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Update of STELLA developments

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STELLA Reminder (1/2)

```
  DO k = 1, ke
!CDIR OUTERUNROLL=4
    DO   j  = 2 , je-1
!CDIR ON_ADB(lap)
!CDIR ON_ADB(s)
      DO i  = 2 , ie-1
        lap (i,j,k)   = s (i+1,j,k) + s (i-1,j,k) - 2.0_ireals*s(i,j,k) &
                      +  crlato(j)*(s(i,j+1,k) - s(i,j  ,k))           &
                      -  crlatu(j)*(s(i,j  ,k) - s(i,j-1,k))
      ENDDO
    ENDDO
  ENDDO
```

- Abstract…
  - explicit data structure (i,j,k)
  - explicit loops and loop order
  - parallelization (e.g. NEc, OpenMP, CUDA, …)
  - optimizations (blocking, fusion, …)

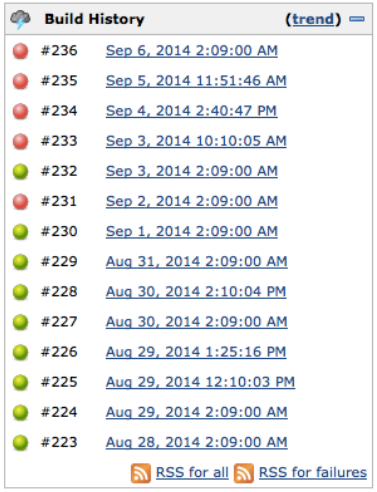
STELLA Reminder (2/2)

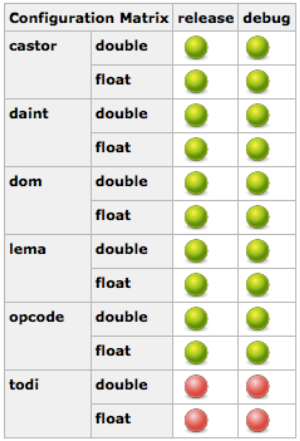
```
__ACC__
static T Do(Context ctx)
{
    ctx[data_out::Center()] = - (T)2.0 * ctx[data_in::Center()]
      + ctx[data_in::At(iplus1)] + ctx[data_in::At(iminus1)]
      + ctx[crlatvo::Center()] * ctx[Call<Delta>::With(jplus1 , data_in::Center())]
      + ctx[crlatvu::Center()] * ctx[Call<Delta>::With(jminus1, data_in::Center())];
}
```

```
// setup the tracer stencil
StencilCompiler::Build(
    stencil_,
    "HorizontalDiffusionTracers",
    dycoreRepository.calculationDomain(),
    StencilConfiguration<Real, HorizontalDiffusionTracersBlockSize>(),
    pack_parameters(
        Param<data_out, cInOut>(data_out_),
        Param<data_in, cIn>(data_in_),
    ),
    concatenate_sweeps(
        define_sweep<cKIncrement>(
            define_stages(
                StencilStage<LapStage, IJRange<cComplete,-2,2,-2,2>,
                                       KRange<FullDomain,0,0> >(),
            )
        )
    )
);
```

Code quality

- 35’000 lines of code (shared, stencil, comm, verif, serial, …)
- 20’000 lines of unit-tests
- Daily builds and regression tests





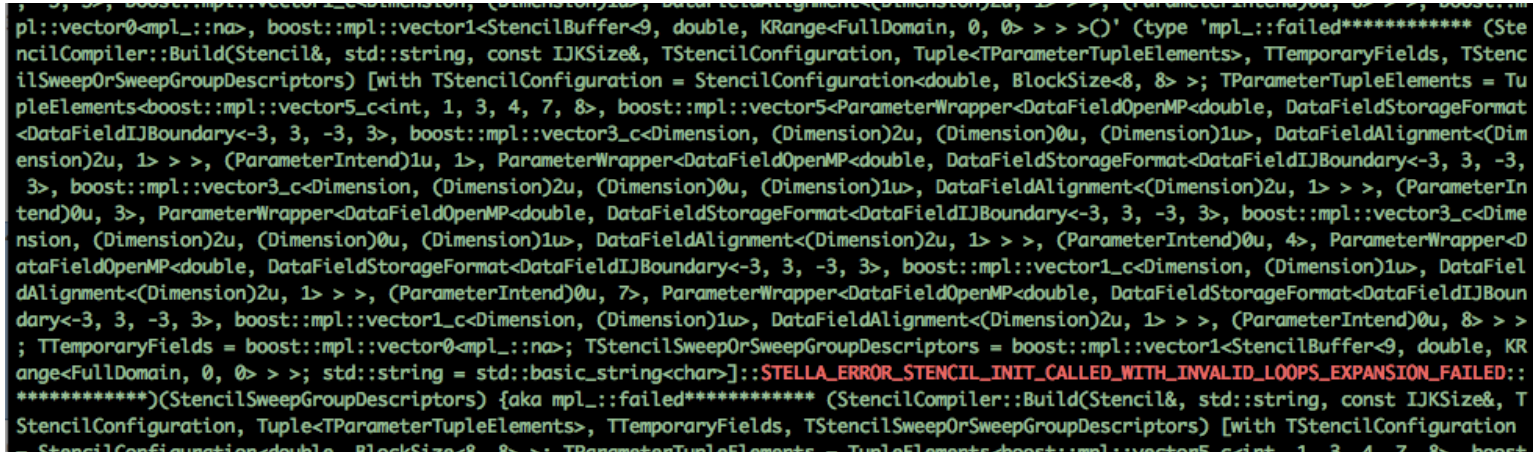
- No error caught by user to date!

