Table of Contents

MATLAB Exercise 2 - STFT Time–Frequency Tradeoff

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```
clear; close all; clc;

fs = 16000;
t = 0:1/fs:5;
duration = max(t);
x_clean = sin(2*pi*500*t) + 0.7*sin(2*pi*1200*t) + 0.6*chirp(t,1000,5,4000);

% Add Gaussian noise (SNR ~ 20 dB)
SNR_dB = 20;
signal_power = mean(x_clean.^2);
noise_power = signal_power / (10^(SNR_dB/10));
x = x_clean + sqrt(noise_power)*randn(size(x_clean));

fprintf('Signal: duration=%.2f s, fs=%d Hz, samples=%d\n', duration, fs,
length(t));
```

```
Signal: duration=5.00 s, fs=16000 Hz, samples=80001
```

Prepare containers to compute ALL STFTs first (so we can get global caxis)

```
allP = {};   % store P (dB) matrices
allF = {};   % corresponding F vectors
allT = {};   % corresponding T vectors
labels = {}; % text labels for each stored spectrogram (for plotting later)
```

Part A: Window Lengths

```
L_values = [256, 1024, 4096];
overlap_ratio = 0.5;
```

```
resultsA = zeros(length(L_values),6);

for i = 1:length(L_values)
    L = L_values(i);
    ov = round(L * overlap_ratio);
    win = rectwin(L);

    tic;
    [S,F,T] = stft(x, fs, 'Window', win, 'OverlapLength', ov, 'FFTLength',
L);
    runtime = toc;

    P = 20*log10(abs(S));
    allP{end+1} = P;
    allF{end+1} = F;
    allT{end+1} = T;
    labels{end+1} = sprintf('Part A: Rect, L=%d', L);

    resultsA(i,:) = [L, overlap_ratio, fs/L, (L-ov)/fs, length(T), runtime];
end
```

Part B: Overlaps (L fixed = 1024)

```
L = 1024;
overlap_ratios = [0, 0.5, 0.75, 0.875];
resultsB = zeros(length(overlap_ratios),6);

for i = 1:length(overlap_ratios)
    ratio = overlap_ratios(i);
    ov = round(L * ratio);
    win = rectwin(L);

    tic;
    [S,F,T] = stft(x, fs, 'Window', win, 'OverlapLength', ov, 'FFTLength',
L);
    runtime = toc;

    P = 20*log10(abs(S));
    allP{end+1} = P;
    allF{end+1} = F;
    allT{end+1} = T;
    labels{end+1} = sprintf('Part B: Rect, Overlap=%.1f%%', ratio*100);

    resultsB(i,:) = [L, ratio, fs/L, (L-ov)/fs, length(T), runtime];
end
```

Part C: Window types (L=1024, overlap=50%)

```
L = 1024; ov = round(L*0.5);
win_list = {'rectwin','hamming','hann'};
resultsC = cell(length(win_list),7);

for i = 1:length(win_list)
```

```
    winfun = str2func(win_list{i});
    win = winfun(L);

    tic;
    [S,F,T] = stft(x, fs, 'Window', win, 'OverlapLength', ov, 'FFTLength',
L);
    runtime = toc;

    P = 20*log10(abs(S));
    allP{end+1} = P;
    allF{end+1} = F;
    allT{end+1} = T;
    labels{end+1} = sprintf('Part C: %s', upper(win_list{i}));

    resultsC{i,1} = upper(win_list{i});
    resultsC{i,2} = L;
    resultsC{i,3} = 0.5;
    resultsC{i,4} = fs/L;
    resultsC{i,5} = (L-ov)/fs;
    resultsC{i,6} = length(T);
    resultsC{i,7} = runtime;
end
```

Part D: Zero padding (L=1024, overlap=50%, Nfft=1024 & 4096)

