DevitoCodes

Imperial College London

AUTOMATIC CODE GENERATION FOR GPUs USING DEVITO

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RICE O&G HPC 2020

bp dug Microsoft

Talk outline

- Motivation - why do we care?
- Who or what is Devito?
- GPU support - without the excruciating pain
- Roadmap
- Closing remarks
- Acknowledgements

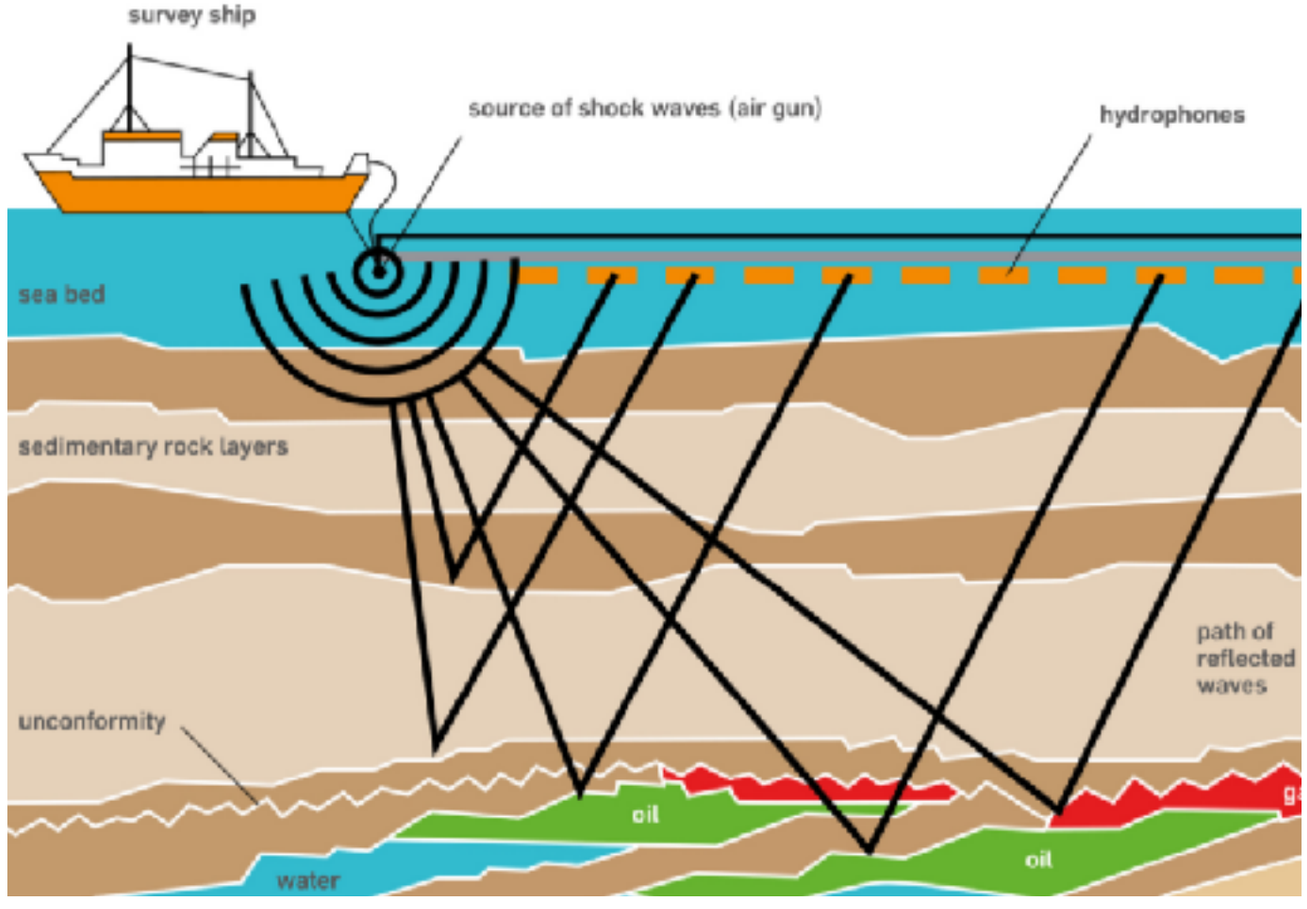
Motivation

- Seismic imaging:
  - FWI, RTM, LS-RTM, TTI, elastic, visco-elastic propagators, etc.
  - Some of the most computational expensive and algorithmically complex workloads found in industry.

