Kevin Shu
Homework 1 Report Summary
BME210, Prof. Kay

Part 1: Report Summary

Measuring heart rate and blood pressure are easy to do noninvasively, but the acquisition of cardiac output information has always been more difficult since draining the blood of patients would put the patient in significant risk, and looking very closely at the patient's heart would require incredibly invasive procedures. Thus, there was a need for a more creative and noninvasive approach to measuring cardiac output, and one of those techniques was the Dye Dilution Technique.

The Dye Dilution Technique essentially entails the injection of an indicator into the venous system of the patient's circulatory system and the measurement of the concentration of the indicator over time in the arterial system as the dye begins to circulate through the bloodstream. The cardiac output can be derived through a number of equations related to each other. Below, this derivation is assuming the blood is in a tank of constant volume, V, and the blood is leaving the tank with D, the amount of dye added to the blood. F will be the volumetric flow rate or the cardiac output. T is the time it takes for the volume in the tank to be emptied.

$$C = D/V\ (mg/L)$$
$$F = V/T\ (L/sec)$$
$$V = F * T = D/C$$
$$F = D/(C * T)$$

Now, in a real patient, the volume of blood is changing per increment of time. So, instead of a fixed volume, we have to work with changes in volume as well as changes in dye pumped out of the heart per time step (dt). Q will be the cardiac output and c(t) will be the concentration of dye over time.

$$\Delta V = Q\,dt$$
$$\Delta Di = c(t) * \Delta V = c(t) * Q\,dt$$

Since we're assuming that Q is constant, using mass balance principles, D, the total amount of dye injected must be equal to the amount of dye measured.

$$D = \sum_{i=1}^{n-1} \Delta Di = \sum_{i=1}^{n-1} c(t) * Q\,dt = Q \sum_{i=1}^{n-1} c(t)dt$$
$$Q \simeq D/\sum_{i=1}^{n-1} c(t)dt \text{ OR } Q = D/\int_{0}^{T} c(t)\,dt$$

However, since we're measuring with discrete data points, we can't use an integral, and will have to use integral approximation methods such as the rectangular, trapezoidal, and Simpson's methods.

Rectangular approximation equation: $\int f(x)\,dx \approx \sum_{i=1}^{n-1} (x(i+1) - x(i))(f(i))$

Trapezoidal approximation equation: $\int f(x)\,dx \approx \frac{1}{2} \sum_{i=1}^{n-1} (x(i+1) - x(i))(f(i) + f(i+1))$

Simpson's method equation:

$$\int f(x)\,dx \approx \frac{\Delta x}{3}[f(x_1) + 4f(x_2) + 2f(x_3) + 4f(x_4) + 2f(x_5) + \ldots + 2f(x_{n-2}) + 4f(x_{n-1}) + f(x_n)]$$

Additionally, this report will cover: 1) A MATLAB script that calculates cardiac output by finding the area under the concentration-time curve and also displays a graph of the concentration time curve. 2) A run of the aforementioned code, and 3) a MATLAB program that calculates the spline approximations

of atrial, aortic, and ventricular pressure information as well as ventricular volume data. The report will also outline the results of this second script.

