

# 1 Calculation of Hermite Polynomials $H_t^{112}(x, y)$ and $H_t^{221}(x, y)$

we need to compute the third-order Hermite polynomials  $H_t^{112}(x, y)$  and  $H_t^{221}(x, y)$  of  $\Delta_t^1$   
please refer to the page 65 ~ 66 of the [PAPER](#)

## 1.1 Setup and Definitions

Given the diffusion matrix  $\sigma(x)$ :

$$\sigma(x) = \begin{pmatrix} s(x_2) & 0 \\ 0 & s(x_1) \end{pmatrix} = \text{diag}(s(x_2), s(x_1))$$

The covariance matrix  $b(x)$  is defined as  $b(x) = \sigma(x)^2$ :

$$b(x) = \begin{pmatrix} s(x_2)^2 & 0 \\ 0 & s(x_1)^2 \end{pmatrix} = \text{diag}(s(x_2)^2, s(x_1)^2)$$

Its inverse  $b^{-1}(x)$  is:

$$b^{-1}(x) = \begin{pmatrix} \frac{1}{s(x_2)^2} & 0 \\ 0 & \frac{1}{s(x_1)^2} \end{pmatrix} = \text{diag}\left(\frac{1}{s(x_2)^2}, \frac{1}{s(x_1)^2}\right)$$

We denote the components of the inverse matrix as  $(b^{-1})_{ij}$ . Thus:

$$(b^{-1})_{11} = \frac{1}{s(x_2)^2}, \quad (b^{-1})_{22} = \frac{1}{s(x_1)^2}, \quad (b^{-1})_{12} = (b^{-1})_{21} = 0$$

## 1.2 Centralized Variables

Let  $r$  be the centered spatial increment (accounting for drift  $a(x)$ ):

$$r = y - x - a(x)t \implies \begin{cases} r_1 = y_1 - x_1 - a_1(x)t \\ r_2 = y_2 - x_2 - a_2(x)t \end{cases}$$

We define the standardized variable  $u = b^{-1}(x)r$ . In component form:

$$u_i = \sum_{j=1}^d (b^{-1})_{ij} r_j$$

Substituting our specific diagonal  $b^{-1}$ :

$$u_1 = (b^{-1})_{11} r_1 = \frac{r_1}{s(x_2)^2}, \quad u_2 = (b^{-1})_{22} r_2 = \frac{r_2}{s(x_1)^2}$$

## 1.3 General Formula for Third-Order Hermite Polynomials

According to page 53 of the [PAPER](#), the general formula for the third-order multi-index Hermite polynomial  $H_t^{ijk}(x, y)$  is:

$$H_t^{ijk}(x, y) = \frac{1}{t^3} u_i u_j u_k - \frac{1}{t^2} ((b^{-1})_{ij} u_k + (b^{-1})_{ik} u_j + (b^{-1})_{jk} u_i)$$

## 1.4 Calculation of $H_t^{112}(x, y)$

We set indices  $(i, j, k) = (1, 1, 2)$ .

**Term<sub>1</sub> of  $H_t^{112}$  :**

$$\text{Term}_1 = \frac{1}{t^3} u_1 u_1 u_2 = \frac{1}{t^3} (u_1)^2 u_2$$

Substituting  $u_1$  and  $u_2$ :

$$\text{Term}_1 = \frac{1}{t^3} \left( \frac{r_1}{s(x_2)^2} \right)^2 \left( \frac{r_2}{s(x_1)^2} \right) = \frac{r_1^2 r_2}{t^3 s(x_2)^4 s(x_1)^2}$$

**Term<sub>2</sub> of  $H_t^{112}$  :**

We need to evaluate the sum  $S = (b^{-1})_{11} u_2 + (b^{-1})_{12} u_1 + (b^{-1})_{12} u_1$ . Using  $(b^{-1})_{12} = (b^{-1})_{21} = 0$ :

$$S = (b^{-1})_{11} u_2 + 0 + 0 = \frac{1}{s(x_2)^2} \cdot \frac{r_2}{s(x_1)^2} = \frac{r_2}{s(x_2)^2 s(x_1)^2}$$

Thus, the second part of the formula is:

$$\text{Term}_2 = -\frac{1}{t^2} S = -\frac{r_2}{t^2 s(x_2)^2 s(x_1)^2}$$

**Final Expression for  $H_t^{112}$**  Combining Term<sub>1</sub> and Term<sub>2</sub>:

$$H_t^{112}(x, y) = \frac{(y_1 - x_1 - a_1(x)t)^2 (y_2 - x_2 - a_2(x)t)}{t^3 s(x_2)^4 s(x_1)^2} - \frac{y_2 - x_2 - a_2(x)t}{t^2 s(x_2)^2 s(x_1)^2}$$

## 1.5 Calculation of $H_t^{221}(x, y)$

We set indices  $(i, j, k) = (2, 2, 1)$ .

