

# MVC Notes

Alex Feng

February 2023

## 1 Vectors

$$\begin{aligned}u \times v &= \begin{vmatrix} i & j & k \\ u_1 & u_2 & u_3 \\ v_1 & v_2 & v_3 \end{vmatrix} = i \begin{vmatrix} u_2 & u_3 \\ v_2 & v_3 \end{vmatrix} - j \begin{vmatrix} u_1 & u_3 \\ v_1 & v_3 \end{vmatrix} + k \begin{vmatrix} u_1 & u_2 \\ v_1 & v_2 \end{vmatrix} \\ &= i(u_2v_3 - u_3v_2) - j(u_1v_3 - u_3v_1) + k(u_1v_2 - u_2v_1)\end{aligned}$$

$$\text{vector projection: } \text{proj}_v u = \frac{u \cdot v}{|v|} \hat{v}$$

$$\text{scalar projection: } |\text{proj}_v u| = \frac{u \cdot v}{|v|}$$

## 2 3D graphs

The distance  $d$  between a point  $Q$  and a line  $r = r_0 + tv$

$$d = \frac{|v \times \vec{PQ}|}{|v|}$$

where  $P$  is any point on the line and  $v$  is a vector parallel to the line. This makes sense since  $d = |\vec{PQ}| \sin \theta$

For a plane  $a(x - x_0) + b(y - y_0) + c(z - z_0) = 0$  the normal vector  $n = (a, b, c)$

## 2.1 Quadric Surfaces

$$\text{Ellipsoid: } \frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1$$

$$\text{Elliptic paraboloid: } z = \frac{x^2}{a^2} + \frac{y^2}{b^2}$$

$$\text{Hyperboloid of one sheet: } \frac{x^2}{a^2} + \frac{y^2}{b^2} - \frac{z^2}{c^2} = 1$$

$$\text{Hyperboloid of two sheets: } -\frac{x^2}{a^2} - \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1$$

$$\text{Elliptic cone } \frac{x^2}{a^2} + \frac{y^2}{b^2} = \frac{z^2}{c^2}$$

$$\text{Hyperbolic paraboloid: } z = \frac{x^2}{a^2} - \frac{y^2}{b^2}$$

## 3 Vector Valued Functions

$$\text{unit tangent vector: } \vec{T} = \frac{\vec{v}}{|\vec{v}|}$$

$$\text{principle unit vector: } \vec{N} = \frac{d\vec{T}/dt}{|d\vec{T}/dt|}$$

The principle unit vector is always perpendicular to the unit tangent vector, which makes sense since it points in the rate of change of the unit tangent vector, which can only change in direction, not length

$$\text{curvature: } \kappa = \left| \frac{d\vec{T}}{ds} \right| = \frac{1}{|\vec{v}|} \left| \frac{d\vec{T}}{dt} \right| = \frac{|\vec{v} \times \vec{a}|}{|\vec{v}|^3}$$

$$\text{components of acceleration: } \vec{a} = a_N \vec{N} + a_T \vec{T}$$

$$a_n = \kappa |\vec{v}|^2 = \frac{|\vec{v} \times \vec{a}|}{|\vec{v}|}$$

$$a_T = \frac{d^2s}{dt^2} = \frac{\vec{v} \cdot \vec{a}}{|\vec{v}|}$$

$$\text{unit binormal vector: } \vec{B} = \vec{T} \times \vec{N} = \frac{\vec{v} \times \vec{a}}{|\vec{v} \times \vec{a}|}$$

$$\text{torsion: } \tau = -\frac{d\vec{B}}{ds} \cdot \vec{N} = \frac{(\vec{v} \times \vec{a}) \cdot \vec{a}'}{|\vec{v} \times \vec{a}|^2} = \frac{(\vec{r}' \times \vec{r}'') \cdot \vec{r}'''}{|\vec{r}' \times \vec{r}''|^2}$$

## 4 Derivatives

Chain Rule for one independent variable:

$$\frac{dz}{dt} = \frac{\partial z}{\partial x} \frac{dx}{dt} + \frac{\partial z}{\partial y} \frac{dy}{dt}$$

Chain Rule for two independent variables:

$$\frac{\partial z}{\partial s} = \frac{\partial z}{\partial x} \frac{\partial x}{\partial s} + \frac{\partial z}{\partial y} \frac{\partial y}{\partial s}$$

$$\frac{\partial z}{\partial t} = \frac{\partial z}{\partial x} \frac{\partial x}{\partial t} + \frac{\partial z}{\partial y} \frac{\partial y}{\partial t}$$

Implicit Differentiation:

$$\frac{dy}{dx} = -\frac{F_x}{F_y}$$

Gradient in 3 dimensions:

For a function  $f(x, y, z)$ ,

$$\nabla f(x, y, z) = f_x \hat{i} + f_y \hat{j} + f_z \hat{k}$$

$\nabla f(x, y, z)$  will be perpendicular to the level surface (3D surface where the value of  $f(x, y, z)$  is constant).

