MATH 3341: Introduction to Scientific Computing Lab

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Lab 02: Variables, Arrays and Scripts

Variables

Variables help us represent quantities or expressions in order to make their use and re-use more convenient.

Naming Variables

- Must start with a letter.
- Followed by letters (a-z, A-Z) or numbers (0-9) or underscores (_).
- Maximum 65 characters (excluding the .m extension).
- Must not be the same as any MATLAB reserved word.
- Space is not permitted.
- Case sensitive, i.e., `a ~= A`.

Naming Variables

- Be as descriptive as possible with your variable names.
- Avoid built-in function/variable names (reserved keywords) such as `pi`, `sin`, `exp`, etc.
- Check if a name is already in use: `which variableName` or `exist variableName`.

Naming Conventions

- snake_case: writing compound words or phrases in which the elements are separated with one underscore character (_) and no spaces, e.g. "foo_bar".
- camelCase: writing compound words or phrases such that each word or abbreviation in the middle of the phrase begins with a capital letter, with no intervening spaces or punctuation, e.g. "fooBar"
- Other conventions: Hungarian notation, positional notation, etc.
- Reference: `https://en.wikipedia.org/wiki/Naming_convention_(programming)`

Default Variable Definitions

Command	Description
`pi`	variable defining π
`i` or `1i`	imaginary number $i = \sqrt{-1}$
`j` or `1j`	imaginary number $j = \sqrt{-1}$

Arrays

Array, Vector, and Matrix

- An array is a data form that can hold several values, all of one type.
- A vector is a 1-D array: we can define row vectors, column vectors.
- A matrix is a 2-D array.
- Also, we can define N-D array.
- The general notation for a vector or matrix is a list of values enclosed in square brackets `[]` separated by commas (space) or semi-colons (or the combination).

Vector: []

- Row vector: $x = \begin{bmatrix} 1 & 2 & 3 & 4 \end{bmatrix}$

```
x = [1,2,3,4]
x = [1 2 3 4]
```

- Column vector: $y = \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$ or $y = \begin{bmatrix} 1 & 2 & 3 & 4 \end{bmatrix}^\top$ or $y = x^\top$.

```
y = [1;2;3;4]
y = transpose([1 2 3 4])
y = [1 2 3 4]'
y = x'
y = x(:)
```

Note: `'` and `.'` are the infix notation for `ctrasnpose`, `transpose` operation.

Vector: `linspace` vs. `colon`

- `linspace(from, to, n)` generates `n` points between `from` (inclusive) and `to` (inclusive). For example,
  ```
  a = linspace(2, 6, 5)  % same as a = [2 3 4 5 6]
  ```
- `colon(from, step, upper_bound)` generates points between `from` (inclusive) and `upper_bound` (may not be inclusive) with spacing `step`. For example,
  ```
  a = colon(2, 1, 6)  % same as a = [2 3 4 5 6]
  a = colon(2, 2, 6)  % same as a = [2 4 6]
  a = colon(2, 1, 7)  % same as a = [2 3 4 5 6 7]
  a = colon(2, 2, 7)  % same as a = [2 4 6]
  ```
- `from:step:upper_bound` is same as `colon(from, step, upper_bound)`.

Vector: `linspace` vs. `colon`

- `linspace(from, to, n)` is equivalent to `colon(from, (to - from) / (n - 1), to)`
- `colon(from, step, upper_bound)` is equivalent to `linspace(from, floor((upper_bound - from) / step) * step + from, floor((upper_bound - from) / step))`
- Use `linspace` when the number of points is given.
- Use `colon` when the spacing/step size is given.

Vector: Slicing

- Define a row vector `rowVec`:

```
rowVec = [2,4,6,8,10]
rowVec = linspace(2,10,5)
rowVec = colon(2,2,10)    % or rowVec = 2:2:10
```

- `array(i)`: the i-th entry of `array`, where `i` is called the index:

`i`	1	2	3	4	5
`rowVec(i)`	2	4	6	8	10

Vector: Slicing

i	1	2	3	4	5
rowVec(i)	2	4	6	8	10

- Extract one entry from a vector: For example, to extract 6 from `rowVec` and assign it to `x`:
  `x = rowVec(3)`
- Extract multiple entries from a vector: For example, to extract 2, 6, 8 from `rowVec` and assign it to `x`:
  `x = rowVec([1,3,4])`
- Extract multiple contingua entries from a vector: For example, to extract 4, 6, 8 from `rowVec` and assign it to `x`:
  `x = rowVec([2,3,4])`
  `x = rowVec(2:4)`

