

1. (a) $\partial T / \partial x$ represents the rate of change of T when we fix y and t and consider T as a function of the single variable x , which describes how quickly the temperature changes when longitude changes but latitude and time are constant. $\partial T / \partial y$ represents the rate of change of T when we fix x and t and consider T as a function of y , which describes how quickly the temperature changes when latitude changes but longitude and time are constant. $\partial T / \partial t$ represents the rate of change of T when we fix x and y and consider T as a function of t , which describes how quickly the temperature changes over time for a constant longitude and latitude.
- (b) $f_x(158, 21, 9)$ represents the rate of change of temperature at longitude 158°W , latitude 21°N at 9:00 AM when only longitude varies. Since the air is warmer to the west than to the east, increasing longitude results in an increased air temperature, so we would expect $f_x(158, 21, 9)$ to be positive. $f_y(158, 21, 9)$ represents the rate of change of temperature at the same time and location when only latitude varies. Since the air is warmer to the south and cooler to the north, increasing latitude results in a decreased air temperature, so we would expect $f_y(158, 21, 9)$ to be negative. $f_t(158, 21, 9)$ represents the rate of change of temperature at the same time and location when only time varies. Since typically air temperature increases from the morning to the afternoon as the sun warms it, we would expect $f_t(158, 21, 9)$ to be positive.

3. (a) By Definition 4, $f_T(-15, 30) = \lim_{h \rightarrow 0} \frac{f(-15 + h, 30) - f(-15, 30)}{h}$, which we can approximate by considering $h = 5$ and $h = -5$ and using the values given in the table:

$$f_T(-15, 30) \approx \frac{f(-10, 30) - f(-15, 30)}{5} = \frac{-20 - (-26)}{5} = \frac{6}{5} = 1.2,$$

$$f_T(-15, 30) \approx \frac{f(-20, 30) - f(-15, 30)}{-5} = \frac{-33 - (-26)}{-5} = \frac{-7}{-5} = 1.4. \text{ Averaging these values, we estimate}$$

$f_T(-15, 30)$ to be approximately 1.3. Thus, when the actual temperature is -15°C and the wind speed is 30 km/h, the apparent temperature rises by about 1.3°C for every degree that the actual temperature rises.

Similarly, $f_v(-15, 30) = \lim_{h \rightarrow 0} \frac{f(-15, 30 + h) - f(-15, 30)}{h}$ which we can approximate by considering $h = 10$ and

$$h = -10: f_v(-15, 30) \approx \frac{f(-15, 40) - f(-15, 30)}{10} = \frac{-27 - (-26)}{10} = \frac{-1}{10} = -0.1,$$

$$f_v(-15, 30) \approx \frac{f(-15, 20) - f(-15, 30)}{-10} = \frac{-24 - (-26)}{-10} = \frac{2}{-10} = -0.2. \text{ Averaging these values, we estimate}$$

$f_v(-15, 30)$ to be approximately -0.15 . Thus, when the actual temperature is -15°C and the wind speed is 30 km/h, the apparent temperature decreases by about 0.15°C for every km/h that the wind speed increases.

- (b) For a fixed wind speed v , the values of the wind-chill index W increase as temperature T increases (look at a column of the table), so $\frac{\partial W}{\partial T}$ is positive. For a fixed temperature T , the values of W decrease (or remain constant) as v increases (look at a row of the table), so $\frac{\partial W}{\partial v}$ is negative (or perhaps 0).
- (c) For fixed values of T , the function values $f(T, v)$ appear to become constant (or nearly constant) as v increases, so the corresponding rate of change is 0 or near 0 as v increases. This suggests that $\lim_{v \rightarrow \infty} (\partial W / \partial v) = 0$.

4. (a) $\partial h / \partial v$ represents the rate of change of h when we fix t and consider h as a function of v , which describes how quickly the wave heights change when the wind speed changes for a fixed time duration. $\partial h / \partial t$ represents the rate of change of h when we fix v and consider h as a function of t , which describes how quickly the wave heights change when the duration of time changes, but the wind speed is constant.

(b) By Definition 4, $f_v(40, 15) = \lim_{h \rightarrow 0} \frac{f(40 + h, 15) - f(40, 15)}{h}$ which we can approximate by considering

$$h = 10 \text{ and } h = -10 \text{ and using the values given in the table: } f_v(40, 15) \approx \frac{f(50, 15) - f(40, 15)}{10} = \frac{36 - 25}{10} = 1.1,$$

$$f_v(40, 15) \approx \frac{f(30, 15) - f(40, 15)}{-10} = \frac{16 - 25}{-10} = 0.9. \text{ Averaging these values, we have } f_v(40, 15) \approx 1.0. \text{ Thus, when}$$

a 40-knot wind has been blowing for 15 hours, the wave heights should increase by about 1 foot for every knot that the

wind speed increases (with the same time duration). Similarly, $f_t(40, 15) = \lim_{h \rightarrow 0} \frac{f(40, 15 + h) - f(40, 15)}{h}$ which we

$$\text{can approximate by considering } h = 5 \text{ and } h = -5: f_t(40, 15) \approx \frac{f(40, 20) - f(40, 15)}{5} = \frac{28 - 25}{5} = 0.6,$$

$$f_t(40, 15) \approx \frac{f(40, 10) - f(40, 15)}{-5} = \frac{21 - 25}{-5} = 0.8. \text{ Averaging these values, we have } f_t(40, 15) \approx 0.7. \text{ Thus, when a}$$

40-knot wind has been blowing for 15 hours, the wave heights increase by about 0.7 feet for every additional hour that the wind blows.

