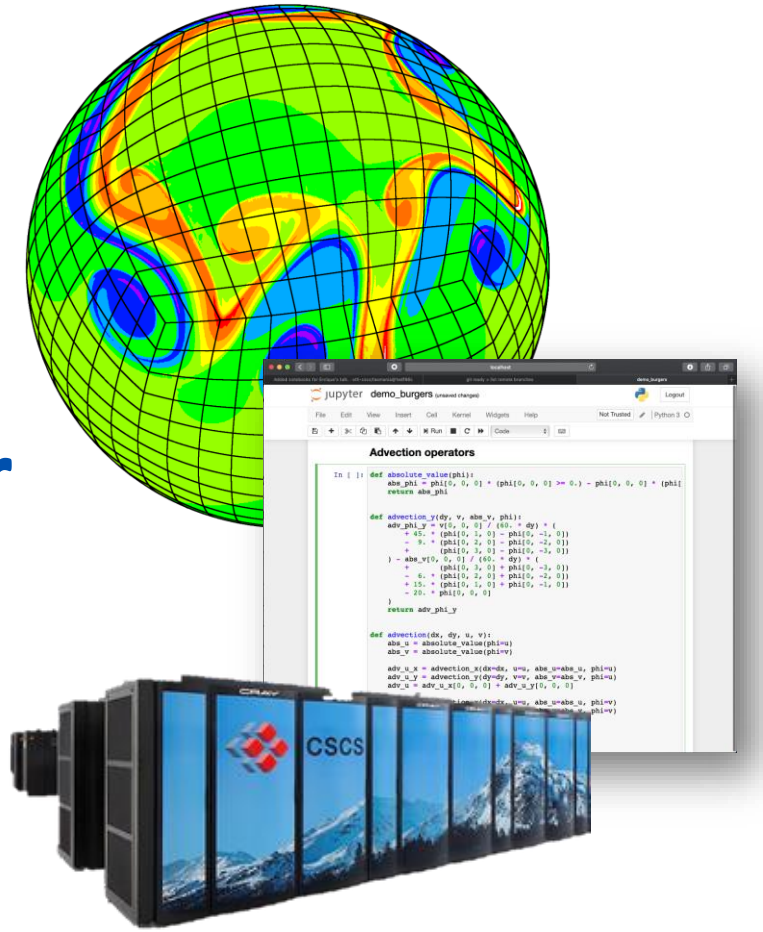
High Performance Computing for Weather and Climate (HPC4WC)

Content: Pace: A model in Python
Lecturer: Tobias Wicky
Block course 701-1270-00L
Summer 2022



Learning Goal

- See the DSL approach in action
- See some of the concepts we've learned applied in a real code

Who are we?

