Advanced Computation and I/O Methods for Earth-System Simulations
Status update

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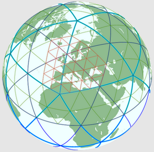
Goals

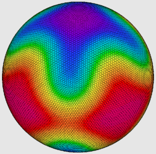
Address key issues of icosahedral earth-system models

- Enhance programmability and performance-portability
- Overcome storage limitations
- Shared benchmark for these models

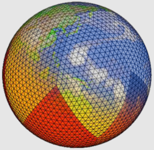
Covered models



ICON



DYNAMICO



NICAM

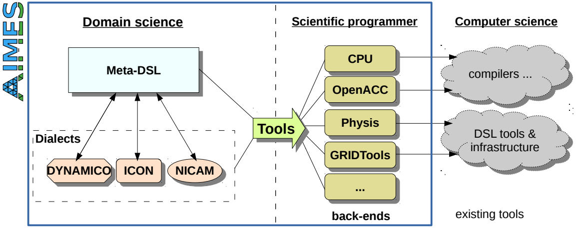
WP1: Towards Higher-Level Code Design

Recap: Goals of the WP

- Bypass shortcomings of general-purpose languages
  - Offer performance-portability
  - Enhance source repositories maintainability
  - Get rid of complexity in optimized-code development
  - Enhance code readability and scientists productivity
- Extend modelling programming language
  - Based on domain science concepts
  - Free of lower level details (e.g., architecture, memory layout)

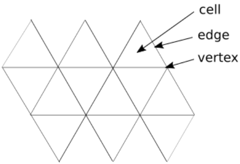
Approach

- Foster separation of concern
  - Domain scientists develop domain logic in source code
  - Scientific programmers write hardware configurations
- Source code written with extended language
  - Closer to domain scientists logic
  - Scientists do not need to learn optimizations
  - Write code once, get performance for various configurations
- Hardware configurations define software performance
  - Written by programmers with more experience in platform
  - Comprise information on target run environment

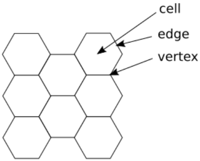


DSL Development

- Co-design with scientists to develop DSL constructs
  - Current version represents several iterations
  - GGDML: *General grid definition and manipulation language*
  - Grid definition
  - Grid-bound variable declaration
  - Grid-bound variable access/update
  - Stencil operations
- Hides memory locations and access details, data iteration
- Abstract higher concepts of grids, hiding connectivity details



a) Triangular grid



b) Hexagonal grid

Fortran vs. GGDML Code Example

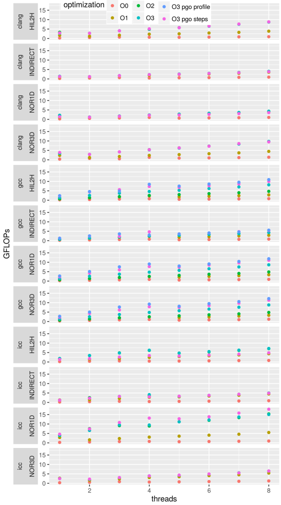
```
DO l=ll_begin,ll_end
!DIR$ SIMD
  DO ij=ij_begin,ij_end
   berni(ij,l) = .5*(geopot(ij,l)+geopot(ij,l+1)) +
       1/(4*Ai(ij)) *
       (le(ij+u_right)*de(ij+u_right)*u(ij+u_right,l)**2 &
       +le(ij+u_rup)  *de(ij+u_rup)  *u(ij+u_rup,l)**2   &
       +le(ij+u_lup)  *de(ij+u_lup)  *u(ij+u_lup,l)**2   &
       +le(ij+u_left) *de(ij+u_left) *u(ij+u_left,l)**2  &
       +le(ij+u_ldown)*de(ij+u_ldown)*u(ij+u_ldown,l)**2 &
       +le(ij+u_rdown)*de(ij+u_rdown)*u(ij+u_rdown,l)**2 )
  ENDDO
ENDDO
```

