History and Applications

- Middle of 20th century
  - Research in artificial intelligence (AI) – connection between human intelligence and machines
  - First robot
    - 1948 – William Grey Walter invented robots Elmer and Elsie that mimic lifelike behavior using simple electronics
    - 1954 – George Devol invented the first digitally operated and a programmable robot called the Unimate.
    - 1956 – Devol and his partner Joseph Engelberger formed the world's first robot company.
    - 1961 – First industrial robot, Unimate, went online in a General Motors automobile factory in USA.

Father of Robotics - Joseph Endgelberger is widely credited for the birth of the industrial robotics industry.

  - Advances in mechanics, controls, computers and electronics
  - Robotics: The science & technology of robots

History (continue)

- 1960s:
  - Numerical control machines for precise manufacturing
  - Teleoperators for remote radioactive material handling
- Late 1970s:
  - Industrial robots became essential components in the automation of flexible manufacturing systems
- 1980s:

Takeo Kanade built the world's first direct-drive robotic arm in 1981. This arm contained all of its motors within the robot assembly itself and thus eliminated long transmissions.

  - Robotics: defined as the science which studies the intelligent connection between perception and action

History (continue)

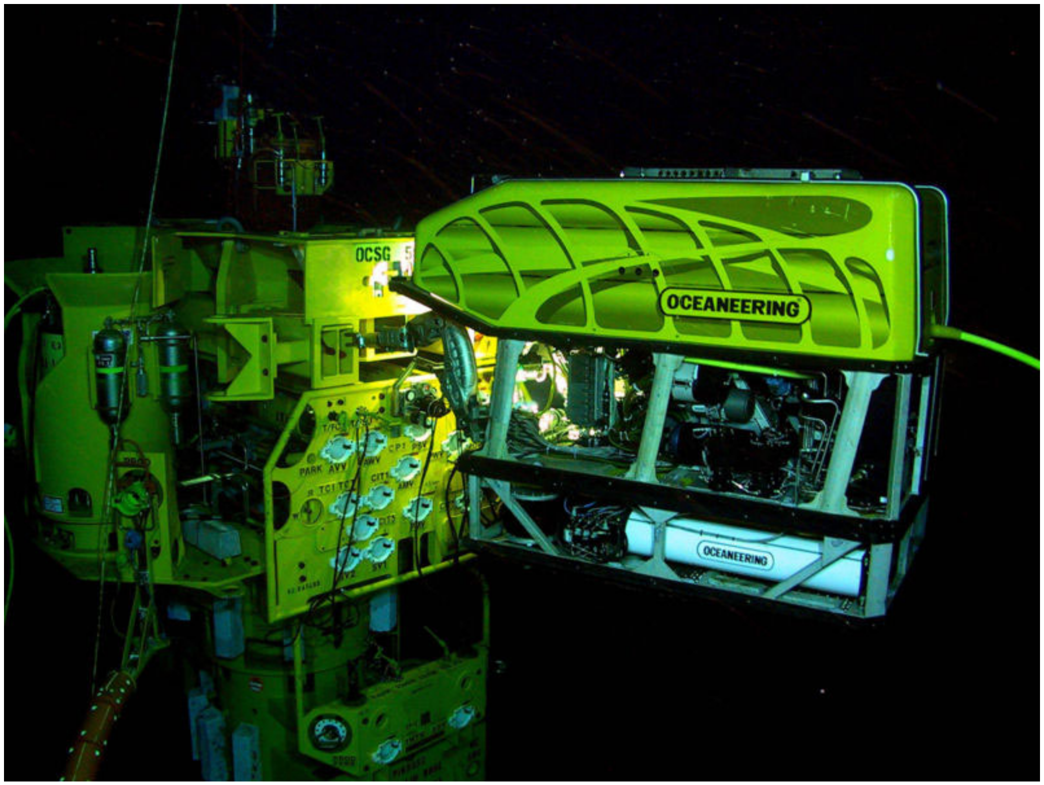
- 1990s:
  - Field robotics to address human safety in hazardous environments
  - Human augmentation
  - Service robotics
- 2000 and beyond:
  - Human-centered and life-like robotics

ASIMO or Advanced Step in Innovative Mobility is the now retired, series of humanoid robots designed and built by Honda since 2000. First to successfully mimic human gait.