Oliver Fuhrer

Johann Dahm

Florian Deconinck

Oliver Elbert

Jeremy McGibbon

Tobias Wicky

Elynn Wu

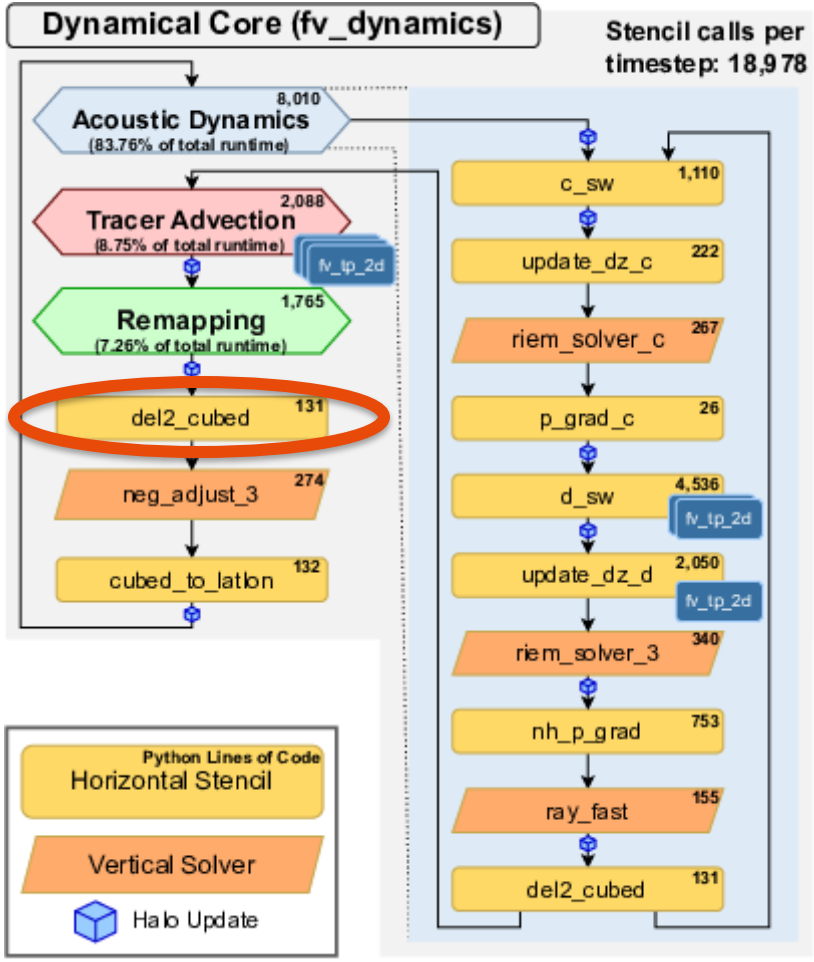
Collaborators

Pace: Python based FV3

GFDL Finite-Volume Cubed-Sphere Dynamical Core (FV3)

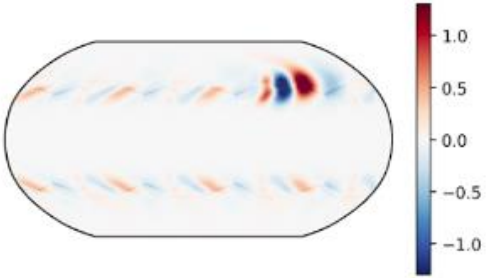
Finite volume transport on a cubed sphere grid

- Integrated into several models, including
  - Operational weather models (Global Forecast System)
  - Next Generation Global Prediction System

