SM223 – Calculus III with Optimization
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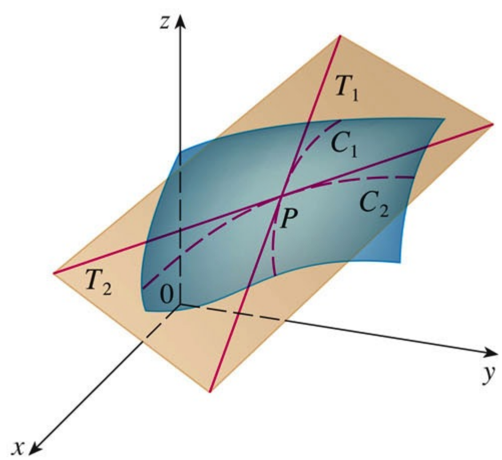
Lesson 22. Tangent Planes and Linear Approximations

0 Warm up

Example 1. Find an equation of the plane that passes through $(-1, 1, 5)$ and is perpendicular to the vector $\langle 2, 4, -3 \rangle$.

1 Tangent planes

- Let S be a surface with equation $z = f(x, y)$
- Let $P(x_0, y_0, z_0)$ be a point on S
  - So $z_0 =$



- Let T_1 and T_2 be the tangent lines at P in the x- and y-directions, respectively
- The **tangent plane** to the surface S at point P is the plane that contains both tangent lines T_1 and T_2
- A normal vector of the tangent plane is

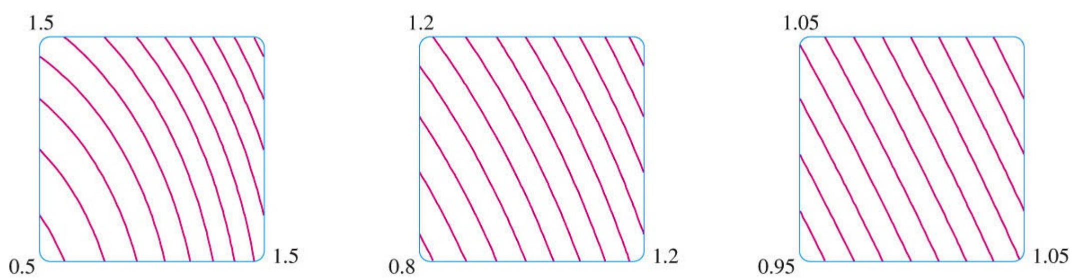
$\Rightarrow$ An equation of the tangent plane to the surface $z = f(x, y)$ at point $P(x_0, y_0, z_0)$ is

Example 2. Find the tangent plane to the surface $z = x^2 + xy + 3y^2$ at the point $(1, 1, 5)$.

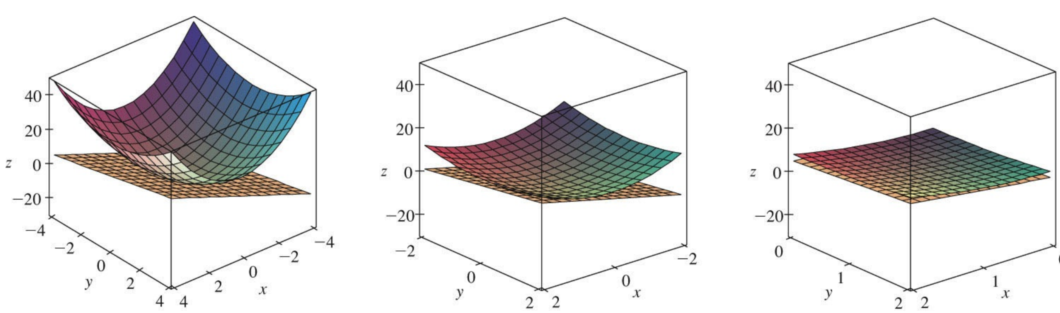
2 Linear approximations

- What do the level curves of a plane look like?

- As we zoom in on the level curves of an arbitrary surface, they start to look more and more like equally spaced parallel lines
  - For example: $f(x, y) = 2x^2 + y^2$



$\Rightarrow$ We can use tangent planes to approximate function values



(a) (b) (c)

- The **linear approximation** of f at (a, b) is

  - Compare to equation for tangent plane above: use $x_0 = a$, $y_0 = b$, $z_0 = f(a, b)$

Example 3. Here is the wind-chill index function $W(T, v)$ from Lessons 18 and 20:

Wind speed (km/h)

Actual temperature (°C)

T \ v	5	10	15	20	25	30	40	50	60	70	80
5	4	3	2	1	1	0	−1	−1	−2	−2	−3
0	−2	−3	−4	−5	−6	−6	−7	−8	−9	−9	−10
−5	−7	−9	−11	−12	−12	−13	−14	−15	−16	−16	−17
−10	−13	−15	−17	−18	−19	−20	−21	−22	−23	−23	−24
−15	−19	−21	−23	−24	−25	−26	−27	−29	−30	−30	−31
−20	−24	−27	−29	−30	−32	−33	−34	−35	−36	−37	−38
−25	−30	−33	−35	−37	−38	−39	−41	−42	−43	−44	−45
−30	−36	−39	−41	−43	−44	−46	−48	−49	−50	−51	−52
−35	−41	−45	−48	−49	−51	−52	−54	−56	−57	−58	−60
−40	−47	−51	−54	−56	−57	−59	−61	−63	−64	−65	−67

In Lesson 20, we estimated $W_T(-15, 40) \approx 1.3$. In a similar fashion, we can estimate $W_v(-15, 40) \approx -0.15$. Find the linear approximation of $W(T, v)$ at $(-15, 40)$. Use it to approximate $W(-12, 45)$.

Example 4. Find the linear approximation of $f(x, y) = xe^{xy}$ at $(1, 0)$. Use it to approximate $f(1.1, -0.1)$.

- Why bother with linear approximations?
  - Desert island
  - More importantly: **linear functions** (functions of the form $f(x, y) = ax + by$) are <u>much</u> easier to deal with that other types of functions
    - $\Rightarrow$ Linear approximations form the basis of many algorithms for complex problems
- Disclaimer: equations for tangent planes and linear approximations above do not necessarily apply when the partial derivatives of f are <u>not</u> continuous