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PREAMBLE

DO NOT REMOVE THE LINE BELOW

```
clear;
```

QUESTION 1: COMMENTING

========================

```
type('eel3135_lab02_comment.m')
```

```
%% ACKNOWLEDGEMENTS / REFERENCES:
% This code uses functions written by Ken Schutte in 2019, which is used to
% read and decode midi files. The code is under a GNU General
% Public License, enabling us to run, study, share, and modify the
% software.
%
% More info can be found at: http://www.kenschutte.com/midi


%% INITIAL SETUP
clear
close all
clc

%% DEFINE MUSIC

% INTITIAL VARIABLES
Fs = 44100;             % ==> This is the cyclic frequency sample that is the audio signal <==

%  ===>
% readmidi loads the gym.mid file and midiInfo processes those results,
% 0 and two specify how it should be decoded. The results come out with Notes
% being the parsed data, and endtime holds the ened time of the data
% <===
[Notes, endtime] = midiInfo(readmidi('gym.mid'), 0, 2);
L = size(Notes,1);      % ==>
                        % Calculates the number of rows in the Notes array
                        % that is tken from the MIDI file, which means that it's
                        % the total number of notes in the MIDI file
                        % <==

%  ===>
% Calls the build_song function where
%   ones(L,1) is the amplitude determined by the number of notes in the MIDI File

%   Notes (:,) is the key numberfor the notes in the MIDI file to determine
%   the corresponding key note

%   Notes(:,6)-Notes(;,5) is how long each note is by calculating the difference
%   between end time in column 6 and start time in column 5 of the notes array

%   Fs is the cyclic sampling frequency that defines the rate the audio signal is sampled
% <===
x = build_song(ones(L,1), Notes(:,3), Notes(:,6)-Notes(:,5), Fs);
```

```
%  ===>
% Calculates the total samples needed to represent the entire audio signal
% The total duration of the song is obtained by adding all the durations of
% the notes taken by subtracting end time with start time, and multiplying
% that sum by the Fs or samples per second (cyclic sample frequency)
% <===
tot_samples = ceil(sum(Notes(:,6)-Notes(:,5))*Fs);

%  ===>
% This line creates the time vector from 0 to the total duration of the song
% based on total number of smaples (tot_samples) and the cyclic sampling frequency (Fs)
% <===
t = 0:1/Fs:(tot_samples-1)/Fs;  % ==> Step size is 1/Fs so that the time vector
                                % corresponds with each audio signal sample. The
                                % resulting t will be used to plot audio waveform
                                % <==

figure(1);                      % Creates a ficure to put the image in
subplot(211)                    % Creates a subplot in the figure(1)
plot(t, x);                     % Plots audio signal x against time vector t the subplot(211)
xlabel('Time [s]')              % Labels x-axis of subplot(211)
ylabel('Amplitude')             % Labels y-axis of subplot(211)
subplot(212)                    % Creaes a second subplot under the first in the figure(1)
plot(t, x);                     % Plots audio signal x against time vector t the subplot(212)
xlabel('Time [s]')              % Labels x-axis of subplot(212)
ylabel('Amplitude')             % Labels y-axis of subplot(212)
axis([0 0.1 -1 1])              % ==> Sets parameters of the x-axis to 0.1
                                % seconds and the y-axis to the range [-1,1],
                                % it basically zooms in on the waveform for
                                % better visualization of the start of the song
                                % <==

%  ===>
% The line pauses to wait for the user to press a button before playing
% a sound inorder to examine the waveform before hearing the audio
% <===
input('Click any button to play sound')
soundsc(x, Fs);                 % Plays the audio signal



% ========
