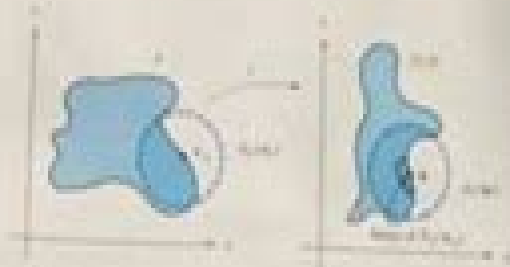


FIGURE 1.1.10 The geometry of the neighborhood of a point



To discuss the neighborhood of the origin, define δ as in Theorem 1.1.9 and use the following example.

example 1.2

Show that $\lim_{x \rightarrow 0} \sqrt{x^2 + 1} = 1$ using the ϵ - δ method.

solution

First, let $\epsilon = 1$. Then, $\sqrt{x^2 + 1} - 1 < 1$ implies $0 < \sqrt{x^2 + 1} < 2$, so $x^2 + 1 < 4$, or $x^2 < 3$. Thus, if $|x| < \sqrt{3}$, then $\sqrt{x^2 + 1} - 1 < 1$. Next, let $\epsilon < 1$. Then, $\sqrt{x^2 + 1} - 1 < \epsilon$ implies $\sqrt{x^2 + 1} < 1 + \epsilon$, or $x^2 + 1 < (1 + \epsilon)^2$, or $x^2 < 2\epsilon + \epsilon^2$. Thus, if $|x| < \sqrt{2\epsilon + \epsilon^2}$, then $\sqrt{x^2 + 1} - 1 < \epsilon$. Now, let $\delta = \min\{\sqrt{3}, \sqrt{2\epsilon + \epsilon^2}\}$. Then, if $|x| < \delta$, we have $\sqrt{x^2 + 1} - 1 < \epsilon$. This shows that $\lim_{x \rightarrow 0} \sqrt{x^2 + 1} = 1$. \square

example 1.3

Consider the function

$$f(x) = \frac{x^2 + 1}{x^2 + 2}$$

Even though f is not defined at 0, determine whether $\lim_{x \rightarrow 0} f(x)$ approaches some number as $x \rightarrow 0$ (approach 0). \square

solution

From our results earlier in §1.1, we know that

$$\lim_{x \rightarrow 0} \frac{x^2 + 1}{x^2 + 2} = 1$$

Thus, it is reasonable to guess that

$$\lim_{x \rightarrow 0} f(x) = \lim_{x \rightarrow 0} \frac{x^2 + 1}{x^2 + 2} = 1$$

Indeed, because $\lim_{x \rightarrow 0} (x^2 + 1) = 1$ and $\lim_{x \rightarrow 0} (x^2 + 2) = 2$, we are able to find $\delta > 0$ with $0 < \delta < 1$ such that $0 < |x| < \delta$ implies that $1 < x^2 + 1 < 2$ and $2 < x^2 + 2 < 3$. Thus $1 < (x^2 + 1)/(x^2 + 2) < 2/3$, and therefore

$$|f(x) - 1| = \left| \frac{x^2 + 1}{x^2 + 2} - 1 \right| < \frac{1}{3}$$



FIGURE 1.1.11 The surface $f(x, y) = x^2 + y^2$

Thus, $\lim_{x \rightarrow 0} f(x) = 1$. If we define $g(x) = x^2/(x^2 + 2)$, then $f(x) = g(x) + 1$. So $\lim_{x \rightarrow 0} g(x) = 0$. \square

example 1.4

Show that

$$\lim_{x \rightarrow 0} \frac{x^2}{x^2 + 1} = 0$$

solution

We want to show that $\lim_{x \rightarrow 0} \frac{x^2}{x^2 + 1} = 0$. For $\epsilon < 1$, we have $0 < \frac{x^2}{x^2 + 1} < \epsilon$ if and only if $x^2 < \epsilon$. Thus, if $|x| < \sqrt{\epsilon}$, then $\frac{x^2}{x^2 + 1} < \epsilon$. This shows that $\lim_{x \rightarrow 0} \frac{x^2}{x^2 + 1} = 0$. \square

$$\frac{x^2}{x^2 + 1} < \epsilon \iff \frac{x^2}{x^2 + 1} < \epsilon \iff x^2 < \epsilon(x^2 + 1) \iff x^2 < \epsilon x^2 + \epsilon \iff x^2(1 - \epsilon) < \epsilon \iff x^2 < \frac{\epsilon}{1 - \epsilon}$$

Thus, if $|x| < \sqrt{\frac{\epsilon}{1 - \epsilon}}$, then $\frac{x^2}{x^2 + 1} < \epsilon$. This shows that $\lim_{x \rightarrow 0} \frac{x^2}{x^2 + 1} = 0$. \square

$$\left| \frac{x^2}{x^2 + 1} - 0 \right| = \frac{x^2}{x^2 + 1} < \epsilon \iff x^2 < \epsilon(x^2 + 1) \iff x^2 < \epsilon x^2 + \epsilon \iff x^2(1 - \epsilon) < \epsilon \iff x^2 < \frac{\epsilon}{1 - \epsilon}$$

Thus, the conditions of Theorem 1.1.9 are satisfied and the limit is verified. \square

example 1.5

Show that

$$\lim_{x \rightarrow 0} \frac{x^2}{x^2 + 1} = 0$$

and $\lim_{x \rightarrow 0} \frac{x^2}{x^2 + 1} = 0$.

Use Theorem 1.1.10 to show that $\lim_{x \rightarrow 0} \frac{x^2}{x^2 + 1} = 0$.

$$\lim_{x \rightarrow 0} \frac{x^2}{x^2 + 1} = 0$$

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