Integrals of bsplines of degree 0,1,2 and 3

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Another tool for ToFu

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Contents

0.1 Introduction

0.1.1 General problem

Quadrature[1] is numerical integration by summing the weighted values of the integrand assessed at well-chosen fixed points $\int_a^b f(x)dx = \sum_{i=1}^n w_i f(x_i)$. The points are found by computing the roots of a set of special orthogonal polynomials.

Gaussian quadrature is a method of choosing n points and weights such that the result is exact for a polynomial of degree $d \leq 2n-1$. Hence, for a bspline of degree d, the gaussian quadrature is exact if we have $n \geq (d+1)/2$ points.

More generally, if $f(x) = h(x)g(x)$ where at least g is a polynom with proper degree and h is know, then modified points $x_i^{/}$ and weights $w_i^{/}$ can be used. When the weight function is $h(x) = 1$ (i.e. when f is a polynomial of appropriate regularity), the best weights and points are the Gauss-Legendre or Gauss-Lobatto ones (we will focus on Gauss-Legendre in the following). In other cases, some special points and weights can be obtained for specific weighting funtions which are not polynomials:

Table 0.1.1: Quadrature formulas vs weighting function

	interval	h	orthogonal polynomials
	$[-1;1]$	1	Gauss-Legendre
	$[-1;1]$	$(1-x)^\alpha(1+x)^\beta,\ \alpha,\beta > -1$	Jacobi
	$[-1;1]$	$1/\sqrt{1-x^2}$	1st kind Chebyshev
$f(x) = h(x)g(x)$ where g is a polynomial and h is the weighting function	$[-1;1]$	$\sqrt{1-x^2}$	2nd kind Chebyshev
	$[0;\infty]$	e^{-x}	Laguerre
	$[0;\infty]$	$x^\alpha e^{-x},\ \alpha > -1$	Generalized Laguerre
	$[-\infty;\infty]$	e^{-x^2}	Hermite

0.1.2 Gauss-Legendre

In this section, the domain of integration is $[-1;1]$.

Table 0.1.2: Gauss-Legendre quadrature formulas on $[-1;1]$

The interval of integration is $[1;1]$

Degree d	Nb. of points n	Points x_i	Weights w_i
0	1	0	2
1	1	0	2
2	2	$\pm 1/\sqrt{3}$	1
3	2	$\pm 1/\sqrt{3}$	1
4	3	$0, \pm\sqrt{\frac{3}{5}}$	$\frac{8}{9}, \frac{5}{9}$
5	3	$0, \pm\sqrt{\frac{3}{5}}$	$\frac{8}{9}, \frac{5}{9}$
6	4	$\pm\sqrt{\frac{3}{7} - \frac{2}{7}\sqrt{\frac{6}{5}}}, \pm\sqrt{\frac{3}{7} + \frac{2}{7}\sqrt{\frac{6}{5}}}$	$\frac{18+\sqrt{30}}{36}, \frac{18-\sqrt{30}}{36}$

0.1.3 Rescaling

Since $\int_a^b f(x)dx = \frac{b-a}{2}\int_{-1}^1 f\left(\frac{b-a}{2}x + \frac{a+b}{2}\right)dx$, we can derive;

$$\int_a^b f(x)dx = \frac{b-a}{2}\sum_{i=1}^n w_i f\left(\frac{b-a}{2}x_i + \frac{a+b}{2}\right)$$

[1] see https://en.wikipedia.org/wiki/Gaussian_quadrature

0.2 1D b-splines

0.2.1 Linear functionals

In the following, we tr to use quadrature formulas to derive, when possible, operators for matrix computation of integrals, noting $\underline{C} = \begin{pmatrix} c_0 \\ \vdots \\ c_j \\ \vdots \\ c_{N-1} \end{pmatrix}$ the vector of N coefficients associated to each b-spline. In the case of linear functionals (i.e.: D0, D0N1, D1, D1N2, D2, D2N2, D3, D3N2), we used Gauss-Legendre quadrature because all integrands are themselves polynomials. By noting $\partial_m b_{d,0}$ the m-th derivative of b-spline $b_{d,0}$, where $m \leq d$, if $g(x) = \sum_{j=0}^{N-1} c_j b_{d,j}$ is a sum of b-splines, then, since a sum of polynomials of any degree is also a polynomial of the same degree:

D0, D1, D2, D3

$$\begin{aligned}
\int_a^b g(x)dx &= \tfrac{b-a}{2} \textstyle\sum_{i=1}^n w_i g\left(\tfrac{b-a}{2}x_i + \tfrac{a+b}{2}\right) && \text{(faster evaluation with known coefs)} \\
&= \tfrac{b-a}{2} \textstyle\sum_{i=1}^n w_i \sum_{j=0}^{N-1} c_j b_{d,j}\left(\tfrac{b-a}{2}x_i + \tfrac{a+b}{2}\right) \\
&= \textstyle\sum_{j=0}^{N-1} c_j \times \left[\tfrac{b-a}{2} \sum_{i=1}^n w_i b_{d,j}\left(\tfrac{b-a}{2}x_i + \tfrac{a+b}{2}\right)\right] \\
&= \textstyle\sum_{j=0}^{N-1} c_j \times A_j && \text{(coefs factorized for pre-computing)}
\end{aligned}$$

So here

$$\int_a^b g(x)dx \quad = \underline{AC} \quad = (A_0 \dots A_j \dots A_{N-1})\, \underline{C}$$

D0N2

Similarly, a polynomial of degree d squared is a polynomial of degree $2d$, but since:

$$\begin{aligned}
\int_a^b g^2(x)dx &= \tfrac{b-a}{2} \textstyle\sum_{i=1}^n w_i g^2\left(\tfrac{b-a}{2}x_i + \tfrac{a+b}{2}\right) && \text{(faster evaluation with known coefs)} \\
&= \tfrac{b-a}{2} \textstyle\sum_{i=1}^n w_i \left(\sum_{j=0}^{N-1} c_j b_{d,j}\left(\tfrac{b-a}{2}x_i + \tfrac{a+b}{2}\right)\right)^2
\end{aligned}$$

Then the factorisation depends on the degree of the b-splines (which determines the overlap, i.e.: the number of terms in the squared brackets).

$d = 0 \Rightarrow$ no overlapping and $n = 1$ ($2 \times 0 = 0$)

$$\begin{aligned}
\int_a^b g^2(x)dx &= \tfrac{b-a}{2} \textstyle\sum_{i=1}^n w_i \sum_{j=0}^{N-1} c_j^2 b_{0,j}^2\left(\tfrac{b-a}{2}x_i + \tfrac{a+b}{2}\right) \\
&= \textstyle\sum_{j=0}^{N-1} c_j^2 \times \left[\tfrac{b-a}{2} \sum_{i=1}^n w_i b_{0,j}^2\left(\tfrac{b-a}{2}x_i + \tfrac{a+b}{2}\right)\right] \\
&= \textstyle\sum_{j=0}^{N-1} c_j^2 \times A_j && \text{(coefs factorized for pre-computing)}
\end{aligned}$$

So, here an operator can be derived in a matrix form:

$$\begin{aligned}
\int_a^b g^2(x)dx &= {}^t\,\underline{C}\underline{\underline{A}}\underline{C} \\
&= {}^t\,\underline{C} \begin{pmatrix} A_0 & & & & \\ & \ddots & & & \\ & & A_j & & \\ & & & \ddots & \\ & & & & A_{N-1} \end{pmatrix} \underline{C}
\end{aligned}$$

$d = 1 \Rightarrow$ **2 b-splines on each interval** $n = 2$ $(2 \times 1 = 2)$ Here, we decompose the total interval $[a; b]$ into elementary intervals $I_k = [a_k; b_k]$ matching the knots of the bsplines $\int_a^b g^2(x)dx = \sum_{k=0}^{K-1} \int_{x_k}^{x_{k+1}} g^2(x)dx$, where $N = K - 1 - d$ To simplify the equations, we note $X_{i,k} = \frac{x_{k+1}-x_k}{2} x_i + \frac{x_k+x_{k+1}}{2}$.
With this notation, each b-spline $b_{d,j}$ lives on an interval $I_j = [x_j; x_{j+1+d}]$. Hence, if we consider just one mesh element $[x_k; x_{k+1}]$, two halves of two bsplines of $d = 1$ live on it:

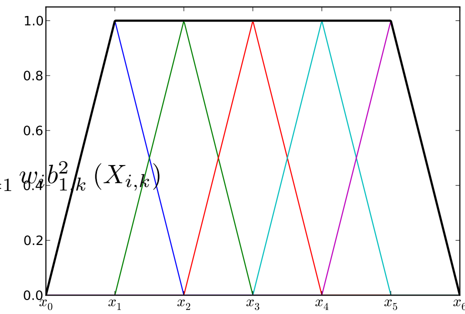

Figure 0.2.1: ToFu-created $d = 1$ bsplines

$$
\begin{array}{rl}
& \int_{x_k}^{x_{k+1}} g^2(x)dx \\
= & \frac{x_{k+1}-x_k}{2} \sum_{i=1}^{n} w_i \left(c_{k-1} b_{1,k-1}\left(X_{i,k}\right) + c_k b_{1,k}\left(X_{i,k}\right)\right)^2 \\
= & \frac{x_{k+1}-x_k}{2} \sum_{i=1}^{n} w_i \left(c_{k-1}^2 b_{1,k-1}^2\left(X_{i,k}\right) + 2c_{k-1}c_k b_{1,k-1}\left(X_{i,k}\right) b_{1,k}\left(X_{i,k}\right) + c_k^2 b_{1,k}^2\left(X_{i,k}\right) + \right) \\
= & c_{k-1}^2 \frac{x_{k+1}-x_k}{2} \sum_{i=1}^{n} w_i b_{1,k-1}^2\left(X_{i,k}\right) + 2c_{k-1}c_k \frac{x_{k+1}-x_k}{2} \sum_{i=1}^{n} w_i b_{1,k-1}\left(X_{i,k}\right) b_{1,k}\left(X_{i,k}\right) + c_k^2 \frac{x_{k+1}-x_k}{2} \sum_{i=1}^{n} w_i b_{1,k}^2\left(X_{i,k}\right) \\
= & c_{k-1}^2 A_{k-1,k-1,k} + 2c_{k-1}c_k A_{k-1,k,k} + c_k^2 A_{k,k,k}
\end{array}
$$

Hence, by summing over all intervals:

$$
\begin{array}{rcll}
\int_a^b g^2(x)dx & = & c_0^2 \int_{x_0}^{x_1} b_{2,0}^2 & (k=0) \\
& & +c_0^2 \int_{x_1}^{x_2} b_{2,0}^2 + c_1^2 \int_{x_1}^{x_2} b_{2,1}^2 + 2c_0c_1 \int_{x_1}^{x_2} b_{2,0}b_{2,1} & (k=1) \\
& & +c_1^2 \int_{x_2}^{x_3} b_{2,1}^2 + c_2^2 \int_{x_2}^{x_3} b_{2,2}^2 + 2c_1c_2 \int_{x_2}^{x_3} b_{2,1}b_{2,2} & (k=2) \\
& & +c_2^2 \int_{x_3}^{x_4} b_{2,2}^2 + c_3^2 \int_{x_3}^{x_4} b_{2,3}^2 + 2c_2c_3 \int_{x_3}^{x_4} b_{2,2}b_{2,3} & (k=3) \\
& & + \dots & \\
& = & c_0^2 \int_{I_0} b_{2,0}^2 + 2c_0c_1 \int_{I_0 \bigcap I_1} b_{2,0}b_{2,1} + c_1^2 \int_{I_1} b_{2,1}^2 + 2c_1c_2 \int_{I_1 \bigcap I_2} b_{2,1}b_{2,2} + \dots &
\end{array}
$$

Where we have introduce I_j the interval on which $b_{1,j}$ lives. Thus noting $A_{i,j} = \int_{I_i \bigcap I_j} b_{2,i} b_{2,j} = A_{j,i}$.

$$
\int_a^b g^2(x)dx = {}^t\underline{C}\underline{\underline{A}}\underline{C} = {}^t\underline{C}
\begin{pmatrix}
\int_{I_0} b_{1,0}^2 & A_{0,1} & & & & & \\
A_{0,1} & \ddots & \ddots & & & & \\
& \ddots & \ddots & A_{j,j-1} & & & \\
& & A_{j,j-1} & \int_{I_j} b_{1,j}^2 & A_{j,j+1} & & \\
& & & A_{j,j+1} & \ddots & \ddots & \\
& & & & \ddots & \ddots & A_{N-2,N-1} \\
& & & & & A_{N-2,N-1} & \int_{I_{N-1}} b_{1,N-1}^2
\end{pmatrix}
\underline{C}
$$

$d=2 \Rightarrow$ **3 b-splines on each interval** $n=3$ $(2\times 2=4)$ Following the same logic, we have here for each interval:

$$
\begin{array}{cl}
 & \int_{x_k}^{x_{k+1}} g^2(x)dx \\
= & \int_{x_k}^{x_{k+1}} \left(c_{k-2}b_{2,k-2}+c_{k-1}b_{2,k-1}+c_k b_{2,k}\right)^2(x)dx \\
= & \int_{x_k}^{x_{k+1}} c_{k-2}^2 b_{2,k-2}^2 + c_{k-1}^2 b_{2,k-1}^2 + 2c_{k-2}b_{2,k-2}c_{k-1}b_{2,k-1} + c_k^2 b_{2,k}^2 + 2c_k b_{2,k}c_{k-2}b_{2,k-2} + 2c_k b_{2,k} c_{k-1} b_{2,k-1} \\
= & c_{k-2}^2 \int_{x_k}^{x_{k+1}} b_{2,k-2}^2 + c_{k-1}^2 \int_{x_k}^{x_{k+1}} b_{2,k-1}^2 + c_k^2 \int_{x_k}^{x_{k+1}} b_{2,k}^2 ... \\
 & +2c_{k-2}c_{k-1}\int_{x_k}^{x_{k+1}} b_{2,k-2}b_{2,k-1} + 2c_k c_{k-2}\int_{x_k}^{x_{k+1}} b_{2,k}b_{2,k-2} + 2c_k c_{k-1}\int_{x_k}^{x_{k+1}} b_{2,k}b_{2,k-1}
\end{array}
$$

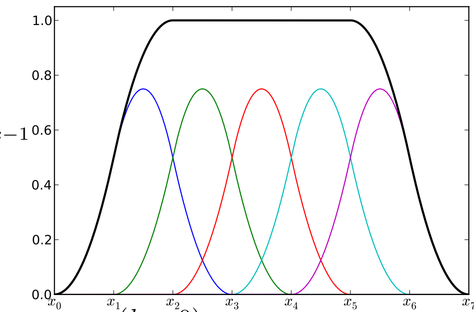

Figure 0.2.2: ToFu-created $d=2$ bsplines

Hence, by summing over all intervals:

$$
\begin{array}{lcll}
\int_a^b g^2(x)dx & = & c_0^2 \int_{x_0}^{x_1} b_{2,0}^2 & (k=0) \\
 & & +c_0^2 \int_{x_1}^{x_2} b_{2,0}^2 + c_1^2 \int_{x_1}^{x_2} b_{2,1}^2 + 2c_0c_1 \int_{x_1}^{x_2} b_{2,0}b_{2,1} & (k=1) \\
 & & +c_0^2 \int_{x_2}^{x_3} b_{2,0}^2 + c_1^2 \int_{x_2}^{x_3} b_{2,1}^2 + c_2^2 \int_{x_2}^{x_3} b_{2,2}^2 + 2c_0c_1 \int_{x_2}^{x_3} b_{2,0}b_{2,1} + 2c_0c_2 \int_{x_2}^{x_3} b_{2,0}b_{2,2} + 2c_1c_2 \int_{x_2}^{x_3} b_{2,1}b_{2,2} & (k=2) \\
 & & +c_1^2 \int_{x_3}^{x_4} b_{2,1}^2 + c_2^2 \int_{x_3}^{x_4} b_{2,2}^2 + c_3^2 \int_{x_3}^{x_4} b_{2,3}^2 + 2c_1c_2 \int_{x_3}^{x_4} b_{2,1}b_{2,2} + 2c_1c_3 \int_{x_3}^{x_4} b_{2,1}b_{2,3} + 2c_2c_3 \int_{x_3}^{x_4} b_{2,2}b_{2,3} & (k=3) \\
 & & + \dots & \\
 & = & c_0^2 \int_{I_0} b_{2,0}^2 + 2c_0c_1 \int_{I_0 \bigcap I_1} b_{2,0}b_{2,1} + 2c_0c_2 \int_{I_0 \bigcap I_2} b_{2,0}b_{2,2} + c_1^2 \int_{I_1} b_{2,1}^2 + 2c_1c_2 \int_{I_1 \bigcap I_2} b_{2,1}b_{2,2} + \dots &
\end{array}
$$

So in matrix form, still noting $A_{i,j} = \int_{I_i \bigcap I_j} b_{2,i}b_{2,j} = A_{j,i}$:

$$
\int_a^b g^2(x)dx = {}^t\underline{C}\underline{\underline{A}}\underline{C} = {}^t\underline{C}
\begin{pmatrix}
\int_{I_0} b_{2,0}^2 & A_{0,1} & A_{0,2} & & & & & & & & \\
A_{0,1} & \ddots & \ddots & \ddots & & & & & & & \\
A_{0,2} & \ddots & \ddots & \ddots & \ddots & & & & & & \\
 & \ddots & \ddots & \ddots & \ddots & A_{j,j-2} & & & & & \\
 & & \ddots & \ddots & \ddots & A_{j,j-1} & \ddots & & & & \\
 & & & A_{j,j-2} & A_{j,j-1} & \int_{I_j} b_{2,j}^2 & A_{j,j+1} & A_{j,j+2} & & & \\
 & & & & \ddots & A_{j,j+1} & \ddots & \ddots & \ddots & & \\
 & & & & & A_{j,j+2} & \ddots & \ddots & \ddots & \ddots & \\
 & & & & & & \ddots & \ddots & \ddots & \ddots & A_{N-1,N-3} \\
 & & & & & & & \ddots & \ddots & \ddots & A_{N-1,N-2} \\
 & & & & & & & & A_{N-1,N-3} & A_{N-1,N-2} & \int_{I_{N-1}} b_{2,N-1}^2
\end{pmatrix}
\underline{C}
$$

∞

$d=3 \Rightarrow$ **4 b-splines on each interval** $n=4$ **(**$2\times 3=6$**)** The degree determines the amount of overlapping (i.e.: the number of non-zero diagonals in the matrix). Apart from that, the rest remains similar since we are still deriving the squared total function.

$$
\begin{aligned}
& \int_{x_k}^{x_{k+1}} g^2(x)dx \\
= \ & \int_{x_k}^{x_{k+1}} \left(c_{k-3}b_{3,k-3} + c_{k-2}b_{3,k-2} + c_{k-1}b_{3,k-1} + c_k b_{3,k}\right)^2(x)dx \\
= \ & c_{k-3}^2 \int_{x_k}^{x_{k+1}} b_{3,k-3}^2 + c_{k-2}^2 \int_{x_k}^{x_{k+1}} b_{3,k-2}^2 + c_{k-1}^2 \int_{x_k}^{x_{k+1}} b_{3,k-1}^2 + c_k^2 \int_{x_k}^{x_{k+1}} b_{3,k}^2 \dots \\
& +2c_{k-3}c_{k-2} \int_{x_k}^{x_{k+1}} b_{3,k-3}b_{3,k-2} + 2c_{k-3}c_{k-1} \int_{x_k}^{x_{k+1}} b_{3,k-3}b_{3,k-1} + 2c_{k-3}c_k \int_{x_k}^{x_{k+1}} b_{3,k-3}b_{3,k} \dots \\
& +2c_{k-2}c_{k-1} \int_{x_k}^{x_{k+1}} b_{3,k-2}b_{3,k-1} + 2c_k c_{k-2} \int_{x_k}^{x_{k+1}} b_{3,k}b_{3,k-2} + 2c_k c_{k-1} \int_{x_k}^{x_{k+1}} b_{3,k}b_{3,k-1}
\end{aligned}
$$

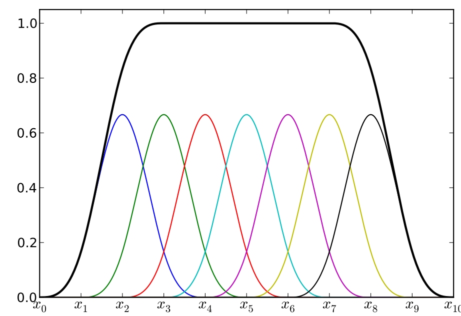

Figure 0.2.3: ToFu-created $d=3$ bsplines

hence, following the same logic:

$$
\int_a^b g^2(x)dx = {}^t\underline{C}\,\underline{\underline{A}}\,\underline{C} = {}^t\underline{C}
\left(
\begin{array}{ccccccccccccccc}
\int_{I_0} b_{3,0}^2 & A_{0,1} & A_{0,2} & A_{0,3} & & & & & & & & & & & \\
A_{0,1} & \ddots & \ddots & \ddots & \ddots & & & & & & & & & & \\
A_{0,2} & \ddots & \ddots & \ddots & \ddots & \ddots & & & & & & & & & \\
A_{0,3} & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & & & & & & & & \\
 & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & A_{j,j-3} & & & & & & & \\
 & & \ddots & \ddots & \ddots & \ddots & \ddots & A_{j,j-2} & \ddots & & & & & & \\
 & & & \ddots & \ddots & \ddots & \ddots & A_{j,j-1} & \ddots & \ddots & & & & & \\
 & & & & A_{j,j-3} & A_{j,j-2} & A_{j,j-1} & \int_{I_j} b_{3,j}^2 & A_{j,j+1} & A_{j,j+2} & A_{j,j+3} & & & & \\
 & & & & & \ddots & \ddots & A_{j,j+1} & \ddots & \ddots & \ddots & & & & \\
 & & & & & & \ddots & A_{j,j+2} & \ddots & \ddots & \ddots & \ddots & & & \\
 & & & & & & & A_{j,j+3} & \ddots & \ddots & \ddots & \ddots & \ddots & & \\
 & & & & & & & & & \ddots & \ddots & \ddots & \ddots & \ddots & A_{N-1,N-4} \\
 & & & & & & & & & & \ddots & \ddots & \ddots & \ddots & A_{N-1,N-3} \\
 & & & & & & & & & & & \ddots & \ddots & \ddots & A_{N-1,N-2} \\
 & & & & & & & & & & & A_{N-1,N-4} & A_{N-1,N-3} & A_{N-1,N-2} & \int_{I_{N-1}} b_{3,N-1}^2
\end{array}
\right.
$$

D1N2

With squared derivatives of any order, the structure of A, determined by the number of overlaps, is identical to $D0N2$. However, the integrands are the chosen derivatives, and computing each integral requires less quadrature points per mesh element (smaller degree).
Here $A_{i,j} = \int_{I_i \bigcap I_j} \partial_x b_{d,i} \partial_x b_{d,j} = A_{j,i}$

