Introduction to DSLs

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What is a Domain Specific Language in scientific computing ?

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Matrix transpose in different languages

matlab

C

```
for(int i=0; i < n; ++i) {
    for(int j=0; j < n; ++j) {
        double z=m[i][j];
        m(i,j)=m[j][i];
        m[j][i]=z;
    }
}
```

Matrix transpose in different languages

matlab

```
A=B.'
```

C

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```

Matrix transpose in different languages

matlab

A=B.'

Domain specific language:
domain = matrix operations
Semantic information: matrix transpose

Concise syntax for a problem
Abstracts implementation and hardware dependent details:
- ✓ OMP parallelization
- ✓ GPU cuda implementation
- ✓ linear algebra calls (blas, mkl,...)

C

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```
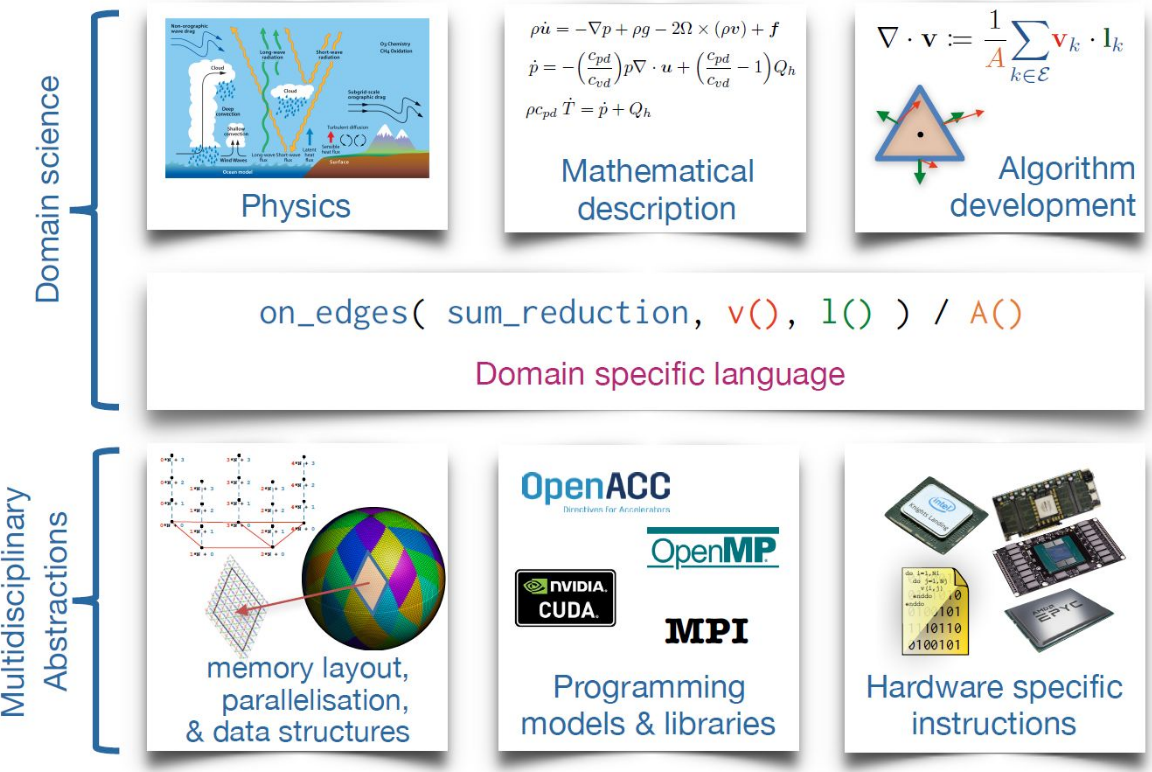

General purpose, it can solve any problem
Semantic information: double nested loop modifying matrix with self-dependencies

DSLs for weather and climate models



- **Concise language** for solving weather problems
- **High scientific productivity**
- Leverage **high-level semantic** of the problem to apply **domain specific optimizations.**

