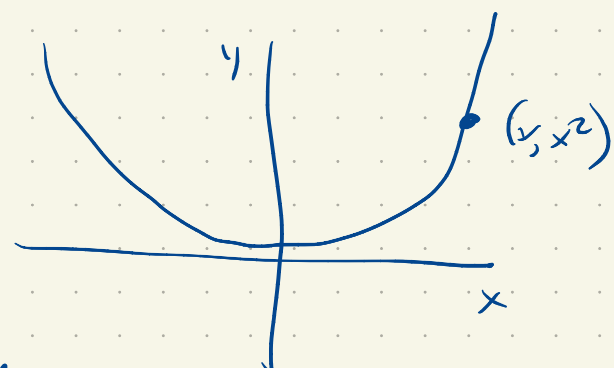
Let's visualize some functions of x, y.

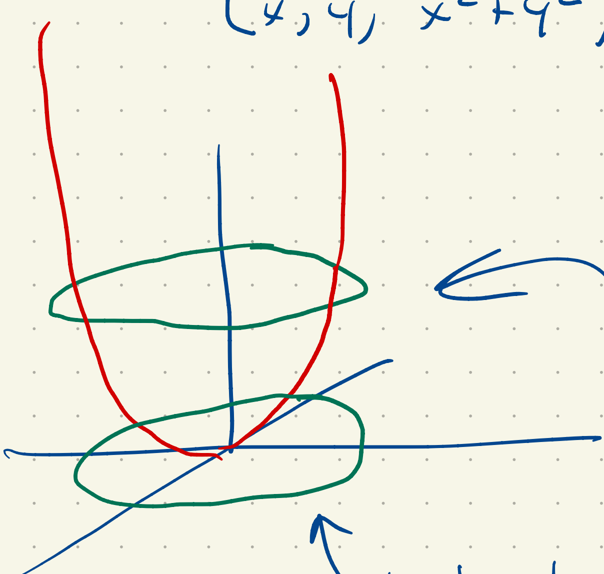
$f(x,y) = x^2 + y^2$



Graph: $(x, y, z = f(x,y))$

$(x, y = f(x))$ in old days

(x, y, x^2+y^2)



