

## Calculus 3 Proof

(jokingly called "The Victor Theorem", according to a classmate)

Written for: Professor Habib Maagoul

Victor C. Van

November 27, 2024

*Proof.* For simplicity, we can start with a basic double integral. This principle can be applied to any arbitrary n-number of iterated integrals.

$$\iint_R f(x, y) dA.$$

For any iterated integral of some function  $f(x, y)$  in any Euclidean coordinate system (e.g. Cartesian, polar, and cylindrical), such that  $f(x, y)$  can be expressed as the product of two independent functions  $g(x)$  and  $h(y)$ , and that the bounds of integration are constants:

$$\int_c^d \int_a^b f(x, y) dA = \int_c^d \int_a^b g(x)h(y) dx dy$$

$$\{(a, b, c, d) \in \mathbb{R}\}$$

$h(y)$  is a constant when you integrate with respect to  $x$ .

$g(x)$  is a constant when you integrate with respect to  $y$ .

We can represent this as the product of two definite integrals of functions that are independent of each other:

$$\int_a^b g(x) dx \cdot \int_c^d h(y) dy$$

If this claim is true, it must also apply to partial derivatives due to the *Fundamental Theorem of Calculus*.

Suppose some function  $f(x, y) = x^2 y^3$ .

$$f(x, y) = g(x) \cdot h(y); \quad g(x) = x^2, \quad h(y) = y^3$$

$$\frac{\partial^2 f}{\partial x \partial y} = \frac{\partial^2 f}{\partial y \partial x} = 6xy^2$$

$$\frac{\partial g}{\partial x} = 2x$$

$$\frac{\partial h}{\partial y} = 3y^2$$

$$\frac{\partial g}{\partial x} \cdot \frac{\partial h}{\partial y} = 6xy^2$$

Thus:

$$\frac{\partial^2 f}{\partial x \partial y} = \frac{\partial^2 f}{\partial y \partial x} = \frac{\partial g}{\partial x} \cdot \frac{\partial h}{\partial y} = \frac{dg}{dx} \cdot \frac{dh}{dy}$$

Therefore, if and only if  $f_i(x_i)$  is independent from  $f_{i+1}(x_{i+1})$

$$\prod_{i=1}^n \int_{a_i}^{b_i} f_i(x_i) dx_i = \int_{a_1}^{b_1} f_1(x_1) dx_1 \cdot \int_{a_2}^{b_2} f_2(x_2) dx_2 \cdots \int_{a_n}^{b_n} f_n(x_n) dx_n$$

$$\{(a_i, b_i) \in \mathbb{R} \mid i \in \mathbb{N}\}$$

The proof is trivial.

QED

**Fubini's Theorem:**

The triple integral of a continuous function  $f(x, y, z)$  over a box  $B$ , where  $a \leq x \leq b$ ,  $c \leq y \leq d$ , and  $e \leq z \leq f$  to the integral:

$$\iiint_B f(x, y, z) dV = \int_a^b \int_c^d \int_e^f f(x, y, z) dz dy dx$$

Below is in-class example that this proof was created for, and my work. Professor Maagoul told me that my method was mathematically incorrect, and that if I used this method of integration on the next exam then he'd take points off even if I got the final answer correct unless I found him a proof. Since I couldn't find a proof that sufficiently backed my claim online, this was motivation for writing the proof myself.

Take note about how my proof is basically just a special case of *Fubini's Theorem* when  $f_1(x_1)$ ,  $f_2(x_2)$ , and  $f_3(x_3)$  are all independent of each other.

**Evaluate**  $\iiint_B xyz^2 dV$  **where**  $B = \{(x, y, z) \mid 0 \leq x \leq 1, -1 \leq y \leq 2, 0 \leq z \leq 3\}$

$$\begin{aligned} & \int_0^1 \int_{-1}^2 \int_0^3 (xyz^2) dz dy dx \\ &= \int_0^1 x dx \cdot \int_{-1}^2 y dy \cdot \int_0^3 z^2 dz \\ &= \frac{1}{2}[x^2]_0^1 \cdot \frac{1}{2}[y^2]_{-1}^2 \cdot \frac{1}{3}[z^3]_0^3 \\ &= \frac{1}{12}[x^2]_0^1 \cdot [y^2]_{-1}^2 \cdot [z^3]_0^3 \\ &= \frac{3^3}{12}((2)^2 - (-1)^2) \\ &= \frac{3^3}{12}(4 - 1) \\ &= \frac{27}{4} \end{aligned}$$