

Lecture 14: The Gauss Map in Local Coordinates

Prof. Weiqing Gu

Math 143:
Topics in Geometry

The Gauss Map in Local Coordinates

Defining Coordinates

Let $N = \frac{\mathbf{x}_u \wedge \mathbf{x}_v}{\|\mathbf{x}_u \wedge \mathbf{x}_v\|}$, and write

$$\|_p(\alpha') = e(u')^2 + 2fu'v' + g(v')^2.$$

The Gauss Map in Local Coordinates

Defining Coordinates

Let $N = \frac{\mathbf{x}_u \wedge \mathbf{x}_v}{\|\mathbf{x}_u \wedge \mathbf{x}_v\|}$, and write

$$I|_p(\alpha') = e(u')^2 + 2fu'v' + g(v')^2.$$

Then

$$dN \begin{pmatrix} u' \\ v' \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} u' \\ v' \end{pmatrix}, \quad \begin{pmatrix} a_{11} & a_{21} \\ a_{12} & a_{22} \end{pmatrix} = - \begin{pmatrix} e & f \\ f & g \end{pmatrix} \begin{pmatrix} E & F \\ F & G \end{pmatrix}^{-1}.$$

The Gauss Map in Local Coordinates

Defining Coordinates

Let $N = \frac{\mathbf{x}_u \wedge \mathbf{x}_v}{\|\mathbf{x}_u \wedge \mathbf{x}_v\|}$, and write

$$I|_p(\alpha') = e(u')^2 + 2fu'v' + g(v')^2.$$

Then

$$dN \begin{pmatrix} u' \\ v' \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} u' \\ v' \end{pmatrix}, \quad \begin{pmatrix} a_{11} & a_{21} \\ a_{12} & a_{22} \end{pmatrix} = - \begin{pmatrix} e & f \\ f & g \end{pmatrix} \begin{pmatrix} E & F \\ F & G \end{pmatrix}^{-1}.$$

That is,

$$a_{11} = \frac{fF - eG}{EG - F^2}, \quad a_{12} = \frac{gF - fG}{EG - F^2},$$
$$a_{21} = \frac{eF - fE}{EG - F^2}, \quad a_{22} = \frac{fF - gE}{EG - F^2}.$$

Curvature in Local Coordinates

Gaussian, Mean, and Principal Curvature

By definition, we have

$$K = \det(a_{ij}) = \frac{eg - f^2}{EG - F^2}$$

$$H = -\frac{1}{2}(a_{11} + a_{22}) = \frac{1}{2} \frac{eG - 2fF + gE}{EG - F^2}$$

$$k = H \pm \sqrt{H^2 - K}$$

Curvature in Local Coordinates

Gaussian, Mean, and Principal Curvature

By definition, we have

$$K = \det(a_{ij}) = \frac{eg - f^2}{EG - F^2}$$

$$H = -\frac{1}{2}(a_{11} + a_{22}) = \frac{1}{2} \frac{eG - 2fF + gE}{EG - F^2}$$

$$k = H \pm \sqrt{H^2 - K}$$

Remark

If a parametrization of a regular surface is such that $F = f = 0$, then the principal curvatures are given by e/E and g/G . In fact, in this case, the Gaussian and the mean curvatures are given by

$$K = \frac{eg}{EG}, \quad H = \frac{1}{2} \frac{eG + gE}{EG}.$$

Examples

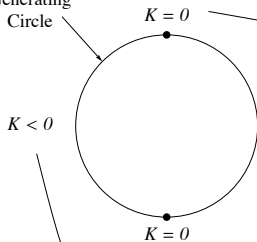
Example

We shall compute the Gaussian curvature of the points of the torus covered by the parametrization (with $0 < u < 2\pi, 0 < v < 2\pi$)