**Term<sub>1</sub> of  $H_t^{221}$  :**

$$\text{Term}_1 = \frac{1}{t^3} u_2 u_2 u_1 = \frac{1}{t^3} (u_2)^2 u_1$$

Substituting  $u_1$  and  $u_2$ :

$$\text{Term}_1 = \frac{1}{t^3} \left( \frac{r_2}{s(x_1)^2} \right)^2 \left( \frac{r_1}{s(x_2)^2} \right) = \frac{r_2^2 r_1}{t^3 s(x_1)^4 s(x_2)^2}$$

**Term<sub>2</sub> of  $H_t^{221}$  :**

We evaluate the sum  $S = (b^{-1})_{22} u_1 + (b^{-1})_{21} u_2 + (b^{-1})_{21} u_2$ . Using  $(b^{-1})_{21} = (b^{-1})_{12} = 0$ :

$$S = (b^{-1})_{22} u_1 + 0 + 0 = \frac{1}{s(x_1)^2} \cdot \frac{r_1}{s(x_2)^2} = \frac{r_1}{s(x_1)^2 s(x_2)^2}$$

Thus, the second part of the formula is:

$$\text{Term}_2 = -\frac{1}{t^2} S = -\frac{r_1}{t^2 s(x_1)^2 s(x_2)^2}$$

## 1.6 Final Expression for $H_t^{221}$

Combining Term<sub>1</sub> and Term<sub>2</sub>:

$$H_t^{221}(x, y) = \frac{(y_2 - x_2 - a_2(x)t)^2 (y_1 - x_1 - a_1(x)t)}{t^3 s(x_1)^4 s(x_2)^2} - \frac{y_1 - x_1 - a_1(x)t}{t^2 s(x_1)^2 s(x_2)^2}$$

## 2 Calculation of Hermite Polynomials of Orders 2 and 4

we need to compute the third-order Hermite polynomials  $H_t^{11}(x, y), H_t^{12}(x, y), H_t^{22}(x, y), H_t^{111}(x, y), H_t^{1112}(x, y), H_t^{112}$  of  $\Delta_t^2$

please refer to the page 65 ~ 66 of the [PAPER](#)

### 2.1 Two-Order Hermite Polynomials

#### 2.1.1 Calculation of $H_t^{11}$

Setting  $(i, j) = (1, 1)$ :

$$H_t^{11}(x, y) = \frac{1}{t^2} u_1^2 - \frac{1}{t} (b^{-1})_{11}.$$

Substituting  $u_1 = \frac{r_1}{s(x_2)^2}$  and  $(b^{-1})_{11} = \frac{1}{s(x_2)^2}$ :

$$H_t^{11}(x, y) = \frac{r_1^2}{t^2 s(x_2)^4} - \frac{1}{t s(x_2)^2} = \frac{(y_1 - x_1 - a_1(x)t)^2}{t^2 s(x_2)^4} - \frac{1}{t s(x_2)^2}$$

#### 2.1.2 Calculation of $H_t^{22}$

Setting  $(i, j) = (2, 2)$ :

$$H_t^{22}(x, y) = \frac{1}{t^2} u_2^2 - \frac{1}{t} (b^{-1})_{22}.$$

Substituting  $u_2 = \frac{r_2}{s(x_1)^2}$  and  $(b^{-1})_{22} = \frac{1}{s(x_1)^2}$ :

$$H_t^{22}(x, y) = \frac{r_2^2}{t^2 s(x_1)^4} - \frac{1}{t s(x_1)^2} = \frac{(y_2 - x_2 - a_2(x)t)^2}{t^2 s(x_1)^4} - \frac{1}{t s(x_1)^2}$$

