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

$$t_{ijk} = \sum_{l,m,n} A_{kn}^T \cdot A_{jm}^T \cdot \cdot A_{il}^T \cdot u_{lmn}$$

$$p_{ijk} = D_{ijk} \cdot t_{ijk}$$

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

Tensor Optimization Frameworks

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

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

# 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])

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

# Transpositions
tmp2t = vtranspose(tmp2, 1, 2)

# Association of iterators to computations
build(D, [td1, td2, td3])
build(tmp1, [i1, i2, i3, i4])

Future Work

- Applications to other domains
  - Syntax refinement
  - Formal semantics

Optimizing CFD Kernels with Existing Tools

- Several limitations
  - Limited expressivity
  - Few opportunities for adaptations
  - Limited optimizations
  - Unadapted heuristics
  - Unadapted constructs

Should we create yet another domain-specific solution?

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

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