$z = x^2$ if $y = 0$

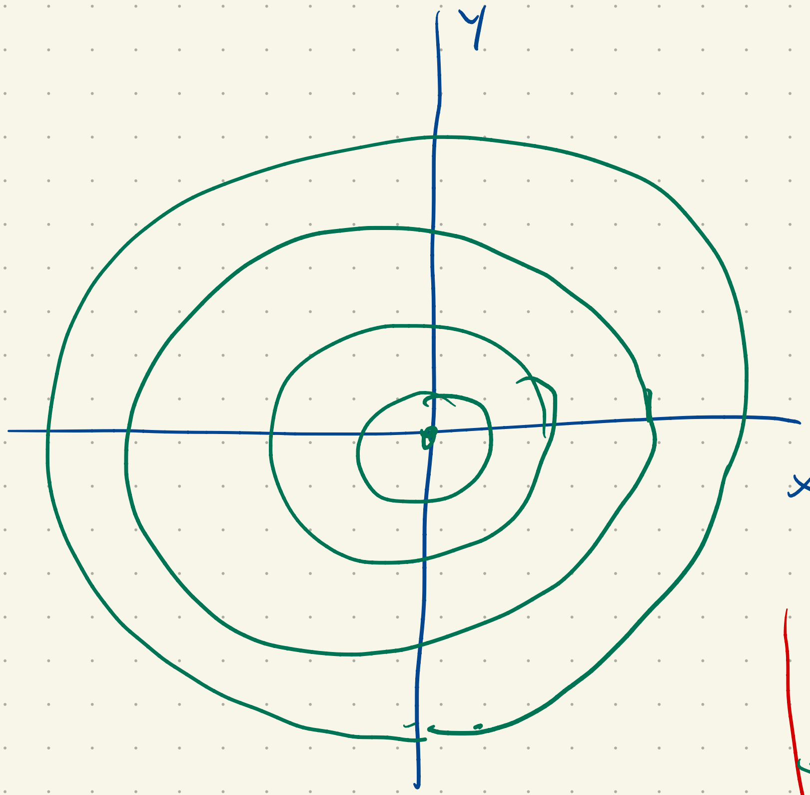
$z = y^2$ if $x = 0$

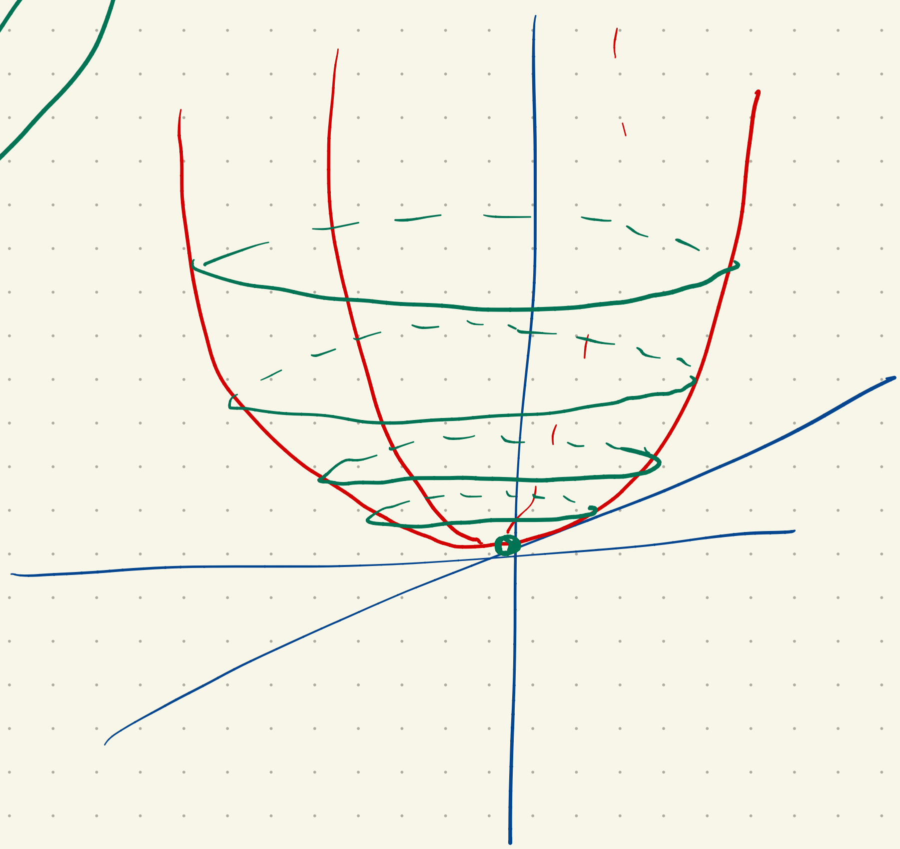
$\{(x,y) : x^2+y^2 = c\}$

$\hookrightarrow$ circle

