

# Introduction to MATLAB

## – exercises and solution notes

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Computer Science Tripos – Part II

**Exercise 1:** Find a *short* MATLAB expression to build the matrix

$$B = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 \\ 9 & 7 & 5 & 3 & 1 & -1 & -3 \\ 4 & 8 & 16 & 32 & 64 & 128 & 256 \end{pmatrix}$$

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*Answer:* `b = [1:7; 9:-2:-3; 2.^(2:8)]`

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**Exercise 2:** Give a MATLAB expression that uses only a single matrix multiplication with  $B$  to obtain

(a) the sum of columns 5 and 7 of  $B$

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*Answer:* `b * [0 0 0 0 1 0 1]'`

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(b) the last row of  $B$

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*Answer:* `[0 0 1] * b`

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(c) a version of  $B$  with rows 2 and 3 swapped

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*Answer:* `[1 0 0; 0 0 1; 0 1 0] * b`

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**Exercise 3:** Give a MATLAB expression that multiplies two vectors to obtain

(a) the matrix  $\begin{pmatrix} 1 & 2 & 3 & 4 & 5 \\ 1 & 2 & 3 & 4 & 5 \\ 1 & 2 & 3 & 4 & 5 \end{pmatrix}$

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*Answer:* `[1 1 1]' * (1:5)`

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(b) the matrix  $\begin{pmatrix} 0 & 0 & 0 \\ 1 & 1 & 1 \\ 2 & 2 & 2 \\ 3 & 3 & 3 \\ 4 & 4 & 4 \end{pmatrix}$

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*Answer:* `(0:4)' * [1 1 1]`

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**Exercise 4:** Modify slide 30 to produce tones of falling frequency instead.

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*Answer:* Replace

```
f = fmin * (fmax/fmin) .^ 1;
```

with

```
f = fmax * (fmin/fmax) .^ 1;
```

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**Exercise 5:**

- (a) Write down the function  $g(t)$  that has the shape of a sine wave that increases linearly in frequency from 0 Hz at  $t = 0$  s to 5 Hz at  $t = 10$  s.

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*Answer:* The instantaneous frequency of function  $g(t)$  at time  $t$  is

$$f(t) = t \cdot \frac{5 \text{ Hz}}{10 \text{ s}} = \frac{t}{2 \text{ s}^2}$$

and since the phase of a sine wave is  $2\pi$  times the integrated frequency so far, we get