W. Deconinck (ECMWF)

From math to implementation:

$$grad f = \nabla f$$

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From math to implementation:

$$grad f = \nabla f$$

```
CALL halo_exchange(psi_c, start_prog_area, start_prog_area+1)

#ifdef _OMP
!$OMP ....
#else
!$ACC ....
#endif
DO jb = i_startblk, i_endblk
 CALL get_indices_e(ptr_patch, ...)
 #ifdef __LOOP_EXCHANGE
 DO je = i_startidx, i_endidx
   DO jk = slev, elev
 #else
   DO jk = slev, elev
     DO je = i_startidx, i_endidx
 #endif
     grad_norm_psi_e(je,jk,jb) =  &
       ( psi_c(iidx(je,jb,2),jk,iblk(je,jb,2)) -
         psi_c(iidx(je,jb,1),jk,iblk(je,jb,1)) )
       / ptr_patch%edges%lhat(je,jb)
   ENDDO
 END DO
END DO
#ifdef _OMP
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```

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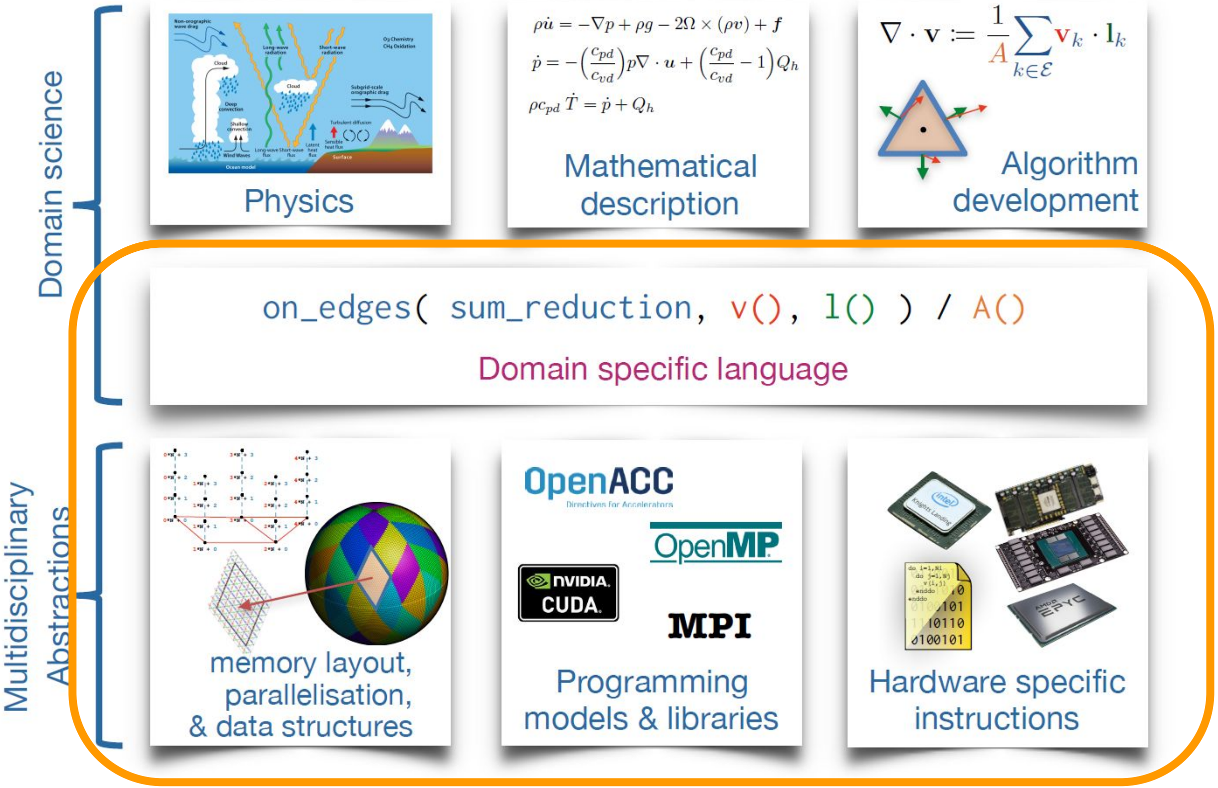
Separation of concerns decompose the implementation layer adding a simple interface to user (DSL syntax)



W. Deconinck (ECMWF)

Separation of concerns:

How do we separate science from complex model implementations for exascale computers ?

```
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         / ptr_patch%edges%lhat(je,jb)
   ENDDO
 END DO
END DO
#ifdef _OMP
!$OMP ...
#else
!$ACC ...
#endif
```

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Separation of concerns:

Option 1: rely on compilers

```
grad_norm_psi_e(:,:,:) =  &
        ( psi_c(iidx(2),:,:) -
          psi_c(iidx(1),:,:))
        / lhat(:,:)
```

Caveat: unrealistic option

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Separation of concerns:

Option 2: use general purpose programming models

OpenCL™

kokkos

Caveat: provides portability, but still complex and low level implementations

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Separation of concerns:

Option 3: DSLs for weather and climate

Caveat: community needs to agree on DSL languages and develop compilers

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Types of DSLs...

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Types of DSLs

High abstractions, provide a new syntax with keyword only for supported concepts.
Eliminate all unnecessary language elements:
for/do loops, memory patterns, indices of an iteration space, parallelization

```
grad_norm_psi_e =
    reduce( psi_c,
            CELL > EDGE,
            [1/lhat, -1/lhat]
    )
```

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Types of DSLs

Low abstractions, support existing programming languages but limit the functionality supported.
Operates on naive implementations of general purpose languages.
Requires Implement a DSL compiler that parses, interprets computational patterns, and produces optimized code.