Part 2: Program to Calculate Cardiac Output

```
clear; clc; close all;
dye = importdata('DyeData_2021.txt');

%this is where my rectangular integral calculation begins
dye1 = dye(2:end-1, 2); %these are the first values of the dye omitting the last value.
timeDiff = dye(3:end,1)-dye(2:end-1,1); %this line is to ensure the time difference is calculated for any type of data set.
rectangular = dot(dye1,timeDiff); %the addition of the rectangles from the dye values times the time differences is the rectangular accumulation.

%this is where my trapezoidal integral calculation begins
dye2 = dye(3:end, 2); %this is the dye data beginning from the second hematocrit value.
trapezoidal = dot(dye2+dye1, timeDiff)/2;

%this is where my Simpson's method calculations begin
h = timeDiff(1);
Sdye = dye(2:end, 2);
%determining if I have to subtract 1 from the end or not. If even number of data points, then subtract 1. If odd, don't.
if (mod(length(Sdye),2) == 0)
   evenodd = 1;
   lastInterval = h*(dye(end-1) + dye(end))/2; %this is the trapezoidal last interval
else
   evenodd = 0;
   lastInterval = 0;
end
coeff1 = [Sdye(1), Sdye(end-evenodd)]; %all of the values that must be multiplied by 1
coeff2 = Sdye(2:2:end-evenodd-1)*2; % all of the values that must be multiplied by 2
coeff4 = Sdye(3:2:end-evenodd-2)*4; %all of the values here must be multipled by 4
Simpsons = h*(sum(coeff1) + sum(coeff2) + sum(coeff4))/3 + lastInterval;

%Cardiac Output calculations below
HCT = dye(1, 2)/100;
QplasmaR = dye(1,1)/rectangular;
Qr = QplasmaR*60/(1-HCT); %in L/min
QplasmaT = dye(1,1)/trapezoidal;
Qt = QplasmaT*60/(1-HCT); %in L/min
QplasmaS = dye(1,1)/Simpsons;
Qs = QplasmaS*60/(1-HCT); %in L/min

%plotting concentration vs. time
```

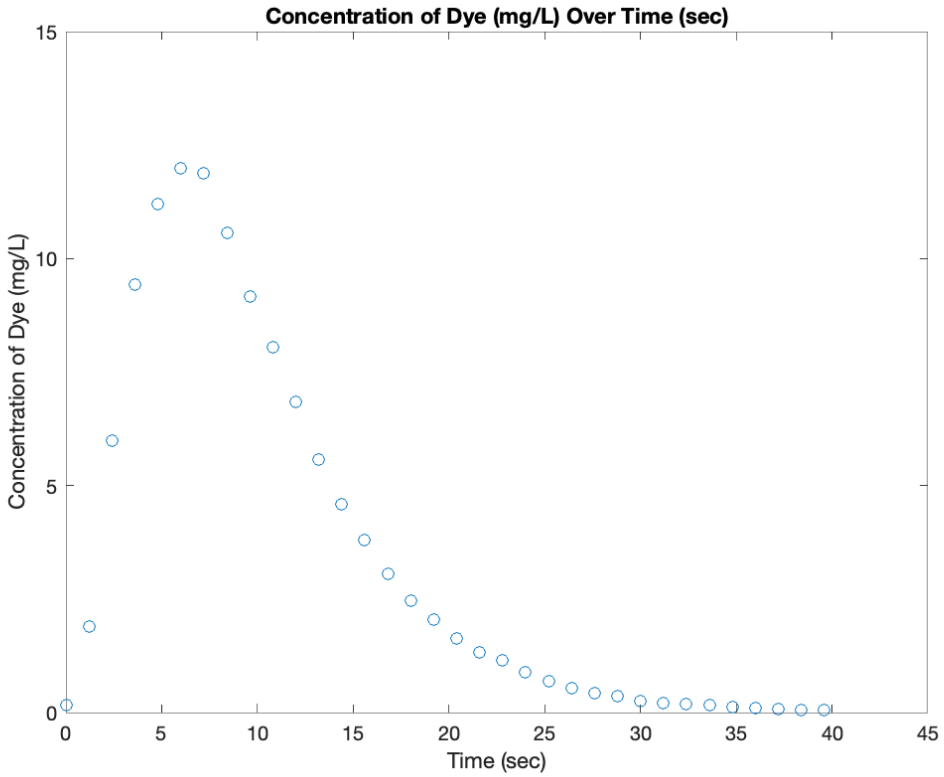
Kevin Shu
Homework 1 Report Summary
BME210, Prof. Kay

```
plot(dye(2:end,1), dye(2:end,2), 'o')
ylim([0 15]);
xlim([0.0 45.0]);
xlabel('Time (sec)');
ylabel('Concentration of Dye (mg/L)');
title('Concentration of Dye (mg/L) Over Time (sec)');

%outputting all of the calculated information
fprintf('Rectangular approximation: %.4f mg-sec/L\n', rectangular);
fprintf('Trapezoidal approximation: %.4f mg-sec/L\n', trapezoidal);
fprintf('Simpson''s rule approximation: %.4f mg-sec/L\n', Simpsons);
fprintf('Cardiac output using rectangular approximation: %.4f L/min\n', Qr);
fprintf('Cardiac output using trapezoidal approximation: %.4f L/min\n', Qt);
fprintf('Cardiac output using Simpson''s approximation: %.4f L/min\n\n', Qs);
```