GGDML version of the code above

```
FOREACH cell IN grid
 berni(cell) = .5*(geopot(cell)+geopot(cell%above)) +
     1/(4*Ai(cell)) * REDUCE(+,N, le(cell%neighbour(N))*
     de(cell%neighbour(N))* u(cell%neighbour(N))**2)
END FOREACH
```

Status of Tools & Performance Analysis Experiments

- Initial tools developed for
  - Source-to-source translation
  - Flexible: adjustable DSLs
  - Performance analysis
  - Integration into build systems
- Explored opt. of mem. layout
  - 3D and 1D transformation
  - Hilbert filling curves & HEVI
  - With various compilers
    - Intel, GCC, CLang
  - Best layout depends on compiler!
- NICAM-DC ported to GridTools
  - Potential back-end for GGDML
- Hybrid Fortran for ASUCA weather
  - Code generation of CUDA

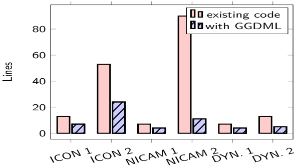


GGDML Impact on the Source Code

The DSL reduces development and maintenance effort

- LOC statistics

Model, kernel	lines (LOC) before DSL	lines (LOC) with DSL	words before DSL	words with DSL	characters before DSL	characters with DSL
ICON 1	13	7	238	174	317	258
ICON 2	53	24	163	83	2002	916
NICAM 1	7	4	40	27	76	86
NICAM 2	90	11	344	53	1487	363
DYNAMICO 1	7	4	96	73	137	150
DYNAMICO 2	13	5	30	20	402	218
total	183	55	911	430	4421	1991
relative size with dsl	30%		47%		45%	



- Predicting saving applying the DSL to 300k code of ICON
  - 100k infrastructure (does not change with the DSL)
  - Remaining code reduced according to our test kernels
  - COCOMO estimations

Software project	Version	Effort Applied	Dev. Time (months)	People require	dev. costs (M€)
Semi-detached		2462	38.5	64	12.3
	DSL	1133	29.3	39	5.7
Organic		1295	38.1	34	6.5
	DSL	625	28.9	22	3.1

WP2: Massive I/O

Recap: Goals of the WP2

- Optimization of I/O middleware for icosahedral data
  - Throughput, metadata handling
- Design of domain-specific compression (ratio $> 10 : 1$)
  - Investigate metrics allowing to define accuracy per variable
  - Design user-interfaces for specifying accuracy
  - Develop a methodology for identifying the required accuracy
  - Implement compression schemes exploiting this knowledge

WP2: Supported Quantities

Quantities defining the residual (error):

absolute tolerance: compressed can become true value ± absolute tolerance

relative tolerance: percentage the compressed value can deviate from true value

relative error finest tolerance: value definining the absolute tolerable error for relative compression for values around 0

significant digits: number of significant decimal digits

significant bits: number of significant decimals in bits

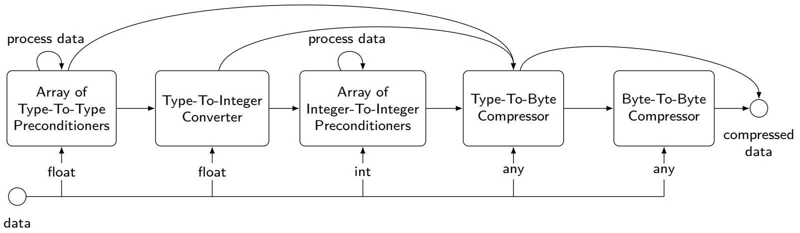
field conservation: limits the sum (mean) of field's change

