13. The Logistic Differential Equation

Suppose that P(t) describes the quantity of a population at time t. For example, P(t) could be the number of milligrams of bacteria in a particular beaker for a biology experiment, or P(t) could be the number of people in a particular country at a time t. A model of population growth tells plausible rules for how such a population changes over time. The simplest model of population growth is the **exponential model**, which assumes that there is a constant parameter r, called the **growth parameter**, such that

$$P'(t) = r P(t)$$

holds for all time t. This differential equation itself might be called the **exponential differential equation**, because its solution is

$$P(t) = P_0 e^{rt}$$

where $P_0 = P(0)$ is the initial population.

One noticeable feature of the exponential model is that, when r is positive, the population always grows larger and larger without any finite limit, as is seen in Figure 1. This kind of growth may be a good model for a new population of bacteria in a beaker, but it does not hold for a long time. It is easy to see that the equation would imply a population of bacteria that ultimately outgrew the beaker and even outgrew the planet earth, since the mass of the bacteria would ultimately exceed the mass of the earth. Such a model is therefore absurd to model a system for long periods of time. The fundamental difficulty is that the exponential differential equation ignores the fact that there are limits to resources needed for the population to grow. It ignores the needs for food, oxygen, and space; and it ignores the accumulation of waste products that inevitably arise.
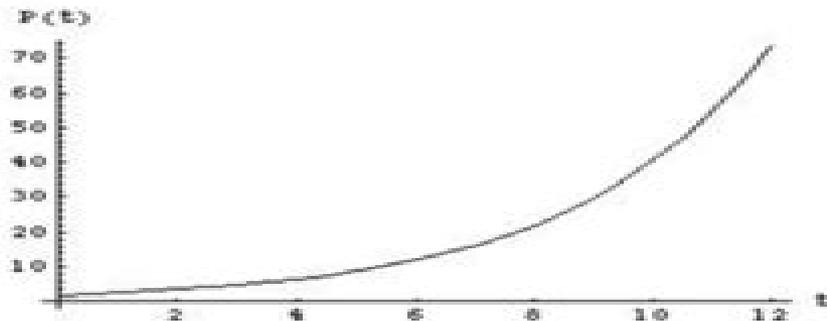

Figure1 : $P(t) = 2 e^{0.3t}$. This example of the exponential model shows a population growing always faster without any bound.

An alternative model was proposed by Verhulst in 1836 to allow for the fact that there are limits to growth in all known biological systems. He proposed what is now called the **logistic differential equation**. The equation involves two positive parameters. The first parameter r is again called the **growth parameter** and plays a role similar to that of r in the exponential differential equation. The second parameter K is called the **carrying capacity**. The logistic differential equation is written

$$P'(t) = r P(t) [1 - P(t)/K].$$

Equivalently, in terms of the d notation, the logistic differential equation is

$$dP/dt = r P [1 - P / K]$$

13 The Logistic Differential Equation

Louis A. Girifalco

13 The Logistic Differential Equation:

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Table of Contents 13 The Logistic Differential Equation

1. Understanding the eBook 13 The Logistic Differential Equation
    - The Rise of Digital Reading 13 The Logistic Differential Equation
    - Advantages of eBooks Over Traditional Books
2. Identifying 13 The Logistic Differential Equation
    - Exploring Different Genres
    - Considering Fiction vs. Non-Fiction
    - Determining Your Reading Goals
3. Choosing the Right eBook Platform
    - Popular eBook Platforms
    - Features to Look for in an 13 The Logistic Differential Equation
    - User-Friendly Interface
4. Exploring eBook Recommendations from 13 The Logistic Differential Equation
    - Personalized Recommendations
    - 13 The Logistic Differential Equation User Reviews and Ratings
    - 13 The Logistic Differential Equation and Bestseller Lists

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