Reference: Bellis, Mary. "Who Invented Robots?" ThoughtCo, Oct. 16, 2017, thoughtco.com/timeline-of-robots-1992363.

https://interestingengineering.com/15-engineers-and-their-inventions-that-defined-robotics

ROV versus AUV



ROV working on a subsea structure

ROV: remotely operated underwater vehicle, is a tethered underwater vehicle.

Autonomous Underwater Vehicles (AUV's): David Barrett's RoboTuna in 1996 was one of the first fully functional robotic fish. It was designed to mimic the shape and motion of a real fish and was controlled by six servo motors.

Degrees –of-Freedom (DOF)

DOF of a system can be viewed as the minimum number of coordinates required to specify a configuration.

• For a single particle in a plane, two coordinates define its location so it has two degrees of freedom.

• A single particle in space requires three coordinates so it has three degrees of freedom.

• Two particles in space have a combined six degrees of freedom.

• If two particles in space are constrained to maintain a constant distance from each other, such as in the case of a diatomic molecule, then the six coordinates must satisfy a single constraint equation defined by the distance formula. If the five coordinates are specified, the distance formula can be used to solve the remaining coordinate. In this case, DOF of the system is Five.

Linear Algebra Review

Matrix is an *m* x *n* array of numbers, where *m* is the number of rows and n is the number of columns.

$$\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & & & \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix}$$

Special matrices: square (m=n), diagonal, identity, symmetric, column vector (mx1), row vector (1xn).

Linear Algebra Review (Continue)

Linear independence of vectors: A set of vectors x_1, x_2, …, x_m each of size *n* in linear space, is said to be linearly dependent if and only if there exists scalars c_1, c_2, …, c_m not all zero, such that

$$c_1\mathbf{x}_1 + c_2\mathbf{x}_2 + \ldots + c_m\mathbf{x}_m = 0$$

If the only set of ci for which the above equation hold is c1=c2=…=cm=0, then the set of vectors x_1, x_2, …, x_m is said to be linearly independent.

Alternatively, a set of vectors are linearly dependent if and only if xi can be expressed as a linear combination of x_j (*j*=1,2,.., *m*, *j*<>*i*).

Linear Algebra Review (Continue)

The dimension of a linear space is defined as the maximum number of linearly independent vectors in the space.

Example. In R^n, we can find at most n linearly independent vectors.

A real coordinate space of dimension n is a coordinate space over the real numbers.
It is a set of n-tuples of real numbers, sequences of n real numbers.
For example, R^2 is a plane.

Linear Algebra Review (Continue)

A set of linearly independent vectors in R^n is called a basis if every vector in R^n can be expressed as a unique linear combination of the set.

In R^n, any set of linearly independent vectors can be used as a basis.
Let ($q_1 \quad q_2 \ldots q_n$) be one basis.
Then every vector a can be uniquely expressed as

$$\mathbf{a} = \mathbf{x}_1 q_1 + \mathbf{x}_2 q_2 + \ldots + \mathbf{x}_n q_n$$

Linear Algebra Review (Continue)

Transpose of a matrix denoted by A^T is given by

$$\begin{bmatrix} a_{11} & a_{21} & \dots & a_{m1} \\ a_{12} & & & \\ \dots & & & \\ a_{1n} & & & a_{mn} \end{bmatrix}$$

Note that $(A+B)^T=A^T+B^T$ and $(AB)^T=B^TA^T$

Linear Algebra Review (Continue)

A matrix A is said to be symmetric if $A=A^T$

A matrix A is said to be skew-symmetric if $A=-A^T$

Note that:

(1) Given any square matrix A, then $A+A^T$ is symmetric and $A-A^T$ is skew-symmetric

(2) For any matrix A, $B=A^TA$ is a symmetric matrix.

Linear Algebra Review (Continue)

Rank of matrix A is the maximum number of linearly independent columns or rows in A.

If $\mathbf{A} \in \mathbf{R}^{mxn}$ then

rank(A) <= min(m,n)

rank(AB) <= min(rank(A), rank(B))

Note that:

(1) If rank(A) is equal to the number of columns or the number of rows of A, then A is said to be full rank.

(2) If A is square and full rank, then A is nonsingular.

