  - » **movie2avi(M,'testMovie.avi','FPS',30);**
- See book appendix or docs for more information

Handles

- Every graphics object has a handle
  - » **`h=plot(1:10,rand(1,10));`**
    - ➢ gets the handle for the plotted line
  - » **`h2=gca;`**
    - ➢ gets the handle for the current axis
  - » **`h3=gcf;`**
    - ➢ gets the handle for the current figure
- To see the current property values, use get
  - » **`get(h);`**
  - » **`yVals=get(h,'YData');`**
- To change the properties, use set
  - » **`set(h2,'FontName','Arial','XScale','log');`**
  - » **`set(h,'LineWidth',1.5,'Marker','*');`**
- Everything you see in a figure is completely customizable through handles

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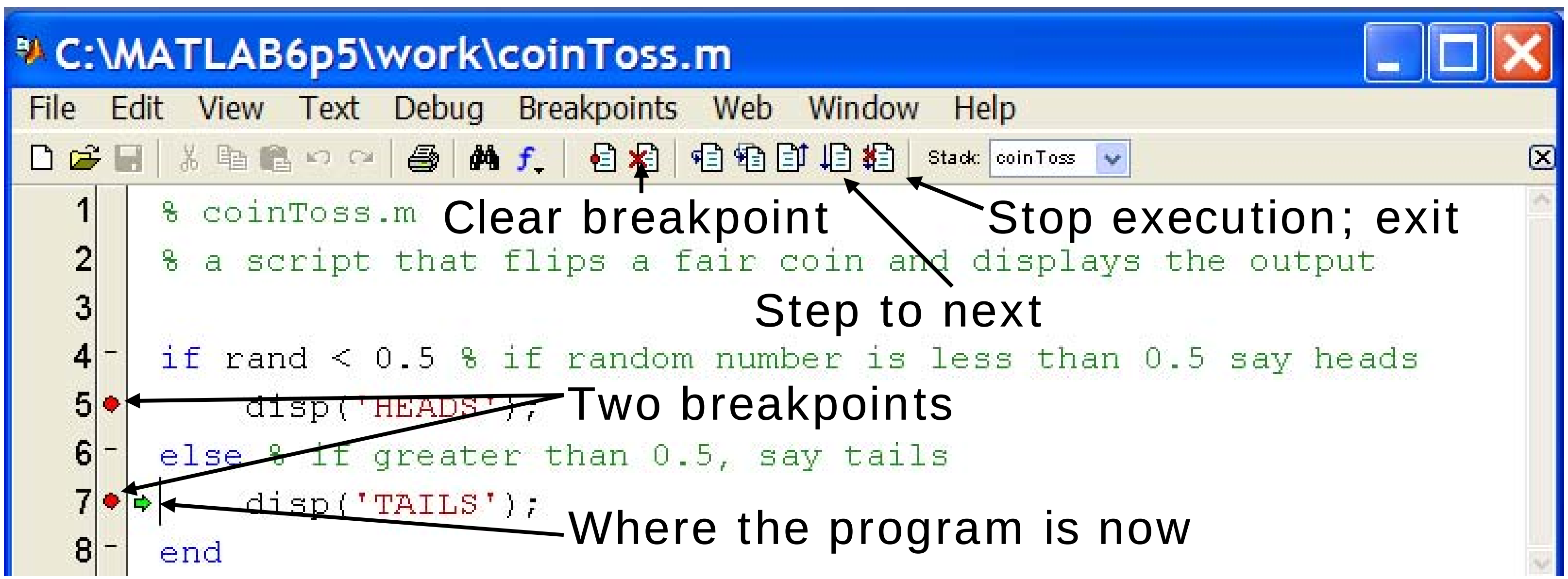
display

- When debugging functions, use **disp** to print messages
  - » `disp('starting loop')`
  - » `disp('loop is over')`
    - ➢ disp prints the given string to the command window

- It's also helpful to show variable values
  - » `disp(strcat(['loop iteration ',num2str(n)]));`
    - ➢ **strcat** concatenates the given strings
    - ➢ Sometimes it's easier to just remove some semicolons

Debugging

- To use the debugger, set breakpoints
  - Click on – next to line numbers in MATLAB files
  - Each red dot that appears is a breakpoint
  - Run the program
  - The program pauses when it reaches a breakpoint
  - Use the command window to probe variables
  - Use the debugging buttons to control debugger



