1 The Arithmetic Derivative

"Momma told me "you can't take derivatives on integers!!!" and I was like "hold my Leibniz rule""

Definition 1 (**The Arithmetic Derivative for natural numbers**).
For any $n \in \mathbb{N}_0$ the **arithmetic derivative**, denoted $(n)'$ is defined as follows:

- $(p)' = 1$, for any prime p
- $(pq)' = (p)'q + p(q)'$, for any $p, q \in \mathbb{N}$ (**Leibniz Rule**)

Corollary 1 (**Elementary derivatives**).
$(0)' = 0$ and $(1)' = 0$

Proof. Follows immediately from the Leibniz rule with $p = q = 1$ □

Corollary 2 (**Power Rule**). For any integers p and $n \geq 0$:

$$(p^n)' = np^{n-1}(p')$$

Proof. Trivial □

Corollary 3 (**Arithmetic derivatives of Integers and rational numbers**).
One can extend the arithmetic derivative to the integers by showing

$$(-x)' = -(x)$$

Further, the **quotient rule** is also well defined on $\mathbb{Q}$:

$$\left(\frac{p}{q}\right)' = \left(\frac{(p)'q - p(q)'}{q^2}\right)$$

Proof. Ain't nobody got da time fo' dis. □

Corollary 4 (**Prime factorization derivative formula**). Let $\omega(x)$ be the prime omega function, indicating the number of distinct prime factors in x, and $\nu_p(x)$ be the p-adic valuation of x. Then,

$$(x)' = \sum_{\substack{p|x \\ p \text{ prime}}} \frac{v_p(x)}{p} x$$

Proof. The prime factorization of an integer $x \in \mathbb{Z}$ is given by

$$x = \prod_{i=1}^{\omega(x)} {p_i}^{v_{p_i}(x)}$$

it follows that

$$D(x) = \sum_{i=1}^{\omega(x)} \left[v_{p_i}(x) \left(\prod_{j=1}^{i-1} {p_j}^{v_{p_j}(x)} \right) p_i^{v_{p_i}-1} \left(\prod_{j=i+1}^{\omega(x)} {p_j}^{v_{p_j}(x)} \right) \right]$$

$$= \sum_{i=1}^{\omega(x)} \frac{v_{p_i}(x)}{p_i} x = \sum_{\substack{p|x \\ p \text{ prime}}} \frac{v_p(x)}{p} x$$

$\square$

Example 1.

$$(60)' = (2^2 \cdot 3 \cdot 5)' = \left(\frac{2}{2} + \frac{1}{3} + \frac{1}{5}\right) \cdot 60 = 92,$$

$$(81)' = D(3^4) = 4 \cdot 3^3 \cdot D(3) = 4 \cdot 27 \cdot 1 = 108.$$

Hello!

$$x + 3 = 67$$

This is really fun!!

$$x + 35^2 = ???$$
$$2x^{(35x + x^x)}$$

Greek letters :

$$\pi$$
$$\beta$$
$$\alpha$$
$$A = \pi r^2$$
$$\log_5(35)$$

fractions:

$$\frac{x}{y}$$
$$\frac{x}{1 + x + x^2}$$
$$\frac{\sqrt{x^2+1}}{\sqrt{x^2-1}}$$

brackets:

$$\{a, b, c\}$$
$$\left(\frac{m_3 + m_4}{x^2}\right)$$

$$\left|\frac{dx}{dy}\right|_{x=1}$$

$$\left|\frac{\delta x}{\delta y}\right|_{x=1}$$

$$\forall n \in \mathbb{Z} \quad a-1|a^n-1$$

$$\int x^{dx}-1$$

This is a table

x	1	2	3	4	5
$f(x)$	10	11	12	13	14

Exercise 1. Prove that if $p : prime$, then $\sqrt{p}$ is irrational. More generally, prove that if $n \in \mathbb{Z}$ and $n \neq m^2$, then $\sqrt{n}$ is irrational.

