# Adaptive and extendable numerical simulations with Trixi.jl

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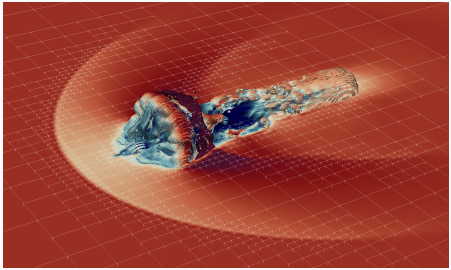


# Main contributors

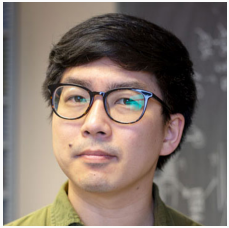
Michael Schlottke-Lakemper

Gregor J. Gassner

Andrew R. Winters

Hendrik Ranocha

Erik Faulhaber



Jesse Chan

# How it got started (in January 2020)

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- FLUXO, a fast, parallel Fortran 3D fluid dynamics code: the race horse

- The one-trick ponies: singular purpose, various languages, discard after use

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The new code should be

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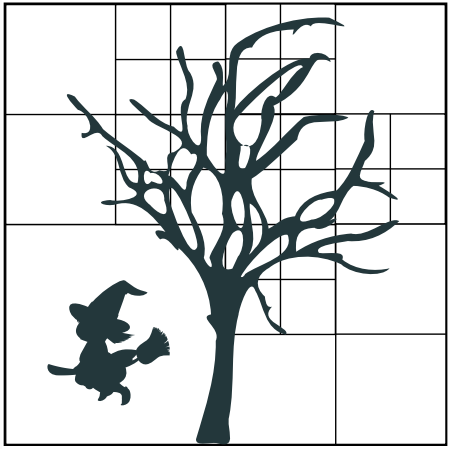
**Is this even achievable with a single code?**

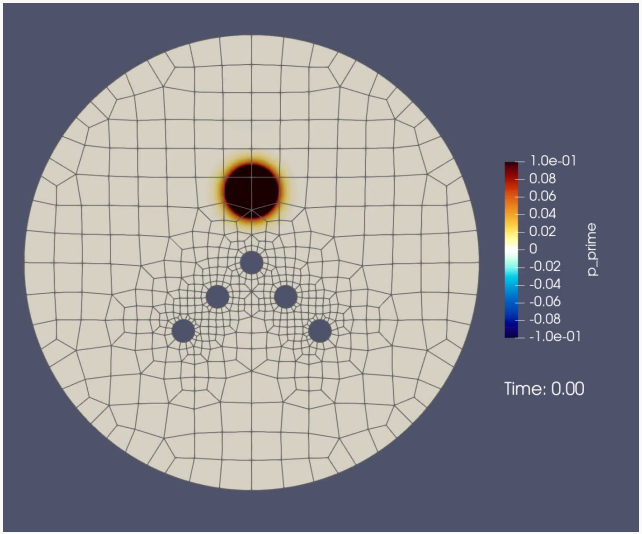
## Trixi.jl

- Adaptive numerical simulation framework for hyperbolic partial differential equations
- 6 core developers, 12 contributors, 30k+ lines
- 18+ students, 2 published papers
- Integration with Julia ecosphere:
  - `OrdinaryDiffEq.jl`: time integration
  - `ForwardDiff.jl`: automatic differentiation
  - `Plots.jl`, `Makie.jl`: plotting
  - `LoopVectorization.jl`: performance
  - `Polyester.jl`: parallelization



