

A STUDY ON PARTIAL DYNAMIC EQUATION ON TIME SCALES INVOLVING DERIVATIVES OF POLYNOMIALS

PETRO KOLOSOV

ABSTRACT. Let $P(m, b, x)$ be a $2m + 1$ -degree polynomial in x, b . Let be a two-dimensional timescale $\Lambda^2 = \mathbb{T}_1 \times \mathbb{T}_2 = \{t = (x, b): x \in \mathbb{T}_1, b \in \mathbb{T}_2\}$ such that $\mathbb{T}_1 = \mathbb{T}_2$. In this manuscript we derive and discuss an identity that connects the timescale derivative of odd-power polynomial with partial derivatives of polynomial $P(m, b, x)$ evaluated in particular points. For every $t \in \mathbb{T}_1$ and $x, b \in \Lambda^2$

$$\frac{\Delta t^{2m+1}}{\Delta t} = \frac{\partial P(m, b, x)}{\Delta x}(m, \sigma(t), t) + \frac{\partial P(m, b, x)}{\Delta b}(m, t, t)$$

such that $\sigma(t) > t$ is forward jump operator. In addition, we discuss various derivative operators in context of partial cases of above equation, we show finite difference, classical derivative, q -derivative, q -power derivative on behalf of it.

CONTENTS

1. Definitions	2
2. Introduction	3
3. Main results	4
4. Discussion and examples	5
4.1. Time scale of integers $\mathbb{T} = \mathbb{Z} \times \mathbb{Z}$	5
4.2. Time scale of real numbers $\mathbb{T} = \mathbb{R} \times \mathbb{R}$	7
4.3. Quantum time scale $\mathbb{T} = q^{\mathbb{R}} \times q^{\mathbb{R}}$	8
4.4. Quantum power time scale $\mathbb{T} = \mathbb{R}^q \times \mathbb{R}^q$	9

Date: September 16, 2024.

2010 Mathematics Subject Classification. 26E70, 05A30.

Key words and phrases. Dynamic equations on time scales, Partial differential equations on time scales, Partial dynamic equations on time scales, Partial differentiation on time scales, Dynamical systems .

4.5. Pure quantum power time scale $\mathbb{T} = q^{\mathbb{R}^n} \times q^{\mathbb{R}^n}$	11
5. Proof of main theorem	12
Proof of theorem 3.1	13
6. Conclusion and future research	14
References	14
7. Addendum 1: Mathematica scripts	15

1. DEFINITIONS

We now set the following notation such that remains fixed for the remainder of this manuscript

- Let be a function $f: \mathbb{T} \rightarrow \mathbb{R}$ and $t \in \mathbb{T}^\kappa$ then $f^\Delta(t)$ is delta timescale derivative [1]

$$f^\Delta(t) = \frac{f(\sigma(t)) - f(t)}{\sigma(t) - t}$$

where $\sigma(t) - t \neq 0$ and $\sigma(t) > t$ is forward jump operator.

- $\frac{\partial f(t_1, \dots, t_n)}{\Delta_i t_i}$ is the delta partial derivative of $f: \Lambda^n \rightarrow \mathbb{R}$ on n -dimensional timescale Λ^n defined via the limit [2, 3, 4]

$$f_{t_i}^{\Delta_i}(t) = \lim_{s_i \rightarrow t_i} \frac{f(t_1, \dots, t_{i-1}, \sigma_i(t_i), t_{i+1}, \dots, t_n) - f(t_1, \dots, t_{i-1}, s_i, t_{i+1}, \dots, t_n)}{\sigma_i(t_i) - s_i}$$

where $\sigma_i(t_i) > t_i$ and $\sigma_i(t_i) - s_i \neq 0$.

- $D_q f(x)$ is q -derivative [5, 6, 7, 8]

$$D_q f(x) = \frac{f(qx) - f(x)}{qx - x}$$

where $x \neq 0$, $x \in \mathbb{R}$, $q \in \mathbb{R}$.

- $D_{n,q}f(t)$ is q -power derivative [9]

$$D_{n,q}f(t) = \frac{f(qt^n) - f(t)}{qt^n - t}$$

where $qt^n - t \neq 0$ and n is odd positive integer and $0 < q < 1$.

- $\mathcal{D}_q f(x)$ is q -power derivative

$$\mathcal{D}_q f(x) = \frac{f(x^q) - f(x)}{x^q - x}$$

where $x^q \neq x$, $x \in \mathbb{R}$, $q \in \mathbb{R}$.

- $P(m, b, x)$, $x, b \in \mathbb{R}$, $m \in \mathbb{N}$ is $2m + 1$ -degree polynomial in x, b

$$P(m, b, x) = \sum_{k=0}^{b-1} \sum_{r=0}^m \mathbf{A}_{m,r} k^r (x - k)^r \quad (1.1)$$

where $\mathbf{A}_{m,r}$ is a real coefficient defined recursively, see [10].

- \mathbb{Z} is an integer timescale such that $\sigma(t) = t + 1$ and $\mu(t) = 1$.
- \mathbb{R} is a real timescale such that $\sigma(t) = t + \Delta t$ and $\mu(t) = \Delta t$, $\Delta t \rightarrow 0$.
- $q^{\mathbb{R}}$ is a quantum timescale such that $\sigma(t) = qt$ and $\mu(t) = qt - t$, [page 18 [1]].
- \mathbb{R}^q is a quantum power timescale such that $\sigma(t) = t^q$ and $\mu(t) = t^q - t$.
- $q^{\mathbb{R}^n}$ is a pure quantum power timescale such that $\sigma(t) = qt^n > t$, $0 < q < 1$, $\mu(t) = qt^n - t$ and n is positive odd integer [9].

2. INTRODUCTION

Time-scale calculus is quite graceful generalization and unification of the theory of differential equations. Firstly being introduced by Hilger [12] in his Ph.D thesis in 1988 and thereafter greatly extended by Bohner and Peterson [1] in 2001, the calculus on time scales

became a sharp tool in the world on differential equations. Various derivative operators like classical derivative $\frac{d}{dx}f(x)$, q -derivative $D_qf(x)$, q -power derivative $\mathcal{D}_qf(x)$, finite difference $\Delta f(x)$ etc, may be simply expressed in terms of time-scale derivative over particular time scale \mathbb{T} . For instance,

$$f'(x) = f^\Delta(x), \quad x \in \mathbb{T} = \mathbb{R}$$

$$\Delta f(x) = f^\Delta(x), \quad x \in \mathbb{T} = \mathbb{Z}$$

$$D_{n,q}f(x) = f^\Delta(x), \quad x \in \mathbb{T} = q^{\mathbb{R}^n}$$

$$D_qf(x) = f^\Delta(x), \quad x \in \mathbb{T} = q^{\mathbb{R}}$$

$$\mathcal{D}_qf(x) = f^\Delta(x), \quad x \in \mathbb{T} = \mathbb{R}^q$$

In context of Computer Science, namely object oriented programming paradigm, the time scale calculus may be thought as unified interface of derivative operator. Furthermore, the idea of time-scale calculus was slightly extended in [13, 14, 15, 16].

