Towards Compositional and Generative Tensor Optimizations
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To cite this version:

HAL Id: hal-01666818
https://minesparis-psl.hal.science/hal-01666818
Submitted on 18 Dec 2017

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

Tensor Optimization Frameworks

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

Related Work

- Different levels of expressiveness and control on optimizations

Flexible/adaptive

Hidden/rigid

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

Search Space Exploration

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

This work was partially funded by the German Research Council (DFG) through the Cluster of Excellence ‘Center for Advancing Electronics Dresden’ (cfaed) and by PSL Research University through the ACOPAL project.