- Reducing the cost of modernizing software for exascale and Cloud.

- Skills/knowledge gap between geophysicists, data scientists and HPC developers.

- **Do researchers/developers have the tools that they need to develop next-generation AI/ML technologies?**

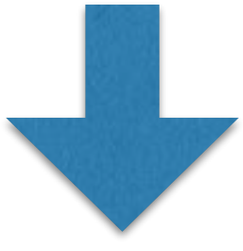


http://www.open.edu/openlearn/science-–maths-–technology/science/environmental-–science/earths-–physical-–resources-–petroleum/content-–section-–3.2.1

Who or what is Devito?

Traditional approach

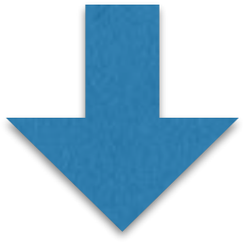
$$m\frac{\partial^2 u}{\partial t^2} + \eta\frac{\partial u}{\partial t} - \Delta u = 0$$



```
void kernel(…) {
  …
  <impenetrable code with aggressive
performance optimizations written
by rockstars, gurus, ninjas,
unicorns and celestial beings>
  …
}
```

Raising the level of abstraction

$$m\frac{\partial^2 u}{\partial t^2} + \eta\frac{\partial u}{\partial t} - \Delta u = 0$$



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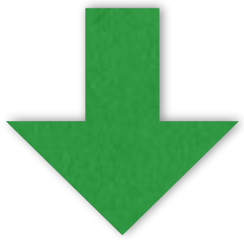

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Raising the level of abstraction

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Devito

```
eqn = m * u.dt2 + eta * u.dt - u.laplace
```

```
void kernel(…) { … }
```

Devito: a DSL and compiler for explicit finite differences

- **Python** package — easy to learn (and no, this does not mean it runs slow)
- **Devito is a compiler** that generates optimized parallel code:
  - C, SIMD, OpenMP, OpenMP 5 offloading, MPI (soon OpenACC)
  - x86 (including Xeon Phi series), **GPUs** , ARM64, Power8/9
- **Composability: integrate with existing codes and AI/ML**
  - Integrate with existing codes in other languages
  - Works out-of-the-box with other popular packages from the Python ecosystem (e.g. PyTorch, NumPy, Dask, TensorFlow)
- **Open source platform** – MIT license.
- **Best practises software engineering:** extensive software testing, code verification, CI/CD, documentation, tutorials and PR code review.
- **Cloud ready** - Wednesdays hands-on workshop+hackathon running on Azure.

Growing open source and commercial community

- Started in 2016 … just released **Devito v4.1**:
  - Core compiler is 17k lines of code, 8k lines of comments for developers
  - 9k lines of unit and regression tests used in CI/CD (ie automated testing)
  - ~40 Jupyter tutorials and examples - included in CI/CD
  - 32 contributors to the code base, 7 people in the core team.

- Users:
  - Several companies financially support the open source Devito consortium. Announced: BP, DUG, Microsoft, Shell (more are welcome!)
  - Worked with DUG to bring Devito from research to production grade.
  - 272 people on our open Slack workspace from 90+ different companies and research institutions.