3. MAIN RESULTS

Timescale derivative of the polynomial t^{2m+1} may be expressed as follows

Theorem 3.1. *Let $P(m, b, x)$ be a $2m+1$ -degree polynomial in x, b . Let be a two-dimensional timescale $\Lambda^2 = \mathbb{T}_1 \times \mathbb{T}_2 = \{t = (x, b): x \in \mathbb{T}_1, b \in \mathbb{T}_2\}$ such that $\mathbb{T}_1 = \mathbb{T}_2$. For every $t \in \mathbb{T}_1$ and $x, b \in \Lambda^2$*

$$\frac{\Delta t^{2m+1}}{\Delta t} = \frac{\partial P(m, b, x)}{\Delta x}(m, \sigma(t), t) + \frac{\partial P(m, b, x)}{\Delta b}(m, t, t)$$

where

- $\sigma(t) > t$ – is forward jump operator
- $\frac{\partial P(m, b, x)}{\Delta x}(m, \sigma(t), t)$ – is the value of the partial derivative on time scales of $P(m, b, x)$ with respect to the variable x evaluated in point $x = t$, $b = \sigma(t)$

- $\frac{\partial P(m,b,x)}{\Delta b}(m,t,t)$ – is the value of the partial derivative on time scales of $P(m,b,x)$ with respect to the variable b , evaluated at $x = t$, $b = t$

In simpler words, the theorem 3.1 says

For every odd-exponent polynomial t^{2m+1} , its derivative on time scales equals to the sum of the value of the partial derivative on time scales of $P(m,b,x)$ with respect to the variable x , evaluated at $x = t$, $b = \sigma(t)$ and the value of the partial derivative on time scales of $P(m,b,x)$ with respect to the variable b , evaluated at $x = t$, $b = t$.

In extended form theorem 3.1 may be written as

$$(t^{2m+1})_t^\Delta = \frac{\partial}{\Delta x} \left(\sum_{k=0}^{b-1} \sum_{r=0}^m \mathbf{A}_{m,r} k^r (x-k)^r \right) \Big|_{x=t, b=\sigma(t)} + \frac{\partial}{\Delta b} \left(\sum_{k=0}^{b-1} \sum_{r=0}^m \mathbf{A}_{m,r} k^r (x-k)^r \right) \Big|_{x=t, b=t}$$

4. DISCUSSION AND EXAMPLES

To understand the nature of theorem 3.1, let's discuss an example of some popular time scales, like integer time scale \mathbb{Z} , real time scale \mathbb{R} , quantum time scale $q^{\mathbb{R}}$, quantum-power time scale \mathbb{R}^q . We use the principle *Divide et Impera !* in order to understand entire behavior of theorem 3.1.

4.1. Time scale of integers $\mathbb{T} = \mathbb{Z} \times \mathbb{Z}$.

Corollary 4.1. (*Finite difference.*) Let be a two-dimensional time scale $\Lambda^2 = \mathbb{Z} \times \mathbb{Z} := \{t = (x, b) : x \in \mathbb{Z}, b \in \mathbb{Z}\}$. For every $t \in \mathbb{Z}$, $x, b \in \Lambda^2 = \mathbb{Z} \times \mathbb{Z}$, $m \in \mathbb{N}$

$$\Delta t^{2m+1} = \frac{\partial P(m,b,x)}{\Delta x} \Big|_{x=t, b=\sigma(t)} + \frac{\partial P(m,b,x)}{\Delta b}(t,t) \Big|_{x=t, b=t},$$

where the forward jump operator $\sigma(t)$ is defined as $\sigma(t) = t + 1$.

Example 4.2. Let be $t \in \mathbb{Z}$, $x, b \in \Lambda^2 = \mathbb{Z} \times \mathbb{Z}$, $m \in \mathbb{N}$ and let $m = 1$, then

$$\begin{aligned}\frac{\partial P(1, b, x)}{\Delta x} &= -3b + 3b^2 \\ \frac{\partial P(1, b, x)}{\Delta x} \Big|_{x=t, b=\sigma(t)} &= 3t + 3t^2 \\ \frac{\partial P(1, b, x)}{\Delta b} &= 1 - 6b^2 + 6bx \\ \frac{\partial P(1, b, x)}{\Delta b} \Big|_{x=t, b=t} &= 1\end{aligned}$$

Summing up previously obtained partial time-scale derivatives, we get the ordinary finite difference of odd polynomial t^{2m+1} , $t \in \mathbb{Z}$, $x, b \in \Lambda^2 = \mathbb{Z} \times \mathbb{Z}$, $m \in \mathbb{N}$

$$\Delta t^3 = \frac{\partial P(1, b, x)}{\Delta x} \Big|_{x=t, b=\sigma(t)} + \frac{\partial P(1, b, x)}{\Delta b} \Big|_{x=t, b=t} = 3t^2 + 3t + 1.$$

Example 4.3. Let be $t \in \mathbb{Z}$, $x, b \in \Lambda^2 = \mathbb{Z} \times \mathbb{Z}$, $m \in \mathbb{N}$ and let $m = 2$, then

$$\begin{aligned}\frac{\partial P(2, b, x)}{\Delta x} &= 5b - 30b^2 + 40b^3 - 15b^4 + 10bx - 30b^2x + 20b^3x \\ \frac{\partial P(2, b, x)}{\Delta b} &= 1 + 30b^4 - 60b^3x + 30b^2x^2 \\ \frac{\partial P(2, b, x)}{\Delta x} \Big|_{x=t, b=\sigma(t)} &= 5t + 10t^2 + 10t^3 + 5t^4 \\ \frac{\partial P(2, b, x)}{\Delta b} \Big|_{x=t, b=t} &= 1\end{aligned}$$

Summing up previously obtained partial time-scale derivatives, we get time ordinary finite difference of odd polynomial t^{2m+1} , $t \in \mathbb{Z}$, $x, b \in \Lambda^2 = \mathbb{Z} \times \mathbb{Z}$, $m \in \mathbb{N}$

$$\Delta t^5 = \frac{\partial P(2, b, x)}{\Delta x} \Big|_{x=t, b=\sigma(t)} + \frac{\partial P(2, b, x)}{\Delta b} \Big|_{x=t, b=t} = 1 + 5t + 10t^2 + 10t^3 + 5t^4.$$