$d = 1 \Rightarrow$ **2 b-splines on each interval** $n = 1$ $(2 \times 0 = 0)$

$$\int_a^b (\partial_x g)^2 =^t \underline{C} \begin{pmatrix} \int_{I_0} (\partial_x b_{1,0})^2 & A_{0,1} & & & & & \\ A_{0,1} & \ddots & \ddots & & & & \\ & \ddots & \ddots & A_{j,j-1} & & & \\ & & A_{j,j-1} & \int_{I_j} (\partial_x b_{1,j})^2 & A_{j,j+1} & & \\ & & & A_{j,j+1} & \ddots & \ddots & \\ & & & & \ddots & \ddots & A_{N-2,N-1} \\ & & & & & A_{N-2,N-1} & \int_{I_{N-1}} (\partial_x b_{1,N-1})^2 \end{pmatrix} \underline{C}$$

$d = 2 \Rightarrow$ **3 b-splines on each interval** $n = 2$ $(2 \times 1 = 2)$

$$\int_a^b (\partial_x g)^2 =^t \underline{C} \begin{pmatrix} \int_{I_0} (\partial_x b_{2,0})^2 & A_{0,1} & A_{0,2} & & & & & & & & \\ A_{0,1} & \ddots & \ddots & \ddots & & & & & & & \\ A_{0,2} & \ddots & \ddots & \ddots & \ddots & & & & & & \\ & \ddots & \ddots & \ddots & \ddots & A_{j,j-2} & & & & & \\ & & \ddots & \ddots & \ddots & A_{j,j-1} & \ddots & & & & \\ & & & A_{j,j-2} & A_{j,j-1} & \int_{I_j} (\partial_x b_{2,j})^2 & A_{j,j+1} & A_{j,j+2} & & & \\ & & & & \ddots & A_{j,j+1} & \ddots & \ddots & \ddots & & \\ & & & & & A_{j,j+2} & \ddots & \ddots & \ddots & \ddots & \\ & & & & & & \ddots & \ddots & \ddots & \ddots & A_{N-1,N-3} \\ & & & & & & & \ddots & \ddots & \ddots & A_{N-1,N-2} \\ & & & & & & & & A_{N-1,N-3} & A_{N-1,N-2} & \int_{I_{N-1}} (\partial_x b_{2,N-1})^2 \end{pmatrix} \underline{C}$$

$d = 3 \Rightarrow$ **4 b-splines on each interval** $n = 3$ $(2 \times 2 = 4)$

$$\int_a^b (\partial_x g)^2 =^t \underline{C} \left(\begin{array}{ccccccccccccccc}
\int_{I_0} (\partial_x b_{3,0})^2 & A_{0,1} & A_{0,2} & A_{0,3} & & & & & & & & & & & \\
A_{0,1} & \ddots & \ddots & \ddots & \ddots & & & & & & & & & & \\
A_{0,2} & \ddots & \ddots & \ddots & \ddots & \ddots & & & & & & & & & \\
A_{0,3} & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & & & & & & & & \\
 & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & A_{j,j-3} & & & & & & & \\
 & & \ddots & \ddots & \ddots & \ddots & \ddots & A_{j,j-2} & \ddots & & & & & & \\
 & & & \ddots & \ddots & \ddots & \ddots & A_{j,j-1} & \ddots & \ddots & & & & & \\
 & & & & A_{j,j-3} & A_{j,j-2} & A_{j,j-1} & \int_{I_j} (\partial_x b_{3,j})^2 & A_{j,j+1} & A_{j,j+2} & A_{j,j+3} & & & & \\
 & & & & & \ddots & \ddots & A_{j,j+1} & \ddots & \ddots & \ddots & & & & \\
 & & & & & & \ddots & A_{j,j+2} & \ddots & \ddots & \ddots & \ddots & & & \\
 & & & & & & & A_{j,j+3} & \ddots & \ddots & \ddots & \ddots & \ddots & & \\
 & & & & & & & & & \ddots & \ddots & \ddots & \ddots & \ddots & A_{N-1,N-} \\
 & & & & & & & & & & \ddots & \ddots & \ddots & \ddots & A_{N-1,N-} \\
 & & & & & & & & & & & \ddots & \ddots & \ddots & A_{N-1,N-} \\
 & & & & & & & & & & & A_{N-1,N-4} & A_{N-1,N-3} & A_{N-1,N-2} & \int_{I_{N-1}} (\partial_x b_{3,N}
\end{array} \right.$$

D2N2

Here again, A has the same structure, but the integrals can be evaluated with fewer points and $A_{i,j} = \int_{I_i \bigcap I_j} \partial_x^2 b_{d,i} \partial_x^2 b_{d,j} = A_{j,i}$

$d = 2 \Rightarrow$ **3 b-splines on each interval** $n = 1$ $(2 \times 0 = 0)$

$d = 3 \Rightarrow$ **4 b-splines on each interval** $n = 2$ $(2 \times 1 = 2)$

D3N2

Here again, A has the same structure, but the integrals can be evaluated with fewer points and $A_{i,j} = \int_{I_i \bigcap I_j} \partial_x^3 b_{3,i} \partial_x^3 b_{3,j} = A_{j,i}$

$d = 3 \Rightarrow$ **4 b-splines on each interval** $n = 1$ $(2 \times 0 = 0)$

0.2.2 Non-linear functionals

In this section, we consider two non-linear functionals: the entropy (D0ME) and the Fisher information (D1FI). Obviously, the non-linearity prevents from building a matrix operator. Instead, we simply want to assess the value of the integral as fast as possible for one set of coefficients.
Since there is no quadrature rule dedicated to these expressions (here g is a sum of b-splines of degree 0,1,2 or 3), we resort to the Gauss-Legendre quadrature, with possibly more points that would be required based on the degree of g.

D0ME

Applicable to all degrees, $D0ME\,(g) = -\int g \ln(g)$.

However, the entropy is in principle computed with a distribution, so alternatively: $D0ME\,(g) = -\int \frac{g}{\int g} \ln\left(\frac{g}{\int g}\right)$.

Since in most cases the considered function g will decrease to 0 at the edge of the domain, it may be necessary to introduce a threshold value ϵ below which the term in the natural logarithm is replaced by ϵ:

$$D0ME\,(g) = -\left[\int_{g \geq \epsilon} \frac{g}{\int g} \ln\left(\frac{g}{\int g}\right) + \int_{g<\epsilon} \frac{g}{\int g} \ln\left(\frac{\epsilon}{\int g}\right)\right]$$

The value of ϵ is an input, provided as an absolute value, as a fraction of $\max(g)$ or of $\int g$. Finally, we also use teh absolute value of g to be able to apply the same method to negative profiles, with ϵ defined from $\max(\|g\|)$ or of $\int \|g\|$:

$$D0ME\,(g) = -\left[\int_{\|g\| \geq \epsilon} \frac{\|g\|}{\int \|g\|} \ln\left(\frac{\|g\|}{\int \|g\|}\right) + \int_{\|g\|<\epsilon} \frac{\|g\|}{\int \|g\|} \ln\left(\frac{\epsilon}{\int \|g\|}\right)\right]$$

D1FI

Applicable to degrees $d \geq 1$, $D1FI\,(g) = \int \frac{(\partial_x g)^2}{g}$ or optionally (experimental): $\int \frac{(\partial_x g)^2}{\|g\|}$
However, the same numerical problem arises: if g goes to 0 the integral diverges or is dominated by its weakest values, hence we also introduce a threshold ϵ from $\max(\|g\|)$ or of $\int \|g\|$:

$$D1FI\,(g) = \int_{\|g\| \geq \epsilon} \frac{\|\partial_x g\|^2}{\|g\|} + \int_{\|g\|<\epsilon} \frac{\|\partial_x g\|^2}{\epsilon}$$

0.3 2D B-SPLINES

.1 D0,D1,D2,D3 - Surf - Exact formulations

.1.1 Deriv = 0 - Deg = 0

$$\int_{x_0}^{x_1} b_{0,0}(x)dx = \int_{x_0}^{x_1} dx = x_1 - x_0$$

.1.2 Deriv = 0 - Deg = 1

$$\begin{aligned}
\int_{x_0}^{x_2} b_{1,0}(x)dx &= \int_{x_0}^{x_1} \frac{x-x_0}{x_1-x_0}dx + \int_{x_1}^{x_2} \frac{x_2-x}{x_2-x_1}dx \\
&= \frac{\left[(x-x_0)^2\right]_{x_0}^{x_1}}{2(x_1-x_0)} + \frac{\left[-(x_2-x)^2\right]_{x_1}^{x_2}}{2(x_2-x_1)} \\
&= \frac{(x_1-x_0)^2}{2(x_1-x_0)} + \frac{(x_2-x_1)^2}{2(x_2-x_1)} \qquad = \frac{x_2-x_0}{2}
\end{aligned}$$

.1.3 Deriv = 0 - Deg = 2

$$\begin{aligned}
\int_{x_0}^{x_3} b_{2,0}(x)dx &= \int_{x_0}^{x_1} \frac{(x-x_0)^2}{(x_2-x_0)(x_1-x0)}dx + \int_{x_1}^{x_2} \frac{(x-x_0)(x_2-x)}{(x_2-x_0)(x_2-x_1)} + \frac{(x-x_1)(x_3-x)}{(x_2-x_1)(x_3-x_1)}dx + \int_{x_2}^{x_3} \frac{(x_3-x)^2}{(x_3-x_2)(x_3-x_1)}dx \\
&= \frac{\left[\frac{(x-x_0)^3}{3}\right]_{x_0}^{x_1}}{(x_2-x_0)(x_1-x0)} + \frac{\left[-\frac{x^3}{3}+(x_0+x_2)\frac{x^2}{2}-xx_0x_2\right]_{x_1}^{x_2}}{(x_2-x_0)(x_2-x_1)} + \frac{\left[-\frac{x^3}{3}+(x_1+x_3)\frac{x^2}{2}-xx_1x_3\right]_{x_1}^{x_2}}{(x_2-x_1)(x_3-x_1)} + \frac{-\left[\frac{(x_3-x)^3}{3}\right]_{x_2}^{x_3}}{(x_3-x_2)(x_3-x_1)} \\
&= \frac{(x_1-x_0)^2}{3(x_2-x_0)} + \frac{-\frac{x_2^2+x_2x_1+x_1^2}{3}+(x_0+x_2)\frac{x_2+x_1}{2}-x_0x_2}{(x_2-x_0)} + \frac{-\frac{x_2^2+x_2x_1+x_1^2}{3}+(x_1+x_3)\frac{x_2+x_1}{2}-x_1x_3}{(x_3-x_1)} + \frac{(x_3-x_2)^2}{3(x_3-x_1)} \\
&= \frac{(x_1-x_0)^2}{3(x_2-x_0)} + \frac{-2(x_2^2+x_2x_1+x_1^2)+3(x_0+x_2)(x_2+x_1)-6x_0x_2}{6(x_2-x_0)} + \frac{-2(x_2^2+x_2x_1+x_1^2)+3(x_1+x_3)(x_2+x_1)-6x_1x_3}{6(x_3-x_1)} + \frac{(x_3-x_2)^2}{3(x_3-x_1)} \\
&= \frac{(x_1-x_0)^2}{3(x_2-x_0)} + \frac{x_2^2+x_2x_1-2x_1^2+3x_0(x_1-x_2)}{6(x_2-x_0)} + \frac{-2x_2^2+x_2x_1+x_1^2+3x_3(x_2-x_1)}{6(x_3-x_1)} + \frac{(x_3-x_2)^2}{3(x_3-x_1)}
\end{aligned}$$

.1.4 Deriv = 0 - Deg = 3

$$b_{3,0} = \begin{cases}
\frac{x^3-3x^2x_0+3xx_0^2-x_0^3}{(x_3-x_0)(x_2-x_0)(x_1-x_0)} & \text{, if} \quad x \in [x_0, x_1[\\
\frac{x^3A+x^2B+xC+D}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} & \text{, if} \quad x \in [x_1, x_2[\\
\frac{x^3A^/+x^2B^/+xC^/+D^/}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} & \text{, if} \quad x \in [x_2, x_3[\\
\frac{-x^3+3x^2x_4-3xx_4^2+x_4^3}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} & \text{, if} \quad x \in [x_3, x_4[
\end{cases}$$

Hence

$$\begin{aligned}
\int_{x_0}^{x_4} b &= \int_{x_0}^{x_1} b + \int_{x_1}^{x_2} b + \int_{x_2}^{x_3} b + \int_{x_3}^{x_4} b \\
&= \int_{x_0}^{x_1} \frac{x^3-3x^2x_0+3xx_0^2-x_0^3}{(x_3-x_0)(x_2-x_0)(x_1-x_0)} + \int_{x_1}^{x_2} \frac{x^3A+x^2B+xC+D}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \int_{x_2}^{x_3} \frac{x^3A^/+x^2B^/+xC^/+D^/}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + \int_{x_3}^{x_4} \frac{-x^3+3x^2x_4-3xx_4^2+x_4^3}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \\
&= \frac{\frac{x_1^4-x_0^4}{4}-3x_0\frac{x_1^3-x_0^3}{3}+3x_0^2\frac{x_1^2-x_0^2}{2}-x_0^3(x_1-x_0)}{(x_3-x_0)(x_2-x_0)(x_1-x_0)} + \frac{A\frac{x_2^4-x_1^4}{4}+B\frac{x_2^3-x_1^3}{3}+C\frac{x_2^2-x_1^2}{2}+D(x_2-x_1)}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{A^/\frac{x_3^4-x_2^4}{4}+x^2B^/\frac{x_3^3-x_2^3}{3}+C^/\frac{x_3^2-x_2^2}{2}+D^/(x_3-x_2)}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + \frac{-\frac{x_4^4-x_3^4}{4}+3x_4\frac{x_4^3-x_3^3}{3}-3x_4^2\frac{x_4^2-x_3^2}{2}+x_4^3(x_4-x_3)}{(x_4-x_3)(x_4-x_2)(x_4-x_1)}
\end{aligned}$$

.1.5 Deriv = 1 - Deg = 2

$$
\begin{aligned}
\int_{x_0}^{x_3} \partial_x b_{2,0} &= \begin{cases} \frac{2}{2(x_2-x_0)(x_1-x_0)} \int_{x_0}^{x_1} (x-x_0)^2 dx & \text{, on} \quad [x_0, x_1[\\ \frac{\int_{x_1}^{x_2} -2x(x_3+x_2-x_1-x_0)+2(x_3x_2-x_1x_0)dx}{(x_2-x_1)(x_2-x_0)(x_3-x_1)} = \frac{\left[-x^2(x_3+x_2-x_1-x_0)+2x(x_3x_2-x_1x_0)\right]_{x_1}^{x_2}}{(x_2-x_1)(x_2-x_0)(x_3-x_1)} & \text{, on} \quad [x_1, x_2[\\ \frac{-2}{-2(x_3-x_2)(x_3-x_1)} \int_{x_2}^{x_3} (x_3-x)^2 dx & \text{, on} \quad [x_2, x_3[\end{cases} \\
&= \begin{cases} \frac{x_1-x_0}{x_2-x_0} & \text{, on} \quad [x_0, x_1[\\ \frac{-x_3x_2^2-x_2^3+x_2^2x_1+x_2^2x_0+2x_3x_2^2-2x_2x_1x_0+x_3x_1^2+x_2x_1^2-x_1^3-x_1^2x_0-2x_3x_2x_1-2x_1^2x_0}{(x_2-x_1)(x_2-x_0)(x_3-x_1)} & \text{, on} \quad [x_1, x_2[\\ -\frac{x_3-x_2}{x_3-x_1} & \text{, on} \quad [x_2, x_3[\end{cases} \\
&= \begin{cases} \frac{x_1-x_0}{x_2-x_0} & \text{, on} \quad [x_0, x_1[\\ \frac{x_3x_2^2-x_2^3+x_2^2x_1+x_2^2x_0-2x_2x_1x_0+x_3x_1^2+x_2x_1^2-x_1^3-2x_3x_2x_1+x_1^2x_0}{(x_2-x_1)(x_2-x_0)(x_3-x_1)} & \text{, on} \quad [x_1, x_2[\\ -\frac{x_3-x_2}{x_3-x_1} & \text{, on} \quad [x_2, x_3[\end{cases}
\end{aligned}
$$

.1.6 Deriv = 1 - Deg = 3

$$
\begin{aligned}
\int_{x_0}^{x_4} \partial_x b_{3,0} &= \begin{cases} \int_{x_0}^{x_1} \frac{3x^2-6xx_0+3x_0^2}{(x_3-x_0)(x_2-x_0)(x_1-x_0)} & \text{, on} \quad [x_0, x_1[\\ \int_{x_1}^{x_2} \frac{3x^2A+2xB+C}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} & \text{, on} \quad [x_1, x_2[\\ \int_{x_2}^{x_3} \frac{3x^2A^/+2xB^/+C^/}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} & \text{, on} \quad [x_2, x_3[\\ \int_{x_3}^{x_4} \frac{-3x^2+6xx_4-3x_4^2}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} & \text{, on} \quad [x_3, x_4[\end{cases} \\
&= \frac{\left[x^3-3x^2x_0+3x_0^2x\right]_{x_0}^{x_1}}{(x_3-x_0)(x_2-x_0)(x_1-x_0)} + \frac{\left[x^3A+x^2B+Cx\right]_{x_1}^{x_2}}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{\left[x^3A^/+x^2B^/+C^/x\right]_{x_2}^{x_3}}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + \frac{\left[-x^3+3x^2x_4-3x_4^2x\right]_{x_3}^{x_4}}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \\
&= \frac{(x_1^3-x_0^3)-3x_0(x_1^2-x_0^2)+3x_0^2(x_1-x_0)}{(x_3-x_0)(x_2-x_0)(x_1-x_0)} + \frac{A(x_2^3-x_1^3)+B(x_2^2-x_1^2)+C(x_2-x_1)}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{A^/(x_3^3-x_1^3)+B^/(x_3^2-x_2^2)+C^/(x_3-x_2)}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + \frac{-(x_4^3-x_3^3)+3x_4(x_4^2-x_3^2)-3x_4^2(x_4-x_3)}{(x_4-x_3)(x_4-x_2)(x_4-x_1)}
\end{aligned}
$$

.1.7 Deriv = 2 - Deg = 3

$$
\begin{aligned}
\int_{x_0}^{x_4} \partial_x^2 b_{3,0} &= \begin{cases} \int_{x_0}^{x_1} \frac{6x-6x_0}{(x_3-x_0)(x_2-x_0)(x_1-x_0)} & \text{, on} \quad [x_0, x_1[\\ \int_{x_1}^{x_2} \frac{6xA+2B}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} & \text{, on} \quad [x_1, x_2[\\ \int_{x_2}^{x_3} \frac{6xA^/+2B^/}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} & \text{, on} \quad [x_2, x_3[\\ \int_{x_3}^{x_4} \frac{-6x+6x_4}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} & \text{, on} \quad [x_3, x_4[\end{cases} \\
&= \frac{3(x_1^2-x_0^2)-6x_0(x_1-x_0)}{(x_3-x_0)(x_2-x_0)(x_1-x_0)} + \frac{3A(x_2^2-x_1^2)+2B(x_2-x_1)}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{3A^/(x_3^2-x_1^2)+2B^/(x_3-x_2)}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + \frac{-3(x_4^2-x_3^2)+6x_4(x_4-x_3)}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \\
&= \frac{3(x_1-x_0)}{(x_3-x_0)(x_2-x_0)} + \frac{3A(x_2^2-x_1^2)+2B(x_2-x_1)}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{3A^/(x_3^2-x_1^2)+2B^/(x_3-x_2)}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + \frac{3(x_4-x_3)}{(x_4-x_2)(x_4-x_1)}
\end{aligned}
$$

.1.8 Deriv = 3 - Deg = 3

$$
\int_{x_0}^{x_4} \partial_x^3 b_{3,0} = \begin{cases} \int_{x_0}^{x_1} \frac{6}{(x_3-x_0)(x_2-x_0)(x_1-x_0)} & \text{, on} \quad [x_0, x_1[\\ \int_{x_1}^{x_2} \frac{6A}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} & \text{, on} \quad [x_1, x_2[\\ \int_{x_2}^{x_3} \frac{6A'}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} & \text{, on} \quad [x_2, x_3[\\ \int_{x_3}^{x_4} \frac{-6}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} & \text{, on} \quad [x_3, x_4[\end{cases}
$$

$$
= \frac{6}{(x_3-x_0)(x_2-x_0)} + \frac{6A(x_2-x_1)}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{6A'(x_3-x_2)}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + \frac{-6}{(x_4-x_2)(x_4-x_1)}
$$

.2 D0,D1,D2,D3 - Vol - Exact formulations

.2.1 Deriv = 0 - Deg = 0

$$\int_{x_0}^{x_1} x b_{0,0}(x) dx = \int_{x_0}^{x_1} x dx = \frac{x_1^2 - x_0^2}{2}$$

.2.2 Deriv = 0 - Deg = 1

$$\begin{aligned}
\int_{x_0}^{x_2} x b_{1,0}(x) dx &= \int_{x_0}^{x_1} x \frac{x-x_0}{x_1-x_0} dx + \int_{x_1}^{x_2} x \frac{x_2-x}{x_2-x_1} dx \\
&= \frac{1}{x_1-x_0} \left[\frac{x^3}{3} - x_0 \frac{x^2}{2}\right]_{x_0}^{x_1} + \frac{1}{x_2-x_1} \left[x_2 \frac{x^2}{2} - \frac{x^3}{3}\right]_{x_1}^{x_2} \\
&= \frac{1}{x_1-x_0} \left(\frac{x_1^3-x_0^3}{3} - x_0 \frac{x_1^2-x_0^2}{2}\right) + \frac{1}{x_2-x_1} \left(x_2 \frac{x_2^2-x_1^2}{2} - \frac{x_2^3-x_1^3}{3}\right) \\
&= \left(\frac{x_1^2+x_1x_0+x_0^2}{3} - x_0 \frac{x_1+x_0}{2}\right) + \left(x_2 \frac{x_2+x_1}{2} - \frac{x_2^2+x_2x_1+x_1^2}{3}\right) \\
&= \frac{2x_1^2-x_1x_0-x_0^2}{6} + \frac{x_2^2+x_2x_1-2x_1^2}{6} \qquad = \frac{x_2^2+x_1(x_2-x_0)-x_0^2}{6}
\end{aligned}$$