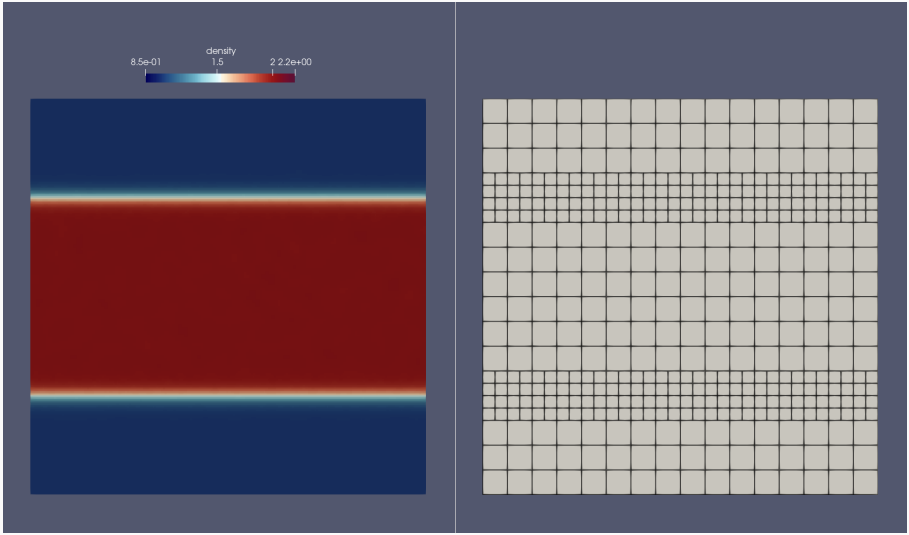
https://github.com/trixi-framework/Trixi.jl

# Acoustic wave scattering on a curved unstructured mesh

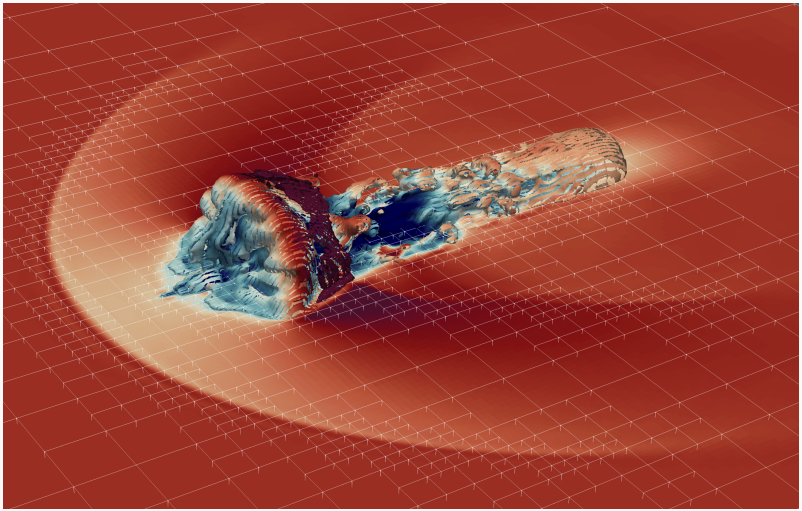



Credit: Andrew R. Winters, Lars Christmann

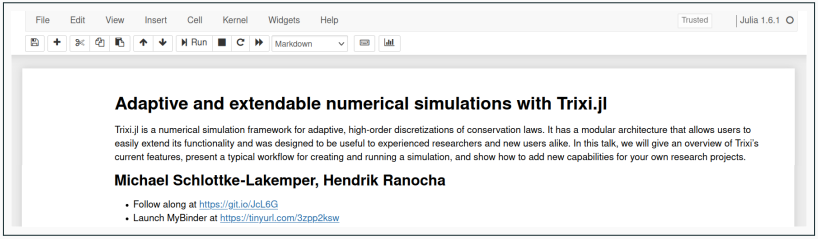
# Kelvin-Helmholtz flow instability with adaptive mesh refinement



# Cold gas cloud interacting with hot supersonic flow



# Live demonstration



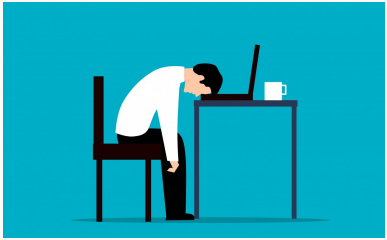

Jupyter notebook and presentation available at

https://github.com/trixi-framework/talk-2021-juliacon

(directly launch notebook: https://tinyurl.com/3zpp2ksw)

# What about the *"look and feel"* performance?

- Startup latency is annoying (Julia v1.6.1/Trixi v0.3.40)
  - Install Trixi + OrdinaryDiffEq + Plots: 4 minutes
  - First result: 45 seconds
  - First plot: 20 seconds
  - Second result + plot: 0.04 seconds



