



## 23. cvičení – Řetízkové pravidlo

<https://www2.karlin.mff.cuni.cz/~kuncova/vyuka.php>, [kuncova@karlin.mff.cuni.cz](mailto:kuncova@karlin.mff.cuni.cz)

### Příklady

1. Vypočtěte derivace složených funkcí

(a)  $z = u\sqrt{1+v^2}$ , kde  $u = e^{2x}$  a  $v = e^{-x}$

**Řešení:** Z řetízkového pravidla máme

$$\frac{\partial f}{\partial x} = \frac{\partial f}{\partial u} \cdot \frac{\partial u}{\partial x} + \frac{\partial f}{\partial v} \cdot \frac{\partial v}{\partial x}$$

Tedy musíme nejprve spočítat

$$\begin{aligned}\frac{\partial f}{\partial u} &= \sqrt{1+v^2} \\ \frac{\partial f}{\partial v} &= u \cdot \frac{1}{2} \cdot \frac{2v}{\sqrt{1+v^2}} \\ \frac{\partial u}{\partial x} &= 2e^{2x} \\ \frac{\partial v}{\partial x} &= -e^{-x}\end{aligned}$$

Dosadíme

$$\begin{aligned}\frac{\partial f}{\partial x} &= \frac{\partial f}{\partial u} \cdot \frac{\partial u}{\partial x} + \frac{\partial f}{\partial v} \cdot \frac{\partial v}{\partial x} = \sqrt{1+v^2} \cdot 2e^{2x} + u \cdot \frac{1}{2} \cdot \frac{2v}{\sqrt{1+v^2}} \cdot (-e^{-x}) \\ &= \sqrt{1+e^{-2x}} \cdot 2e^{2x} + e^{2x} \cdot \frac{e^{-x}}{\sqrt{1+e^{-2x}}} \cdot (-e^{-x}) \\ &= \frac{2e^{2x}(1+e^{-2x}) - 1}{\sqrt{1+e^{-2x}}} \\ &= \frac{2e^{2x} + 1}{\sqrt{1+e^{-2x}}}\end{aligned}$$

(b)  $z = uv^2w^3$ , kde  $u = \sin x$ ,  $v = -\cos x$  a  $w = e^x$

**Řešení:** Z řetízkového pravidla máme

$$\frac{\partial f}{\partial x} = \frac{\partial f}{\partial u} \cdot \frac{\partial u}{\partial x} + \frac{\partial f}{\partial v} \cdot \frac{\partial v}{\partial x} + \frac{\partial f}{\partial w} \cdot \frac{\partial w}{\partial x}$$

Tedy musíme nejprve spočítat

$$\begin{aligned}\frac{\partial f}{\partial u} &= v^2 w^3 \\ \frac{\partial f}{\partial v} &= 2uvw^3 \\ \frac{\partial f}{\partial w} &= 3uv^2 w^2 \\ \frac{\partial u}{\partial x} &= \cos x \\ \frac{\partial v}{\partial x} &= \sin x \\ \frac{\partial w}{\partial x} &= e^x\end{aligned}$$

Dosadíme

$$\begin{aligned}\frac{\partial f}{\partial x} &= v^2 w^3 \cdot \cos x + 2uvw^3 \cdot \sin x + 3uv^2 w^2 \cdot e^x \\ &= \cos^2 x e^{3x} \cos x + 2 \sin x (-\cos x) e^{3x} \sin x + 3 \sin x \cos^2 x e^{2x} e^x \\ &= e^3 x \cos x (\cos^2 x - 2 \sin^2 x + 3 \sin x \cos x)\end{aligned}$$

(c)  $z = \sin u \cos v$ , kde  $u = (x - y)^2$  a  $v = x^2 - y^2$

**Řešení:** Z řetízkového pravidla máme

$$\begin{aligned}\frac{\partial f}{\partial x} &= \frac{\partial f}{\partial u} \cdot \frac{\partial u}{\partial x} + \frac{\partial f}{\partial v} \cdot \frac{\partial v}{\partial x} \\ \frac{\partial f}{\partial y} &= \frac{\partial f}{\partial u} \cdot \frac{\partial u}{\partial y} + \frac{\partial f}{\partial v} \cdot \frac{\partial v}{\partial y}\end{aligned}$$