```
! Horizontal tracer gradient
DO jk = 1, jpkm1
   DO jj = 1, jpjm1
      DO ji = 1, jpim1   ! vector opt.
         zdit(ji,jj,jk) = ( ptb(ji+1,jj  ,jk,jn) - ptb(ji,jj,jk,jn) ) * umask(ji,jj,jk)
         zdjt(ji,jj,jk) = ( ptb(ji  ,jj+1,jk,jn) - ptb(ji,jj,jk,jn) ) * vmask(ji,jj,jk)
      END DO
   END DO
END DO
```

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Types of DSLs

Dusk /dawn -> Python DSL language
PSyclone -> Fortran DSL language

PSyclone -> Fortran

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GridTools: Early examples

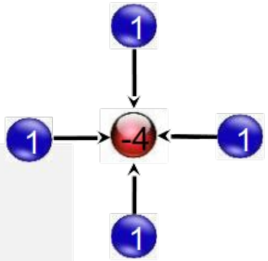
- In production at MeteoSwiss since 2016 for COSMO dynamical core.
- First operational case successfully using DSLs for dynamical core.
- Low level C++ syntax.
- Requires an HPC/C++ expert to develop model using DSL.

GridTools DSL example (in production)

- Syntax for a stencil

```
struct Laplace{
  typedef in_accessor<0, extent<-1,1,-1,1> > u;
  typedef out_accessor<1> lap;

  template <typename Evaluation>
  static void Do(Evaluation eval, domain)
  {
      eval(lap()) = eval(-4*u() + u(i+1) + u(i-1) + u(j+1) + u(j-1));
   }
};
```



- Composing stencils

```
auto hori_diff =
    make_computation<Cuda>(
        domain, grid,
        make_multistage(
            execute<forward>(),

            make_stage<Laplace>(lap(), u(), crlat0()),
            make_stage<Div>(u(), lap(), coeff())
    )
);
hori_diff->run();
```

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dusk/dawn: towards new generation Python DSLs

The DSL Idea

$$\underline{\nabla}_n \psi(e) = \frac{\psi(c_1(e)) - \psi(c_0(e))}{\hat{l}}$$

```
grad_norm_psi_e =
      reduce( psi_c,
              CELL > EDGE,
              [1/lhat, -1/lhat]
          )
```

OMP

DSL compiler