Part 3: Run of Cardiac Output Program

Rectangular approximation: 140.1960 mg-sec/L
Trapezoidal approximation: 140.1300 mg-sec/L
Simpson's rule approximation: 140.1140 mg-sec/L
Cardiac output using rectangular approximation: 5.8129 L/min
Cardiac output using trapezoidal approximation: 5.8156 L/min
Cardiac output using Simpson's approximation: 5.8163 L/min

Kevin Shu
Homework 1 Report Summary
BME210, Prof. Kay



Error that could occur due to the code may be that the approximation of the area underneath the curve disproportionately, making it somewhat inaccurate in measuring the accumulation of concentration going through the heart. In terms of error occurring simply due to Dye Dilution, the assumption that the cardiac output of the patient is constant, can be easily be disputed when used practically, so only the approximate *average* cardiac output can be calculated at best with possibly significantly skewed data. Additionally, the diffusion of the dye is entirely random, so random error is inherent to the calculations.

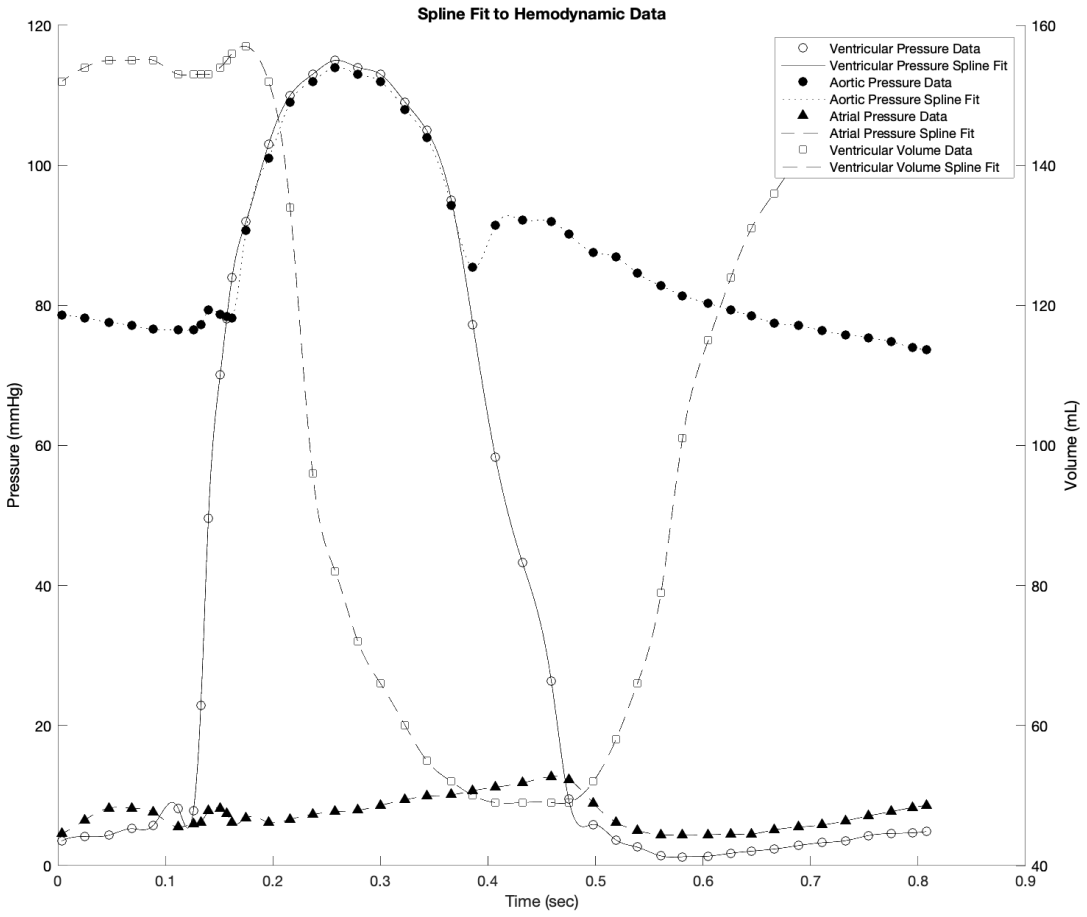
Part 4: Spline Fit to Hemodynamic Data

```
clear; clc; close all;
hemoData = importdata('HemodynamicData.txt');

time = hemoData(:,2); %seconds
lvP = hemoData(:,3); %mmHg Left Ventricular Pressure
aortaP = hemoData(:,4); %mmHg Aortic Pressure
lvV = hemoData(:, 5); %mL Left Ventricular Volume
laP = hemoData(:, 6); %mmHg Left Atrial Pressure

timeSteps = time(1):0.0001:time(end); %making the more dense x values
```