Quantities defining the performance behavior:

absolute throughput: in MiB or GiB, or relative to network or storage speed

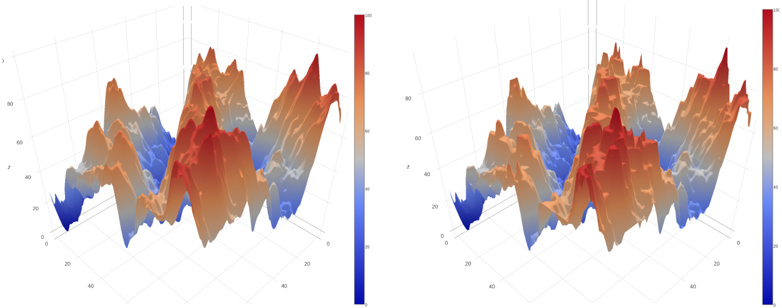
Architecture of SCIL

- Contains tools to
  - Create random patterns, compress/decompress, add noise, plot
- HDF5 and NetCDF4 integration; tools support NetCDF3, CSV
- Library with
  - Automatic algorithm selection (under development)
  - Flexible compression chain:



WP2: Example Synthetic Data

Simplex (options 206, 2D: 100x100 points)



Right picture compressed with Sigbits 3bits (ratio 11.3:1)

Analyzing Performance of Lossy Compression using SCIL

An initial experiment is conducted with SCIL

Data

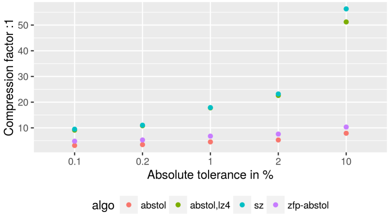
- Single precision (1+8+23 bits)
- Synthetic, generated by SCIL's pattern lib.
  - e.g., Random, Steps, Sinus, Simplex
- Data of the variables created by ECHAM
  - The climate model creates up to 123 vars

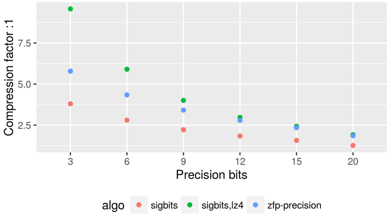
Experiments

- Single thread, 10 repeats
- Lossless (memcopy and lz4)
- Lossy compression with significant bits (zfp, sigbits, sigbits+lz4)
- Lossy compression with absolute tolerance (zfp, sz, abstol, abstol+lz4)
  - Tolerance: 10%, 2%, 1%, 0.2%, 0.1% of the data maximum value

WP2: Tolerance-Based Results

- Mean compression factor across all scientific files
- Factor 50:1 means space is reduced to 2% of the original size
- Note that SZ and ZFP do not always reach the set precision
  - Often the absolute and precision bit tolerance cannot be met





WP2: Comparing Algorithms for the Scientific Files

		Throughput [MiB/s]	
Algorithm	Ratio	Compr.	Decomp.
sigbits	0.45	464.4	620.7
sigbits,lz4	0.23	401.6	585.2
zfp	0.30	194.8	418.3

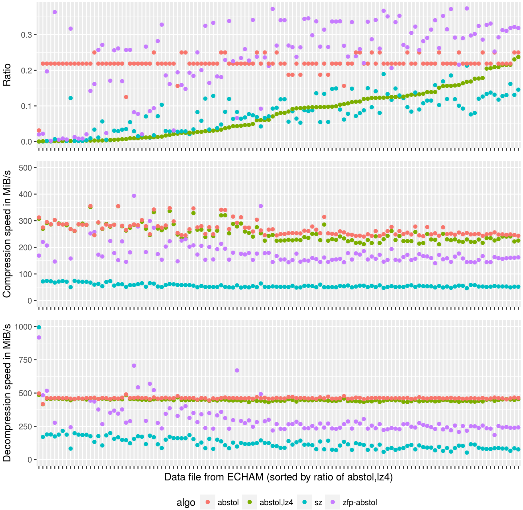
Table: Preserving 9 precision bits (instead of 23 from float) ≤ 0.56

		Throughput [MiB/s]	
Algorithm	Ratio	Compr.	Decomp.
abstol	0.22	269.3	461.7
abstol,lz4	0.08	253.4	446.8
sz	0.08	66.0	127.4
zfp	0.24	263.9	492.9