```
!$OMP PARALLEL
!$OMP DO PRIVATE(jb, i_startidx, i_endidx, je, jk)
DO jb = i_startblk, i_endblk
 CALL get_indices_e(ptr_patch, ...)
 DO je = i_startidx, i_endidx
   DO jk = slev, elev
     grad_norm_psi_e(je,jk,jb) =  &
       ( psi_c(iidx(je,jb,2),jk,iblk(je,jb,2)) -
         psi_c(iidx(je,jb,1),jk,iblk(je,jb,1)) )
       / ptr_patch%edges%lhat(je,jb)
   ENDDO
 END DO
END DO
!$OMP END DO NOWAIT
!$OMP END PARALLEL
```

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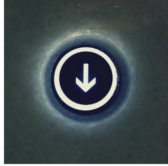

Existing code & DSLs

Evolution rather than Revolution

- Although DSLs are very powerful, an application must be re-written in order to use them
- Applications in the weather/climate domain are large and under continuous development
- DSLs are relatively new and untested in this domain
  - Concerns over longevity of necessary tool chains
- To stop development on existing code and re-develop from scratch is expensive (time and effort)
- Community has a lot of skill and knowledge in existing coding approaches (Fortran)

Very attractive to be able to *translate* existing code into a DSL or use existing code in a DSL rather than re-write:

- Support science that cannot be specified in the DSL language
- Transition to high level DSLs by evolution not revolution
- Support code generation and translation

Need to regain lost information

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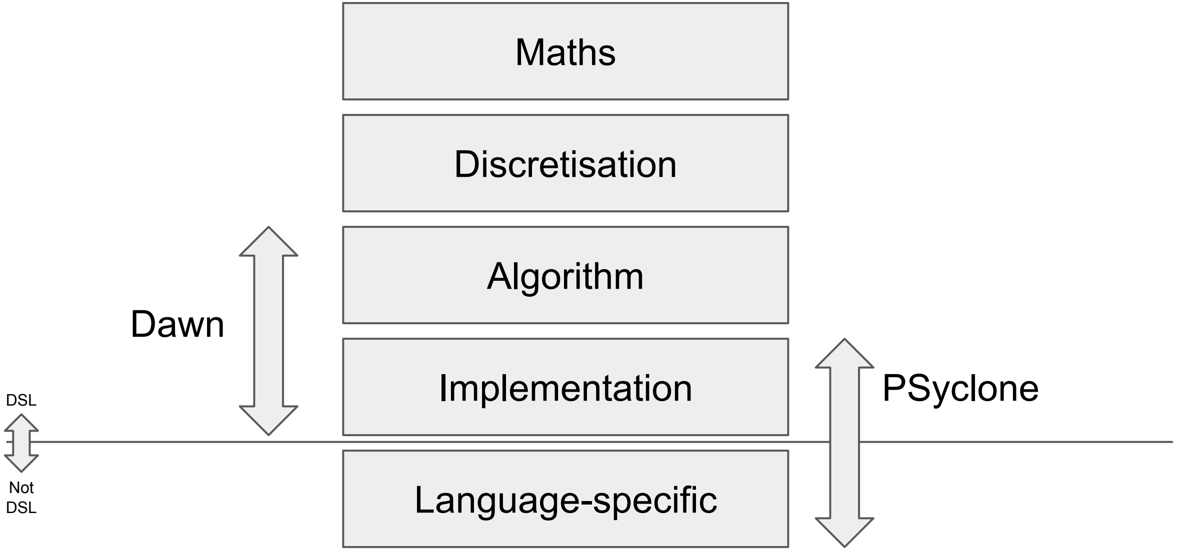
Levels of abstraction



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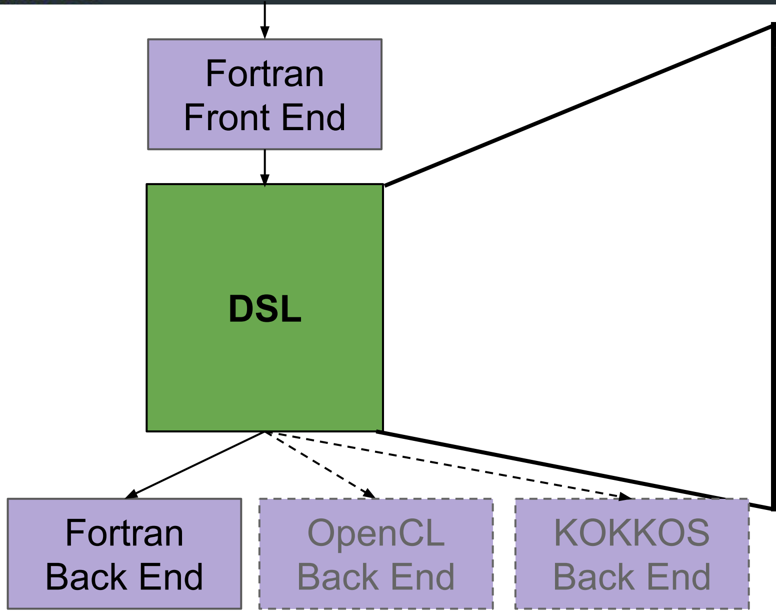


```
4: Loop[type='levels', field_space='None', it_space='None']
    Literal[value:'1']
    Reference[name:'jpkm1']
    Literal[value:'1']
    Schedule[]
        0: Loop[type='lat', field_space='None', it_space='None']
            Literal[value:'1']
            Reference[name:'jpjm1']
            Literal[value:'1']
            Schedule[]
                0: Loop[type='lon', field_space='None', it_space='None']
                    Literal[value:'1']
                    Reference[name:'jpim1']
                    Literal[value:'1']
                    Schedule[]
                        0: CodedKern[]
```


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Summary

- Modelling required expertise in multiple disciplines (co-design)
- These disciplines work at different levels of abstraction
- Mixing science and performance can produce complex code
- Good to separate these concerns
- DSLs offer a way to do this
- DSLs support working at a high level of abstraction
- Higher level of abstraction allows a greater choice of implementation -> more performance
- Different DSLs can work at different levels of abstraction
- DSLs might support revolution and/or evolution

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