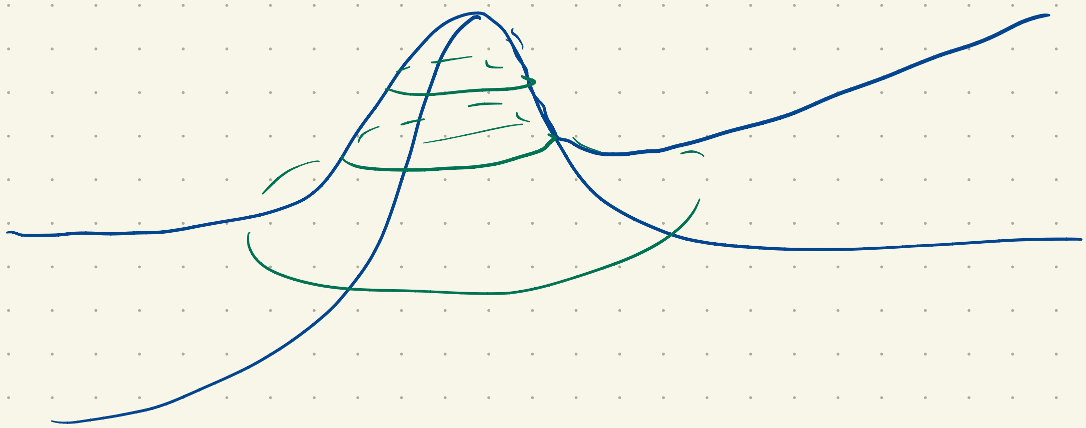
level set

Contour plot

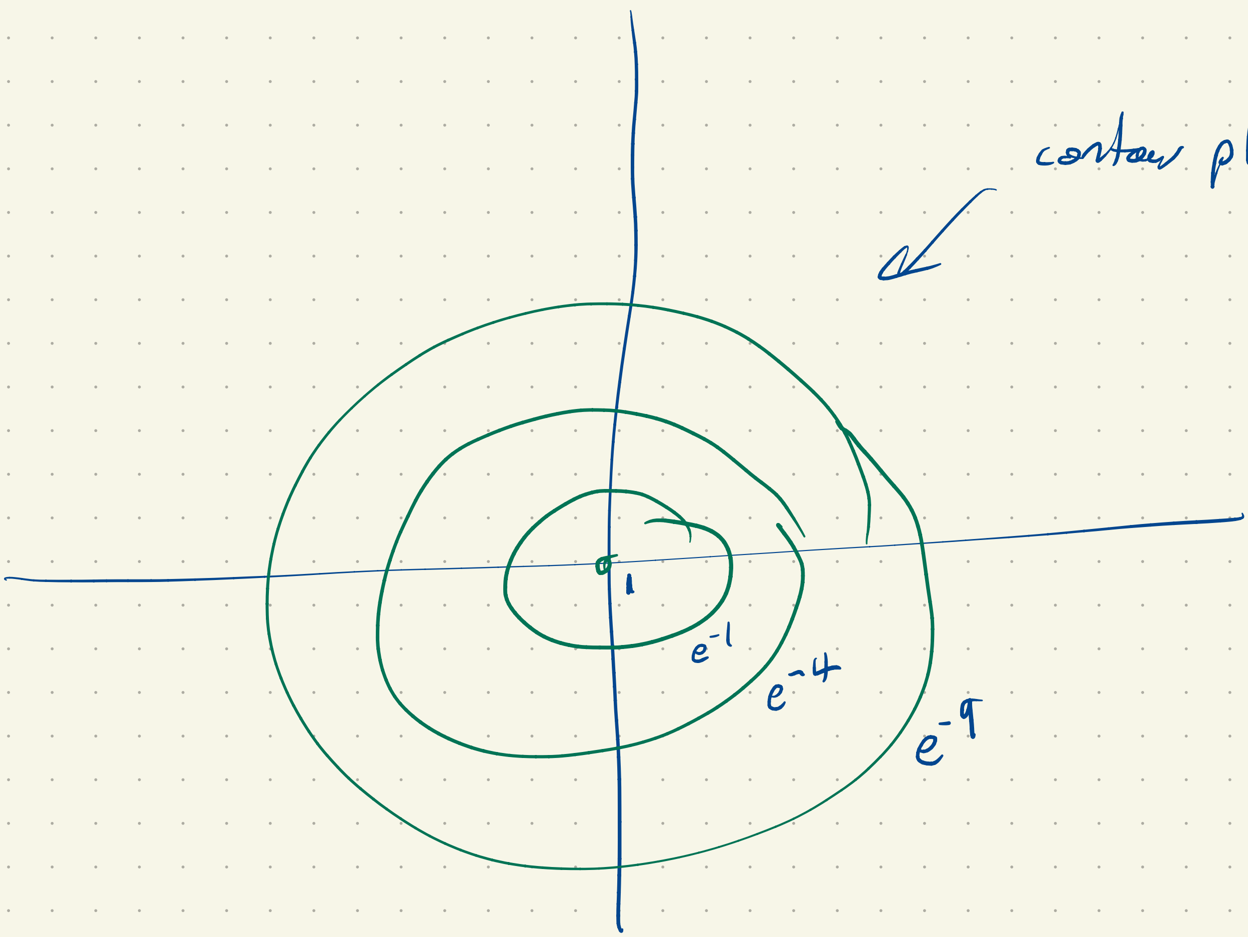




e.g. $\quad f(x,y) = \exp(-x^2-y^2)$



contour plot.