Corollary 4.4. For every $t \in \mathbb{Z}$, $x, b \in \Lambda^2 = \mathbb{Z} \times \mathbb{Z}$, $m \in \mathbb{N}$

$$\frac{\partial P(m, b, x)}{\Delta x} \Big|_{x=t, b=\sigma(t)} = \sum_{r=1}^{2m} \binom{2m+1}{r} t^r$$

Corollary 4.5. For every $t \in \mathbb{Z}$, $x, b \in \Lambda^2 = \mathbb{Z} \times \mathbb{Z}$, $m \in \mathbb{N}$

$$\frac{\partial P(m, b, x)}{\Delta b} \Big|_{x=t, b=t} = 1$$

4.2. Time scale of real numbers $\mathbb{T} = \mathbb{R} \times \mathbb{R}$.

Corollary 4.6. *(Classical derivative.) Let be a two-dimensional time scale $\Lambda^2 = \mathbb{R} \times \mathbb{R} := \{t = (x, b) : x \in \mathbb{R}, b \in \mathbb{R}\}$. For every $t \in \mathbb{R}$, $x, b \in \Lambda^2 = \mathbb{R} \times \mathbb{R}$, $m \in \mathbb{N}$*

$$\frac{d}{dt} t^{2m+1} = \frac{\partial P(m, b, x)}{\partial x} \Big|_{x=t, b=\sigma(t)} + \frac{\partial P(m, b, x)}{\partial b} \Big|_{x=t, b=t},$$

where $\sigma(t) = t + \Delta t$, $\Delta t \rightarrow 0$.

Example 4.7. Let be $t \in \mathbb{R}$, $x, b \in \Lambda^2 = \mathbb{R} \times \mathbb{R}$, $m \in \mathbb{N}$ and let $m = 1$, then

$$\begin{aligned} \frac{\partial P(1, b, x)}{\partial x} &= -3b + 3b^2 \\ \frac{\partial P(1, b, x)}{\partial b} &= 6b - 6b^2 - 3x + 6bx \\ \frac{\partial P(1, b, x)}{\partial x} \Big|_{x=t, b=\sigma(t)} &= -3t + 3t^2 \\ \frac{\partial P(1, b, x)}{\partial b} \Big|_{x=t, b=t} &= 3t \end{aligned}$$

Summing up previously obtained partial time-scale derivatives, we get classical derivative of odd polynomial t^{2m+1} , $t \in \mathbb{R}$, $x \in \Lambda^2 = \mathbb{R} \times \mathbb{R}$, $m \in \mathbb{N}$

$$\frac{d}{dt} t^3 = \frac{\partial P(1, b, x)}{\partial x} \Big|_{x=t, b=\sigma(t)} + \frac{\partial P(1, b, x)}{\partial b} \Big|_{x=t, b=t} = 3t^2.$$

Example 4.8. Let be $t \in \mathbb{R}$, $x, b \in \Lambda^2 = \mathbb{R} \times \mathbb{R}$, $m \in \mathbb{N}$ and let $m = 2$, then

$$\begin{aligned} \frac{\partial P(2, b, x)}{\partial x} &= -15b^2 + 30b^3 - 15b^4 + 10bx - 30b^2x + 20b^3x, \\ \frac{\partial P(2, b, x)}{\partial b} &= 30b^2 - 60b^3 + 30b^4 - 30bx + 90b^2x - 60b^3x + 5x^2 - 30bx^2 + 30b^2x^2 \\ \frac{\partial P(2, b, x)}{\partial x} \Big|_{x=t, b=\sigma(t)} &= -5t^2 + 5t^4 \\ \frac{\partial P(2, b, x)}{\partial b} \Big|_{x=t, b=t} &= 5t^2 \end{aligned}$$

Summing up previously obtained partial time-scale derivatives, we get classical derivative of an odd polynomial t^{2m+1} , $t \in \mathbb{R}$, $x \in \Lambda^2 = \mathbb{R} \times \mathbb{R}$, $m \in \mathbb{N}$

$$\frac{d}{dt}t^5 = \frac{\partial P(2, b, x)}{\partial x} \Big|_{x=t, b=\sigma(t)} + \frac{\partial P(2, b, x)}{\partial b} \Big|_{x=t, b=t} = 5t^4.$$

4.3. Quantum time scale $\mathbb{T} = q^{\mathbb{R}} \times q^{\mathbb{R}}$.

Corollary 4.9. (*Q-derivative* [5].) *Let be a two-dimensional time scale $\Lambda^2 = q^{\mathbb{R}} \times q^{\mathbb{R}} := \{t = (x, b) : x \in q^{\mathbb{R}}, b \in q^{\mathbb{R}}\}$. For every $t \in q^{\mathbb{R}}$, $x, b \in \Lambda^2 = q^{\mathbb{R}} \times q^{\mathbb{R}}$, $m \in \mathbb{N}$*

$$D_q t^{2m+1} = \frac{\partial P(m, b, x)}{\Delta x} \Big|_{x=t, b=\sigma(t)} + \frac{\partial P(m, b, x)}{\Delta b} \Big|_{x=t, b=t},$$

where $\sigma(t) = qt$, $q > 1$.

Example 4.10. *Let be $t \in q^{\mathbb{R}}$, $x, b \in \Lambda^2 = q^{\mathbb{R}} \times q^{\mathbb{R}}$, $m \in \mathbb{N}$ and let $m = 1$, then*

$$\begin{aligned} \frac{\partial P(1, b, x)}{\Delta x} &= -3b + 3b^2 \\ \frac{\partial P(1, b, x)}{\Delta b} &= 3b - 2b^2 + 3bq - 2b^2q - 2b^2q^2 - 3x + 3bx + 3bqx \\ \frac{\partial P(1, b, x)}{\Delta x} \Big|_{x=t, b=\sigma(t)} &= -3qt + 3q^2t^2 \\ \frac{\partial P(1, b, x)}{\Delta b} \Big|_{x=t, b=t} &= 3qt + t^2 + qt^2 - 2q^2t^2 \end{aligned}$$

Summing up previously obtained partial time-scale derivatives, we get q -derivative of odd polynomial t^{2m+1} , $t \in q^{\mathbb{R}}$, $x, b \in \Lambda^2 = q^{\mathbb{R}} \times q^{\mathbb{R}}$, $m \in \mathbb{N}$

$$D_q t^3 = \frac{\partial P(1, b, x)}{\Delta x} \Big|_{x=t, b=\sigma(t)} + \frac{\partial P(1, b, x)}{\Delta b} \Big|_{x=t, b=t} = t^2 + qt^2 + q^2t^2.$$

