

Calculus III Running Notes

Points of Interest in Multivariable Functions

Finding POE(s): find x when $(f_x=0, f_y=0)$
End $D = f_{xx} \cdot f_{yy} - (f_{xy})^2$
Case 1: $D > 0, f_{xx} > 0, f(x, y) \rightarrow$ local min
Case 2: $D > 0, f_{xx} < 0, f(x, y) \rightarrow$ local max
Case 3: $D < 0, f(x, y) \rightarrow$ neither. $P(x, y)$ is saddle point, "if D is negative" and the graph crosses the tangent plane at (x, y)
Case 4: if $D = 0$, no information is given. The point (x, y) can be a local min, local max or a saddle point

Lagrange Multipliers

$\nabla f(x, y, z) = \lambda \nabla g(x, y, z) \quad g(x, y, z) = h$
 $f_x = \lambda g_x \quad f_y = \lambda g_y \quad f_z = \lambda g_z$

Triple Integrals

if f is continuous for the rectangular box $B = [a, b] \times [c, d] \times [e, f]$, then
 $\iiint_B f(x, y, z) \, dV = \int_c^f \int_a^b \int_e^d f(x, y, z) \, dz \, dy \, dx$
Type I plane region:
 $\iiint f(x, y, z) \, dV = \int_a^b \int_c^d \int_{h_1(x, y)}^{h_2(x, y)} f(x, y, z) \, dz \, dy \, dx$
Type II region:
 $\iiint f(x, y, z) \, dV = \int_c^d \int_a^b \int_{h_1(y, z)}^{h_2(y, z)} f(x, y, z) \, dx \, dy \, dz$

Double Integrals Over Rectangles

$$R = [a, b] \times [c, d] = \{(x, y) \in \mathbb{R}^2 \mid a \leq x \leq b, c \leq y \leq d\}$$

$$S = \{(x, y, z) \in \mathbb{R}^3 \mid 0 \leq z \leq f(x, y), (x, y) \in R\}$$

Definition:
 $\iint_R f(x, y) \, dA = \lim_{m, n \rightarrow \infty} \sum_{i=1}^m \sum_{j=1}^n f(x_i^*, y_j^*) \Delta A$

Iterated Integrals
 $\iint_R f(x, y) \, dA = \int_a^b \left[\int_c^d f(x, y) \, dy \right] dx$

Fubini's Theorem:
 if $R = \{(x, y) \mid a \leq x \leq b, c \leq y \leq d\}$ — must be continuous rectangle!

Then:
 $\iint_R f(x, y) \, dA = \int_a^b \int_c^d f(x, y) \, dy \, dx = \int_c^d \int_a^b f(x, y) \, dx \, dy$

Special Case:
 $\iint_R xy \, dA = \int_a^b \int_c^d xy \, dy \, dx$ where $R = [a, b] \times [c, d]$

Average value:
 $f_{avg} = \frac{1}{\text{Area } R} \iint_R f(x, y) \, dA$

Double Integrals over General Regions

Type I:
 $D = \{(x, y) \mid a \leq x \leq b, g_1(x) \leq y \leq g_2(x)\}$
 $\iint_D f(x, y) \, dA = \int_a^b \int_{g_1(x)}^{g_2(x)} f(x, y) \, dy \, dx$

Type II:
 $D = \{(x, y) \mid c \leq y \leq d, h_1(y) \leq x \leq h_2(y)\}$
 $\iint_D f(x, y) \, dA = \int_c^d \int_{h_1(y)}^{h_2(y)} f(x, y) \, dx \, dy$

Double Integrals in Polar Co-ordinates

$$\iint_D f(x, y) \, dA = \iint_D f(r \cos \theta, r \sin \theta) \cdot r \, dr \, d\theta$$

$(r \cos \theta)^2 + (r \sin \theta)^2 = r^2$
 $= r^2 \cos^2 \theta + r^2 \sin^2 \theta = r^2 (\cos^2 \theta + \sin^2 \theta) = r^2 \cdot 1 = r^2$