Code owner

- Tobias Gysi (CS, SCS) left the project
- Ben Cumming (Math, CSCS) code owner since 08.2013
  - Minor developments
  - Code reviews
- Carlos Osuna (Physics, C2SM) main developer since 04.2014
  - Major developments

Compile time errors

- Nice example



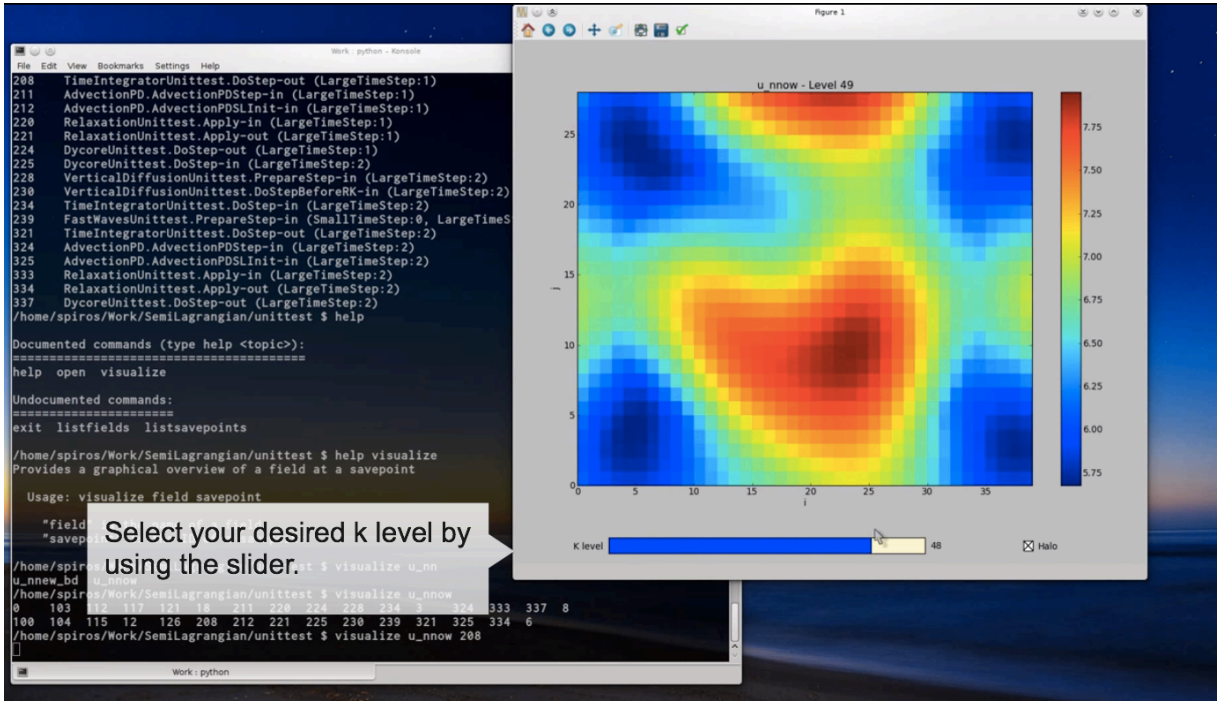
- All syntax protections of STELLA now produce a common error message

  `STELLA_ERROR_STENCIL_INIT_CALLED_WITH_INVALID_LOOPS_EXPANSION_FAILED`

- Just “grep STELLA_ERROR” compiler output
- Documentation with error message explanations in progress

Debug / verbose mode

- Fields and temporaries (automatically) initialized with NaN
- C++, Fortran and (prototype) Python interface to serialized fields