Vector: Append/Delete Element

```
% 1-D array
rowVec = 1:5
rowVec(end + 1) = 6  % append 6 to rowVec
rowVec = [rowVec,7]  % append 7 to rowVec
rowVec(5) = []       % delete 5 from rowVec
rowVec(2:4) = []     % delete 2, 3, 4 from rowVec
```

Vector Operations

- `sum(vec)/prod(vec)`: sum/product of all elements of `vec`.
- `max(vec)/min(vec)`: maximum/minimum of `vec`.
- `rowVec = rowVec1 .* rowVec2`: elementwise multiplication, where `rowVec(i) = rowVec1(i) * rowVec2(i)`.
- `rowVec .* colVec`: Kronecker product. If `rowVec` has length `m` and `colVec` has length `n`, then the resulting matrix is `m`-by-`n`.
- `dot(vec1, vec2)`: dot product of `vec1` and `vec2`, `vec1` and `vec2` must be of the same length.
- `sum(rowVec1 .* rowVec2)`: `dot(rowVec1, rowVec2)`.
- `rowVec1 * rowVec2'`: `dot(rowVec1, rowVec2)`.
- `indices = find(vec > n)`: find indices of elements greater than `n` in `vec`. Note: > can also be <, ==.

Dimension: `size`, `length`, `reshape`

- `size(array)`: size of `array`. If `array` is n-dimensional, `size` will return a vector of length `n`.
- `size(array, 1)`: number of rows of `array`.
- `size(array, 2)`: number of columns of `array`.
- `length(vec)`: length of vector `vec`, equivalent to `max(size(vec))`.
- `reshape(array, dim1, dim2, dim3, ...)`.

```
rowVec = 1:8
matrix = reshape(rowVec, 2, 4)
% same as matrix = [1,3,5,7;2,4,6,8]
```

- `reshape(array, prod(size(array)), 1)` is same as `array(:)`.

Matrix: []

Define a 2×3 matrix $A = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix}$

```
A = [1,2,3;4,5,6]
```

or

```
row1 = [1,2,3]
row2 = [4,5,6]
A = [row1;row2]
```

or

```
col1 = [1;4]
col2 = [2;5]
col3 = [3;6]
A = [col1,col2,col3]
```

Matrix: `zeros`, `ones`, `eye`, `rand`, `randn`, `magic`

- `zeros(m, n)`: define a `m`-by-`n` matrix with zeros.

```
zeroRowVec = zeros(1, 5)
zeroColVec = zeros(5, 1)
zeroMatrix = zeros(5, 5)
zeroMatrix = zeros(5)
```

- `ones(m, n)`: define a `m`-by-`n` matrix with ones.
- `eye(m, n)`: define a `m`-by-`n` matrix with diagonals being ones.
- `rand(m, n)`: define a `m`-by-`n` matrix with uniformly distributed numbers.
- `randn(m, n)`: define a `m`-by-`n` matrix with normally distributed numbers.
- `magic(n)`: define a `n`-by-`n` magic square with row sums, column sums and diagonal sum being equal.

Matrix: Slicing

- Define a matrix `mat`

  `mat = reshape(1:8, 2, 4)`

- `array(i, j)`: the entry of `array` at row `i` and column `j`, where `i` is colled row index, `j` is called column index:

`mat(i, j)` (i \ j)	1	2	3	4
1	1	3	5	7
2	2	4	6	8

Matrix: Slicing

mat(i, j) \ j ; i	1	2	3	4
1	1	3	5	7
2	2	4	6	8

Extract multiple rows and multiple columns from `mat`: For example, to extract entries at row 1, row 2, and column 2, column 4:

```
A = mat([1,2], [2,4])
A = mat(1:2, [2,4])
A = mat(1:end, [2,4])
A = mat(:, [2,4])
```

Matrix: Append/Delete Element

```
% 2-D array
matrix = magic(5)
matrix(:, end + 1) = 1:5    % append a column vector
matrix = [matrix,[6:10]']   % append a column vector
matrix(end + 1, :) = 1:7    % append a row vector
matrix = [matrix;8:14]      % append a row vector
matrix(:,6) = []            % Libao Jin 6
matrix(:,3:5) = []          % Libao Jin 3, 4, 5
matrix(2:4,:) = []          % Libao Jin 2, 3, 4
```

Matrix Operations

- `mat = mat1 .* mat2`: elementwise multiplication, where `mat(i, j) = mat1(i, j) * mat2(i, j)`.
- `mat = mat1 * mat2`: matrix multiplication, where `mat1` is `m`-by-`p`, `mat2` is `p`-by-`n`, and `mat` is `m`-by-`n`.
- `sum/prod(mat, 'all')`: sum/product of all elements of `mat`.
- `sum/prod(mat, 1)`: column sums/products.
- `sum/prod(mat, 2)`: row sums/products.
- `max/min(mat, [], 'all')`: maximum/minimum of `mat`.
- `max/min(mat, [], 1)`: column maximums/minimums.
- `max/min(mat, [], 2)`: row maximums/minimums.
- `[row, col] = find(mat > n)`: find indices of elements greater than `n` in `mat`, `row`/`col` stores row/column indices.