Linear Algebra Review (Continue)

If $\mathbf{x} \in R^n$ then $\frac{d}{dt}\mathbf{x}(t) = \begin{bmatrix} \frac{d}{dt}x_1(t) \\ . \\ . \\ \frac{d}{st}x_n(t) \end{bmatrix}$

$\frac{d\mathbf{A}}{dt} = \left[\frac{da_{ij}}{dt}\right]$ and $\int \mathbf{A}dt = \left\lfloor \int a_{ij}dt \right\rfloor$

If J($\mathbf{x}$)is a scalar function of $\mathbf{x} \in R^n$ then $\frac{\partial}{\partial \mathbf{x}}\mathrm{J}(\mathbf{x}) = \begin{bmatrix} \frac{\partial J}{\partial x_1} \\ . \\ . \\ \frac{\partial J}{\partial x_n} \end{bmatrix}$ $\quad \frac{\partial^2 \mathrm{J}}{\partial \mathbf{x}^2} = \begin{bmatrix} \frac{\partial^2 \mathrm{J}}{\partial x_1{}^2} & . & . & \frac{\partial^2 \mathrm{J}}{\partial x_1 \partial x_n} \\ . & . & . & . \\ . & . & . & . \\ \frac{\partial^2 \mathrm{J}}{\partial x_n \partial x_1} & . & . & \frac{\partial^2 \mathrm{J}}{\partial x_n{}^2} \end{bmatrix}$

Linear Algebra Review (Continue)

If $\mathbf{A} \in \mathbf{R}^{nxn}$ then trace of matrix $\mathbf{A}$, $\mathrm{Tr}(\mathbf{A}) = \sum_{i=1}^{n} a_{ii}$.

$$\mathrm{Tr}(\mathbf{A}+\mathbf{B}) = \mathrm{Tr}(\mathbf{A}) + \mathrm{Tr}(\mathbf{B})$$

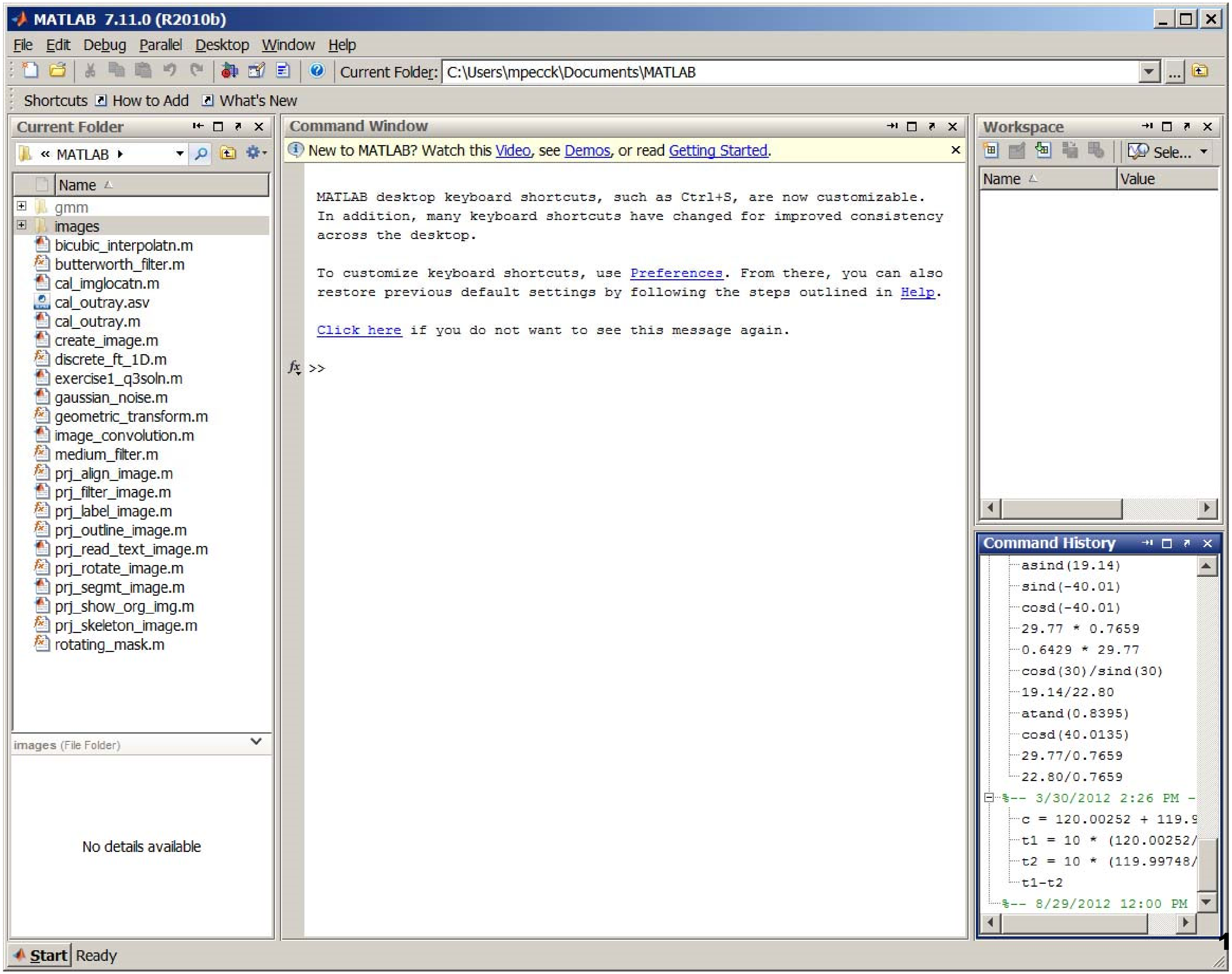
$$\mathrm{Tr}(\mathbf{AB}) = \mathrm{Tr}(\mathbf{B}^{\mathrm{T}}\mathbf{A}^{\mathrm{T}}) = \mathrm{Tr}(\mathbf{BA}) = \mathrm{Tr}(\mathbf{A}^{\mathrm{T}}\mathbf{B}^{\mathrm{T}})$$