Debug / verbose mode

- Logging (verbose) mode (STELLA_ENABLE_LOGGING)

```
Stencil Coriolis Apply() started...
Bounding Box Info:
utens                          RW  from 0 0 0 to  41  26  59
vtens                          RW  from 0 0 0 to  41  26  59
u_nnow                         R   from -1  0 0 to  41  27  59
v_nnow                         R   from 0 -1  0 to  42  26  59
fc                             R   from -1  -1  0 to  41  26  59
Stencil Coriolis Apply() end
Stencil ConvertTemperatureTP Apply(const IJBoundary&) started...
Bounding Box Info:
tp_nnow                        RW  from -3  -3  0 to  44  29  59
tp_nnew_bd                     RW  from -3  -3  0 to  44  29  59
t_nnow                         R   from -3  -3  0 to  44  29  59
t_nnew_bd                      R   from -3  -3  0 to  44  29  59
t0                             R   from -3  -3  0 to  44  29  59
Stencil ConvertTemperatureTP Apply(const IJBoundary&) end
Stencil VerticalDiffusionPrepareStep Apply() started...
Bounding Box Info:
vdtch                          RW  from 0 0 59  to  42  27  59
vdtcm                          RW  from 0 0 59  to  42  27  59
kh                             RW  from 0 0 1 to  41  26  59
tmkvm                          RW  from -1  -1  1 to  42  27  59
tmkvw                          RW  from 0 0 1 to  41  26  59
sqrtgrhors                     RW  from 0 0 0 to  41  26  59
u_nnow                         R   from -1  0 59  to  42  27  59
v_nnow                         R   from 0 -1  59  to  42  27  59
rho                            R   from -1  -1  0 to  42  27  59
sqrtgrs                        R   from 0 0 0 to  41  26  59
sqrtgrw                        R   from -1  -1  1 to  42  27  59
tkvh                           R   from -1  -1  0 to  42  27  58
tkvm                           R   from -1  -1  0 to  42  27  58
p_s                            R   from 0 0 59  to  42  27  59
t_s                            R   from 0 0 59  to  42  27  59
qv_s                           R   from 0 0 59  to  42  27  59
tch                            R   from 0 0 59  to  42  27  59
```

Currently
- Workflow
- Inputs / Outputs
- Dependencies
- Halo-updates

Outlook
- Stage level info
- DAG
- … (your ideas)

Static parser

- Static parser for STELLA code being developed (PhD Tobias Gysi)
- Only possible due to DSL syntax
- Example

```
-> stencil: AdvectionPDBottPrepareTracers1
-> stage PremultiplyWithRhoStage1
-> method FullDomain
-> input fields
   -> data1_nnow: (0, 0, 0)
   -> rho: (0, 0, 0)
-> output fields
   -> data1: (0, 0, 0)
-> stage PremultiplyWithRhoStage2
-> method FullDomain
-> input fields
   -> data1_nnow: (0, 0, 0), (-1, 0, 0), (1, 0, 0)
   -> rho: (0, 0, 0)
   -> data2_nnow: (0, 0, 0)
-> output fields
   -> data1: (0, 0, 0)
   -> data2: (0, 0, 0)
```

Powerful tool for

- Syntax checker
- Dependency checker
- Halo-update checker
- Optimization hints (caching)
- Stage level information
- Exact access patterns
- FLOP counts
- Combine with runtime information
- Source-to-source translation

Configuration flexibility

- Developer feedback on C++ dynamical core
  - STELLA is not flexible enough for options
  - Too many compile time options
- **Note 1** Developer feedback on Fortran side is opposite → Trend to move runtime namelist options to hardcoded options (e.g. lcarlrho_advprog, ldiabf_satad, l_hor_p_grad_Mahrer, …)
- **Note 2** Compile time of compiling three (!) fast-waves solvers in current Fortran code can be significant
- **Note 3** Switches inside loop may impact performance, switches outside loop may lead to code duplication

Conditions in STELLA

- Conditional sweep execution (IJK-loop)

