Workshop on

Domain-Specific Languages for Performance-Portable Weather and Climate Models

Content: Advanced Concepts II
(Decorations, regional computation, and the future of GT4Py)

Presenter: Johann Dahm

Learning goals for this session

- Understand the power of the syntax `@gtscript.stencil`
- How to restrict/specialize computation on portions of the IJ axes
- Future design of the toolchain: Storages, horizontal reductions, etc.

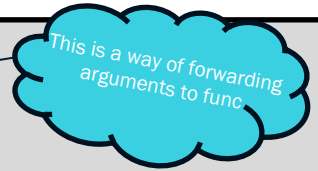
What does @gtscript.stencil actually do?

Python Decorators

A decorator is a function that accepts and returns a function.

```
import time
def timeit(func):
    def wrapper(*args, **kwargs):
        start = time.perf_counter()
        func(*args, **kwargs)
        print("Time: " + str(time.perf_counter() - start))
    return wrapper

@timeit
def say_whee():
    time.sleep(0.5)
    print("Whee!")
```




```
>>> say_whee()
```

What is output when say_whee is executed?

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    return wrapper

@timeit
def say_whee():
    time.sleep(0.5)
    print("Whee!")
```

```
>>> say_whee()
Whee!
Time: 0.5012413430013112
```

This is the normal syntax for decorators

Python Decorators

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        print("Time: " + str(time.perf_counter() - start))
    return wrapper

def say_whee():
    time.sleep(0.5)
    print("Whee!")
say_whee = timeit(say_whee)
```
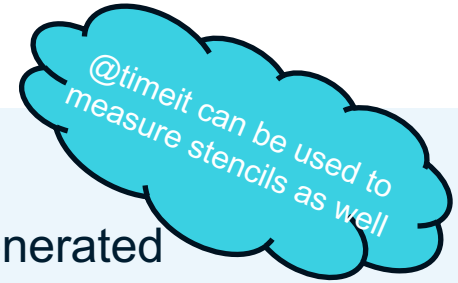

Since decorators are just functions, they can be called in this way as well with the same effect

How does this relate to GT4Py?



`@gtscript.stencil` returns an entirely new function of generated code instead of a wrapper as `@timeit` does. It:

1. Analyzes the source code from the decorated function
2. Lowers through a series of intermediate representations
3. Generates optimized source code in some language (and if need be, compiles it)
4. Wraps the optimized version in a python function and returns it

Regional Computation

Porting Conditionals?

```
389
390   do j=js-1,jep1
391   do i=is-1,iep1
392   if ( ua(i,j) > 0. ) then
393       if ( i==1 ) then
394           ke(1,j) = uc(1,  j)*sin_sg(1,j,1)+v(1,j)*cos_sg(1,j,1)
395       elseif ( i==npx  ) then
396           ke(i,j) = uc(npx,j)*sin_sg(npx,j,1)+v(npx,j)*cos_sg(npx,j,1)
397       else
398           ke(i,j) = uc(i,j)
399       endif
400   else
401       if ( i==0   ) then
402           ke(0,j) = uc(1,  j)*sin_sg(0,j,3)+v(1,j)*cos_sg(0,j,3)
403       elseif ( i==(npx-1)   ) then
404           ke(i,j) = uc(npx,j)*sin_sg(npx-1,j,3)+v(npx,j)*cos_sg(npx-1,j,3)
405       else
406           ke(i,j) = uc(i+1,j)
407       endif
408   endif
409   enddo
410   enddo
```

Conditionals on the iteration position cannot be expressed based on gtscript introduced so far…

Review of the GridTools Parallel Model

Stencils iterate sequentially over ***computations*** in the order they appear in the code

A computation is composed of ***vertical intervals*** that are executed sequentially in the order defined by the ***iteration policy*** of the computation

A vertical interval is executed as a sequential for-loop over the K-range, following the order defined in the iteration policy

Vertical intervals are composed of ***statements***, with ***horizontal extents*** determined automatically

- Parallel model (left) iterates a single statement over the entire horizontal plane
- There are cases where special computation needs to happen on points of the domain
  - BCs
  - Corner cases on multiblock meshes
  - …

