

In the chapter on first order differential equations we showed that the solution is analytic at ordinary points. One would guess that this remains true for higher order equations. Consider the second order equation

$$y'' + p(z)y' + q(z)y = 0,$$

where p and q are analytic at the origin.

$$p(z) = \sum_{n=0}^{\infty} p_n z^n, \quad \text{and} \quad q(z) = \sum_{n=0}^{\infty} q_n z^n$$

Assume that one of the solutions is not analytic at the origin and behaves like z^α at $z = 0$ where $\alpha \neq 0, 1, 2, \dots$. That is, we can approximate the solution with $w(z) = z^\alpha + o(z^\alpha)$. Let's substitute $w = z^\alpha + o(z^\alpha)$ into the differential equation and look at the lowest power of z in each of the terms.

$$[\alpha(\alpha - 1)z^{\alpha-2} + o(z^{\alpha-2})] + [\alpha z^{\alpha-1} + o(z^{\alpha-1})] \sum_{n=0}^{\infty} p_n z^n + [z^\alpha + o(z^\alpha)] \sum_{n=0}^{\infty} q_n z^n = 0.$$

We see that the solution could not possibly behave like z^α , $\alpha \neq 0, 1, 2, \dots$ because there is no term on the left to cancel out the $z^{\alpha-2}$ term. The terms on the left side could not add to zero.

You could also check that a solution could not possibly behave like $\log z$ at the origin. Though we will not prove it, if z_0 is an ordinary point of a homogeneous differential equation, then all the solutions are analytic at the point z_0 . Since the solution is analytic at z_0 we can expand it in a Taylor series.

Now we are prepared to answer our second question. From complex variables, we know that the radius of convergence of the Taylor series expansion of a function is the distance to the nearest singularity of that function. Since the solutions to a differential equation are analytic at ordinary points of the equation, the series expansion about an ordinary point will have a radius of convergence at least as large as the distance to the nearest singularity of the coefficient functions.

Example 25.1.2 Consider the equation

$$w'' + \frac{1}{\cos z} w' + z^2 w = 0.$$

Mathematical Methods For Engineers

ML Morrison



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