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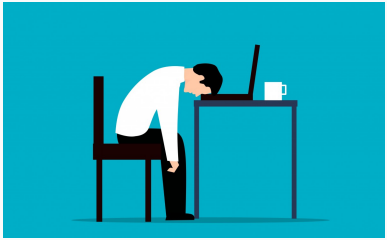

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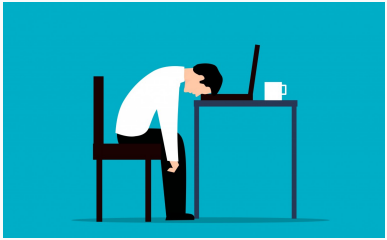
- Reason: code compilation at first use → cache
- Upside: REPL + Revise.jl takes away (most of) the pain



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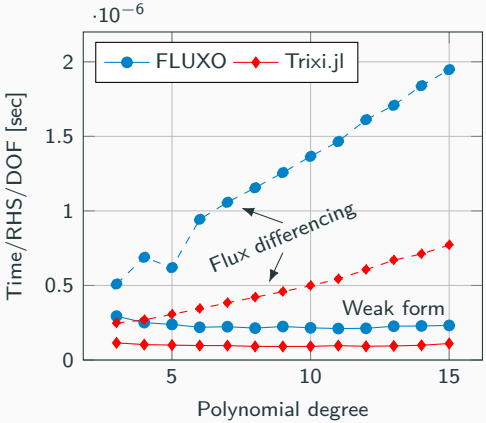
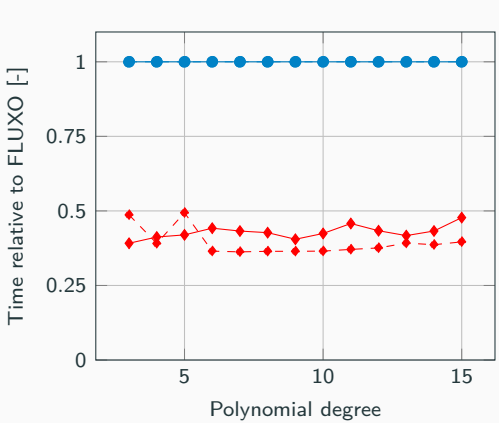
- Upside: many Julia-based tools for introspection and performance optimization

# What about *serial* performance?




- Performance comparison with optimized Fortran-based FLUXO code (lower is better)
- Trixi: faster for realistic example (3D compressible Euler on curved mesh)

# What about *parallel* performance for *simulation science*?

- Shared-memory parallelization works well
- Not many MPI-based massively parallel simulation codes out there (yet)
- Open question: How to integrate MPI without creating a "Frankencode"?
- New momentum from projects such as `https://github.com/CliMA/ClimateMachine.jl`

**Parallel performance: the verdict is still out**

# What about *ease of use* when installing Trixi?

- Built-in package manager `Pkg` handles everything
- Install Trixi + dependencies + postprocessing tools with two lines of code

```
julia> import Pkg
julia> Pkg.add(["Trixi", "Trixi2Vtk", "OrdinaryDiffEq", "Plots"])
```

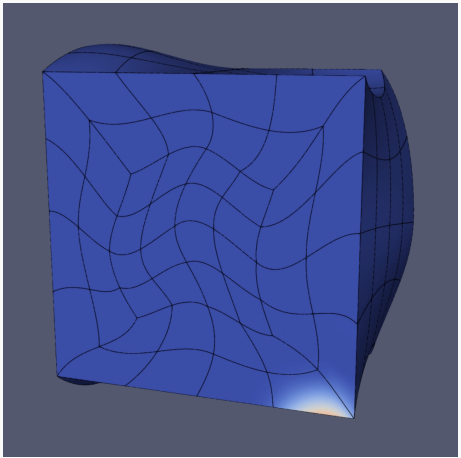
# What about *binary dependencies*?