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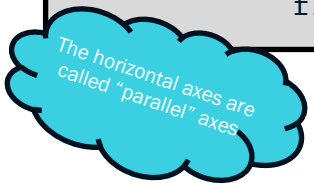
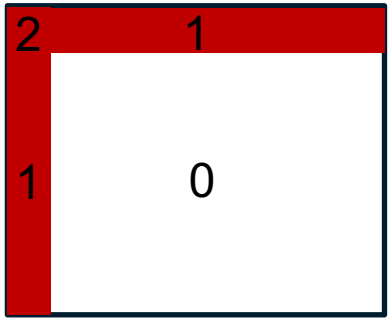
New Feature: Statements can now be restricted to a portion of the ***extended*** IJ plane

Frontend Feature

Simple stencil to set an inout field to the following values

```
@gtscript.stencil(…)
def set_field(field: Field[float]):
    with computation(PARALLEL), interval(…):
        field = 0.
        with parallel(region[I[0]:I[2], :],
                      region[:, I[-2]:]):
            field = 1.
        with parallel(region[:I[2], I[-2]:]):
            field = 2.
```





Wrap statements in `with parallel(…)` to restrict to portion(s) of the IJ axes

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```

The indices used in these slices are relative to the start or end of the ***stencil compute domain***

Each argument to `parallel(…)` is a ***region***, which is like a 2D array using numpy slice notation

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```

Statements are still executed in order, so the order matters to get the the corner value correct

Axis Offsets

New ***Axis Offset*** syntax subscripts the axes I, J, K inside the compute domain with wrap-around:

- `region[I[0], :]`: first I-axis point in compute domain (west edge)
- `region[I[-1], :]`: last I-axis point in the compute domain (east edge)

To access points in the ***extended compute domain*** for a statement, offset these:

- `region[I[0]-1, :]`: point in extended compute domain (if needed)
- `region[I[-1]+1, :]`: point in extended compute domain (if needed)

The region will only exist in generated code if

1. It sets a field value in the compute domain
2. It sets a temporary value that is consumed in the stencil domain (via offset)

Back to the Example…

Scenario: we want to fill a halo value on the east side, then consume it by using that field with an offset…

```
@gtscript.stencil(…)
def set_field(in_field: Field[float], out_field: Field[float]):
    with computation(PARALLEL), interval(…):
        with parallel(region[I[-1] + 1, :]):
            in_field = 0.5 * (in_field[-1, 0, 0] + in_field[-2, 0, 0])
        out_field = in_field[1, 0, 0]
```

The value is consumed here, so gt4py generates code for the region

Domain Decomposition & Distributed Memory

Regional computations can also be used to enable domain decomposition in GT4Py

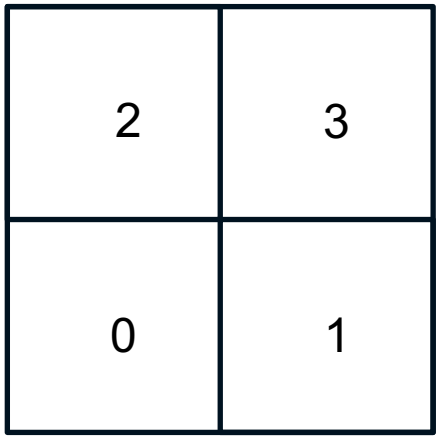
Axis Offsets like `I[0]` can be named externals, such as `istart`

Ranks may have a different value for these externals – leading to different code!

If `istart is None`, then regions using this external are automatically removed from the generated code

- `istart = I[0] if rank % 2 else None`
- `jstart = J[0] if rank < 2 else None`
- …

Domain distributed over 4 ranks



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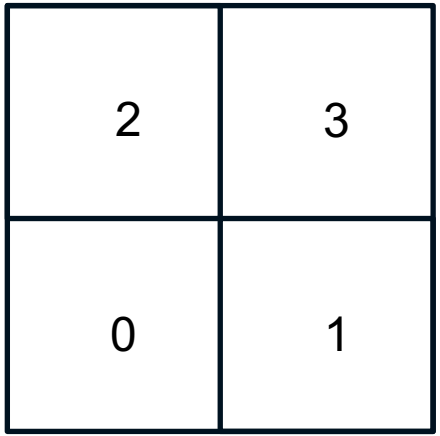



```
def stencil(…):
    from __externals__ import istart
    with computation(PARALLEL), interval(…):
        with parallel(region[istart, :]):
            field = 0.
```