For every $t \in q^{\mathbb{R}}$, $x, b \in \Lambda^2 = q^{\mathbb{R}} \times q^{\mathbb{R}}$ the following polynomial identity holds as q tends to zero

$$\lim_{q \rightarrow 0} \frac{\partial P(1, b, x)}{\Delta b} \Big|_{x=t, b=t} = t^2$$

However, it would be generalized as follows

Corollary 4.11. *For every $t \in q^{\mathbb{R}}$, $x, b \in \Lambda^2 = q^{\mathbb{R}} \times q^{\mathbb{R}}$, $m \in \mathbb{N}$*

$$\lim_{q \rightarrow 0} \frac{\partial P(m, b, x)}{\Delta b} \Big|_{x=t, b=t} = t^{2m}.$$

Example 4.12. *Let be $t \in q^{\mathbb{R}}$, $x, b \in \Lambda^2 = q^{\mathbb{R}} \times q^{\mathbb{R}}$, $m \in \mathbb{N}$ and let $m = 2$, then*

$$\begin{aligned} \frac{\partial P(2, b, x)}{\Delta x} &= -15b^2 + 30b^3 - 15b^4 + 5bx - 15b^2x + 10b^3x + 5bqx - 15b^2qx + 10b^3qx \\ \frac{\partial P(2, b, x)}{\Delta b} &= 10b^2 - 15b^3 + 6b^4 + 10b^2q - 15b^3q + 6b^4q + 10b^2q^2 - 15b^3q^2 + 6b^4q^2 - 15b^3q^3 \\ &\quad + 6b^4q^3 + 6b^4q^4 - 15bx + 30b^2x - 15b^3x - 15bqx + 30b^2qx - 15b^3qx + 30b^2q^2x \\ &\quad - 15b^3q^2x - 15b^3q^3x + 5x^2 - 15bx^2 + 10b^2x^2 - 15bqx^2 + 10b^2qx^2 + 10b^2q^2x^2 \end{aligned}$$

$$\frac{\partial P(2, b, x)}{\Delta x} \Big|_{x=t, b=\sigma(t)} = 5qt^2 - 10q^2t^2 - 15q^2t^3 + 15q^3t^3 + 10q^3t^4 - 5q^4t^4$$

$$\frac{\partial P(2, b, x)}{\Delta b} \Big|_{x=t, b=t} = -5qt^2 + 10q^2t^2 + 15q^2t^3 - 15q^3t^3 + t^4 + qt^4 + q^2t^4 - 9q^3t^4 + 6q^4t^4$$

Summing up previously obtained partial time-scale derivatives, we get the q -derivative of odd polynomial t^{2m+1} , $t \in q^{\mathbb{R}}$, $x, b \in \Lambda^2 = q^{\mathbb{R}} \times q^{\mathbb{R}}$, $m \in \mathbb{N}$

$$D_q t^5 = \frac{\partial P(2, b, x)}{\Delta x} \Big|_{x=t, b=\sigma(t)} + \frac{\partial P(2, b, x)}{\Delta b} \Big|_{x=t, b=t} = t^4 + qt^4 + q^2t^4 + q^3t^4 + q^4t^4.$$

4.4. Quantum power time scale $\mathbb{T} = \mathbb{R}^q \times \mathbb{R}^q$.

Corollary 4.13. (*Q -power derivative [9].*) *Let be a two-dimensional time scale $\Lambda^2 = \mathbb{R}^q \times \mathbb{R}^q := \{t = (x, b) : b \in \mathbb{R}^q, x \in \mathbb{R}^q\}$. For every $t \in \mathbb{R}^q$, $x, b \in \Lambda^2 = \mathbb{R}^q \times \mathbb{R}^q$, $m \in \mathbb{N}$*

$$\mathcal{D}_q t^{2m+1} = \frac{\partial P(m, b, x)}{\Delta x}(t, \sigma(t)) + \frac{\partial P(m, b, x)}{\Delta b}(t, t),$$

where the forward jump operator is defined as $\sigma(t) = t^q$, $q > 1$.

Example 4.14. Let be $t \in \mathbb{R}^q$, $x, b \in \Lambda^2 = \mathbb{R}^q \times \mathbb{R}^q$, $m \in \mathbb{N}$ and let $m = 1$, then

$$\begin{aligned}\frac{\partial P(1, b, x)}{\Delta x} &= -3b + 3b^2 \\ \frac{\partial P(1, b, x)}{\Delta b} &= 3b - 2b^2 + 3b^q - 2b^{2q} - 2b^{1+q} - 3x + 3bx + 3b^q x \\ \left. \frac{\partial P(1, b, x)}{\Delta x} \right|_{x=t, b=\sigma(t)} &= -3t^q + 3t^{2q} \\ \left. \frac{\partial P(1, b, x)}{\Delta b} \right|_{x=t, b=t} &= t^2 + 3t^q - 2t^{2q} + t^{1+q}\end{aligned}$$

Summing up previously obtained partial time-scale derivatives, we get q -power derivative of odd polynomial t^{2m+1} , $t \in \mathbb{R}^q$, $x, b \in \Lambda^2 = \mathbb{R}^q \times \mathbb{R}^q$, $m \in \mathbb{N}$

$$\mathcal{D}_q t^3 = \left. \frac{\partial P(1, b, x)}{\Delta x} \right|_{x=t, b=\sigma(t)} + \left. \frac{\partial P(1, b, x)}{\Delta b} \right|_{x=t, b=t} = t^2 + t^{2q} + t^{1+q}.$$

Example 4.15. Let be $t \in \mathbb{R}^q$, $x, b \in \Lambda^2 = \mathbb{R}^q \times \mathbb{R}^q$, $m \in \mathbb{N}$ and let $m = 2$, then

$$\begin{aligned}\frac{\partial P(2, b, x)}{\Delta x} &= -15b^2 + 30b^3 - 15b^4 + 5bx - 15b^2x + 10b^3x + 5bx^q - 15b^2x^q + 10b^3x^q \\ \frac{\partial P(2, b, x)}{\Delta b} &= 10b^2 - 15b^3 + 6b^4 + 10b^{2q} - 15b^{3q} + 6b^{4q} + 10b^{1+q} - 15b^{2+q} + 6b^{3+q} \\ &\quad - 15b^{1+2q} + 6b^{2+2q} + 6b^{1+3q} - 15bx + 30b^2x - 15b^3x - 15b^qx + 30b^{2q}x \\ &\quad - 15b^{3q}x + 30b^{1+q}x - 15b^{2+q}x - 15b^{1+2q}x + 5x^2 - 15bx^2 + 10b^2x^2 \\ &\quad - 15b^qx^2 + 10b^{2q}x^2 + 10b^{1+q}x^2 \\ \left. \frac{\partial P(2, b, x)}{\Delta x} \right|_{x=t, b=\sigma(t)} &= -10t^{2q} + 15t^{3q} - 5t^{4q} + 5t^{1+q} - 15t^{1+2q} + 10t^{1+3q} \\ \left. \frac{\partial P(2, b, x)}{\Delta b} \right|_{x=t, b=t} &= t^4 + 10t^{2q} - 15t^{3q} + 6t^{4q} - 5t^{1+q} + t^{3+q} + 15t^{1+2q} + t^{2+2q} - 9t^{1+3q}\end{aligned}$$