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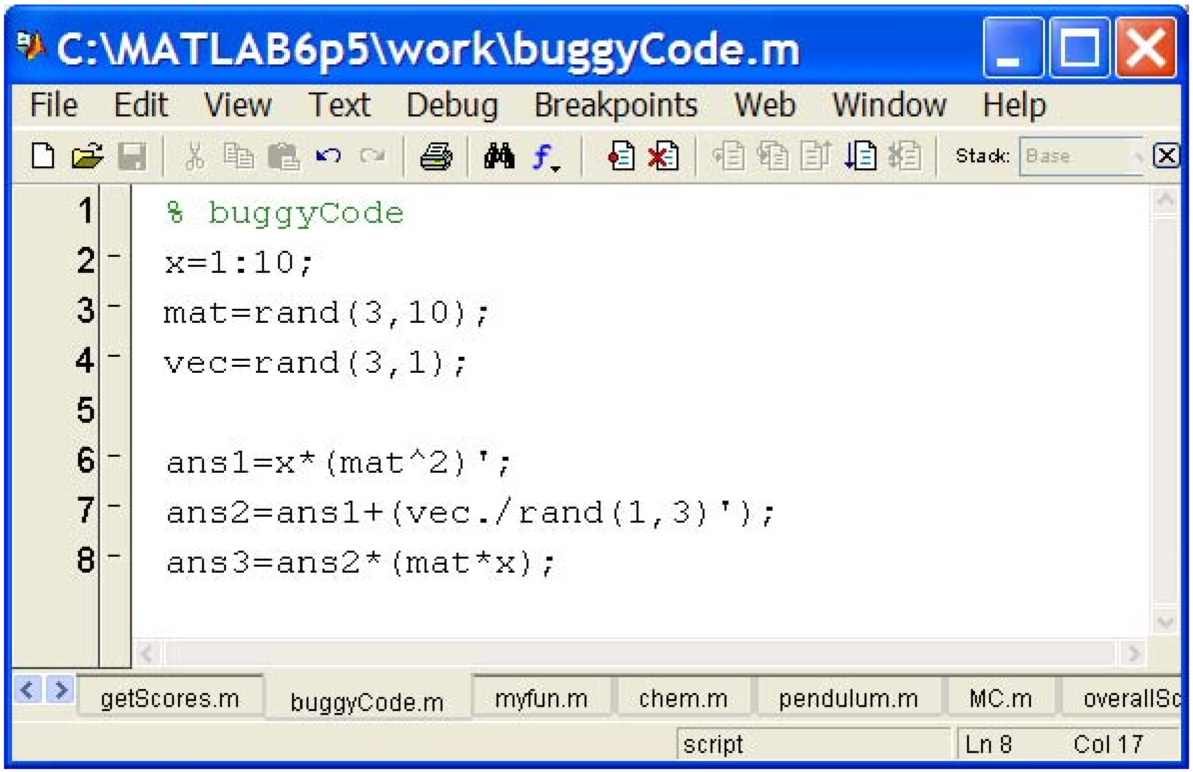
Exercise: Debugging

- Use the debugger to fix the errors in the following code:



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Performance Measures

- It can be useful to know how long your code takes to run
  - To predict how long a loop will take
  - To pinpoint inefficient code
- You can time operations using **tic**/**toc**:

```
» tic
» CommandBlock1
» a=toc;
» CommandBlock2
» b=toc;
```

  - tic resets the timer
  - Each toc returns the current value in seconds
  - Can have multiple tocs per tic

Performance Measures

- For more complicated programs, use the profiler
  - » **`profile on`**
    - ➢ Turns on the profiler. Follow this with function calls
  - » **`profile viewer`**
    - ➢ Displays gui with stats on how long each subfunction took

Profile Summary

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Number of files called: 19

Filename	File Type	Calls	Total Time	Time Plot
newplot	M-function	1	0.802 s	
gcf	M-function	1	0.460 s	
newplot/ObserveAxesNextPlot	M-subfunction	1	0.291 s	
...matlab/graphics/private/clo	M-function	1	0.251 s	
allchild	M-function	1	0.100 s	
setdiff	M-function	1	0.050 s	

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What are Toolboxes?

- Toolboxes contain functions specific to a particular field
  - ➢ for example: signal processing, statistics, optimization

- It's generally more efficient to use MATLAB's toolboxes rather than redefining the functions yourself
  - ➢ saves coding/debugging time
  - ➢ some functions are compiled, so they run faster
  - ➢ HOWEVER there may be mistakes in MATLAB's functions and there may also be surprises

- MATLAB on Athena contains all the toolboxes

- Here are a few particularly useful ones for EECS...