Tedy musíme nejprve spočítat

$$\begin{aligned}\frac{\partial f}{\partial u} &= \cos u \cos v \\ \frac{\partial f}{\partial v} &= -\sin u \sin v \\ \frac{\partial u}{\partial x} &= 2(x - y) \\ \frac{\partial u}{\partial y} &= -2(x - y) \\ \frac{\partial v}{\partial x} &= 2x \\ \frac{\partial v}{\partial y} &= -2y\end{aligned}$$

Dosadíme

$$\begin{aligned}\frac{\partial f}{\partial x} &= \cos u \cos v \cdot 2(x - y) - \sin u \sin v \cdot 2x \\ &= \cos(x - y)^2 \cos(x^2 - y^2) \cdot 2(x - y) - \sin(x - y)^2 \sin(x^2 - y^2) \cdot 2x\end{aligned}$$

a

$$\begin{aligned}\frac{\partial f}{\partial y} &= \cos u \cos v \cdot (-2(x-y)) - \sin u \sin v \cdot (-2y) \\ &= -\cos(x-y)^2 \cos(x^2-y^2) \cdot 2(x-y) + \sin(x-y)^2 \sin(x^2-y^2) \cdot 2y\end{aligned}$$

(d)  $w = yz^2 - x^3$ , kde  $x = e^{r-t}$ ,  $y = \ln(r+2s+3t)$  a  $z = \sqrt{rs+t}$

**Řešení:** Z řetězkového pravidla máme

$$\begin{aligned}\frac{\partial f}{\partial r} &= \frac{\partial f}{\partial x} \cdot \frac{\partial x}{\partial r} + \frac{\partial f}{\partial y} \cdot \frac{\partial y}{\partial r} + \frac{\partial f}{\partial z} \cdot \frac{\partial z}{\partial r} \\ \frac{\partial f}{\partial s} &= \frac{\partial f}{\partial x} \cdot \frac{\partial x}{\partial s} + \frac{\partial f}{\partial y} \cdot \frac{\partial y}{\partial s} + \frac{\partial f}{\partial z} \cdot \frac{\partial z}{\partial s} \\ \frac{\partial f}{\partial t} &= \frac{\partial f}{\partial x} \cdot \frac{\partial x}{\partial t} + \frac{\partial f}{\partial y} \cdot \frac{\partial y}{\partial t} + \frac{\partial f}{\partial z} \cdot \frac{\partial z}{\partial t}\end{aligned}$$

Tedy musíme nejprve spočítat

$$\begin{aligned}\frac{\partial f}{\partial x} &= -3x^2 & \frac{\partial f}{\partial y} &= z^2 & \frac{\partial f}{\partial z} &= 2yz \\ \frac{\partial x}{\partial r} &= e^{r-t} & \frac{\partial x}{\partial s} &= 0 & \frac{\partial x}{\partial t} &= -e^{r-t} \\ \frac{\partial y}{\partial r} &= \frac{1}{r+2s+3t} & \frac{\partial y}{\partial s} &= \frac{2}{r+2s+3t} & \frac{\partial y}{\partial t} &= \frac{3}{r+2s+3t} \\ \frac{\partial z}{\partial r} &= \frac{s}{2\sqrt{rs+t}} & \frac{\partial z}{\partial s} &= \frac{r}{2\sqrt{rs+t}} & \frac{\partial z}{\partial t} &= \frac{1}{2\sqrt{rs+t}}\end{aligned}$$