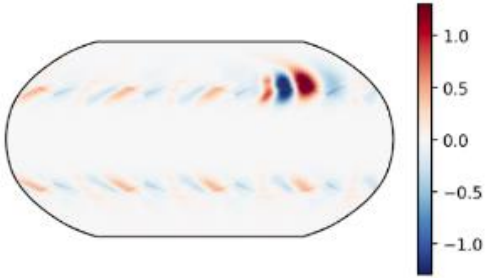


Validation

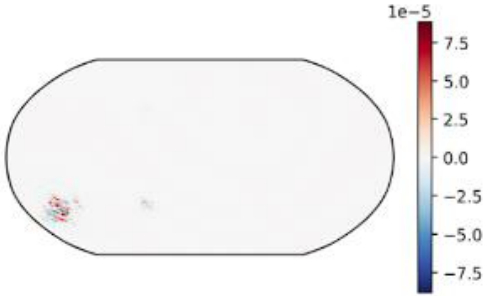
Fortran



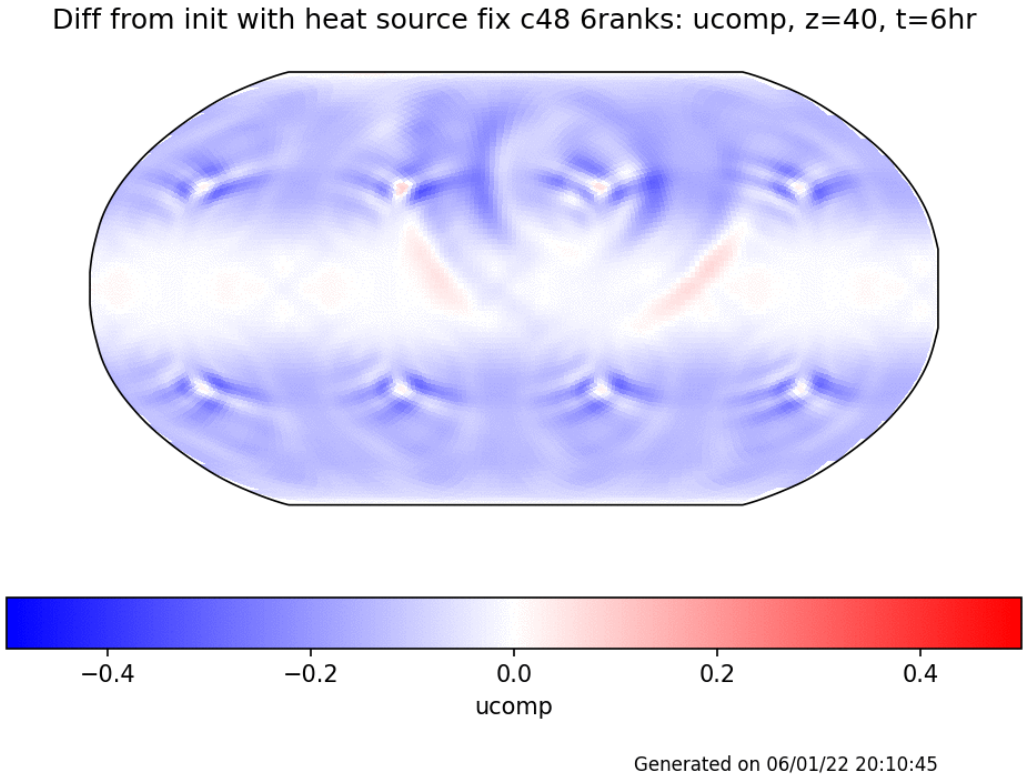
GT4Py



Difference



Validation


Diff from init with heat source fix c48 6ranks: ucomp, z=40, t=6hr
−0.4
−0.2
0.0
0.2
0.4
ucomp
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Physical Parametrizations

	Microphysics	PBL & Turbulence	Sea-Ice	Shallow Convection	LSM	Radiation
Authors	 Mikael	 Chris Kung (NASA)	 Vera  Nadja  Nicolai	 Mikael  Chenwei  Langwen	 Safira	 Andrew
Scheme	**GFDL Cloud Microphysics Scheme**	GFS scale-aware EDMF PBL and Free Atmospheric Turbulence Scheme	GFS Sea Ice Scheme	GFS SAS-based Mass-Flux Scheme for Shallow convection	GFS Noah Land Surface Model	GFS RRTMG