Second Derivative Test:

For a function  $f(x, y)$ , the discriminant is

$$D(x, y) = \begin{vmatrix} f_{xx} & f_{xy} \\ f_{yx} & f_{yy} \end{vmatrix} = f_{xx}f_{yy} - (f_{xy})^2$$

When  $D(a, b) > 0$  then the surface has the same general behavior in all directions near  $(a, b)$  (use normal partial derivative to determine if it is min or max). There is a saddle point when  $D(a, b) < 0$ . The test is inconclusive when  $D(a, b) = 0$

Lagrange Multipliers:

For an objective function  $f(x, y, z)$  and constraint  $g(x, y, z) = 0$ , at a relative extrema  $(a, b, c)$  there exists a Lagrange Multiplier,  $\lambda$ , where

$$\nabla f(a, b, c) = \lambda \nabla g(a, b, c)$$

Intuitively, the relative extrema is located at a point where objective function surface and the constraint surface are tangent to each other. The gradient for both are orthogonal to the level surface (since it points to the next increasing level surface direction), so the two gradients must be parallel to each other and can be multiplied by a scalar to equal each other.

## 5 Integration

Polar Coordinates:

$$x = r \cos \theta, \quad y = r \sin \theta, \quad r^2 = x^2 + y^2$$

$$\iint_R f(x, y) dA = \int_{\alpha}^{\beta} \int_{g(\theta)}^{h(\theta)} f(r \cos \theta, r \sin \theta) r dr d\theta$$

Cylindrical Coordinates:

$$x = r \cos \theta, \quad y = r \sin \theta, \quad r^2 = x^2 + y^2, \quad z = z$$

$$\iiint_D f(x, y, z) dV = \int_{\alpha}^{\beta} \int_{g(\theta)}^{h(\theta)} \int_{G(r \cos \theta, r \sin \theta)}^{H(r \cos \theta, r \sin \theta)} f(r \cos \theta, r \sin \theta, z) r dz dr d\theta$$

Spherical Coordinates:

$$x = \rho \sin \phi \cos \theta, \quad y = \rho \sin \phi \sin \theta, \quad z = \rho \cos \phi, \quad \rho^2 = x^2 + y^2 + z^2$$

$$\iiint_D f(x, y, z) dV = \int_{\alpha}^{\beta} \int_a^b \int_{G(\phi, \theta)}^{H(\phi, \theta)} f(\rho \sin \phi \cos \theta, \rho \sin \phi \sin \theta, \rho \cos \phi) \rho^2 \sin \phi d\rho d\phi d\theta$$

Jacobian:

The Jacobian is the "u-sub" for integrating functions of multiple variables. It is convenient for simplifying the integrand (similar to single variable calculus), but it is also used to simplify the bounds of multivariable integrals.

For two independent variables,

$$J(u, v) = \frac{\partial(x, y)}{\partial(u, v)} = \begin{vmatrix} \frac{\partial x}{\partial u} & \frac{\partial x}{\partial v} \\ \frac{\partial y}{\partial u} & \frac{\partial y}{\partial v} \end{vmatrix} = \frac{\partial x}{\partial u} \frac{\partial y}{\partial v} - \frac{\partial x}{\partial v} \frac{\partial y}{\partial u}$$

$$\iint_R f(x, y) dA = \iint_S f(g(u, v), h(u, v)) |J(u, v)| dA$$

Where S is the region R transformed from the  $xy$ -plane to the  $uv$ -plane, and  $J(u, v)$  is the Jacobian for the transformation  $x = g(u, v), y = h(u, v)$ .

For three independent variables,

$$J(u, v, w) = \frac{\partial(x, y, z)}{\partial(u, v, w)} = \begin{vmatrix} \frac{\partial x}{\partial u} & \frac{\partial x}{\partial v} & \frac{\partial x}{\partial w} \\ \frac{\partial y}{\partial u} & \frac{\partial y}{\partial v} & \frac{\partial y}{\partial w} \\ \frac{\partial z}{\partial u} & \frac{\partial z}{\partial v} & \frac{\partial z}{\partial w} \end{vmatrix}$$

$$\iiint_D f(x, y, z) dV = \iiint_S f(g(u, v, w), h(u, v, w), p(u, v, w)) |J(u, v, w)| dV$$

Where S is the region D transformed from  $xyz$ -space to the  $uvw$ -space, and  $J(u, v, w)$  is the Jacobian for the transformation  $x = g(u, v, w), y = h(u, v, w), z = p(u, v, w)$ .