Summing up previously obtained partial time-scale derivatives, we get q -power derivative of odd polynomial t^{2m+1} , $t \in \mathbb{R}^q$, $x, b \in \Lambda^2 = \mathbb{R}^q \times \mathbb{R}^q$, $m \in \mathbb{N}$

$$\mathcal{D}_q t^5 = \left. \frac{\partial P(2, b, x)}{\Delta x} \right|_{x=t, b=\sigma(t)} + \left. \frac{\partial P(2, b, x)}{\Delta b} \right|_{x=t, b=t} = t^4 + t^{4q} + t^{3+q} + t^{2+2q} + t^{1+3q}.$$

Another polynomial identity, that is exponential sum holds

Corollary 4.16. *For every $t \in \mathbb{R}^q$, $x, b \in \Lambda^2 = \mathbb{R}^q \times \mathbb{R}^q$, $t \in \mathbb{R}$, $m \in \mathbb{N}$*

$$\lim_{q \rightarrow 0} \left. \frac{\partial P(m, b, x)}{\Delta b} \right|_{x=t, b=t} = \sum_{k=0}^{2m} t^k$$

4.5. Pure quantum power time scale $\mathbb{T} = q^{\mathbb{R}^n} \times q^{\mathbb{R}^n}$. In this subsection we discuss a pure quantum power time scale $q^{\mathbb{R}^j}$ provided by Aldwoah, Malinowska and Torres in [9], among with the q -power derivative operator $D_{n,q}f(t)$ defined by

$$D_{n,q}f(t) = \frac{f(qt^n) - f(t)}{qt^n - t},$$

where n is odd positive integer and $0 < q < 1$.

Corollary 4.17. *(Quantum power derivative [9].) Let be a two-dimensional time scale $\Lambda^2 = q^{\mathbb{R}^j} \times q^{\mathbb{R}^j} := \{t = (x, b) : b \in q^{\mathbb{R}^j}, x \in q^{\mathbb{R}^j}\}$. For every $t \in q^{\mathbb{R}^j}$, $x, b \in \Lambda^2 = q^{\mathbb{R}^j} \times q^{\mathbb{R}^j}$, $m \in \mathbb{N}$*

$$D_{n,q}t^{2m+1} = \left. \frac{\partial P(m, b, x)}{\Delta x} \right|_{x=t, b=\sigma(t)} + \left. \frac{\partial P(m, b, x)}{\Delta b} \right|_{x=t, b=t},$$

where $\sigma(t) = qt^n$, $\sigma(t) > t$.

Example 4.18. *Let be $t \in q^{\mathbb{R}^j}$, $x, b \in \Lambda^2 = q^{\mathbb{R}^j} \times q^{\mathbb{R}^j}$, $m \in \mathbb{N}$ and let $m = 1$, then*

$$\begin{aligned} \frac{\partial P(1, b, x)}{\Delta x} &= -3b + 3b^2 \\ \frac{\partial P(1, b, x)}{\Delta b} &= 3b - 2b^2 + 3b^j q - 2b^{1+j} q - 2b^{2j} q^2 - 3x + 3bx + 3b^j qx \\ \frac{\partial P(1, b, x)}{\Delta x}(t, \sigma(t)) &= -3qt^j + 3q^2 t^{2j} \\ \frac{\partial P(1, b, x)}{\Delta b}(t, t) &= t^2 + 3qt^j - 2q^2 t^{2j} + qt^{1+j} \end{aligned}$$

Summing up previously obtained partial time-scale derivatives, we get q -power derivative of odd polynomial t^{2m+1} , $t \in q^{\mathbb{R}^j}$, $x, b \in \Lambda^2 = q^{\mathbb{R}^j} \times q^{\mathbb{R}^j}$, $m \in \mathbb{N}$

$$D_{n,q}t^3 = \left. \frac{\partial P(1, b, x)}{\Delta x} \right|_{x=t, b=\sigma(t)} + \left. \frac{\partial P(1, b, x)}{\Delta b} \right|_{x=t, b=t} = t^2 + q^2 t^{2j} + qt^{1+j}.$$

Another polynomial identity, that is exponential sum holds

Corollary 4.19. *For every $t \in q^{\mathbb{R}^j}$, $x, b \in \Lambda^2 = q^{\mathbb{R}^j} \times q^{\mathbb{R}^j}$, $t \in \mathbb{R}$, $m \in \mathbb{N}$*

$$\lim_{j \rightarrow 0} \lim_{q \rightarrow 1} \frac{\partial P(m, b, x)}{\Delta b} \Big|_{x=t, b=t} = \sum_{k=0}^{2m} t^k$$

An identity in even polynomials holds too

Corollary 4.20. *For every $t \in q^{\mathbb{R}^j}$, $x, b \in \Lambda^2 = q^{\mathbb{R}^j} \times q^{\mathbb{R}^j}$, $t \in \mathbb{R}$, $m \in \mathbb{N}$*

$$\lim_{j \rightarrow 0} \lim_{q \rightarrow 0} \frac{\partial P(m, b, x)}{\Delta b} \Big|_{x=t, b=t} = t^{2m}$$

Example 4.21. *Let be $t \in q^{\mathbb{R}^j}$, $x, b \in \Lambda^2 = q^{\mathbb{R}^j} \times q^{\mathbb{R}^j}$, $m \in \mathbb{N}$ and let $m = 2$, then*

$$\begin{aligned} \frac{\partial P(2, b, x)}{\Delta x} &= -15b^2 + 30b^3 - 15b^4 + 5bx - 15b^2x + 10b^3x + 5bqx^j - 15b^2qx^j + 10b^3qx^j \\ \frac{\partial P(2, b, x)}{\Delta b} &= 10b^2 - 15b^3 + 6b^4 + 10b^{1+j}q - 15b^{2+j}q + 6b^{3+j}q + 10b^{2j}q^2 - 15b^{1+2j}q^2 \\ &\quad + 6b^{2+2j}q^2 - 15b^{3j}q^3 + 6b^{1+3j}q^3 + 6b^{4j}q^4 - 15bx + 30b^2x - 15b^3x - 15b^j qx \\ &\quad + 30b^{1+j}qx - 15b^{2+j}qx + 30b^{2j}q^2x - 15b^{1+2j}q^2x - 15b^{3j}q^3x + 5x^2 - 15bx^2 \\ &\quad + 10b^2x^2 - 15b^j qx^2 + 10b^{1+j}qx^2 + 10b^{2j}q^2x^2 \end{aligned}$$