Code duplication
- Caches (not shown)
- Stencil stages

```
define_switch<ltadvlimiter> (

  define_case<int, 1>(
    define_sweep<cKIncrement>(
      define_caches( ........... ),
      define_stages(
        StencilStage<TrivialStage, IJRange<cIndented,0,0,0,0>, KRange<KMinimumCenter,0,0> >(),
        StencilStage<ComputeTheta0Stage, IJRange<cIndented,-1,1,-1,1>, KRange<FullDomain,0,0> >(),
        StencilStage<PPTPStage, IJRange<cComplete,0,0,0,0>, KRange<FullDomain,0,0> >(),
        StencilStage<DataStage, IJRange<cComplete,0,0,0,0>, KRange<FullDomain,0,0> >()
      )
    )
  ),

  define_case<int, 0>(
    define_sweep<cKIncrement>(
      define_caches( ........... ),
      define_stages(
        StencilStage<TrivialStage, IJRange<cIndented,0,0,0,0>, KRange<KMinimumCenter,0,0> >(),
        StencilStage<PPTPStage, IJRange<cComplete,0,0,0,0>, KRange<FullDomain,0,0> >()
        StencilStage<DataStage, IJRange<cComplete,0,0,0,0>, KRange<FullDomain,0,0> >()
      )
    )
  ),

  define_case<int, 2> (
    ...
  )

)
```

Conditions in STELLA

- **New** Conditional stage execution (IJ-loop)

```
define_sweep<cKIncrement> (
  define_caches( ..... ),

  define_stages(
    StencilStage<TrivialStage, IJRange<cIndented,0,0,0,0>, KRange<KMinim
  ),

  define_stage_switch<iadvorder>(
    define_stage_case<int, 3>(
      define_stages(
        StencilStage<HorAdv3rdOrder, IJRange<cIndented,-1,1,-1,1>, KRa
      )
    ),
    define_stage_case<int, 5>)(
      define_stages(
        StencilStage<HorAdv5thOrder, IJRange<cIndented,-1,1,-1,1>, KRange<
      )
    )
  ),

  define_stages(
    StencilStage<PPTPStage, IJRange<cComplete,0,0,0,0>, KRange<FullDomain,0,0> >()
  ),

  define_stage_if<ltadvlimiter, 1>(
    define_stages(
      StencilStage<ComputeTheta0Stage, IJRange<cIndented,-1,1,-1,1>, KRange<FullDomain,0,0> >()
    )
  )

)
```

Benefit

- Easier to introduce conditional code
- Little or no code duplication
- Both **switch/case** and **if(cond)** behaviour

Global parameters

- **NEW** Global parameter handling
- In GlobalParam_params.h name of th
  and (default / fixed) value

```
DEFINE_DYNAMIC_GLOBAL(iadv_order, 5)
DEFINE_STATIC_GLOBAL(itheta_adv, 0)
```

- Easy to switch from compile time to runtime switch
- GlbParSet will throw an error for compile time switch

- Initialization with GlbParInit()
- To set the value of a dynamic option

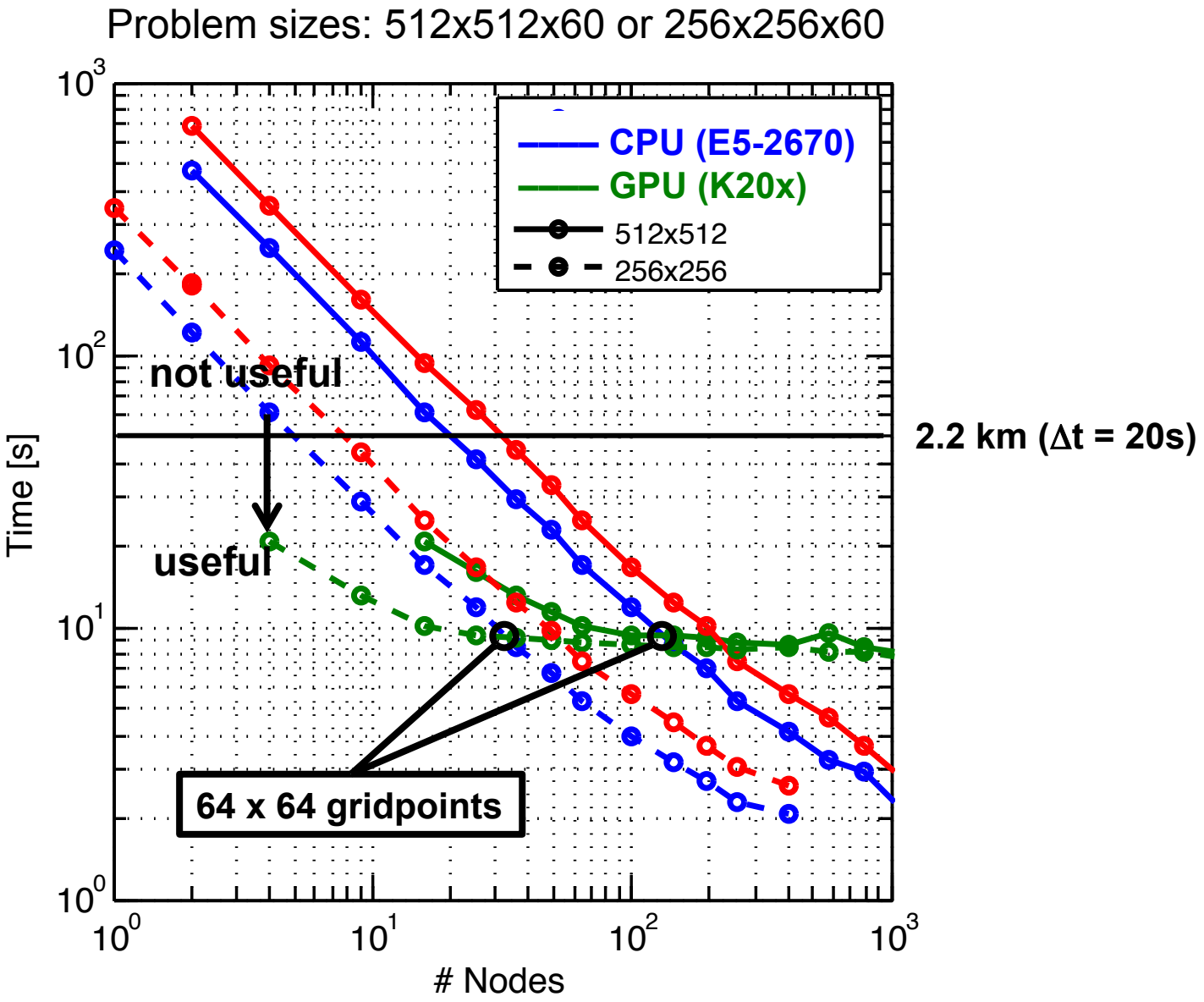
```
GlbParSet(iadv_order, 3);
GlbParSet("iadv_order", 3);
```

