2023 Spring VLSI DSP Homework Assignment #4

Due date: 2023/5/02

Q1. For the convolution DG shown in Figure 1, assume each DG node performs a multiply-and-accumulate operation, where bi's stand for parameters, and u(·)'s indicate input samples.

(a) Which of the following sets of scheduling and projection are permissible?

i. $\mathbf{s} = [1\ 0]^T$, $\mathbf{d} = [1\ 0]^T$

ii. $\mathbf{s} = [0\ 1]^T$, $\mathbf{d} = [1\ 0]^T$

iii. $\mathbf{s} = [1\ 1]^T$, $\mathbf{d} = [1\ 0]^T$

iv. $\mathbf{s} = [1\ 1]^T$, $\mathbf{d} = [0\ 1]^T$

(b) derive the mapping for each permissible set

(c) reverse the direction of data accumulation in the DG, derive a systolic array mapping (all inter-PE data links should have at least one delay element) for it

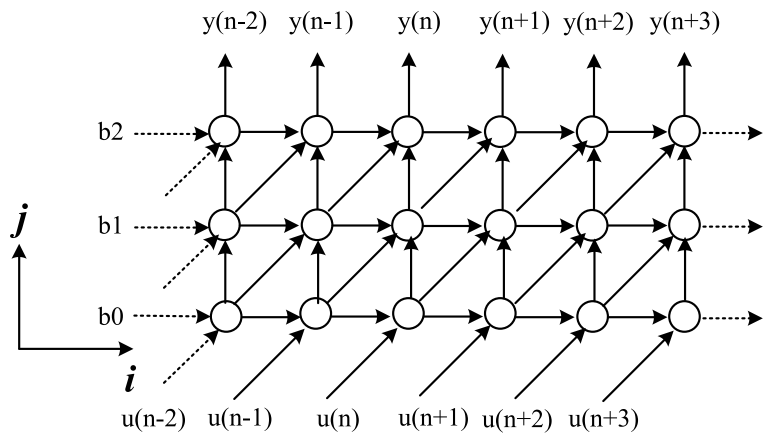

Figure 1

Q2. Vector quantization design

Given an input k-dimensional column vector $\mathbf{r}_{k\times1}$, and a codebook $\mathfrak{B}=\{\mathbf{b}_i \mid i = 1 \sim N\}$ consists of N k-dimensional column vectors, vector quantization (VQ) is to find a vector in that codebook that has the shortest Euclidean distance from the input vector $\mathbf{r}_{k\times1}$. The Euclidean distance between two vectors is defined as

$$d'(\mathbf{x},\mathbf{y}) = ||\mathbf{x}-\mathbf{y}|| = \sqrt{\textstyle\sum_{j=0}^{k-1}(x_j - y_j)^2} \tag{1}$$

For simplicity, we may use the square distance instead.

$$d(\mathbf{x},\mathbf{y}) = ||\mathbf{x}-\mathbf{y}||^2 = \textstyle\sum_{j=0}^{k-1}(x_j - y_j)^2 \tag{2}$$

Let $\mathbf{x} = \mathbf{r}$ and $\mathbf{y} = \mathbf{b}_i$, Eq(2) can be rewritten as $d(\mathbf{r},\mathbf{b}_i) = ||\mathbf{r}||^2 - 2\mathbf{r}'\mathbf{b}_i + ||\mathbf{b}_i||^2$. Since $||\mathbf{r}||^2$ is a constant term in all distance calculations, and $||\mathbf{b}_i||^2$ can be precomputed, VQ calculation can be expressed as

$$\arg\{\min\{c_i - \mathbf{r}'\mathbf{b}_i \mid i = 1, N\}\}, \tag{3}$$

where $c_i = ||\mathbf{b}_i||^2/2$. In other words, VQ can be accomplished by calculating $c_i - \mathbf{r}'\mathbf{b}_i$, for all $\mathbf{b}_i$'s in the codebook, and recording the one with the smallest distance. Note that $\mathbf{r}'\mathbf{b}_i$ is an inner product operation, and c_i can be input from a pre-computed table.

(a) Please draw the DG of the $y(i) = c_i - \mathbf{r}^t\mathbf{b}_i$ for i = $1 \sim N$. For simplicity, assume the vector dimension k is 4. In each iteration, c_i and $\mathbf{b}_i$ are regarded as input and $y(i)$ is the output.

(b) Select a scheduling and projection scheme to obtain its systolic array design (at least one delay element in every inter-processor data link).

(c) Add a comparator module so that the vector index i corresponding to the minimum Euclidean distance can be obtained at the end of N iterations.