Symbolic Toolbox

- Don’t do nasty calculations by hand!
- Symbolics vs. Numerics

	Advantages	Disadvantages
Symbolic	•Analytical solutions •Lets you intuit things about solution form	•Sometimes can't be solved •Can be overly complicated
Numeric	•Always get a solution •Can make solutions accurate •Easy to code	•Hard to extract a deeper understanding •Num. methods sometimes fail •Can take a while to compute

Symbolic Variables

- Symbolic variables are a type, like double or char

- To make symbolic variables, use sym
  - » **`a=sym('1/3');`**
  - » **`b=sym('4/5');`**
    - ➢ fractions remain as fractions
  - » **`c=sym('c','positive');`**
    - ➢ can add tags to narrow down scope
    - ➢ see **`help sym`** for a list of tags

- Or use syms
  - » **`syms x y real`**
    - ➢ shorthand for x=sym('x','real'); y=sym('y','real');

Symbolic Expressions

- Multiply, add, divide expressions
  - » **d=a*b**
    - ➢ does 1/3*4/5=4/15;

```
ans =
4/15
```

  - » **expand((a-c)^2);**
    - ➢ multiplies out

```
ans =
1/9-2/3*c+c^2
```

  - » **factor(ans)**
    - ➢ factors the expression

```
ans =
1/9*(3*c-1)^2
```

Cleaning up Symbolic Statements

» **pretty(ans)**

- makes it look nicer

```
                2
1/9 - 2/3 c + c
```

» **collect(3*x+4*y-1/3*x^2-x+3/2*y)**

- collects terms

```
ans =
2*x+11/2*y-1/3*x^2
```

» **simplify(cos(x)^2+sin(x)^2)**

- simplifies expressions

```
ans =
1
```

» **subs('c^2',c,5)**

- Replaces variables with numbers or expressions

```
ans=
25
```

» **subs('c^2',c,x/7)**

```
ans=
1/49*x^2
```

More Symbolic Operations

- We can do symbolics with matrices too
  - » **mat=sym('[a b;c d]');**
  - » **mat2=mat*[1 3;4 -2];**
    - ➢ compute the product
  - » **d=det(mat)**
    - ➢ compute the determinant
  - » **i=inv(mat)**
    - ➢ find the inverse

```
mat2 =
[    a+4*b, 3*a-2*b]
[    c+4*d, 3*c-2*d]
```

```
d =
a*d-b*c
```

```
i =
[  d/(a*d-b*c), -b/(a*d-b*c)]
[ -c/(a*d-b*c),  a/(a*d-b*c)]
```

- You can access symbolic matrix elements as before
  - » **i(1,2)**

```
ans =
-b/(a*d-b*c)
```

Exercise: Symbolics

- The equation of a circle of radius r centered at (a,b) is given by: $(x-a)^2 + (y-b)^2 = r^2$.
- Expand this equation into the form $Ax^2 + Bx+Cxy + Dy + Ey^2 = F$ and find the expression for the coefficients in terms of a,b, and r.

Exercise: Symbolics

- The equation of a circle of radius r centered at (a,b) is given by: (x-a)^2 + (y-b)^2 = r^2.
- Expand this equation into the form Ax^2 + Bx+Cxy + Dy + Ey^2 = F and find the expression for the coefficients in terms of a,b, and r.

```
» syms a b r x y
» pretty(expand((x-a).^2 + (y-b).^2))
```

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Signal Processing Toolbox

- MATLAB is often used for signal processing (fft)
- What you can do:
  - filter design
  - statistical signal processing
  - Laplace transforms

- Related Toolboxes
  - Communications
  - Wavelets
  - RF
  - Image Processing

Control System Toolbox

- The control systems toolbox contains functions helpful for analyzing systems with feedback

- Simulation of LTI system function
- Discrete time or continuous time
- You will be exposed to it in 6.003
- Can easily study step response, etc. modal analysis.

- Related toolboxes:
  - System Identification
  - Robust Control – modern control theory
  - Model Predictive Control

Statistics Toolbox

- For hardcore statistics and data-analysis
  - Principal component analysis
  - Independent component analysis
  - Tests of significance (chi squared, t-tests...)

