Introduction to MATLAB
– exercises and solution notes

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

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

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

**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 \( B \)

*Answer:* \( b * [0 0 0 0 1 0 1]' \)

(b) the last row of \( B \)

*Answer:* \([0 0 1] * b \)

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

*Answer:* \([1 0 0; 0 0 1; 0 1 0] * b \)

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

(a) the matrix

\[
\begin{pmatrix}
1 & 2 & 3 & 4 & 5 \\
1 & 2 & 3 & 4 & 5 \\
1 & 2 & 3 & 4 & 5
\end{pmatrix}
\]

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

(b) the matrix

\[
\begin{pmatrix}
0 & 0 & 0 \\
1 & 1 & 1 \\
2 & 2 & 2 \\
3 & 3 & 3 \\
4 & 4 & 4
\end{pmatrix}
\]

*Answer:* \((0:4)' * [1 1 1] \)
Exercise 4: Modify slide 30 to produce tones of falling frequency instead.

Answer: Replace
\[ f = \text{fmin} * (\text{fmax}/\text{fmin}) \cdot 1; \]

with
\[ f = \text{fmax} * (\text{fmin}/\text{fmax}) \cdot 1; \]

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.

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

(b) Plot the graph of this function using MATLAB’s \texttt{plot} command.

(c) Add to the same figure (this can be achieved using the \texttt{hold} command) in a different colour a graph of the same function sampled at 5 Hz, using the \texttt{stem} command.

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');

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

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. Append 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 spectrogram command to plot its spectrogram with correctly labelled time and frequency axis.

Answer:
\( f = [659 \ 622 \ 659 \ 622 \ 659 \ 494 \ 587 \ 523 \ 440]; \)
\( fs = 8000; \quad \% \text{ sampling frequency} \)
\( d = 0.5; \quad \% \text{ duration per tone} \)
\( t = 0:1/fs:d-1/fs; \)
\( w = \sin(2 \pi f' * t)/2; \)
\( w = w'; \quad w = w(:)'; \)
\( w = [w, w .* \mod((1:length(w)), 2) * 2 - 1]; \)
\( \text{audiowrite('matlab_answer-2.wav', w, fs);} \)
\( \text{spectrogram(w, 1024, [], [], fs, 'yaxis');} \)