$$x \approx 1.567$$
$$4x+3^x \quad = \quad 12$$

Solve the following systems of congruences:

$$\begin{cases} 12x+31y \equiv 2 \ (mod 127) \\ 2x+89y \equiv 23 \ (mod 127) \end{cases} \tag{1}$$

$$\begin{cases} x \equiv 1 \ (mod 3) \\ x \equiv 1 \ (mod 4) \\ x \equiv 1 \ (mod 5) \\ x \equiv 0 \ (mod 7) \end{cases} \tag{2}$$

Solve the following congruence polynomials:

$$x^2 \equiv 29 \ (mod 35) \tag{3}$$

$$3x^2+6x+5 \equiv 0 \ (mod 7) \tag{4}$$

Find y such that the following holds:

$$19^{y^{1000}} \equiv 1 \ mod(20) \tag{5}$$

Assume p is prime, and $\exists a \ 1 \leq a \leq (p-1)$ then

$$\text{Show } [a],[2a],...,[(p-1)a] \text{ are all residue classes} \tag{6}$$

Prove that if $n \in \mathbb{Z}$ and $n > 0$, then the prime factorization of the binomial coefficient $C(n,k)$ is given by

$$\binom{n}{k} = \prod_{i=1}^{n} p_k^{\sum_{i=1}^{n} \left\lfloor \frac{n}{p_k^i} \right\rfloor - \left\lfloor \frac{n-k}{p_k^i} \right\rfloor - \left\lfloor \frac{k}{p_k^i} \right\rfloor} \tag{7}$$

Proof. This is written in LaTeX, so it must be true. □

Theorem 1. P = NP

Proof. Let $S = \{X | X \notin X\}$, and let $NP \in S$. Since $P \subseteq NP$ then $P \in P \iff P \notin P$, but clearly, we also have that $NP \in NP \iff NP \notin NP$. It follows trivially that $P \in NP \iff P \notin NP$ and $NP \in P \iff NP \notin P$. Thus we conclude that $P = NP$ $\square$

Corollary 5. Where is my million dollars???

$$I_n = \begin{pmatrix} 1 & 0 & 0 & \cdots & 0 \\ 0 & 1 & 0 & \cdots & 0 \\ 0 & 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & 1 \end{pmatrix}$$

$$I = (\delta_{ij})$$

$$A = U\Sigma V^*$$

Prove Mantel's Theorem, that is, prove that

$$|E| \leq \frac{|V^2|}{4} \tag{8}$$

Theorem 1 (LaPlace Expansion). *The determinant of an $n \times n$ matrix can be calculated as follows:*

$$det(A) = \sum_{i=1}^{n} a_{i,j} Cof(A_{i,j})$$

where

$$Cof(A_{i,j}) = (-1)^{i+j} det \left(\underbrace{A_{i,j}}_{(n-1) \times (n-1)} \right)$$

and the expansion occurs along the i-th row. (Note the expansion can also be taken along the j-th column).

If A is an $n \times n$ matrix, and $E_1, E_2, ..., E_k$ are elementary matrices resulting from taking $[A \overset{RREF}{\rightarrow} I_n]$, then $A = E_1^{-1} E_2^{-1} \dots E_k^{-1} I_n$, and so

$$det(A) = det(E_1^{-1}) \dots det(E_k^{-1})$$

Exercise 1. Let

$$A = \begin{bmatrix} a & d & 2 \\ b & e & 1 \\ c & f & 1 \end{bmatrix}, B = \begin{bmatrix} d & e & f \\ a & b & c \\ 1 & 1 & 0 \end{bmatrix}, C = \begin{bmatrix} -a & 2c+3a & 1 \\ -b & 2e+3b & 0 \\ -c & 2f+3c & 1 \end{bmatrix}$$