```
L = 1024; ov = round(L*0.5); win = hamming(L);
Nfft_values = [1024, 4096];
resultsD = zeros(length(Nfft_values),7);

for i = 1:length(Nfft_values)
    Nfft = Nfft_values(i);

    tic;
    [S,F,T] = stft(x, fs, 'Window', win, 'OverlapLength', ov, 'FFTLength',
Nfft);
    runtime = toc;

    P = 20*log10(abs(S));
    allP{end+1} = P;
    allF{end+1} = F;
    allT{end+1} = T;
    labels{end+1} = sprintf('Part D: NFFT=%d', Nfft);

    resultsD(i,:) = [Nfft, L, 0.5, fs/Nfft, (L-ov)/fs, length(T), runtime];
end
```

Determine global color scale and axis limits

```
maxVals = cellfun(@(p) max(p(:)), allP);
global_max = max(maxVals);
```

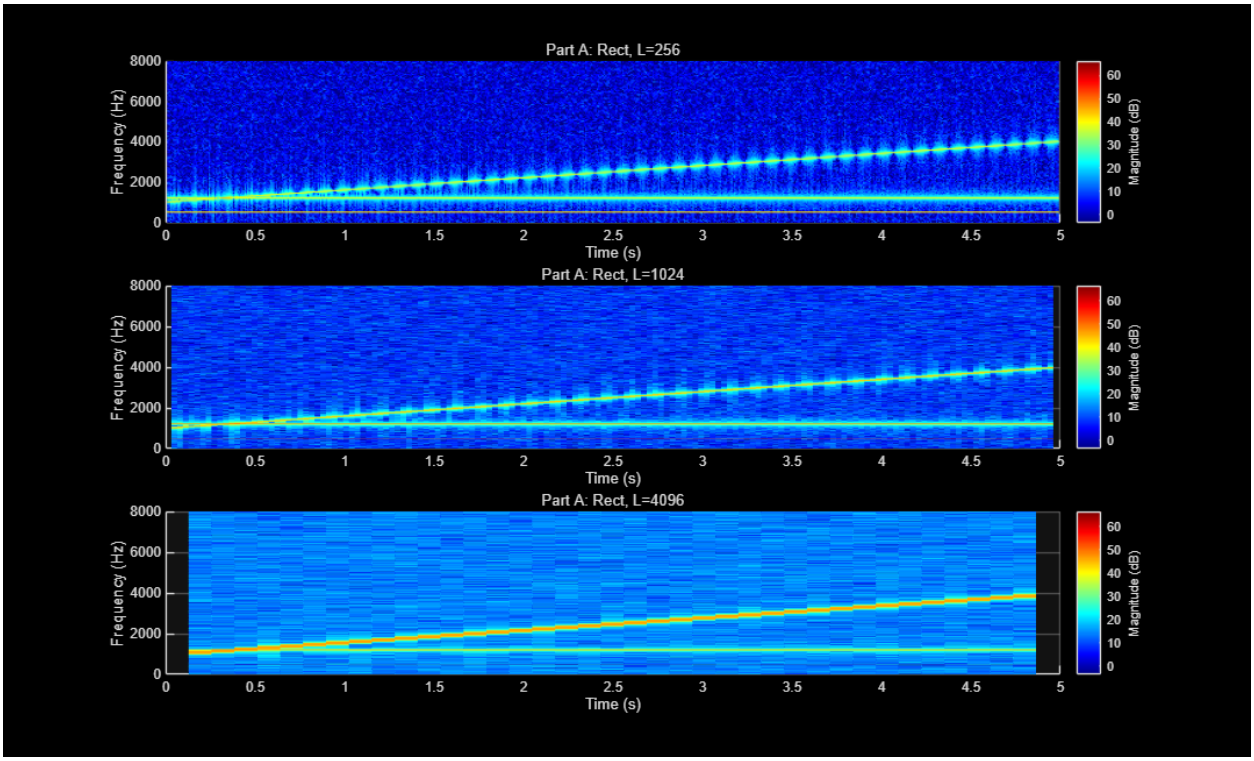
```
% Use fixed dynamic range (70 dB window)
cmax = global_max;
cmin = cmax - 70;

