

Solving PDEs using Laplace Transforms, Chapter 15

Given a function $u(x, t)$ defined for all $t > 0$ and assumed to be bounded we can apply the Laplace transform in t considering x as a parameter.

$$L(u(x, t)) = \int_0^{\infty} e^{-st} u(x, t) dt \equiv U(x, s)$$

In applications to PDEs we need the following:

$$L(u_t(x, t)) = \int_0^{\infty} e^{-st} u_t(x, t) dt = e^{-st} u(x, t) \Big|_0^{\infty} + s \int_0^{\infty} e^{-st} u(x, t) dt = sU(x, s) - u(x, 0)$$

so we have

$$L(u_t(x, t)) = sU(x, s) - u(x, 0)$$

In exactly the same way we obtain

$$L(u_{tt}(x, t)) = s^2 U(x, s) - su(x, 0) - u_t(x, 0).$$

We also need the corresponding transforms of the x derivatives:

$$L(u_x(x, t)) = \int_0^{\infty} e^{-st} u_x(x, t) dt = U_x(x, s)$$

$$L(u_{xx}(x, t)) = \int_0^{\infty} e^{-st} u_{xx}(x, t) dt = U_{xx}(x, s)$$

Consider the following examples.

Example 1.

$$\frac{\partial u}{\partial x} + \frac{\partial u}{\partial t} = x, \quad x > 0, \quad t > 0,$$

with boundary and initial condition

$$u(0, t) = 0 \quad t > 0, \quad \text{and} \quad u(x, 0) = 0, \quad x > 0.$$

As above we use the notation $U(x, s) = L(u(x, t))(s)$ for the Laplace transform of u . Then applying the Laplace transform to this equation we have

$$\frac{dU}{dx}(x, s) + sU(x, s) - u(x, 0) = \frac{x}{s} \quad \Rightarrow \quad \frac{dU}{dx}(x, s) + sU(x, s) = \frac{x}{s}.$$

This is a constant coefficient first order ODE. We solve it by finding the integrating factor

$$\mu = e^{\int s dx} = e^{sx}$$

Thus we have

$$\frac{d}{dx} [e^{sx} U(x, s)] = e^{sx} \frac{x}{s}.$$

We integrate both sides to get

$$U(x, s) = \frac{e^{-sx}}{s} \left(\int e^{sx} x dx \right) + C e^{-sx}.$$

Solving Pdes Using Laplace Transforms Chapter 15

G Thomas



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