Matrix Operations

- `[V, D] = eig(mat)`: `V(:, i)` and `D(i, i)` are the i-th eigenvector and eigenvalue of `mat`.
- `d = diag(mat, k)`: extract `k`-th diagonal elements that is above (`k > 0`) / below (`k < 0`) the main diagonal.
- `mat = diag(d, k)`: construct a matrix with `k`-th diagonal elements being `d`.
- `mat = diag(diag(mat, k), k)`: set elements to zero except the `k`-th diagonal elements.
- `fliplr(mat)`: flip `mat` in left/right direction.
- `flipud(mat)`: flip `mat` in up/down direction.
- `rot90(mat, k)`: rotate `mat` `k * 90` degrees.

N-D array: reshape and slicing

Define 3-D array using reshape:

```
rowVec = 1:8
array = reshape(rowVec, 2, 2, 2);
length(size(array))  % Libao Jin dimension
```

or using slicing:

```
slice1 = [1,2;3,4]
slice2 = [5,6;7,8]
C(:,:,1) = slice1
C(:,:,2) = slice2
```

Char Array vs. String Array

```
str = "abc"
arrayOfChars1 = 'abc'
arrayOfChars2 = ['a','b','c']
arrayOfChars1 == arrayOfChars2 % Libao Jinl 1 (true)
arrayOfChars1 == str           % Libao Jinl 1 (true)
class(str)                     % string
class(arrayOfChars1)           % char
[arrayOfChars1,arrayOfChars2]  % return 'abcabc'
[arrayOfChars1;arrayOfChars2]  % return ['abc';'abc']
[str,str]                      % return ["abc","abc"]
[str;str]                      % return ["abc";"abc"]
```

Cell Array: array of elements of different types

- `cell(n)`: create 1-D cell array of length `n`
- `cell(m,n)`: create 2-D cell array of size `m` by `n`
- Create a cell array of types `char`, `string`, `double`:

```
cellArray = {[1,2,3], "abc", 'def'}
cellArray{1}              % return [1,2,3]
cellArray{2}              % return "abc"
cellArray{3}              % return 'def'
cellArray{4} = 'ghi'
cellArray{4}              % return 'ghi'
```

Application: Image Processing

- A grayscale image is a 2-D array of pixels, each pixel has a integer value that represent depth of color.
- A colored image is a 3-D array of pixels with RGB channels, each channel is a 2-D array.
- `img = imread(filename)`: read image from graphics file `filename` and assign it `img`.
- `imshow(img)`: display image `img` in handle graphics figure.
- `imwrite(img, filename)`: write image `img` to graphics file named `filename`.

```
uw = imread('UW.png');
uwFlipud = flipud(uw);
imshow(uwFlipud);
imwrite(uwFlipud, 'UW_flipud.png');
```

Summary

Command	Description
`transpose` or `'`	Non-conjugate transpose of a vector
`linspace`	Linearly spaced vector
`logspace`	Logarithmically spaced vector
`colon` or `:`	Colon
`zeros`	Zeros array
`ones`	Ones array
`eye`	Identity matrix
`rand`	Uniformly distributed pseudorandom numbers
`randn`	Normally distributed pseudorandom numbers
`magic`	Magic square
`size`	Size of array
`length`	Length of vector
`reshape`	Reshape array

Summary

Command	Description
`diag`	Diagonal matrices and diagonals of a matrix
`cell`	Create cell array
`sum/prod`	Sum/Product of elements
`min/max`	Minimum/Maximum of elements
`dot`	Vector dot product
`find`	Find indices of nonzero elements
`eig`	Find eigenvalues and eigenvectors
`diag`	Diagonal matrices and diagonals of a matrix
`fliplr/flipud`	Flip an array
`rot90`	Rotate an array 90 degrees
`imread/imwrite`	Read/Write image from graphics file
`imshow`	display image in Handle Graphics figure
`uint8`	Convert to unsigned 8-bit integer

Additional Commands

Command	Description
`iskeyword`	Check if input is a keyword
`who`	List current variables
`whos`	List current variables, long form
`which`	Locate functions and files
`clear`	Clear variables and functions from memory
`clc`	Clear command window
`clf`	Clear current figure
`close`	Close figure
`exist`	Check existence of variable/script/function/folder/class
`disp`	Display array

Script Files

A script file is simply a file that contains a chain of commands that you edit in a separate window, then execute with a single mouse click or command. This is where we can define variables, perform calculations and leave comments to remind us what the file calculates.