If $det(A) = 2$ and $det(B) = -3$, find $det[2A^3 B^{-1} A^T adj(3C^2)]$

Theorem 2 (**Inclusion-Exclusion for Probability**)**.** *The general inclusion-exclusion formula for the union of sets* $A_1, A_2, ..., A_n$ *is completely determined by the simple formula*

$$\mathbb{P}\left(\bigcup_{i=1}^{n} A_i\right) = \mathbb{P}(\emptyset) - \sum_{n}^{k=1}\left(\left[sin\left(k\pi + \frac{\pi}{2}\right)\right] \sum_{\substack{I\subset\{n,,...,1\}\\|I|=k}} \left(1 - \mathbb{P}\left(\overline{\bigcap_{i\in I} A_i}\right)\right)\right)$$

Proof. The proof is trivial and left as an exercise for the reader. □

$$(\mathbf{w}^*, \xi^*, \alpha^*, \beta^*) = \underset{\mathbf{w},\xi}{argmin}\ \underset{\alpha,\beta}{argmax} \mathcal{L}(\mathbf{w}, \xi, \alpha, \beta)$$

$$= \underset{\mathbf{w},\xi}{argmin}\ \underset{\alpha,\beta}{argmax}\ \frac{1}{2}\|\mathbf{w}\| + C\sum_{i=1}^{n} \xi_i - \sum_{i=1}^{n} \alpha_i(y_i\mathbf{w}^T x_i - 1 + \xi_i) - \sum_{i=1}^{n} \beta_i\xi_i$$

Proposition 3. Let $\delta^{\mathrm{TM}} = (\Sigma, q, \Phi, \gamma, Q_O, q_{rEjEcT}, q_{ACCepT})$ be a **Turing Machine**. you know the rest.

$$\forall u \in U, \mathbf{w} \in u\mathbb{W}, U_{\mathbf{w}} \bigcup_{u\in\mathcal{U}} uWu \bigcup_{w\in\mathcal{W}} w_u := \mathcal{O}w\mathcal{O}$$

$$A = \{u1v : u, v \in \Sigma^* \text{ and } |u|, |v| \geq 1\}\ .$$

2 Gradient Descent for Linear Regression

Suppose we have a hypothesis $h : \mathbb{R}^n \to \mathbb{R}$, $h_\theta(\mathbf{x}) = \hat{y}$ with paramters $\theta \in \mathbb{R}^n$. Recall the **Mean-Squared Loss** (MSE) metric, applied to linear regression:

$$MSE(y, h_\theta(\mathbf{x})) = \frac{1}{n}||\mathbf{y} - h_\theta(\mathbf{x})||_2^2 = \frac{1}{2n}\sum_{i=1}^{n}(y^{(i)} - \hat{y}^{(i)})^2 = \frac{1}{2n}\sum_{i=1}^{n}(y^{(i)} - \mathbf{w}^T x^{(i)})^2$$

Then we have the general update:

$$\mathbf{w}^{k+1} = \mathbf{w}^k + \alpha \frac{\partial}{\partial \mathbf{w}} MSE(y, \hat{y})$$

Batch Gradient Descent: For $k = 0, 1, \ldots$

1. For $k = 0, 1, \ldots$

$$\mathbf{w}^{k+1} = \mathbf{w}^k + \alpha \frac{1}{n} \sum_{i=1}^{n} (y^{(i)} - \mathbf{w}^T x^{(i)})\mathbf{x}^{(i)}$$

Mini-batch Gradient Descent:

1. For $k = 0, 1, \ldots$
   (a) Split data D into T subsets D_t of sizes $n_0, \ldots, n_{T-1}$, s.t. $\sum_t n_t = 1$.
   (b) For each subset D_t:

$$\mathbf{w} := \mathbf{w} + \alpha \frac{1}{n_t} \sum_{i:x^{(i)} \in D_t}^{n_t} (y^{(i)} - \mathbf{w}^T x^{(i)})\mathbf{x}^{(i)}$$

Stochastic Gradient Descent:

1. For $k = 0, 1, \ldots$
   (a) For $i = 1, \ldots, n$:

$$\mathbf{w} := \mathbf{w} + \alpha(y^{(i)} - \mathbf{w}^T x^{(i)})\mathbf{x}^{(i)}$$

