Multiphysics Coupling and Adaptive Model Selection Using p4est Meshes in Trixi.jl

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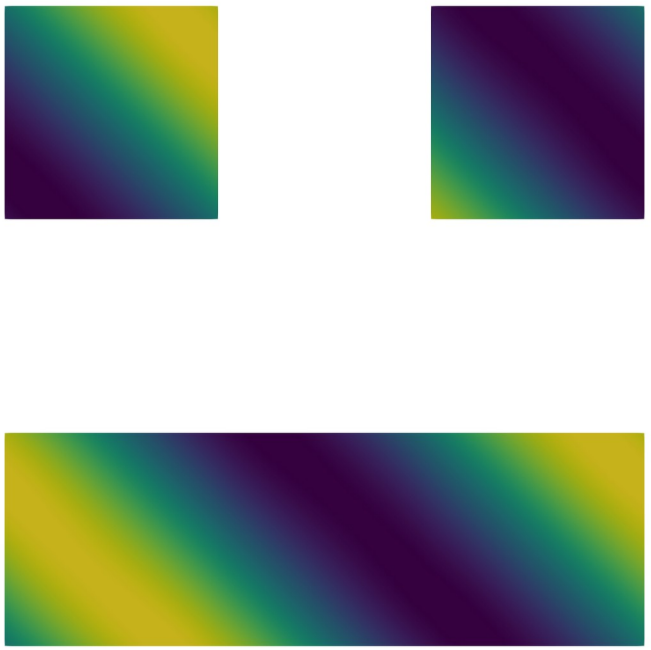
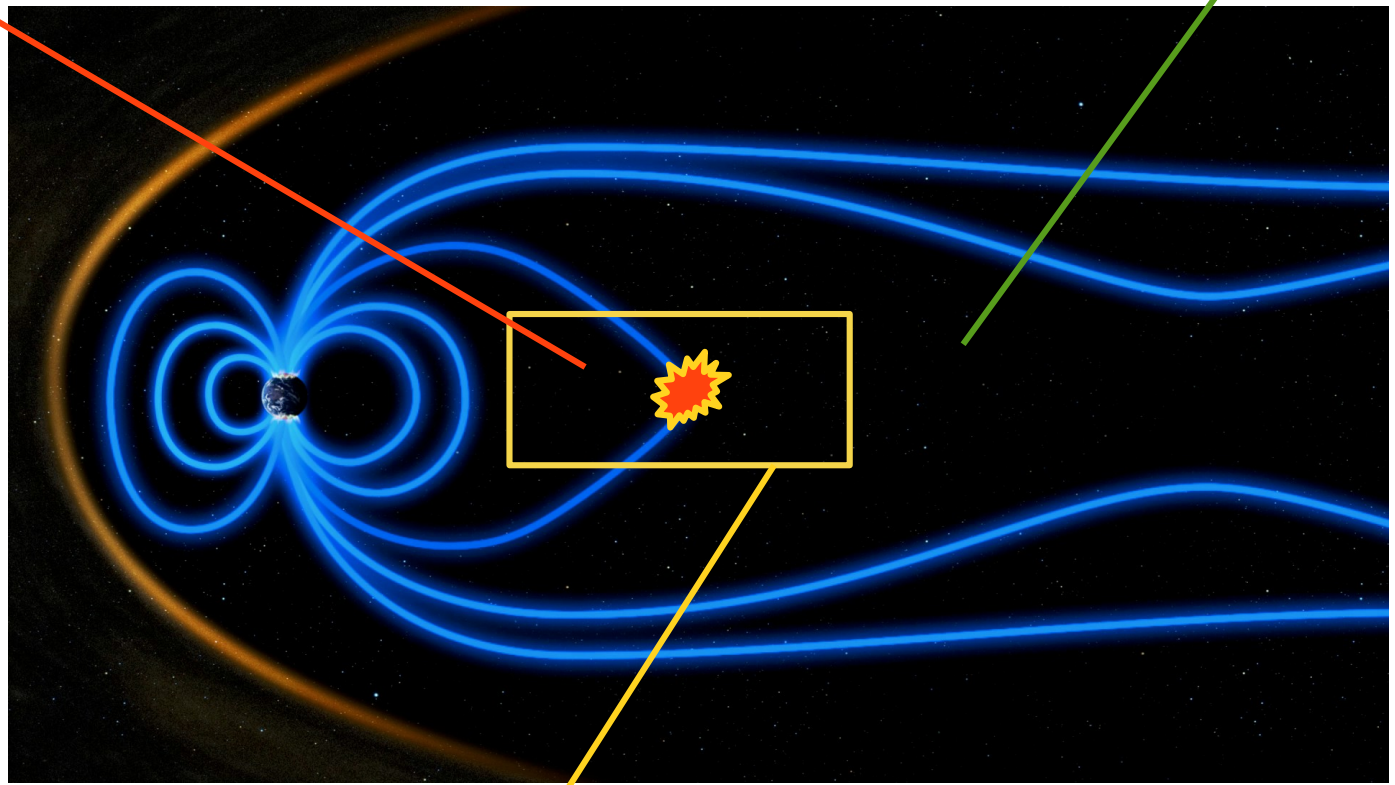