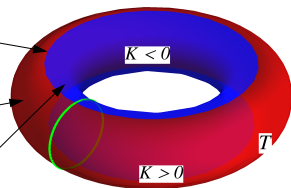
$$\mathbf{x}(u, v) = ((a + r \cos u) \cos v, (a + r \cos u) \sin v, r \sin u)$$

Rotation
Axis

Generating
Circle



$K > 0$



Examples

Example (Surfaces of Revolution)

Consider a surface of revolution parametrized by

$$\mathbf{x}(u, v) = (\varphi(v) \cos u, \varphi(v) \sin u, \psi(v)), \\ 0 < u < 2\pi, \quad a < v < b, \varphi(v) \neq 0.$$

Examples

Example (Surfaces of Revolution)

Consider a surface of revolution parametrized by

$$\mathbf{x}(u, v) = (\varphi(v) \cos u, \varphi(v) \sin u, \psi(v)), \\ 0 < u < 2\pi, \quad a < v < b, \varphi(v) \neq 0.$$

The coefficients of the first fundamental form are given by

$$E = \varphi^2, \quad F = 0, \quad G = (\varphi')^2 + (\psi')^2.$$

Examples

Example (Surfaces of Revolution)

Consider a surface of revolution parametrized by

$$\mathbf{x}(u, v) = (\varphi(v) \cos u, \varphi(v) \sin u, \psi(v)), \\ 0 < u < 2\pi, \quad a < v < b, \varphi(v) \neq 0.$$

The coefficients of the first fundamental form are given by

$$E = \varphi^2, \quad F = 0, \quad G = (\varphi')^2 + (\psi')^2.$$

It is convenient to assume that the rotating curve is parametrized by arc length, that is, that

$$(\varphi')^2 + (\psi')^2 = G = 1.$$

Examples

Example (cont'd)

Thus, we compute

$$K = -\frac{\psi'(\psi'\varphi'' - \psi''\varphi')}{\varphi} = -\frac{(\psi')^2\varphi'' + (\varphi')^2\varphi''}{\varphi} = -\frac{\varphi''}{\varphi},$$

$$H = \frac{1 - \psi' + \varphi(\psi'\varphi'' - \psi''\varphi')}{2\varphi},$$

$$\frac{e}{E} = -\frac{\psi'\varphi}{\varphi^2} = -\frac{\psi'}{\varphi},$$

$$\frac{g}{G} = \psi'\varphi'' - \psi''\varphi'.$$

Examples

Example

Very often a surface is given as the graph of a differentiable function $z = h(x, y)$, where (x, y) belong to an open set $U \subset \mathbb{R}^2$. In this case, the Gauss map is

$$N(x, y) = \frac{(-h_x, -h_y, 1)}{\sqrt{1 + h_x^2 + h_y^2}},$$

Examples

Example

Very often a surface is given as the graph of a differentiable function $z = h(x, y)$, where (x, y) belong to an open set $U \subset \mathbb{R}^2$. In this case, the Gauss map is

$$N(x, y) = \frac{(-h_x, -h_y, 1)}{\sqrt{1 + h_x^2 + h_y^2}},$$

the second fundamental form is given by

$$e = \frac{h_{xx}}{\sqrt{1 + h_x^2 + h_y^2}}, \quad f = \frac{h_{xy}}{\sqrt{1 + h_x^2 + h_y^2}}, \quad g = \frac{h_{yy}}{\sqrt{1 + h_x^2 + h_y^2}},$$