Dosadíme

$$\begin{aligned}\frac{\partial f}{\partial r} &= -3x^2 e^{r-t} + z^2 \cdot \frac{1}{r+2s+3t} + 2yz \cdot \frac{s}{2\sqrt{rs+t}} \\ &= -3e^{2(r-t)} e^{r-t} + (rs+t) \cdot \frac{1}{r+2s+3t} + 2 \log(r+2s+3t) \sqrt{rs+t} \cdot \frac{s}{2\sqrt{rs+t}} \\ &= -3e^{3(r-t)} + \frac{rs+t}{r+2s+3t} + s \log(r+2s+3t)\end{aligned}$$

$$\begin{aligned}\frac{\partial f}{\partial s} &= -3x^2 \cdot 0 + z^2 \cdot \frac{2}{r+2s+3t} + 2yz \cdot \frac{r}{2\sqrt{rs+t}} \\ &= (rs+t) \cdot \frac{2}{r+2s+3t} + 2 \log(r+2s+3t) \sqrt{rs+t} \cdot \frac{r}{2\sqrt{rs+t}} \\ &= \frac{2(rs+t)}{r+2s+3t} + r \log(r+2s+3t)\end{aligned}$$

$$\begin{aligned}\frac{\partial f}{\partial t} &= -3x^2 (-e^{r-t}) + z^2 \cdot \frac{3}{r+2s+3t} + 2yz \cdot \frac{1}{2\sqrt{rs+t}} \\ &= -3e^{2(r-t)} (-e^{r-t}) + (rs+t) \cdot \frac{3}{r+2s+3t} + 2 \log(r+2s+3t) \sqrt{rs+t} \cdot \frac{1}{2\sqrt{rs+t}} \\ &= 3e^{3(r-t)} + \frac{3(rs+t)}{r+2s+3t} + \log(r+2s+3t)\end{aligned}$$

2. Spočítejte parciální derivace  $g(x, y) = f(x^2 + y^2)$ .

**Řešení:** Uvažujme funkci  $f(u)$ , kde  $u(x, y) = x^2 + y^2$ .

Z řetízkového pravidla máme

$$\begin{aligned}\frac{\partial g}{\partial x} &= \frac{\partial f}{\partial u} \cdot \frac{\partial u}{\partial x} = \frac{\partial f}{\partial u} \cdot 2x \\ \frac{\partial g}{\partial y} &= \frac{\partial f}{\partial u} \cdot \frac{\partial u}{\partial y} = \frac{\partial f}{\partial u} \cdot 2y\end{aligned}$$

3. Necht'  $f(x, y) = x^2 + 3y^2$ . Určete derivace  $f$  vzhledem k polárním souřadnicím.

Polární souřadnice:  $x = r \cos \alpha$ ,  $y = r \sin \alpha$ .

**Řešení:** Z řetízkového pravidla máme

$$\frac{\partial f}{\partial r} = \frac{\partial f}{\partial x} \cdot \frac{\partial x}{\partial r} + \frac{\partial f}{\partial y} \cdot \frac{\partial y}{\partial r} = 2x \cdot \cos \alpha + 6y \cdot \sin \alpha = 2r \cos \alpha \cos \alpha + 6r \sin \alpha \sin \alpha$$

a

$$\begin{aligned}\frac{\partial f}{\partial \alpha} &= \frac{\partial f}{\partial x} \cdot \frac{\partial x}{\partial \alpha} + \frac{\partial f}{\partial y} \cdot \frac{\partial y}{\partial \alpha} = 2x \cdot (-r \sin \alpha) + 6y \cdot r \cos \alpha \\ &= -2r^2 \cos \alpha \sin \alpha + 6r^2 \sin \alpha \cos \alpha = 4r^2 \cos \alpha \sin \alpha\end{aligned}$$

4. Necht'  $f(x, y) = e^{-(x^2+y^2)}$ . Určete derivace  $f$  vzhledem k polárním souřadnicím.

**Řešení:** Z řetízkového pravidla máme

$$\begin{aligned}\frac{\partial f}{\partial r} &= \frac{\partial f}{\partial x} \cdot \frac{\partial x}{\partial r} + \frac{\partial f}{\partial y} \cdot \frac{\partial y}{\partial r} = e^{-(x^2+y^2)}(-2x) \cdot \cos \alpha + e^{-(x^2+y^2)}(-2y) \cdot \sin \alpha \\ &= -e^{-r^2} 2r \cos^2 \alpha - e^{-r^2} 2r \sin^2 \alpha = -2r e^{-r^2}\end{aligned}$$

a

$$\begin{aligned}\frac{\partial f}{\partial \alpha} &= \frac{\partial f}{\partial x} \cdot \frac{\partial x}{\partial \alpha} + \frac{\partial f}{\partial y} \cdot \frac{\partial y}{\partial \alpha} = e^{-(x^2+y^2)}(-2x) \cdot (-r \sin \alpha) + e^{-(x^2+y^2)}(-2y) \cdot r \cos \alpha \\ &= e^{-r^2} 2r^2 \cos \alpha \sin \alpha - e^{-r^2} 2r^2 \cos \alpha \sin \alpha = 0\end{aligned}$$

