SpMV Sections

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Sparse linear algebra libraries and the methods they employ are vitally important in the domain of scientific computing (TODO: why?). Of particular interest is the sparse matrix-vector product, which solves $y = \boldsymbol{A}x$ where $\boldsymbol{A}$ is a sparse matrix and the vectors y and x are dense. Because SpMV usage is often highly repetitive within, e.g., iterative solvers, performance improvements via novel algorithms and the exploitation of modern hardware are areas of ongoing research (TODO: citations).

...why is SpMV difficult? Things like array indirection, varying sparsity patterns, it's memory bound...

As modern hardware introduces higher levels of parallelism and SpMV algorithms become more complex, the likelihood of introducing subtle bugs becomes decidedly higher. In this section we present a method for reasoning about the structural complexities and verifying the correctness of SpMV algorithms. We first model an abstract matrix-vector multiplication and subsequently demonstrate that a CSR SpMV algorithm is a valid functional refinement.

1 ABSTRACT MATRIX-VECTOR MULTIPLICATION

In order to demonstrate that an SpMV algorithm is correct, we must first create a model of matrix-vector multiplication to act as the arbiter of correctness. The result of a matrix-vector multiplication is a densely populated vector in which each value is the dot product of a single row of the matrix with the other vector. A dot product is simply a sum of products in which each product is of two values located at the same index within two vectors, as shown in Figure 1.

$$\begin{bmatrix} A_{00} & A_{01} & A_{02} \\ A_{10} & A_{11} & A_{12} \\ A_{20} & A_{21} & A_{22} \end{bmatrix} \times \left\{ \begin{matrix} x_0 \\ x_1 \\ x_2 \end{matrix} \right\} = \left\{ \begin{matrix} \boldsymbol{A_0} \cdot \boldsymbol{x_0} \\ A_1 \cdot x_1 \\ A_2 \cdot x_2 \end{matrix} \right\}$$

$$\boldsymbol{A_0} \cdot \boldsymbol{x_0} = A_{00} * x_0 + A_{01} * x_1 + A_{02} * x_2$$

Figure 1: MVM and Dot Product

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