- (c) For fixed values of v , the function values $f(v, t)$ appear to increase in smaller and smaller increments, becoming nearly constant as t increases. Thus, the corresponding rate of change is nearly 0 as t increases, suggesting that

$$\lim_{t \rightarrow \infty} (\partial h / \partial t) = 0.$$

5. (a) If we start at $(1, 2)$ and move in the positive x -direction, the graph of f increases. Thus $f_x(1, 2)$ is positive.

(b) If we start at $(1, 2)$ and move in the positive y -direction, the graph of f decreases. Thus $f_y(1, 2)$ is negative.

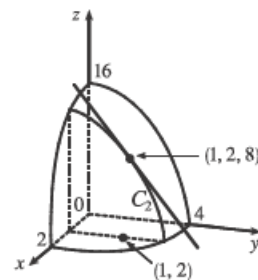
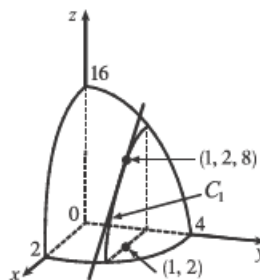
6. (a) The graph of f decreases if we start at $(-1, 2)$ and move in the positive x -direction, so $f_x(-1, 2)$ is negative.

(b) The graph of f decreases if we start at $(-1, 2)$ and move in the positive y -direction, so $f_y(-1, 2)$ is negative.

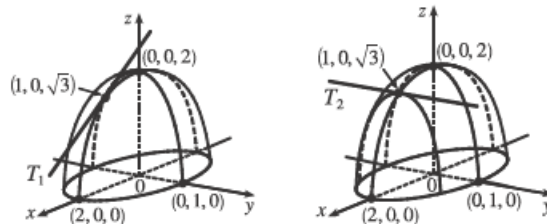
7. (a) $f_{xx} = \frac{\partial}{\partial x}(f_x)$, so f_{xx} is the rate of change of f_x in the x -direction. f_x is negative at $(-1, 2)$ and if we move in the positive x -direction, the surface becomes less steep. Thus the values of f_x are increasing and $f_{xx}(-1, 2)$ is positive.

(b) f_{yy} is the rate of change of f_y in the y -direction. f_y is negative at $(-1, 2)$ and if we move in the positive y -direction, the surface becomes steeper. Thus the values of f_y are decreasing, and $f_{yy}(-1, 2)$ is negative.