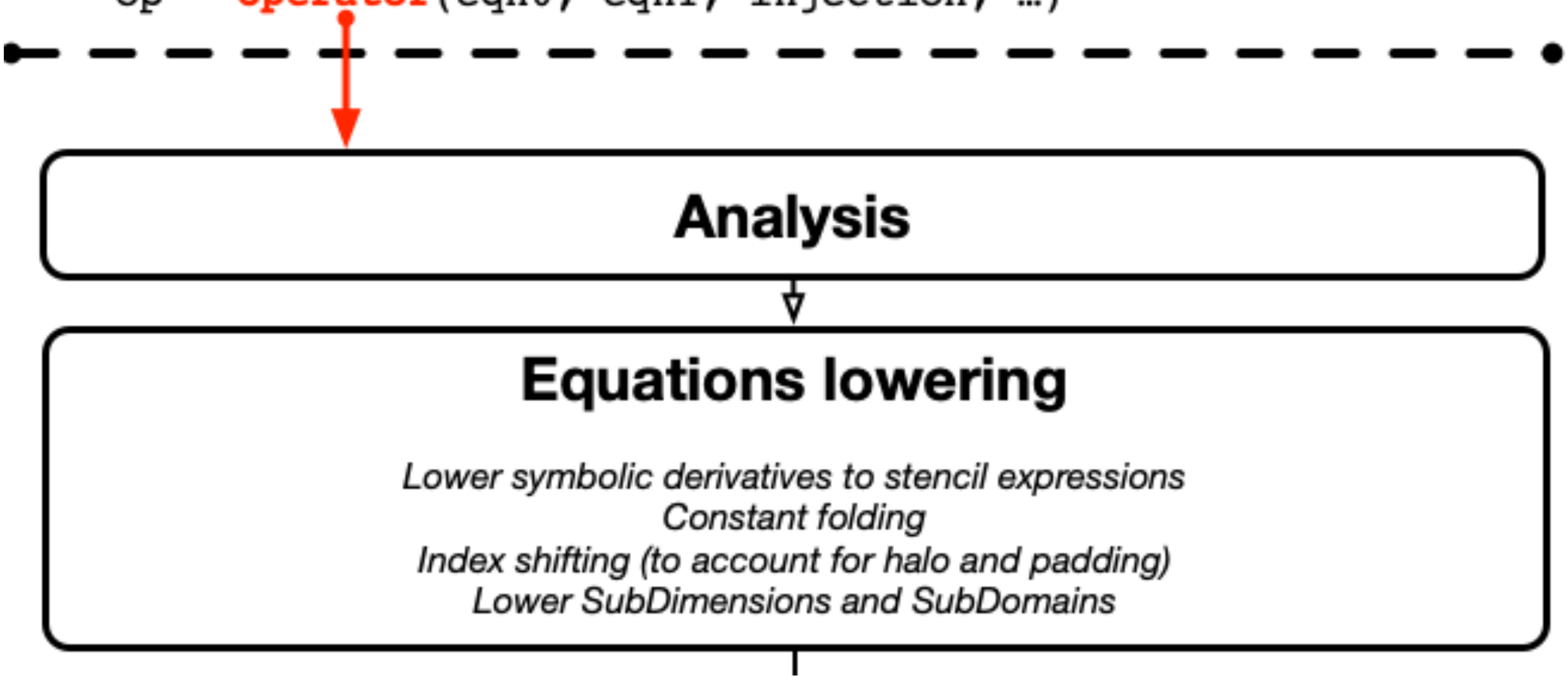
GPU support - without the excruciating pain

```
grid = Grid(shape=…)

u = TimeFunction(name='u', grid=grid)
m = Function(name='m', grid=grid)
src = SparseFunction(name='src', grid=grid, npoints=…)

eqn0 = m * u.dt2 - u.laplace
eqn1 = …
injection = src.inject(field=u.forward, expr=src*s*s**2/m)

op = Operator(eqn0, eqn1, injection, …)
```



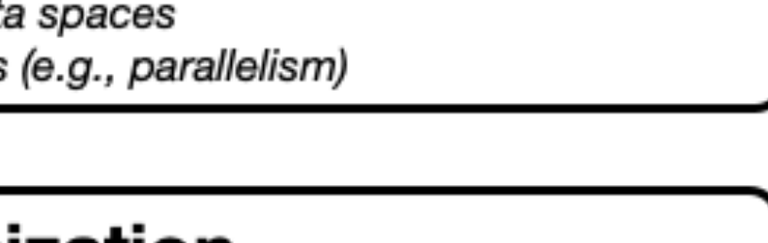
Clustering

Group equations into "Clusters", based on data dependencies
Derive iteration and data spaces
Detect computational properties (e.g., parallelism)

