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Towards Compositional and Generative Tensor Optimizations

Adilla Susungi, Norman A. Rink, Jerónimo Castrillón, Immo Huisman, Albert Cohen, Claude Tadonki, Jörg Stiller and Jochen Fröhlich

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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

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

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

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

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
- Specific
  - chill
  - pluto
  - tensorflow
  - tvm
  - tensor contraction engine
  - numpy
  - tensor algebra compiler
- Generic
  - 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
- Generic expressivity
- Flexible/Adaptive optimization heuristics

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)

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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