- Install pre-compiled binaries via `Pkg`
- Can be used for libraries and executables

**Example: adaptive meshes with p4est**

- Wrapper package P4est.jl
- Auto-installs OS-specific binaries
- Works on Linux, MacOS, Windows

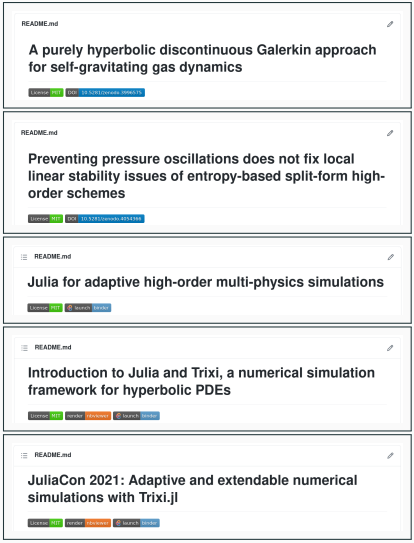
`https://github.com/trixi-framework/P4est.jl`



Credit: Erik Faulhaber

# What about *reproducibility*?

- Provision reproducible compute environments
- All information in `Project.toml` + `Manifest.toml`
- Excellent for reproducible science:
  - Paper #1: `https://git.io/JYBtP`
  - Paper #2: `https://git.io/JYBtA`
  - Talk #1: `https://git.io/JqnrE`
  - Talk #2: `https://git.io/JcLMy`
  - This talk: `https://git.io/JcL6G`



# What about *extendability*?

- Multiple dispatch + Just-Ahead-Of-Time compilation
  $\Rightarrow$ No difference between standard library code, package code, own code
- Easily extend existing functionality and remain fast

Trixi.jl

```
1 calc_volint(solver::DGSEM, volint_type::WeakForm, equations)
2 calc_volint(solver::DGSEM, volint_type::StrongForm, equations)
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```
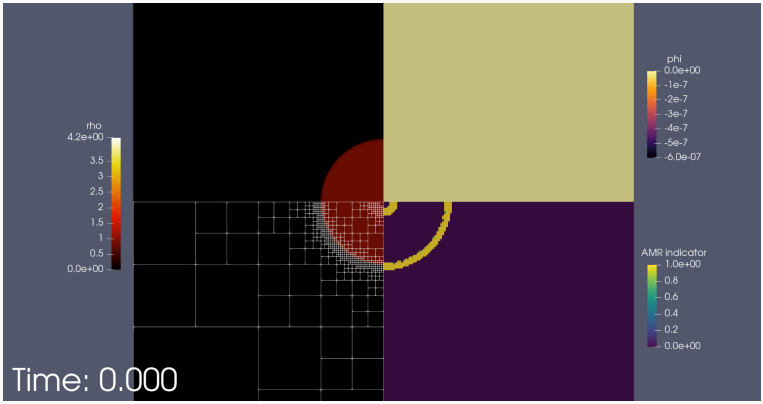

User code

```
3 calc_volint(solver::DGSEM, volint_type::StrongForm, equations::CompressibleEuler)
```

# What about *extendability*?

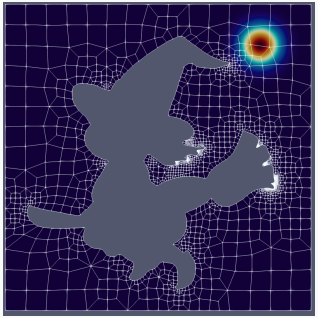
- Flow-gravity simulation with shock capturing and adaptive mesh refinement
- Multi-physics coupling with less than 350 lines of code




Schlottke-Lakemper, Winters, Ranocha, Gassner, Journal of Computational Physics, 2021.
doi:10.1016/j.jcp.2021.110467 | arXiv:2008.10593

# Conclusions and outlook

- Trixi.jl: adaptive high-order numerical simulations
- Focus on extendability, ease of use, performance
- Julia well-suited for simulation science (with small caveats)
- Future: MPI parallelization, more physics, GPUs



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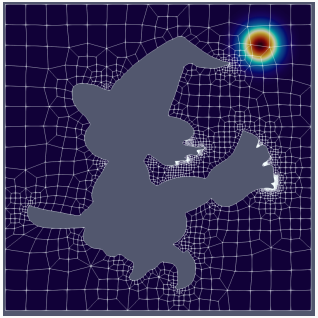

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## Thank you for your interest!

Get in touch: join us on Trixi's Slack or open an issue!

https://github.com/trixi-framework/Trixi.jl