L1-norm

$$\|\mathbf{w}\|_1 = \sum_i |w_i|$$

$$\frac{\partial}{\partial \mathbf{w}} \|\mathbf{w}\|_1 = sign(\mathbf{w}) = [sign(w_1), \ldots, sign(w_m)]^T$$

$$C = \sum_{w \in LDA(D)} E[idx(w)]$$

Theorem 4 (**Inclusion-Exclusion in Measure Theory**). *Let* (X, μ) *be a finite measure space. For any finite measurable sets* $A_1, \ldots, A_n \subseteq X$

$$\mu\left(\bigcup_{i=1}^{n} A_i\right)$$

$$= \sum_{i=1}^{n} \mu(A_i) - \sum_{1 \leqslant i < j \leqslant n} \mu(A_i \cap A_j) + \sum_{1 \leqslant i < j < k \leqslant n} \mu(A_i \cap A_j \cap A_k) - \cdots + (-1)^{n-1} \mu(A_1 \cap \cdots \cap A_n)$$

$$= \mu\left(\bigcup_{i=1}^{n} A_i\right) = \sum_{\emptyset \neq J \subseteq \{1,\ldots,n\}} (-1)^{|J|+1} \mu\left(\bigcap_{j \in J} A_j\right).$$

$$= \mu\left(\bigcup_{i=1}^{n} A_i\right) = \sum_{k=1}^{n} \left((-1)^{k-1} \sum_{\substack{I \subseteq \{1,\ldots,n\} \\ |I|=k}} \mu(A_I)\right),$$

$$= \mu(\emptyset) - \sum_{n}^{k=1} \left(\left[sin\left(k\pi + \frac{\pi}{2}\right)\right] \sum_{\substack{I \subset \{n,\ldots,1\} \\ |I|=k}} \left(1 - \mu\left(\overline{\bigcap_{i \in I} A_i}\right)\right)\right)$$

Proof. Yikes ☐

Theorem 5 (**Inclusion-Exclusion**). *Given* n *sets* $A_1, \ldots, A_n$ *in an universal space* S*, the cardinality of the union of* n *such sets is given by*

$$\left|\bigcup_{i=1}^{n} A_i\right|$$

$$= \sum_{i=1}^{n} |A_i| - \sum_{1 \leqslant i < j \leqslant n} |A_i \cap A_j| + \sum_{1 \leqslant i < j < k \leqslant n} |A_i \cap A_j \cap A_k| - \cdots + (-1)^{n-1} |A_1 \cap \cdots \cap A_n|$$

$$= \left|\bigcup_{i=1}^{n} A_i\right| = \sum_{\emptyset \neq J \subseteq \{1,\ldots,n\}} (-1)^{|J|+1} \left|\bigcap_{j \in J} A_j\right|.$$

$$= \left|\bigcup_{i=1}^{n} A_i\right| = \sum_{k=1}^{n} \left((-1)^{k-1} \sum_{\substack{I \subseteq \{1,\ldots,n\} \\ |I|=k}} |A_I|\right),$$

$$= |\emptyset| - \sum_{n}^{k=1} \left(\left[sin\left(k\pi + \frac{\pi}{2}\right)\right] \sum_{\substack{I \subset \{n,\ldots,1\} \\ |I|=k}} \left(1 - \left|\overline{\bigcap_{i \in I} A_i}\right|\right)\right)$$

Proof. Yikes ☐

Claim 6. The Post-Correspondence Problem PCP is decidable relative to the acceptance problem A_{TM}.

Proof. We essentially want to show PCP is reducible to ATM, i.e., if ATM were decidable, then the PCP problem would also be decidable. For this purpose, we suppose A_{TM} were decidable, and use the fact that mapping reducibility is transitive. We first reduce $HALT_{TM}$ to A_{TM}. If A_{TM} were decidable, $HALT_{TM}$ would also be decidable. Let S be Turing Machine deciding A_{TM}. We construct the T.M. H for $HALT_{TM}$ as follows:

$H =$ "On input $< M, x >$, where M is a Turing Machine and w its input:

1. Construct machine M' from M by marking all rejecting states of M as accepting.

2. Run S on $< M', x >$, if it accepts, **accept**, if it rejects **reject**. "

Clearly, $< M, x > \in HALT_{TM}$ if $< M', w > \in A_{TM}$. Let this machine H also be an oracle T.M. Now, by using the transitivity of mapping reduction, if A_{TM} were decidable, then $HALT_{TM}$ would also be decidable, so we can show that if $HALT_{TM}$ were decidable, PCP would also be. Now let R be a Turing Machine that recognizes PCP, (which checks in linear time whether a proposed match is an actual solution to PCP by simply comparing the top and bottom symbols and accepting if all of them are equal and rejecting otherwise). Assume that $s_1, s_2, \ldots$ is a list of all possible strings in PCP. Construct the following enumerator E.

$E =$ "Ignore the input.

1. Repeat the following for $i = 1, 2, 3, \ldots$

2. Run R for i steps on each input $s_1, s_2, \ldots, s_i$.

3. If any computations accept, print out the corresponding s_j."

If R accepts a particular string s, eventually it will appear on the list generated by E. Finally, we construct the decider P for PCP:

$P =$ "On input $< R, x >$, where R is the machine described above:

1. Query the oracle for H on input $< E, x >$.

2. If $E \in HALT_{TM}$, a solution to PCP exists, so run E until the solution is out and **accept**.

3. If $E \notin HALT_{TM}$, no solution to PCP exists, so **reject**. "

This shows that PCP is decidable relative to A_{TM}

□

Claim 7. Use the languages $A = a^m b^n c^n | m, n \geq 0$ together with example 2.36 to show that the class of context-free languages is not closed under intersection.

Proof. Note that

$$L(A \cap B) = w | w = a^m b^n c^n \wedge$$

$\square$

$$C = \sum_{w \in D, tfidf(w) > t} E[idx(w)]$$

$$\xRightarrow{\text{Proposed change}}$$

$$C = \sum_{w \in LDA(D)} E[idx(w)]$$

$$\int x^{dx} - 1$$

$$\int \frac{x^{dx} - 1}{dx} dx = \int \lim_{\Delta x \to 0} \frac{x^{\Delta x} - 1}{\Delta x} dx$$

Theorem 8 (**Freshman's Dream**).

Roses are red

$$\textit{Violets are blue}$$
$$(x + y)^n = x^n + y^n \textit{ is true}$$
$$\textit{in } \mathbb{Z}/2\mathbb{Z} \quad (9)$$

Theorem 9 (**Fubini's Theorem**). *Let X and Y be σ-finite measure spaces, and suppose $X \times Y$ is the given product measure. Then, if f is a $X \times Y$ (measurable) function and*

$$\int_{X \times Y} |f(x, y)| d(x, y) < \infty$$

then

$$\int_X \left(\int_Y f(x, y) dy \right) dx = \int_Y \left(\int_X f(x, y) dx \right) dy = \int_{X \times Y} f(x, y) d(x, y)$$

Theorem 10 (**Freshman's dream**). *Let n be prime, then*

$$(x+y)^n = x^n + y^n$$

holds in $\mathbb{Z}/n\mathbb{Z}$

Proof. Let p be a prime, and note that

$$(x+y)^p = x^p + \binom{p}{1}x^{p-1}y + \binom{p}{2}x^{p-2}y^2 + \cdots + \binom{p}{p-1}x^{p-1}y + y^p$$

Let $1 \leq i \leq p-1$, and consider

$$\binom{p}{i} = \frac{p!}{i!(p-1)!} = p\frac{(p-1)!}{i!(p-i!)} \in \mathbb{N}$$

Any factor from $i!(p-i)!$ is not going to divide p.
Why is this is true? We know that

$$i! = 1 * 2 * \cdots * i < p$$
$$(p-1)! = 1 * 2 * \cdots * (p-1) < p$$

which implies that none of the factors above can divide $p \implies$ any of them must divide $(p-i)!$.