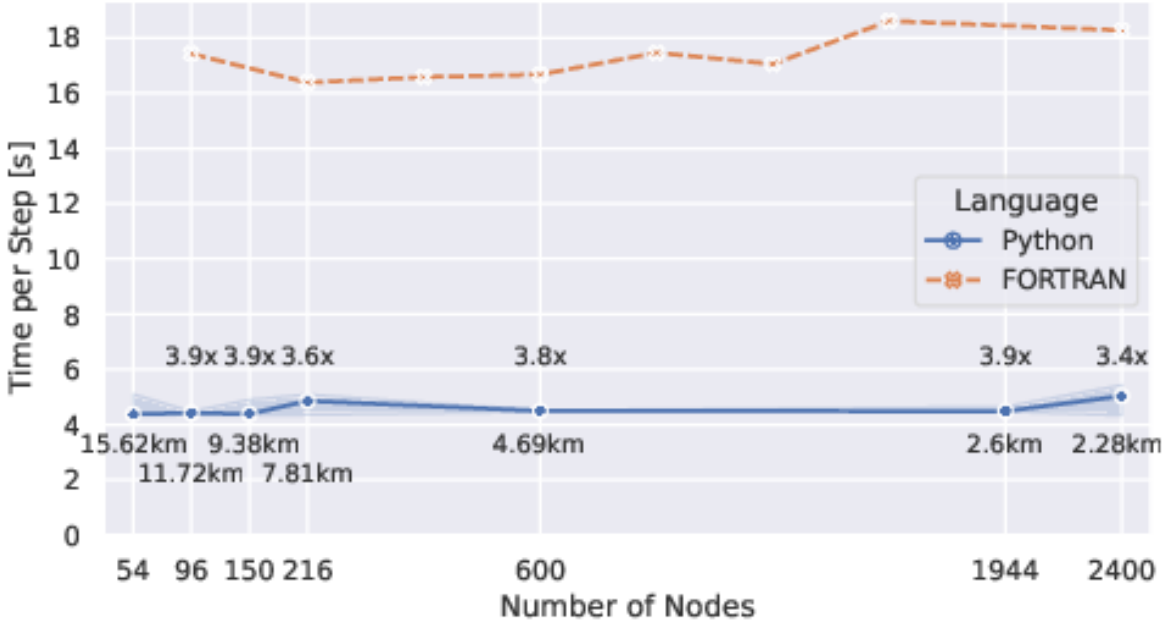
The Pace Model

Full program optimization

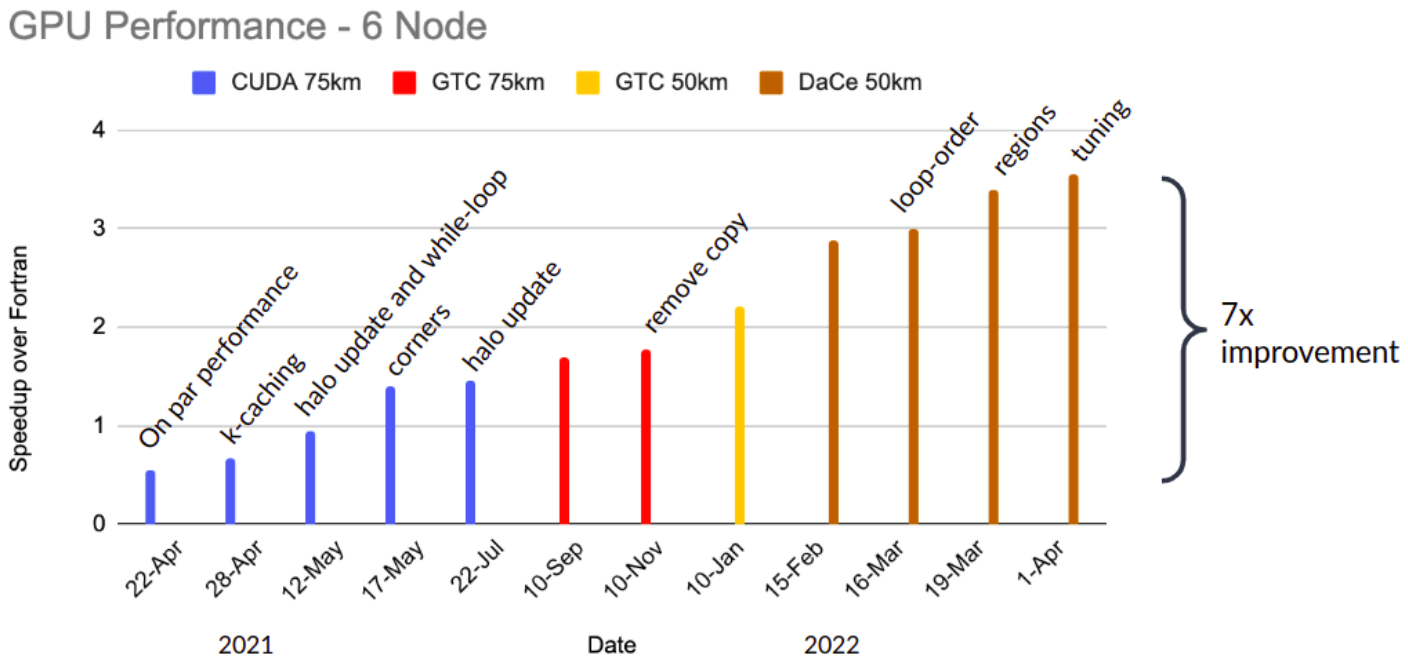
DSL coverage of all main numerical computation

Custom code for halo updates

New DSL concepts for FV3-specific motifs



The Pace Model



Why did you torture us for 4 days?

DSL still uses these concepts under the hood

```python
def visit_Stencil(self, node: oir.Stencil, **kwargs: Any) -> oir.Stencil:
    write_before_read_tmps = {
        symbol
        for symbol, value in kwargs["symtable"].items()
        if isinstance(value, oir.Temporary)
    }
    horizontal_executions = node.iter_tree().if_isinstance(oir.HorizontalExecution)

    for horizontal_execution in horizontal_executions:
        accesses = AccessCollector.apply(horizontal_execution)
        offsets = accesses.offsets()
        ordered_accesses = accesses.ordered_accesses()

        def write_before_read(tmp: str) -> bool:
            if tmp not in offsets:
                return True
            if offsets[tmp] != {(0, 0, 0)}:
                return False
            return next(
                o.is_write and o.horizontal_mask is None
                for o in ordered_accesses
                if o.field == tmp
            )

        write_before_read_tmps = {
            tmp for tmp in write_before_read_tmps if write_before_read(tmp)
        }

    return super().visit_Stencil(node, tmps_to_replace=write_before_read_tmps, **kwargs)
```

Why did you torture us for 4 days?

