

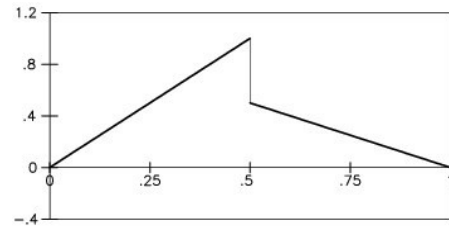
MAE502 Spring 2010 Homework #3

Prob. 1 (3 points)

(a) Given the function defined on the interval, $x \in [0,1]$,

$$f(x) = 2x, \quad 0 \leq x \leq 1/2$$

$$= 1 - x, \quad 1/2 < x \leq 1,$$



work out the Fourier Cosine series expansion,

$$F(x) \approx F_C(x) = \sum_{n=0}^{\infty} a_n \cos(n\pi x),$$

where $F(x)$ is the even extension of $f(x)$ and $F_C(x)$ denotes the Fourier Cosine series representation of $F(x)$. A sketch of $f(x)$ is shown at right; Notice a discontinuity at $x = 1/2$.

(b) Plot the original $f(x)$ and its Fourier Cosine series representation, $F_C(x)$, truncated (inclusively) at $n = 5, 10,$ and 30 . Please collect all four curves in a single plot. What are the values of $F_C(x)$ at $x = 0.35$ for the three cases truncated at $n = 5, 10,$ and 30 ? Compare them to the exact value, $f(0.35)$, to determine the percentage error (using the exact value as denominator) for the three cases. Repeat the exercise for $x = 0.49$ (a point close to the discontinuity). Discuss the results.

(c) Find the analytic expression for the value of $F_C(x)$ at $x = 1/2$. Define $S(N)$ as the value of $F_C(1/2)$ calculated from the Fourier Cosine series truncated at $n = N$, plot $S(N)$ as a function of N for the range $1 \leq N \leq 30$. What value does $S(N)$ converge to at large N ?

Prob. 2 (4 points)

(a) Solve the two-dimensional wave equation

$$\frac{\partial^2 u}{\partial t^2} = \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2},$$

for $u(x, y, t)$ defined within the domain of $x \in [0,1], y \in [0,1],$ and $t \in [0, \infty),$ with the following boundary conditions

- (i) $u(0, y, t) = 0$
- (ii) $u(1, y, t) = 0$
- (iii) $u(x, 0, t) = 0$
- (iv) $u(x, 1, t) = 0$
- (v) $u(x, y, 0) = (x - x^2)[\sin(\pi y) + \sin(2\pi y)]$
- (vi) $u_t(x, y, 0) = 0$ (Note: $u_t \equiv \partial u / \partial t$).

(b) Plot the solution $u(x, y, t)$ at $t = 0$ (initial state), $0.3, 0.7,$ and 2.47 as contour/color maps. Discuss your results. You may recycle the relevant mathematical formulas that you used in HW2 Prob 2. No need to repeat the overlapping details.

Prob. 3 (3 points)

We have extensively used the orthogonality relation of eigenfunctions to construct the solutions for PDEs with a large class of boundary conditions. Yet, there is no guarantee that the eigenfunctions will be mutually orthogonal under all types of boundary conditions. To prepare for the upcoming discussion for Chapter 5, let us consider the following eigenvalue problem,

$$\frac{d^2 G}{dx^2} = c G \quad , \quad G(0) = 0 \quad , \quad G(1) = 1 .$$

(a) Determine the eigenvalues and the corresponding eigenfunctions of this problem.

Do consider all three possibilities with $c > 0$, $c = 0$, and $c < 0$. Are the eigenvalues discrete? (For instance, if the boundary conditions are replaced by the familiar $G(0) = 0$ and $G(1) = 0$, we would have $c = c_n = -n^2 \pi^2$ as the eigenvalues. In that case, the eigenvalues are discrete. A situation when the eigenvalues are not discrete is if all values within an interval, $A < c < B$, are valid eigenvalues. We call the interval a *continuum*, which contains *continuous eigenvalues*.)

(b) Plot the eigenfunctions, $G_c(x)$, that correspond to the eigenvalues $c = -1, -2, -3, 0, 1, 2$, and 3 . (It is useful to group the cases with $c = -1, -2, -3$ in one figure, and $c = 0, 1, 2$, and 3 in another.) You will find in Part (a) that all of these values of c are indeed valid eigenvalues.

(c) Do the eigenfunctions of this problem satisfy the orthogonality relation,

$$\int_0^1 G_p(x) G_q(x) dx = 0 \quad , \quad \text{if } p \neq q \quad ,$$

where $G_p(x)$ and $G_q(x)$ are two eigenfunctions that correspond to two distinctive eigenvalues p and q ? Please provide a concrete discussion to support your conclusion. Your answer should be more than just "yes" or "no". For example, in order to claim that two eigenfunctions are not mutually orthogonal, you may evaluate the above integral of $G_p(x)G_q(x)$ and show that it leads to a non-zero value even when $p \neq q$.