#### 2.1.3 Calculation of $H_t^{12}$

Setting  $(i, j) = (1, 2)$ :

$$H_t^{12}(x, y) = \frac{1}{t^2} u_1 u_2 - \frac{1}{t} (b^{-1})_{12}.$$

Since  $(b^{-1})_{12} = 0$ :

$$H_t^{12}(x, y) = \frac{r_1 r_2}{t^2 s(x_2)^2 s(x_1)^2} = \frac{(y_1 - x_1 - a_1(x)t)(y_2 - x_2 - a_2(x)t)}{t^2 s(x_2)^2 s(x_1)^2}$$

## 2.2 Fourth-Order Hermite Polynomials

We use the recurrence relation (The page 53, Eq. A.5 or A.7 of the [PAPER](#)) to derive higher orders. For any multi-index  $\alpha = (i_1, \dots, i_n)$ , adding an index  $j$  yields:

$$H_t^{j, \alpha}(x, y) = \frac{1}{t} u_j H_t^\alpha(x, y) - \sum_{k=1}^n (b^{-1})_{j, i_k} H_t^{\alpha \setminus \{i_k\}}(x, y) \quad (k \in (1, \dots, n))$$

Since  $b$  is diagonal, the sum only survives when  $i_k = j$ .

### 2.2.1 Calculation of $H_t^{1111}$

This is effectively the 1D Hermite polynomial of degree 4 in the variable  $r_1$ . From the recurrence on  $H_t^{111}$  (derived similarly):

$$H_t^{111} = \frac{u_1^3}{t^3} - \frac{3(b^{-1})_{11}u_1}{t^2}.$$

Applying the recurrence for  $H_t^{1111}$  (adding index 1 to  $H_t^{111}$ ):

$$H_t^{1111} = \frac{u_1}{t} H_t^{111} - \frac{3(b^{-1})_{11}}{t} H_t^{11}.$$

Substituting the expressions:

$$\begin{aligned} H_t^{1111} &= \frac{u_1}{t} \left( \frac{u_1^3}{t^3} - \frac{3(b^{-1})_{11}u_1}{t^2} \right) - \frac{3(b^{-1})_{11}}{t} \left( \frac{u_1^2}{t^2} - \frac{(b^{-1})_{11}}{t} \right) \\ &= \frac{u_1^4}{t^4} - \frac{3(b^{-1})_{11}u_1^2}{t^3} - \frac{3(b^{-1})_{11}u_1^2}{t^3} + \frac{3(b^{-1})_{11}^2}{t^2} \\ &= \frac{u_1^4}{t^4} - \frac{6(b^{-1})_{11}u_1^2}{t^3} + \frac{3(b^{-1})_{11}^2}{t^2}. \end{aligned}$$

Substituting  $u_1 = \frac{r_1}{s(x_2)^2}$  and  $(b^{-1})_{11} = \frac{1}{s(x_2)^2}$ :

$$\begin{aligned} H_t^{1111}(x, y) &= \frac{r_1^4}{t^4 s(x_2)^8} - \frac{6r_1^2}{t^3 s(x_2)^6} + \frac{3}{t^2 s(x_2)^4} \\ &= \boxed{\frac{(y_1 - x_1 - a_1(x)t)^4}{t^4 s(x_2)^8} - \frac{6(y_1 - x_1 - a_1(x)t)^2}{t^3 s(x_2)^6} + \frac{3}{t^2 s(x_2)^4}} \end{aligned}$$

### 2.2.2 Calculation of $H_t^{2222}$

By symmetry with  $H_t^{1111}$ , replacing index 1 with 2:

$$\begin{aligned} H_t^{2222}(x, y) &= \frac{r_2^4}{t^4 s(x_1)^8} - \frac{6r_2^2}{t^3 s(x_1)^6} + \frac{3}{t^2 s(x_1)^4} \\ &= \boxed{\frac{(y_2 - x_2 - a_2(x)t)^4}{t^4 s(x_1)^8} - \frac{6(y_2 - x_2 - a_2(x)t)^2}{t^3 s(x_1)^6} + \frac{3}{t^2 s(x_1)^4}} \end{aligned}$$

### 2.2.3 Calculation of $H_t^{1112}$

We add index 2 to  $H_t^{111}$ . Since  $(b^{-1})_{21} = 0$ , the correction terms in the recurrence vanish:

$$H_t^{1112} = \frac{u_2}{t} H_t^{111} - \sum_{k=1}^3 (b^{-1})_{21} H_t^{11} = \frac{u_2}{t} H_t^{111}.$$