Clusters Optimization

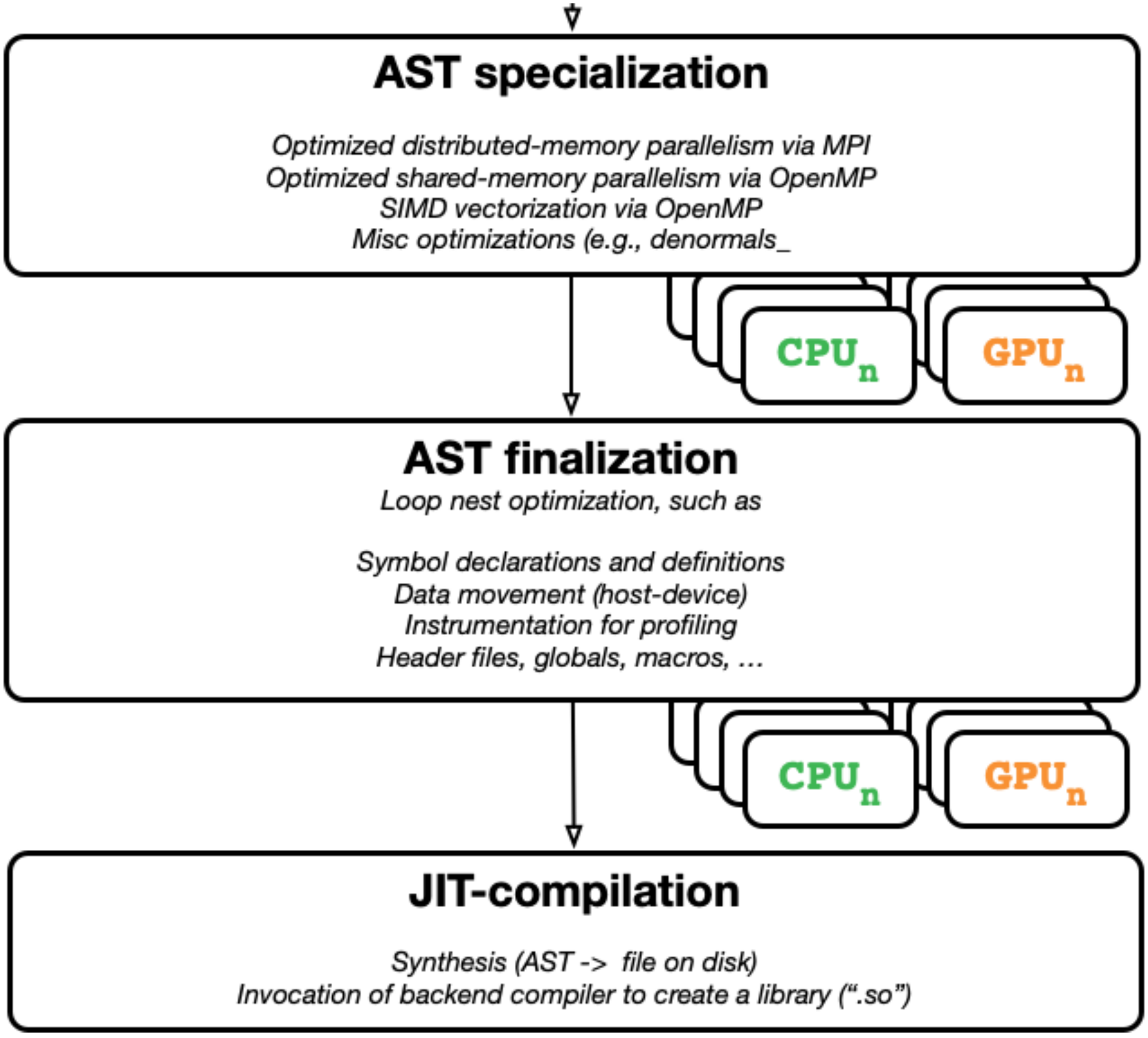
Symbolic (flop-reducing) transformations:
Common sub-expressions elimination
Aliases detection and precomputation
Factorization
Code motion
...

