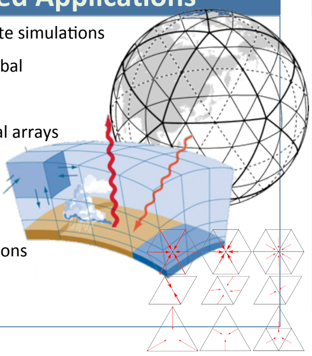
GridTools: A C++ Library for Computations on Grids

Mauro Bianco, Paolo Crosetto, Oliver Fuhrer,
Stefan Moosbrugger, Carlos Osuna, Hannes Vogt, Thomas C. Schulthess

Targeted Applications

- ✓ Weather and climate simulations
  - ✓ Regional and global
- ✓ Regular Grids
  - ✓ Multidimensianal arrays
- ✓ Structured grids
  - ✓ Icosahedral
  - ✓ A- and C-grids
  - ✓ Regular tasselations
  - ✓ Possibly others

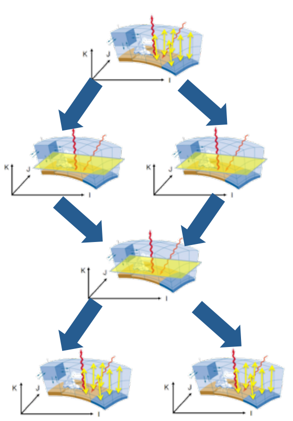


Properties & Requirements

- ✓ **Regular grids** and **stencils** are main motifs
- ✓ Stencils are typically memory **bandwidth bound**
- ✓ Applications run **many stencils** in sequence
- ✓ Compilers find these problems **hard to optimize**
- ✓ Typical time-loop optimizations are unpractical
- ✓ **Portability of performance**
- ✓ **Maintainability** and **separation of concerns**
  - ✓ Between application developers and performance specialists

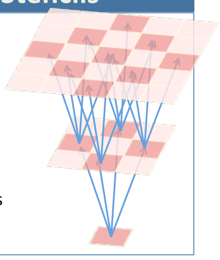
GridTools Ecosystem

Stencil Dependencies



Multi-Stage Stencils

- ✓ GridTools is for complex problems
- ✓ **Operator Splitting** for
  - ✓ Tractability
  - ✓ Maintainability
- ✓ **Dependencies** b/w operators
- ✓ **Time and space** dependencies
- ✓ GridTools provides easy composition of the stages



Stencil Operator

```
struct lap_function {
  typedef inout_accessor<0> out;
  typedef in_accessor<1, extent<-1,1,-1,1> > in;
  typedef arg_list = make_arg_list<out, in>;

  template <typename Evaluator>
  static void Do(Evaluator& eval) {
    eval(out()) = eval(4*in() -
                  in( 1, 0, 0) + in( 0, 1, 0) +
                  in(-1, 0, 0) + in( 0,-1, 0));
  }
};
```

Traditional Approach

```
for i=bi-1, ei+1
 for j=bj-1, ej+1
  for k=bk, ek
    lap(i,j,k) = 4*in(i,j,k) -
          (in(i+1,j,k) + in(i,j+1,k) +
           in(i-1,j,k) + in(i,j-1,k))

for i=bi-1, ei
 for j=bj, ej
  for k=bk, ek
    flx(i,j,k) = lap(i+1,j,k)-
lap(i,j,k);
     if (flx(i,j,k)*(in(i+1,j,k)-
in(i,j,k)))
       then flx(i,j,k) = 0.

for i=bi, ei
 for j=bj-1, ej
  for k=bk, ek
    fly(i,j,k) = lap(i,j+1,k)-
lap(i,j,k);
     if (fly(i,j,k)*(in(i,j+1,k)-
in(i,j,k)))
       then fly(i,j,k) = 0.

for i=bi, ei
 for j=bj, ej
  for k=bk, ek
    out(i,j,k) = in(i,j,k) -
      (flx(i,j,k) - flx(i-1,j,k) +
       fly(i,j,k) - fly(i,j-1,k))
```

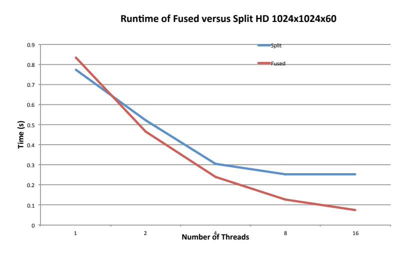
Multi-Stage Stencil Composition

```
auto horizontal_diffusion =
  make_computation<BACKEND> (
    make_multistage(
      execute<forward>,
      make_stage<lap_f>(lap(), in()),
      make_independent(
        make_stage<flx_f>(flx(),in(),lap()),
        make_stage<fly_f>(fly(),in(),lap())),
      make_stage<comb_f>(out(),in(),flx(),fly())),
    data_fields, coords);

horizontal_diffusion->run();
```

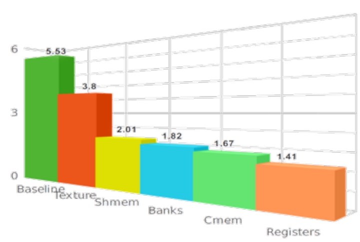
Grid-Independent Operator

```
template < uint_t Color > struct sum_on_cells {
  using in = in_accessor<0, cells, extent<-1,1,-1,1>>;
  using out = inout_accessor<1, cells>;
  using arg_list = make_arg_list<in, out>;

  template < typename Evaluator >
  static void Do(Evaluator& eval) {
    eval(out()) = eval(on_cells(
            [](double _i, double _r) {return _i+_r;},
            0.0, in()));
  }
};
```

Impact of Fusion



Incremental Optimization



Contact

Mauro Bianco
Swiss National Supercomputing Centre
Email: mbianco@cscs.ch
Phone: +41 (0) 91 610 8279

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