Homework: Study the notes Linear Algebra Review

MATLAB for Robotics Research

- Simulate robotic systems with accurate kinematics and dynamics properties

- MATLAB (short for Matrix Laboratory)
- An interpreter:
  - Program remains in computer's memory after it is launched.
  - Command window for interpreting commands
  - If commands are considered correct, MATLAB executes it.
- Allows quick prototyping
- Can be easily rewritten in C, C++ or Java
- Public domain/open source clones of MATLAB are widely available, for examples, Octava and SciLab.


MATLAB 7.11.0 (R2010b)
File Edit Debug Parallel Desktop Window Help
Current Folder: C:\Users\mpecck\Documents\MATLAB
Shortcuts How to Add What's New
Current Folder
MATLAB
Name
gmm
images
bicubic_interpolatn.m
butterworth_filter.m
cal_imglocatn.m
cal_outray.asv
cal_outray.m
create_image.m
discrete_ft_1D.m
exercise1_q3soln.m
gaussian_noise.m
geometric_transform.m
image_convolution.m
medium_filter.m
prj_align_image.m
prj_filter_image.m
prj_label_image.m
prj_outline_image.m
prj_read_text_image.m
prj_rotate_image.m
prj_segmt_image.m
prj_show_org_img.m
prj_skeleton_image.m
rotating_mask.m
images (File Folder)
No details available
Command Window
New to MATLAB? Watch this Video, see Demos, or read Getting Started.
MATLAB desktop keyboard shortcuts, such as Ctrl+S, are now customizable.
In addition, many keyboard shortcuts have changed for improved consistency across the desktop.
To customize keyboard shortcuts, use Preferences. From there, you can also restore previous default settings by following the steps outlined in Help.
Click here if you do not want to see this message again.
>>
Workspace
Name
Value
Command History
asind(19.14)
sind(-40.01)
cosd(-40.01)
29.77 * 0.7659
0.6429 * 29.77
cosd(30)/sind(30)
19.14/22.80
atand(0.8395)
cosd(40.0135)
29.77/0.7659
22.80/0.7659
%-- 3/30/2012 2:26 PM --
c = 120.00252 + 119.9
t1 = 10 * (120.00252/
t2 = 10 * (119.99748/
t1-t2
%-- 8/29/2012 12:00 PM
Start Ready

Vectors and matrices:

```
>> % assignment of a real matrix
>> a = [1 2 3; 4 5 6]

a =

     1     2     3
     4     5     6

>> % implicit enumeration
>> a = (0:10) % or a = (0:1:10)

a =

     0     1     2     3     4     5     6     7     8     9    10

>> % incremental implicit enumeration
>> a = (0:2:9)

a =

     0     2     4     6     8
```

An *m* x *n* matrix is a rectangular array of entries or elements enclosed typically by square bracket, where *m* is the number of rows and *n* the number of columns.

A vector of dimension *n* is an ordered collection of *n* entries or elements.

An element can be a number or symbol representing number.