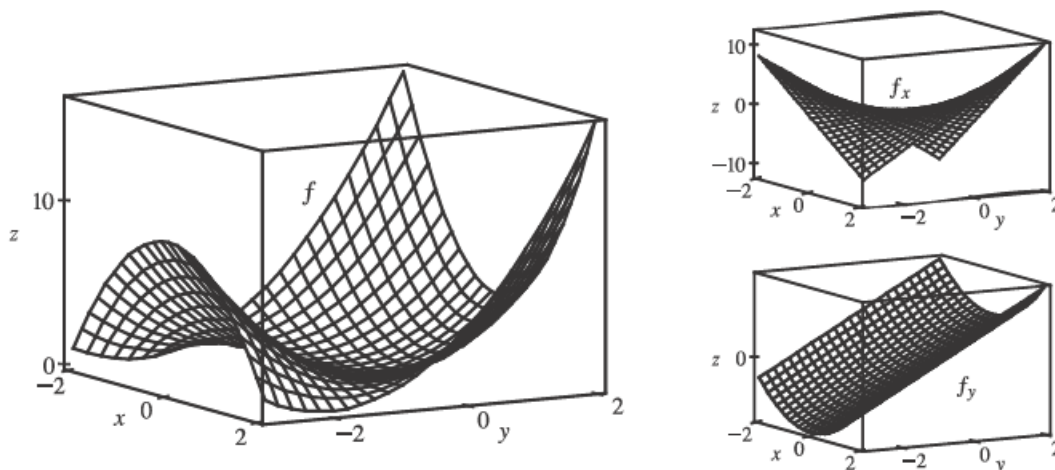
8. (a) $f_{xy} = \frac{\partial}{\partial y}(f_x)$, so f_{xy} is the rate of change of f_x in the y -direction. f_x is positive at $(1, 2)$ and if we move in the positive y -direction, the surface becomes steeper, looking in the positive x -direction. Thus the values of f_x are increasing and $f_{xy}(1, 2)$ is positive.
- (b) f_x is negative at $(-1, 2)$ and if we move in the positive y -direction, the surface gets steeper (with negative slope), looking in the positive x -direction. This means that the values of f_x are decreasing as y increases, so $f_{xy}(-1, 2)$ is negative.
9. First of all, if we start at the point $(3, -3)$ and move in the positive y -direction, we see that both b and c decrease, while a increases. Both b and c have a low point at about $(3, -1.5)$, while a is 0 at this point. So a is definitely the graph of f_y , and one of b and c is the graph of f . To see which is which, we start at the point $(-3, -1.5)$ and move in the positive x -direction. b traces out a line with negative slope, while c traces out a parabola opening downward. This tells us that b is the x -derivative of c . So c is the graph of f , b is the graph of f_x , and a is the graph of f_y .
10. $f_x(2, 1)$ is the rate of change of f at $(2, 1)$ in the x -direction. If we start at $(2, 1)$, where $f(2, 1) = 10$, and move in the positive x -direction, we reach the next contour line (where $f(x, y) = 12$) after approximately 0.6 units. This represents an average rate of change of about $\frac{2}{0.6}$. If we approach the point $(2, 1)$ from the left (moving in the positive x -direction) the output values increase from 8 to 10 with an increase in x of approximately 0.9 units, corresponding to an average rate of change of $\frac{2}{0.9}$. A good estimate for $f_x(2, 1)$ would be the average of these two, so $f_x(2, 1) \approx 2.8$. Similarly, $f_y(2, 1)$ is the rate of change of f at $(2, 1)$ in the y -direction. If we approach $(2, 1)$ from below, the output values decrease from 12 to 10 with a change in y of approximately 1 unit, corresponding to an average rate of change of -2 . If we start at $(2, 1)$ and move in the positive y -direction, the output values decrease from 10 to 8 after approximately 0.9 units, a rate of change of $\frac{-2}{0.9}$. Averaging these two results, we estimate $f_y(2, 1) \approx -2.1$.
11. $f(x, y) = 16 - 4x^2 - y^2 \Rightarrow f_x(x, y) = -8x$ and $f_y(x, y) = -2y \Rightarrow f_x(1, 2) = -8$ and $f_y(1, 2) = -4$. The graph of f is the paraboloid $z = 16 - 4x^2 - y^2$ and the vertical plane $y = 2$ intersects it in the parabola $z = 12 - 4x^2, y = 2$ (the curve C_1 in the first figure). The slope of the tangent line to this parabola at $(1, 2, 8)$ is $f_x(1, 2) = -8$. Similarly the plane $x = 1$ intersects the paraboloid in the parabola $z = 12 - y^2, x = 1$ (the curve C_2 in the second figure) and the slope of the tangent line at $(1, 2, 8)$ is $f_y(1, 2) = -4$.



12. $f(x, y) = (4 - x^2 - 4y^2)^{1/2} \Rightarrow f_x(x, y) = -x(4 - x^2 - 4y^2)^{-1/2}$ and $f_y(x, y) = -4y(4 - x^2 - 4y^2)^{-1/2} \Rightarrow f_x(1, 0) = -\frac{1}{\sqrt{3}}, f_y(1, 0) = 0$. The graph of f is the upper half of the ellipsoid $z^2 + x^2 + 4y^2 = 4$ and the plane $y = 0$ intersects the graph in the semicircle $x^2 + z^2 = 4, z \geq 0$ and the slope of the tangent line T_1 to this semicircle at $(1, 0, \sqrt{3})$ is $f_x(1, 0) = -\frac{1}{\sqrt{3}}$. Similarly the plane $x = 1$ intersects the graph in the semi-ellipse $z^2 + 4y^2 = 3, z \geq 0$ and the slope of the tangent line T_2 to this semi-ellipse at $(1, 0, \sqrt{3})$ is $f_y(1, 0) = 0$.