There are things that we still need to do manually:

E.g. Halo updates

```
        )

    # Post recv MPI order
    with self._timer.clock("Irecv"):
        self._recv_requests = []
        for to_rank, transformer in self._transformers.items():
            self._recv_requests.append(
                self._comm.comm.Irecv(
                    transformer.get_unpack_buffer().array,
                    source=to_rank,
                    tag=self._tag,
                )
            )

    # Pack quantities halo points data into buffers      FlorianDeco
    with self._timer.clock("pack"):
        for transformer in self._transformers.values():
            transformer.async_pack(quantities_x, quantities_y)
```

What does Python bring us?

```
class Physics:
...
prepare_microphysics(physics_state)
microph_state = physics_state.microphysics
microphysics(microph_state)
```

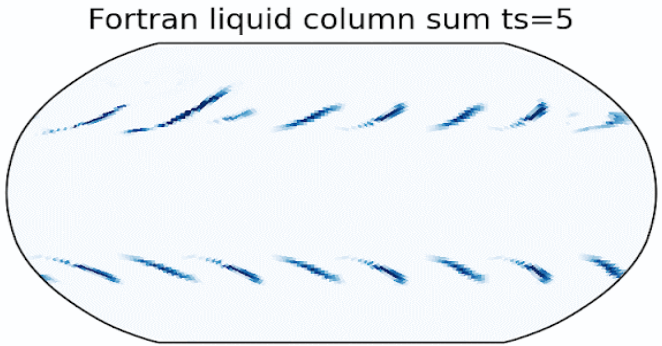
GT4Py stencil-based

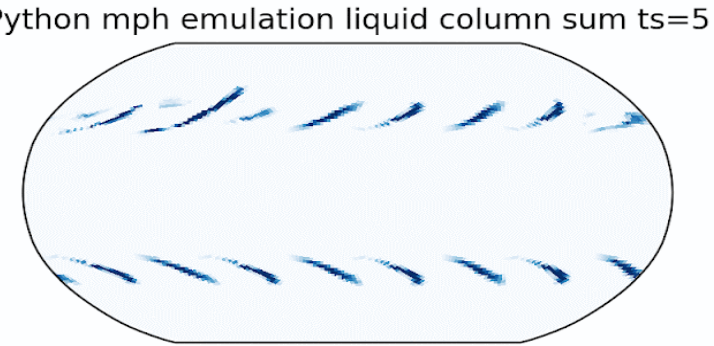
```
emulation_model = tf.keras.models.load_model("model.tf")
```

ML-based microphysics

```
emulation_dict = prepare_emulation_data(physics_state.microphysics)
predictions = emulation_model(emulation_dict)
model_outputs = unpack_predictions(predictions, emulation_model.output_names, …)
```

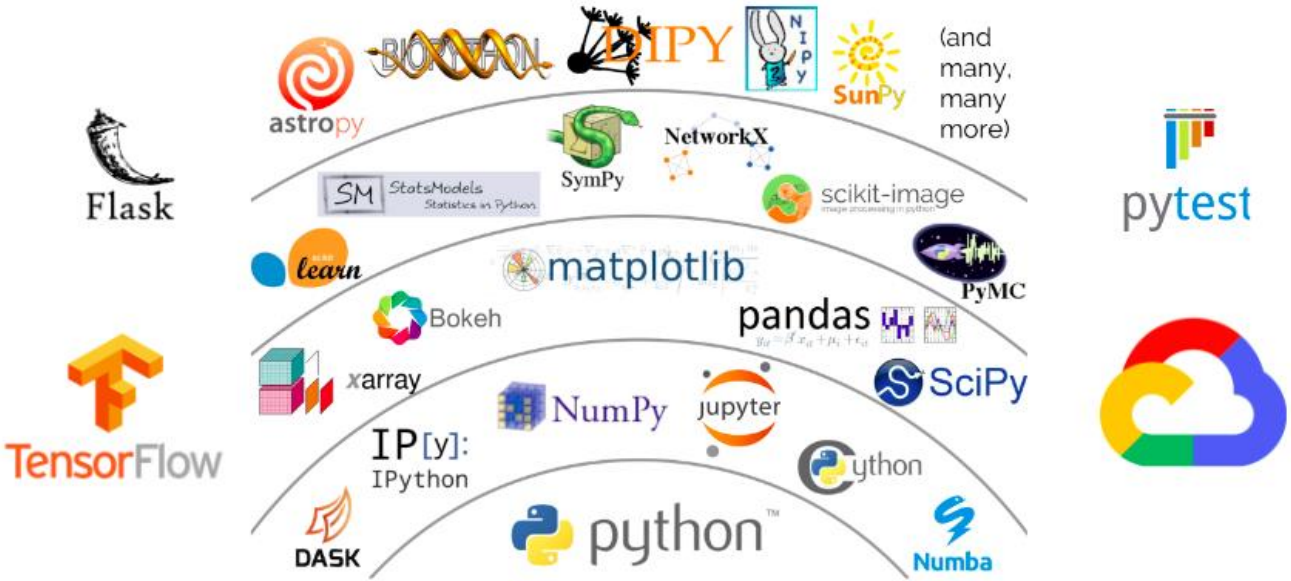
ML-based Microphysics





Why else is Python awesome?