$$\frac{\partial P(2, b, x)}{\Delta x} \Big|_{x=t, b=\sigma(t)} = -10q^2t^{2j} + 15q^3t^{3j} - 5q^4t^{4j} + 5qt^{1+j} - 15q^2t^{1+2j} + 10q^3t^{1+3j}$$

$$\frac{\partial P(2, b, x)}{\Delta b} \Big|_{x=t, b=t} = t^4 + 10q^2t^{2j} - 15q^3t^{3j} + 6q^4t^{4j} - 5qt^{1+j} + qt^{3+j} + 15q^2t^{1+2j} + q^2t^{2+2j} - 9q^3t^{1+3j}$$

Summing up previously obtained partial time-scale derivatives, we q -power derivative of odd polynomial t^{2m+1} , $t \in q^{\mathbb{R}^j}$, $x, b \in \Lambda^2 = q^{\mathbb{R}^j} \times q^{\mathbb{R}^j}$, $m \in \mathbb{N}$

$$D_{n,q}t^5 = \frac{\partial P(1, b, x)}{\Delta x} \Big|_{x=t, b=\sigma(t)} + \frac{\partial P(1, b, x)}{\Delta b} \Big|_{x=t, b=t} = t^4 + q^4t^{4j} + qt^{3+j} + q^2t^{2+2j} + q^3t^{1+3j}.$$

5. PROOF OF MAIN THEOREM

By [Lemma 3.1 [10]], for every $x \in \mathbb{R}$, $m \in \mathbb{N}$ it is true that

$$P(m, x, x) = x^{2m+1} \tag{5.1}$$

Proof of theorem 3.1. Let be $x, b \in \Lambda^2 = \mathbb{T}_1 \times \mathbb{T}_2 := \{t = (x, b) : x \in \mathbb{T}_1, b \in \mathbb{T}_2\}$. Let be $\mathbb{T}_1 = \mathbb{T}_2$. Assume that time-scale derivative $(x^{2m+1})^\Delta$ is

$$(x^{2m+1})^\Delta = \lim_{b \rightarrow x} \lim_{t \rightarrow x} \frac{P(m, \sigma(b), \sigma(x)) - P(m, b, t)}{\sigma(x) - t}, \quad (5.2)$$

where $\sigma(x) > x$ is forward jump operator. However, equation (5.2) is not a timescale derivative of $P(m, b, x)$ over x how it might seem because of denominator $\sigma(x) - t$. Parameter b of $P(m, b, x)$ is implicitly incremented as well. Let's try to express nominator of (5.2) in terms of partial derivative $\frac{\partial P(m, b, x)}{\Delta b}$ on timescales. Let be the following equation

$$P(m, \sigma(b), x) - P(m, b, x) = P(m, b, x)_b^\Delta \cdot \Delta b$$

Let $t \rightarrow x$ in (5.2). Then nominator of (5.2) equals to

$$P(m, \sigma(b), \sigma(x)) - P(m, b, x) = P(m, \sigma(b), x) - P(m, b, x) + A$$

where A is yet implicit term. Let's now collapse the terms $f_m(x, b)$ from both sides of above equation, such that

$$P(m, \sigma(b), \sigma(x)) = P(m, \sigma(b), \sigma(x)) + A$$

Therefore,

$$A = P(m, \sigma(b), \sigma(x)) - P(m, \sigma(b), \sigma(x)) = P(m, b, x)_x^\Delta(x, \sigma(b)) \cdot \Delta x$$

Now, let's express the nominator of (5.2) as follows

$$P(m, \sigma(b), \sigma(x)) - P(m, b, x) = P(m, b, x)_x^\Delta(x, \sigma(b)) \cdot \Delta x + P(m, b, x)_b^\Delta(x, b) \cdot \Delta b$$

$$P(m, \sigma(b), \sigma(x)) - P(m, b, x) = P(m, b, x)_x^\Delta(x, \sigma(b)) \cdot (\sigma(x) - x) + P(m, b, x)_b^\Delta(x, b) \cdot (\sigma(b) - b)$$

We can collapse the terms $(\sigma(x) - x)$, $(\sigma(b) - b)$ in above expressions, as $b \rightarrow x$. Therefore,

$$\frac{P(m, \sigma(x), \sigma(x)) - P(m, x, x)}{\sigma(x) - x} = P(m, b, x)_x^\Delta(x, \sigma(x)) + P(m, b, x)_b^\Delta(x, x)$$

Finally, by the identity (5.1) we can express timescale derivative of x^{2m+1} , $x \in \Lambda^2 = \mathbb{T}_1 \times \mathbb{T}_2$, $m \in \mathbb{N}$ as

$$(x^{2m+1})^\Delta(t) = \left. \frac{\partial P(m, b, x)}{\Delta x} \right|_{x=t, b=\sigma(t)} + \left. \frac{\partial P(m, b, x)}{\Delta b} \right|_{x=t, b=t}$$

This completes the proof. \square

6. CONCLUSION AND FUTURE RESEARCH

In this manuscript we have discussed partial time scale differential equation involving derivatives of polynomials in context of time scale $\Lambda^2 = \mathbb{T}_1 \times \mathbb{T}_2$ where $\mathbb{T}_1 = \mathbb{T}_2$. Future research can be conducted to study the case $\mathbb{T}_1 \neq \mathbb{T}_2$, which makes the theorem 3.1 to be generalised

$$\frac{\partial P(m, b, x)}{\Delta x} + \frac{\partial P(m, b, x)}{\Delta b} = \alpha_m(x, b)(x^{2m+1})^\Delta,$$

where $\alpha_m(x, b)$ is arbitrary differentiable function. Also, it is worth to discuss the theorem 3.1 in context of high order derivatives on time scales. We have established a few power identities, and shown the theorem 3.1 for different 2-dimensional time scales Λ^2 like integer time scale $\mathbb{Z} \times \mathbb{Z}$, real time scale $\mathbb{R} \times \mathbb{R}$, quantum time scale $q^\mathbb{R} \times q^\mathbb{R}$ and quantum power time scale $\mathbb{R}^q \times \mathbb{R}^q$.

