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Towards Compositional and Generative Tensor Optimizations

Adilla Susungi, Norman A. Rink, Jerónimo Castrillón, Immo Huismann, Albert Cohen, Claude Tadonki, Jörg Stiller and Jochen Fröhlich

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Tensors in Computational Fluid Dynamics (CFD)

- Loop characteristics:
  - 3 to 4 dimensions nesting
  - Few iterations per dimension (e.g., 17 or 33 iterations)
- Type of computations:
  - Tensor contractions
  - Outer products
  - Element-wise multiplications
- Computations on each element of a structured mesh

Invert Helmholtz

\[ t_{ijk} = \sum_{l,m,n} A_{kn}^T \cdot A_{jm}^T \cdot A_{il}^T \cdot w_{lmn} \]

\[ p_{ijk} = D_{ijk} \cdot t_{ijk} \]

\[ u_{ijk} = \sum_{l,m,n} A_{kn} \cdot A_{jm} \cdot A_{il} \cdot p_{lmn} \]

Tensor Optimization Frameworks

- Domain-specific expressivity
- Flexible/Adaptive optimization heuristics
- Hidden and/or rigid optimization heuristics

Related Work

- Different levels of expressiveness and control on optimizations

<table>
<thead>
<tr>
<th>Flexible/adaptive</th>
<th>Hidden/rigid</th>
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<tbody>
<tr>
<td>Specific</td>
<td>Generic</td>
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</tbody>
</table>

Envisioned Tool

- Modular constructs
- First-class citizens:
  - Arrays
  - Tensor operators
  - Loop iterators
  - Transformations

Intermediate Language

- Basic array declaration
  \( A = \text{array}(\text{2, double, [N, N]}) \)
  \( u = \text{array}(\text{3, double, [N, N, N]}) \)
  \( D = \text{array}(\text{3, double, [N, N, N]}) \)
- Transposition
  \( A^T = \text{vtranspose}(A, 1, 2) \)
- Tensor contractions
  \( \text{tmp1} = \text{contract}(A, u, [2, 1]) \)
  \( \text{tmp2} = \text{contract}(A, \text{tmp1}, [2, 2]) \)
- Iterators declaration
  \( i1 = \text{iterator}(0, N, 1) \)
  \( i2 = \text{iterator}(0, N, 1) \)
- Element-wise multiplication
  \( \text{tmp4} = \text{entrywise}(D, \text{tmp3}) \)

Inverse Helmholtz by Example

Example of assessment: Different heuristics of loop interchanges (+ parallelization)

| Variant L1: Loop interchanges only; |
| Variant L2: Loop interchanges + data transpositions with copying; |
| Variant L3: Loop interchanges + data transpositions without copying. |

Future Work

- Applications to other domains
- Syntax refinement
- Formal semantics

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