5. Ukažte, že funkce  $F(x, y, z) = \frac{xy}{z} \ln x + x f\left(\frac{y}{x}, \frac{z}{x}\right)$  vyhovuje vztahu  $x \frac{\partial F}{\partial x} + y \frac{\partial F}{\partial y} + z \frac{\partial F}{\partial z} = F + \frac{xy}{z}$ .

**Řešení:** Uvažujme funkci  $f(u, v)$ , kde  $u(x, y, z) = \frac{y}{x}$  a  $v(x, y, z) = \frac{z}{x}$ .

Pak dle řetízkového pravidla je

$$\begin{aligned}\frac{\partial F}{\partial x} &= \frac{y}{z} \log x + \frac{xy}{z} \cdot \frac{1}{x} + f(u, v) + x \left( \frac{\partial f}{\partial u} \cdot \frac{\partial u}{\partial x} + \frac{\partial f}{\partial v} \cdot \frac{\partial v}{\partial x} \right) \\ &= \frac{y}{z} \log x + \frac{xy}{z} \cdot \frac{1}{x} + f(u, v) + x \left( \frac{\partial f}{\partial u} \cdot -\frac{y}{x^2} + \frac{\partial f}{\partial v} \cdot -\frac{z}{x^2} \right) \\ \frac{\partial F}{\partial y} &= \frac{x}{z} \log x + x \left( \frac{\partial f}{\partial u} \cdot \frac{\partial u}{\partial y} + \frac{\partial f}{\partial v} \cdot \frac{\partial v}{\partial y} \right) \\ &= \frac{x}{z} \log x + x \left( \frac{\partial f}{\partial u} \cdot \frac{1}{x} + \frac{\partial f}{\partial v} \cdot 0 \right) \\ \frac{\partial F}{\partial z} &= -\frac{xy}{z^2} \log x + x \left( \frac{\partial f}{\partial u} \cdot \frac{\partial u}{\partial z} + \frac{\partial f}{\partial v} \cdot \frac{\partial v}{\partial z} \right) \\ &= -\frac{xy}{z^2} \log x + x \left( \frac{\partial f}{\partial u} \cdot 0 + \frac{\partial f}{\partial v} \cdot \frac{1}{x} \right)\end{aligned}$$

Dosadíme do zadaného vztahu:

$$\begin{aligned}&\left( \frac{xy}{z} \log x + \frac{xy}{z} + xf(u, v) - y \frac{\partial f}{\partial u} - z \frac{\partial f}{\partial v} \right) + \left( \frac{yx}{z} \log x + y \frac{\partial f}{\partial u} \right) + \left( -\frac{xy}{z} \log x + z \frac{\partial f}{\partial v} \right) \\ &= \frac{xy}{z} \log x + \frac{xy}{z} + xf(u, v) = F + \frac{xy}{z}\end{aligned}$$

6. Necht  $g(x, y) = f(x + y, x - y)$ , spočítejte  $\frac{\partial^2 g}{\partial x \partial y}$  v bodě  $(a, b)$ .

**Řešení:** Uvažujme funkci  $f(u, v)$ , kde  $u(x, y) = x + y$ ,  $v(x, y) = x - y$ .

Z řetízkového pravidla máme

$$\frac{\partial g}{\partial y} = \frac{\partial f}{\partial u} \cdot \frac{\partial u}{\partial y} + \frac{\partial f}{\partial v} \cdot \frac{\partial v}{\partial y} = \frac{\partial f}{\partial u} \cdot 1 + \frac{\partial f}{\partial v} \cdot (-1).$$