% YOU DO *NOT* NEED TO DESCRIBE THESE LINES (your free to figure it out though)
W = 0.1;    % Window size
tic;
for mm = 1:ceil(tot_samples/Fs/W)
    % PAUSE UNTIL NEXT FRAME
    xlim([(mm-1)*W+[0 W]]); % Set limits of plot
    tm = toc;                       % Check current time
    if mm*W < tm, disp(['Warning: Visualization is ' num2str(mm*W-tm)  's behind']); end
    drawnow; pause(mm*0.1-tm);      % Synchronize with clock
end
% =======



%%
% ========================================
% SUPPORTING FUNCTIONS FOUND BELOW
% Add comments appropriately below
% ========================================


function x = key_to_note(A, key, dur, fs)
% key_to_note: ========> Creates the sinusoid waveform of a single note <=========
%
% Input Args:
%     A: complex amplitude
%   key: number of the note on piano keyboard
%   dur: duration of each note (in seconds)
%    fs: A scalar sampling rate value
%
% Output:
%     x: sinusoidal waveform of the note

    %  ===> Takes apart the components of the note based on the MIDI key number <===
    N    = floortol(dur*fs);            % Calculates the number of samples needed for each note using floortol to prevent floating points
    t    = (0:(N-1)).'/fs;              % Creates a time vector that spans the duration of the note, t corresponds to each sample point in
                                        % note duration
    freq = (440/32)*2^((key-9)/12);     % Calulates frequency of note based on MIDI key number, 440 Hz corresponds to note A4 or key number 49, 2^(key - 9) / 12)
                                        % shifts frequency based on MIDI key number, using equal-tempered scale where each key is a half-step apart

    %  ===> Generates sinusoidal waveform for the note <===
    x    = real(A*exp(1j*2*pi*freq*t));
```

```
end


function x = build_song(As, keys, durs, fs)
% build_song:  ========>
% Creates the full audio signal by placing each individual note int he correct
% position based on the start time and duration after calling key_to_note to generate
% waveform for each note
% <=========
%
% Input Args:
%         As: A length-N array of complex amplitudes for building notes
%       keys: A length-N array of key numbers (which key on a keyboard) for building notes
%   durs: A length-N array of durations (in seconds) for building notes
%     fs: A scalar sampling rate value
%
% Output Args:
%      x: A length-(N*fs) length raw audio signal
%
    %  ===>
    % Initializes the audio signal with zeros the same size as all the
    % song notes by summing all note durations times the cyclic sampling rate (Fs)
    % <===
    x = zeros(ceil(sum(durs)*fs), 1);
    for k = 1:length(keys)

        %  ===>
        % note generates the waveform of the single note, start_time calculates
        % the total start time for the current note by calculating all the durations
        % of previous notes (basically calculates when the note should begin in the final audio
        % <===
        note       = key_to_note(As(k), keys(k), durs(k), fs);
        start_time = sum(durs(1:k-1));

        %  ===>
        % This line calulates sample indices of the current note, n1 is
        % start and n2 is end, flortol rounds to avoid float point errors
        % <===
        n1         = floortol(start_time*fs) + 1;
        n2         = floortol(start_time*fs) + floortol(durs(k)*fs);
        x(n1:n2)   = x(n1:n2) + note;                                % This line places the generated waveform note into the correct position
                                                                     % in the audio signal x. The note is added to x between the indices n1 and
                                                                     % 2 so each note is placed at the correct time in the final audio signal

    end

end

function x = floortol(x)
%FLOORTOL Apply floor operation after adding 0.5 to ensure no
%   floating-point rounding errors that unintendedly decrease the
%   value
%

    x = floor(x+0.5);

end
```