Applications of Double Integrals

$M(x, y) = \text{mass}$
 $m = \iint_R \rho(x, y) \, dA$
 $\bar{x} = \frac{1}{m} \iint_R x \rho(x, y) \, dA$
 $\bar{y} = \frac{1}{m} \iint_R y \rho(x, y) \, dA$

center of mass: $\bar{x} = \frac{1}{M} \iint_R x \rho(x, y) \, dA$
 $\bar{y} = \frac{1}{M} \iint_R y \rho(x, y) \, dA$
Moment of inertia: $I_x = \iint_R y^2 \rho(x, y) \, dA$
 $I_y = \iint_R x^2 \rho(x, y) \, dA$

Green's Theorem:

Let C be a positively oriented, piecewise smooth, simple closed curve in the plane D bounded by C . If P and Q have continuous partial derivatives on an open region that contains D , then:

$$\int_C P \, dx + Q \, dy = \iint_D \left(\frac{\partial Q}{\partial x} - \frac{\partial P}{\partial y} \right) \, dA$$

In a simple region:

$$\int_C P \, dx = \iint_D \frac{\partial P}{\partial y} \, dA$$

$$\int_C Q \, dy = \iint_D \frac{\partial Q}{\partial x} \, dA$$

for a counter-clockwise circle:
 $A = \oint_C x \, dy = - \oint_C y \, dx = \frac{1}{2} \oint_C x \, dy - y \, dx$

Extend:
 $\int_C P \, dx + Q \, dy = \iint_D \left(\frac{\partial Q}{\partial x} - \frac{\partial P}{\partial y} \right) \, dA$

Triple integrals in Cylindrical Co-ordinates

Cylindrical coordinate system:
 $x = r \cos \theta, y = r \sin \theta, z = z$
Rectangular to cylindrical coordinates:
 $r = \sqrt{x^2 + y^2}, \theta = \arctan \frac{y}{x}, z = z$
Combining with Triple Integral Equations:
 $\iiint_D f(x, y, z) \, dV = \int_a^b \int_c^d \int_{h_1(r, \theta)}^{h_2(r, \theta)} f(r \cos \theta, r \sin \theta, z) \cdot r \, dz \, dr \, d\theta$

Triple integrals in Spherical Co-ordinates

$\rho =$ ρ -radius $\theta =$ θ -polar angle $\phi =$ ϕ -azimuthal angle
Distance formula:
 $\rho^2 = x^2 + y^2 + z^2$
In triple integral formula:
 $\iiint_D f(x, y, z) \, dV = \int_a^b \int_c^d \int_{h_1(\rho, \theta, \phi)}^{h_2(\rho, \theta, \phi)} f(\rho \sin \theta \cos \phi, \rho \sin \theta \sin \phi, \rho \cos \theta) \cdot \rho^2 \sin \theta \, d\rho \, d\theta \, d\phi$

Vector Fields

A vector field is a function that maps points to vectors.
In \mathbb{R}^2 (plane):
 $\vec{F}(x, y) = P(x, y)\mathbf{i} + Q(x, y)\mathbf{j} = \langle P, Q \rangle$
In \mathbb{R}^3 (space):
 $\vec{F}(x, y, z) = P(x, y, z)\mathbf{i} + Q(x, y, z)\mathbf{j} + R(x, y, z)\mathbf{k} = \langle P, Q, R \rangle$

Curl and Divergence

For $F = P\mathbf{i} + Q\mathbf{j} + R\mathbf{k}$:
 $\text{curl } F = \left(\frac{\partial R}{\partial y} - \frac{\partial Q}{\partial z} \right)\mathbf{i} + \left(\frac{\partial P}{\partial z} - \frac{\partial R}{\partial x} \right)\mathbf{j} + \left(\frac{\partial Q}{\partial x} - \frac{\partial P}{\partial y} \right)\mathbf{k}$
 $\nabla \cdot F = \left(\frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y} + \frac{\partial R}{\partial z} \right)$
 and $\text{curl } F = \nabla \times F$
 If F is a function of 3 variables that has continuous second order partial derivatives then $\text{curl } (\nabla \cdot F) = 0$
 $\text{curl } (\nabla \times F) = \nabla(\nabla \cdot F) - \nabla^2 F$