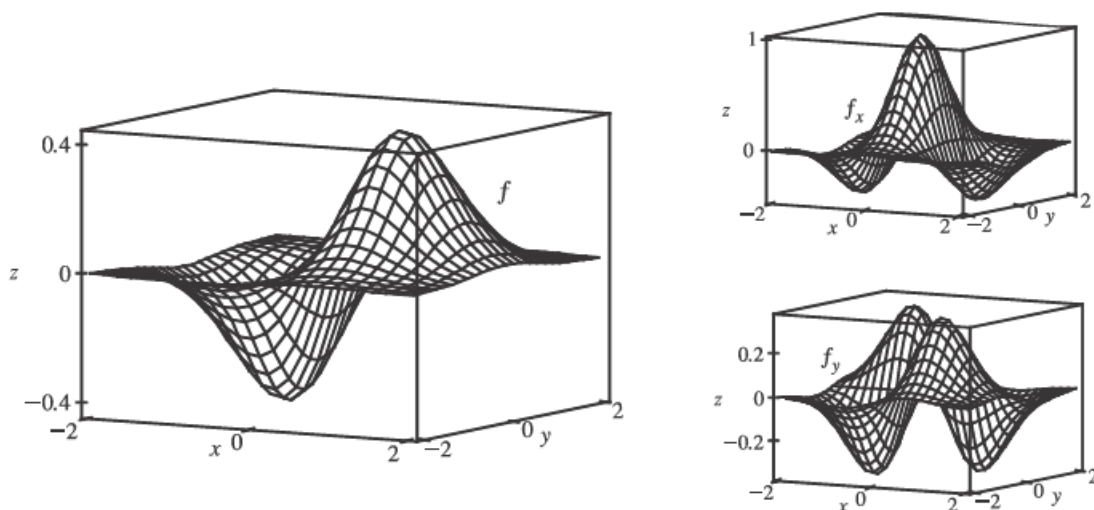


13. $f(x, y) = x^2 + y^2 + x^2y \Rightarrow f_x = 2x + 2xy, f_y = 2y + x^2$



Note that the traces of f in planes parallel to the xz -plane are parabolas which open downward for $y < -1$ and upward for $y > -1$, and the traces of f_x in these planes are straight lines, which have negative slopes for $y < -1$ and positive slopes for $y > -1$. The traces of f in planes parallel to the yz -plane are parabolas which always open upward, and the traces of f_y in these planes are straight lines with positive slopes.

$$14. f(x, y) = xe^{-x^2-y^2} \Rightarrow f_x = x(-2xe^{-x^2-y^2}) + e^{-x^2-y^2} = e^{-x^2-y^2}(1-2x^2), \quad f_y = -2xye^{-x^2-y^2}$$



Note that traces of f in planes parallel to the xz -plane have two extreme values, while traces of f_x in these planes have two zeros. Traces of f in planes parallel to the yz -plane have only one extreme value (a minimum if $x < 0$, a maximum if $x > 0$), and traces of f_y in these planes have only one zero (going from negative to positive if $x < 0$ and from positive to negative if $x > 0$).

$$15. f(x, y) = y^5 - 3xy \Rightarrow f_x(x, y) = 0 - 3y = -3y, \quad f_y(x, y) = 5y^4 - 3x$$

$$16. f(x, y) = x^4y^3 + 8x^2y \Rightarrow$$

$$f_x(x, y) = 4x^3 \cdot y^3 + 8 \cdot 2x \cdot y = 4x^3y^3 + 16xy, \quad f_y(x, y) = x^4 \cdot 3y^2 + 8x^2 \cdot 1 = 3x^4y^2 + 8x^2$$

$$17. f(x, t) = e^{-t} \cos \pi x \Rightarrow f_x(x, t) = e^{-t} (-\sin \pi x) (\pi) = -\pi e^{-t} \sin \pi x, \quad f_t(x, t) = e^{-t} (-1) \cos \pi x = -e^{-t} \cos \pi x$$

$$18. f(x, t) = \sqrt{x} \ln t \Rightarrow f_x(x, t) = \frac{1}{2} x^{-1/2} \ln t = (\ln t)/(2\sqrt{x}), \quad f_t(x, t) = \sqrt{x} \cdot \frac{1}{t} = \sqrt{x}/t$$

$$19. z = (2x + 3y)^{10} \Rightarrow \frac{\partial z}{\partial x} = 10(2x + 3y)^9 \cdot 2 = 20(2x + 3y)^9, \quad \frac{\partial z}{\partial y} = 10(2x + 3y)^9 \cdot 3 = 30(2x + 3y)^9$$

$$20. z = \tan xy \Rightarrow \frac{\partial z}{\partial x} = (\sec^2 xy)(y) = y \sec^2 xy, \quad \frac{\partial z}{\partial y} = (\sec^2 xy)(x) = x \sec^2 xy$$

$$21. f(x, y) = \frac{x-y}{x+y} \Rightarrow f_x(x, y) = \frac{(1)(x+y) - (x-y)(1)}{(x+y)^2} = \frac{2y}{(x+y)^2},$$

$$f_y(x, y) = \frac{(-1)(x+y) - (x-y)(1)}{(x+y)^2} = -\frac{2x}{(x+y)^2}$$

$$22. f(x, y) = x^y \Rightarrow f_x(x, y) = yx^{y-1}, \quad f_y(x, y) = x^y \ln x$$

$$23. w = \sin \alpha \cos \beta \Rightarrow \frac{\partial w}{\partial \alpha} = \cos \alpha \cos \beta, \frac{\partial w}{\partial \beta} = -\sin \alpha \sin \beta$$