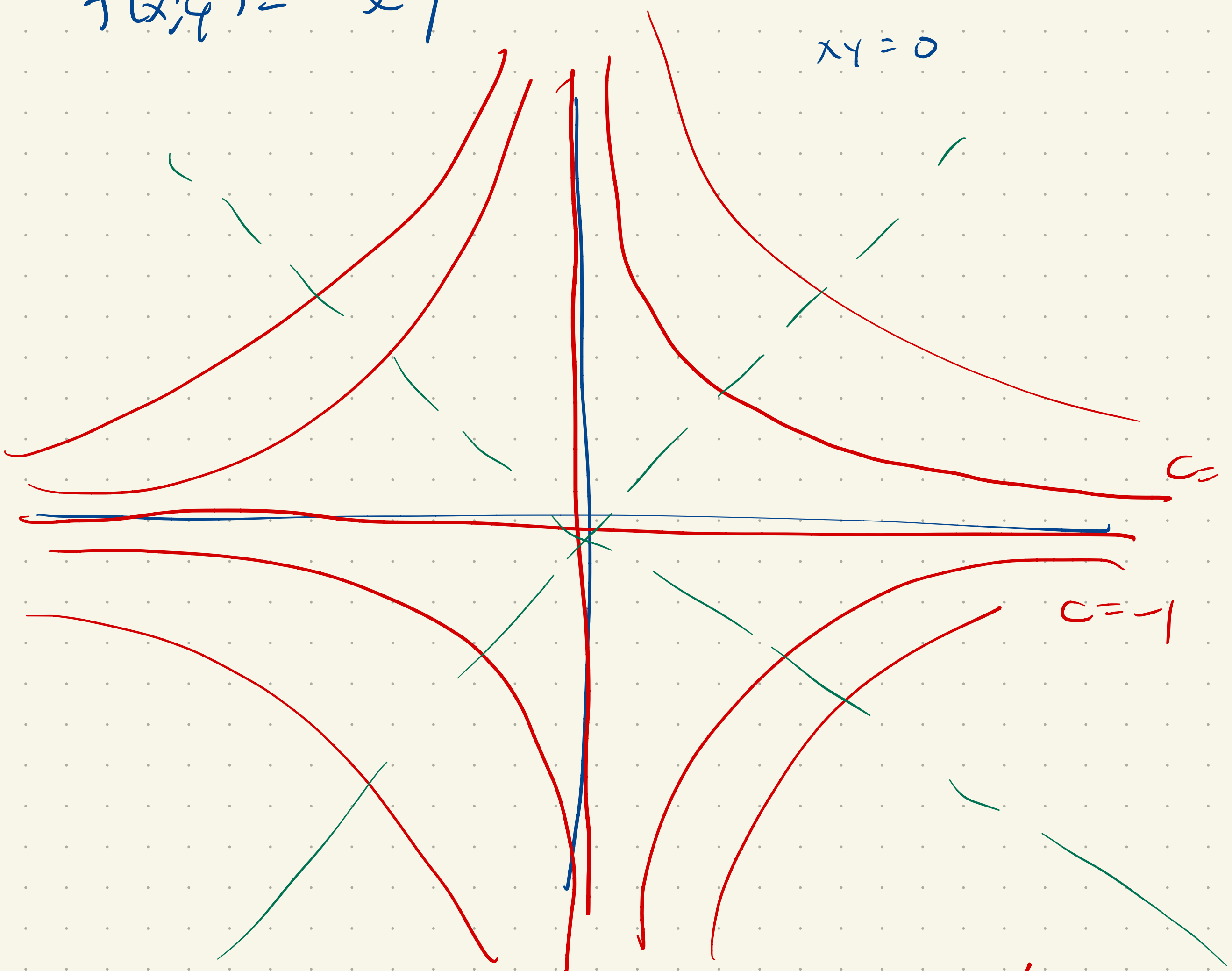


$xy = 1$

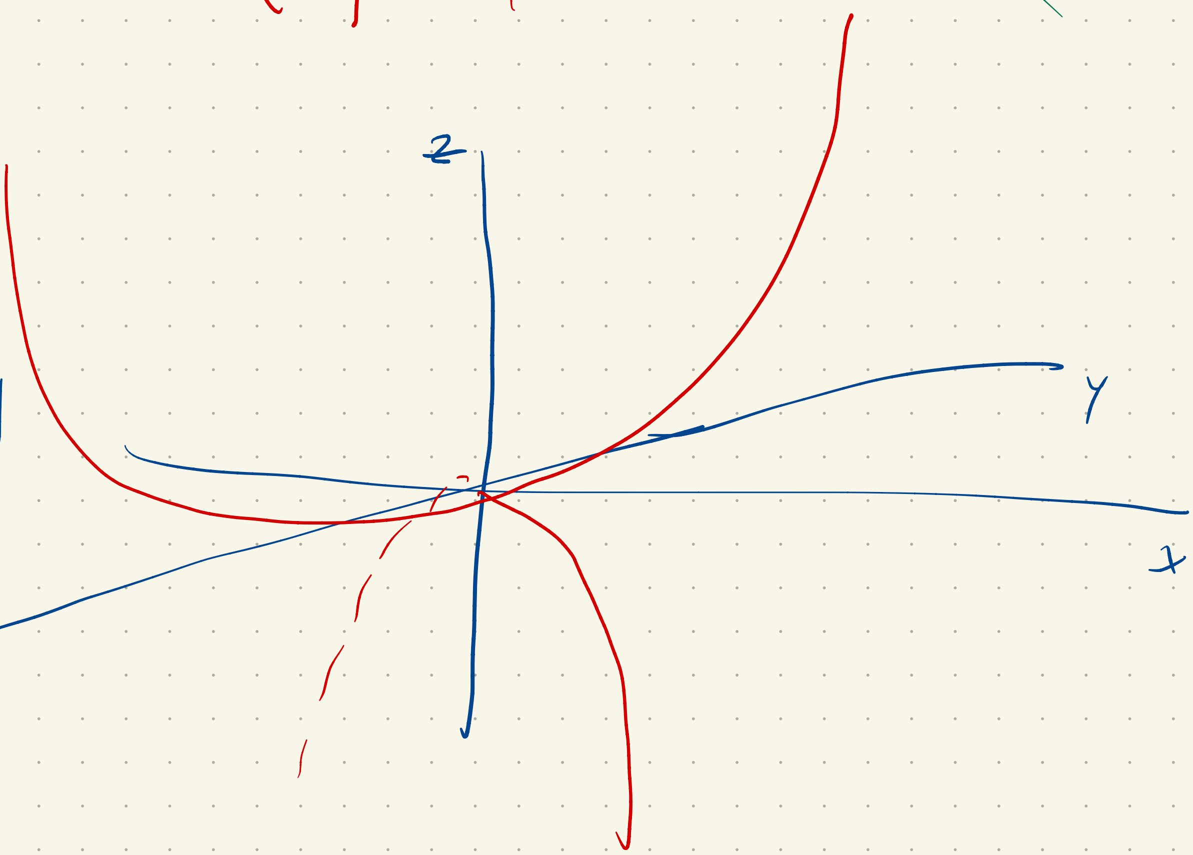
$xy = -1$ etc.

$f(x,y) = xy$

$xy = 0$



$z = xy$



We can also have functions of 3 variables. It's harder to graph them. (don't have the dims)

But we can still talk about level sets

$$F(x,y,z) = x^2+y^2+z^2$$

Level set r: sphere of radius r.

14.2 Limits, Continuity

Why do we care about limits? $\frac{0}{0}$ is the main suspect.

average rate of change $\frac{x(t+h)-x(t)}{h}$

but put $h=0$ $\frac{x(t)-x(t)}{0}$ $\frac{0}{0}$ oops!

We can still ask what happens as $h \to 0$

$\frac{\sin(x)}{x}$ not defined at $x=0$

But $\lim\limits_{x \to 0} \frac{\sin(x)}{x} = 1$ [Try it!]

