

Line Integrals

In these notes we are primarily concerned with integrals over a plane curve C .

Multivariable Functions

We define the line integral $\int_C f \, ds$ of a multivariable function f in a similar manner to that of a standard 1D integral $\int_a^b f \, dx$ where we approximate the curve with small line segments and add up the areas of the resulting rectangles. Note that ds refers to a small increment in arc length. In practice, there is only one method of calculating this integral: we parameterize C by $\vec{r}(t) = \langle x(t), y(t) \rangle$, $a \leq t \leq b$ and then calculate $\int_C f \, ds = \int_a^b f(x(t), y(t)) |\vec{r}'(t)| \, dt$ where the speed $|\vec{r}'(t)|$ gives the change in arc length (see Chapter 13). This calculation does not depend on the particular parameterization chosen. We can also define a line integral where we consider the variation in one spatial coordinate at a time:

$$\int_C f \, dx = \int_a^b f(x(t), y(t)) x'(t) \, dt, \quad \int_C f \, dy = \int_a^b f(x(t), y(t)) y'(t) \, dt.$$

Example 1: If C is a wire with density function ρ , then the mass of the wire is given by $\int_C \rho \, ds$.

Vector Fields

For a vector field (VF) $\vec{F} = \langle P, Q \rangle$, we define the line integral $\int_C \vec{F} \cdot d\vec{r} = \int_C P \, dx + Q \, dy$ where P, Q are the multivariable function components of $\vec{F}$. As before, there is always the possibility of evaluating this integral using the parameterization C by $\vec{r}(t) = \langle x(t), y(t) \rangle$, $a \leq t \leq b$:

$$\int_C \vec{F} \cdot d\vec{r} = \int_a^b \vec{F}(x(t), y(t)) \cdot \vec{r}'(t) \, dt.$$

Since we are integrating the dot product of $\vec{F}$ and the direction vector $\vec{r}'(t)$, this will give us a measure of how much $\vec{F}$ and the curve ‘line up’ with each other, with a positive value if they are generally going in the same direction, a negative value if they are generally going in opposite directions, and zero if $\vec{F}$ is orthogonal to the curve or alternates direction with respect to it. We see therefore that the orientation of the curve C matters in this case, and that an opposite orientation will give an integral with opposite sign. We will see for vector fields, as opposed to the multivariable function case, there are potentially other ways to evaluate besides parameterizing and interesting theory at play.

Conservative Vector Fields

Recall that a vector field $\vec{F}$ is conservative if it is the gradient of some multivariable function f called the *potential*, i.e. $\vec{F} = \nabla f$. A potential is analogous to the antiderivative in 1D calculus, and so in this case we get a corresponding theorem of the Fundamental Theorem of Calculus (FTC) called the Fundamental Theorem of Line Integrals (FTLI):

$$\int_C \vec{F} \cdot d\vec{r} = f(\vec{b}) - f(\vec{a})$$

where the oriented curve C travels from the point $\vec{a}$ to the point $\vec{b}$ in the plane. From this theorem we see that the only part of the curve C that affects the value of the line integral are the endpoints $\vec{a}$ and $\vec{b}$, so any curve with the same endpoints will give the same value of the line integral. This property is called *path independence* and holds for all conservative VFs. In fact the converse is true, since for a path independent VF we can fix any point $\vec{a}$ in the plane and define a potential $f(\vec{x}) = \int_C \vec{F} \cdot d\vec{r}$ where C is any curve from $\vec{a}$ to $\vec{x}$. Thus a VF $\vec{F}$ is path independent $\iff \vec{F}$ is conservative.

A curve is *closed* if it starts and ends at the same point so that it makes a loop. Since for a closed curve $\vec{a} = \vec{b}$, by the FTLI $\int_C \vec{F} \cdot d\vec{r} = 0$ for any closed curve C and conservative VF $\vec{F}$. Having zero line integrals on closed curves is equivalent to path independence since if two curves C_1, C_2 start and end at the same point, then the curve C obtained by following C_1 forward then C_2 backwards is a loop, i.e.

$$0 = \int_C \vec{F} \cdot d\vec{r} = \int_{C_1} \vec{F} \cdot d\vec{r} - \int_{C_2} \vec{F} \cdot d\vec{r} \iff \int_{C_1} \vec{F} \cdot d\vec{r} = \int_{C_2} \vec{F} \cdot d\vec{r}.$$

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R Barnett



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Nuclear Science Abstracts ,1975 *Hearings* United States. Congress. House. Committee on Science and Astronautics,1964 **Integral Geometry and Tomography** Andrew Markoe,2006 This volume consists of a collection of papers that brings together fundamental research in Radon transforms integral geometry and tomography It grew out of the Special Session at a Sectional Meeting of the American Mathematical Society in 2004 The book contains very recent work of some of the top researchers in the field The articles in the book deal with the determination of properties of functions on a manifold by integral theoretic methods or by determining the geometric structure of subsets of a manifold by analytic methods Of particular concern are ways of reconstructing an unknown function from some of its projections Radon transforms were developed at the beginning of the twentieth century by researchers who were motivated by problems in differential geometry mathematical physics and partial differential equations Later medical applications of these transforms produced breakthroughs in imaging technology that resulted in the 1979 Nobel Prize in Physiology and Medicine for the development of computerized tomography Today the subject boasts substantial cross disciplinary interactions both in pure and applied mathematics as well as medicine engineering biology physics geosciences and industrial testing Therefore this volume should be of interest to a wide spectrum of researchers both in mathematics and in other fields **American Journal of Physics** ,1989 **Notices of the American Mathematical Society** American Mathematical Society,1978 Contains articles of significant interest to mathematicians including reports on current mathematical research

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