.2.3 Deriv = 0 - Deg = 2

$$\begin{aligned}
\int_{x_0}^{x_3} x b_{2,0}(x) dx \quad = \quad & \int_{x_0}^{x_1} x \frac{(x-x_0)^2}{(x_2-x_0)(x_1-x0)} dx + \int_{x_1}^{x_2} x \frac{(x-x_0)(x_2-x)}{(x_2-x_0)(x_2-x_1)} + x \frac{(x-x_1)(x_3-x)}{(x_2-x_1)(x_3-x_1)} dx + \int_{x_2}^{x_3} x \frac{(x_3-x)^2}{(x_3-x_2)(x_3-x_1)} dx \\
= \quad & \frac{\left[\frac{x^4}{4} - 2x_0 \frac{x^3}{3} + x_0^2 \frac{x^2}{2}\right]_{x_0}^{x_1}}{(x_2-x_0)(x_1-x0)} + \frac{\left[-\frac{x^4}{4} + (x_0+x_2) \frac{x^3}{3} - x_0x_2 \frac{x^2}{2}\right]_{x_1}^{x_2}}{(x_2-x_0)(x_2-x_1)} + \frac{\left[-\frac{x^4}{4} + (x_1+x_3) \frac{x^3}{3} - x_1x_3 \frac{x^2}{2}\right]_{x_1}^{x_2}}{(x_2-x_1)(x_3-x_1)} + \frac{\left[\frac{x^4}{4} - 2x_3 \frac{x^3}{3} + x_3^2 \frac{x^2}{2}\right]_{x_2}^{x_3}}{(x_3-x_2)(x_3-x_1)} \\
= \quad & \frac{3(x_1^4-x_0^4)-8x_0(x_1^3-x_0^3)+6x_0^2(x_1^2-x_0^2)}{12(x_2-x_0)(x_1-x0)} + \frac{-3(x_2^4-x_1^4)+4(x_0+x_2)(x_2^3-x_1^3)-6x_0x_2(x_2^2-x_1^2)}{12(x_2-x_0)(x_2-x_1)} + \frac{-3(x_2^4-x_1^4)+4(x_1+x_3)(x_2^3-x_1^3)-6x_1x_3(x_2^2-x_1^2)}{12(x_2-x_1)(x_3-x_1)} + \frac{3(x_3^4-x_2^2)-8x_3(x_3^3-x_2^3)+6x_3^2(x_3^2-x_2^2)}{12(x_3-x_2)(x_3-x_1)} \\
= \quad & \frac{3(x_1^2+x_0^2)(x_1+x_0)-8x_0(x_1^2+x_1x_0+x_0^2)+6x_0^2(x_1+x_0)}{12(x_2-x_0)} \\
& + \frac{-3(x_2^2+x_1^2)(x_2+x_1)+4(x_0+x_2)(x_2^2+x_2x_1+x_1^2)-6x_0x_2(x_2+x_1)}{12(x_2-x_0)} + \frac{-3(x_2^2+x_1^2)(x_2+x_1)+4(x_1+x_3)(x_2^2+x_2x_1+x_1^2)-6x_1x_3(x_2+x_1)}{12(x_3-x_1)} \\
& + \frac{3(x_3^2+x_2^2)(x_3+x_2)-8x_3(x_3^2+x_3x_2+x_2^2)+6x_3^2(x_3+x_2)}{12(x_3-x_1)} \\
= \quad & \frac{3x_1^3+3x_0^2x_1+3x_0x_1^2+3x_0^3-8x_0x_1^2-8x_0^2x_1-8x_0^3+6x_0^2x_1+6x_0^3}{12(x_2-x_0)} \\
& + \frac{-3x_2^3-3x_1x_2^2-3x_1^2x_2-3x_1^3+4x_0x_2^2+4x_0x_1x_2+4x_0x_1^2+4x_2^3+4x_2^2x_1+4x_1^2x_2-6x_0x_2^2-6x_0x_1x_2}{12(x_2-x_0)} + \frac{-3x_2^3-3x_1x_2^2-3x_1^2x_2-3x_1^3+4x_1x_2^2+4x_1^2x_2+4x_1^3+4x_2^2x_3+4x_1x_2x_3+4x_1^2x_3-6x_1x_2x_3-6x}{12(x_3-x_1)} \\
& + \frac{3x_3^3+3x_2x_3^2+3x_2^2x_3+3x_2^3-8x_3^3-8x_2x_3^2-8x_2^2x_3+6x_3^3+6x_2x_3^2}{12(x_3-x_1)} \\
= \quad & \frac{3x_1^3+x_0^2x_1-5x_0x_1^2+x_0^3}{12(x_2-x_0)} \\
& + \frac{x_2^3+x_1x_2^2+x_1^2x_2-3x_1^3-2x_0x_2^2-2x_0x_1x_2+4x_0x_1^2}{12(x_2-x_0)} + \frac{-3x_2^3+x_1x_2^2+x_1^2x_2+x_1^3+4x_2^2x_3-2x_1x_2x_3-2x_1^2x_3}{12(x_3-x_1)} \\
& + \frac{x_3^3+x_2x_3^2-5x_2^2x_3+3x_2^3}{12(x_3-x_1)} \\
= \quad & \frac{(3x_1+x_0)(x_1-x_0)^2}{12(x_2-x_0)} + \frac{(x_2-x_1)\big(x_2^2+2x_1x_2+3x_1^2-2x_0(x_2+2x_1)\big)}{12(x_2-x_0)} - \frac{(x_2-x_1)\big(x_1^2+2x_1x_2+3x_2^2-2x_3(2x_2+x_1)\big)}{12(x_3-x_1)} + \frac{(3x_2+x_3)(x_3-x_2)^2}{12(x_3-x_1)}
\end{aligned}$$

.2.4 Deriv = 0 - Deg = 3

$$
\begin{aligned}
\int_{x_0}^{x_4} xb_{3,0}(x)dx &= \int_{x_0}^{x_1} x\frac{x^3-3x_0x^2+3x_0^2x-x_0^3}{(x_3-x_0)(x_2-x_0)(x_1-x_0)}dx + \int_{x_1}^{x_2} x\frac{Ax^3+Bx^2+Cx+D}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)}dx + \int_{x_2}^{x_3} x\frac{A^/x^3+B^/x^2+C^/x+D^/}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)}dx + \int_{x_3}^{x_4} x\frac{-x^3+3x_4x^2-3x_4^2x+x_4^3}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \\
&= \frac{\left[\frac{x^5}{5}-3x_0\frac{x^4}{4}+3x_0^2\frac{x^3}{3}-x_0^3\frac{x^2}{2}\right]_{x_0}^{x_1}}{(x_3-x_0)(x_2-x_0)(x_1-x_0)} + \frac{\left[A\frac{x^5}{5}+B\frac{x^4}{4}+C\frac{x^3}{3}+D\frac{x^2}{2}\right]_{x_1}^{x_2}}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{\left[A^/\frac{x^5}{5}+B^/\frac{x^4}{4}+C^/\frac{x^3}{3}+D^/\frac{x^2}{2}\right]_{x_2}^{x_3}}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + \frac{\left[-\frac{x^5}{5}+3x_4\frac{x^4}{4}-3x_4^2\frac{x^3}{3}+x_4^3\frac{x^2}{2}\right]_{x_3}^{x_4}}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \\
&= \frac{12(x_1^5-x_0^5)-45x_0(x_1^4-x_0^4)+60x_0^2(x_1^3-x_0^3)-30x_0^3(x_1^2-x_0^2)}{60(x_3-x_0)(x_2-x_0)(x_1-x_0)} \\
&+\frac{12A(x_2^5-x_1^5)+15B(x_2^4-x_1^4)+20C(x_2^3-x_1^3)+30D(x_2^2-x_1^2)}{60(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} \\
&+\frac{12A^/(x_3^5-x_2^5)+15B^/(x_3^4-x_2^4)+20C^/(x_3^3-x_2^3)+30D^/(x_3^2-x_2^2)}{60(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} \\
&+\frac{-12(x_4^5-x_3^5)+45x_4(x_4^4-x_3^4)-60x_4^2(x_4^3-x_3^3)+30x_4^3(x_4^2-x_3^2)}{60(x_4-x_3)(x_4-x_2)(x_4-x_1)}
\end{aligned}
$$

.2.5 Deriv = 1 - Deg = 1

$$
\begin{aligned}
\int_{x_0}^{x_2} x\partial_x b_{1,0}(x)dx &= \int_{x_0}^{x_1} x\frac{1}{x_1-x_0}dx - \int_{x_1}^{x_2} x\frac{1}{x_2-x_1}dx \\
&= \frac{x_1^2-x_0^2}{2(x_1-x_0)} - \frac{x_2^2-x_1^2}{2(x_2-x_1)} \\
&= \frac{x_1+x_0}{2} - \frac{x_2+x_1}{2} \qquad = -\frac{x_2-x_0}{2}
\end{aligned}
$$

.2.6 Deriv = 1 - Deg = 2

$$
\begin{aligned}
\int_{x_0}^{x_3} xb_{2,0}(x)dx &= \int_{x_0}^{x_1} x\frac{2(x-x_0)}{(x_2-x_0)(x_1-x0)}dx + \int_{x_1}^{x_2} x\frac{-2x+(x_2+x_0)}{(x_2-x_0)(x_2-x_1)} + x\frac{-2x+(x_3+x_1)}{(x_2-x_1)(x_3-x_1)}dx + \int_{x_2}^{x_3} x\frac{-2(x_3-x)}{(x_3-x_2)(x_3-x_1)}dx \\
&= 2\frac{\left[\frac{x^3}{3}-x_0\frac{x^2}{2}\right]_{x_0}^{x_1}}{(x_2-x_0)(x_1-x0)} + \frac{\left[-2\frac{x^3}{3}+(x_2+x_0)\frac{x^2}{2}\right]_{x_1}^{x_2}}{(x_2-x_0)(x_2-x_1)} + \frac{\left[-2\frac{x^3}{3}+(x_3+x_1)\frac{x^2}{2}\right]_{x_1}^{x_2}}{(x_2-x_1)(x_3-x_1)} + 2\frac{\left[\frac{x^3}{3}-x_3\frac{x^2}{2}\right]_{x_2}^{x_3}}{(x_3-x_2)(x_3-x_1)} \\
&= 2\frac{2(x_1^3-x_0^3)-3x_0(x_1^2-x_0^2)}{6(x_2-x_0)(x_1-x0)} + \frac{-4(x_2^3-x_1^3)+3(x_2+x_0)(x_2^2-x_1^2)}{6(x_2-x_0)(x_2-x_1)} + \frac{-4(x_2^3-x_1^3)+3(x_3+x_1)(x_2^2-x_1^2)}{6(x_2-x_1)(x_3-x_1)} + 2\frac{2(x_3^3-x_2^3)-3x_3(x_3^2-x_2^2)}{6(x_3-x_2)(x_3-x_1)} \\
&= 2\frac{2(x_1^2+x_1x_0+x_0^2)-3x_0(x_1+x_0)}{6(x_2-x_0)} + \frac{-4(x_2^2+x_2x_1+x_1^2)+3(x_2+x_0)(x_2+x_1)}{6(x_2-x_0)} + \frac{-4(x_2^2+x_2x_1+x_1^2)+3(x_3+x_1)(x_2+x_1)}{6(x_3-x_1)} + 2\frac{2(x_3^2+x_3x_2+x_2^2)-3x_3(x_3+x_2)}{6(x_3-x_1)} \\
&= \frac{2x_1^2-x_1x_0-x_0^2}{3(x_2-x_0)} + \frac{-x_2^2-x_2x_1-4x_1^2+3x_0x_2+3x_0x_1}{6(x_2-x_0)} + \frac{-4x_2^2-x_2x_1-x_1^2+3x_3x_2+3x_3x_1}{6(x_3-x_1)} + \frac{-x_3^2-x_3x_2+2x_2^2}{3(x_3-x_1)}
\end{aligned}
$$

.2.7 Deriv = 1 - Deg = 3

$$
\begin{aligned}
\int_{x_0}^{x_4} xb_{3,0}(x)dx &= \int_{x_0}^{x_1} x\frac{3x^2-6x_0x+3x_0^2}{(x_3-x_0)(x_2-x_0)(x_1-x_0)}dx + \int_{x_1}^{x_2} x\frac{3Ax^2+2Bx+C}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)}dx + \int_{x_2}^{x_3} x\frac{3A^/x^2+2B^/x+C^/}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)}dx + \int_{x_3}^{x_4} x\frac{-3x^2+6x_4x-3x_4^2}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \\
&= \frac{\left[3\frac{x^4}{4}-6x_0\frac{x^3}{3}+3x_0^2\frac{x^2}{2}\right]_{x_0}^{x_1}}{(x_3-x_0)(x_2-x_0)(x_1-x_0)} + \frac{\left[3A\frac{x^4}{4}+2B\frac{x^3}{3}+C\frac{x^2}{2}\right]_{x_1}^{x_2}}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{\left[3A^/\frac{x^4}{4}+2B^/\frac{x^3}{3}+C^/\frac{x^2}{2}\right]_{x_2}^{x_3}}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + \frac{\left[-3\frac{x^4}{4}+6x_4\frac{x^3}{3}-3x_4^2\frac{x^2}{2}\right]_{x_3}^{x_4}}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \\
&= \frac{9(x_1^4-x_0^4)-24x_0(x_1^3-x_0^3)+18x_0^2(x_1^2-x_0^2)}{12(x_3-x_0)(x_2-x_0)(x_1-x_0)} + \frac{9A(x_2^4-x_1^4)+8B(x_2^3-x_1^3)+6C(x_2^2-x_1^2)}{12(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{9A^/(x_3^4-x_2^4)+8B^/(x_3^3-x_2^3)+6C^/(x_3^2-x_2^2)}{12(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + \frac{-9(x_4^4-x_3^4)+24x_4(x_4^3-x_3^3)-18x_4^2(x_4^2-x_3^2)}{12(x_4-x_3)(x_4-x_2)(x_4-x_1)} \\
&= \frac{9(x_1^2+x_0^2)(x_1+x_0)-24x_0(x_1^2+x_1x_0+x_0^2)+18x_0^2(x_1+x_0)}{12(x_3-x_0)(x_2-x_0)} + \frac{9A(x_2^4-x_1^4)+8B(x_2^3-x_1^3)+6C(x_2^2-x_1^2)}{12(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{9A^/(x_3^4-x_2^4)+8B^/(x_3^3-x_2^3)+6C^/(x_3^2-x_2^2)}{12(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + \frac{-9(x_4^2+x_3^2)(x_4+x_3)+24x_4(x}{12(x_4-x_2} \\
&= \frac{3x_1^3-5x_1^2x_0+x_1x_0^2+x_0^3}{4(x_3-x_0)(x_2-x_0)} + \frac{9A(x_2^4-x_1^4)+8B(x_2^3-x_1^3)+6C(x_2^2-x_1^2)}{12(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{9A^/(x_3^4-x_2^4)+8B^/(x_3^3-x_2^3)+6C^/(x_3^2-x_2^2)}{12(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + \frac{-x_4^3+5x_4x_3^2-x_4^2x_3-3x_3^3}{4(x_4-x_2)(x_4-x_1)}
\end{aligned}
$$

.2.8 Deriv = 2 - Deg = 2

$$\begin{aligned}
\int_{x_0}^{x_3} x b_{2,0}(x)dx &= \int_{x_0}^{x_1} x \frac{2}{(x_2-x_0)(x_1-x0)}dx + \int_{x_1}^{x_2} x \frac{-2}{(x_2-x_0)(x_2-x_1)} + x \frac{-2}{(x_2-x_1)(x_3-x_1)}dx + \int_{x_2}^{x_3} x \frac{2}{(x_3-x_2)(x_3-x_1)}dx \\
&= \frac{(x_1^2-x_0^2)}{(x_2-x_0)(x_1-x0)} - \frac{x_2^2-x_1^2}{(x_2-x_0)(x_2-x_1)} - \frac{x_2^2-x_1^2}{(x_2-x_1)(x_3-x_1)} + \frac{x_3^2-x_2^2}{(x_3-x_2)(x_3-x_1)} \\
&= \frac{x_1+x_0}{x_2-x_0} - \frac{x_2+x_1}{x_2-x_0} - \frac{x_2+x_1}{x_3-x_1} + \frac{x_3+x_2}{x_3-x_1}
\end{aligned}$$

.2.9 Deriv = 2 - Deg = 3

$$\begin{aligned}
\int_{x_0}^{x_4} x b_{3,0}(x)dx &= \int_{x_0}^{x_1} x \frac{6x-6x_0}{(x_3-x_0)(x_2-x_0)(x_1-x_0)}dx + \int_{x_1}^{x_2} x \frac{6Ax+2B}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)}dx + \int_{x_2}^{x_3} x \frac{6A^{/}x+2B^{/}}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)}dx + \int_{x_3}^{x_4} x \frac{-6x+6x_4}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \\
&= \frac{\left[6\frac{x^3}{3}-6x_0\frac{x^2}{2}\right]_{x_0}^{x_1}}{(x_3-x_0)(x_2-x_0)(x_1-x_0)} + \frac{\left[6A\frac{x^3}{3}+2B\frac{x^2}{2}\right]_{x_1}^{x_2}}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{\left[6A^{/}\frac{x^3}{3}+2B^{/}\frac{x^2}{2}\right]_{x_2}^{x_3}}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + \frac{\left[-6\frac{x^3}{3}+6x_4\frac{x^2}{2}\right]_{x_3}^{x_4}}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \\
&= \frac{12(x_1^3-x_0^3)-18x_0(x_1^2-x_0^2)}{6(x_3-x_0)(x_2-x_0)(x_1-x_0)} + \frac{12A(x_2^3-x_1^3)+6B(x_2^2-x_1^2)}{6(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{12A^{/}(x_3^3-x_2^3)+6B^{/}(x_3^2-x_2^2)}{6(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + \frac{-12(x_4^3-x_3^3)+18x_4(x_4^2-x_3^2)}{6(x_4-x_3)(x_4-x_2)(x_4-x_1)} \\
&= \frac{2x_1^2-x_1x_0-x_0^2}{(x_3-x_0)(x_2-x_0)} + \frac{2A(x_2^3-x_1^3)+B(x_2^2-x_1^2)}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{2A^{/}(x_3^3-x_2^3)+B^{/}(x_3^2-x_2^2)}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + \frac{x_4^2+x_4x_3-2x_3^2}{(x_4-x_2)(x_4-x_1)}
\end{aligned}$$

.2.10 Deriv = 3 - Deg = 3

$$\begin{aligned}
\int_{x_0}^{x_4} x b_{3,0}(x)dx &= \int_{x_0}^{x_1} x \frac{6}{(x_3-x_0)(x_2-x_0)(x_1-x_0)}dx + \int_{x_1}^{x_2} x \frac{6A}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)}dx + \int_{x_2}^{x_3} x \frac{6A^{/}}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)}dx + \int_{x_3}^{x_4} x \frac{-6}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \\
&= \frac{3(x_1^2-x_0^2)}{(x_3-x_0)(x_2-x_0)(x_1-x_0)} + \frac{3A(x_2^2-x_1^2)}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{3A^{/}(x_3^2-x_2^2)}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + \frac{-3(x_4^2-x_3^2)}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \\
&= \frac{3(x_1+x_0)}{(x_3-x_0)(x_2-x_0)} + \frac{3A(x_2^2-x_1^2)}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{3A^{/}(x_3^2-x_2^2)}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} - \frac{3(x_4+x_3)}{(x_4-x_2)(x_4-x_1)}
\end{aligned}$$

.3 D0N2 - Exact formulations

.3.1 Deg = 0, Surf

$$\int_{x_0}^{x_1} \|b_{0,0}(x)\|^2 dx = \int_{x_0}^{x_1} dx = x_1 - x_0$$

.3.2 Deg = 0, Vol

$$\int_{x_0}^{x_1} x\|b_{0,0}(x)\|^2 dx = \int_{x_0}^{x_1} x dx = \frac{x_1^2 - x_0^2}{2}$$

.3.3 Deg = 1, Surf

$$\begin{aligned}
\int_{x_0}^{x_2} \|b_{1,0}(x)\|^2 dx &= \int_{x_0}^{x_1} \left(\tfrac{x-x_0}{x_1-x_0}\right)^2 dx + \int_{x_1}^{x_2} \left(\tfrac{x_2-x}{x_2-x_1}\right)^2 dx \\
&= \frac{\left[\frac{(x-x_0)^3}{3}\right]_{x_0}^{x_1}}{(x_1-x_0)^2} + \frac{\left[-\frac{(x_2-x)^3}{3}\right]_{x_1}^{x_2}}{(x_2-x_1)^2} \\
&= \tfrac{x_1-x_0}{3} + \tfrac{x_2-x_1}{3} \qquad = \tfrac{x_2-x_0}{3}
\end{aligned}$$

and

$$\begin{aligned}
\int_{x_1}^{x_2} b_{1,0}(x) \times b_{1,1}(x) dx &= \int_{x_1}^{x_2} \tfrac{x_2-x}{x_2-x_1} \tfrac{x-x_1}{x_2-x_1} dx \\
&= \frac{\left[-\frac{x^3}{3} + (x_2+x_1)\frac{x^2}{2} - x_2 x_1 x\right]_{x_1}^{x_2}}{(x_2-x_1)^2} \\
&= \frac{-2(x_2^3-x_1^3)+3(x_2+x_1)(x_2^2-x_1^2)-6x_2x_1(x_2-x_1)}{6(x_2-x_1)^2} \\
&= \frac{-2(x_2^2+x_2x_1+x_1^2)+3(x_2+x_1)(x_2+x_1)-6x_2x_1}{6(x_2-x_1)} \\
&= \frac{-2x_2^2-2x_2x_1-2x_1^2+3x_2^2+6x_2x_1+3x_1^2-6x_2x_1}{6(x_2-x_1)} \\
&= \frac{x_2^2-2x_2x_1+x_1^2}{6(x_2-x_1)} \qquad = \tfrac{x_2-x_1}{6}
\end{aligned}$$