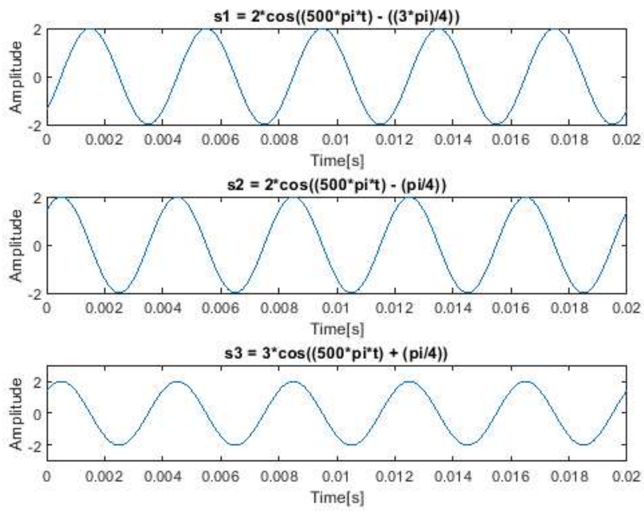
QUESTION 2

========================

2(a) PLOT FIRST FOUR PERIODS

```
% Define sampling frequency and the time vector
fs = 8000;                                                      % Sampling frequency (8000 Hz)
t = 0:1/fs:0.02;                                                % Time vector from 0 to 0.02 with step size of 1/fs to correspond to each audio signal s

% Define sinusoids
s1 = 2*cos((500*pi*t) - ((3*pi)/4));
s2 = 2*cos((500*pi*t) - (pi/4));
s3 = 3*cos((500*pi*t) + (pi/4));

% Plot sinusoids
figure(1);

% Subplot s1
subplot(311);
plot(t,s1);
title('s1 = 2*cos((500*pi*t) - ((3*pi)/4))');
xlabel('Time[s]');
ylabel('Amplitude');
axis([0 0.02 -2 2]);                                            % y-axis is -2 to 2 because s1 amplitude is 2

% Subplot s2
subplot(312);
```

```
plot(t,s2);
title('s2 = 2*cos((500*pi*t) - (pi/4))');
xlabel('Time[s]');
ylabel('Amplitude');
axis([0 0.02 -2 2]);

% Subplot s3
subplot(313);
plot(t,s2);
title('s3 = 3*cos((500*pi*t) + (pi/4))');
xlabel('Time[s]');
ylabel('Amplitude');
axis([0 0.02 -3 3]);
```

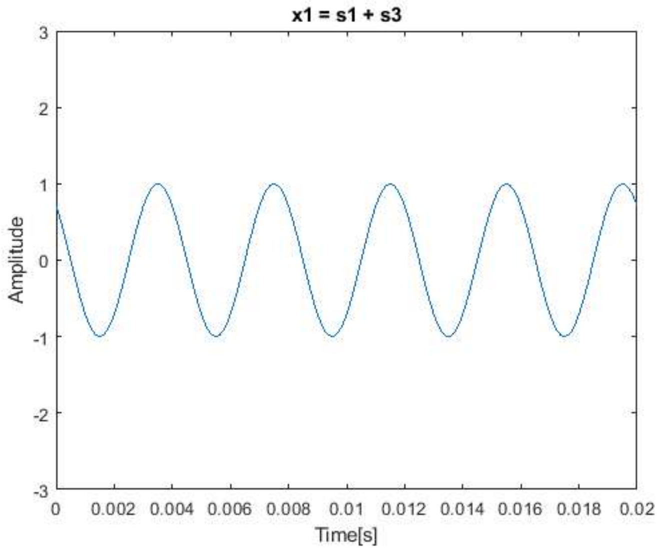


2(b) CREATE AND SUBMIT .WAV FILE

```
t_2 = 0:1/fs:2;                                                   % Time vector from 0 to 2 with step size of 1/fs to correspond to each audio signal samp

% Define sinusoids with new t
s1_2 = 2*cos((500*pi*t_2) - ((3*pi)/4));
s2_2 = 2*cos((500*pi*t_2) - (pi/4));
s3_2 = 3*cos((500*pi*t_2) + (pi/4));

% Scale sinusoids to be in range [-1 1] for audio writing
s1_scaled = s1_2 / max(abs(s1_2));
s2_scaled = s2_2 / max(abs(s2_2));
s3_scaled = s3_2 / max(abs(s3_2));

% Use audiowrite to save the sinusoids as .wav files
audiowrite('s1.wav', s1_scaled, fs);
audiowrite('s2.wav', s2_scaled, fs);
audiowrite('s3.wav', s3_scaled, fs);
```

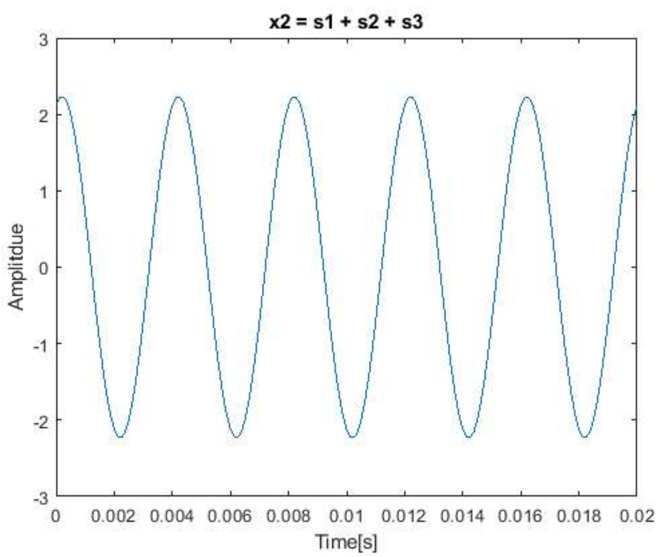
2(c) PLOT FIRST FOUR PERIODS

```
% x1(t) = s1(t) + s3(t)
x1 = s1 + s3;

% Plot the first four periods of x1(t)
subplot(111);
plot(t,x1);
title('x1 = s1 + s3');
xlabel('Time[s]');
ylabel('Amplitude');
axis([0 0.02 -3 3]);                                              % Adjust axis to fit first 4 periods
```