REFERENCES

- [1] Martin Bohner and Allan Peterson. *Dynamic equations on time scales: An introduction with applications*. Springer Science & Business Media, 2001. <https://web.mst.edu/~bohner/sample.pdf>.
- [2] Martin Bohner and Gusein Sh Guseinov. Partial differentiation on time scales. *Dynamic systems and applications*, 13(3-4):351–379, 2004. <http://web.mst.edu/~bohner/papers/pdots.pdf>.
- [3] Calvin D Ahlbrandt and Christina Morian. Partial differential equations on time scales. *Journal of Computational and Applied Mathematics*, 141(1-2):35–55, 2002. [https://doi.org/10.1016/S0377-0427\(01\)00434-4](https://doi.org/10.1016/S0377-0427(01)00434-4).
- [4] B. Jackson. Partial dynamic equations on time scales. *Journal of Computational and Applied Mathematics*, 186(2):391 – 415, 2006. <https://doi.org/10.1016/j.cam.2005.02.011>.
- [5] Frederick H Jackson. Xi.—on q-functions and a certain difference operator. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh*, 46(2):253–281, 1909.

- [6] Thomas Ernst. *The history of q-calculus and a new method*. Citeseer, 2000.
- [7] Thomas Ernst. The different tongues of q-calculus. *Proceedings of the Estonian Academy of Sciences*, 57(2), 2008.
- [8] Victor Kac and Pokman Cheung. *Quantum calculus*. Springer Science & Business Media, 2001.
- [9] Khaled A Aldwoah, Agnieszka B Malinowska, and Delfim FM Torres. The power quantum calculus and variational problems. *arXiv preprint arXiv:1107.0344*, 2011. <https://arxiv.org/abs/1107.0344>.
- [10] Petro Kolosov. On the link between Binomial Theorem and Discrete Convolution of Polynomials. *arXiv preprint arXiv:1603.02468*, 2016. <https://arxiv.org/abs/1603.02468>.
- [11] Eric W Weisstein. "Bernoulli Number." From MathWorld – A Wolfram Web Resource. <http://mathworld.wolfram.com/BernoulliNumber.html>.
- [12] S Hilger. *Eine Maßkettenkalkül mit Anwendung auf Zentrumsmannigfaltigkeit*. PhD thesis, Ph. D. Thesis, Universität Würzburg, 1988.
- [13] Benaoumeur Bayour, Ahmed Hammoudi, and Delfim FM Torres. A truly conformable calculus on time scales. *arXiv preprint arXiv:1705.08928*, 2017. <https://arxiv.org/abs/1705.08928>.
- [14] Nadia Benkhettou, Salima Hassani, and Delfim FM Torres. A conformable fractional calculus on arbitrary time scales. *Journal of King Saud University-Science*, 28(1):93–98, 2016.
- [15] M Cristina Caputo. Time scales: from nabla calculus to delta calculus and vice versa via duality. *arXiv preprint arXiv:0910.0085*, 2009.
- [16] Natália Martins and Delfim FM Torres. Calculus of variations on time scales with nabla derivatives. *Nonlinear Analysis: Theory, Methods & Applications*, 71(12):e763–e773, 2009.
- [17] Petro Kolosov. Supplementary Mathematica Programs. 2020. <https://github.com/kolosovpetro/AStudyOnDynamicEquations/tree/develop/mathematica>.

Version: Local-0.1.0

7. ADDENDUM 1: MATHEMATICA SCRIPTS

To fulfill our study, we attach here a link to the set of *Mathematica* programs, designed to verify the results of current manuscript. To reach these programs follow the link [17]. To reproduce results, proceed as follows:

- Time scale of integers $\mathbb{T} = \mathbb{Z} \times \mathbb{Z}$:
 - Example 4.2: Execute the commands of Mathematica package

- * Set `sigma[x_] := x + 1` in Mathematica package and execute definition.
 - * Execute `timeScaleDerivativeX[1, x, b]` which produces $-3b + 3b^2$.
 - * Execute `Expand[timeScaleDerivativeX[1, t, sigma[t]]]` which produces $3t + 3t^2$.
 - * Execute `timeScaleDerivativeB[1, x, b]` which produces $1 - 6b^2 + 6bx$.
 - * Execute `timeScaleDerivativeB[1, t, t]` which produces 1.
 - * Execute `mainTheorem[1]` which produces $1 + 3t + 3t^2$.
- Example 4.3: Execute the commands of Mathematica package
- * Set `sigma[x_] := x + 1` in Mathematica package and execute definition.
 - * `timeScaleDerivativeX[2, x, b]` which produces $5b - 30b^2 + 40b^3 - 15b^4 + 10bx - 30b^2x + 20b^3x$.
 - * `Expand[timeScaleDerivativeX[2, t, sigma[t]]]` which produces $5t + 10t^2 + 10t^3 + 5t^4$.
 - * `timeScaleDerivativeB[2, x, b]` which produces $1 + 30b^4 - 60b^3x + 30b^2x^2$.
 - * `timeScaleDerivativeB[2, t, t]` which produces 1.
 - * `mainTheorem[2]` which produces $1 + 5t + 10t^2 + 10t^3 + 5t^4$.
- Time scale of real numbers $\mathbb{T} = \mathbb{R} \times \mathbb{R}$:
 - Example 4.7: Execute the commands of Mathematica package
 - * Set `sigma[x_] := x + Global`dx` in Mathematica package and execute definition.
 - * Execute `timeScaleDerivativeX[1, x, b]` which produces $-3b + 3b^2$.
 - * Execute `Limit[Expand[timeScaleDerivativeB[1, x, b]], dx -> 0]` which produces $6b - 6b^2 - 3x + 6bx$.

- * Execute `timeScaleDerivativeX[1, t, t]` which produces $-3t + 3t^2$.
 - * Execute `Limit[Expand[timeScaleDerivativeB[1, t, t]], dx -> 0]` which produces $3t$.
 - * Execute `Limit[mainTheorem[1], dx -> 0]` which produces $3t^2$.
- Example 4.8: Execute the commands of Mathematica package
- * Set `sigma[x_] := x + Global`dx` in Mathematica package and execute definition.
 - * Execute `Limit[Expand[timeScaleDerivativeX[2, x, b]], dx -> 0]` which produces $-15b^2 + 30b^3 - 15b^4 + 10bx - 30b^2x + 20b^3x$.
 - * Execute `Limit[Expand[timeScaleDerivativeB[2, x, b]], dx -> 0]` which produces $30b^2 - 60b^3 + 30b^4 - 30bx + 90b^2x - 60b^3x + 5x^2 - 30bx^2 + 30b^2x^2$.
 - * Execute `Limit[Expand[timeScaleDerivativeX[2, t, sigma[t]]], dx -> 0]` which produces $-5t^2 + 5t^4$.
 - * Execute `Limit[Expand[timeScaleDerivativeB[2, t, t]], dx -> 0]` which produces $5t^2$.
 - * Execute `Limit[mainTheorem[2], dx -> 0]` which produces $5t^4$.
- Quantum time scale $\mathbb{T} = q^{\mathbb{R}} \times q^{\mathbb{R}}$:
 - Example 4.10: Execute the commands of Mathematica package
 - * Set `sigma[x_] := x * Global`q` in Mathematica package and execute definition.
 - * Execute `Expand[Simplify[timeScaleDerivativeX[1, x, b]]]` which produces $-3b + 3b^2$.
 - * Execute `Expand[Simplify[timeScaleDerivativeB[1, x, b]]]` which produces $3b - 2b^2 + 3bq - 2b^2q - 2b^2q^2 - 3x + 3bx + 3bqx$.
 - * Execute `Expand[Simplify[timeScaleDerivativeX[1, t, sigma[t]]]]` which produces $-3qt + 3q^2t^2$.