.3.4 Deg = 1, Vol

$$
\begin{aligned}
\int_{x_0}^{x_2} x\|b_{1,0}(x)\|^2dx &= \int_{x_0}^{x_1} x\left(\frac{x-x_0}{x_1-x_0}\right)^2 dx + \int_{x_1}^{x_2} x\left(\frac{x_2-x}{x_2-x_1}\right)^2 dx \\
&= \frac{\left[\frac{x^4}{4}-2x_0\frac{x^3}{3}+x_0^2\frac{x^2}{2}\right]_{x_0}^{x_1}}{(x_1-x_0)^2} + \frac{\left[\frac{x^4}{4}-2x_2\frac{x^3}{3}+x_2^2\frac{x^2}{2}\right]_{x_1}^{x_2}}{(x_2-x_1)^2} \\
&= \frac{3(x_1^4-x_0^4)-8x_0(x_1^3-x_0^3)+6x_0^2(x_1^2-x_0^2)}{12(x_1-x_0)^2} + \frac{3(x_2^4-x_1^4)-8x_2(x_2^3-x_1^3)+6x_2^2(x_2^2-x_1^2)}{12(x_2-x_1)^2} \\
&= \frac{3(x_1^2+x_0^2)(x_1+x_0)-8x_0(x_1^2+x_1x_0+x_0^2)+6x_0^2(x_1+x_0)}{12(x_1-x_0)} + \frac{3(x_2^2+x_1^2)(x_2+x_1)-8x_2(x_2^2+x_2x_1+x_1^2)+6x_2^2(x_2+x_1)}{12(x_2-x_1)} \\
&= \frac{3x_1^3+3x_1^2x_0+3x_0^2x_1+3x_0^3-8x_0x_1^2-8x_1x_0^2-8x_0^3+6x_0^2x_1+6x_0^3}{12(x_1-x_0)} + \frac{3x_2^3+3x_2^2x_1+3x_2x_1^2+3x_1^3-8x_2^3-8x_2^2x_1-8x_2x_1^2+6x_2^3+6x_2^2x_1}{12(x_2-x_1)} \\
&= \frac{3x_1^3-5x_1^2x_0+x_0^2x_1+x_0^3}{12(x_1-x_0)} + \frac{x_2^3+x_2^2x_1-5x_2x_1^2+3x_1^3}{12(x_2-x_1)} \\
&= \frac{(3x_1^3-5x_1^2x_0+x_0^2x_1+x_0^3)(x_2-x_1)+(x_2^3+x_2^2x_1-5x_2x_1^2+3x_1^3)(x_1-x_0)}{12(x_1-x_0)(x_2-x_1)} \\
&= \frac{x_2(3x_1^3-5x_1^2x_0+x_0^2x_1+x_0^3)+x_1(x_2^3+x_2^2x_1-5x_2x_1^2+5x_1^2x_0-x_0^2x_1-x_0^3)-x_0(x_2^3+x_2^2x_1-5x_2x_1^2+3x_1^3)}{12(x_1-x_0)(x_2-x_1)}
\end{aligned}
$$

and

$$
\begin{aligned}
\int_{x_1}^{x_2} xb_{1,0}(x)\times b_{1,1}(x)dx &= \int_{x_1}^{x_2} x\frac{x_2-x}{x_2-x_1}\frac{x-x_1}{x_2-x_1}dx \\
&= \frac{\left[-\frac{x^4}{4}+(x_2+x_1)\frac{x^3}{3}-x_2x_1\frac{x^2}{2}\right]_{x_1}^{x_2}}{(x_2-x_1)^2} \\
&= \frac{-3(x_2^4-x_1^4)+4(x_2+x_1)(x_2^3-x_1^3)-6x_2x_1(x_2^2-x_1^2)}{12(x_2-x_1)^2} \\
&= \frac{-3(x_2^2+x_1^2)(x_2+x_1)+4(x_2+x_1)(x_2^2+x_2x_1+x_1^2)-6x_2x_1(x_2+x_1)}{12(x_2-x_1)} \\
&= \frac{-3x_2^3-3x_2x_1^2-3x_2^2x_1-3x_1^3+4x_2^3+4x_2^2x_1+4x_2x_1^2+4x_2^2x_1+4x_2x_1^2+4x_1^3-6x_2^2x_1-6x_2x_1^2}{12(x_2-x_1)} \\
&= \frac{x_2^2-x_1^2}{12}
\end{aligned}
$$

.3.5 Deg = 2, Surf

$$
\begin{aligned}
\int_{x_0}^{x_3}\|b_{2,0}(x)\|^2dx &= \int_{x_0}^{x_1}\left(\frac{(x-x_0)^2}{(x_2-x_0)(x_1-x_0)}\right)^2dx + \int_{x_1}^{x_2}\left(\frac{(x-x_0)(x_2-x)}{(x_2-x_0)(x_2-x_1)}+\frac{(x-x_1)(x_3-x)}{(x_2-x_1)(x_3-x_1)}\right)^2dx + \int_{x_2}^{x_3}\left(\frac{(x_3-x)^2}{(x_3-x_2)(x_3-x_1)}\right)^2dx \\
&= \frac{\left[\frac{(x-x_0)^5}{5}\right]_{x_0}^{x_1}}{(x_2-x_0)^2(x_1-x_0)^2} + \int_{x_1}^{x_2}\frac{(x-x_0)^2(x_2-x)^2}{(x_2-x_0)^2(x_2-x_1)^2} + 2\frac{(x-x_0)(x-x_1)(x_2-x)(x_3-x)}{(x_2-x_0)(x_2-x_1)^2(x_3-x_1)} + \frac{(x-x_1)^2(x_3-x)^2}{(x_2-x_1)^2(x_3-x_1)^2}dx - \frac{\left[\frac{(x_3-x)^5}{5}\right]_{x_2}^{x_3}}{(x_3-x_2)^2(x_3-x_1)^2} \\
&= \frac{(x_1-x_0)^5}{5(x_2-x_0)^2(x_1-x_0)^2} \\
&\quad+\int_{x_1}^{x_2}\frac{x^4-2x^3(x_2+x_0)+x^2(x_2^2+4x_2x_0+x_0^2)-2xx_2x_0(x_2+x_0)+x_2^2x_0^2}{(x_2-x_0)^2(x_2-x_1)^2}dx \\
&\quad+2\int_{x_1}^{x_2}\frac{x^4-x^3(x_0+x_1+x_2+x_3)+x^2(x_0x_1+x_0x_2+x_0x_3+x_1x_2+x_1x_3+x_2x_3)-x(x_0x_1x_2+x_0x_1x_3+x_0x_2x_3+x_1x_2x_3)+x_0x_1x_2x_3}{(x_2-x_0)(x_2-x_1)^2(x_3-x_1)}dx \\
&\quad+\int_{x_1}^{x_2}\frac{x^4-2x^3(x_3+x_1)+x^2(x_3^2+4x_3x_1+x_1^2)-2xx_3x_1(x_3+x_1)+x_3^2x_1^2}{(x_2-x_1)^2(x_3-x_1)^2}dx \\
&\quad+\frac{(x_3-x_2)^5}{5(x_3-x_2)^2(x_3-x_1)^2}
\end{aligned}
$$

Hence

$$
\begin{aligned}
\int_{x_0}^{x_3} \|b_{2,0}(x)\|^2 dx \quad = \quad & \frac{(x_1-x_0)^3}{5(x_2-x_0)^2} \\
& + \frac{\left[\frac{x^5}{5} - 2(x_2+x_0)\frac{x^4}{4} + (x_2^2+4x_2x_0+x_0^2)\frac{x^3}{3} - 2x_2x_0(x_2+x_0)\frac{x^2}{2} + x_2^2x_0^2x\right]_{x_1}^{x_2}}{(x_2-x_0)^2(x_2-x_1)^2} \\
& + 2\frac{\left[\frac{x^5}{5} - (x_0+x_1+x_2+x_3)\frac{x^4}{4} + (x_0x_1+x_0x_2+x_0x_3+x_1x_2+x_1x_3+x_2x_3)\frac{x^3}{3} - (x_0x_1x_2+x_0x_1x_3+x_0x_2x_3+x_1x_2x_3)\frac{x^2}{2} + x_0x_1x_2x_3x\right]_{x_1}^{x_2}}{(x_2-x_0)(x_2-x_1)^2(x_3-x_1)} \\
& + \frac{\left[\frac{x^5}{5} - 2(x_3+x_1)\frac{x^4}{4} + (x_3^2+4x_3x_1+x_1^2)\frac{x^3}{3} - 2x_3x_1(x_3+x_1)\frac{x^2}{2} + x_3^2x_1^2x\right]_{x_1}^{x_2}}{(x_2-x_1)^2(x_3-x_1)^2} \\
& + \frac{(x_3-x_2)^3}{5(x_3-x_1)^2} \\
= \quad & \frac{(x_1-x_0)^3}{5(x_2-x_0)^2} \\
& + \frac{6(x_2^4+x_2^3x_1+x_2^2x_1^2+x_2x_1^3+x_1^4) - 15(x_2+x_0)(x_2^2+x_1^2)(x_2+x_1) + 10(x_2^2+4x_2x_0+x_0^2)(x_2^2+x_2x_1+x_1^2) - 30x_2x_0(x_2+x_0)(x_2+x_1) + 30x_2^2x_0^2}{30(x_2-x_0)^2(x_2-x_1)} \\
& + 2\frac{12(x_2^4+x_2^3x_1+x_2^2x_1^2+x_2x_1^3+x_1^4) - 15(x_0+x_1+x_2+x_3)(x_2^2+x_1^2)(x_2+x_1) + 20(x_0x_1+x_0x_2+x_0x_3+x_1x_2+x_1x_3+x_2x_3)(x_2^2+x_2x_1+x_1^2) - 30(x_0x_1x_2+x_0x_1x_3+x_0x_2x_3+x_1x_2x_3)(x_2+x_1) + 6}{60(x_2-x_0)(x_2-x_1)(x_3-x_1)} \\
& + \frac{6(x_2^4+x_2^3x_1+x_2^2x_1^2+x_2x_1^3+x_1^4) - 15(x_3+x_1)(x_2^2+x_1^2)(x_2+x_1) + 10(x_3^2+4x_3x_1+x_1^2)(x_2^2+x_2x_1+x_1^2) - 30x_3x_1(x_3+x_1)(x_2+x_1) + 30x_3^2x_1^2}{30(x_2-x_1)(x_3-x_1)^2} \\
& + \frac{(x_3-x_2)^3}{5(x_3-x_1)^2} \\
= \quad & \frac{(x_1-x_0)^3}{5(x_2-x_0)^2} \\
& + \frac{x_2^4+x_2^3x_1+x_2^2x_1^2-9x_2x_1^3+6x_1^4-5x_2^3x_0+25x_2x_1^2x_0-5x_2^2x_1x_0-15x_1^3x_0+10x_2^2x_0^2-20x_2x_1x_0^2+10x_1^2x_0^2}{30(x_2-x_0)^2(x_2-x_1)} \\
& + \frac{-3x_2^4+2x_2^3x_1+2x_2^2x_1^2+2x_2x_1^3-3x_1^4+5x_2^3x_0-5x_2x_1^2x_0-5x_2^2x_1x_0+5x_1^3x_0+5x_3x_2^3-5x_3x_2x_1^2-5x_3x_2^2x_1+5x_3x_1^3-10x_3x_2^2x_0+20x_3x_2x_1x_0-10x_3x_1^2x_0}{30(x_2-x_0)(x_2-x_1)(x_3-x_1)} \\
& + \frac{6x_2^4-9x_2^3x_1+x_2^2x_1^2+x_2x_1^3+x_1^4-15x_3x_2^3-5x_3x_2x_1^2+25x_3x_2^2x_1-5x_3x_1^3+10x_3^2x_2^2-20x_3^2x_2x_1+10x_3^2x_1^2}{30(x_2-x_1)(x_3-x_1)^2} \\
& + \frac{(x_3-x_2)^3}{5(x_3-x_1)^2} \\
= \quad & \frac{(x_1-x_0)^3}{5(x_2-x_0)^2} \\
& + \frac{(x_2^2+3x_2x_1+6x_1^2)(x_2-x_1)^2 - 5x_0(x_2+3x_1)(x_2-x_1)^2 + 10x_0^2(x_2-x_1)^2}{30(x_2-x_0)^2(x_2-x_1)} \\
& + \frac{(-3x_2^2-4x_2x_1-3x_1^2)(x_2-x_1)^2 + 5x_0(x_2+x_1)(x_2-x_1)^2 + 5x_3(x_2+x_1)(x_2-x_1)^2 - 10x_3x_0(x_2-x_1)^2}{30(x_2-x_0)(x_2-x_1)(x_3-x_1)} \\
& + \frac{(6x_2^2+3x_2x_1+x_1^2)(x_2-x_1)^2 - 5x_3(3x_2+x_1)(x_2-x_1)^2 + 10x_3^2(x_2-x_1)^2}{30(x_2-x_1)(x_3-x_1)^2} \\
& + \frac{(x_3-x_2)^3}{5(x_3-x_1)^2} \\
= \quad & \frac{(x_1-x_0)^3}{5(x_2-x_0)^2} \\
& + (x_2-x_1)\frac{x_2^2+3x_2x_1+6x_1^2-5x_0(x_2+3x_1)+10x_0^2}{30(x_2-x_0)^2} + (x_2-x_1)\frac{-3x_2^2-4x_2x_1-3x_1^2+5(x_3+x_0)(x_2+x_1)-10x_3x_0}{30(x_2-x_0)(x_3-x_1)} + (x_2-x_1)\frac{6x_2^2+3x_2x_1+x_1^2-5x_3(3x_2+x_1)+10x_3^2}{30(x_3-x_1)^2} \\
& + \frac{(x_3-x_2)^3}{5(x_3-x_1)^2}
\end{aligned}
$$

And:

$$
\begin{aligned}
\int_{x_1}^{x_3} b_{2,0}(x)\times b_{2,1}(x)dx &= \int_{x_1}^{x_2}\left(\frac{(x-x_0)(x_2-x)}{(x_2-x_0)(x_2-x_1)}+\frac{(x-x_1)(x_3-x)}{(x_2-x_1)(x_3-x_1)}\right)\frac{(x-x_1)^2}{(x_3-x_1)(x_2-x_1)}dx+\int_{x_2}^{x_3}\left(\frac{(x-x_1)(x_3-x)}{(x_3-x_1)(x_3-x_2)}+\frac{(x-x_2)(x_4-x)}{(x_3-x_2)(x_4-x_2)}\right)\frac{(x_3-x)^2}{(x_3-x_2)(x_3-x_1)}dx \\
&= \int_{x_1}^{x_2}\frac{(x-x_0)(x_2-x)(x-x_1)^2}{(x_3-x_1)(x_2-x_1)^2(x_2-x_0)}+\frac{(x-x_1)^3(x_3-x)}{(x_3-x_1)^2(x_2-x_1)^2}dx \\
&\quad +\int_{x_2}^{x_3}\frac{(x-x_1)(x_3-x)^3}{(x_3-x_2)^2(x_3-x_1)^2}+\frac{(x-x_2)(x_4-x)(x_3-x)^2}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)}dx \\
&= \int_{x_1}^{x_2}\frac{-x^4+2x_1x^3-x_1^2x^2+(x_2+x_0)x^3-2(x_2+x_0)x_1x^2+(x_2+x_0)x_1^2x-x_2x_0x^2+2x_2x_1x_0x-x_2x_1^2x_0}{(x_3-x_1)(x_2-x_1)^2(x_2-x_0)}dx \\
&\quad +\int_{x_1}^{x_2}\frac{x_3x^3-3x_3x_1x^2+3x_3x_1^2x-x_3x_1^3-x^4+3x_1x^3-3x_1^2x^2+x_1^3x}{(x_3-x_1)^2(x_2-x_1)^2}dx \\
&\quad +\int_{x_2}^{x_3}\frac{x_3^3x-3x_3^2x^2+3x_3x^3-x^4-x_3^3x_1+3x_3^2x_1x-3x_3x_1x^2+x_1x^3}{(x_3-x_2)^2(x_3-x_1)^2}dx \\
&\quad +\int_{x_2}^{x_3}\frac{-x^4+2x_3x^3-x_3^2x^2+(x_4+x_2)x^3-2(x_4+x_2)x_3x^2+(x_4+x_2)x_3^2x-x_4x_2x^2+2x_4x_3x_2x-x_4x_3^2x_2}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)}dx \\
&= \int_{x_1}^{x_2}\frac{-x^4+(x_2+2x_1+x_0)x^3-(x_2x_0+2x_2x_1+2x_1x_0+x_1^2)x^2+(x_2x_1^2+x_1^2x_0+2x_2x_1x_0)x-x_2x_1^2x_0}{(x_3-x_1)(x_2-x_1)^2(x_2-x_0)}dx \\
&\quad +\int_{x_1}^{x_2}\frac{-x^4+(x_3+3x_1)x^3-(3x_3x_1+3x_1^2)x^2+(3x_3x_1^2+x_1^3)x-x_3x_1^3}{(x_3-x_1)^2(x_2-x_1)^2}dx \\
&\quad +\int_{x_2}^{x_3}\frac{-x^4+(3x_3+x_1)x^3-(3x_3^2+3x_3x_1)x^2+(3x_3^2x_1+x_3^3)x-x_3^3x_1}{(x_3-x_2)^2(x_3-x_1)^2}dx \\
&\quad +\int_{x_2}^{x_3}\frac{-x^4+(x_4+2x_3+x_2)x^3-(2x_4x_3+2x_3x_2+x_4x_2+x_3^2)x^2+(x_4x_3^2+2x_4x_3x_2+x_3^2x_2)x-x_4x_3^2x_2}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)}dx \\
&= \frac{\left[-12x^5+15(x_2+2x_1+x_0)x^4-20(x_2x_0+2x_2x_1+2x_1x_0+x_1^2)x^3+30(x_2x_1^2+x_1^2x_0+2x_2x_1x_0)x^2-60x_2x_1^2x_0x\right]_{x_1}^{x_2}}{60(x_3-x_1)(x_2-x_1)^2(x_2-x_0)} \\
&\quad +\frac{\left[-4x^5+5(x_3+3x_1)x^4-20(x_3x_1+x_1^2)x^3+10(3x_3x_1^2+x_1^3)x^2-20x_3x_1^3x\right]_{x_1}^{x_2}}{20(x_3-x_1)^2(x_2-x_1)^2} \\
&\quad +\frac{\left[-4x^5+5(3x_3+x_1)x^4-20(x_3^2+x_3x_1)x^3+10(3x_3^2x_1+x_3^3)x^2-20x_3^3x_1x\right]_{x_2}^{x_3}}{20(x_3-x_2)^2(x_3-x_1)^2} \\
&\quad +\frac{\left[-12x^5+15(x_4+2x_3+x_2)x^4-20(2x_4x_3+2x_3x_2+x_4x_2+x_3^2)x^3+30(x_4x_3^2+2x_4x_3x_2+x_3^2x_2)x^2-60x_4x_3^2x_2x\right]_{x_2}^{x_3}}{60(x_4-x_2)(x_3-x_2)^2(x_3-x_1)} \\
&= \frac{-12(x_2^4+x_2^3x_1+x_2^2x_1^2+x_2x_1^3+x_1^4)+15(x_2+2x_1+x_0)(x_2^2+x_1^2)(x_2+x_1)-20(x_2x_0+2x_2x_1+2x_1x_0+x_1^2)(x_2^2+x_2x_1+x_1^2)+30(x_2x_1^2+x_1^2x_0+2x_2x_1x_0)(x_2+x_1)-60x_2x_1^2x_0}{60(x_3-x_1)(x_2-x_1)(x_2-x_0)} \\
&\quad +\frac{-4(x_2^4+x_2^3x_1+x_2^2x_1^2+x_2x_1^3+x_1^4)+5(x_3+3x_1)(x_2^2+x_1^2)(x_2+x_1)-20(x_3x_1+x_1^2)(x_2^2+x_2x_1+x_1^2)+10(3x_3x_1^2+x_1^3)(x_2+x_1)-20x_3x_1^3}{20(x_3-x_1)^2(x_2-x_1)} \\
&\quad +\frac{-4(x_3^4+x_3^3x_2+x_3^2x_2^2+x_3x_2^3+x_2^4)+5(3x_3+x_1)(x_3^2+x_2^2)(x_3+x_2)-20(x_3^2+x_3x_1)(x_3^2+x_3x_2+x_2^2)+10(3x_3^2x_1+x_3^3)(x_3+x_2)-20x_3^3x_1}{20(x_3-x_2)(x_3-x_1)^2} \\
&\quad +\frac{-12(x_3^4+x_3^3x_2+x_3^2x_2^2+x_3x_2^3+x_2^4)+15(x_4+2x_3+x_2)(x_3^2+x_2^2)(x_3+x_2)-20(2x_4x_3+2x_3x_2+x_4x_2+x_3^2)(x_3^2+x_3x_2+x_2^2)+30(x_4x_3^2+2x_4x_3x_2+x_3^2x_2)(x_3+x_2)-60x_4x_3^2x_2}{60(x_4-x_2)(x_3-x_2)(x_3-x_1)} \\
&= \frac{3x_2^4-7x_2^3x_1+3x_2^2x_1^2+3x_2x_1^3-2x_1^4-5x_2^3x_0+15x_2^2x_1x_0-15x_2x_1^2x_0+5x_1^3x_0}{60(x_3-x_1)(x_2-x_1)(x_2-x_0)} \\
&\quad +\frac{-4x_2^4+11x_2^3x_1-9x_2^2x_1^2+x_2x_1^3+x_1^4+5x_3x_2^3-15x_3x_2^2x_1+15x_3x_2x_1^2-5x_3x_1^3}{20(x_3-x_1)^2(x_2-x_1)} \\
&\quad +\frac{x_3^4+x_3^3x_2-9x_3^2x_2^2+11x_3x_2^3-4x_2^4-5x_3^3x_1+15x_3^2x_2x_1-15x_3x_2^2x_1+5x_2^3x_1}{20(x_3-x_2)(x_3-x_1)^2} \\
&\quad +\frac{-2x_3^4+3x_3^3x_2+3x_3^2x_2^2-7x_3x_2^3+3x_2^4+5x_4x_3^3+15x_4x_3x_2^2-15x_4x_3^2x_2-5x_4x_2^3}{60(x_4-x_2)(x_3-x_2)(x_3-x_1)} \\
&= \frac{(3x_2+2x_1)(x_2-x_1)^3-5x_0(x_2-x_1)^3}{60(x_3-x_1)(x_2-x_1)(x_2-x_0)}+\frac{-(4x_2+x_1)(x_2-x_1)^3+5x_3(x_2-x_1)^3}{20(x_3-x_1)^2(x_2-x_1)} \\
&\quad +\frac{(4x_2+x_3)(x_3-x_2)^3-5x_1(x_3-x_2)^3}{20(x_3-x_2)(x_3-x_1)^2}+\frac{-(2x_3+3x_2)(x_3-x_2)^3+5x_4(x_3-x_2)^3}{60(x_4-x_2)(x_3-x_2)(x_3-x_1)}
\end{aligned}
$$

Thus

$$
\begin{aligned}
\int_{x_1}^{x_3} b_{2,0}(x)\times b_{2,1}(x)dx &= \frac{(3x_2+2x_1-5x_0)(x_2-x_1)^2}{60(x_3-x_1)(x_2-x_0)}+\frac{(5x_3-4x_2-x_1)(x_2-x_1)^2}{20(x_3-x_1)^2} \\
&\quad +\frac{(4x_2+x_3-5x_1)(x_3-x_2)^2}{20(x_3-x_1)^2}+\frac{(5x_4-2x_3-3x_2)(x_3-x_2)^2}{60(x_4-x_2)(x_3-x_1)}
\end{aligned}
$$

