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

Inverse Helmholtz

\[ t_{ijk} = \sum_{l,m,n} A_{kl}^T \cdot A_{lm}^T \cdot A_{jn}^T \cdot w_{mn} \]

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

\[ u_{ijk} = \sum_{l,m,n} A_{kl} \cdot A_{lm} \cdot A_{jn} \cdot p_{mn} \]

Tensor Optimization Frameworks

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

Related Work

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

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

Optimizing CFD Kernels with Existing Tools

- Several limitations
- Few opportunities for adaptations

Should we create yet another domain-specific solution?

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)

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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