Universität
Augsburg
University

Modeling

kinetic model
(expensive)

magnetohydrodynamics (MHD)
(cheap)



(ESA)

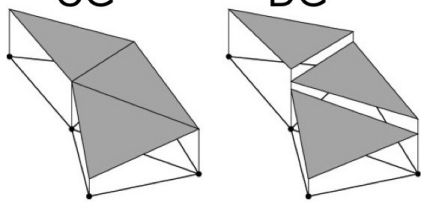
interface coupling

Trixi.jl

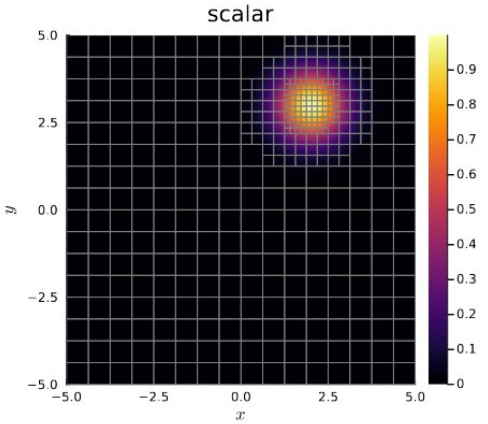
open source:
github.com/trixi-framework/Trixi.jl

Discontinuous Galerkin

CG DG

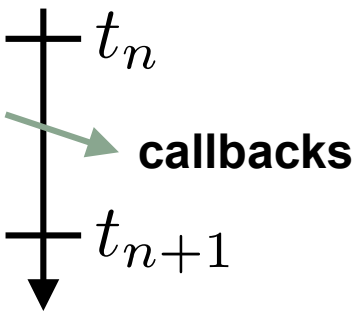


(Stack Overflow)