$$24. w = \frac{e^v}{u+v^2} \Rightarrow \frac{\partial w}{\partial u} = \frac{0(u+v^2) - e^v(1)}{(u+v^2)^2} = -\frac{e^v}{(u+v^2)^2}, \frac{\partial w}{\partial v} = \frac{e^v(u+v^2) - e^v(2v)}{(u+v^2)^2} = \frac{e^v(u+v^2-2v)}{(u+v^2)^2}$$

$$25. f(r, s) = r \ln(r^2 + s^2) \Rightarrow f_r(r, s) = r \cdot \frac{2r}{r^2 + s^2} + \ln(r^2 + s^2) \cdot 1 = \frac{2r^2}{r^2 + s^2} + \ln(r^2 + s^2),$$

$$f_s(r, s) = r \cdot \frac{2s}{r^2 + s^2} + 0 = \frac{2rs}{r^2 + s^2}$$

$$26. f(x, t) = \arctan(x \sqrt{t}) \Rightarrow f_x(x, t) = \frac{1}{1 + (x \sqrt{t})^2} \cdot \sqrt{t} = \frac{\sqrt{t}}{1 + x^2 t},$$

$$f_t(x, t) = \frac{1}{1 + (x \sqrt{t})^2} \cdot x \left(\frac{1}{2} t^{-1/2} \right) = \frac{x}{2 \sqrt{t} (1 + x^2 t)}$$

$$27. u = t e^{w/t} \Rightarrow \frac{\partial u}{\partial t} = t \cdot e^{w/t} (-w t^{-2}) + e^{w/t} \cdot 1 = e^{w/t} - \frac{w}{t} e^{w/t} = e^{w/t} \left(1 - \frac{w}{t} \right), \frac{\partial u}{\partial w} = t e^{w/t} \cdot \frac{1}{t} = e^{w/t}$$

$$28. f(x, y) = \int_y^x \cos(t^2) dt \Rightarrow f_x(x, y) = \frac{\partial}{\partial x} \int_y^x \cos(t^2) dt = \cos(x^2) \text{ by the Fundamental Theorem of Calculus, Part 1;}$$

$$f_y(x, y) = \frac{\partial}{\partial y} \int_y^x \cos(t^2) dt = -\frac{\partial}{\partial y} \cos(y^2) = -\cos(y^2).$$

$$29. f(x, y, z) = xz - 5x^2 y^3 z^4 \Rightarrow f_x(x, y, z) = z - 10xy^3 z^4, f_y(x, y, z) = -15x^2 y^2 z^4, f_z(x, y, z) = x - 20x^2 y^3 z^3$$

$$30. f(x, y, z) = x \sin(y - z) \Rightarrow f_x(x, y, z) = \sin(y - z), f_y(x, y, z) = x \cos(y - z),$$

$$f_z(x, y, z) = x \cos(y - z)(-1) = -x \cos(y - z)$$

$$31. w = \ln(x + 2y + 3z) \Rightarrow \frac{\partial w}{\partial x} = \frac{1}{x + 2y + 3z}, \frac{\partial w}{\partial y} = \frac{2}{x + 2y + 3z}, \frac{\partial w}{\partial z} = \frac{3}{x + 2y + 3z}$$

$$32. w = z e^{xyz} \Rightarrow$$

$$\frac{\partial w}{\partial x} = z e^{xyz} \cdot yz = yz^2 e^{xyz}, \frac{\partial w}{\partial y} = z e^{xyz} \cdot xz = xz^2 e^{xyz}, \frac{\partial w}{\partial z} = z e^{xyz} \cdot xy + e^{xyz} \cdot 1 = (xyz + 1) e^{xyz}$$

$$33. u = xy \sin^{-1}(yz) \Rightarrow \frac{\partial u}{\partial x} = y \sin^{-1}(yz), \frac{\partial u}{\partial y} = xy \cdot \frac{1}{\sqrt{1 - (yz)^2}}(z) + \sin^{-1}(yz) \cdot x = \frac{xyz}{\sqrt{1 - y^2 z^2}} + x \sin^{-1}(yz),$$

$$\frac{\partial u}{\partial z} = xy \cdot \frac{1}{\sqrt{1 - (yz)^2}}(y) = \frac{xy^2}{\sqrt{1 - y^2 z^2}}$$

$$34. u = x^{y/z} \Rightarrow u_x = \frac{y}{z} x^{(y/z)-1}, u_y = x^{y/z} \ln x \cdot \frac{1}{z} = \frac{x^{y/z}}{z} \ln x, u_z = x^{y/z} \ln x \cdot \frac{-y}{z^2} = -\frac{yx^{y/z}}{z^2} \ln x$$

$$35. f(x, y, z, t) = xyz^2 \tan(yt) \Rightarrow f_x(x, y, z, t) = yz^2 \tan(yt),$$