We need limits to define derivatives of multivariable functions

so we might as well talk about

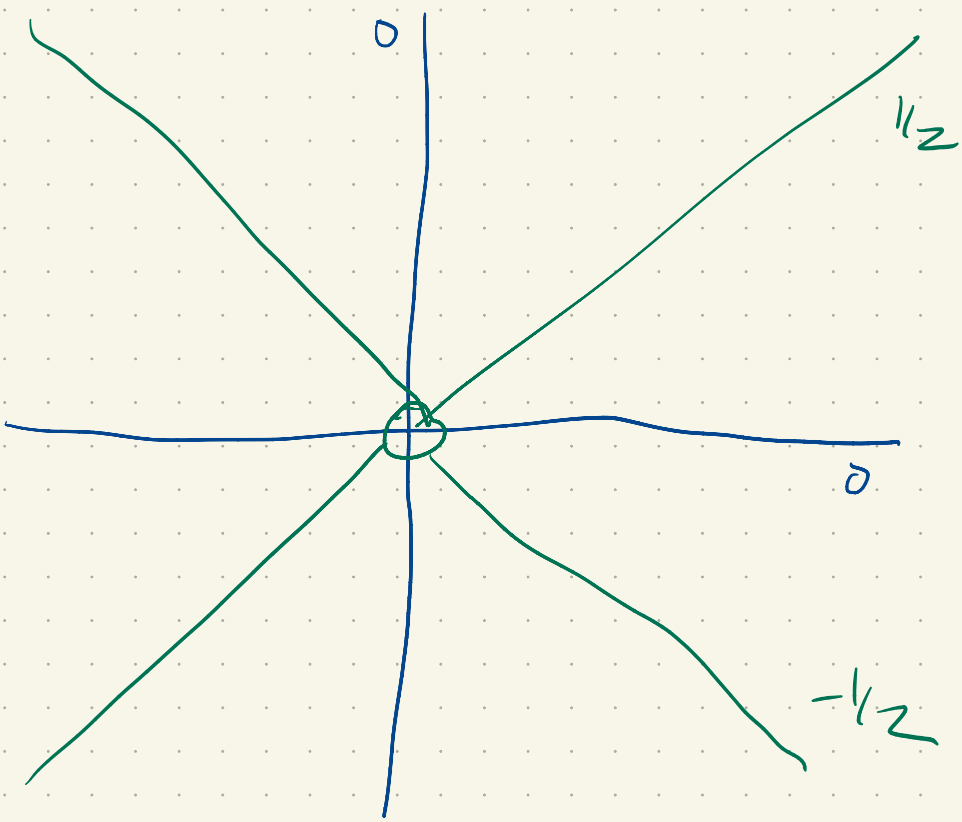
them now.

$f(x,y) = \dfrac{xy}{x^2+y^2}$ is a fun function.

$x=0, y=0$ $\quad \dfrac{0}{0}$, uh oh. not defined at $(0,0)$

We can still ask whether $\lim\limits_{(x,y)\to(0,0)} f(x,y)$ exists.

Contour plot:



$y = x \qquad \dfrac{x^2}{x^2+y^2} = \dfrac{1}{2}$

$y = -x \qquad \dfrac{-x^2}{x^2+y^2} = -\dfrac{1}{2}$

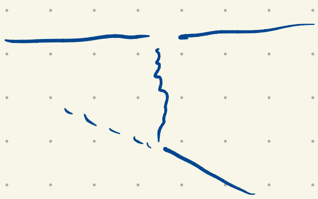
$x = \cos\theta \quad y = \sin\theta \qquad \dfrac{\sin\theta\cos\theta}{1} = \dfrac{1}{2}\sin 2\theta$

$x = r\cos\theta \quad y = r\sin\theta$ same! (does not depend on r)

MATLAB

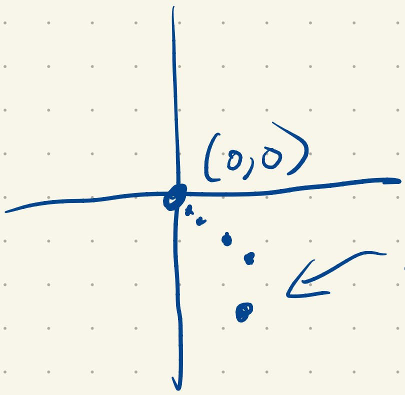
```
surf(XX, YY, XX.*YY./(XX.^2 + YY.^2))
```

Informal notion of limit



$$\lim_{(x,y)\to(0,0)} f(x,y) = L$$

means what?



sequence of inputs

(x_n, y_n)

