DSL Developments

Julian M. Kunkel

DKRZ

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Outline

Introduction

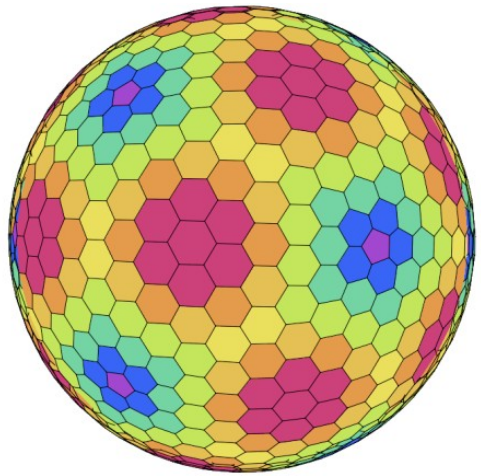
Motivation

- General purpose programming languages face hurdles to express scientist's thoughts well
- In HPC, scientists code domain knowledge but also performance aspects (computer science knowledge)

if possible

ICON

- ICON (climate and NWP) model
- Ocean, Atmosphere, SeaIce, ...
- MPI-M led approach to DSLlize the code in the ICOMEX project



Why Manual Optimization?

General Purpose Programming Languages

- Standard implies limitations, e.g. memory layout is fixed
- Difficulty to express architecture-specific attributes
- Existing tools: CPP macros, templates from C++

Compilers

- Need to follow the standard (conservatively)
- Uncertainties (data alignment, array size) $\Rightarrow$ suboptimal code
- Cannot change memory-layout (1D array vs. 3D indirect array)

Consequence

- Architecture/compiler-specific branches of code
- CPP directives to select the system to build for
- Directive based approach (OpenMP, OpenACC) bloats the code

Example Operator in Fortran

```
1  ...
2  !ICON_OMP_PARALLEL_DO PRIVATE(edge__index, edge__level,
       ↪ edge__startIndex, edge__endIndex) SCHEDULE(static,2)
3  DO edge__block = edge__subset%startBlock, edge__subset%EndBlock
4    ! get the start/end index in the block
5    edge__startIndex = 1
6    edge__endIndex = edge__gridEntity%blockSize_2D
7    IF (edge__block == edge__subset%startBlock) &
8      edge__startIndex = edge__subset%startBlockIndex
9    IF (edge__block == edge__subset%endBlock) &
10     edge__endIndex = edge__subset%endBlockIndex
11   DO edge__index = edge__startIndex, edge__endIndex
12     DO edge__level = 1,
           ↪ edge__gridEntity%numberOfLevels(edge__index,edge__block)
13 flux%value(edge__index,edge__block,edge__level) =  div%value(
       ↪ cell__ofedge_index_p(edge__index,edge__block,1),cell&
14 &__ofedge_block_p(edge__index,edge__block,1),edge__level) *
       ↪ grad_coeffs%value(edge__index,edge__block,edge__level,&
15 &1) +  div%value(
       ↪ cell__ofedge_index_p(edge__index,edge__block,2),cell__ofedge_block_
16 &edge__level) *
       ↪ grad_coeffs%value(edge__index,edge__block,edge__level,2)
```

Issues

Code is readable only for experts

- Original code is re-formatted and comments purged
- Handling of special cases
- Memory layout is optimized for parallelism (block structure, indirect access)
- Additionally: Different versions of the code exist based on the connectivity...

DSL Version of the Operator

```
1 <on edge do:
2   edge%flux = SUM[on cell] cell%div * cell%grad_coeffs;
3 end do>
```

Additional benefit

- Alternative (system-specific) memory layouts are possible
- Domain-specific variation in connectivity level is expressable (SUM[] operator)

Example: Full DSL Code

So far, declaration of variables have been omitted.

```
1  SUBROUTINE grad_oce_3D_dsl_2(div, flux, grad_coeffs,
       ↪ subset_range)
2    <OnCells_3D_double  :: div>
3    <OnEdges_3D_double  :: flux>
4    <OnEdgesToCells_3D_double :: grad_coeffs>
5    <Edges_SubsetRange, INTENT(in), OPTIONAL :: subset_range>
6    <Edges_3D_SubsetRange     :: edges_subset>
7    <Edges_3D_Element         :: edge>
8    <CellsOfEdges_3D_Element :: cell>
9
10   <edges_subset = getDefaultSubset(subset_range, flux)>
11   <edge .belongsTo. edges_subset>
12   <cell .belongsTo. edge>
13
14   <on edge do:
15      edge%flux = SUM[on cell] cell%div * cell%grad_coeffs;
16    end do>
17
18 END SUBROUTINE grad_oce_3D_dsl_2
```

Results from ICOMEX

Most project runtime, ANTLR and ROSE have been used

Moderate success

- Source-to-Source translator (Fortran+DSL $\Rightarrow$ Fortran)
- Arrays could be swapped, e.g. x[i][j][k] became x[j][k][i]
- Inlining was possible
- Configuration file

Issues

- Tools are complex by themselves
- ANother Tool for Language Recognition (ANTLR) does not offer Fortran support
- ROSE Fortran support is limited and required workarounds
- Issues with pre-processor macros

Recent Approach

Idea

Parse and alter only text regions that matter for us

DSLL

Light-weight tool for template processing in Python supporting

- Symbol-table
- Hooks to invocate actions in the tool
- Nested namespace and templating
- Flexible templates
- Command line options can alter templates
- Incremental DSLization [1]

It can handle our example from the beginning!