$$f_y(x, y, z, t) = xyz^2 \cdot \sec^2(yt) \cdot t + xz^2 \tan(yt) = xyz^2 t \sec^2(yt) + xz^2 \tan(yt),$$

$$f_z(x, y, z, t) = 2xyz \tan(yt), f_t(x, y, z, t) = xyz^2 \sec^2(yt) \cdot y = xy^2 z^2 \sec^2(yt)$$

$$36. f(x, y, z, t) = \frac{xy^2}{t+2z} \Rightarrow f_x(x, y, z, t) = \frac{y^2}{t+2z}, f_y(x, y, z, t) = \frac{2xy}{t+2z},$$

$$f_z(x, y, z, t) = xy^2(-1)(t+2z)^{-2}(2) = -\frac{2xy^2}{(t+2z)^2}, f_t(x, y, z, t) = xy^2(-1)(t+2z)^{-2}(1) = -\frac{xy^2}{(t+2z)^2}$$

$$37. u = \sqrt{x_1^2 + x_2^2 + \cdots + x_n^2}. \text{ For each } i = 1, \dots, n, u_{x_i} = \frac{1}{2}(x_1^2 + x_2^2 + \cdots + x_n^2)^{-1/2}(2x_i) = \frac{x_i}{\sqrt{x_1^2 + x_2^2 + \cdots + x_n^2}}.$$

$$38. u = \sin(x_1 + 2x_2 + \cdots + nx_n). \text{ For each } i = 1, \dots, n, u_{x_i} = i \cos(x_1 + 2x_2 + \cdots + nx_n).$$

$$39. f(x, y) = \ln(x + \sqrt{x^2 + y^2}) \Rightarrow$$

$$f_x(x, y) = \frac{1}{x + \sqrt{x^2 + y^2}} \left[1 + \frac{1}{2}(x^2 + y^2)^{-1/2}(2x) \right] = \frac{1}{x + \sqrt{x^2 + y^2}} \left(1 + \frac{x}{\sqrt{x^2 + y^2}} \right),$$

$$\text{so } f_x(3, 4) = \frac{1}{3 + \sqrt{3^2 + 4^2}} \left(1 + \frac{3}{\sqrt{3^2 + 4^2}} \right) = \frac{1}{8} \left(1 + \frac{3}{5} \right) = \frac{1}{5}.$$

$$40. f(x, y) = \arctan(y/x) \Rightarrow f_x(x, y) = \frac{1}{1 + (y/x)^2} (-yx^{-2}) = \frac{-y}{x^2(1 + y^2/x^2)} = -\frac{y}{x^2 + y^2},$$

$$\text{so } f_x(2, 3) = -\frac{3}{2^2 + 3^2} = -\frac{3}{13}.$$

$$41. f(x, y, z) = \frac{y}{x+y+z} \Rightarrow f_y(x, y, z) = \frac{1(x+y+z) - y(1)}{(x+y+z)^2} = \frac{x+z}{(x+y+z)^2},$$

$$\text{so } f_y(2, 1, -1) = \frac{2 + (-1)}{(2 + 1 + (-1))^2} = \frac{1}{4}.$$

$$42. f(x, y, z) = \sqrt{\sin^2 x + \sin^2 y + \sin^2 z} \Rightarrow$$

$$f_z(x, y, z) = \frac{1}{2}(\sin^2 x + \sin^2 y + \sin^2 z)^{-1/2} (0 + 0 + 2 \sin z \cdot \cos z) = \frac{\sin z \cos z}{\sqrt{\sin^2 x + \sin^2 y + \sin^2 z}},$$

$$\text{so } f_z(0, 0, \frac{\pi}{4}) = \frac{\sin \frac{\pi}{4} \cos \frac{\pi}{4}}{\sqrt{\sin^2 0 + \sin^2 0 + \sin^2 \frac{\pi}{4}}} = \frac{\frac{\sqrt{2}}{2} \cdot \frac{\sqrt{2}}{2}}{\sqrt{0 + 0 + \left(\frac{\sqrt{2}}{2}\right)^2}} = \frac{\frac{1}{2}}{\frac{\sqrt{2}}{2}} = \frac{1}{\sqrt{2}} \text{ or } \frac{\sqrt{2}}{2}.$$

$$43. f(x, y) = xy^2 - x^3y \Rightarrow$$

$$\begin{aligned} f_x(x, y) &= \lim_{h \rightarrow 0} \frac{f(x+h, y) - f(x, y)}{h} = \lim_{h \rightarrow 0} \frac{(x+h)y^2 - (x+h)^3y - (xy^2 - x^3y)}{h} \\ &= \lim_{h \rightarrow 0} \frac{h(y^2 - 3x^2y - 3xyh - yh^2)}{h} = \lim_{h \rightarrow 0} (y^2 - 3x^2y - 3xyh - yh^2) = y^2 - 3x^2y \\ f_y(x, y) &= \lim_{h \rightarrow 0} \frac{f(x, y+h) - f(x, y)}{h} = \lim_{h \rightarrow 0} \frac{x(y+h)^2 - x^3(y+h) - (xy^2 - x^3y)}{h} = \lim_{h \rightarrow 0} \frac{h(2xy + xh - x^3)}{h} \\ &= \lim_{h \rightarrow 0} (2xy + xh - x^3) = 2xy - x^3 \end{aligned}$$