Using  $H_t^{111} = \frac{u_1^3}{t^3} - \frac{3(b^{-1})_{11}u_1}{t^2}$ :

$$H_t^{1112} = \frac{u_2}{t} \left( \frac{u_1^3}{t^3} - \frac{3(b^{-1})_{11}u_1}{t^2} \right) = \frac{u_1^3 u_2}{t^4} - \frac{3(b^{-1})_{11}u_1 u_2}{t^3}.$$

Substituting variables:

$$\begin{aligned} H_t^{1112}(x, y) &= \frac{r_1^3 r_2}{t^4 s(x_2)^6 s(x_1)^2} - \frac{3r_1 r_2}{t^3 s(x_2)^4 s(x_1)^2} \\ &= \boxed{\frac{(y_1 - x_1 - a_1(x)t)^3 (y_2 - x_2 - a_2(x)t)}{t^4 s(x_2)^6 s(x_1)^2} - \frac{3(y_1 - x_1 - a_1(x)t)(y_2 - x_2 - a_2(x)t)}{t^3 s(x_2)^4 s(x_1)^2}} \end{aligned}$$

#### 2.2.4 Calculation of $H_t^{1222}$

By symmetry with  $H_t^{1112}$ , swapping indices 1 and 2:

$$H_t^{1222}(x, y) = \frac{r_2^3 r_1}{t^4 s(x_1)^6 s(x_2)^2} - \frac{3r_2 r_1}{t^3 s(x_1)^4 s(x_2)^2}$$

$$= \boxed{\frac{(y_1 - x_1 - a_1(x)t)(y_2 - x_2 - a_2(x)t)^3}{t^4 s(x_2)^2 s(x_1)^6} - \frac{3(y_1 - x_1 - a_1(x)t)(y_2 - x_2 - a_2(x)t)}{t^3 s(x_2)^2 s(x_1)^4}}$$

#### 2.2.5 Calculation of $H_t^{1122}$

We add index 2 to  $H_t^{112}$ . Recall (from previous derivation) that:

$$H_t^{112} = \frac{u_1^2 u_2}{t^3} - \frac{(b^{-1})_{11} u_2}{t^2}.$$

Using the recurrence to add index 2:

$$H_t^{1122} = \frac{u_2}{t} H_t^{112} - ((b^{-1})_{21} H_t^{12} + (b^{-1})_{21} H_t^{12} + (b^{-1})_{22} H_t^{11})$$

$$= \frac{u_2}{t} H_t^{112} - \frac{(b^{-1})_{22}}{t} H_t^{11}.$$

Where,  $(b^{-1})_{21} = 0$

The sum over indices in  $H^{112}$  (indices 1,1,2) involves  $(b^{-1})_{21}, (b^{-1})_{21}, (b^{-1})_{22}$ . Only the last term survives. Substituting expressions:

$$H_t^{1122} = \frac{u_2}{t} \left( \frac{u_1^2 u_2}{t^3} - \frac{(b^{-1})_{11} u_2}{t^2} \right) - \frac{(b^{-1})_{22}}{t} \left( \frac{u_1^2}{t^2} - \frac{(b^{-1})_{11}}{t} \right)$$

$$= \frac{u_1^2 u_2^2}{t^4} - \frac{(b^{-1})_{11} u_2^2}{t^3} - \frac{(b^{-1})_{22} u_1^2}{t^3} + \frac{(b^{-1})_{11} (b^{-1})_{22}}{t^2}.$$

Substituting variables:

$$H_t^{1122}(x, y) = \frac{r_1^2 r_2^2}{t^4 s(x_2)^4 s(x_1)^4} - \frac{r_2^2}{t^3 s(x_2)^2 s(x_1)^4} - \frac{r_1^2}{t^3 s(x_1)^2 s(x_2)^4} + \frac{1}{t^2 s(x_2)^2 s(x_1)^2}$$

$$= \boxed{\frac{(y_1 - x_1 - a_1(x)t)^2 (y_2 - x_2 - a_2(x)t)^2}{t^4 s(x_2)^4 s(x_1)^4} - \frac{(y_1 - x_1 - a_1(x)t)^2}{t^3 s(x_2)^4 s(x_1)^2} - \frac{(y_2 - x_2 - a_2(x)t)^2}{t^3 s(x_2)^2 s(x_1)^4} + \frac{1}{t^2 s(x_2)^2 s(x_1)^2}}$$