AMR

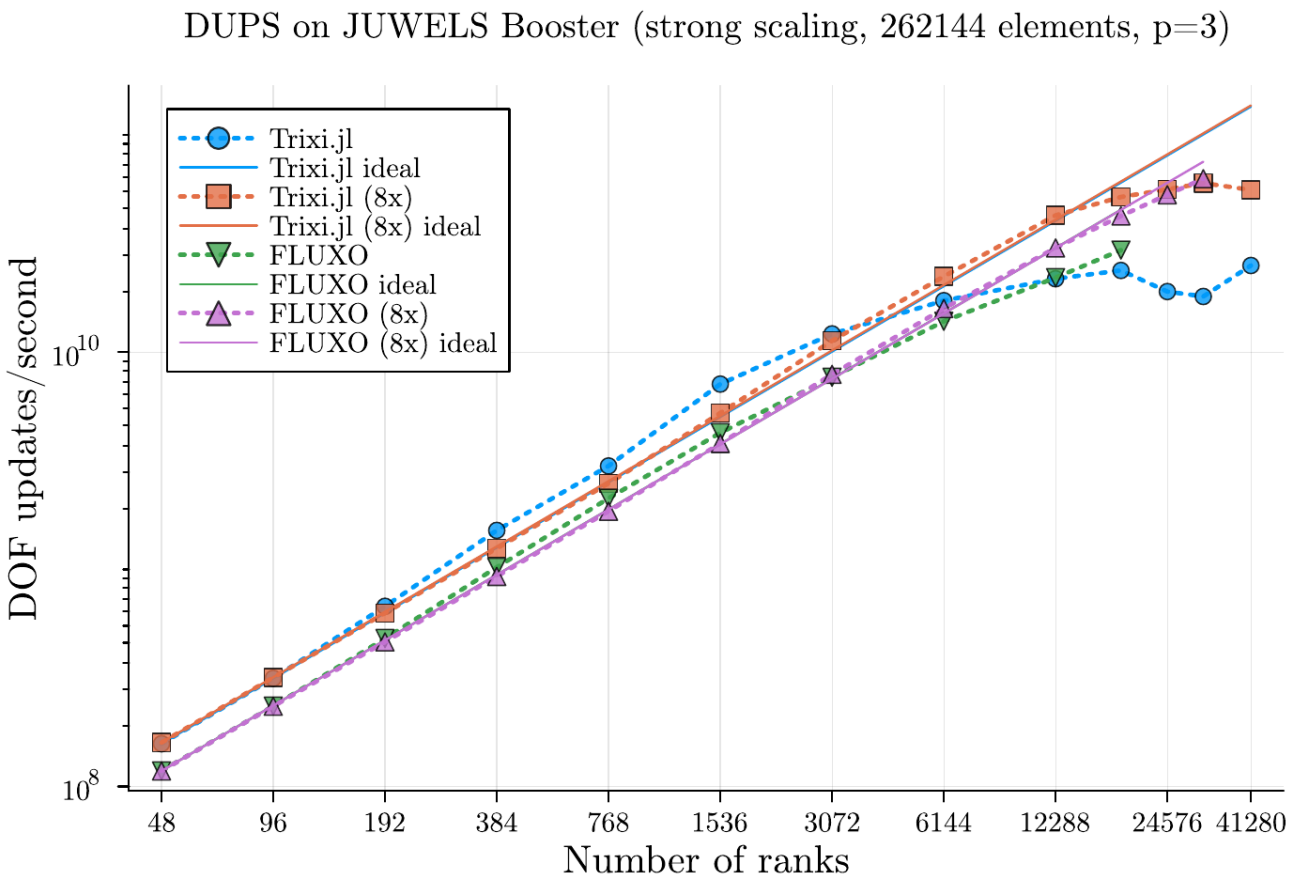
julia



OrdinaryDiffEq (SciML)

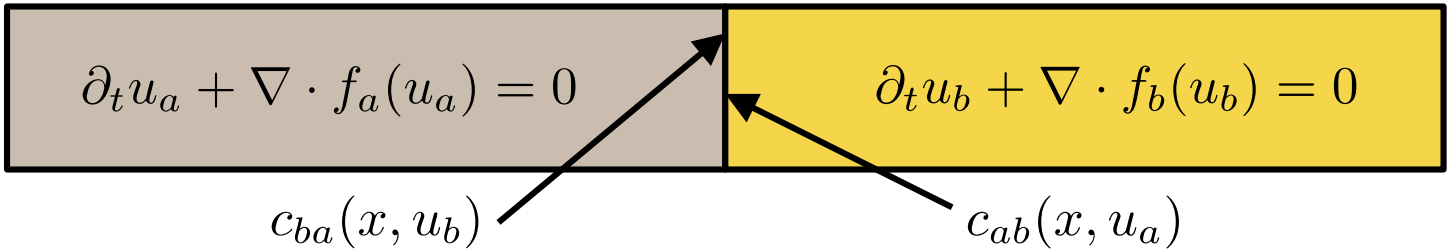
```
using Trixi

equations = LinearScalarAdvectionEquation2D((0.5, -0.3)
solver = DGSEM(polydeg = 3)
cells_per_dimension = (16, 16)

mesh = StructuredMesh(cells_per_dimension, (-1, -1), (1, 1))

semi = SemidiscretizationHyperbolic(mesh, equations,
                                    initial_condition, solver)
ode = semidiscretize(semi, (0.0, 1.0));

stepsize_callback = StepsizeCallback(cfl = 1.6)
callbacks = CallbackSet(stepsize_callback)

sol = solve(ode, CarpenterKennedy2N54(),
            dt = 1.0, callback = callbacks);
```

Trixi.jl


DUPS on JUWELS Booster (strong scaling, 262144 elements, p=3)
DOF updates/second
10^{10}
10^{8}
Trixi.jl
Trixi.jl ideal
Trixi.jl (8x)
Trixi.jl (8x) ideal
FLUXO
FLUXO ideal
FLUXO (8x)
FLUXO (8x) ideal
48
96
192
384
768
1536
3072
6144
12288
24576
41280
Number of ranks

Coupling via Converter Functions

Two system with any number of shared variables, including 0:



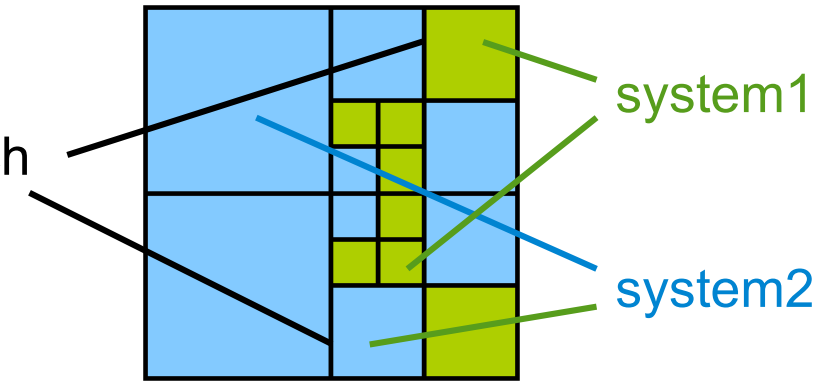
2.5d MHD $\rho, v_1, v_2, v_3, p, B_1, B_2, B_3, \Psi$ | ρ, v_1, v_2, p 2d Euler