% Frequency axis limits and time limits
freq_lim = [0, fs/2];
time_lim = [0, duration];

fprintf('Global color scale: [%.1f, %.1f] dB (cmin, cmax)\n', cmin, cmax);
```

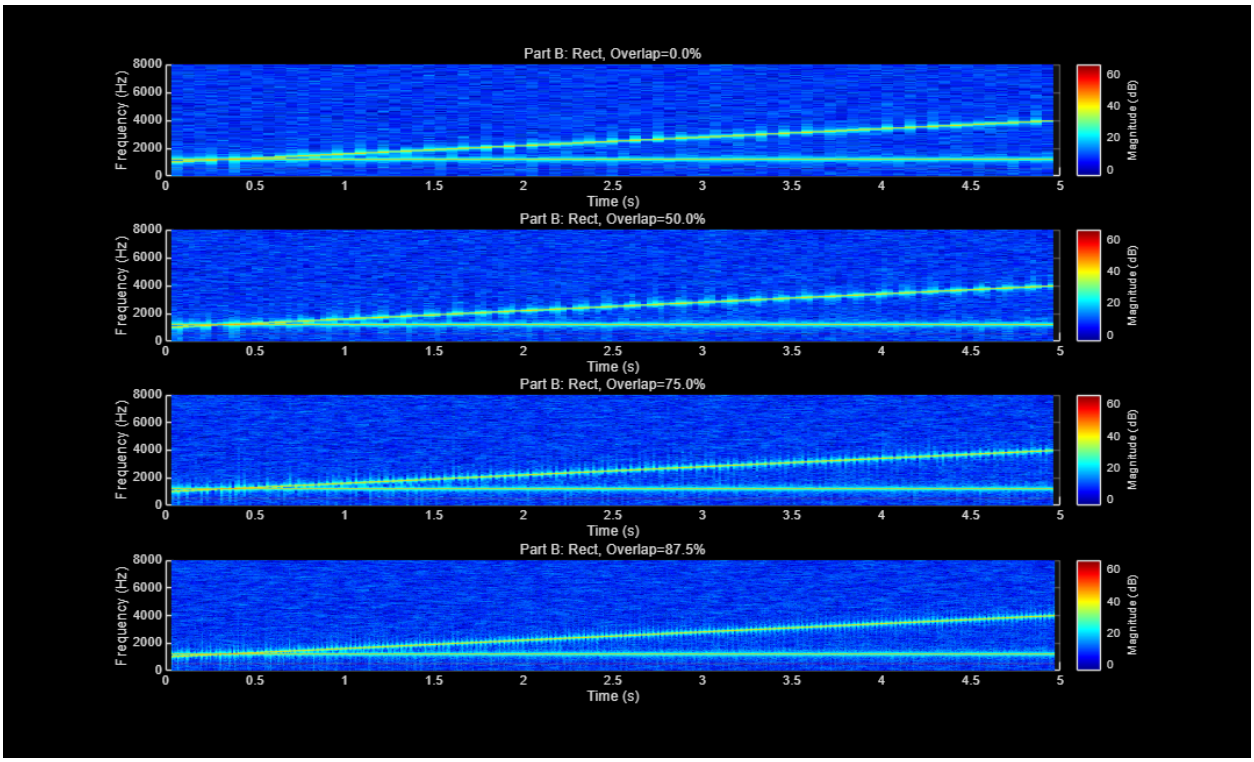
Global color scale: [-3.7, 66.3] dB (cmin, cmax)

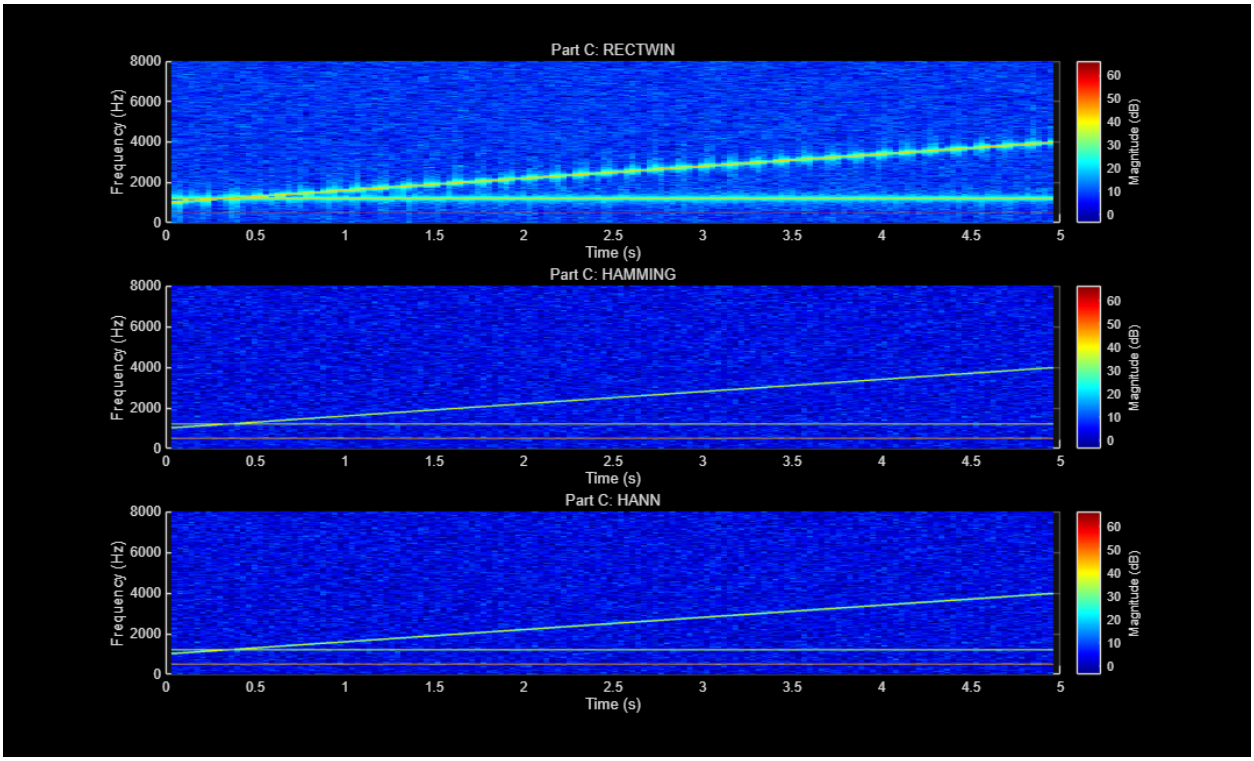
Plots

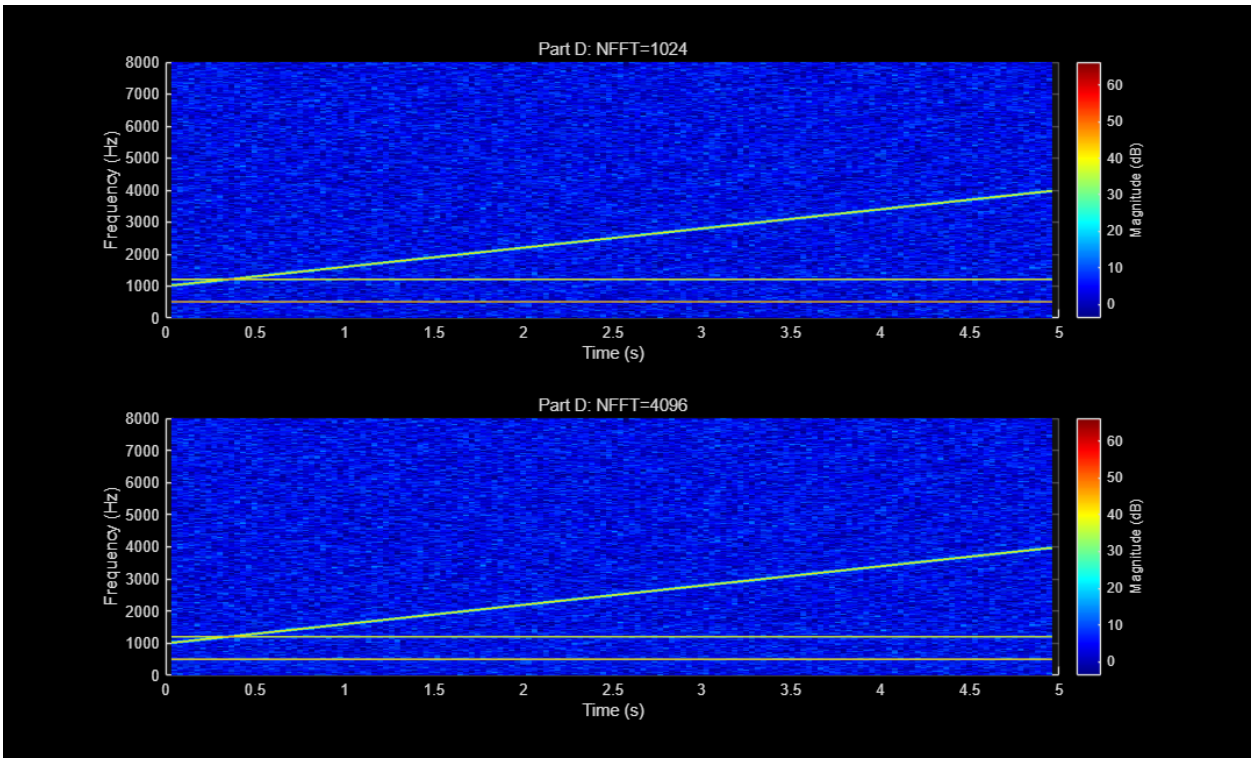
```
plotIdx = 1;

