Towards Compositional and Generative Tensor Optimizations

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To cite this version:

HAL Id: hal-01666818
https://hal-mines-paristech.archives-ouvertes.fr/hal-01666818
Submitted on 18 Dec 2017

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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

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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

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

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

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

Tensor Optimization Frameworks

- Domain-specific
- Flexible/Adaptive
- Generic

- Hidden and/or rigid
- Limited

Related Work

- Different levels of expressiveness and control on optimizations

Flexible/adaptive
Hidden/rigid
Specific
Generic

Optimizing CFD Kernels with Existing Tools

- Several limitations
- Few opportunities for adaptations

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

Intermediate language
Optimized C

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)

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

# Element-wise multiplication

# Tensor contractions
tmp5 = contract(A, tmp4, [2, 1])
tmp6 = contract(A, tmp5, [2, 2])

# Loop interchanges
interchange(i4, i3)
interchange(i4, i2)
interchange(j2, j1)
interchange(j1, j4)

# Transpositions
tmp2t = vtranspose(tmp2, 1, 2)
replace_array(j3, tmp2, tmp2t)
tmp3t = vtranspose(tmp3, 1, 3)
replace_array(k4, tmp3, tmp3t)

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

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.