And

$$
\begin{aligned}
\int_{x_2}^{x_3} b_{2,0}(x) \times b_{2,2}(x) dx &= \int_{x_2}^{x_3} \frac{(x_3-x)^2}{(x_3-x_2)(x_3-x_1)} \frac{(x-x_2)^2}{(x_4-x_2)(x_3-x_2)} dx \\
&= \int_{x_2}^{x_3} \frac{(x^2-2x_3x+x_3^2)(x^2-2x_2x+x_2^2)}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)} dx \\
&= \int_{x_2}^{x_3} \frac{x^4-2x_3x^3+x_3^2x^2-2x_2x^3+4x_3x_2x^2-2x_3^2x_2x+x_2^2x^2-2x_3x_2^2x+x_3^2x_2^2}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)} dx \\
&= \int_{x_2}^{x_3} \frac{x^4-2(x_3+x_2)x^3+(x_3^2+4x_3x_2+x_2^2)x^2-2(x_3^2x_2+x_3x_2^2)x+x_3^2x_2^2}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)} dx \\
&= \frac{\left[6x^5-15(x_3+x_2)x^4+10(x_3^2+4x_3x_2+x_2^2)x^3-30(x_3^2x_2+x_3x_2^2)x^2+30x_3^2x_2^2x\right]_{x_2}^{x_3}}{30(x_4-x_2)(x_3-x_2)^2(x_3-x_1)} \\
&= \frac{6(x_3^4+x_3^3x_2+x_3^2x_2^2+x_3x_2^3+x_2^4)-15(x_3+x_2)(x_3^2+x_2^2)(x_3+x_2)+10(x_3^2+4x_3x_2+x_2^2)(x_3^2+x_3x_2+x_2^2)-30(x_3^2x_2+x_3x_2^2)(x_3+x_2)+30x_3^2x_2^2}{30(x_4-x_2)(x_3-x_2)(x_3-x_1)} \\
&= \frac{x_3^4-4x_3^3x_2+6x_3^2x_2^2-4x_3x_2^3+x_2^4}{30(x_4-x_2)(x_3-x_2)(x_3-x_1)} \\
&= \frac{(x_3-x_2)^3}{30(x_4-x_2)(x_3-x_1)}
\end{aligned}
$$

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$$
\begin{aligned}
\int_{x_0}^{x_3} x\|b_{2,0}(x)\|^2 dx &= \int_{x_0}^{x_1} x \left(\frac{(x-x_0)^2}{(x_2-x_0)(x_1-x_0)}\right)^2 dx + \int_{x_1}^{x_2} x \left(\frac{(x-x_0)(x_2-x)}{(x_2-x_0)(x_2-x_1)} + \frac{(x-x_1)(x_3-x)}{(x_2-x_1)(x_3-x_1)}\right)^2 dx + \int_{x_2}^{x_3} x \left(\frac{(x_3-x)^2}{(x_3-x_2)(x_3-x_1)}\right)^2 dx \\
&= \frac{\left[\frac{x^6}{6}-4x_0\frac{x^5}{5}+6x_0^2\frac{x^4}{4}-4x_0^3\frac{x^3}{3}+x_0^4\frac{x^2}{2}\right]_{x_0}^{x_1}}{(x_2-x_0)^2(x_1-x_0)^2} + \int_{x_1}^{x_2} \frac{x(x-x_0)^2(x_2-x)^2}{(x_2-x_0)^2(x_2-x_1)^2} + 2\frac{x(x-x_0)(x-x_1)(x_2-x)(x_3-x)}{(x_2-x_0)(x_2-x_1)^2(x_3-x_1)} + \frac{x(x-x_1)^2(x_3-x)^2}{(x_2-x_1)^2(x_3-x_1)^2} dx + \frac{\left[\frac{x^6}{6}-4x_3\frac{x^5}{5}+6x_3^2\frac{x^4}{4}-4x_3^3\frac{x^3}{3}+x_3^4\frac{x^2}{2}\right]_{x_2}^{x_3}}{(x_3-x_2)^2(x_3-x_1)^2} \\
&= \frac{5(x_1^5+x_1^4x_0+x_1^3x_0^2+x_1^2x_0^3+x_1x_0^4+x_0^5)-24x_0(x_1^4+x_1^3x_0+x_1^2x_0^2+x_1x_0^3+x_0^4)+45x_0^2(x_1^3+x_1^2x_0+x_1x_0^2+x_0^3)-40x_0^3(x_1^2+x_1x_0+x_0^2)+15x_0^4(x_1+x_0)}{30(x_2-x_0)^2(x_1-x_0)} \\
&\quad + \int_{x_1}^{x_2} \frac{x^5-2x^4(x_2+x_0)+x^3(x_2^2+4x_2x_0+x_0^2)-2x^2x_2x_0(x_2+x_0)+x_2^2x_0^2x}{(x_2-x_0)^2(x_2-x_1)^2} dx \\
&\quad +2\int_{x_1}^{x_2} \frac{x^5-x^4(x_0+x_1+x_2+x_3)+x^3(x_0x_1+x_0x_2+x_0x_3+x_1x_2+x_1x_3+x_2x_3)-x^2(x_0x_1x_2+x_0x_1x_3+x_0x_2x_3+x_1x_2x_3)+xx_0x_1x_2x_3}{(x_2-x_0)(x_2-x_1)^2(x_3-x_1)} dx \\
&\quad + \int_{x_1}^{x_2} \frac{x^5-2x^4(x_3+x_1)+x^3(x_3^2+4x_3x_1+x_1^2)-2x^2x_3x_1(x_3+x_1)+x_3^2x_1^2x}{(x_2-x_1)^2(x_3-x_1)^2} dx \\
&\quad + \frac{5(x_3^5+x_3^4x_2+x_3^3x_2^2+x_3^2x_2^3+x_3x_2^4+x_2^5)-24x_3(x_3^4+x_3^3x_2+x_3^2x_2^2+x_3x_2^3+x_2^4)+45x_3^2(x_3^3+x_3^2x_2+x_3x_2^2+x_2^3)-40x_3^3(x_3^2+x_3x_2+x_2^2)+15x_3^4(x_3+x_2)}{30(x_3-x_2)(x_3-x_1)^2} \\
&= \frac{5x_1^5-19x_1^4x_0+26x_1^3x_0^2-14x_1^2x_0^3+x_1x_0^4+x_0^5}{30(x_2-x_0)^2(x_1-x_0)} \\
&\quad + \frac{\left[10x^6-24(x_2+x_0)x^5+15(x_2^2+4x_2x_0+x_0^2)x^4-40x_2x_0(x_2+x_0)x^3+30x_2^2x_0^2x^2\right]_{x_1}^{x_2}}{60(x_2-x_0)^2(x_2-x_1)^2} \\
&\quad +2\frac{\left[10x^6-12(x_0+x_1+x_2+x_3)x^5+15(x_0x_1+x_0x_2+x_0x_3+x_1x_2+x_1x_3+x_2x_3)x^4-20(x_0x_1x_2+x_0x_1x_3+x_0x_2x_3+x_1x_2x_3)x^3+30x_0x_1x_2x_3x^2\right]_{x_1}^{x_2}}{60(x_2-x_0)(x_2-x_1)^2(x_3-x_1)} \\
&\quad + \frac{\left[10x^6-24(x_3+x_1)x^5+15(x_3^2+4x_3x_1+x_1^2)x^4-40x_3x_1(x_3+x_1)x^3+30x_3^2x_1^2x^2\right]_{x_1}^{x_2}}{60(x_2-x_1)^2(x_3-x_1)^2} \\
&\quad + \frac{x_3^5+x_3^4x_2-14x_3^3x_2^2+26x_3^2x_2^3-19x_3x_2^4+5x_2^5}{30(x_3-x_2)(x_3-x_1)^2}
\end{aligned}
$$

Hence:

$$
\begin{aligned}
\int_{x_0}^{x_3} x\|b_{2,0}(x)\|^2 dx \quad = \quad & \frac{(5x_1+x_0)(x_1-x_0)^4}{30(x_2-x_0)^2(x_1-x_0)} \\
& + \frac{10(x_2^5+x_2^4x_1+x_2^3x_1^2+x_2^2x_1^3+x_2x_1^4+x_1^5)-24(x_2+x_0)(x_2^4+x_2^3x_1+x_2^2x_1^2+x_2x_1^3+x_1^4)+15(x_2^2+4x_2x_0+x_0^2)(x_2^3+x_2^2x_1+x_2x_1^2+x_1^3)-40x_2x_0(x_2+x_0)(x_2^2+x_2x_1+x_1^2)+30x_2^2x_0^2(x_2+x_1)}{60(x_2-x_0)^2(x_2-x_1)} \\
& + 2\frac{10(x_2^5+x_2^4x_1+x_2^3x_1^2+x_2^2x_1^3+x_2x_1^4+x_1^5)-12(x_0+x_1+x_2+x_3)(x_2^4+x_2^3x_1+x_2^2x_1^2+x_2x_1^3+x_1^4)+15(x_0x_1+x_0x_2+x_0x_3+x_1x_2+x_1x_3+x_2x_3)(x_2^3+x_2^2x_1+x_2x_1^2+x_1^3)-20(x_0x_1x_2+x_0x_1x_3+x_0}{60(x_2-x_0)(x_2-x_1)(x_3-x_1)} \\
& + \frac{10(x_2^5+x_2^4x_1+x_2^3x_1^2+x_2^2x_1^3+x_2x_1^4+x_1^5)-24(x_3+x_1)(x_2^4+x_2^3x_1+x_2^2x_1^2+x_2x_1^3+x_1^4)+15(x_3^2+4x_3x_1+x_1^2)(x_2^3+x_2^2x_1+x_2x_1^2+x_1^3)-40x_3x_1(x_3+x_1)(x_2^2+x_2x_1+x_1^2)+30x_3^2x_1^2(x_2+x_1)}{60(x_2-x_1)(x_3-x_1)^2} \\
& + \frac{(x_3+5x_2)(x_3-x_2)^4}{30(x_3-x_2)(x_3-x_1)^2} \\
= \quad & \frac{(5x_1+x_0)(x_1-x_0)^3}{30(x_2-x_0)^2} \\
& + \frac{x_2^5+x_2^4x_1+x_2^3x_1^2+x_2^2x_1^3-14x_2x_1^4+10x_1^5-4x_0(x_2^4+x_2^3x_1+x_2^2x_1^2-9x_2x_1^3+6x_1^4)+5x_0^2(x_2^3+x_2^2x_1-5x_2x_1^2+3x_1^3)}{60(x_2-x_0)^2(x_2-x_1)} \\
& + \frac{-2x_2^5+x_2^4x_1+x_2^3x_1^2+x_2^2x_1^3+x_2x_1^4-2x_1^5+x_0(3x_2^4-2x_2^3x_1-2x_2^2x_1^2-2x_2x_1^3+3x_1^4)+x_3(3x_2^4-2x_2^3x_1-2x_2^2x_1^2-2x_2x_1^3+3x_1^4)-5x_3x_0(x_2^3-x_2^2x_1-x_2x_1^2+x_1^3)}{30(x_2-x_0)(x_2-x_1)(x_3-x_1)} \\
& + \frac{10x_2^5-14x_2^4x_1+x_2^3x_1^2+x_2^2x_1^3+x_2x_1^4+x_1^5-4x_3(6x_2^4-9x_2^3x_1+x_2^2x_1^2+x_2x_1^3+x_1^4)+5x_3^2(3x_2^3-5x_2^2x_1+x_2x_1^2+x_1^3)}{60(x_2-x_1)(x_3-x_1)^2} \\
& + \frac{(x_3+5x_2)(x_3-x_2)^3}{30(x_3-x_1)^2} \\
= \quad & \frac{(5x_1+x_0)(x_1-x_0)^3}{30(x_2-x_0)^2} \\
& + (x_2-x_1)\frac{x_2^3+3x_2^2x_1+6x_2x_1^2+10x_1^3-4x_0(x_2^2+3x_2x_1+6x_1^2)+5x_0^2(x_2+3x_1)}{60(x_2-x_0)^2} \\
& + (x_2-x_1)\frac{-2x_2^3-3x_2^2x_1-3x_2x_1^2-2x_1^3+(x_3+x_0)(3x_2^2+4x_2x_1+3x_1^2)-5x_3x_0(x_2+x_1)}{30(x_2-x_0)(x_3-x_1)} \\
& + (x_2-x_1)\frac{10x_2^3+6x_2^2x_1+3x_2x_1^2+x_1^3-4x_3(6x_2^2+3x_2x_1+x_1^2)+5x_3^2(3x_2+x_1)}{60(x_3-x_1)^2} \\
& + \frac{(x_3+5x_2)(x_3-x_2)^3}{30(x_3-x_1)^2}
\end{aligned}
$$

And

$$
\begin{aligned}
\int_{x_1}^{x_3} xb_{2,0}(x)\times b_{2,1}(x)dx &= \int_{x_1}^{x_2} x\left(\frac{(x-x_0)(x_2-x)}{(x_2-x_0)(x_2-x_1)}+\frac{(x-x_1)(x_3-x)}{(x_2-x_1)(x_3-x_1)}\right)\frac{(x-x_1)^2}{(x_3-x_1)(x_2-x_1)}dx+\int_{x_2}^{x_3} x\left(\frac{(x-x_1)(x_3-x)}{(x_3-x_1)(x_3-x_2)}+\frac{(x-x_2)(x_4-x)}{(x_3-x_2)(x_4-x_2)}\right)\frac{(x_3-x)^2}{(x_3-x_2)(x_3-x_1)}dx \\
&= \int_{x_1}^{x_2} x\frac{(x-x_0)(x_2-x)(x-x_1)^2}{(x_3-x_1)(x_2-x_1)^2(x_2-x_0)}+x\frac{(x-x_1)^3(x_3-x)}{(x_3-x_1)^2(x_2-x_1)^2}dx \\
&\quad +\int_{x_2}^{x_3} x\frac{(x-x_1)(x_3-x)^3}{(x_3-x_2)^2(x_3-x_1)^2}+x\frac{(x-x_2)(x_4-x)(x_3-x)^2}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)}dx \\
&= \int_{x_1}^{x_2} x\frac{-x^4+2x_1x^3-x_1^2x^2+(x_2+x_0)x^3-2(x_2+x_0)x_1x^2+(x_2+x_0)x_1^2x-x_2x_0x^2+2x_2x_1x_0x-x_2x_1^2x_0}{(x_3-x_1)(x_2-x_1)^2(x_2-x_0)}dx \\
&\quad +\int_{x_1}^{x_2} x\frac{x_3x^3-3x_3x_1x^2+3x_3x_1^2x-x_3x_1^3-x^4+3x_1x^3-3x_1^2x^2+x_1^3x}{(x_3-x_1)^2(x_2-x_1)^2}dx \\
&\quad +\int_{x_2}^{x_3} x\frac{x_3^3x-3x_3^2x^2+3x_3x^3-x^4-x_3^3x_1+3x_3^2x_1x-3x_3x_1x^2+x_1x^3}{(x_3-x_2)^2(x_3-x_1)^2}dx \\
&\quad +\int_{x_2}^{x_3} x\frac{-x^4+2x_3x^3-x_3^2x^2+(x_4+x_2)x^3-2(x_4+x_2)x_3x^2+(x_4+x_2)x_3^2x-x_4x_2x^2+2x_4x_3x_2x-x_4x_3^2x_2}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)}dx \\
&= \int_{x_1}^{x_2} \frac{-x^5+(x_2+2x_1+x_0)x^4-(x_2x_0+2x_2x_1+2x_1x_0+x_1^2)x^3+(x_2x_1^2+x_1^2x_0+2x_2x_1x_0)x^2-x_2x_1^2x_0x}{(x_3-x_1)(x_2-x_1)^2(x_2-x_0)}dx \\
&\quad +\int_{x_1}^{x_2} \frac{-x^5+(x_3+3x_1)x^4-(3x_3x_1+3x_1^2)x^3+(3x_3x_1^2+x_1^3)x^2-x_3x_1^3x}{(x_3-x_1)^2(x_2-x_1)^2}dx \\
&\quad +\int_{x_2}^{x_3} \frac{-x^5+(3x_3+x_1)x^4-(3x_3^2+3x_3x_1)x^3+(3x_3^2x_1+x_3^3)x^2-x_3^3x_1x}{(x_3-x_2)^2(x_3-x_1)^2}dx \\
&\quad +\int_{x_2}^{x_3} \frac{-x^5+(x_4+2x_3+x_2)x^4-(2x_4x_3+2x_3x_2+x_4x_2+x_3^2)x^3+(x_4x_3^2+2x_4x_3x_2+x_3^2x_2)x^2-x_4x_3^2x_2x}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)}dx \\
&= \frac{\left[-10x^6+12(x_2+2x_1+x_0)x^5-15(x_2x_0+2x_2x_1+2x_1x_0+x_1^2)x^4+20(x_2x_1^2+x_1^2x_0+2x_2x_1x_0)x^3-30x_2x_1^2x_0x^2\right]_{x_1}^{x_2}}{60(x_3-x_1)(x_2-x_1)^2(x_2-x_0)} \\
&\quad +\frac{\left[-10x^6+12(x_3+3x_1)x^5-45(x_3x_1+x_1^2)x^4+20(3x_3x_1^2+x_1^3)x^3-30x_3x_1^3x^2\right]_{x_1}^{x_2}}{60(x_3-x_1)^2(x_2-x_1)^2} \\
&\quad +\frac{\left[-10x^6+12(3x_3+x_1)x^5-45(x_3^2+x_3x_1)x^4+20(3x_3^2x_1+x_3^3)x^3-30x_3^3x_1x^2\right]_{x_2}^{x_3}}{60(x_3-x_2)^2(x_3-x_1)^2} \\
&\quad +\frac{\left[-10x^6+12(x_4+2x_3+x_2)x^5-15(2x_4x_3+2x_3x_2+x_4x_2+x_3^2)x^4+20(x_4x_3^2+2x_4x_3x_2+x_3^2x_2)x^3-30x_4x_3^2x_2x^2\right]_{x_2}^{x_3}}{60(x_4-x_2)(x_3-x_2)^2(x_3-x_1)} \\
&= \frac{-10(x_2^5+x_2^4x_1+x_2^3x_1^2+x_2^2x_1^3+x_2x_1^4+x_1^5)+12(x_2+2x_1+x_0)(x_2^4+x_2^3x_1+x_2^2x_1^2+x_2x_1^3+x_1^4)-15(x_2x_0+2x_2x_1+2x_1x_0+x_1^2)(x_2^3+x_2^2x_1+x_2x_1^2+x_1^3)+20(x_2x_1^2+x_1^2x_0+2x_2x_1x_0)(x_2^2+x_2x}{60(x_3-x_1)(x_2-x_1)(x_2-x_0)} \\
&\quad +\frac{-10(x_2^5+x_2^4x_1+x_2^3x_1^2+x_2^2x_1^3+x_2x_1^4+x_1^5)+12(x_3+3x_1)(x_2^4+x_2^3x_1+x_2^2x_1^2+x_2x_1^3+x_1^4)-45(x_3x_1+x_1^2)(x_2^3+x_2^2x_1+x_2x_1^2+x_1^3)+20(3x_3x_1^2+x_1^3)(x_2^2+x_2x_1+x_1^2)-30x_3x_1^3(x_2+x_1)}{60(x_3-x_1)^2(x_2-x_1)} \\
&\quad +\frac{-10(x_3^5+x_3^4x_2+x_3^3x_2^2+x_3^2x_2^3+x_3x_2^4+x_2^5)+12(3x_3+x_1)(x_3^4+x_3^3x_2+x_3^2x_2^2+x_3x_2^3+x_2^4)-45(x_3^2+x_3x_1)(x_3^3+x_3^2x_2+x_3x_2^2+x_2^3)+20(3x_3^2x_1+x_3^3)(x_3^2+x_3x_2+x_2^2)-30x_3^3x_1(x_3+x_2)}{60(x_3-x_2)(x_3-x_1)^2} \\
&\quad +\frac{-10(x_3^5+x_3^4x_2+x_3^3x_2^2+x_3^2x_2^3+x_3x_2^4+x_2^5)+12(x_4+2x_3+x_2)(x_3^4+x_3^3x_2+x_3^2x_2^2+x_3x_2^3+x_2^4)-15(2x_4x_3+2x_3x_2+x_4x_2+x_3^2)(x_3^3+x_3^2x_2+x_3x_2^2+x_2^3)+20(x_4x_3^2+2x_4x_3x_2+x_3^2x_2)(x_3^2+x}{60(x_4-x_2)(x_3-x_2)(x_3-x_1)} \\
&= \frac{2x_2^5-4x_2^4x_1+x_2^3x_1^2+x_2^2x_1^3+x_2x_1^4-x_1^5-x_0(3x_2^4-7x_2^3x_1+3x_2^2x_1^2+3x_2x_1^3-2x_1^4)}{60(x_3-x_1)(x_2-x_1)(x_2-x_0)}+\frac{-10x_2^5+26x_2^4x_1-19x_2^3x_1^2+x_2^2x_1^3+x_2x_1^4+x_1^5+3x_3(4x_2^4-11x_2^3x_1+9x_2^2x_1^2-x_2x_1^3-x_1^4)}{60(x_3-x_1)^2(x_2-x_1)} \\
&\quad +\frac{x_3^5+x_3^4x_2+x_3^3x_2^2-19x_3^2x_2^3+26x_3x_2^4-10x_2^5-3x_1(x_3^4+x_3^3x_2-9x_3^2x_2^2+11x_3x_2^3-4x_2^4)}{60(x_3-x_2)(x_3-x_1)^2}+\frac{-x_3^5+x_3^4x_2+x_3^3x_2^2+x_3^2x_2^3-4x_3x_2^4+2x_2^5-x_4(3x_2^4-7x_3x_2^3+3x_3^2x_2^2+3x_3^3x_2-2x_3^4)}{60(x_4-x_2)(x_3-x_2)(x_3-x_1)} \\
&= (x_2-x_1)^2\frac{2x_2^2+2x_2x_1+x_1^2-x_0(3x_2+2x_1)}{60(x_3-x_1)(x_2-x_0)}+(x_2-x_1)^2\frac{(-10x_2^2-4x_2x_1-x_1^2)+3x_3(4x_2+x_1)}{60(x_3-x_1)^2} \\
&\quad +(x_3-x_2)^2\frac{x_3^2+4x_3x_2+10x_2^2-3x_1(x_3+4x_2)}{60(x_3-x_1)^2}+(x_3-x_2)^2\frac{(-x_3^2-2x_3x_2-2x_2^2)+x_4(2x_3+3x_2)}{60(x_4-x_2)(x_3-x_1)}
\end{aligned}
$$

And

$$
\begin{aligned}
\int_{x_2}^{x_3} x b_{2,0}(x) \times b_{2,2}(x)dx &= \int_{x_2}^{x_3} x \frac{(x_3-x)^2}{(x_3-x_2)(x_3-x_1)} \frac{(x-x_2)^2}{(x_4-x_2)(x_3-x_2)} dx \\
&= \int_{x_2}^{x_3} x \frac{(x^2-2x_3x+x_3^2)(x^2-2x_2x+x_2^2)}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)} dx \\
&= \int_{x_2}^{x_3} x \frac{x^4-2x_3x^3+x_3^2x^2-2x_2x^3+4x_3x_2x^2-2x_3^2x_2x+x_2^2x^2-2x_3x_2^2x+x_3^2x_2^2}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)} dx \\
&= \int_{x_2}^{x_3} \frac{x^5-2(x_3+x_2)x^4+(x_3^2+4x_3x_2+x_2^2)x^3-2(x_3^2x_2+x_3x_2^2)x^2+x_3^2x_2^2x}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)} dx \\
&= \frac{\left[10x^6-24(x_3+x_2)x^5+15(x_3^2+4x_3x_2+x_2^2)x^4-40(x_3^2x_2+x_3x_2^2)x^3+30x_3^2x_2^2x^2\right]_{x_2}^{x_3}}{60(x_4-x_2)(x_3-x_2)^2(x_3-x_1)} \\
&= \frac{10(x_3^5+x_3^4x_2+x_3^3x_2^2+x_3^2x_2^3+x_3x_2^4+x_2^5)-24(x_3+x_2)(x_3^4+x_3^3x_2+x_3^2x_2^2+x_3x_2^3+x_2^4)+15(x_3^2+4x_3x_2+x_2^2)(x_3^3+x_3^2x_2+x_3x_2^2+x_2^3)-40(x_3^2x_2+x_3x_2^2)(x_3^2+x_3x_2+x_2^2)+30x_3^2x_2^2(x_3+x_2)}{60(x_4-x_2)(x_3-x_2)(x_3-x_1)} \\
&= \frac{x_3^5-3x_3^4x_2+2x_3^3x_2^2+2x_3^2x_2^3-3x_3x_2^4+x_2^5}{60(x_4-x_2)(x_3-x_2)(x_3-x_1)} \\
&= \frac{(x_3+x_2)(x_3-x_2)^3}{60(x_4-x_2)(x_3-x_1)}
\end{aligned}
$$