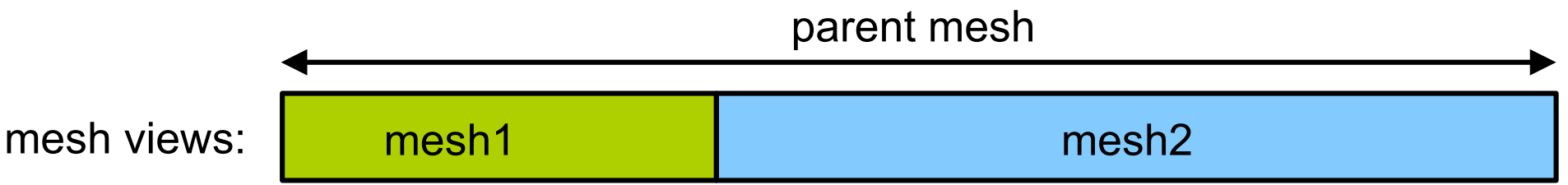
```
coupling_function12 = (x, u, equations_other, equations_own)
                      -> SVector(u[1], u[2], u[3], 0.0, u[4], 0.0, 0.0, 0.0, 0.0)
coupling_function21 = (x, u, equations_other, equations_own) -> SVector(u[1], u[2], u[3], u[5])
```

- User can define converter functions.
- Any pair of systems can be coupled.

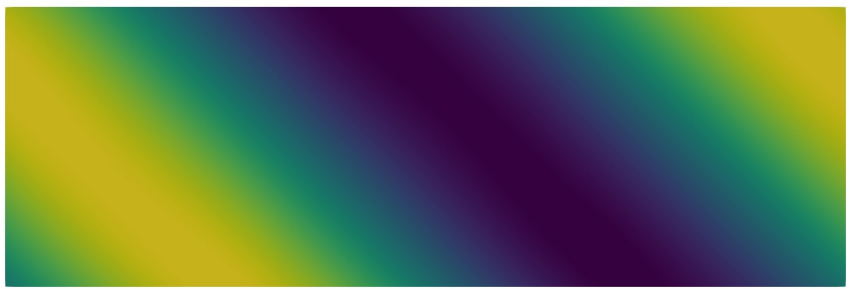
p4est Meshes

We can define the b.c. for each cell boundary.