$$44. f(x, y) = \frac{x}{x+y^2} \Rightarrow$$

$$\begin{aligned} f_x(x, y) &= \lim_{h \rightarrow 0} \frac{f(x+h, y) - f(x, y)}{h} = \lim_{h \rightarrow 0} \frac{\frac{x+h}{x+h+y^2} - \frac{x}{x+y^2}}{h} \cdot \frac{(x+h+y^2)(x+y^2)}{(x+h+y^2)(x+y^2)} \\ &= \lim_{h \rightarrow 0} \frac{(x+h)(x+y^2) - x(x+h+y^2)}{h(x+h+y^2)(x+y^2)} = \lim_{h \rightarrow 0} \frac{y^2h}{h(x+h+y^2)(x+y^2)} \\ &= \lim_{h \rightarrow 0} \frac{y^2}{(x+h+y^2)(x+y^2)} = \frac{y^2}{(x+y^2)^2} \\ f_y(x, y) &= \lim_{h \rightarrow 0} \frac{f(x, y+h) - f(x, y)}{h} = \lim_{h \rightarrow 0} \frac{\frac{x}{x+(y+h)^2} - \frac{x}{x+y^2}}{h} \cdot \frac{[x+(y+h)^2](x+y^2)}{[x+(y+h)^2](x+y^2)} \\ &= \lim_{h \rightarrow 0} \frac{x(x+y^2) - x[x+(y+h)^2]}{h[x+(y+h)^2](x+y^2)} = \lim_{h \rightarrow 0} \frac{h(-2xy - xh)}{h[x+(y+h)^2](x+y^2)} \\ &= \lim_{h \rightarrow 0} \frac{-2xy - xh}{[x+(y+h)^2](x+y^2)} = \frac{-2xy}{(x+y^2)^2} \end{aligned}$$

$$45. x^2 + y^2 + z^2 = 3xyz \Rightarrow \frac{\partial}{\partial x}(x^2 + y^2 + z^2) = \frac{\partial}{\partial x}(3xyz) \Rightarrow 2x + 0 + 2z \frac{\partial z}{\partial x} = 3y \left(x \frac{\partial z}{\partial x} + z \cdot 1 \right) \Leftrightarrow$$

$$2z \frac{\partial z}{\partial x} - 3xy \frac{\partial z}{\partial x} = 3yz - 2x \Leftrightarrow (2z - 3xy) \frac{\partial z}{\partial x} = 3yz - 2x, \text{ so } \frac{\partial z}{\partial x} = \frac{3yz - 2x}{2z - 3xy}.$$

$$\frac{\partial}{\partial y}(x^2 + y^2 + z^2) = \frac{\partial}{\partial y}(3xyz) \Rightarrow 0 + 2y + 2z \frac{\partial z}{\partial y} = 3x \left(y \frac{\partial z}{\partial y} + z \cdot 1 \right) \Leftrightarrow 2z \frac{\partial z}{\partial y} - 3xy \frac{\partial z}{\partial y} = 3xz - 2y \Leftrightarrow$$

$$(2z - 3xy) \frac{\partial z}{\partial y} = 3xz - 2y, \text{ so } \frac{\partial z}{\partial y} = \frac{3xz - 2y}{2z - 3xy}.$$

$$46. yz = \ln(x+z) \Rightarrow \frac{\partial}{\partial x}(yz) = \frac{\partial}{\partial x}(\ln(x+z)) \Rightarrow y \frac{\partial z}{\partial x} = \frac{1}{x+z} \left(1 + \frac{\partial z}{\partial x}\right) \Leftrightarrow \left(y - \frac{1}{x+z}\right) \frac{\partial z}{\partial x} = \frac{1}{x+z},$$

$$\text{so } \frac{\partial z}{\partial x} = \frac{1/(x+z)}{y - 1/(x+z)} = \frac{1}{y(x+z) - 1}.$$

$$\frac{\partial}{\partial y}(yz) = \frac{\partial}{\partial y}(\ln(x+z)) \Rightarrow y \frac{\partial z}{\partial y} + z \cdot 1 = \frac{1}{x+z} \left(0 + \frac{\partial z}{\partial y}\right) \Leftrightarrow \left(y - \frac{1}{x+z}\right) \frac{\partial z}{\partial y} = -z,$$

$$\text{so } \frac{\partial z}{\partial y} = \frac{-z}{y - 1/(x+z)} = \frac{z(x+z)}{1 - y(x+z)}.$$