File Naming Conventions

- Start with a letter, followed by letters or numbers or underscore, maximum 63 characters (excluding the .m extension), and must not be the same as any MATLAB reserved word.
- None of the conventions matter to MATLAB itself: they only matter to the people writing the code, and the people maintaining the code (usually a much harder task), and to the people paying for the code (you'd be amazed how much gets written into contract specifications.)
- Reference:
  `https://www.mathworks.com/matlabcentral/answers/30223-what-are-the-rules-for-naming-script-files`

Put Comments to Your Script File

```
% MATH 3341, Semester Year
% Lab 02: Variables, Arrays, and Scripts
% Author: first_name last_name
% Date: mm/dd/yyyy
```

Useful MATLAB Shortcuts

- Windows shortcuts
  - Press `Ctrl` + `A` to select all
  - Press `Ctrl` + `I` to adjust indentation
  - Press `Ctrl` + `R` to comment
  - Press `Ctrl` + `T` to uncomment
- macOS shortcuts
  - Press `command` + `A` to select all
  - Press `command` + `I` to adjust indentation
  - Press `command` + `/` to comment
  - Press `command` + `T` to uncomment

LaTeX Primer

table Environment

```
\begin{table}[!hbtp]
  \caption{This is a table}
  \begin{tabular}{rcl}
  \toprule
  Column 1 & Column 2 & Column 3 \\
  \midrule
  1        & 1        & 1        \\
  12       & 12       & 12       \\
  123      & 123      & 123      \\
  \bottomrule
  \end{tabular}
\end{table}
```

`table` Environment

Table 1: This is a table

Column 1	Column 2	Column 3
1	1	1
12	12	12
123	123	123

figure Environment

```
\begin{figure}[!hbtp]
  \centering
  \includegraphics[height=0.3\textheight]{./fig/figure.pdf}
  \caption{Plot of $\sin{x}$}
  \label{fig:sin}
\end{figure}
```

generates

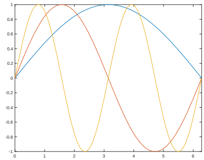

Figure 1:Plot of $\sin x$

\left and \right vs. \big, \Big, \Bigg

```
\begin{align*}
\|x\|_2 & = \big(\sum_{i = 1}^{n} x_i^2 \big)^{1/2},
\|x\|_2 = \Big(\sum_{i = 1}^{n} x_i^2 \Big)^{1/2}, \\
\|x\|_2 & = \Bigg(\sum_{i = 1}^{n} x_i^2 \Bigg)^{1/2},
\|x\|_2 = \left(\sum_{i = 1}^{n} x_i^2 \right)^{1/2}.
\end{align*}
```

generates

$$\begin{aligned} \|x\|_2 &= \big(\sum_{i=1}^{n} x_i^2 \big)^{1/2}, \|x\|_2 = \Big(\sum_{i=1}^{n} x_i^2 \Big)^{1/2}, \\ \|x\|_2 &= \Bigg(\sum_{i=1}^{n} x_i^2 \Bigg)^{1/2}, \|x\|_2 = \left(\sum_{i=1}^{n} x_i^2 \right)^{1/2}. \end{aligned}$$

Links

```
\href{https://www.google.com}{Google}
```

Google

Or simply

```
\url{https://www.google.com}
```

https://www.google.com

case Environment

```
$$
f(x) =
\begin{cases}
5 x + 4   & \text{if~} x \leq 1, \\
3 x^2 + 6 & \text{if~} x > 1
\end{cases}
$$
```

generates

$$f(x) = \begin{cases} 5x + 4 & \text{if } x \leq 1, \\ 3x^2 + 6 & \text{if } x > 1 \end{cases}$$

Cross-Reference

```
\begin{equation}
\label{eq:ls}
A \mathbf{x} = \mathbf{b}.
\end{equation}

The expression \eqref{eq:ls} is a linear system.
```

generates

$$A\mathbf{x} = \mathbf{b}. \tag{1}$$

The expression (1) is a linear system.

Cross-Reference

```
\begin{table}[!hbtp]
\caption{$y = 2x$}
\label{tab:xy}
  \begin{tabular}{cc}
  \toprule
  $x$ & $y$ \\
  \midrule
  $6$ & $12$ \\
  $7$ & $14$ \\
  $8$ & $16$ \\
  \bottomrule
  \end{tabular}
\end{table}
Table \ref{tab:xy} gives the result of $y = 2x$.
```

Cross-Reference

Table 2: $y = 2x$

x	y
6	12
7	14
8	16

Table 2 gives the result of $y = 2x$.