- * Execute `Expand[Simplify[timeScaleDerivativeB[1, t, t]]]` which produces $3qt + t^2 + qt^2 - 2q^2t^2$.
- * Execute `Expand[Simplify[mainTheorem[1]]]` which produces $t^2 + qt^2 + q^2t^2$.
- Example 4.12: Execute the commands of Mathematica package
 - * Set `sigma[x_] := x * Global`q` in Mathematica package and execute definition.
 - * Execute `Expand[Simplify[timeScaleDerivativeX[2, x, b]]]` which produces $-15b^2 + 30b^3 - 15b^4 + 5bx - 15b^2x + 10b^3x + 5bqx - 15b^2qx + 10b^3qx$.
 - * Execute `Expand[Simplify[timeScaleDerivativeB[2, x, b]]]` which produces $10b^2 - 15b^3 + 6b^4 + 10b^2q - 15b^3q + 6b^4q + 10b^2q^2 - 15b^3q^2 + 6b^4q^2 - 15b^3q^3 + 6b^4q^3 + 6b^4q^4 - 15bx + 30b^2x - 15b^3x - 15bqx + 30b^2qx - 15b^3qx + 30b^2q^2x - 15b^3q^2x - 15b^3q^3x + 5x^2 - 15bx^2 + 10b^2x^2 - 15bqx^2 + 10b^2qx^2 + 10b^2q^2x^2$.
 - * Execute `Expand[Simplify[timeScaleDerivativeX[2, t, sigma[t]]]` which produces $5qt^2 - 10q^2t^2 - 15q^2t^3 + 15q^3t^3 + 10q^3t^4 - 5q^4t^4$.
 - * Execute `Expand[Simplify[timeScaleDerivativeB[2, t, t]]]` which produces $-5qt^2 + 10q^2t^2 + 15q^2t^3 - 15q^3t^3 + t^4 + qt^4 + q^2t^4 - 9q^3t^4 + 6q^4t^4$.
 - * Execute `Expand[Simplify[mainTheorem[2]]]` which produces $t^4 + qt^4 + q^2t^4 + q^3t^4 + q^4t^4$.
- Corollary 4.11: Execute the commands of Mathematica package
 - * Set `sigma[x_] := x * Global`q` in Mathematica package and execute definition.
 - * Execute `Limit[Expand[Simplify[timeScaleDerivativeB[m, t, t]]], q -> 0]` for various values of m .

• Quantum power time scale $\mathbb{T} = \mathbb{R}^q \times \mathbb{R}^q$:

- Example 4.14: Execute the commands of Mathematica package

- * Set `sigma[x_] := x ^ Global`q` in Mathematica package and execute definition.
 - * Execute `Expand[Simplify[timeScaleDerivativeX[1, x, b]]]` which produces $-3b + 3b^2$.
 - * Execute `Expand[Simplify[timeScaleDerivativeB[1, x, b]]]` which produces $3b - 2b^2 + 3b^q - 2b^{2q} - 2b^{1+q} - 3x + 3bx + 3b^q x$.
 - * Execute `Expand[Simplify[timeScaleDerivativeX[1, t, sigma[t]]]]` which produces $-3t^q + 3t^{2q}$.
 - * Execute `Expand[Simplify[timeScaleDerivativeB[1, t, t]]]` which produces $t^2 + 3t^q - 2t^{2q} + t^{1+q}$.
 - * Execute `Expand[Simplify[mainTheorem[1]]]` which produces $t^2 + t^{2q} + t^{1+q}$.
- Example 4.15: Similarly to Example 4.14 with $m = 2$.
 - Corollary 4.16: Execute the commands of Mathematica package
 - * Set `sigma[x_] := x ^ Global`q` in Mathematica package and execute definition.
 - * Execute `Limit[Expand[Simplify[timeScaleDerivativeB[m, t, t]]], q -> 0]` for various values of m .
- Pure quantum power time scale $\mathbb{T} = q^{\mathbb{R}^n} \times q^{\mathbb{R}^n}$:
 - Example 4.18: Execute the commands of Mathematica package
 - * Set `sigma[x_] := Global`q * x ^ Global`j` in Mathematica package and execute definition.
 - * Execute `Expand[Simplify[timeScaleDerivativeX[1, x, b]]]` which produces $-3b + 3b^2$.
 - * Execute `Expand[Simplify[timeScaleDerivativeB[1, x, b]]]` which produces $3b - 2b^2 + 3b^j q - 2b^{1+j} q - 2b^{2j} q^2 - 3x + 3bx + 3b^j qx$.

- * Execute `Expand[Simplify[timeScaleDerivativeX[1, t, sigma[t]]]` which produces $-3qt^j + 3q^2t^{2j}$.
- * Execute `Expand[Simplify[timeScaleDerivativeB[1, t, t]]]` which produces $t^2 + 3qt^j - 2q^2t^{2j} + qt^{1+j}$.
- * Execute `Expand[Simplify[mainTheorem[1]]]` which produces $t^2 + q^2t^{2j} + qt^{1+j}$.
- Example 4.21: Similarly as Example 4.18 for $m = 2$.
- Corollary 4.19: Execute the commands of Mathematica package
 - * Set `sigma[x_] := Global`q * x ^ Global`j` in Mathematica package and execute definition.
 - * Execute `Limit[Limit[Expand[Simplify[timeScaleDerivativeB[m, t, t]]], q -> 1], j -> 0]` for various values of m .
- Corollary 4.20: Execute the commands of Mathematica package
 - * Set `sigma[x_] := Global`q * x ^ Global`j` in Mathematica package and execute definition.
 - * Execute `Limit[Limit[Expand[Simplify[timeScaleDerivativeB[5, t, t]]], q -> 0], j -> 0]` for various values of m .

Email address: kolosovp94@gmail.com

URL: <https://kolosovpetro.github.io>