$$\implies \binom{p}{i} = p * k_i \in \mathbb{N} \implies p \mid \binom{p}{i}, i = 1, \ldots, (p-1)$$
$$\therefore (x+y)^p \equiv x^p + y^p \; mod \; p$$

$\square$

$$J(\Theta) = -\frac{1}{n}\left[\sum_{i=1}^{n}\sum_{k=1}^{K} y_k^{(i)} \log h_\theta(x^{(i)})_k + (1-y_k^{(i)}) \log(1-h_\theta(x^{(i)})_k)\right] + \frac{\lambda}{2n}\sum_{l=1}^{L-1}\sum_{i=1}^{s_l}\sum_{j=1}^{s_l+1}(\Theta_j^l)^2$$

$$\frac{d^2y}{dx^2} = \left(\frac{dy}{dx}\right)^2$$

$$\lim_{\Delta x \to 0} \int_{-1}^{0} \left(\frac{1}{x^2} + \mathbb{B}ruh\right) \Delta x$$

$$\int_a^b f(x)dx = -\int_b^a f(x)dx$$

$$\implies \underset{N\to\infty}{lim} \sum_{i=1}^{N} f(x_i^*)\Delta x = \underset{N\to\infty}{lim} \sum_{i=1}^{N} f(x_i^*)\left(\frac{b-a}{N}\right) = -\underset{N\to\infty}{lim} \sum_{i=1}^{N} f(x_i^*)\left(\frac{a-b}{N}\right)$$

$$\implies \sum_{i=1}^{N} f(x_i^*)\left(\frac{b-a}{N}\right) = -\sum_{i=1}^{N} f(x_i^*)\left(\frac{a-b}{N}\right) := -\sum_{N}^{i=1} f(x_i^*)\left(\frac{b-a}{N}\right)$$

Define

$$\sum_{N}^{n=1} a_n := -a_N - a_{N-1} - \cdots - a_1$$

Then

$$\sum_{n=1}^{N} a_n = -\sum_{N}^{n=1} a_n$$

This is well-defined as it is no more than a special case of the definite integral :

$$\sum_{k=a}^{b} f(k) = \int_{[a,b]} f d\mu$$

where μ is the **counting measure**.

$$\int_0^{\phi=y} exp\left\{\int_{-\infty}^{x=t} e^x dx\right\} d\phi = ye^{e^t}$$

Exercise 2. Let $x \in \mathbb{R}$, $N \in \mathbb{Z}$, $m \in \mathbb{N}$. Find the exact value of

$$\underbrace{\sqrt[N]{x\sqrt[N]{x\sqrt[N]{x\ldots\sqrt[N]{x}}}}}_{m\text{-times}}$$

1. When $m < \infty$
2. Show that the expression above converges when $m \to \infty$ and find describe the conditions for convergence on the value of x and N.

Proof. Note that

$$\sqrt[N]{x} = x^{\frac{1}{N}} \quad (m = 1)$$

$$\sqrt[N]{x\sqrt[N]{x}} = \sqrt[N]{x * x^{\frac{1}{N}}} = x^{\frac{1}{N}} * x^{\frac{1}{N^2}} \quad (m = 2)$$

$$\sqrt[N]{x\sqrt[N]{x\sqrt[N]{x}}} = \sqrt[N]{x * x^{\frac{1}{N}} * x^{\frac{1}{N^2}}} = x^{\frac{1}{N}} * x^{\frac{1}{N^2}} * x^{\frac{1}{N^3}} \quad (m = 3)$$

$$\vdots$$

$$\sqrt[N]{x\sqrt[N]{x\sqrt[N]{x\ldots\sqrt[N]{x}}}} = \prod_{i=1}^{m} x^{1/N^i} \quad (m = m)$$

But this is simply

$$\prod_{i=1}^{m} x^{1/N^i} = x^{\sum_{i=1}^{m} \frac{1}{N^i}}$$

When $m < \infty$, when $N \neq 1 \implies \frac{1}{N} \neq 1$

$$\sum_{i=1}^{m} \frac{1}{N^i} \overset{i=j+1}{=} \sum_{j=0}^{m-1} \frac{1}{N^{i+1}} = \frac{1}{N}\sum_{j=0}^{m-1} \frac{1}{N^i} = \frac{1}{N}\left(\frac{1-\left(\frac{1}{N}\right)^m}{1-\frac{1}{N}}\right)$$