- To read the value of an option in device code

```
iadv = GlbParGet(iadv_order);
```

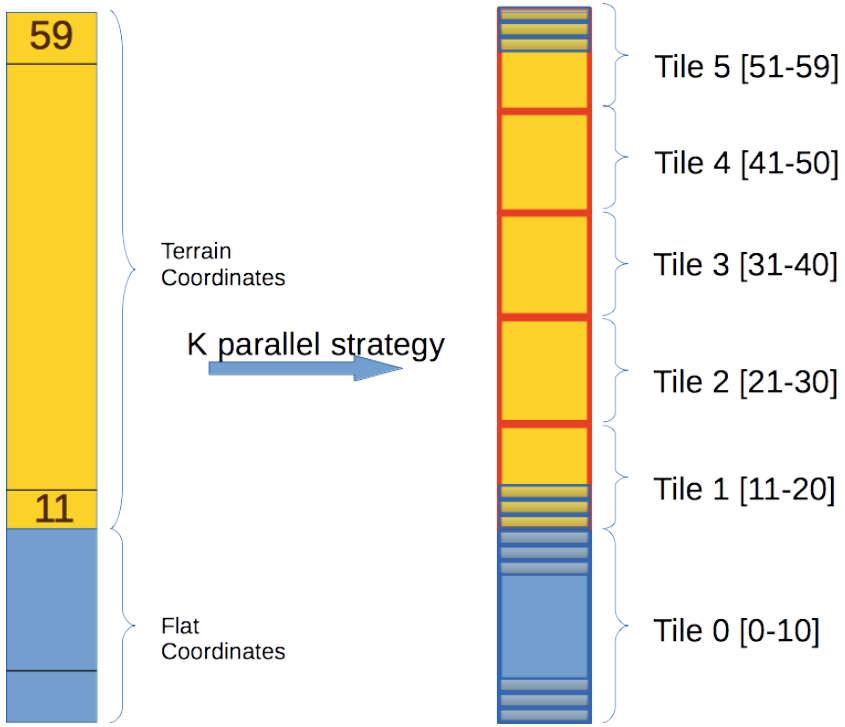
- **Important** Do not use inside loops!

