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

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
Specific
Generic

Chill
Pluto
TensorFlow
TVM
Tensor Contraction Engine
Numpy
Tensor Algebra Compiler

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

# 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])
tmp2 = contract(At, tmp1, [2, 2])
tmp3 = contract(At, tmp2, [2, 3])

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

# Association of iterators
# to computations
build(D, [td1, td2, td3])
build(tmp1, [i1, i2, i3, i4])
# Also applies to tmp2, ..., tmp6

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.

Baseline: sequential execution (3.32s). Machine: 24-core Intel(R) Xeon(R) CPU E5-2680 v3 @ 2.50GHz (Haswell)

Future Work
- Applications to other domains
- Syntax refinement
- Formal semantics

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