Further, when $m \to \infty$, as for $|N| > 1$, $\left|\frac{1}{N}\right| < 1$

$$\lim_{m\to\infty} \sum_{i=1}^{m} \frac{1}{N^i} = \frac{1}{N}\sum_{i=1}^{\infty} \frac{1}{N^{i-1}} = \frac{1}{N}\sum_{i=1}^{\infty}\left(\frac{1}{N}\right)^{i-1} = \frac{1}{N}\left(\frac{1}{1-\frac{1}{N}}\right)$$

So that

$$\underbrace{\sqrt[N]{x\sqrt[N]{x\sqrt[N]{x\ldots\sqrt[N]{x}}}}}_{m\text{-times}}=\prod_{i=1}^{m}x^{1/N^i}=x^{\sum_{i=1}^{m}\frac{1}{N^i}}=x^{\left\{\frac{1}{N}\left(\frac{1-\left(\frac{1}{N}\right)^m}{1-\frac{1}{N}}\right)\right\}} \tag{10}$$

and

$$\underbrace{\sqrt[N]{x\sqrt[N]{x\sqrt[N]{x\ldots\sqrt[N]{x}}}}}_{m\to\infty}=\prod_{i=1}^{\infty}x^{1/N^i}=x^{\sum_{i=1}^{\infty}\frac{1}{N^i}}=x^{\left\{\frac{1}{N}\left(\frac{1}{1-\frac{1}{N}}\right)\right\}} \tag{11}$$

□

Corollary 6 (**Infinite nested square root of 2**).

$$\underbrace{\sqrt{2\sqrt{2\sqrt{2\ \ldots\sqrt{2}}}}}_{m\to\infty}=2$$

Proof. Trivial y the formula above with $x = 2$, $N = 2$ □

Excuse me sir, do you have a moment to talk about our God and saviour

LaTeX?

$$y_{+++}=\sum_{I=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}y_{ijk}$$

Theorem 11. *Let $D = diag(d_1, \dots, d_m) \in \mathbb{F}^{m \times m}$ de a real or complex-valued matrix. Then*

$$e^D = \begin{pmatrix} e^{d_1} & & & & \\ & \ddots & & & \\ & & e^{d_j} & & \\ & & & \ddots & \\ & & & & e^m \end{pmatrix}$$

Proof. We have that

$$\begin{aligned} e^D &= \boldsymbol{I}_m e^D && (12) \\ &= \boldsymbol{I}_m \sum_{n=0}^{\infty} \frac{1}{n!} D^n && (13) \\ &= \sum_{n=0}^{\infty} \frac{1}{n!} \left(\sum_j [\boldsymbol{I}_m]_{ij} D_{jk} \right)^n && (14) \end{aligned}$$

Since

$$[\boldsymbol{I}_m]_{ij} D_{jk} = \begin{cases} D_{jk} & \forall \quad i = j, j = k \\ 0 & \text{else} \end{cases}$$

$$\begin{aligned} \implies e^D &= \sum_{n=0}^{\infty} \frac{1}{n!} \left(\sum_j D_{jj} \right)^n && (15) \\ &= \sum_{n=0}^{\infty} \frac{1}{n!} \left(\sum_j d_j \right)^n && (16) \\ &= e^{\sum_j d_j} && (17) \end{aligned}$$

$$\begin{aligned} \therefore e^D &= \boldsymbol{I}_m e^D && (18) \\ &= \boldsymbol{I}_m e^{\sum_j d_j} && (19) \\ &= \begin{pmatrix} e^{d_1} & & & & \\ & \ddots & & & \\ & & e^{d_j} & & \\ & & & \ddots & \\ & & & & e^m \end{pmatrix} && (20) \end{aligned}$$

□