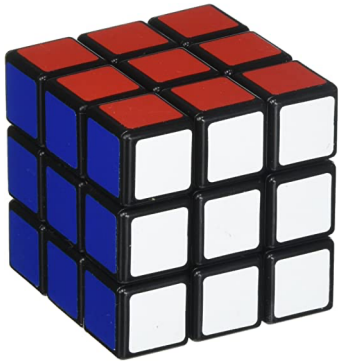
Applied to the Example...

```
iend = I[-1] if proc % 2 == 1 else None
@gtscript.stencil(…)
def set_field(in_field: Field[float], out_field: Field[float]):
    from __externals__ import iend
    with computation(PARALLEL), interval(…):
        with parallel(region[iend + 1, :]):
            in_field = 0.5 * (in_field[-1, 0, 0] + in_field[-2, 0, 0])
        out_field = in_field[1, 0, 0]
```

Can offset the Axis Offset in the region slices

FV3 Application: Corner Computation

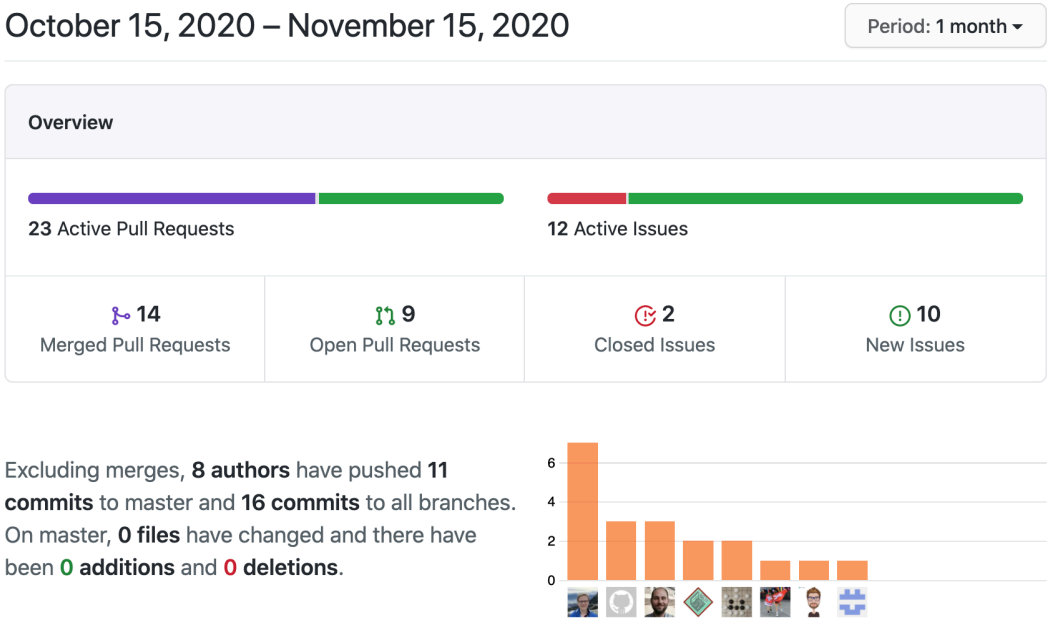
- Finite difference operators must be specialized at the corners of the cubed sphere tiles, since the values do not really exist
- The hands-on tutorial will walk you though an example that applies the bi-Laplacian operator in a cubed sphere context, where special computation happens at the corners



Which concepts / motifs that are missing in GT4Py?

GT4Py: Stable, yet Active Project

- Formal GDP-based process to introduce new features
- Everyday focus on improving testing and error messages



GT4Py Upcoming Features

Recent workshop identified the following items:

- Storages are being replaced by a framework independent of numpy, allowing for cupy, xarray, etc. to be tightly integrated
- Frontend feature to to explicitly obtain the I, J, K positions
- Enable compact access syntax compatible with lower-dimensional storages
  - `field[0, 0, 1] = field[K+1]`
  - `field[1, 1, 0] = field[I+1,J+1]`
- Further reduce the overhead of calling a python stencil
- Simple optimization passes to compute redundant code to remove memory reads

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GT4Py Future Extensions and Features

We know there are other motifs that may not map directly to stencils that also need to be fast

- Horizontal reductions on fields
- …

We need your help to identify these. GT4Py can only be great if we all work together to bring ideas from the science domain to the DSL!

Questions?

Hands-on Session

Now it's your turn!

`Session-2B.ipynb` to work on

- Writing an efficient transient diffusion code (§1)
- Exploring corner computation (§2)
- Experimenting with decorators (§3)

See you on Slack! **Next huddle at 4:30pm EST**