Examples

Example

Very often a surface is given as the graph of a differentiable function $z = h(x, y)$, where (x, y) belong to an open set $U \subset \mathbb{R}^2$. In this case, the Gauss map is

$$N(x, y) = \frac{(-h_x, -h_y, 1)}{\sqrt{1 + h_x^2 + h_y^2}},$$

the second fundamental form is given by

$$e = \frac{h_{xx}}{\sqrt{1 + h_x^2 + h_y^2}}, \quad f = \frac{h_{xy}}{\sqrt{1 + h_x^2 + h_y^2}}, \quad g = \frac{h_{yy}}{\sqrt{1 + h_x^2 + h_y^2}},$$

and the curvature is

$$K = \frac{h_{xx}h_{yy} - h_{xy}^2}{(1 + h_x^2 + h_y^2)^2}, \quad 2H = \frac{(1 + h_x^2)h_{yy} - 2h_xh_yh_{xy} + (1 + h_y^2)h_{xx}}{(1 + h_x^2 + h_y^2)^{3/2}}.$$

Graphs of Functions

Given a point p of a surface S , we can choose the coordinate axis of \mathbb{R}^3 so that the origin O of the coordinates is at p and the z axis is directed along the positive normal of S at p (thus, the xy plane agrees with $T_p(S)$). It follows that a neighborhood of p in S can be represented in the form $z = h(x, y)$, $(x, y) \in U \subset \mathbb{R}^2$, where U is an open set and h is a differentiable function with $h(0, 0) = h_x(0, 0) = h_y(0, 0) = 0$.

Graphs of Functions

Given a point p of a surface S , we can choose the coordinate axis of \mathbb{R}^3 so that the origin O of the coordinates is at p and the z axis is directed along the positive normal of S at p (thus, the xy plane agrees with $T_p(S)$). It follows that a neighborhood of p in S can be represented in the form $z = h(x, y)$, $(x, y) \in U \subset \mathbb{R}^2$, where U is an open set and h is a differentiable function with $h(0, 0) = h_x(0, 0) = h_y(0, 0) = 0$.

The second fundamental form of S at p applied to the vector $(x, y) \in \mathbb{R}^2$ becomes, in this case,

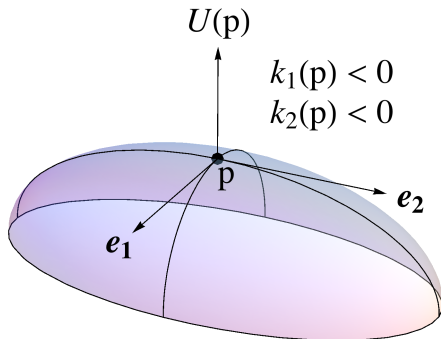
$$h_{xx}(0, 0)x^2 + 2h_{xy}(0, 0)xy + h_{yy}(0, 0)y^2.$$

In elementary calculus of two variables, the above quadratic form is known as the *Hessian* of h at $0, 0$. Thus, the Hessian of h at $(0, 0)$ is the second fundamental form of S at p .

The Sign of the Gaussian Curvature

Remark

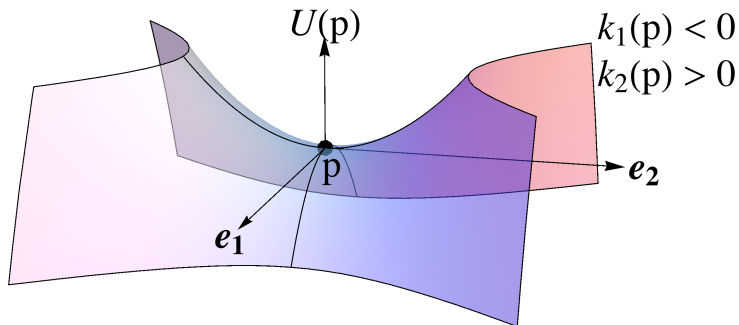
1. *Positive.* If $K(p) > 0$, then



The Sign of the Gaussian Curvature

Remark

2. *Negative.* If $K(p) < 0$, then



The Sign of the Gaussian Curvature

Remark

3. *Zero.* If $K(p) = 0$, then

(a) Only one principal curvature is zero, say

$$k_1(p) \neq 0, \quad k_2(p) = 0.$$

(b) Both principal curvatures are zero:

$$k_1(p) = k_2(p) = 0.$$