Pak

$$\frac{\partial^2 g}{\partial x \partial y} = \frac{\partial}{\partial x} \left( \frac{\partial f}{\partial u} - \frac{\partial f}{\partial v} \right)$$

Označíme-li funkce  $h(u, v) = \frac{\partial f}{\partial u}$  a  $j(u, v) = \frac{\partial f}{\partial v}$ , máme z řetízkového pravidla

$$\begin{aligned}\frac{\partial^2 g}{\partial x \partial y} &= \frac{\partial h}{\partial u} \cdot \frac{\partial u}{\partial x} + \frac{\partial h}{\partial v} \cdot \frac{\partial v}{\partial x} - \left( \frac{\partial j}{\partial u} \cdot \frac{\partial u}{\partial x} + \frac{\partial j}{\partial v} \cdot \frac{\partial v}{\partial x} \right) \\ &= \frac{\partial h}{\partial u} \cdot 1 + \frac{\partial h}{\partial v} \cdot 1 - \left( \frac{\partial j}{\partial u} \cdot 1 + \frac{\partial j}{\partial v} \cdot 1 \right) \\ &= \frac{\partial^2 f}{\partial u \partial u} + \frac{\partial^2 f}{\partial v \partial u} - \frac{\partial^2 f}{\partial u \partial v} - \frac{\partial^2 f}{\partial v \partial v}\end{aligned}$$

Protože jsou splněny předpoklady, tak máme záměnné 2. smíšené parciální derivace.

Tedy

$$\frac{\partial^2 g}{\partial x \partial y} = \frac{\partial^2 f}{\partial u \partial u} - \frac{\partial^2 f}{\partial v \partial v}$$

V konkrétním bodě  $(a, b)$  pak platí

$$\frac{\partial^2 g}{\partial x \partial y}(a, b) = \frac{\partial^2 f}{\partial u \partial u}(a + b, a - b) - \frac{\partial^2 f}{\partial v \partial v}(a + b, a - b)$$

7. Ukažte, že funkce  $F(x, y) = xf(x+y) + yg(x+y)$  vyhovuje rovnici  $\frac{\partial^2 F}{\partial x^2} - 2\frac{\partial^2 F}{\partial x \partial y} + \frac{\partial^2 F}{\partial y^2} = 0$ .

**Řešení:** Uvažujme funkce  $f(u)$  a  $g(u)$ , kde  $u(x, y) = x + y$ . Dále označme  $\frac{\partial f}{\partial u} = f'$  a  $\frac{\partial g}{\partial u} = g'$ . Z řetízkového pravidla je

$$\frac{\partial F}{\partial x} = f + xf' \cdot \frac{\partial u}{\partial x} + yg' \cdot \frac{\partial u}{\partial x} = f + xf' + yg'$$

a

$$\frac{\partial F}{\partial y} = xf' \cdot \frac{\partial u}{\partial y} + g + yg' \cdot \frac{\partial u}{\partial y} = xf' + g + yg'$$

Analogicky pak

$$\frac{\partial^2 F}{\partial x^2} = f' + f' + xf'' + yg''$$

$$\frac{\partial^2 F}{\partial y^2} = xf'' + g' + g' + yg''$$

$$\frac{\partial^2 F}{\partial x \partial y} = f' + xf'' + g' + yg''$$

Po dosazení do rovnice je

$$f' + f' + xf'' + yg'' - 2(f' + xf'' + g' + yg'') + xf'' + g' + g' + yg'' = 0$$

8. Výraz  $x\frac{\partial^2 f}{\partial x^2} + y\frac{\partial^2 f}{\partial y \partial x}$  přetranformujte pro funkci  $F(u, v) = f(x, y)$ , kde  $u = y$  a  $v = y/x$ .