.3.7 Deg = 3, Surf - to be finished and checked

$$
\begin{aligned}
\int_{x_0}^{x_4} \|b_{3,0}(x)\|^2 dx &= \int_{x_0}^{x_1} \left(\frac{x^3-3x^2x_0+3xx_0^2-x_0^3}{(x_3-x_0)(x_2-x_0)(x_1-x_0)}\right)^2 dx + \int_{x_1}^{x_2} \left(\frac{x^3A+x^2B+xC+D}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)}\right)^2 dx + \int_{x_2}^{x_3} \left(\frac{x^3A^{/}+x^2B^{/}+xC^{/}+D^{/}}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)}\right)^2 dx + \int_{x_3}^{x_4} \left(\frac{-x^3+3x^2x_4 \ldots}{(x_4-x_3)(x_4- \ldots}\right. \\
&= \int_{x_0}^{x_1} \frac{x^6-6x_0x^5+15x_0^2x^4-20x_0^3x^3+15x_0^4x^2-6x_0^5x+x_0^6}{(x_3-x_0)^2(x_2-x_0)^2(x_1-x_0)^2} dx \\
&\quad + \int_{x_1}^{x_2} \frac{A^2x^6+2ABx^5+(2AC+B^2)x^4+(2AD+2BC)x^3+(2BD+C^2)x^2+2CDx+D^2}{((x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0))^2} dx \\
&\quad + \int_{x_2}^{x_3} \frac{A^{/2}x^6+2A^{/}B^{/}x^5+(2A^{/}C^{/}+B^{/2})x^4+(2A^{/}D^{/}+2B^{/}C^{/})x^3+(2B^{/}D^{/}+C^{/2})x^2+2C^{/}D^{/}x+D^{/2}}{((x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0))^2} dx \\
&\quad + \int_{x_3}^{x_4} \frac{x^6-6x_4x^5+15x_4^2x^4-20x_4^3x^3+15x_4^4x^2-6x_4^5x+x_4^6}{(x_4-x_3)^2(x_4-x_2)^2(x_4-x_1)^2} dx \\
&= \frac{\left[x^7-7x_0x^6+21x_0^2x^5-35x_0^3x^4+35x_0^4x^3-21x_0^5x^2+7x_0^6x\right]_{x_0}^{x_1}}{7(x_3-x_0)^2(x_2-x_0)^2(x_1-x_0)^2} \\
&\quad + \frac{\left[30A^2x^7+70ABx^6+42(2AC+B^2)x^5+105(AD+BC)x^4+70(2BD+C^2)x^3+210CDx^2+210D^2x\right]_{x_1}^{x_2}}{210((x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0))^2} \\
&\quad + \frac{\left[30A^{/2}x^7+70A^{/}B^{/}x^6+42(2A^{/}C^{/}+B^{/2})x^5+105(A^{/}D^{/}+B^{/}C^{/})x^4+70(2B^{/}D^{/}+C^{/2})x^3+210C^{/}D^{/}x^2+210D^{/2}x\right]_{x_2}^{x_3}}{210((x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0))^2} \\
&\quad + \frac{\left[x^7-7x_4x^6+21x_4^2x^5-35x_4^3x^4+35x_4^4x^3-21x_4^5x^2+7x_4^6x\right]_{x_3}^{x_4}}{7(x_4-x_3)^2(x_4-x_2)^2(x_4-x_1)^2} \\
&= \frac{x_1^6-6x_1^5x_0+15x_1^4x_0^2-20x_1^3x_0^3+15x_1^2x_0^4-6x_1x_0^5+x_0^6}{7(x_3-x_0)^2(x_2-x_0)^2(x_1-x_0)} \\
&\quad + \frac{\left[30A^2x^7+70ABx^6+42(2AC+B^2)x^5+105(AD+BC)x^4+70(2BD+C^2)x^3+210CDx^2+210D^2x\right]_{x_1}^{x_2}}{210((x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0))^2} \\
&\quad + \frac{\left[30A^{/2}x^7+70A^{/}B^{/}x^6+42(2A^{/}C^{/}+B^{/2})x^5+105(A^{/}D^{/}+B^{/}C^{/})x^4+70(2B^{/}D^{/}+C^{/2})x^3+210C^{/}D^{/}x^2+210D^{/2}x\right]_{x_2}^{x_3}}{210((x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0))^2} \\
&\quad + \frac{x_4^6-6x_4^5x_3+15x_4^4x_3^2-20x_4^3x_3^3+15x_4^2x_3^4-6x_4x_3^5+x_3^6}{7(x_4-x_3)(x_4-x_2)^2(x_4-x_1)^2}
\end{aligned}
$$

Hence:

$$\begin{aligned}
\int_{x_0}^{x_4} \|b_{3,0}(x)\|^2 dx \quad = \quad & \frac{(x_1-x_0)^5}{7(x_3-x_0)^2(x_2-x_0)^2} \\
& + \frac{\left[30A^2x^7+70ABx^6+42(2AC+B^2)x^5+105(AD+BC)x^4+70(2BD+C^2)x^3+210CDx^2+210D^2x\right]_{x_1}^{x_2}}{210((x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0))^2} \\
& + \frac{\left[30A'^2x^7+70A'B'x^6+42(2A'C'+B'^2)x^5+105(A'D'+B'C')x^4+70(2B'D'+C'^2)x^3+210C'D'x^2+210D'^2x\right]_{x_2}^{x_3}}{210((x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0))^2} \\
& + \frac{(x_4-x_3)^5}{7(x_4-x_2)^2(x_4-x_1)^2}
\end{aligned}$$

And:

$$\begin{aligned}
\int_{x_1}^{x_4} b_{3,0}(x) \times b_{3,1}(x) dx \quad = \quad & \int_{x_1}^{x_2} \frac{x^3-3x_1x^2+3x_1^2x-x_1^3}{(x_4-x_1)(x_3-x_1)(x_2-x_1)} \frac{Ax^3+Bx^2+Cx+D}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} dx \\
& + \int_{x_2}^{x_3}
\end{aligned}$$

To be refined / simplified, apparently, the reduced expression with A, B, C, D is not numerically accurate.... (check)

.3.8 Deg = 3, Vol - to do

.4 D1N2 - Exact formulations

.4.1 Deg = 1, Surf

$$\begin{aligned}
\int_{x_0}^{x_2} \|\partial_x b_{1,0}(x)\|^2 dx &= \int_{x_0}^{x_1} \left(\tfrac{1}{x_1-x_0}\right)^2 dx + \int_{x_1}^{x_2} \left(\tfrac{-1}{x_2-x_1}\right)^2 dx \\
&= \tfrac{x_1-x_0}{(x_1-x_0)^2} + \tfrac{x_2-x_1}{(x_2-x_1)^2} &= \tfrac{1}{x_1-x_0} + \tfrac{1}{x_2-x_1}
\end{aligned}$$

and

$$\int_{x_1}^{x_2} \partial_x b_{1,0}(x) \times \partial_x b_{1,1}(x) dx = \int_{x_1}^{x_2} \tfrac{-1}{x_2-x_1} \tfrac{1}{x_2-x_1} dx = \tfrac{-1}{x_2-x_1}$$

.4.2 Deg = 1, Vol

$$\begin{aligned}
\int_{x_0}^{x_2} x\|\partial_x b_{1,0}(x)\|^2 dx &= \int_{x_0}^{x_1} x \left(\tfrac{1}{x_1-x_0}\right)^2 dx + \int_{x_1}^{x_2} x \left(\tfrac{-1}{x_2-x_1}\right)^2 dx \\
&= \tfrac{x_1^2-x_0^2}{2(x_1-x_0)^2} + \tfrac{x_2^2-x_1^2}{2(x_2-x_1)^2} &= \tfrac{x_1+x_0}{2(x_1-x_0)} + \tfrac{x_2+x_1}{2(x_2-x_1)}
\end{aligned}$$

and

$$\begin{aligned}
\int_{x_1}^{x_2} x\partial_x b_{1,0}(x) \times \partial_x b_{1,1}(x) dx &= \int_{x_1}^{x_2} x \tfrac{-1}{x_2-x_1} \tfrac{1}{x_2-x_1} dx \\
&= -\tfrac{x_2^2-x_1^2}{2(x_2-x_1)^2} &= -\tfrac{x_2+x_1}{2(x_2-x_1)}
\end{aligned}$$

.4.3 Deg = 2, Surf

$$\begin{aligned}
\int_{x_0}^{x_3} \|\partial_x b_{2,0}(x)\|^2 dx &= \int_{x_0}^{x_1} \left(\tfrac{2(x-x_0)}{(x_2-x_0)(x_1-x_0)}\right)^2 dx + \int_{x_1}^{x_2} \left(\tfrac{-2(x_3+x_2-x_1-x_0)x+2(x_3x_2-x_1x_0)}{(x_3-x_1)(x_2-x_1)(x_2-x_0)}\right)^2 dx + \int_{x_2}^{x_3} \left(\tfrac{-2(x_3-x)}{(x_3-x_2)(x_3-x_1)}\right)^2 dx \\
&= \tfrac{\left[4(x-x_0)^3\right]_{x_0}^{x_1}}{3(x_2-x_0)^2(x_1-x_0)^2} + \tfrac{\left[4(x_3+x_2-x_1-x_0)^2x^3-12(x_3+x_2-x_1-x_0)(x_3x_2-x_1x_0)x^2+12(x_3x_2-x_1x_0)^2x\right]_{x_1}^{x_2}}{3(x_3-x_1)^2(x_2-x_1)^2(x_2-x_0)^2} + \tfrac{\left[4(x-x_3)^3\right]_{x_2}^{x_3}}{3(x_3-x_2)^2(x_3-x_1)^2} \\
&= \tfrac{4(x_1-x_0)}{3(x_2-x_0)^2} \\
&\quad+\tfrac{4x_2^4-4x_2^3x_1-4x_2x_1^3+4x_1^4+4(x_3^2+x_0^2)(x_2^2-2x_2x_1+x_1^2)-4x_3(x_2^3-3x_2x_1^2+2x_1^3)+4x_0(3x_2^2x_1-2x_2^3-x_1^3)+4x_3x_0(x_2^2-2x_2x_1+x_1^2)}{3(x_3-x_1)^2(x_2-x_1)(x_2-x_0)^2} \\
&\quad+\tfrac{4(x_3-x_2)}{3(x_3-x_1)^2} \\
&= \tfrac{4(x_1-x_0)}{3(x_2-x_0)^2} \\
&\quad+4(x_2-x_1)\tfrac{x_2^2+x_2x_1+x_1^2+x_3^2+x_3x_0+x_0^2-x_3(x_2+2x_1)-x_0(2x_2+x_1)}{3(x_3-x_1)^2(x_2-x_0)^2} \\
&\quad+\tfrac{4(x_3-x_2)}{3(x_3-x_1)^2}
\end{aligned}$$

And

$$\begin{aligned}
\int_{x_1}^{x_3} \partial_x b_{2,0}(x) \times \partial_x b_{2,1}(x) dx &= \int_{x_1}^{x_2} \tfrac{-2(x_3+x_2-x_1-x_0)x+2(x_3x_2-x_1x_0)}{(x_3-x_1)(x_2-x_1)(x_2-x_0)} \tfrac{2(x-x_1)}{(x_3-x_1)(x_2-x_1)} dx + \int_{x_2}^{x_3} \tfrac{-2(x_4+x_3-x_2-x_1)x+2(x_4x_3-x_2x_1)}{(x_4-x_2)(x_3-x_2)(x_3-x_1)} \tfrac{2(x-x_3)}{(x_3-x_2)(x_3-x_1)} dx \\
&= \int_{x_1}^{x_2} 4\tfrac{-(x_3+x_2-x_1-x_0)x^2+(x_3x_2+x_3x_1+x_2x_1-x_1^2-2x_1x_0)x-x_3x_2x_1+x_1^2x_0}{(x_3-x_1)^2(x_2-x_1)^2(x_2-x_0)} dx \\
&\quad+\int_{x_2}^{x_3} 4\tfrac{-(x_4+x_3-x_2-x_1)x^2+(2x_4x_3+x_3^2-x_3x_2-x_3x_1-x_2x_1)x-x_4x_3^2+x_3x_2x_1}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)^2} dx
\end{aligned}$$

Hence:

$$
\begin{aligned}
\int_{x_1}^{x_3} \partial_x b_{2,0}(x) \times \partial_x b_{2,1}(x)dx &= \frac{-4(x_3+x_2-x_1-x_0)(x_2^2+x_2x_1+x_1^2)+6(x_3x_2+x_3x_1+x_2x_1-x_1^2-2x_1x_0)(x_2+x_1)-12x_3x_2x_1+12x_1^2x_0}{3(x_3-x_1)^2(x_2-x_1)(x_2-x_0)} \\
&+\frac{-4(x_4+x_3-x_2-x_1)(x_3^2+x_3x_2+x_2^2)+6(2x_4x_3+x_3^2-x_3x_2-x_3x_1-x_2x_1)(x_3+x_2)-12x_4x_3^2+12x_3x_2x_1}{3(x_4-x_2)(x_3-x_2)(x_3-x_1)^2} \\
&= \frac{-4x_3x_2^2-4x_2^3+4x_2^2x_1+4x_2^2x_0-4x_3x_2x_1-4x_2^2x_1+4x_2x_1^2+4x_2x_1x_0-4x_3x_1^2-4x_2x_1^2+4x_1^3+4x_1^2x_0+6x_3x_2^2+6x_3x_2x_1+6x_2^2x_1-6x_2x_1^2-12x_2x_1x_0+6x_3x_2x_1+6x_3x_1^2+6x_2x_1^2-6x}{3(x_3-x_1)^2(x_2-x_1)(x_2-x_0)} \\
&+\frac{-4x_4x_3^2-4x_3^3+4x_3^2x_2+4x_3^2x_1+-4x_4x_3x_2-4x_3^2x_2+4x_3x_2^2+4x_3x_2x_1+-4x_4x_2^2-4x_3x_2^2+4x_2^3+4x_2^2x_1+12x_4x_3^2+6x_3^3-6x_3^2x_2-6x_3^2x_1-6x_3x_2x_1+12x_4x_3x_2+6x_3^2x_2-6x_3x_2^2-6}{3(x_4-x_2)(x_3-x_2)(x_3-x_1)^2} \\
&= \frac{-4x_2^3+6x_2^2x_1-2x_1^3+x_0(4x_2^2-8x_2x_1+4x_1^2)+x_3(-4x_2x_1+2x_1^2+2x_2^2)}{3(x_3-x_1)^2(x_2-x_1)(x_2-x_0)} \\
&+\frac{2x_3^3-6x_3x_2^2+4x_2^3+x_4(-4x_3^2+8x_3x_2-4x_2^2)-x_1(2x_3^2-4x_3x_2+2x_2^2)}{3(x_4-x_2)(x_3-x_2)(x_3-x_1)^2} \\
&= 2(x_2-x_1)\frac{x_3-2x_2-x_1+2x_0}{3(x_3-x_1)^2(x_2-x_0)} \\
&+2(x_3-x_2)\frac{-2x_4+x_3+2x_2-x_1}{3(x_4-x_2)(x_3-x_1)^2}
\end{aligned}
$$

And

$$
\begin{aligned}
\int_{x_2}^{x_3} \partial_x b_{2,0}(x) \times \partial_x b_{2,2}(x)dx &= \int_{x_2}^{x_3} \frac{2(x-x_3)}{(x_3-x_2)(x_3-x_1)} \frac{2(x-x_2)}{(x_4-x_2)(x_3-x_2)} dx \\
&= \int_{x_2}^{x_3} 4\frac{x^2-(x_3+x_2)x+x_3x_2}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)} dx \\
&= \frac{\left[4x^3-6(x_3+x_2)x^2+12x_3x_2x\right]_{x_2}^{x_3}}{3(x_4-x_2)(x_3-x_2)^2(x_3-x_1)} \\
&= \frac{4(x_3^2+x_3x_2+x_2^2)-6(x_3+x_2)(x_3+x_2)+12x_3x_2}{3(x_4-x_2)(x_3-x_2)(x_3-x_1)} \quad = -2\frac{x_3-x_2}{3(x_4-x_2)(x_3-x_1)}
\end{aligned}
$$

.4.4 Deg = 2, Vol

$$
\begin{aligned}
\int_{x_0}^{x_3} x\|\partial_x b_{2,0}(x)\|^2 dx &= \int_{x_0}^{x_1} x\left(\frac{2(x-x_0)}{(x_2-x_0)(x_1-x_0)}\right)^2 dx + \int_{x_1}^{x_2} x\left(\frac{-2(x_3+x_2-x_1-x_0)x+2(x_3x_2-x_1x_0)}{(x_3-x_1)(x_2-x_1)(x_2-x_0)}\right)^2 dx + \int_{x_2}^{x_3} x\left(\frac{-2(x_3-x)}{(x_3-x_2)(x_3-x_1)}\right)^2 dx \\
&= \int_{x_0}^{x_1} 4\frac{x^3-2x_0x^2+x_0^2x}{(x_2-x_0)^2(x_1-x_0)^2}dx \\
&\quad + \int_{x_1}^{x_2} 4\frac{(x_3+x_2-x_1-x_0)^2x^3-2(x_3+x_2-x_1-x_0)(x_3x_2-x_1x_0)x^2+(x_3x_2-x_1x_0)^2x}{(x_3-x_1)^2(x_2-x_1)^2(x_2-x_0)^2}dx \\
&\quad + \int_{x_2}^{x_3} 4\frac{x^3-2x_3x^2+x_3^2x}{(x_3-x_2)^2(x_3-x_1)^2}dx \\
&= \frac{\left[3x^4-8x_0x^3+6x_0^2x^2\right]_{x_0}^{x_1}}{3(x_2-x_0)^2(x_1-x_0)^2} \\
&\quad + \frac{\left[3(x_3+x_2-x_1-x_0)^2x^4-8(x_3+x_2-x_1-x_0)(x_3x_2-x_1x_0)x^3+6(x_3x_2-x_1x_0)^2x^2\right]_{x_1}^{x_2}}{3(x_3-x_1)^2(x_2-x_1)^2(x_2-x_0)^2} \\
&\quad + \frac{\left[3x^4-8x_3x^3+6x_3^2x^2\right]_{x_2}^{x_3}}{3(x_3-x_2)^2(x_3-x_1)^2} \\
&= \frac{3(x_1^3+x_1^2x_0+x_1x_0^2+x_0^3)-8x_0(x_1^2+x_1x_0+x_0^2)+6x_0^2(x_1+x_0)}{3(x_2-x_0)^2(x_1-x_0)} \\
&\quad + \frac{3(x_3+x_2-x_1-x_0)^2(x_2^3+x_2^2x_1+x_2x_1^2+x_1^3)-8(x_3^2x_2+x_3x_2^2-x_3x_2x_1-x_3x_2x_0-x_3x_1x_0-x_2x_1x_0+x_1^2x_0+x_1x_0^2)(x_2^2+x_2x_1+x_1^2)+6(x_3x_2-x_1x_0)^2(x_2+x_1)}{3(x_3-x_1)^2(x_2-x_1)(x_2-x_0)^2} \\
&\quad + \frac{3(x_3^3+x_3^2x_2+x_3x_2^2+x_2^3)-8x_3(x_3^2+x_3x_2+x_2^2)+6x_3^2(x_3+x_2)}{3(x_3-x_2)(x_3-x_1)^2} \\
&= \frac{3x_1^3-5x_1^2x_0+x_1x_0^2+x_0^3}{3(x_2-x_0)^2(x_1-x_0)} \\
&\quad + \frac{x_3^2x_2^3+3x_2^5+3x_2^3x_0^2-2x_3x_2^4+2x_3x_2^3x_0-3x_2^4x_1-6x_2^4x_0+8x_2^3x_1x_0+x_3^2x_2^2x_1-5x_2^2x_1x_0^2-2x_3x_2^2x_1x_0-5x_3^2x_2x_1^2-3x_2x_1^4+x_2x_1^2x_0^2+8x_3x_2x_1^3-2x_3x_2x_1^2x_0+3x_3^2x_1^3+3x_1^5+x_1^3x_0^2-6x_3x_1^4+2x}{3(x_3-x_1)^2(x_2-x_1)(x_2-x_0)^2} \\
&\quad + \frac{x_3^3+x_3^2x_2-5x_3x_2^2+3x_2^3}{3(x_3-x_2)(x_3-x_1)^2} \\
&= \frac{(3x_1+x_0)(x_1-x_0)^2}{3(x_2-x_0)^2(x_1-x_0)} \\
&\quad + \frac{3(x_2^5-x_2^4x_1-x_2x_1^4+x_1^5)+x_3^2(x_2^3+x_2^2x_1-5x_2x_1^2+3x_1^3)+x_0^2(3x_2^3-5x_2^2x_1+x_2x_1^2+x_1^3)-2x_3(x_2^4-4x_2x_1^3+3x_1^4)-2x_0(3x_2^4-4x_2^3x_1+x_1^4)+2x_3x_0(x_2^3-x_2^2x_1-x_2x_1^2+x_1^3)}{3(x_3-x_1)^2(x_2-x_1)(x_2-x_0)^2} \\
&\quad + \frac{(x_3+3x_2)(x_3-x_2)^2}{3(x_3-x_2)(x_3-x_1)^2} \\
&= \frac{(3x_1+x_0)(x_1-x_0)}{3(x_2-x_0)^2} \\
&\quad + (x_2-x_1)\frac{3(x_2+x_1)(x_2^2+x_1^2)+x_3^2(x_2+3x_1)+x_0^2(3x_2+x_1)-2x_3(x_2^2+2x_2x_1+3x_1^2)-2x_0(3x_2^2+2x_2x_1+x_1^2)+2x_3x_0(x_2+x_1)}{3(x_3-x_1)^2(x_2-x_0)^2} \\
&\quad + \frac{(x_3+3x_2)(x_3-x_2)}{3(x_3-x_1)^2}
\end{aligned}
$$

