Towards Compositional and Generative Tensor Optimizations

Adilla Susungi, Norman Rink, Jerónimo Castrillón, Immo Huismann, Albert Cohen, Claude Tadonki, Jörg Stiller, Jochen Fröhlich

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Towards Compositional and Generative Tensor Optimizations
Adilla Susungi, Norman A. Rink, Jerónimo Castrillón, Immo Huismann, Albert Cohen, Claude Tadonki, Jörg Stiller and Jochen Fröhlich
adilla.susungi@mines-paristech.fr — norman.rink@tu-dresden.de

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

Tensor Optimization Frameworks

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

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 ●

Tensor Optimization Frameworks

- 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.

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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