Surface Area:

Area:
 $A(S) = \iint_R \sqrt{f_x^2 + f_y^2 + 1} \, dA$

Line Integrals:

If f is defined on a smooth curve C given by $x = x(t), y = y(t), z = z(t)$ then the line integral along C is:

$$\int_C f(x, y, z) \, ds = \int_a^b f(x(t), y(t), z(t)) \sqrt{\left(\frac{dx}{dt} \right)^2 + \left(\frac{dy}{dt} \right)^2 + \left(\frac{dz}{dt} \right)^2} \, dt$$

Line integral with respect to Arc Length:
 $\int_C f(x, y, z) \, ds = \int_a^b f(x(t), y(t), z(t)) \sqrt{x'(t)^2 + y'(t)^2 + z'(t)^2} \, dt$

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

Vector representation of a line segment that starts at (x_1, y_1, z_1) and ends at (x_2, y_2, z_2) is given by:
 $\vec{r}(t) = (x_2 - x_1)t + x_1, (y_2 - y_1)t + y_1, (z_2 - z_1)t + z_1 \quad 0 \leq t \leq 1$

$$\int_C f(x, y, z) \, dz = \int_a^b f(x(t), y(t), z(t)) z'(t) \sqrt{x'(t)^2 + y'(t)^2 + z'(t)^2} \, dt$$

Line Integrals (Cont)

with respect to Arc Length:
 $\int_C f(x, y, z) \, ds = \int_a^b f(x(t), y(t), z(t)) \sqrt{x'(t)^2 + y'(t)^2 + z'(t)^2} \, dt$

$$\int_C f(x, y, z) \, dy = \int_a^b f(x(t), y(t), z(t)) y'(t) \sqrt{x'(t)^2 + y'(t)^2 + z'(t)^2} \, dt$$

$$W = \int_C f(x, y, z) \cdot T \, ds = \int_a^b f(x(t), y(t), z(t)) \cdot \langle x'(t), y'(t), z'(t) \rangle \sqrt{x'(t)^2 + y'(t)^2 + z'(t)^2} \, dt$$

$$W = \int_a^b [f(x(t), y(t), z(t)) \cdot (x'(t) \frac{dx}{dt} + y'(t) \frac{dy}{dt} + z'(t) \frac{dz}{dt})] \sqrt{x'(t)^2 + y'(t)^2 + z'(t)^2} \, dt$$

$$W = \int_a^b f(x(t), y(t), z(t)) \cdot (x'(t) \frac{dx}{dt} + y'(t) \frac{dy}{dt} + z'(t) \frac{dz}{dt}) \sqrt{x'(t)^2 + y'(t)^2 + z'(t)^2} \, dt$$

Fundamental Theorem of Line Integrals

$$\int_C \nabla f \cdot dr = f(x_2, y_2, z_2) - f(x_1, y_1, z_1)$$

if $\vec{F}(x, y, z) = \langle P(x, y, z), Q(x, y, z), R(x, y, z) \rangle$ is a conservative vector field:
 $\frac{\partial P}{\partial y} = \frac{\partial Q}{\partial x}$
 $\frac{\partial P}{\partial z} = \frac{\partial R}{\partial x}$
 $\frac{\partial Q}{\partial z} = \frac{\partial R}{\partial y}$

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Robert Burton



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Recommendations for a General Mathematical Sciences Program Mathematical Association of America. Committee on the Undergraduate Program in Mathematics, 1981

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Monthly Catalog of United States Government Publications, 1972

International Books in Print, 1990

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