$x_n \to 0$

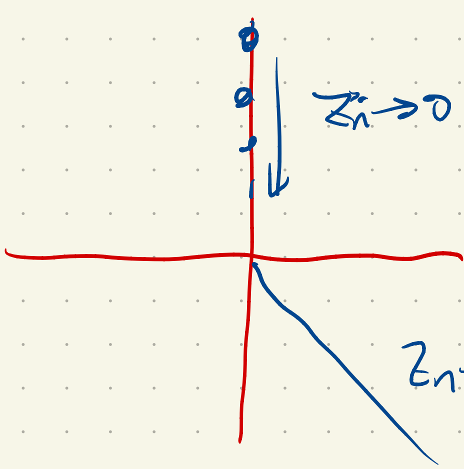
$y_n \to 0$

$z_n = f(x_n, y_n)$

$$\lim_{(x,y)\to(a,b)} f(x,y) = L$$

needs $z_n \to L$

$\boxed{\text{no matter what sequence you pick.}}$

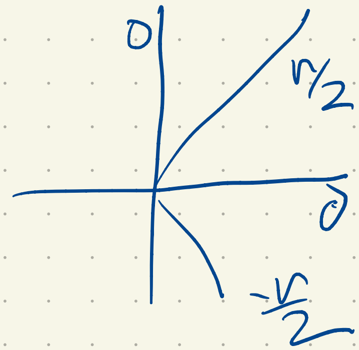


$z_n \to 0$

$z_n \to -\frac{1}{2}$

$\Rightarrow$ limit doesn't exist.

$$f(x,y) = \frac{xy}{\sqrt{x^2+y^2}} \qquad \frac{r\cos\theta\, r\sin\theta}{r} = r\sin(2\theta)$$



Still 0/0

$x_n \to 0 \qquad x_n^2 \to 0$ also

$y_n \to 0 \qquad y_n^2 \to 0$ also

$r_n = \sqrt{x_n^2+y_n^2} \to 0$ (continuity)

$$-r_n \leq f(x_n, y_n) \leq r_n$$

Squeeze theorem $\quad r_n \to 0 \quad \Rightarrow \quad f(x_n, y_n) \to 0.$

$-r_n \to 0$

Plot this in Matlab.

To show $\lim_{(x,y)\to(a,b)} f(x,y)$ does not exist, one

approach: find two sequences $x_n \to a$ $\hat{x}_n \to a$

$y_n \to b$ $\hat{y}_n \to b$

such that $z_n = f(x_n, y_n)$

$$\hat{z}_n = f(\hat{x}_n, \hat{y}_n)$$

$z_n \to L_1$ $\quad \hat{z}_n \to L_2$ $\quad L_1 \neq L_2$

e.g. $f(x,y) = \dfrac{xy^2}{x^2+y^4}$

$$f(x, mx) = \frac{x m^2 x^2}{x^2 + m^4 x^4} = \frac{x m^2}{1 + m^4 x^2} \longrightarrow 0$$

as $x \to 0$

$f\left(\frac{1}{n}, 0\right) = 0$ for all n.

$x = y^2$ $\qquad \dfrac{y^4}{y^4 + y^4} = \dfrac{1}{2} \quad (y \neq 0)$

$(x_n, y_n) = \left(\dfrac{1}{n^2}, \dfrac{1}{n} \right) \qquad f(x_n, y_n) = \dfrac{1}{2}$

Continuity:

We say $f(x,y)$ is cts at (a,b) if

$$\lim_{(x,y) \to (a,b)} f(x,y) = f(a,b).$$

$\boxed{\text{cts} \Rightarrow \text{continuous on all domain}}$

It's a question of approximation.

$(x_n, y_n) \to (a,b)$

$f(x_n, y_n) \to f(a,b)$

error in inputs small $\Rightarrow$ error in output small.

Continuous functions: (of x,y)

1) constants,

2) x

3) y

4) sums, products, differences of cts functions

$$f(x,y) = xy$$

$$f(x,y) = 1+xy$$

$$f(x,y) = 1+7xy$$

4') polynomials in x,y

5) old friends: sin, cos, ln, exp, arctan

on their domains

6) quotients $\dfrac{f(x,y)}{g(x,y)}$ on domain $\left(g(x,y) \neq 0 ! \right)$

7) rational functions $\dfrac{p(x,y)}{q(x,y)}$