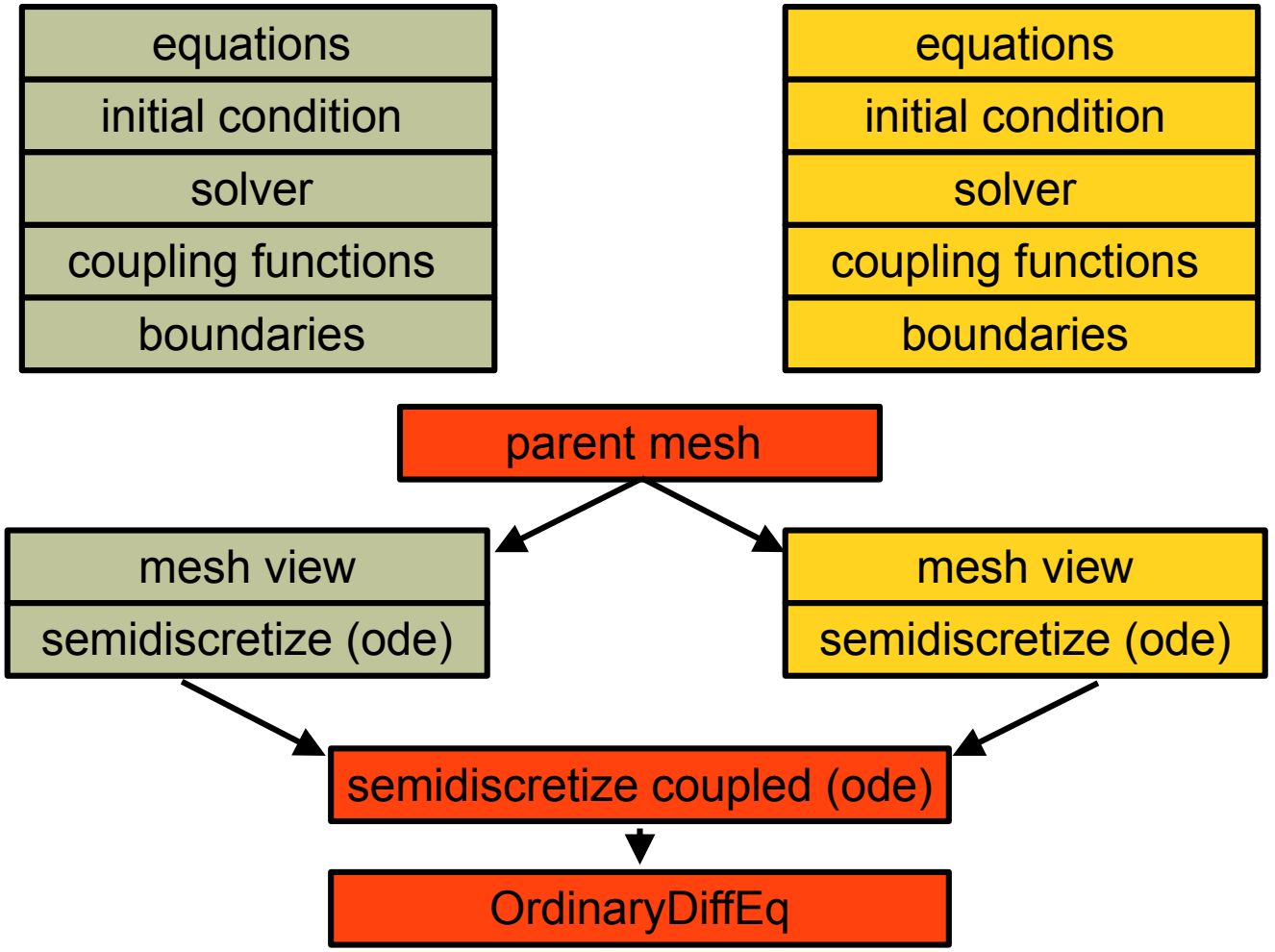


p4est Mesh Views

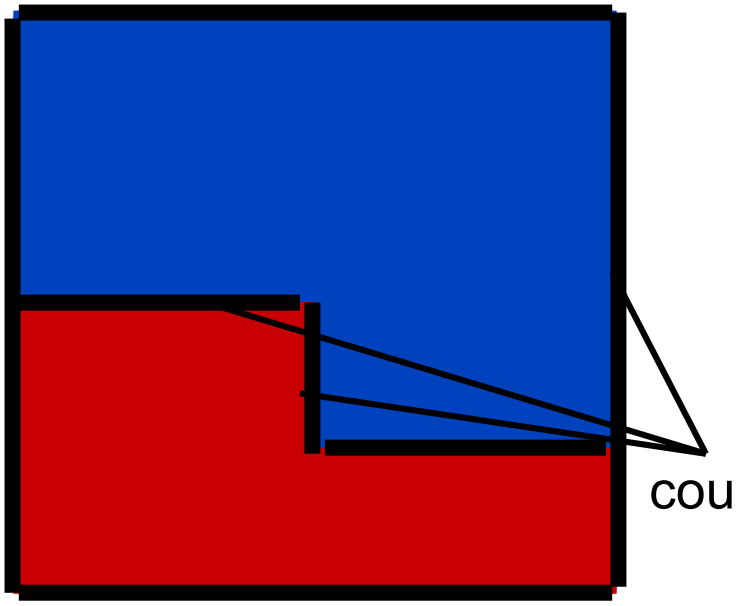


- p4est mesh views in Trixi.jl
- arbitrary topology
- views on smallest (cell) scale