Kevin Shu
Homework 1 Report Summary
BME210, Prof. Kay

```
%Calculating all of the spline approximations
splineLvP = spline(time, lvP, timeSteps);
splineAortaP = spline(time, aortaP, timeSteps);
splineLvV = spline(time, lvV, timeSteps);
splineLaP = spline(time, laP, timeSteps);

%making sure everything including the axes are black.
fig = figure;
leftColor = [0 0 0];
rightColor = [0 0 0];
set(fig, 'defaultAxesColorOrder', [leftColor; rightColor]);

yyaxis left %making the pressure axis.
hold on;
title('Spline Fit to Hemodynamic Data');
ylabel('Pressure (mmHg)');
xlabel('Time (sec)');
plot(time, lvP, 'o k');
plot(timeSteps, splineLvP,'-k');
plot(time, aortaP, 'o', 'MarkerFaceColor', 'k');
plot(timeSteps, splineAortaP, ': k');
plot(time, laP, '^', 'MarkerFaceColor', 'k');
plot(timeSteps, splineLaP, '-- k');

yyaxis right %making the volume axis.
hold on;
plot(time, lvV, 's k');
plot(timeSteps, splineLvV, '-- k');
ylabel('Volume (mL)');

legend('Ventricular Pressure Data', 'Ventricular Pressure Spline Fit', 'Aortic Pressure Data', 'Aortic
Pressure Spline Fit', 'Atrial Pressure Data', 'Atrial Pressure Spline Fit', 'Ventricular Volume Data',
'Ventricular Volume Spline Fit');
```

Kevin Shu
Homework 1 Report Summary
BME210, Prof. Kay



1) The mitral valve closes when the left ventricular pressure exceeds the left atrial pressure. Therefore, the mitral valve closes right around the **0.1 second mark**.
2) The mitral valve opens when the left atrial pressure exceeds the left ventricular pressure. Therefore, the mitral valve opens right around the **0.48 second mark**.
3) The aortic valve closes when the aortic pressure exceeds the left ventricular pressure. Therefore, the aortic valve closes right around the **0.39 second mark**.
4) The aortic valve opens when the left ventricular pressure exceeds the aortic pressure. Therefore, the aortic valve opens right around the **0.15 second mark**.
5) The stroke volume is the amount of blood pumped out of the left ventricle in one contraction. Therefore, it would be the range of the left ventricular volume which is about **109 mL**.
6) The cardiac output is the stroke volume over the total time of systole and diastole, so it would be 109/0.808 mL/sec. Now to convert to L/min, divide that value by 1000 and multiply it by 60 to get **8.09 L/min**.
7) The systolic blood pressure is the pressure in the arteries when the heart is beating, so it would be at the height of the aortic pressure. Therefore, the systolic blood pressure is around **112 mmHg**.
8) The diastolic blood pressure is the pressure of the arteries in between beats. Therefore, the diastolic pressure is when the aortic pressure is at a resting state or around **79 mmHg**.