Table: For absolute tolerance with 1% of max value < 0.22

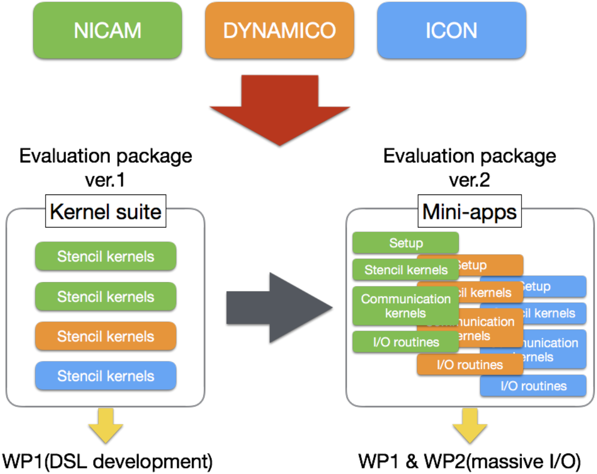
WP2: Results for Absolute Tolerance

Comparing algorithms using an absolute tolerance of 1% of the maximum value



WP 3: Evaluation

- Evaluating the DSL and domain-specific I/O advancements
- Providing a common benchmark package for all models



Kernel Extraction

- Extracted kernels (e.g. from NICAM)
  - 2-D(horizontal) diffusion: simple stencil
  - 1-D(vertical) tridiagonal matrix solver: with (i*j,k) array, recurrence k-axis
  - 3-D divergence damping: simple but large memory footprint
  - 2-D(horizontal) flux calculation with remapping: large memory footprint
  - 2-D(horizontal) flux limiter for tracer transport: complex, max()/min()
  - 1-D(vertical) flux limiter for tracer transport: complex, max()/min()

  - Setup routine for the coefficients of the stencil operators
  - Communication kernel

Summary

- AIMES covers programmability issues on the high-level
  - DSL-extensions enrich existing languages
  - Fosters separation of concerns, increase performance portability
  - We have reached a first concensus between scientists
  - Will work on further examples and (next) revision for the DSL
  - An initial prototype has been developed
  - Several backends have been explored
- AIMES addresses domain-specific lossy compression
  - (Help) scientists to define the variable accuracy
  - Exploit this knowledge in the compression scheme
  - Novel schemes compete with exististing algorithms
    - The choosing algorithm should always pick the best

Next Steps

- Bring together individual work on DSL backends
  - GridTools is a good candidate for a backend
- Refine project plan for next 12 month
- Explore use of further potential, e.g., YASK
- Provide shared DSL conventions and survey more scientists
- Extract and convert mini-apps of models to DSL
- Finalize SCIL API and interfaces to NetCDF/HDF5
- Integrate algorithm covering all accuracy quantities

Backup

Backup

Differences among three icosahedral atmospheric models

- Horizontal grid system
  - NICAM: co-located, semi-structured
  - DYNAMICO: staggered, semi-structured
  - ICON: staggered, unstructured

  - semi-structured means... "structured for stencil operation, unstructured for communication topology"

Partners and Expertise

Funded partners

- Thomas Ludwig (Universität Hamburg)
  I/O middleware, compression, ICON DSL
- Thomas Dubos (Institut Pierre Simon Laplace)
  Application I/O servers, compression, DYNAMICO
- Naoya Maruyama (RIKEN)
  DSL (Physis), GPUs, NICAM
- Takayuki Aoki (Tokio Institute of Technology)
  DSL (HybridFortran), language extension, peta-scale apps

Cooperation Partners

- DKRZ *(I/O, DSL)*
- DWD *(ICON, DSL, I/O)*
- University of Exeter *(Math. aspects in the DSL)*
- CSCS *(GPU/ICON, GRIDTool, compression)*
- Intel *(DSL-backend optimization for XeonPhi, CPU)*
- NVIDIA *(DSL-backend optimization for GPU)*
- The HDF Group *(I/O, unstructured data, compression)*
- NCAR (MPAS developers, another icosahedral model)
- Bull
- Cray

Information exchange, participate in workshops, [hardware access]