And

$$
\begin{aligned}
\int_{x_1}^{x_3} x\partial_x b_{2,0}(x)\times\partial_x b_{2,1}(x)dx &= \int_{x_1}^{x_2} x\frac{-2(x_3+x_2-x_1-x_0)x+2(x_3x_2-x_1x_0)}{(x_3-x_1)(x_2-x_1)(x_2-x_0)}\frac{2(x-x_1)}{(x_3-x_1)(x_2-x_1)}dx + \int_{x_2}^{x_3} x\frac{-2(x_4+x_3-x_2-x_1)x+2(x_4x_3-x_2x_1)}{(x_4-x_2)(x_3-x_2)(x_3-x_1)}\frac{2(x-x_3)}{(x_3-x_2)(x_3-x_1)}dx \\
&= \int_{x_1}^{x_2} 4\frac{-(x_3+x_2-x_1-x_0)x^3+(x_3x_2+x_3x_1+x_2x_1-x_1^2-2x_1x_0)x^2+(x_1^2x_0-x_3x_2x_1)x}{(x_3-x_1)^2(x_2-x_1)^2(x_2-x_0)}dx \\
&\quad + \int_{x_2}^{x_3} 4\frac{-(x_4+x_3-x_2-x_1)x^3+(2x_4x_3+x_3^2-x_3x_2-x_3x_1-x_2x_1)x^2+(x_3x_2x_1-x_4x_3^2)x}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)^2}dx \\
&= \frac{\left[-3(x_3+x_2-x_1-x_0)x^4+4(x_3x_2+x_3x_1+x_2x_1-x_1^2-2x_1x_0)x^3+6(x_1^2x_0-x_3x_2x_1)x^2\right]_{x_1}^{x_2}}{3(x_3-x_1)^2(x_2-x_1)^2(x_2-x_0)} \\
&\quad + \frac{\left[-3(x_4+x_3-x_2-x_1)x^4+4(2x_4x_3+x_3^2-x_3x_2-x_3x_1-x_2x_1)x^3+6(x_3x_2x_1-x_4x_3^2)x^2\right]_{x_2}^{x_3}}{3(x_4-x_2)(x_3-x_2)^2(x_3-x_1)^2}
\end{aligned}
$$

So

$$
\begin{aligned}
\int_{x_1}^{x_3} x\partial_x b_{2,0}(x)\times\partial_x b_{2,1}(x)dx &= \frac{-3(x_3+x_2-x_1-x_0)(x_2^3+x_2^2x_1+x_2x_1^2+x_1^3)+4(x_3x_2+x_3x_1+x_2x_1-x_1^2-2x_1x_0)(x_2^2+x_2x_1+x_1^2)+6(x_1^2x_0-x_3x_2x_1)(x_2+x_1)}{3(x_3-x_1)^2(x_2-x_1)(x_2-x_0)} \\
&+\frac{-3(x_4+x_3-x_2-x_1)(x_3^3+x_3^2x_2+x_3x_2^2+x_2^3)+4(2x_4x_3+x_3^2-x_3x_2-x_3x_1-x_2x_1)(x_3^2+x_3x_2+x_2^2)+6(x_3x_2x_1-x_4x_3^2)(x_3+x_2)}{3(x_4-x_2)(x_3-x_2)(x_3-x_1)^2} \\
&= \frac{-3x_2^4+4x_2^3x_1-x_1^4+x_3(x_2^3-x_2^2x_1-x_2x_1^2+x_1^3)+x_0(3x_2^3-5x_2^2x_1+x_2x_1^2+x_1^3)}{3(x_3-x_1)^2(x_2-x_1)(x_2-x_0)} \\
&+\frac{x_3^4-4x_3x_2^3+3x_2^4-x_4(x_3^3+x_3^2x_2-5x_3x_2^2+3x_2^3)-x_1(x_3^3-x_3^2x_2-x_3x_2^2+x_2^3)}{3(x_4-x_2)(x_3-x_2)(x_3-x_1)^2} \\
&= (x_2-x_1)\frac{-(3x_2^2+2x_2x_1+x_1^2)+x_3(x_2+x_1)+x_0(3x_2+x_1)}{3(x_3-x_1)^2(x_2-x_0)} \\
&+(x_3-x_2)\frac{x_3^2+2x_3x_2+3x_2^2-x_4(x_3+3x_2)-x_1(x_3+x_2)}{3(x_4-x_2)(x_3-x_1)^2}
\end{aligned}
$$

And

$$
\begin{aligned}
\int_{x_2}^{x_3} x\partial_x b_{2,0}(x)\times\partial_x b_{2,2}(x)dx &= \int_{x_2}^{x_3} x\frac{2(x-x_3)}{(x_3-x_2)(x_3-x_1)}\frac{2(x-x_2)}{(x_4-x_2)(x_3-x_2)}dx \\
&= \int_{x_2}^{x_3} 4\frac{x^3-(x_3+x_2)x^2+x_3x_2x}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)}dx \\
&= \frac{\left[3x^4-4(x_3+x_2)x^3+6x_3x_2x^2\right]_{x_2}^{x_3}}{3(x_4-x_2)(x_3-x_2)^2(x_3-x_1)} \\
&= -\frac{x_3^3-x_3^2x_2-x_3x_2^2+x_2^3}{3(x_4-x_2)(x_3-x_2)(x_3-x_1)} \qquad = -\frac{(x_3+x_2)(x_3-x_2)}{3(x_4-x_2)(x_3-x_1)}
\end{aligned}
$$

.4.5 Deg = 3, Surf - to be finished and checked

$$
\begin{aligned}
\int_{x_0}^{x_4}\|\partial_x b_{3,0}(x)\|^2dx &= \int_{x_0}^{x_1}\left(\frac{3(x-x_0)^2}{(x_3-x_0)(x_2-x_0)(x_1-x_0)}\right)^2dx+\int_{x_1}^{x_2}\left(\frac{3Ax^2+2Bx+C}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)}\right)^2dx+\int_{x_2}^{x_3}\left(\frac{3A^/x^2+2B^/x+C^/}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)}\right)^2dx+\int_{x_3}^{x_4}\Big(\frac{-3}{(x_4-x_3)(x} \\
&= \frac{\left[9(x-x_0)^5\right]_{x_0}^{x_1}}{5(x_3-x_0)^2(x_2-x_0)^2(x_1-x_0)^2}dx \\
&+\int_{x_1}^{x_2}\frac{9A^2x^4+12ABx^3+2(2B^2+3AC)x^2+4BCx+C^2}{((x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0))^2}dx \\
&+\int_{x_1}^{x_2}\frac{9A^{/2}x^4+12ABx^3+2(2B^{/2}+3AC)x^2+4BCx+C^{/2}}{((x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0))^2}dx \\
&+\frac{\left[-9(x_4-x)^5\right]_{x_3}^{x_4}}{5(x_4-x_3)^2(x_4-x_2)^2(x_4-x_1)^2} \\
&= \frac{9(x_1-x_0)^3}{5(x_3-x_0)^2(x_2-x_0)^2} \\
&+\frac{\left[27A^2x^5+45ABx^4+10(2B^2+3AC)x^3+30BCx^2+15C^2x\right]_{x_1}^{x_2}}{15((x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0))^2} \\
&+\frac{\left[27A^{/2}x^5+45ABx^4+10(2B^{/2}+3AC)x^3+30BCx^2+15C^{/2}x\right]_{x_1}^{x_2}}{15((x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0))^2} \\
&+\frac{9(x_4-x_3)^3}{5(x_4-x_2)^2(x_4-x_1)^2}
\end{aligned}
$$

and

$$
\begin{aligned}
\int_{x_1}^{x_4}\partial_x b_{3,0}(x)\times\partial_x b_{3,1}dx &= \int_{x_1}^{x_2}\frac{3Ax^2+2Bx+C}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)}\frac{3(x-x_1)^2}{(x_4-x_1)(x_3-x_1)(x_2-x_1)}dx \\
&+\int_{x_2}^{x_3}\frac{3A^/x^2+2B^/x+C^/}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)}\frac{3A(1)x^2+2B(1)x+C(1)}{(x_5-x_2)(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)}dx \\
&+\int_{x_3}^{x_4}\frac{-3(x_4-x)^2}{(x_4-x_3)(x_4-x_2)(x_4-x_1)}\frac{3A(1)^/x^2+2B(1)^/x+C(1)^/}{(x_5-x_3)(x_5-x_2)(x_4-x_3)(x_4-x_2)(x_4-x_1)}
\end{aligned}
$$

and

$$
\begin{aligned}
\int_{x_2}^{x_4}\partial_x b_{3,0}(x)\times\partial_x b_{3,2}dx &= \int_{x_2}^{x_3}\frac{3A^/x^2+2B^/x+C^/}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)}\frac{3(x-x_2)^2}{(x_5-x_2)(x_4-x_2)(x_3-x_2)}dx \\
&+\int_{x_3}^{x_4}\frac{-3(x_4-x)^2}{(x_4-x_3)(x_4-x_2)(x_4-x_1)}\frac{3A(2)x^2+2B(2)x+C(2)}{(x_6-x_3)(x_5-x_3)(x_5-x_2)(x_4-x_3)(x_4-x_2)}
\end{aligned}
$$

and

$$
\begin{aligned}
\int_{x_3}^{x_4} \partial_x b_{3,0}(x) \times \partial_x b_{3,3} dx &= \int_{x_3}^{x_4} \frac{-3(x_4-x)^2}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \frac{3(x-x_3)^2}{(x_6-x_3)(x_5-x_3)(x_4-x_3)} dx \\
&= \int_{x_3}^{x_4} \frac{-9(x-x_3)^2(x_4-x)^2}{(x_6-x_3)(x_5-x_3)(x_4-x_3)^2(x_4-x_2)(x_4-x_1)} dx \\
&= \int_{x_3}^{x_4} -9\frac{x^4-2(x_4+x_3)x^3+(x_3^2+4x_4x_3+x_4^2)x^2-2(x_4x_3^2+x_4^2x_3)x+x_4^2x_3^2}{(x_6-x_3)(x_5-x_3)(x_4-x_3)^2(x_4-x_2)(x_4-x_1)} dx \\
&- \frac{\left[18x^5-45(x_4+x_3)x^4+30(x_3^2+4x_4x_3+x_4^2)x^3-90(x_4x_3^2+x_4^2x_3)x^2+90x_4^2x_3^2x\right]_{x_3}^{x_4}}{10(x_6-x_3)(x_5-x_3)(x_4-x_3)^2(x_4-x_2)(x_4-x_1)} \\
&- \frac{18(x_4^4+x_4^3x_3+x_4^2x_3^2+x_4x_3^3+x_3^4)-45(x_4+x_3)(x_4^3+x_4^2x_3+x_4x_3^2+x_3^3)+30(x_3^2+4x_4x_3+x_4^2)(x_4^2+x_4x_3+x_3^2)-90(x_4x_3^2+x_4^2x_3)(x_4+x_3)+90x_4^2x_3^2}{10(x_6-x_3)(x_5-x_3)(x_4-x_3)(x_4-x_2)(x_4-x_1)} \\
&- \frac{3x_4^4-12x_4^3x_3+18x_4^2x_3^2-12x_4x_3^3+3x_3^4}{10(x_6-x_3)(x_5-x_3)(x_4-x_3)(x_4-x_2)(x_4-x_1)} \\
&= -3\frac{(x_4-x_3)^3}{10(x_6-x_3)(x_5-x_3)(x_4-x_2)(x_4-x_1)}
\end{aligned}
$$

.4.6 Deg = 3, Vol - to be done

.5 D2N2 - Exact formulations

.5.1 Deg = 2, Surf

$$
\begin{aligned}
\int_{x_0}^{x_3} \|\partial_x^2 b_{2,0}(x)\|^2 dx &= \int_{x_0}^{x_1} \left(\frac{2}{(x_2-x_0)(x_1-x_0)}\right)^2 dx + \int_{x_1}^{x_2} \left(\frac{-2(x_3+x_2-x_1-x_0)}{(x_3-x_1)(x_2-x_1)(x_2-x_0)}\right)^2 dx + \int_{x_2}^{x_3} \left(\frac{2}{(x_3-x_2)(x_3-x_1)}\right)^2 dx \\
&= \int_{x_0}^{x_1} \frac{4}{(x_2-x_0)^2(x_1-x_0)^2} dx + \int_{x_1}^{x_2} \frac{4(x_3+x_2-x_1-x_0)^2}{(x_3-x_1)^2(x_2-x_1)^2(x_2-x_0)^2} dx + \int_{x_2}^{x_3} \frac{4}{(x_3-x_2)^2(x_3-x_1)^2} dx \\
&= \frac{4}{(x_2-x_0)^2(x_1-x_0)} + \frac{4(x_3+x_2-x_1-x_0)^2}{(x_3-x_1)^2(x_2-x_1)(x_2-x_0)^2} + \frac{4}{(x_3-x_2)(x_3-x_1)^2}
\end{aligned}
$$

and

$$
\begin{aligned}
\int_{x_1}^{x_3} \partial_x^2 b_{2,0}(x) \times \partial_x^2 b_{2,1}(x) dx &= \int_{x_1}^{x_2} \frac{-2(x_3+x_2-x_1-x_0)}{(x_3-x_1)(x_2-x_1)(x_2-x_0)} \frac{2}{(x_3-x_1)(x_2-x_1)} dx + \int_{x_2}^{x_3} \frac{-2(x_4+x_3-x_2-x_1)}{(x_4-x_2)(x_3-x_2)(x_3-x_1)} \frac{2}{(x_3-x_2)(x_3-x_1)} dx \\
&= \int_{x_1}^{x_2} \frac{-4(x_3+x_2-x_1-x_0)}{(x_3-x_1)^2(x_2-x_1)^2(x_2-x_0)} dx + \int_{x_2}^{x_3} \frac{-4(x_4+x_3-x_2-x_1)}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)^2} dx \\
&= \frac{-4(x_3+x_2-x_1-x_0)}{(x_3-x_1)^2(x_2-x_1)(x_2-x_0)} + \frac{-4(x_4+x_3-x_2-x_1)}{(x_4-x_2)(x_3-x_2)(x_3-x_1)^2}
\end{aligned}
$$

and

$$
\begin{aligned}
\int_{x_2}^{x_3} \partial_x^2 b_{2,0}(x) \times \partial_x^2 b_{2,2}(x) dx &= \int_{x_2}^{x_3} \frac{2}{(x_3-x_2)(x_3-x_1)} \frac{2}{(x_4-x_2)(x_3-x_2)} dx \\
&= \int_{x_2}^{x_3} \frac{4}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)} dx \qquad = \frac{4}{(x_4-x_2)(x_3-x_2)(x_3-x_1)}
\end{aligned}
$$

.5.2 Deg = 2, Vol

$$
\begin{aligned}
\int_{x_0}^{x_3} x\|\partial_x^2 b_{2,0}(x)\|^2 dx &= \int_{x_0}^{x_1} x \left(\frac{2}{(x_2-x_0)(x_1-x_0)}\right)^2 dx + \int_{x_1}^{x_2} x \left(\frac{-2(x_3+x_2-x_1-x_0)}{(x_3-x_1)(x_2-x_1)(x_2-x_0)}\right)^2 dx + \int_{x_2}^{x_3} x \left(\frac{2}{(x_3-x_2)(x_3-x_1)}\right)^2 dx \\
&= \int_{x_0}^{x_1} \frac{4x}{(x_2-x_0)^2(x_1-x_0)^2} dx + \int_{x_1}^{x_2} \frac{4(x_3+x_2-x_1-x_0)^2 x}{(x_3-x_1)^2(x_2-x_1)^2(x_2-x_0)^2} dx + \int_{x_2}^{x_3} \frac{4x}{(x_3-x_2)^2(x_3-x_1)^2} dx \\
&= \frac{2(x_1+x_0)}{(x_2-x_0)^2(x_1-x_0)} + \frac{2(x_3+x_2-x_1-x_0)^2(x_2+x_1)}{(x_3-x_1)^2(x_2-x_1)(x_2-x_0)^2} + \frac{2(x_3+x_2)}{(x_3-x_2)(x_3-x_1)^2}
\end{aligned}
$$

and

$$
\begin{aligned}
\int_{x_1}^{x_3} x\partial_x^2 b_{2,0}(x) \times \partial_x^2 b_{2,1}(x) dx &= \int_{x_1}^{x_2} x \frac{-2(x_3+x_2-x_1-x_0)}{(x_3-x_1)(x_2-x_1)(x_2-x_0)} \frac{2}{(x_3-x_1)(x_2-x_1)} dx + \int_{x_2}^{x_3} x \frac{-2(x_4+x_3-x_2-x_1)}{(x_4-x_2)(x_3-x_2)(x_3-x_1)} \frac{2}{(x_3-x_2)(x_3-x_1)} dx \\
&= \int_{x_1}^{x_2} \frac{-4(x_3+x_2-x_1-x_0)x}{(x_3-x_1)^2(x_2-x_1)^2(x_2-x_0)} dx + \int_{x_2}^{x_3} \frac{-4(x_4+x_3-x_2-x_1)x}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)^2} dx \\
&= \frac{-2(x_3+x_2-x_1-x_0)(x_2+x_1)}{(x_3-x_1)^2(x_2-x_1)(x_2-x_0)} + \frac{-2(x_4+x_3-x_2-x_1)(x_3+x_2)}{(x_4-x_2)(x_3-x_2)(x_3-x_1)^2}
\end{aligned}
$$

and

$$
\begin{aligned}
\int_{x_2}^{x_3} x\partial_x^2 b_{2,0}(x) \times \partial_x^2 b_{2,2}(x) dx &= \int_{x_2}^{x_3} x \frac{2}{(x_3-x_2)(x_3-x_1)} \frac{2}{(x_4-x_2)(x_3-x_2)} dx \\
&= \int_{x_2}^{x_3} \frac{4x}{(x_4-x_2)(x_3-x_2)^2(x_3-x_1)} dx \\
&= \frac{2(x_3+x_2)}{(x_4-x_2)(x_3-x_2)(x_3-x_1)}
\end{aligned}
$$

.5.3 Deg = 3, Surf - to be simplified

$$
\begin{aligned}
\int_{x_0}^{x_4} \|\partial_x^2 b_{3,0}(x)\|^2 dx &= \int_{x_0}^{x_1} \left(\frac{6(x-x_0)}{(x_3-x_0)(x_2-x_0)(x_1-x_0)}\right)^2 dx + \int_{x_1}^{x_2} \left(\frac{6Ax+2B}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)}\right)^2 dx + \int_{x_2}^{x_3} \left(\frac{6A^{/}x+2B^{/}}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)}\right)^2 dx + \int_{x_3}^{x_4} \\
&= \int_{x_0}^{x_1} \frac{36(x-x_0)^2}{(x_3-x_0)^2(x_2-x_0)^2(x_1-x_0)^2} dx + \int_{x_1}^{x_2} \frac{36A^2x^2+24ABx+4B^2}{((x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0))^2} dx + \int_{x_2}^{x_3} \frac{36A^{/2}x^2+24A^{/}B^{/}x+4B^{/2}}{((x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0))^2} dx + \int_{x_3}^{x_4} \\
&= \frac{12(x_1-x_0)}{(x_3-x_0)^2(x_2-x_0)^2} + \frac{\left[12A^2x^3+12ABx^2+4B^2x\right]_{x_1}^{x_2}}{((x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0))^2} + \frac{\left[12A^{/2}x^3+12A^{/}B^{/}x^2+4B^{/2}x\right]_{x_2}^{x_3}}{((x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0))^2} + \frac{12(x_4-x_3)}{(x_4-x_2)^2(x_4-x_1)^2} \\
&= \frac{12(x_1-x_0)}{(x_3-x_0)^2(x_2-x_0)^2} \\
&\quad + \frac{12A^2(x_2^2+x_2x_1+x_1^2)+12AB(x_2+x_1)+4B^2}{((x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_0))^2(x_2-x_1)} \\
&\quad + \frac{12A^{/2}(x_3^2+x_3x_2+x_2^2)+12A^{/}B^{/}(x_3+x_2)+4B^{/2}}{((x_4-x_2)(x_4-x_1)(x_3-x_1)(x_3-x_0))^2(x_3-x_2)} \\
&\quad + \frac{12(x_4-x_3)}{(x_4-x_2)^2(x_4-x_1)^2}
\end{aligned}
$$