2(d) PLOT FIRST FOUR PERIODS

```
x2 = s1 + s2 + s3;

% Plot the first four periods of x2(t)
subplot(111);
plot(t,x2);
title('x2 = s1 + s2 + s3');
xlabel('Time[s]');
ylabel('Amplitdue');
axis([0 0.02 -3 3]);                                              % Adjusted axis to fit first 4 periods
```



QUESTION 3

=========================

```
fs = 32000;
```

DEFINE MUSIC

Music is "Frog's Theme" from the Chrono Trigger soundtrack

INSTRUCTIONS: Generate each set of notes individually with your functions and then add them together to create the music

```
% MELODY LINE 1
key1 = [87    87    87    83    85    87    92    90    87    83    80 ...
        80    82    83    82    83    85    83    85    87    85    87 ...
        90    87    87    87    83    85    87    92    94    95    94 ...
        92    90    92    92     0];
dur1 = [34    17    17    17    17    50    50   101    84    17   202 ...
        17    17    17    17    17    17    17    17    17    17    17 ...
```

```
        17    34    17    17    17    17    50    50    67    17    17 ...
        50    50   202   101   100]/100;
A1   = ones(length(key1),1);


% BASS LINE
key2 = [71    71    71    71    68    68    70    70    71    71    70  ...
        70    68    68    68    65    68    71    80    68     0];
dur2 = [101   101   101   101   101   101   101   101   101   101   101 ...
        101   101   101    50    17    17    17    50    17    34]/100;
A2   = ones(length(key2),1);

% BASS LINE 2
key3 = [44    44    44    44    44    44    47    47    47    47    47  ...
        47    47    40    40    40    40    40    40    42    42    42  ...
        42    42    42    44    44    44    44    44    44    42    42  ...
        42    42    42    42    40];
dur3 = [50    17    17    17    50    50    50    67    34    34    67  ...
       100    50    50    17    17    17    50    50    50    17    17  ...
        17    50    50    50    17    17    17    50    50    50    17  ...
        17    17    50    50    50    17    17    17    50    50     8]/100;
A3   = ones(length(key3),1);
```

3(a) CREATE SOUND

```
% Creates the songs
melody = build_song(A1, key1, dur1, fs);
bass1 = build_song(A2, key2, dur2, fs);
bass2 = build_song(A3, key3, dur3, fs);

% Combine melody and bass lines
combined_song = melody + bass1 + bass2;

% Normalize the combined song to ensure the signal stays within the [-1, 1] range
combined_song = combined_song / max(abs(combined_song));

audiowrite('song.wav', combined_song, fs);
```

3(b) MODIFY FUNCTION (key_to_note_violin function is at end of file)

Only need to modify function -- this area can be empty

3(c) CREATE SOUND (build_song_violin function is at end of file)

```
melody_violin = build_song_violin(A1, key1, dur1, fs);
bass1_violin = build_song_violin(A2, key2, dur2, fs);
bass2_violin = build_song_violin(A3, key3, dur3, fs);

% Combine melody and bass lines
combined_song_violin = melody_violin + bass1_violin + bass2_violin;

% Normalize the combined song to ensure the signal stays within the [-1, 1] range
combined_song_violin = combined_song_violin / max(abs(combined_song_violin));

audiowrite('song_violin.wav', combined_song_violin, fs);
```

DEFINE MUSIC (NEW FORM)