The rich python ecosystem is valuable – new options for development



Credit: Jake VanderPlas, "The Unexpected Effectiveness of Python in Science", PyCon 2017

Why else is Python awesome?

Testing is WAY easier!

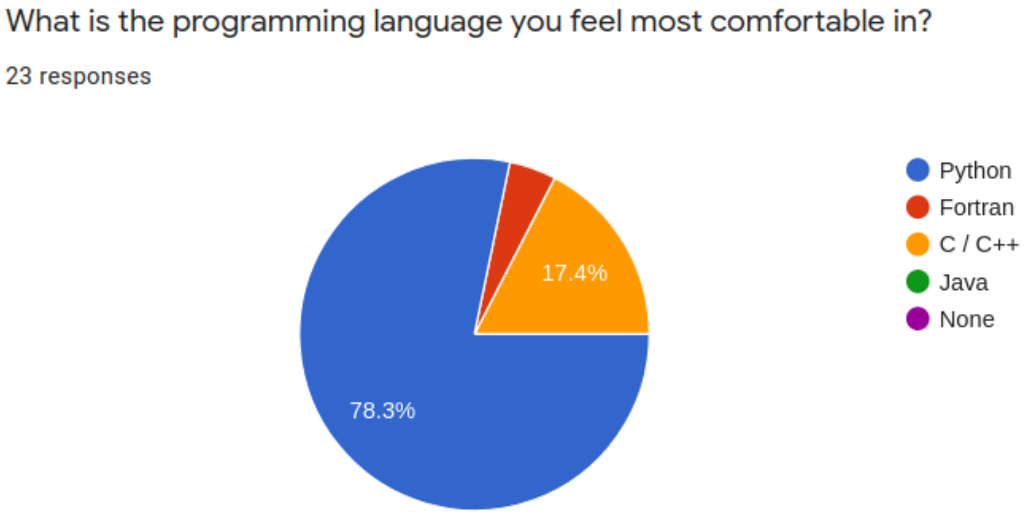
```python
def test_temporaries_are_deterministic():
    """
    This is a precursor test to the next one, ensuring that two
    identically-initialized dycores called on identically-initialized
    states produce identical temporaries.

    This will fail if there is non-determinism in the initialization,
    for example from using `empty` instead of `zeros` to initialize data.
    """
    dycore1, state1, timer1 = setup_dycore()
    dycore2, state2, timer2 = setup_dycore()

    dycore1.step_dynamics(state1, timer1)
    first_temporaries = copy_temporaries(dycore1, max_depth=10)
    assert len(first_temporaries) > 0
    dycore2.step_dynamics(state2, timer2)
    second_temporaries = copy_temporaries(dycore2, max_depth=10)
    assert_same_temporaries(second_temporaries, first_temporaries)
```

Why else is Python awesome?

You!



Are we seeing what DSLs promise?

Overarching Goals (The 3 P's)

- **Productivity**
  Easy to implement.
  Easy to **read**.
  Easy to **maintain**.
- **Performance**
  Is **fast**.
- **Portability**
  Single **hardware-agnostic** application code.
  Runs efficiently on **different hardware** targets.

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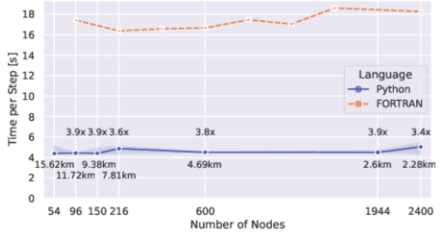

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```yaml
stencil_config:
  backend: numpy
  rebuild: false
  validate_args: true
  format_source: false
  device_sync: true
initialization:
  type: baroclinic
performance_config:
  performance_mode: false
  experiment_name: c12_baroclinic
comm_config:
  type: read
  config:
    path: comm
    rank: 0
nx_tile: 12
```