Towards Compositional and Generative Tensor Optimizations

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Towards Compositional and Generative Tensor Optimizations

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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

\[
\begin{align*}
\text{Inverse Helmholtz} \\
\tau_{ijk} &= \sum_{l,m,n} A_{kn}^T \cdot A_{jm}^T \cdot A_{il}^T \cdot \omega_{lmn} \\
p_{ijk} &= D_{ijk} \cdot \tau_{ijk} \\
v_{ijk} &= \sum_{l,m,n} A_{kn}^T \cdot A_{jm}^T \cdot A_{il}^T \cdot p_{lmn}
\end{align*}
\]

Tensor Optimization Frameworks

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

Tensor Optimization Frameworks

Related Work

- Different levels of expressiveness and control on optimizations
- Flexible/adaptive
- Hidden/rigid

Optimizing CFD Kernels with Existing Tools

- Several limitations
- Few opportunities for adaptations

Search Space Exploration

- Evaluation order of tensor contractions
- Fusions
- Permutations
- Vectorization
- Collapsing
- Unrolling

Inverse Helmholtz by Example

# Basic array declaration
A = array(2, double, [N, N])
u = array(3, double, [N, N, N])
D = array(3, double, [N, N, N])

# Transposition
At = vtranspose(A, 1, 2)

# Tensor contractions
tmp1 = contract(At, u, [2, 1])
tmp6 = contract(At, tmp5, [2, 2])

# Iterator declaration
i1 = iterator(0, N, 1)
i2 = iterator(0, N, 1)

# Element-wise multiplication
tmp4 = entrywise(D, tmp3)

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

Future Work

- Applications to other domains
- Syntax refinement
- Formal semantics

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