And

$$
\begin{aligned}
\int_{x_1}^{x_4} \partial_x^2 b_{3,0}(x) \times \partial_x^2 b_{3,1}(x) dx &= \int_{x_1}^{x_2} \frac{6Ax+2B}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} \frac{6(x-x_1)}{(x_4-x_1)(x_3-x_1)(x_2-x_1)} dx + \int_{x_2}^{x_3} \frac{6A^{/}x+2B^{/}}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} \frac{6A(1)x+2B(1)}{\cdots} \\
&= \int_{x_1}^{x_2} 12 \frac{3Ax^2-(3Ax_1-B)x-Bx_1}{(x_4-x_1)^2(x_3-x_1)^2(x_3-x_0)(x_2-x_1)^2(x_2-x_0)} dx \\
&\quad + \int_{x_2}^{x_3} 4 \frac{9A^{/}A(1)x^2+3(A(1)B^{/}+A^{/}B(1))x+B^{/}B(1)}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)^2(x_3-x_2)^2(x_3-x_1)^2(x_3-x_0)} dx \\
&\quad + \int_{x_3}^{x_4} 12 \frac{-3A^{/}(1)x^2+(3A^{/}(1)x_4-B^{/}(1))x+B^{/}(1)x_4}{(x_5-x_3)(x_5-x_2)(x_4-x_3)^2(x_4-x_2)^2(x_4-x_1)^2} dx \\
&= 6\frac{2A(x_2^2+x_2x_1+x_1^2)-(3Ax_1-B)(x_2+x_1)-2Bx_1}{(x_4-x_1)^2(x_3-x_1)^2(x_3-x_0)(x_2-x_1)(x_2-x_0)} + 2\frac{6A^{/}A(1)(x_3^2+x_3x_2+x_2^2)+3(A(1)B^{/}+A^{/}B(1))(x_3+x_2)+2B^{/}B(1)}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)^2(x_3-x_2)(x_3-x_1)^2(x_3-x_0)} - 6\frac{2A^{/}(1)(x_4^2+x_4x_3+x_3^2)-(3A^{/}(1)x_4-B^{/}(1))(\cdots}{(x_5-x_3)(x_5-x_2)(x_4-x_3)(x_4-x_2)^2(\cdots} \\
&= 6\frac{A(2x_2^2-x_2x_1-x_1^2)+B(x_2-x_1)}{(x_4-x_1)^2(x_3-x_1)^2(x_3-x_0)(x_2-x_1)(x_2-x_0)} + 2\frac{6A^{/}A(1)(x_3^2+x_3x_2+x_2^2)+3(A(1)B^{/}+A^{/}B(1))(x_3+x_2)+2B^{/}B(1)}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)^2(x_3-x_2)(x_3-x_1)^2(x_3-x_0)} - 6\frac{-A^{/}(1)(x_4^2+x_4x_3-2x_3^2)-B^{/}(1)(x_4-x_3)}{(x_5-x_3)(x_5-x_2)(x_4-x_3)(x_4-x_2)^2(x_4-x_1)^2} \\
&= 6\frac{A(2x_2+x_1)+B}{(x_4-x_1)^2(x_3-x_1)^2(x_3-x_0)(x_2-x_0)} + 2\frac{6A^{/}A(1)(x_3^2+x_3x_2+x_2^2)+3(A(1)B^{/}+A^{/}B(1))(x_3+x_2)+2B^{/}B(1)}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)^2(x_3-x_2)(x_3-x_1)^2(x_3-x_0)} + 6\frac{A^{/}(1)(x_4+2x_3)+B^{/}(1)}{(x_5-x_3)(x_5-x_2)(x_4-x_2)^2(x_4-x_1)^2}
\end{aligned}
$$

and

$$
\begin{aligned}
\int_{x_2}^{x_4} \partial_x^2 b_{3,0}(x) \times \partial_x^2 b_{3,2}(x) dx &= \int_{x_2}^{x_3} \frac{6A^{/}x+2B^{/}}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} \frac{6(x-x_2)}{(x_5-x_2)(x_4-x_2)(x_3-x_2)} dx + \int_{x_3}^{x_4} \frac{6(x_4-x)}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \frac{6A(2)x+2B(2)}{(x_6-x_3)(x_5-x_3)(x_5-x_2)(x_4-x_3)(x_4-x_2)} dx \\
&= \int_{x_2}^{x_3} \frac{36A^{/}x^2+12(B^{/}-3A^{/}x_2)x-12B^{/}x_2}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)(x_3-x_2)^2(x_3-x_1)(x_3-x_0)} dx + \int_{x_3}^{x_4} \frac{-36A(2)x^2+12(3A(2)x_4-B(2))x+12B(2)x_4}{(x_6-x_3)(x_5-x_3)(x_5-x_2)(x_4-x_3)^2(x_4-x_2)^2(x_4-x_1)} dx \\
&= 6\frac{2A^{/}(x_3^2+x_3x_2+x_2^2)+(B^{/}-3A^{/}x_2)(x_3+x_2)-2B^{/}x_2}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} - 6\frac{2A(2)(x_4^2+x_4x_3+x_3^2)+(B(2)-3A(2)x_4)(x_4+x_3)-2B(2)x_4}{(x_6-x_3)(x_5-x_3)(x_5-x_2)(x_4-x_3)(x_4-x_2)^2(x_4-x_1)} \\
&= 6\frac{A^{/}(2x_3^2-x_3x_2-x_2^2)+B^{/}(x_3-x_2)}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + 6\frac{A(2)(x_4^2+x_4x_3-2x_3^2)+B(2)(x_4-x_3)}{(x_6-x_3)(x_5-x_3)(x_5-x_2)(x_4-x_3)(x_4-x_2)^2(x_4-x_1)} \\
&= 6\frac{A^{/}(2x_3+x_2)+B^{/}}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)(x_3-x_1)(x_3-x_0)} + 6\frac{A(2)(x_4+2x_3)+B(2)}{(x_6-x_3)(x_5-x_3)(x_5-x_2)(x_4-x_2)^2(x_4-x_1)}
\end{aligned}
$$

and

$$
\begin{aligned}
\int_{x_3}^{x_4} \partial_x^2 b_{3,0}(x) \times \partial_x^2 b_{3,3}(x) dx &= \int_{x_3}^{x_4} \frac{6(x_4-x)}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \frac{6(x-x_3)}{(x_6-x_3)(x_5-x_3)(x_4-x_3)} dx \\
&= \int_{x_3}^{x_4} 36 \frac{-x^2+(x_4+x_3)x-x_4x_3}{(x_6-x_3)(x_5-x_3)(x_4-x_3)^2(x_4-x_2)(x_4-x_1)} dx \\
&= 6\frac{-2(x_4^2+x_4x_3+x_3^2)+3(x_4+x_3)^2-6x_4x_3}{(x_6-x_3)(x_5-x_3)(x_4-x_3)(x_4-x_2)(x_4-x_1)} \\
&= 6\frac{x_4-x_3}{(x_6-x_3)(x_5-x_3)(x_4-x_2)(x_4-x_1)}
\end{aligned}
$$

.5.4 Deg = 3, Vol - to be finished

$$
\begin{aligned}
\int_{x_0}^{x_4} x\|\partial_x^2 b_{3,0}(x)\|^2 dx &= \int_{x_0}^{x_1} x\left(\frac{6(x-x_0)}{(x_3-x_0)(x_2-x_0)(x_1-x_0)}\right)^2 dx + \int_{x_1}^{x_2} x\left(\frac{6Ax+2B}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)}\right)^2 dx + \int_{x_2}^{x_3} x\left(\frac{6A'x+2B'}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)}\right)^2 dx + \int_{x_3}^{x_4} x\Big(\\
&= \int_{x_0}^{x_1} \frac{36x(x-x_0)^2}{(x_3-x_0)^2(x_2-x_0)^2(x_1-x_0)^2}dx + \int_{x_1}^{x_2} \frac{36A^2x^3+24ABx^2+4B^2x}{((x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0))^2}dx + \int_{x_2}^{x_3} \frac{36A'^2x^3+24A'B'x^2+4B'^2x}{((x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0))^2}dx + \int_{x_3}^{x_4} \frac{36x(x_4-}{(x_4-x_3)^2(x_4-x_2} \\
&= 3\frac{3(x_1^3+x_1^2x_0+x_1x_0^2+x_0^3)-8x_0(x_1^2+x_1x_0+x_0^2)+6x_0^2(x_1+x_0)}{(x_3-x_0)^2(x_2-x_0)^2(x_1-x_0)} + \frac{9A^2(x_2^3+x_2^2x_1+x_2x_1^2+x_1^3)+8AB(x_2^2+x_2x_1+x_1^2)+2B^2(x_2+x_1)}{(x_4-x_1)^2(x_3-x_1)^2(x_3-x_0)^2(x_2-x_1)(x_2-x_0)^2} + \frac{9A'^2(x_3^3+x_3^2x_2+x_3x_2^2+x_2^3)+8A'B'(x_3^2+x_3x_2+x_2^2}{(x_4-x_2)^2(x_4-x_1)^2(x_3-x_2)(x_3-x_1)^2(x} \\
&= 3\frac{(3x_1+x_0)(x_1-x_0)}{(x_3-x_0)^2(x_2-x_0)^2} + \frac{9A^2(x_2^3+x_2^2x_1+x_2x_1^2+x_1^3)+8AB(x_2^2+x_2x_1+x_1^2)+2B^2(x_2+x_1)}{(x_4-x_1)^2(x_3-x_1)^2(x_3-x_0)^2(x_2-x_1)(x_2-x_0)^2} + \frac{9A'^2(x_3^3+x_3^2x_2+x_3x_2^2+x_2^3)+8A'B'(x_3^2+x_3x_2+x_2^2)+2B'^2(x_3+x_2)}{(x_4-x_2)^2(x_4-x_1)^2(x_3-x_2)(x_3-x_1)^2(x_3-x_0)^2} + 3\frac{(x_4+3x_3)(x_4-}{(x_4-x_2)^2(x_4-}
\end{aligned}
$$

And

$$
\begin{aligned}
\int_{x_1}^{x_4} x\partial_x^2 b_{3,0}(x)\times\partial_x^2 b_{3,1}(x)dx &= \int_{x_1}^{x_2} x\frac{6Ax+2B}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)}\frac{6(x-x_1)}{(x_4-x_1)(x_3-x_1)(x_2-x_1)}dx + \int_{x_2}^{x_3} x\frac{6A'x+2B'}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)}\frac{6A(1)x+2B(1)}{(x_5-x_2)(x_4-x_2)(x_4-x_1)(x_3-x_2)(} \\
&= \int_{x_1}^{x_2} 12\frac{3Ax^3-(3Ax_1-B)x^2-Bx_1x}{(x_4-x_1)^2(x_3-x_1)^2(x_3-x_0)(x_2-x_1)^2(x_2-x_0)}dx \\
&\quad + \int_{x_2}^{x_3} 4\frac{9A'A(1)x^3+3(A(1)B'+A'B(1))x^2+B'B(1)x}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)^2(x_3-x_2)^2(x_3-x_1)^2(x_3-x_0)}dx \\
&\quad + \int_{x_3}^{x_4} 12\frac{-3A'(1)x^3+(3A'(1)x_4-B'(1))x^2+B'(1)x_4x}{(x_5-x_3)(x_5-x_2)(x_4-x_3)^2(x_4-x_2)^2(x_4-x_1)^2}dx \\
&= \frac{3A(3x_2^3-x_2^2x_1-x_2x_1^2-x_1^3)+2B(2x_2^2-x_2x_1-x_1^2)}{(x_4-x_1)^2(x_3-x_1)^2(x_3-x_0)(x_2-x_1)(x_2-x_0)} \\
&\quad + \frac{9A'A(1)(x_3^3+x_3^2x_2+x_3x_2^2+x_2^3)+4(A(1)B'+A'B(1))(x_3^2+x_3x_2+x_2^2)+2B'B(1)(x_3+x_2)}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)^2(x_3-x_2)(x_3-x_1)^2(x_3-x_0)} \\
&\quad + \frac{3A'(1)(x_4^3+x_4^2x_3+x_4x_3^2-3x_3^3)+2B'(1)(x_4^2+x_4x_3-2x_3^2)}{(x_5-x_3)(x_5-x_2)(x_4-x_3)(x_4-x_2)^2(x_4-x_1)^2} \\
&= \frac{3A(3x_2^2+2x_2x_1+x_1^2)+2B(2x_2+x_1)}{(x_4-x_1)^2(x_3-x_1)^2(x_3-x_0)(x_2-x_0)} \\
&\quad + \frac{9A'A(1)(x_3^3+x_3^2x_2+x_3x_2^2+x_2^3)+4(A(1)B'+A'B(1))(x_3^2+x_3x_2+x_2^2)+2B'B(1)(x_3+x_2)}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)^2(x_3-x_2)(x_3-x_1)^2(x_3-x_0)} \\
&\quad + \frac{3A'(1)(x_4^2+2x_4x_3+3x_3^2)+2B'(1)(x_4+2x_3)}{(x_5-x_3)(x_5-x_2)(x_4-x_2)^2(x_4-x_1)^2}
\end{aligned}
$$

and

$$
\begin{aligned}
\int_{x_2}^{x_4} x\partial_x^2 b_{3,0}(x)\times\partial_x^2 b_{3,2}(x)dx &= \int_{x_2}^{x_3} x\frac{6A'x+2B'}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)}\frac{6(x-x_2)}{(x_5-x_2)(x_4-x_2)(x_3-x_2)}dx + \int_{x_3}^{x_4} x\frac{6(x_4-x)}{(x_4-x_3)(x_4-x_2)(x_4-x_1)}\frac{6A(2)x+2B(2)}{(x_6-x_3)(x_5-x_3)(x_5-x_2)(x_4-x_3)(x_4-x_2)}dx \\
&= \int_{x_2}^{x_3} \frac{36A'x^3+12(B'-3A'x_2)x^2-12B'x_2x}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)(x_3-x_2)^2(x_3-x_1)(x_3-x_0)}dx + \int_{x_3}^{x_4} \frac{-36A(2)x^3+12(3A(2)x_4-B(2))x^2+12B(2)x_4x}{(x_6-x_3)(x_5-x_3)(x_5-x_2)(x_4-x_3)^2(x_4-x_2)^2(x_4-x_1)}dx \\
&= \frac{3A'(3x_3^3-x_3^2x_2-x_3x_2^2-x_2^3)+2B'(2x_3^2-x_3x_2-x_2^2)}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} + \frac{3A(2)(x_4^3+x_4^2x_3+x_4x_3^2-3x_3^3)+2B(2)(x_4^2+x_4x_3-2x_3^2)}{(x_6-x_3)(x_5-x_3)(x_5-x_2)(x_4-x_3)(x_4-x_2)^2(x_4-x_1)} \\
&= \frac{3A'(3x_3^2+2x_3x_2+x_2^2)+2B'(2x_3+x_2)}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)(x_3-x_1)(x_3-x_0)} + \frac{3A(2)(x_4^2+2x_4x_3+3x_3^2)+2B(2)(x_4+2x_3)}{(x_6-x_3)(x_5-x_3)(x_5-x_2)(x_4-x_2)^2(x_4-x_1)}
\end{aligned}
$$

and

$$
\begin{aligned}
\int_{x_3}^{x_4} x\partial_x^2 b_{3,0}(x)\times\partial_x^2 b_{3,3}(x)dx &= \int_{x_3}^{x_4} x\frac{6(x_4-x)}{(x_4-x_3)(x_4-x_2)(x_4-x_1)}\frac{6(x-x_3)}{(x_6-x_3)(x_5-x_3)(x_4-x_3)}dx \\
&= \int_{x_3}^{x_4} 36\frac{-x^3+(x_4+x_3)x^2-x_4x_3x}{(x_6-x_3)(x_5-x_3)(x_4-x_3)^2(x_4-x_2)(x_4-x_1)}dx \\
&= 3\frac{x_4^3-x_4^2x_3-x_4x_3^2+x_3^3}{(x_6-x_3)(x_5-x_3)(x_4-x_3)(x_4-x_2)(x_4-x_1)} \\
&= 3\frac{x_4^2-x_3^2}{(x_6-x_3)(x_5-x_3)(x_4-x_2)(x_4-x_1)}
\end{aligned}
$$

.6 D3N2 - Exact formulations

.6.1 Deg = 3, Surf

$$\begin{aligned}
\int_{x_0}^{x_4} \|\partial_x^3 b_{3,0}(x)\|^2 dx &= \int_{x_0}^{x_1} \left(\frac{6}{(x_3-x_0)(x_2-x_0)(x_1-x_0)}\right)^2 dx + \int_{x_1}^{x_2} \left(\frac{6A}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)}\right)^2 dx + \int_{x_2}^{x_3} \left(\frac{6A^{/}}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)}\right)^2 dx + \int_{x_3}^{x_4} \left(\frac{}{(x_4-x_3)(x}\right.\\
&= \frac{36}{(x_3-x_0)^2(x_2-x_0)^2(x_1-x_0)} + \frac{36A^2}{(x_4-x_1)^2(x_3-x_1)^2(x_3-x_0)^2(x_2-x_1)(x_2-x_0)^2} + \frac{36A^{/2}}{(x_4-x_2)^2(x_4-x_1)^2(x_3-x_2)(x_3-x_1)^2(x_3-x_0)^2} + \frac{36}{(x_4-x_3)(x_4-x_2)^2(x_4-x_1)^2}
\end{aligned}$$

And

$$\begin{aligned}
\int_{x_1}^{x_4} \partial_x^3 b_{3,0}(x) \times \partial_x^3 b_{3,1}(x) dx &= \int_{x_1}^{x_2} \frac{6A}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} \frac{6}{(x_4-x_1)(x_3-x_1)(x_2-x_1)} dx\\
&\quad \int_{x_2}^{x_3} \frac{6A^{/}}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} \frac{6A(1)}{(x_5-x_2)(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)} dx\\
&\quad \int_{x_3}^{x_4} \frac{-6}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \frac{6A^{/}(1)}{(x_5-x_3)(x_5-x_2)(x_4-x_3)(x_4-x_2)(x_4-x_1)} dx\\
&= \int_{x_1}^{x_2} \frac{36A}{(x_4-x_1)^2(x_3-x_1)^2(x_3-x_0)(x_2-x_1)^2(x_2-x_0)} dx + \int_{x_2}^{x_3} \frac{36A^{/}A(1)}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)^2(x_3-x_2)^2(x_3-x_1)^2(x_3-x_0)} dx + \int_{x_3}^{x_4} \frac{-36A^{/}(1)}{(x_5-x_3)(x_5-x_2)(x_4-x_3)^2(x_4-x_2)^2(x}\\
&= \frac{36A}{(x_4-x_1)^2(x_3-x_1)^2(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{36A^{/}A(1)}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)^2(x_3-x_2)(x_3-x_1)^2(x_3-x_0)} + \frac{-36A^{/}(1)}{(x_5-x_3)(x_5-x_2)(x_4-x_3)(x_4-x_2)^2(x_4-x_1)^2}
\end{aligned}$$

and

$$\begin{aligned}
\int_{x_2}^{x_4} \partial_x b_{3,0}(x) \times \partial_x b_{3,2} dx &= \int_{x_2}^{x_3} \frac{6A^{/}}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} \frac{6}{(x_5-x_2)(x_4-x_2)(x_3-x_2)} dx + \int_{x_3}^{x_4} \frac{-6}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \frac{6A(2)}{(x_6-x_3)(x_5-x_3)(x_5-x_2)(x_4-x_3)(x_4-x_2)}\\
&= \frac{36A^{/}}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)(x_3-x_2)^2(x_3-x_1)(x_3-x_0)} + \frac{-36A(2)}{(x_6-x_3)(x_5-x_3)(x_5-x_2)(x_4-x_3)^2(x_4-x_2)^2(x_4-x_1)}
\end{aligned}$$

and

$$\begin{aligned}
\int_{x_3}^{x_4} \partial_x^3 b_{3,0}(x) \times \partial_x^3 b_{3,3}(x) dx &= \int_{x_3}^{x_4} \frac{-6}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \frac{6}{(x_6-x_3)(x_5-x_3)(x_4-x_3)} dx\\
&= \frac{-36}{(x_6-x_3)(x_5-x_3)(x_4-x_3)^2(x_4-x_2)(x_4-x_1)}
\end{aligned}$$

.6.2 Deg = 3, Vol

$$\begin{aligned}
\int_{x_0}^{x_4} x\|\partial_x^3 b_{3,0}(x)\|^2 dx &= \int_{x_0}^{x_1} x \left(\frac{6}{(x_3-x_0)(x_2-x_0)(x_1-x_0)}\right)^2 dx + \int_{x_1}^{x_2} x \left(\frac{6A}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)}\right)^2 dx + \int_{x_2}^{x_3} x \left(\frac{6A^{/}}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)}\right)^2 dx + \int_{x_3}^{x_4} x \left(\right.\\
&= \frac{18(x_1+x_0)}{(x_3-x_0)^2(x_2-x_0)^2(x_1-x_0)} + \frac{18A^2(x_2+x_1)}{(x_4-x_1)^2(x_3-x_1)^2(x_3-x_0)^2(x_2-x_1)(x_2-x_0)^2} + \frac{18A^{/2}(x_3+x_2)}{(x_4-x_2)^2(x_4-x_1)^2(x_3-x_2)(x_3-x_1)^2(x_3-x_0)^2} + \frac{18(x_4+x_3)}{(x_4-x_3)(x_4-x_2)^2(x_4-x_1)^2}
\end{aligned}$$

And

$$\begin{aligned}
\int_{x_1}^{x_4} x\partial_x^3 b_{3,0}(x) \times \partial_x^3 b_{3,1}(x) dx &= \int_{x_1}^{x_2} x \frac{6A}{(x_4-x_1)(x_3-x_1)(x_3-x_0)(x_2-x_1)(x_2-x_0)} \frac{6}{(x_4-x_1)(x_3-x_1)(x_2-x_1)} dx\\
&\quad \int_{x_2}^{x_3} x \frac{6A^{/}}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} \frac{6A(1)}{(x_5-x_2)(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)} dx\\
&\quad \int_{x_3}^{x_4} x \frac{-6}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \frac{6A^{/}(1)}{(x_5-x_3)(x_5-x_2)(x_4-x_3)(x_4-x_2)(x_4-x_1)} dx\\
&= \int_{x_1}^{x_2} \frac{36Ax}{(x_4-x_1)^2(x_3-x_1)^2(x_3-x_0)(x_2-x_1)^2(x_2-x_0)} dx + \int_{x_2}^{x_3} \frac{36A^{/}A(1)x}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)^2(x_3-x_2)^2(x_3-x_1)^2(x_3-x_0)} dx + \int_{x_3}^{x_4} \frac{-36A^{/}(1)x}{(x_5-x_3)(x_5-x_2)(x_4-x_3)^2(x_4-x_2)^2(}\\
&= \frac{18A(x_2+x_1)}{(x_4-x_1)^2(x_3-x_1)^2(x_3-x_0)(x_2-x_1)(x_2-x_0)} + \frac{18A^{/}A(1(x_3+x_2)}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)^2(x_3-x_2)(x_3-x_1)^2(x_3-x_0)} + \frac{-18A^{/}(1)(x_4+x_3)}{(x_5-x_3)(x_5-x_2)(x_4-x_3)(x_4-x_2)^2(x_4-x_1)^2}
\end{aligned}$$

and

$$\begin{aligned}
\int_{x_2}^{x_4} x\partial_x b_{3,0}(x) \times \partial_x b_{3,2} dx &= \int_{x_2}^{x_3} x \frac{6A^{/}}{(x_4-x_2)(x_4-x_1)(x_3-x_2)(x_3-x_1)(x_3-x_0)} \frac{6}{(x_5-x_2)(x_4-x_2)(x_3-x_2)} dx + \int_{x_3}^{x_4} x \frac{-6}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \frac{6A(2)}{(x_6-x_3)(x_5-x_3)(x_5-x_2)(x_4-x_3)(x_4-x_2)}\\
&= \frac{18A^{/}(x_3+x_2)}{(x_5-x_2)(x_4-x_2)^2(x_4-x_1)(x_3-x_2)^2(x_3-x_1)(x_3-x_0)} + \frac{-18A(2)(x_4+x_3)}{(x_6-x_3)(x_5-x_3)(x_5-x_2)(x_4-x_3)^2(x_4-x_2)^2(x_4-x_1)}
\end{aligned}$$

and

$$\begin{aligned}
\int_{x_3}^{x_4} \partial_x^3 b_{3,0}(x) \times \partial_x^3 b_{3,3}(x) dx &= \int_{x_3}^{x_4} x \frac{-6}{(x_4-x_3)(x_4-x_2)(x_4-x_1)} \frac{6}{(x_6-x_3)(x_5-x_3)(x_4-x_3)} dx \\
&= \frac{-18(x_4+x_3)}{(x_6-x_3)(x_5-x_3)(x_4-x_3)^2(x_4-x_2)(x_4-x_1)}
\end{aligned}$$

.1 Derivations for Deg = 3 - D2N2

$$
\begin{aligned}
A^2 &= (-((x_3 - x_1)(x_4 - x_1) + (x_2 - x_0)(x_4 - x_1) + (x_3 - x_0)(x_2 - x_0)))^2 \\
&= ((x_3 - x_1)(x_4 - x_1) + (x_2 - x_0)(x_4 - x_1) + (x_3 - x_0)(x_2 - x_0))^2 \\
&= (x_3 - x_1)^2(x_4 - x_1)^2 + (x_2 - x_0)^2(x_4 - x_1)^2 + (x_3 - x_0)^2(x_2 - x_0)^2 + 2(x_3 - x_1)(x_4 - x_1)(x_3 - x_0)(x_2 - x_0) + 2(x_3 - x_1)(x_4 - x_1)(x_3 - x_0)(x_2 - x_0) + 2(x_2 - x \\
&=
\end{aligned}
$$