% Part A plots
figure('Name','Part A - Spectrograms','NumberTitle','off');
for i = 1:length(L_values)
    P = allP{plotIdx}; F = allF{plotIdx}; T = allT{plotIdx}; lbl =
labels{plotIdx};
    mask = F >= 0;
    subplot(length(L_values),1,i);
    surf(T, F(mask), P(mask,:), 'EdgeColor', 'none');
    view(0,90); axis tight;
    ylim(freq_lim); xlim(time_lim);
    colormap jet; caxis([cmin cmax]);
    xlabel('Time (s)'); ylabel('Frequency (Hz)');
    title(lbl);
    c=colorbar;
    c.Label.String = 'Magnitude (dB)';
    plotIdx = plotIdx + 1;
end

% Part B plots
figure('Name','Part B - Spectrograms','NumberTitle','off');
for i = 1:length(overlap_ratios)
    P = allP{plotIdx}; F = allF{plotIdx}; T = allT{plotIdx}; lbl =
labels{plotIdx};
    mask = F >= 0;
    subplot(length(overlap_ratios),1,i);
    surf(T, F(mask), P(mask,:), 'EdgeColor', 'none');
    view(0,90); axis tight;
    ylim(freq_lim); xlim(time_lim);
    colormap jet; caxis([cmin cmax]);
    xlabel('Time (s)'); ylabel('Frequency (Hz)');
    title(lbl);
    c=colorbar;
    c.Label.String = 'Magnitude (dB)';
    plotIdx = plotIdx + 1;
end
```

