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: \(b \times [0 \ 0 \ 0 \ 0 \ 1 \ 0 \ 1]'\)

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

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

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

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

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: \([1 \ 1 \ 1]' \times (1:5)\)

(b) the matrix

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

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

Answer: Replace

\[ f = \text{fmin} \ast (\text{fmax}/\text{fmin}) \cdot l; \]

with

\[ f = \text{fmax} \ast (\text{fmin}/\text{fmax}) \cdot l; \]

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 `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.

Answer: for (b) and (c)
\( t = 0:0:01:10; \)
\( f = \sin(\pi \cdot t^2/2); \)
\( \text{plot}(t,f); \)
\( \text{hold}; \)
\( t2 = 0:1/5:10; \)
\( \text{stem}(t2, \sin(\pi \cdot t2^2/2), 'r'); \)

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

\textit{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.]

\textbf{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 \texttt{spectrogram} command to plot its spectrogram with correctly labelled time and frequency axis.

\textit{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);
spectrogram(w, 1024, [], [], fs, 'yaxis');