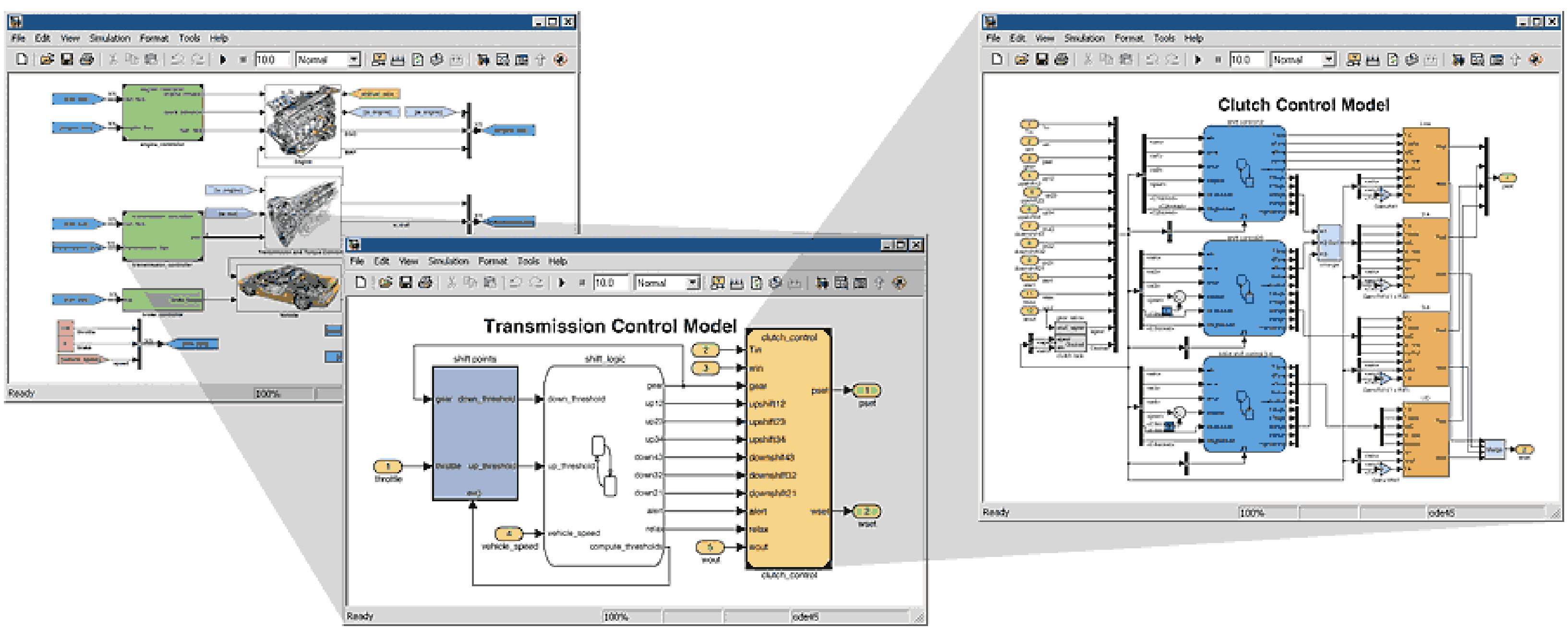
- Related Toolboxes
  - Spline – for fitting
  - Bioinformatics
  - Neural Networks

Optimization Toolbox

- For more hardcore optimization problems – that occur in OR, business, engineering
  - linear programming
  - interior point methods
  - quadratic methods

SIMULINK

- Interactive graphical environment
- Block diagram based MATLAB add-on environment
- Design, simulate, implement, and test control, signal processing, communications, and other time-varying systems



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Central File Exchange

- The website – the MATLAB Central File Exchange!!
- Lots of people's code is there
- Tested and rated – use it to expand MATLAB's functionality

- http://www.mathworks.com/matlabcentral/

MATLAB Final Exam

- Brownian Motion stop-animation – integrating loops, randomization, visualization

- Make a function brown2d(numPts), where numPts is the number of points that will be doing Brownian motion
- Plot the position in (x,y) space of each point (start initially at 0,0). Set the x and y limits so they're consistent.
- After each timestep, move each x and y coordinate by randn*.1
- Pause by 0.001 between frames
- Turn on the DoubleBuffer property to remove flicker
  » `set(gcf,'DoubleBuffer','on');`

- Ask us for help if needed!