Strong scalability

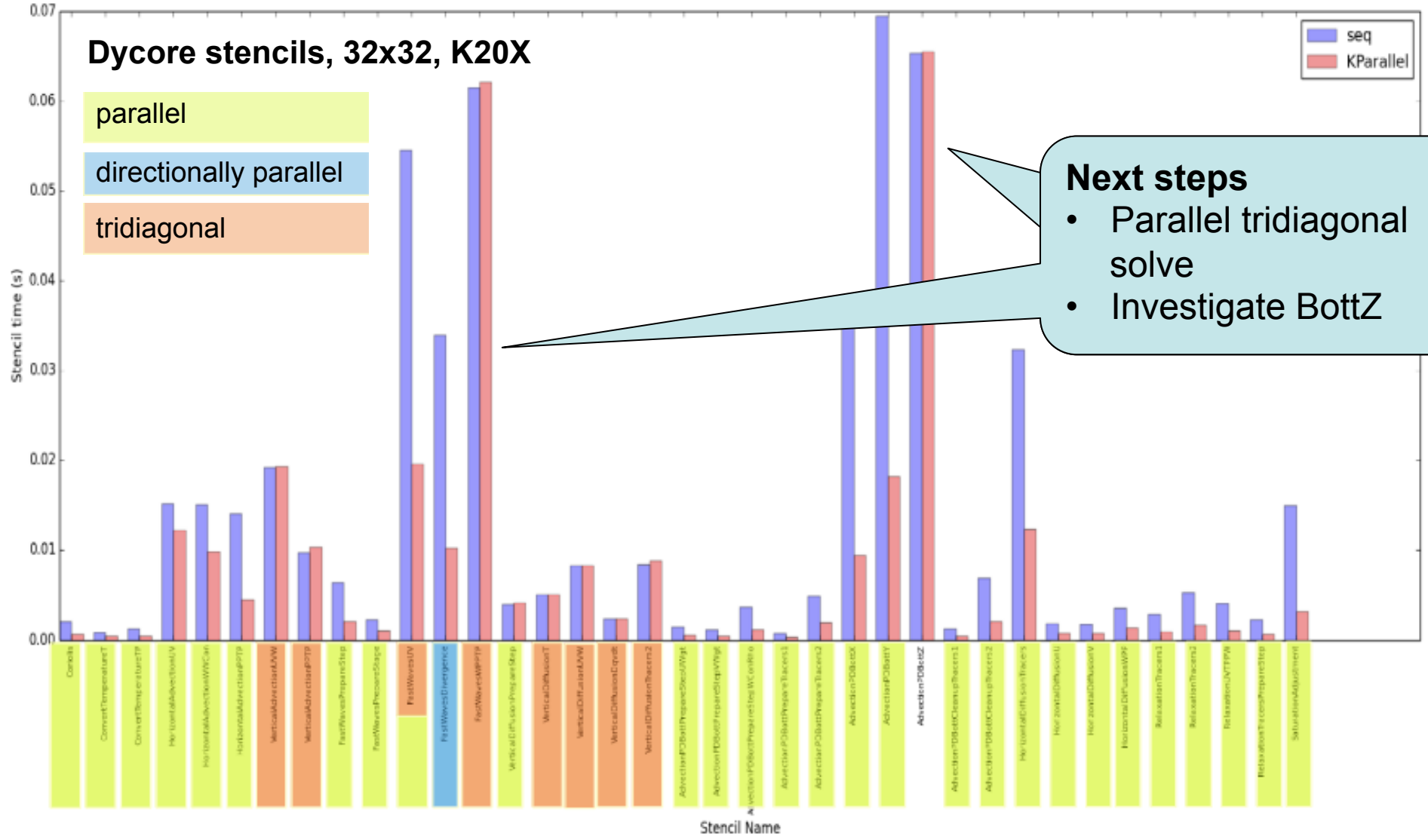


Vertical parallelization

- Parallelize along k-direction (GPU threads) in order to improve strong scalability
- API: cKIncrement, cKDecrement, **cKParallel**
- Split into blocks in order to retain ILP



Vertical parallelization

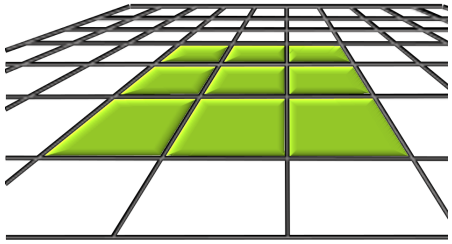


Caching

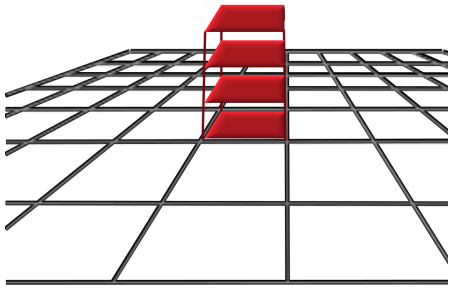
- Trend from **compute-centric** to **data-centric** programming models
- Many GPU programming models explicitly expose memory hierarchy to user
- **STELLA eases this burden** with high-level constructs (temporaries, caches, …)