$$47. x - z = \arctan(yz) \Rightarrow \frac{\partial}{\partial x}(x - z) = \frac{\partial}{\partial x}(\arctan(yz)) \Rightarrow 1 - \frac{\partial z}{\partial x} = \frac{1}{1 + (yz)^2} \cdot y \frac{\partial z}{\partial x} \Leftrightarrow$$

$$1 = \left(\frac{y}{1 + y^2 z^2} + 1\right) \frac{\partial z}{\partial x} \Leftrightarrow 1 = \left(\frac{y + 1 + y^2 z^2}{1 + y^2 z^2}\right) \frac{\partial z}{\partial x}, \text{ so } \frac{\partial z}{\partial x} = \frac{1 + y^2 z^2}{1 + y + y^2 z^2}.$$

$$\frac{\partial}{\partial y}(x - z) = \frac{\partial}{\partial y}(\arctan(yz)) \Rightarrow 0 - \frac{\partial z}{\partial y} = \frac{1}{1 + (yz)^2} \cdot \left(y \frac{\partial z}{\partial y} + z \cdot 1\right) \Leftrightarrow$$

$$-\frac{z}{1 + y^2 z^2} = \left(\frac{y}{1 + y^2 z^2} + 1\right) \frac{\partial z}{\partial y} \Leftrightarrow -\frac{z}{1 + y^2 z^2} = \left(\frac{y + 1 + y^2 z^2}{1 + y^2 z^2}\right) \frac{\partial z}{\partial y} \Leftrightarrow \frac{\partial z}{\partial y} = -\frac{z}{1 + y + y^2 z^2}.$$

$$48. \sin(xyz) = x + 2y + 3z \Rightarrow \frac{\partial}{\partial x}(\sin(xyz)) = \frac{\partial}{\partial x}(x + 2y + 3z) \Rightarrow \cos(xyz) \cdot y \left(x \frac{\partial z}{\partial x} + z\right) = 1 + 3 \frac{\partial z}{\partial x} \Leftrightarrow$$

$$(xy \cos(xyz) - 3) \frac{\partial z}{\partial x} = 1 - yz \cos(xyz), \text{ so } \frac{\partial z}{\partial x} = \frac{1 - yz \cos(xyz)}{xy \cos(xyz) - 3}.$$

$$\frac{\partial}{\partial y}(\sin(xyz)) = \frac{\partial}{\partial y}(x + 2y + 3z) \Rightarrow \cos(xyz) \cdot x \left(y \frac{\partial z}{\partial y} + z\right) = 2 + 3 \frac{\partial z}{\partial y} \Leftrightarrow$$

$$(xy \cos(xyz) - 3) \frac{\partial z}{\partial y} = 2 - xz \cos(xyz), \text{ so } \frac{\partial z}{\partial y} = \frac{2 - xz \cos(xyz)}{xy \cos(xyz) - 3}.$$

$$49. (a) z = f(x) + g(y) \Rightarrow \frac{\partial z}{\partial x} = f'(x), \quad \frac{\partial z}{\partial y} = g'(y)$$

$$(b) z = f(x + y). \text{ Let } u = x + y. \text{ Then } \frac{\partial z}{\partial x} = \frac{df}{du} \frac{\partial u}{\partial x} = \frac{df}{du}(1) = f'(u) = f'(x + y),$$

$$\frac{\partial z}{\partial y} = \frac{df}{du} \frac{\partial u}{\partial y} = \frac{df}{du}(1) = f'(u) = f'(x + y).$$

50. (a) $z = f(x)g(y) \Rightarrow \frac{\partial z}{\partial x} = f'(x)g(y), \quad \frac{\partial z}{\partial y} = f(x)g'(y)$

(b) $z = f(xy)$. Let $u = xy$. Then $\frac{\partial u}{\partial x} = y$ and $\frac{\partial u}{\partial y} = x$. Hence $\frac{\partial z}{\partial x} = \frac{df}{du} \frac{\partial u}{\partial x} = \frac{df}{du} \cdot y = yf'(u) = yf'(xy)$

and $\frac{\partial z}{\partial y} = \frac{df}{du} \frac{\partial u}{\partial y} = \frac{df}{du} \cdot x = xf'(u) = xf'(xy)$.

(c) $z = f\left(\frac{x}{y}\right)$. Let $u = \frac{x}{y}$. Then $\frac{\partial u}{\partial x} = \frac{1}{y}$ and $\frac{\partial u}{\partial y} = -\frac{x}{y^2}$. Hence $\frac{\partial z}{\partial x} = \frac{df}{du} \frac{\partial u}{\partial x} = f'(u) \frac{1}{y} = \frac{f'(x/y)}{y}$

and $\frac{\partial z}{\partial y} = \frac{df}{du} \frac{\partial u}{\partial y} = f'(u) \left(-\frac{x}{y^2}\right) = -\frac{xf'(x/y)}{y^2}$.