```
% Part C plots
figure('Name','Part C - Spectrograms','NumberTitle','off');
for i = 1:length(win_list)
    P = allP{plotIdx}; F = allF{plotIdx}; T = allT{plotIdx}; lbl =
labels{plotIdx};
    mask = F >= 0;
    subplot(length(win_list),1,i);
    surf(T, F(mask), P(mask,:), 'EdgeColor', 'none');
    view(0,90); axis tight;
    ylim(freq_lim); xlim(time_lim);
    colormap jet; caxis([cmin cmax]);
    xlabel('Time (s)'); ylabel('Frequency (Hz)');
    title(lbl);
    c=colorbar;
    c.Label.String = 'Magnitude (dB)';
    plotIdx = plotIdx + 1;
end

% Part D plots
figure('Name','Part D - Spectrograms','NumberTitle','off');
for i = 1:length(Nfft_values)
    P = allP{plotIdx}; F = allF{plotIdx}; T = allT{plotIdx}; lbl =
labels{plotIdx};
    mask = F >= 0;
    subplot(length(Nfft_values),1,i);
    surf(T, F(mask), P(mask,:), 'EdgeColor', 'none');
    view(0,90); axis tight;
    ylim(freq_lim); xlim(time_lim);
    colormap jet; caxis([cmin cmax]);
    xlabel('Time (s)'); ylabel('Frequency (Hz)');
    title(lbl);
    c=colorbar;
    c.Label.String = 'Magnitude (dB)';
    plotIdx = plotIdx + 1;
end
```


Part A: Rect, L=256
Part A: Rect, L=1024
Part A: Rect, L=4096
Frequency (Hz)
Time (s)
Magnitude (dB)


Part B: Rect, Overlap=0.0%
Part B: Rect, Overlap=50.0%
Part B: Rect, Overlap=75.0%
Part B: Rect, Overlap=87.5%
Frequency (Hz)
Time (s)
Magnitude (dB)





Display Summary Tables

```
disp('--- Part A Summary Table ---');
disp(array2table(resultsA, 'VariableNames',
```

```
{'L','OverlapRatio','Δf','Δt','NumFrames','Runtime_s'}));

disp('--- Part B Summary Table ---');
disp(array2table(resultsB, 'VariableNames',
{'L','OverlapRatio','Δf','Δt','NumFrames','Runtime_s'}));

disp('--- Part C Summary Table ---');
disp(cell2table(resultsC, 'VariableNames',
{'Window','L','OverlapRatio','Δf','Δt','NumFrames','Runtime_s'}));

disp('--- Part D Summary Table ---');
disp(array2table(resultsD, 'VariableNames',
{'FFTLength','L','OverlapRatio','Δf','Δt','NumFrames','Runtime_s'}));
```

```
--- Part A Summary Table ---
     L      OverlapRatio      Δf       Δt      NumFrames    Runtime_s
    ____    ____________    ______    _____    _________    _________

     256        0.5           62.5    0.008       624       0.0048094
    1024        0.5         15.625    0.032       155       0.0037926
    4096        0.5         3.9062    0.128        38       0.0038261

--- Part B Summary Table ---
     L      OverlapRatio      Δf       Δt      NumFrames    Runtime_s
    ____    ____________    ______    _____    _________    _________

    1024           0        15.625    0.064        78       0.0027153
    1024         0.5        15.625    0.032       155       0.0034603
    1024        0.75        15.625    0.016       309       0.0053758
    1024       0.875        15.625    0.008       618       0.0091647

--- Part C Summary Table ---
      Window        L      OverlapRatio      Δf       Δt      NumFrames
Runtime_s
    ___________    ____    ____________    ______    _____    _________
_________

    {'RECTWIN'}    1024        0.5         15.625    0.032       155
0.003914
    {'HAMMING'}    1024        0.5         15.625    0.032       155
0.0035527
    {'HANN'   }    1024        0.5         15.625    0.032       155
0.0038672

--- Part D Summary Table ---
    FFTLength     L      OverlapRatio      Δf       Δt      NumFrames
Runtime_s
    _________    ____    ____________    ______    _____    _________
_________

      1024       1024        0.5         15.625    0.032       155
0.0038815
      4096       1024        0.5         3.9062    0.032       155
```

```
0.0060927
```

Report

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