NEW

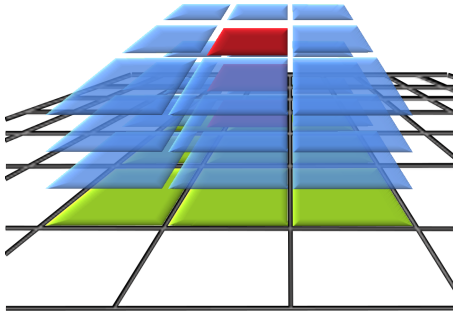
IJCache
(shared memory)



KCache
(registers)



IJKCache
(shared memory)



IJK-Caching

- Caching on 3D-accesses of temporaries

128x128	no IJKCache	IJKCache
Benchmark	33.3 ms	9.0 ms
FastWavesDivergence	0.089 ms	0.069 ms

- Caching on 3D-accesses of input fields

128x128	**no IJKCache**	**IJKCache**
5x5x3 benchmark		
time	24.4 ms	10 ms
n regs	52	34
occupancy	49%	64%
AdvectionPD Semilagrangian Interpolate (Dycore)		
time	300 ms	70 ms

- Side effect: Caching on 2D accesses of input fields

128x128	**no IJKCache (ms)**	**IJKCache (ms)**
AdvectionPDBottY	0.15	0.14
AdvectionPDBottX	0.077	0.044
HorizontalAdvectionPPTP	0.039	0.024

Python interface

- Interface

```
~:> ipython
In [1]: from stella import Dycore
In [2]: from stella.stencil import Coriolis
```

- Help

```
In [11]: Coriolis?
Type:        builtin_function_or_method
String form: <built-in function fromfile>
Docstring: Coriolis (in_u, in_v, in_fc, out_utens, out_vtens)
Applies the Coriolis stencil using the given force over the input data
fields, generating two independent output fields.
Parameters:
in_u  : input data field;
in_v  : input data field;
in_fc : a scalar representing the force applied;
...
```

- Stencil execution (NumPy compatible)

```
In [12]: d = Dycore ( )
In [13]: d._init ( (42, 27, 60) )
In [14]: v = np.random.rand (48, 33, 60)
In [15]: d.add_external_storage ('v_nnow', v)
In [16]: d._allocate_data_fields ( )
In [17]: c = Coriolis (d)
In [18]: c.do ( )
```

Python interface

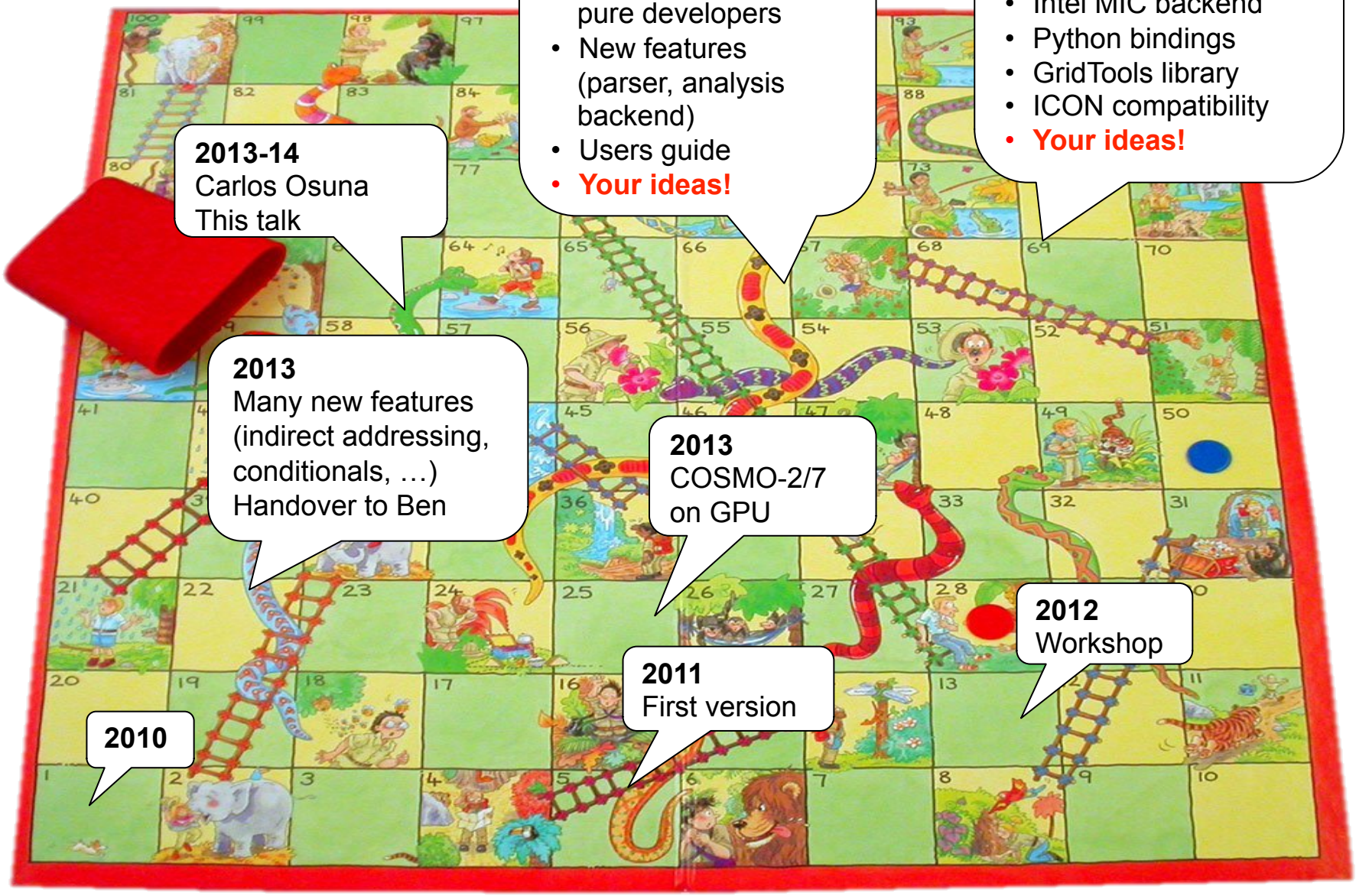
- Serialization

```
Serializer ser; ser.Init (...);
IJKRealField u; u.Init (...);
SavePoint sp; sp.Init (...);
serializer.SaveToNumPy (u, sp, "u");
```