Optimizations for data locality and parallelism:
Fusion
Fission
Blocking



Tree-fication

Turn an ordered list of Clusters into an Abstract Syntax Tree (AST)


AST specialization
Optimized distributed-memory parallelism via MPI
Optimized shared-memory parallelism via OpenMP
SIMD vectorization via OpenMP
Misc optimizations (e.g., denormals_
CPUn
GPUn
AST finalization
Loop nest optimization, such as
Symbol declarations and definitions
Data movement (host-device)
Instrumentation for profiling
Header files, globals, macros, …
CPUn
GPUn
JIT-compilation
Synthesis (AST -> file on disk)
Invocation of backend compiler to create a library (“.so”)

Generated code

https://github.com/devitocodes/devito/blob/master/examples/gpu/01_diffusion_with_openmp_offloading.ipynb

```
…
#pragma omp target enter data map(to: u[0:u_vec->size[0]][0:u_vec->size[1]][0:u_vec->size[2]])
for (int time = time_m; time <= time_M; time += 1)
{
  …
  #pragma omp target teams distribute parallel for collapse(2)
  for (int x = x_m; x <= x_M; x += 1)
  {
    for (int y = y_m; y <= y_M; y += 1)
    {
      <stencil update for the 2D diffusion equation>
    }
  }
  …
}
#pragma omp target update from(u[0:u_vec->size[0]][0:u_vec->size[1]][0:u_vec->size[2]])
#pragma omp target exit data map(release: u[0:u_vec->size[0]][0:u_vec->size[1]][0:u_vec->size[2]])
…
```

Through sophisticated data dependence analysis, the Devito compiler knows:

- where to insert the OpenMP pragmas for host-device data movement
- what the parallel and reduction loops are, so it knows where to insert the OpenMP pragmas for parallelism and synchronization

Current performance on GPUs

- Devito v4.1 - https://github.com/devitocodes/devito/releases/tag/v4.1
- GPU offloading via OpenMP 5
- NVidia V100
- *Propagator performance* (includes BCs/sources/receivers/…)
- **No performance optimizations yet (join us on Wednesday!)**

	OI (Flops/Bytes)	GFlops/s	attainable peak	FD-GPoints/s
iso-acoustic (12th order, 512^3 points)	**3.74**	**600**	**18%**	**8.80**
TTI (12th order, 350^3 points)	**3.64** *(thanks to symbolic optimizations)*	**387**	**11%**	**1.15**

MPI support — so far, only for CPUs

```
mpirun <mpi args> python app.py
```

No changes to user code required!

GPU support roadmap

- JIT-backdoor to engage HPC/GPU developers directly in Devito development
- MPI support for domain decomposition across multiple devices
  - UCX proposed as an alternative
- Strategies for checkpointing (optimal strategies, lossy compression)
- OpenACC backend (started last week; PR at Wednesdays hackathon?)
- Performance optimization (shared memory?)
- Other backends (OneAPI, CUDA, …) ?

Conclusions

- Devito is an open-source high-productivity and high-performance Python framework for finite-differences.
- Driven by commercial & research seismic imaging demands:
  - Industrial advisory board == Devito consortium.
- Based on actual compiler technology (not a source-to-source translator!)
- Interdisciplinary, interinstitutional, international open source effort.
- Growing open source community and commercial users
- Gentle request: Many(!) silent/semi-anonymous industry users - open source is still a novel idea in this industry despite clear evidence from tech industry that it is a critical business strategy. Please engage.

Website: http://www.devitoproject.org
GitHub: https://github.com/opesci/devito
Slack: https://opesci-slackin.now.sh

Acknowledgements

- Thanks for our sponsors who are supporting and collaborating on the continued open source development of Devito for the wider community

- Thanks to our many collaborators and contributors, in particular (those in bold are at OGHPC running the workshop on Wednesday)

  - **George Bisbas** (see poster session)
  - **Edward Caunt** (see poster session)
  - **Navjot Kukreja** (ask about AD and compression)
  - Fabio Luporini (lead Devito developer, and GPU support)
  - **Vitor Mickus** (see poster session)
  - **Rhodri Nelson** (ask about PDE's/solvers)
  - SLIM Group: Felix Herrmann, Mathias Louboutin, **Philipp Witte** (talk)

  For a full list of contributors for each release please see https://github.com/devitocodes/devito/releases