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

Inverse Helmholtz

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

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

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

Tensor Optimization Frameworks

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

Related Work

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

Tensor Optimization Frameworks

- Chill
- Pluto
- TensorFlow
- TVM
- Tensor Contraction Engine
- Numpy
- Tensor Algebra Compiler

Optimizing CFD Kernels with Existing Tools

- Several limitations
- Few opportunities for adaptations

Goal

A cross-domain intermediate language for tensor optimizations

Intermediate Language

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

Envisioned Tool

- Meta-programming
- Iterative search

Search Space Exploration

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

Inverse Helmholtz by Example

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

Future Work

- Applications to other domains
- Syntax refinement
- Formal semantics

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