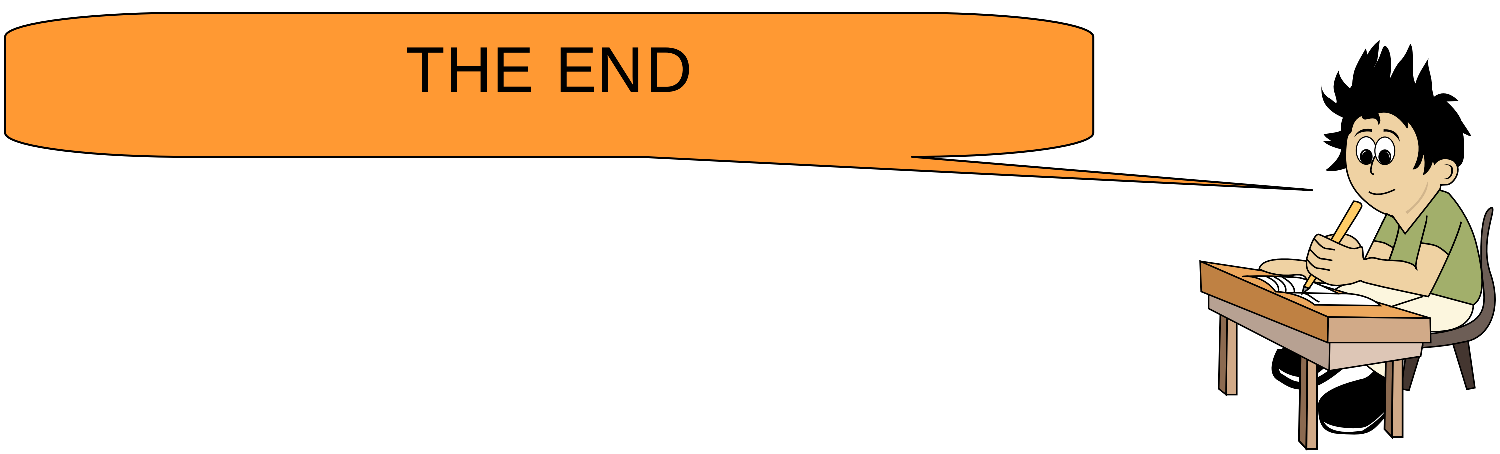
End of Lecture 4

(1) Data Structures

(2) Symbolics

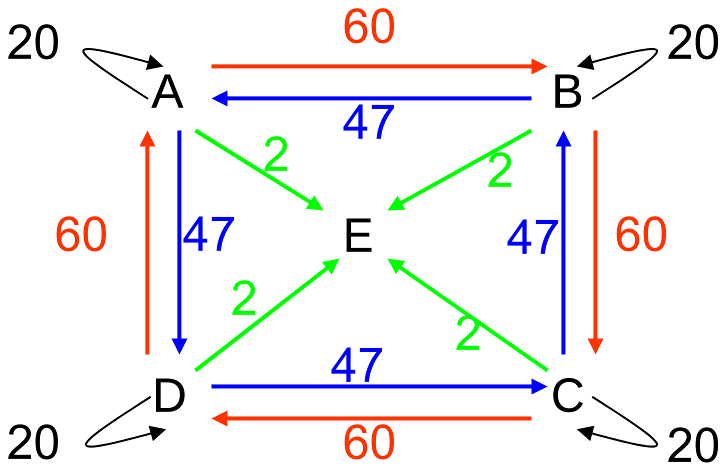
(3) Probability

(4) Toolboxes



Monte-Carlo Simulation

- A simple way to model complex stochastic systems
- Use random numbers to control state changes



- This system represents a complex reaction
- The numbers by the arrows show the propensity of the system to go from one state to another
- If you start with 1 molecule of A, how does the system behave with time?

Example: Monte-Carlo

- This MATLAB file will track the behavior of the molecule

```
function s=MC(timeSteps)
state=0; % start off in A
% B=1, C=2, D=3, E=4 to make things easy
s=zeros(timeSteps,1); % to store current state
borders=[20 60 47 2]/sum([20 60 47 2]);
outcome=cumsum(borders);
direction=[0 1 -1];
for n=1:timeSteps
    s(n)=state;
    if state~=4 %if not in E
        C=min(find(rand<outcome));
        if C==4 % enter E
            state=4;
        else % go right or left
            state=mod(state+direction(C),4);
        end
    end
end
```

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Example: Monte-Carlo

- We can run the code 1000 times to simulate 1000 molecules

```
» s=zeros(200,5);
» for n=1:1000
»   st=MC(200);
»   for state=0:4
»       s(:,state+1)= s(:,state+1)+(st==state);
»   end
» end
```