Vectors and matrices (Continue):

```
>> % extension of matrix
>> a = [1 2 3; 4 5 6];
>> a = [a a]

a =

     1     2     3     1     2     3
     4     5     6     4     5     6

>> a = [a; a]

a =

     1     2     3     1     2     3
     4     5     6     4     5     6
     1     2     3     1     2     3
     4     5     6     4     5     6
```

Arrays:

```
>> clear all
>> A = [1:3; 4:6]

A =

     1     2     3
     4     5     6

>> A

A =

     1     2     3
     4     5     6

>> A(:, :, 2)=zeros(2, 3), % or A(:, :, 2) =0

A(:,:,1) =

     1     2     3
     4     5     6


A(:,:,2) =

     0     0     0
     0     0     0
```

Array is a data structure; matrix is a mathematical concept.

All MATLAB variables are multidimensional arrays. A matrix is a two-dimensional (2D) array often used for linear algebra. A vector is a one-dimensional (1D) array.

Simple matrix and array operations:

```
>> a = [ 1 2; 3 4] * [5; 6]

a =

    17
    39

>> size(a)

ans =

     2     1

>> A = [ 1 2 ; 2 1]; b = [1; 1]

b =

     1
     1
```

```
>> x = inv(A) * b

x =

    0.3333
    0.3333

>> a^2
??? Error using ==> mpower
Inputs must be a scalar and a square matrix.

>> A^2

ans =

     5     4
     4     5
```

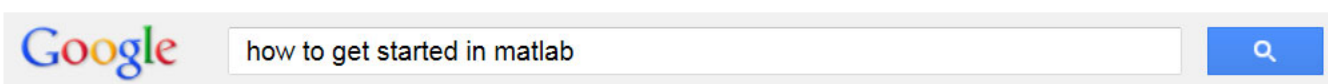
```
>> A'

ans =

     1     2
     2     1

>> A' .* 2

ans =

     2     4
     4     2
```

".*": element-wise multiplication, is an example of array operations

```
>> help edit
 EDIT Edit or create a file
    EDIT FUN opens the file FUN.M in a text editor.  FUN must be the
    name of a file with a .m extension or a MATLABPATH relative
    partial pathname (see PARTIALPATH).

    EDIT FILE.EXT opens the specified file.  MAT and MDL files will
    only be opened if the extension is specified.  P and MEX files
    are binary and cannot be directly edited.

    EDIT X Y Z ... will attempt to open all specified files in an
    editor.  Each argument is treated independently.

    EDIT, by itself, opens up a new editor window.

    By default, the MATLAB built-in editor is used.  The user may
    specify a different editor by modifying the Editor/Debugger
    Preferences.

    If the specified file does not exist and the user is using the
    MATLAB built-in editor, an empty file may be opened depending on
    the Editor/Debugger Preferences.  If the user has specified a
    different editor, the name of the non-existent file will always
    be passed to the other editor.

    Overloaded methods:
       axischild/edit
       vrworld/edit

    Reference page in Help browser
       doc edit

>> edit create_image
>>
```

Editor - C:\Users\mpecck\Documents\MATLAB\create_image.m

```
clear all;

% input image
g = [ 0 0 0 0 0 0; 0 10 10 10 0 0; 0 0 10 0 0 0; ...
      0 0 10 0 0 0; 0 0 10 0 0 0; 0 0 0 0 0 0];

figure(1);
imshow(g);

break;

colormap(gray(16));
image(g);

f = zeros(6, 6);
for row = 1:6
    for column = 1:6
        f(row, column) = g(row, column) + random('unif', 0, 1);
    end
end

figure(2);
imshow(f, [0, 15]);

figure(3);
I = histeq(f);
imshow(I, [0, 15]);
```



http://www.mathworks.com/videos/matlab/getting-started-with-matlab.html

Homework:

- Download and install MATLAB from Software for Students (https://nusit.nus.edu.sg/services/software_and_os/software/software-student/) if you have not done so.

- Familiarize yourself with MATLAB programming environment. At MATLAB software prompt, type demo and help. Use the MATLAB editor, learn how to create, edit, save, run and debug m-files (ASCII vectors), and explore the built-in MATLAB linear algebra functions for various vector and matrix operations. Learn how to program logical constructs and loops in MATLAB. Learn how to use subprograms and functions. Learn how to use comments (%) for explaining your programs.

- Check out www.mathworks.com for more information and tutorials.