Music is "Frog's Theme" from the Chrono Trigger soundtrack

INSTRUCTIONS: Generate the notes individually with one build_song_time function to make the music

```
keys = [87    87    87    83    85    87    92    90    87    83    80 ...
        80    82    83    82    83    85    83    85    87    85    87 ...
        90    87    87    87    83    85    87    92    94    95    94 ...
        92    90    92    92      ...
         0    71    71    71    71    68    68    70    70    71    71 ...
        70    70    68    68    68    65    68    71    80    68 ...
         0    44    44    44    44    44    44    47    47    47    47  ...
        47    47    47    40    40    40    40    40    40    42    42  ...
        42    42    42    42    44    44    44    44    44    44    42  ...
        42    42    42    42    42    40];

srt_time = [0     34    50    67    84   101   151   202   303   387   403 ...
        605  622   639   655   672   689   706   723   739   756   773 ...
        790  807   840   857   874   891   908   958   1008  1076 1092 ...
       1109 1160  1210  1412  1512 ...
          0  101   202   303   403   504   605   706   807   908  1008 ...
       1109 1210  1311  1412  1462  1479  1496  1513  1563  1580 ...
          0   50    67    84   101   151   202   202   252   269   286 ...
        303  353   403   454   471   487   504   555   605   655   672  ...
        689  706   756   807   857   874   891   908   958  1008  1059 ...
       1076 1092  1109  1160  1210  1261  1277  1294  1311  1361  1412 ...
```

```
       1462 1479  1496  1513  1562]/100;

end_time = [34    49    66    83   100   151   202   302   387   403   605 ...
        616  632   649   666   683   700   716   733   750   767   784 ...
        800  840   857   874   891   908   957  1008  1076  1092  1109 ...
       1159 1210  1411  1512  1613 ...
         25   151   227   353   429   555   630   756   832   958  1034 ...
       1160  1235  1361  1437  1475  1492  1508  1563  1580  1613 ...
         50    67    84   101   151   202   252   269   286   303   352 ...
        403   403   453   471   487   504   554   605   655   672   689 ...
        706   756   807   857   874   891   908   957  1008  1058  1076 ...
        1092 1109  1159  1210  1260  1277  1294  1311  1361  1412  1462 ...
        1479 1496  1513  1562  1613]/100;

As   = ones(length(keys),1);
```

3(d) CREATE SOUND (build_song_time function is at end of file)

```
% Scale song time?
song_time = build_song_time(As, keys, srt_time, end_time, fs);

song_time = song_time / max(abs(song_time));

audiowrite('song_time.wav', song_time, fs);
```

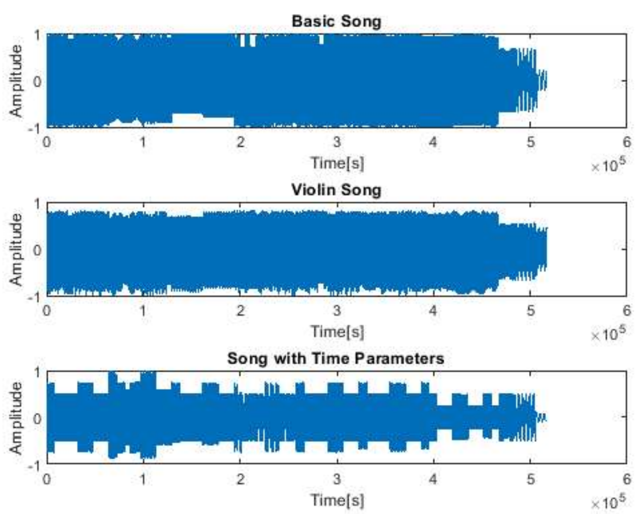
3(e) ANSWER QUESTION

```
% The benefits of the new structure is that it allows for better control
% over placement and timing of each note in the song and allows for precise
% time manipulation. Essentially it is more flexible to handle musicals
% pieces by decoupling not duration from timing.
```

3(f) PLOT COMPARISONS

Generate song for each

```
% Plot results
subplot(311);
plot(combined_song);
title('Basic Song');
xlabel('Time[s]');
ylabel('Amplitude');

subplot(312);
plot(combined_song_violin);
title('Violin Song');
xlabel('Time[s]');
ylabel('Amplitude');

subplot(313);
plot(song_time);
title('Song with Time Parameters');
xlabel('Time[s]');
ylabel('Amplitude');
```



3(g) ANSWER QUESTION

```
% The plots show difference in how the strong is constructed,
%   build_song generates a continuous waveform in fixed durations as a result
%   the overall shape of the plot is thicker and less defined in the [-1 1] parameters,

%   build_song_violin adds harmonics to each note to make the waveform more
%   complex and closer to real instrumental sounds, as a result it is
%   easier to see the shape of the plot and it isn't as close to the [-1 1]
%   parameters

%   build_song_time allows for finer control of the start and end times of
%   each note as a result, of the three plot the song_time plot is the most
%   defined in shape
```