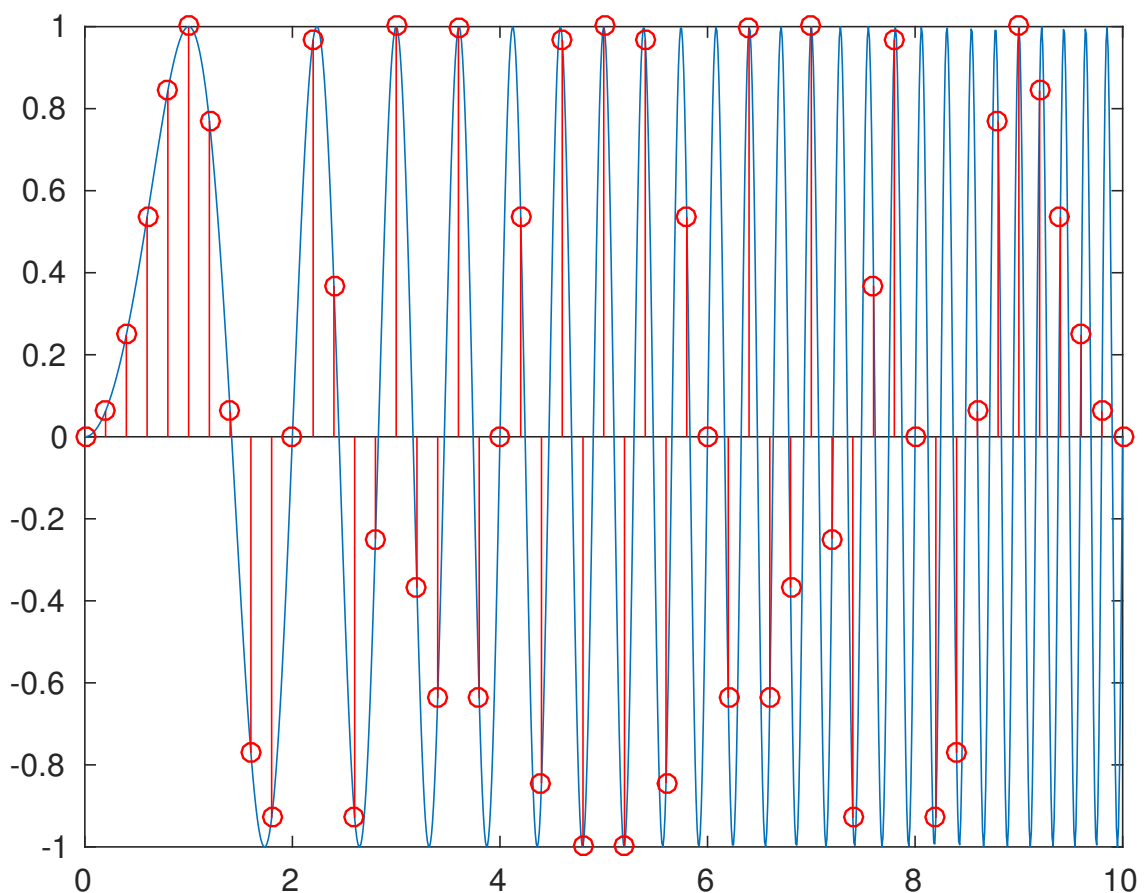
$$g(t) = \sin\left(2\pi \int_0^t f(t') dt'\right) = \sin\left(2\pi \frac{t^2}{4 \text{ s}^2}\right) = \sin\left(\frac{\pi t^2}{2 \text{ s}^2}\right)$$

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- (b) Plot the graph of this function using MATLAB's `plot` command.
- (c) Add to the same figure (this can be achieved using the `hold` command) in a different colour a graph of the same function sampled at 5 Hz, using the `stem` command.

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*Answer:* for (b) and (c)



```

t = 0:0.01:10;
f = sin(pi*t.^2/2);
plot(t,f);
hold;
t2 = 0:1/5:10;
stem(t2, sin(pi*t2.^2/2), 'r');