[1] if memory layout is not modified

Example Code for a Synthetic Test

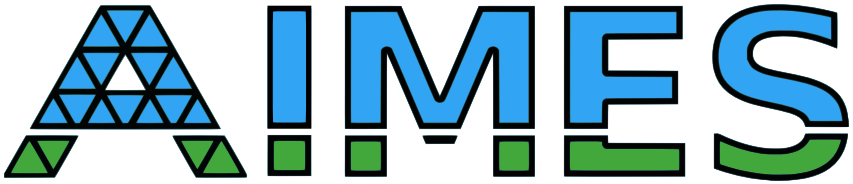
```
1 Grid :: myGrid
2 GridVar :: varCreation
3 for c in myGrid do:
4    ! Print the value of var for each grid point
5    print *, c%var
6 end do
```

Example source code to translate with `dsll`

Example Template

```
OPTIONS = [
   ("debugging", "Enable extra debugging", False),
   ("size", "Dimension of the problem", 10) ],
TEMPLATE = [
  ("Grid $extra=[^:]+$:: $var$",
    """TYPE(grid3D) $extra$ :: $var$
       integer :: index_$var$
       ~~LOOKUPTABLE_SET($var$,Grid)"""),
  ("GridVar $extra=[^:]+$:: $var$",
   "real gridVar dimension(@VAR(size)@):: $var$
       ↪ ~~LOOKUPTABLE_SET($var$,GridVar)"),
  ("for $cell$ in $Grid:grid$ do :,
    {
     "substitute", """DO index_$grid$ = 0, @VAR(size)@
       @if(debugging) print *, index_$grid$@ ~~BEGIN_BLOCK""",
     "childs" :[
       "$cell$%$var$, "$var$[index_$grid$]",
       "end do", "END DO~~END_BLOCK"
    }),
  ("for":, "~~ERROR(Invalid syntax)")\item The compiler cannot
      ↪ optimize all code
]
```

New Project: AIMES



Advanced **I**/O and Computational **M**ethods for **E**arth-**S**ystem Models

I/O

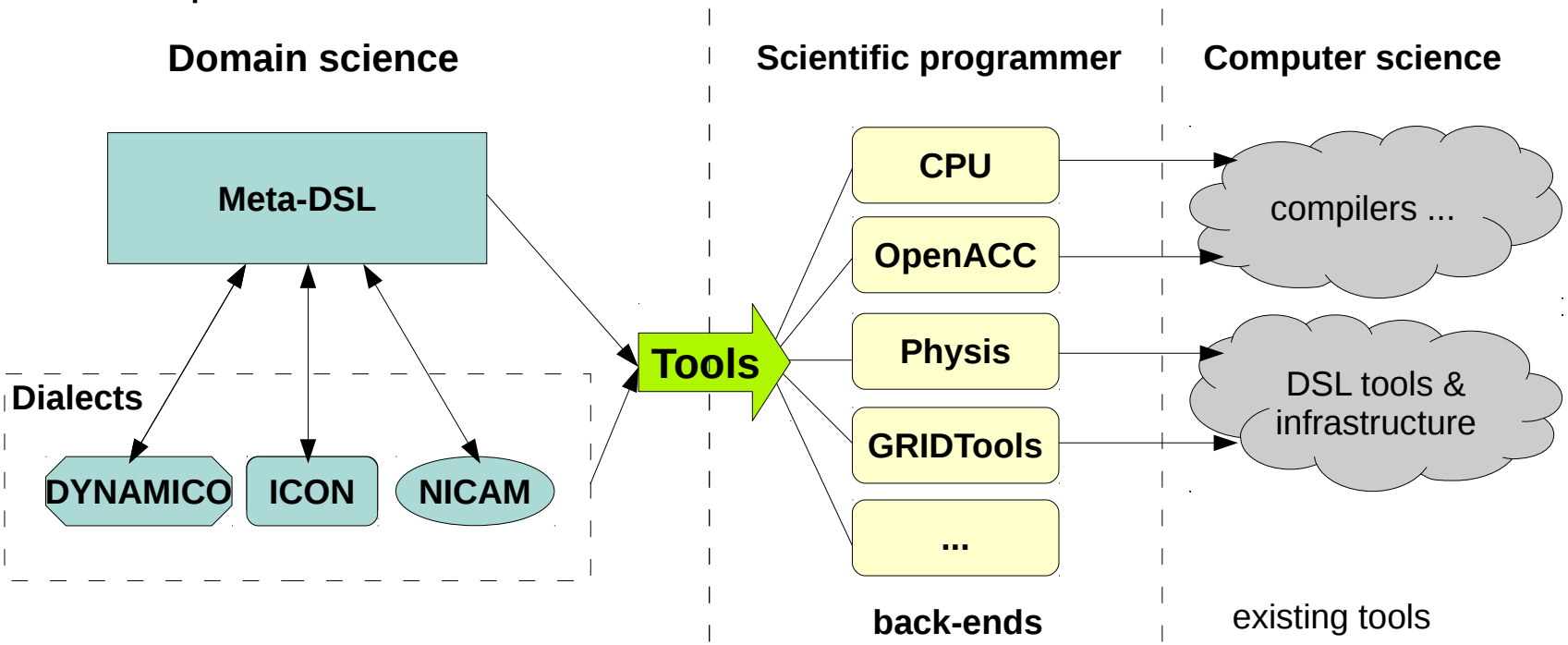
- Data layouts for ICO data
- Lossy compression (interface, methodology, schemes)

DSL

- Common (meta-)DSL for multiple (earth-system) models
- Tools for flexible creation of “Dialects”
- Full memory abstraction
- Source-to-source translation to existing language AND DSLs

Abstraction Level

Clear separation of concerns



Summary & Conclusions

- DSLs can simplify code significantly
- Allow separation of concern (DS, SP, CS)
- Existing heavy-weight tools are not well suited/trusted
- In AIMES, we go for high-level concepts