== SUPPORTING FUNCTIONS FOUND BELOW ==

```
function x = key_to_note(A, key, dur, fs)
% key_to_note:
%
% Input Args:
%     A: complex amplitude
%   key: number of the note on piano keyboard
%   dur: duration of each note (in seconds)
%    fs: A scalar sampling rate value
%
% Output:
%     x: sinusoidal waveform of the note

    N    = floortol(dur*fs);
    t    = (0:(N-1)).'/fs;
    freq = (440/32)*2^((key-9)/12);
    x    = real(A*exp(1j*2*pi*freq*t));


end


function x = build_song(As, keys, durs, fs)
% build_song:
%
% Input Args:
%         As: A length-N array of complex amplitudes for building notes
%       keys: A length-N array of key numbers (which key on a keyboard) for building notes
%   durs: A length-N array of durations (in seconds) for building notes
%     fs: A scalar sampling rate value
%
% Output Args:
%      x: A length-(N*fs) length raw audio signal
%

    x = zeros(floortol(sum(durs)*fs), 1);
    for k = 1:length(keys)
        note       = key_to_note(As(k), keys(k), durs(k), fs);
        start_time = sum(durs(1:k-1));
        n1         = floortol(start_time*fs) + 1;
        n2         = floortol(start_time*fs) + floortol(durs(k)*fs);

        x(n1:n2)   = x(n1:n2) + note;
    end

end


function x = key_to_note_violin(A, key, dur, fs)
% key_to_note_violin: Produces a sinusoidal waveform corresponding to a
%       given piano key number
%
% Input Args:
%     A: complex amplitude
%   key: number of the note on piano keyboard
%   dur: duration of each note (in seconds)
%    fs: A scalar sampling rate value
%
% Output:
%     x: sinusoidal waveform of the note
    harmonics = [1, 2, 3, 4, 5, 6, 7, 8, 9, 10];  % Harmonics
    amplitudes = [1.59, 0.40, 3.98, 0.25, 0.10, 0.04, 0.15, 0.01, 0.05, 0.02];  % Amplitudes for each harmonic
    phases = [0, 1.6, -2.5, 0.6, -2.0, 2.1, -1.0, 1.8, -2.3, -2.1];  % Phases for each harmonic

    N    = floortol(dur*fs);

    % Time vector for note
    t    = (0:(N-1)).'/fs;

    % Initialize note signal
    x = zeros(size(t));
```

```
    frequency = (440/32)*2^((key-9)/12);

    % Sum harmonics
    for k = 1:length(harmonics)

        % Have k value inside
        x = x + amplitudes(k) * cos(2 * pi * frequency * t*k + phases(k)); % Add harmonic to signal
    end

    % Scale signal by amplitude
    x = real(A * x);

end


function x = build_song_violin(As, keys, durs, fs)
% build_song_violin:
%
% Input Args:
%         As: A length-N array of complex amplitudes for building notes
%       keys: A length-N array of key numbers (which key on a keyboard) for building notes
%   durs: A length-N array of durations (in seconds) for building notes
%     fs: A scalar sampling rate value
%
% Output Args:
%      x: A length-(N*fs) length raw audio signal
%
    x = zeros(ceil(sum(durs)*fs), 1);
    for k = 1:length(keys)
        note       = key_to_note_violin(As(k), keys(k), durs(k), fs);
        start_time = sum(durs(1:k-1));
        n1         = floortol(start_time*fs) + 1;
        n2         = floortol(start_time*fs) + floortol(durs(k)*fs);

        x(n1:n2)   = x(n1:n2) + note;
    end
end



function x = build_song_time(As, keys, start_time, end_time, fs)
% build_song:
%
% Input Args:
%          As: A length-N array of complex amplitudes for building notes
%        keys: A length-N array of key numbers (which key on a keyboard) for building notes
%  start_time: A length-N array of start times (in seconds) for notes
%    end_time: A length-N array of end times (in seconds) for notes
%          fs: A scalar sampling rate value
%
% Output Args:
%      x: A length-(N*fs) length raw audio signal
%
    total_duration = end_time - start_time;
    x = zeros(floortol(max(end_time) * fs), 1);                             % not total_duration because the sum of all the individual
                                                                             % durations is both the start and end times

    for k = 1:length(keys)

        % Calculate the start and end times for the current note
        note_start = start_time(k);
        note_end = end_time(k);

        % Calculate the duration of the current note
        note_duration = note_end - note_start;

        % Generate the note waveform using key_to_note
        note = key_to_note(As(k), keys(k), note_duration, fs);

        % Calculate the sample indices corresponding to the start and end times
        n1 = floortol(note_start * fs) + 1;                                 % Start sample index
        n2 = floortol(note_end * fs);                                       % End sample index

        % Add the note waveform to the output signal
        x(n1:n2) = x(n1:n2) + note;
    end

end


function x = floortol(x)
%FLOORTOL Apply floor operation after adding 0.5 to ensure no
%   floating-point rounding errors that unintendedly decrease the
%   value
%
```

```
    x = floor(x+0.5);

end
```

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