**Řešení:** Aplikujeme řetízkové pravidlo

$$\frac{\partial f}{\partial x} = \frac{\partial F}{\partial u} \cdot \frac{\partial u}{\partial x} + \frac{\partial F}{\partial v} \cdot \frac{\partial v}{\partial x} = \frac{\partial F}{\partial v} \left(-\frac{y}{x^2}\right)$$

$$\begin{aligned} \frac{\partial^2 f}{\partial x^2} &= \frac{\partial}{\partial x} \left( \frac{\partial F}{\partial v} \left(-\frac{y}{x^2}\right) \right) = 2\frac{y}{x^3} \frac{\partial F}{\partial v} - \frac{y}{x^2} \left( \frac{\partial^2 F}{\partial u \partial v} \cdot \frac{\partial u}{\partial x} + \frac{\partial^2 F}{\partial v \partial v} \cdot \frac{\partial v}{\partial x} \right) \\ &= 2\frac{y}{x^3} \frac{\partial F}{\partial v} - \frac{y}{x^2} \left( \frac{\partial^2 F}{\partial v \partial v} \cdot -\frac{y}{x^2} \right) \end{aligned}$$

$$\begin{aligned} \frac{\partial^2 f}{\partial y \partial x} &= \frac{\partial}{\partial y} \left( \frac{\partial F}{\partial v} \left(-\frac{y}{x^2}\right) \right) = \frac{-1}{x^2} \frac{\partial F}{\partial v} - \frac{y}{x^2} \left( \frac{\partial^2 F}{\partial u \partial v} \cdot \frac{\partial u}{\partial y} + \frac{\partial^2 F}{\partial v \partial v} \cdot \frac{\partial v}{\partial y} \right) \\ &= \frac{-1}{x^2} \frac{\partial F}{\partial v} - \frac{y}{x^2} \left( \frac{\partial^2 F}{\partial u \partial v} \cdot 1 + \frac{\partial^2 F}{\partial v \partial v} \cdot \frac{1}{x} \right) \end{aligned}$$

Dosadíme

$$\begin{aligned} x\frac{\partial^2 f}{\partial x^2} + y\frac{\partial^2 f}{\partial y \partial x} &= x \left( 2\frac{y}{x^3} \frac{\partial F}{\partial v} - \frac{y}{x^2} \left( \frac{\partial^2 F}{\partial v \partial v} \cdot -\frac{y}{x^2} \right) \right) + y \left( \frac{-1}{x^2} \frac{\partial F}{\partial v} - \frac{y}{x^2} \left( \frac{\partial^2 F}{\partial u \partial v} \cdot 1 + \frac{\partial^2 F}{\partial v \partial v} \cdot \frac{1}{x} \right) \right) \\ &= \frac{y}{x^2} \frac{\partial F}{\partial v} - \frac{y^2}{x^2} \frac{\partial^2 F}{\partial u \partial v} \end{aligned}$$

Z předpisů pro  $u$  a  $v$  navíc máme  $x = \frac{u}{v}$ ,  $y = u$ .

Dohromady

$$\frac{y}{x^2} \frac{\partial F}{\partial v} - \frac{y^2}{x^2} \frac{\partial^2 F}{\partial u \partial v} = \frac{v^2}{u} \frac{\partial F}{\partial v} - v^2 \frac{\partial^2 F}{\partial u \partial v}$$

9. Necht'  $F = (F_1, F_2) : \mathbb{R}^3 \rightarrow \mathbb{R}^2$  je zobrazení definované předpisem

$$F(x, y, z) = ((x + 1)^2(y + 1)(z + 2), \sin x \cos(2y + z)).$$

Zobrazení  $G : \mathbb{R}^2 \rightarrow \mathbb{R}^3$  má v bodě  $[2, 0]$  derivaci representovanou maticí

$$\begin{pmatrix} 2 & 1 \\ 0 & -1 \\ 1 & 0 \end{pmatrix}$$

- (a) Dokažte, že v bodě  $[0, 0, 0]$  existuje derivace zobrazení  $G \circ F$  a spočtete její reprezentující matici.  
 (b) Spočtete derivaci funkce  $F_1$  v bodě  $[0, 0, 0]$  podle vektoru  $(1, 2, 0)$ .