- Next step: defining stencils (JIT)

```
# --- DEFINITION of the Coriolis stencil object
class CoriolisKernel (StencilKernel):
    """Class definition of the Coriolis stencil.-"""
    def __init__ (self, utens, vtens):
        super.__init__ (self)
        # output fields
        self.utens = utens
        self.vtens = vtens
    def _USlowTensStage (self, ctr, in_v, in_fc):
        """The 'Do' function of the U stage.-"""
        return ( in_fc * np.average ((in_v, in_v[1, 0])) +
                 in_fc * np.average ((in_v[0, -1], in_v[1, -1])) ) / 2.0
    def _VSlowTensStage (self, ctr, in_u, in_fc):
        """The 'Do' function of the V stage.-"""
        return ( in_fc * np.average (in_u[0, 0], in_u[0, 1]) +
                 in_fc * np.average (in_u[-1, 0], in_u[-1, 1]) ) / 2.0
    def kernel (self, in_u, in_v, in_fc):
        """This stencil comprises two independent stages.-"""
        for p in out_utens.interior_points (sweep='cKIncrement'):
            self.out_utens[p] += self._USlowTensStage (p, in_v, in_fc)
        for p in out_vtens.interior_points (sweep='cKIncrement'):
            self.out_vtens[p] -= self._VSlowTensStage (p, in_u, in_fc)
# --- USAGE of the Coriolis stencil object
kernel = CoriolisKernel (utens, vtens)
kernel.compilation.should_unroll = False
kernel.compilation.backend       = 'cxx'
kernel.kernel (u, v, 3.5)
```

Roadmap


2014-15
• Official version (5.2)
• Improvements for pure developers
• New features (parser, analysis backend)
• Users guide
• Your ideas!
2015-16
• Operational @ MCH
• New features
• Intel MIC backend
• Python bindings
• GridTools library
• ICON compatibility
• Your ideas!
2013-14
Carlos Osuna
This talk
2013
Many new features (indirect addressing, conditionals, …)
Handover to Ben
2013
COSMO-2/7 on GPU
2012
Workshop
2011
First version
2010

Publications

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An International Journal

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STELLA & GCL: Domain-specific tools for structured grid methods

Tobias Gysi*†, Oliver Fuhrer‡, Carlos Osuna§, Mauro Bianco¶, and Thomas C. Schulthess¶‖**

Conclusions

- Several improvements (usability, performance) in STELLA
- Improvements were all user driven
  → If you give us constructive feedback what is missing or hard, we'll work for you!
- Roadmap for the near and far future
  - STELLA will continue to improve
  - Funding secured (GridTools, Python, MIC, …)
  - More proposals pending

  → Collaboration is highly welcome (e.g. ICON)

Thank you!