Work Flow Coupling

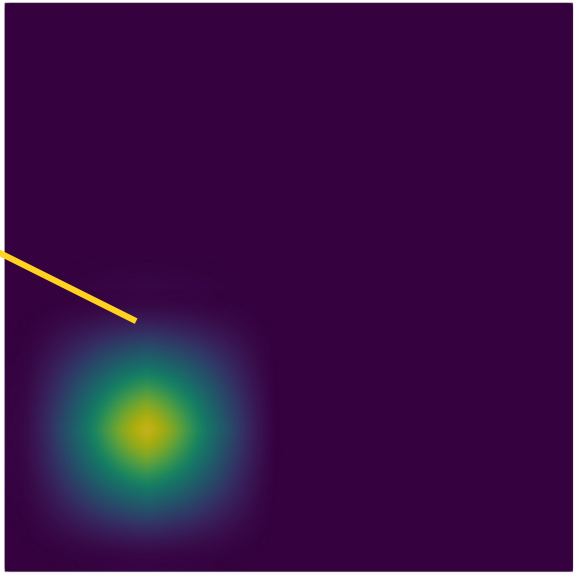


Linear Advection



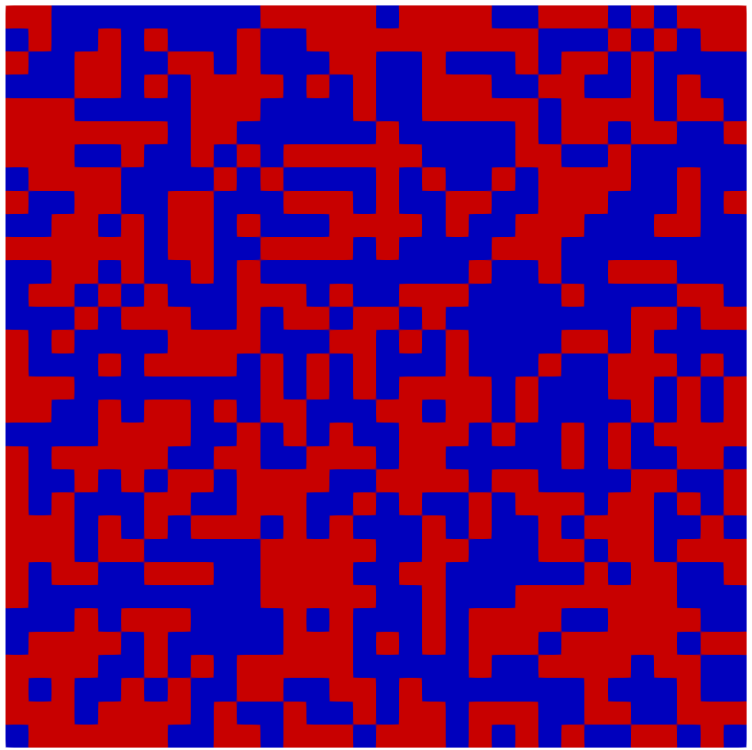
coupled interfaces

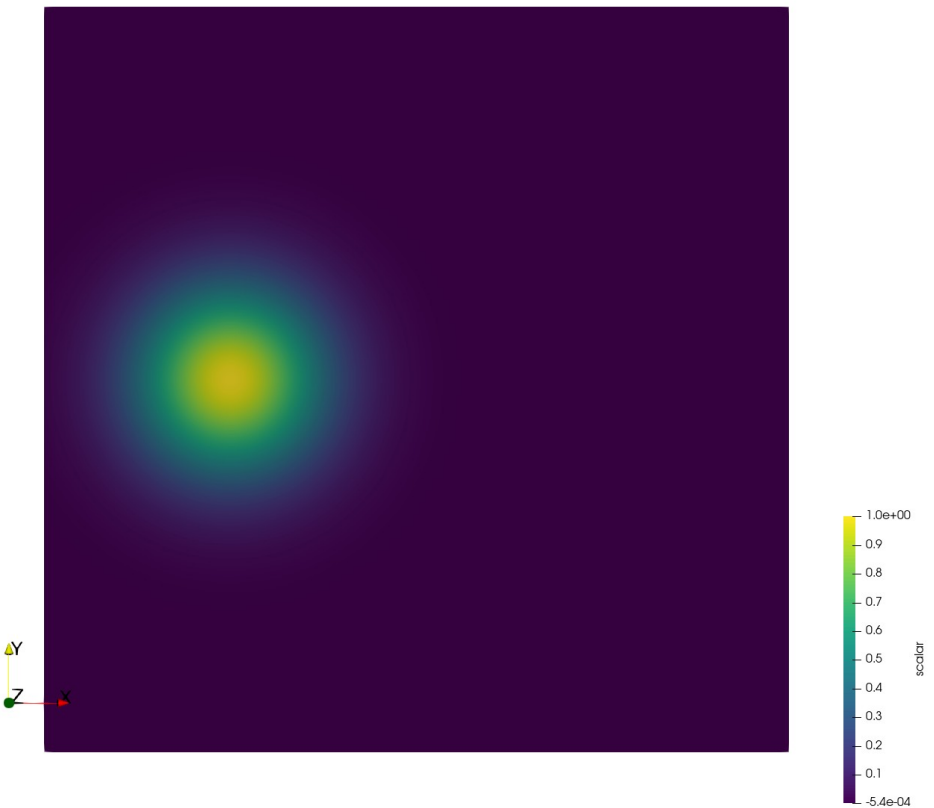
scalar advection



$$\partial_t u + a_x \partial_x u + a_y \partial_y u = 0 \qquad (a_x, a_y) = (0.05, 0.02)$$

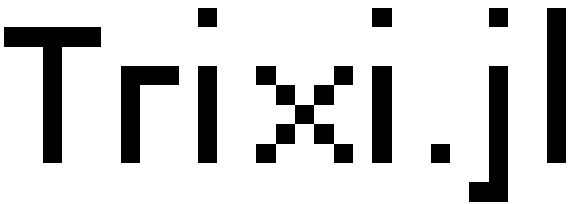
Linear Advection



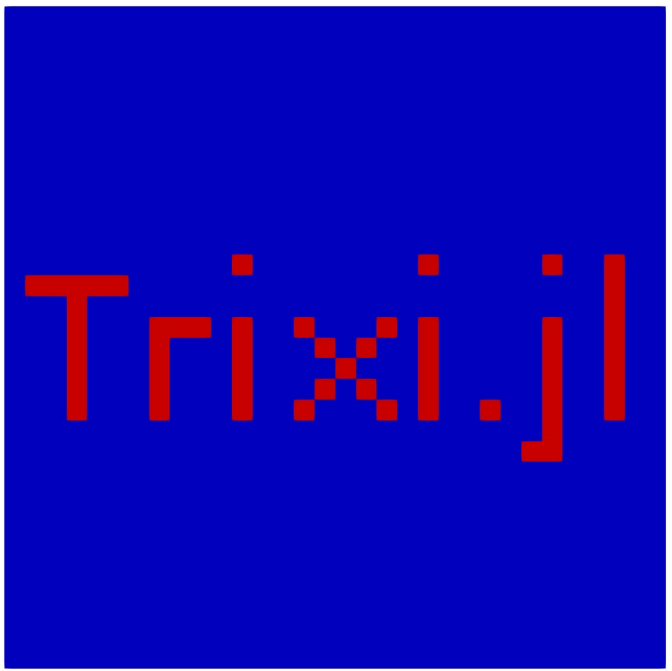


Linear Advection

BMP file:

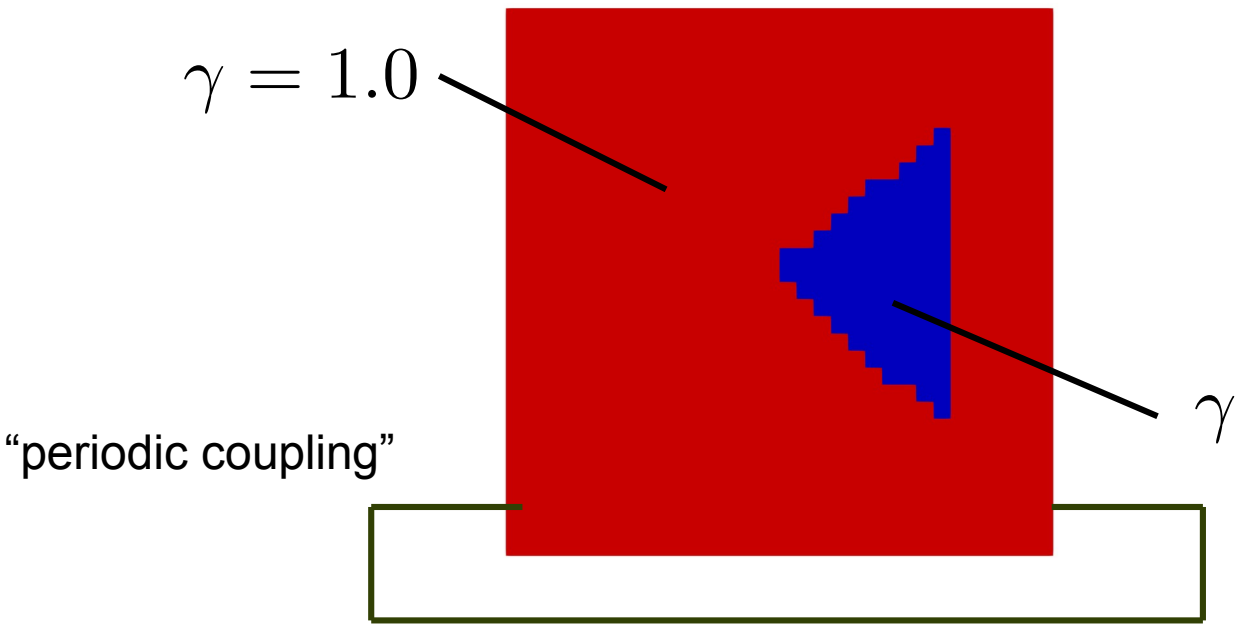


p4est domains:



Isothermal-Polytropic

$$\partial t \begin{pmatrix} \rho \\ \rho v_1 \\ \rho v_2 \end{pmatrix} + \partial x \begin{pmatrix} \rho v_1 \\ \rho v_1^2 + \rho^\gamma \\ \rho v_1 v_2 \end{pmatrix} + \partial y \begin{pmatrix} \rho v_2 \\ \rho v_1 v_2 \\ \rho v_2^2 + \rho^\gamma \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}$$

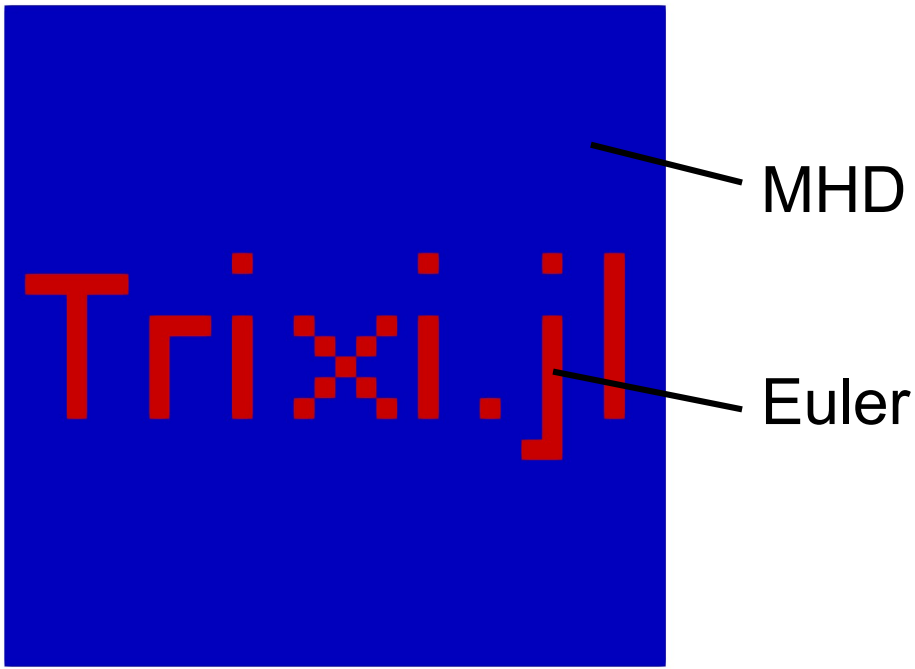


coupling functions:

$$c_{ab} = u^b$$

$$c_{ba} = u^a$$

MHD-Euler

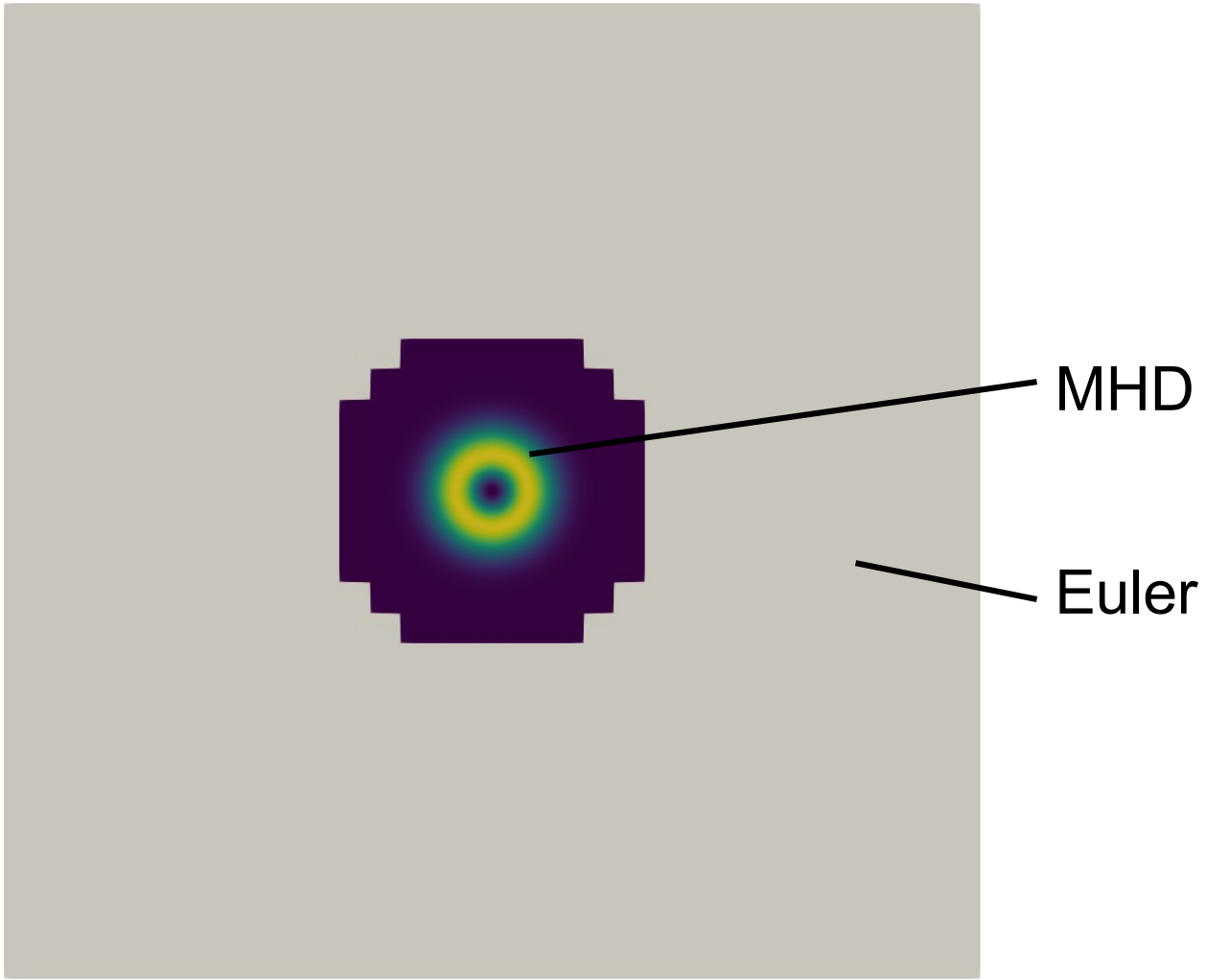

Trixi.jl
MHD
Euler


1.0e+00
1.008
1.006
1.004
1.002
1
0.998
0.996
0.994
0.992
0.99
9.9e-01
rho

Adaptive Model Selection

1. Generate the new grid (mesh views).
2. Write new u-solution vectors
3. Generate new ODE for OrdinaryDiffEq (integrator).
4. Reinitialize ODE integrator with new problem and new solution vector.

MHD-Euler AMS



Conclusion

- Free domain definitions.
- Import meshes from an image.
- Coupled p4est simulations.
- Non-simply connected meshes in p4est.
- Adaptive model selection with arbitrary criteria.

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