**Řešení:**

(a) Nejdříve najdeme reprezentující matici funkce  $F$ . Pro  $(x, y, z) \in \mathbb{R}^3$  je

$$\begin{aligned} \frac{\partial F_1}{\partial x} &= 2(x + 1)(y + 1)(z + 2) & \frac{\partial F_1}{\partial y} &= (x + 1)^2(z + 2) & \frac{\partial F_1}{\partial z} &= (x + 1)^2(y + 1) \\ \frac{\partial F_2}{\partial x} &= \cos x \cos(2y + z) & \frac{\partial F_2}{\partial y} &= \sin x(-2 \sin(2y + z)) & \frac{\partial F_2}{\partial z} &= \sin x(-\sin(2y + z)) \end{aligned}$$

Všechny parciální derivace jsou spojité na  $\mathbb{R}^3$ , tedy existuje derivace zobrazení  $F$ .  
 V bodě  $[0, 0, 0]$  pak je representována maticí

$$\begin{pmatrix} 4 & 2 & 1 \\ 1 & 0 & 0 \end{pmatrix}$$

Obě zobrazení mají derivaci, tedy ji má i zobrazení  $G(F)$ . Matici zobrazení  $G(F)$  pak získáme jako

$$\begin{pmatrix} 2 & 1 \\ 0 & -1 \\ 1 & 0 \end{pmatrix} \cdot \begin{pmatrix} 4 & 2 & 1 \\ 1 & 0 & 0 \end{pmatrix} = \begin{pmatrix} 9 & 4 & 2 \\ -1 & 0 & 0 \\ 4 & 2 & 1 \end{pmatrix}$$

(b) Všechny parciální derivace funkce  $F_1$  jsou spojité, tedy existuje derivace  $F_1$ . Speciálně pro derivaci funkce  $F_1$  v bodě  $[0, 0, 0]$  máme

$$(4, 2, 1)$$

Pro derivaci ve směru pak platí

$$D_{(1,2,0)}F_1(0, 0, 0) = (4, 2, 1) \cdot (1, 2, 0) = 4 + 4 + 0 = 8.$$

10. Necht'  $F = (F_1, F_2, F_3, F_4) : \mathbb{R}^2 \rightarrow \mathbb{R}$  je zobrazení definované předpisem

$$F(x, y) = \left( \arctan(x + 2y), x + y, (x^2 + y^2) \frac{|x|}{1 + |y|}, ye^x \right).$$

- (a) Ukažte, že v bodě  $(-1, 1)$  existuje derivace funkce  $F$  a spočtěte její reprezentující matici.  
 (b) Spočtěte  $\frac{\partial F_3}{\partial x}(0, 0)$ , pokud existuje.

**Řešení:**

- (a) Uvažujme  $(x, y) \in B((-1, 1), \frac{1}{2})$ . Pak platí  $|x| = -x$ ,  $|y| = y$ .

Zderivujeme

$$\begin{aligned} \frac{\partial F_1}{\partial x} &= \frac{1}{1 + (x + 2y)^2} & \frac{\partial F_1}{\partial y} &= \frac{2}{1 + (x + 2y)^2} \\ \frac{\partial F_2}{\partial x} &= 1 & \frac{\partial F_2}{\partial y} &= 1, \\ \frac{\partial F_3}{\partial x} &= \frac{-3x^2 - y^2}{1 + y} & \frac{\partial F_3}{\partial y} &= \frac{x^3 - xy(y + 2)}{(1 + y)^2} \\ \frac{\partial F_4}{\partial x} &= e^{xy} & \frac{\partial F_4}{\partial y} &= e^x \end{aligned}$$

Všechny parciální derivace jsou v bodě  $(-1, 1)$  spojité, tedy existuje derivace funkce  $F$ . Její reprezentující matice pak je

$$\begin{pmatrix} \frac{1}{2} & 1 \\ 1 & 1 \\ -2 & \frac{1}{2} \\ e^{-1} & e^{-1} \end{pmatrix}$$

- (b) Spočteme z definice.

$$\frac{\partial F_3}{\partial x}(0, 0) = \lim_{t \rightarrow 0} \frac{((0 + t)^2 + 0^2)^{\frac{|0+t|}{1+|0|}} - 0}{t} = \lim_{t \rightarrow 0} \frac{t^2 |t|}{t} = \lim_{t \rightarrow 0} t |t| = 0.$$