```

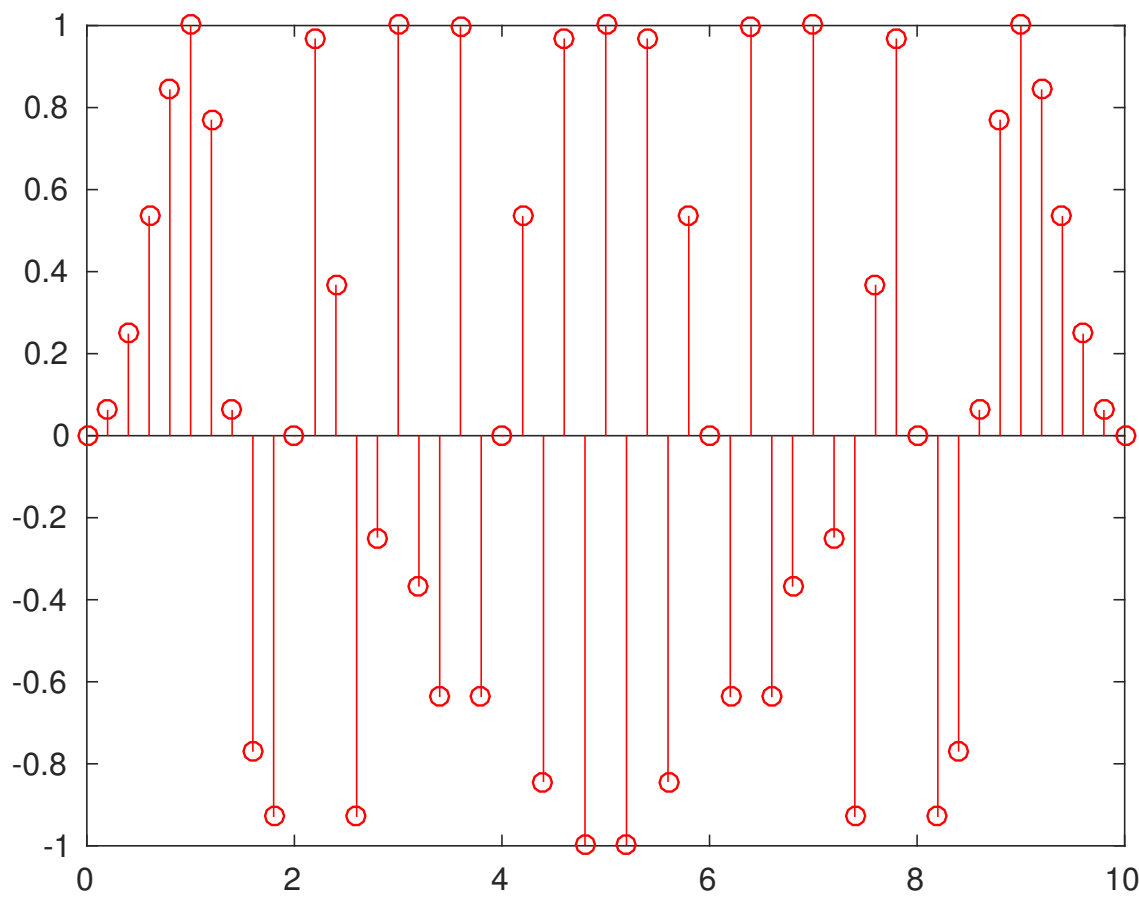
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- (d) [Extra credit] Plot the graph from (c) separately. Can you explain its symmetry? [Hints: sampling theorem, aliasing].

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*Answer:* A sine wave with a frequency  $f$  larger than half the sampling frequency  $f_s$  cannot be distinguished based on the sample values from a sine wave of frequency  $f_s - f$ . In other words, the sample values would have looked the same had we replaced the instantaneous frequency  $f(t)$  with  $f_s/2 - |f_s/2 - f(t)|$ , and the latter is symmetric around  $f_s/2$ , which is in this graph 2.5 Hz and occurs at  $t = 5$  s.

[The above is of course just a hand-waving argument, but shall be sufficient for this exercise. There are actually a few more conditions fulfilled here that lead to the exact symmetry of the plot. Firstly, since we started sampling at  $t = 0$  s with  $f_s = 5$  Hz, the positions of the sample values end up being symmetric around  $t = 5$  s. Secondly, at the symmetry point  $t = 5$  s, the sine wave was at a symmetric peak from where increasing or decreasing the phase has the same result.]



**Exercise 6:** Use MATLAB to write an audio waveform (8 kHz sampling frequency) that contains a sequence of nine tones with frequencies 659, 622, 659, 622, 659, 494, 587, 523, and 440 Hz. Then add to this waveform a copy of itself in which every other sample has been multiplied by  $-1$ . Play the waveform, write it to a WAV file, and use the `specgram` command to plot its spectrogram with correctly labelled time and frequency axis.

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*Answer:*

```

f = [659 622 659 622 659 494 587 523 440];
fs = 8000; % sampling frequency
d = 0.5; % duration per tone
t = 0:1/fs:d-1/fs;
w = sin(2 * pi * f' * t)/2;
w = w'; w = w(:)';
w = [w, w .* (mod((1:length(w)), 2) * 2 - 1)];
audiowrite('matlab_answer-2.wav', w, fs);
specgram(w, [], fs);

```

