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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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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

\[
t_{ijk} = \sum_{l,m,n} A_{kl}^{T} \cdot A_{lm}^{T} \cdot A_{mn}^{T} \cdot u_{lmn}
\]

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

\[
v_{ijk} = \sum_{l,m,n} A_{kl} \cdot A_{lm} \cdot A_{mn} \cdot p_{lmn}
\]

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

Optimizing CFD Kernels with Existing Tools

- Several limitations
- Few opportunities for adaptations

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
tmp5 = contract(At, u, [2, 1])
tmp6 = contract(At, tmp5, [2, 2])
v = contract(At, tmp6, [2, 3])

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

# ... other iterator declarations

# Association of iterators to computations
build(D, [td1, td2, td3])
build(D, [td1, td2, td3])
build(D, [td1, td2, td3])
build(D, [td1, td2, td3])

# Applications to other domains
- Syntax refinement
- Formal semantics

Future Work

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.