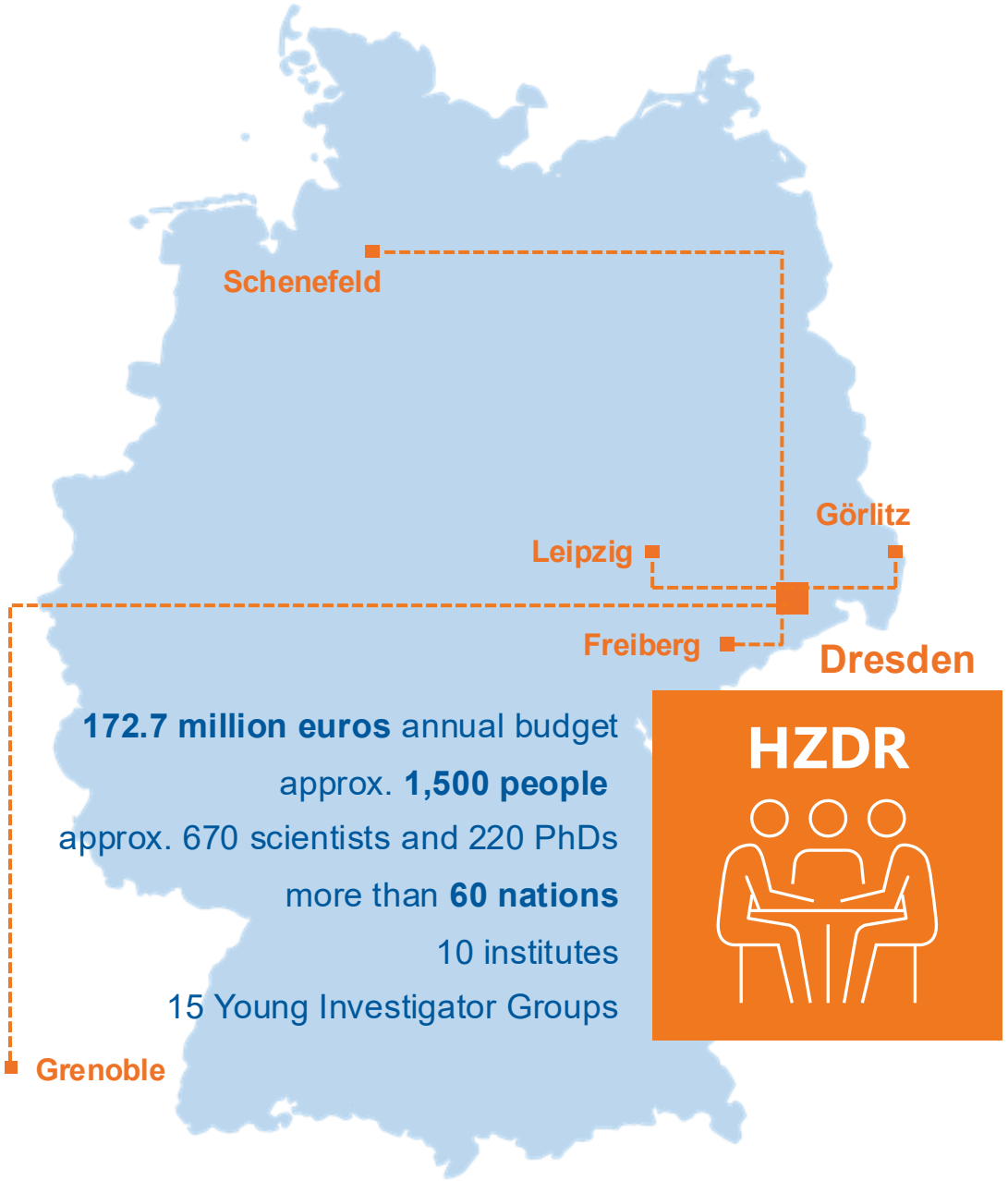
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Multiphase Developments with OpenFOAM Foundation Software at HZDR

Keynote at OpenFOAM Stammtisch, Göttingen

Institute of Fluid Dynamics – Department Computational Fluid Dynamics – Dr. Fabian Schlegel – www.hzdr.de/multimorph



172.7 million euros annual budget

approx. **1,500 people**

approx. 670 scientists and 220 PhDs

more than **60 nations**

10 institutes

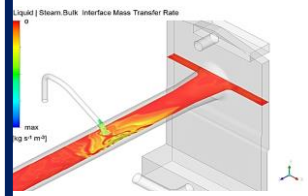
15 Young Investigator Groups

HZDR

WHO ARE WE?

WHO WE ARE?

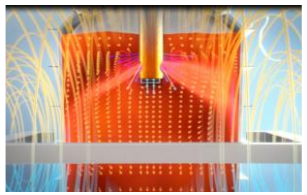
INSTITUTE OF FLUID DYNAMICS



Computational Fluid Dynamics

Dirk Lucas

Main subject is the CFD-model development and validation for multiphase flows for medium and large scale industrial applications basing on the multi-fluid approach.



Process Diagnostics

Sven Eckert

Focus on experimental and numerical research on flow control by means of electromagnetic forces in conducting fluids.

Thermal Energy and Process Technology

Sebastian Unger

Research on innovative supercritical CO_2 energy systems and optimized separation processes is crucial for resource-efficient energy generation and global energy consumption.

Water and Environmental Technologies

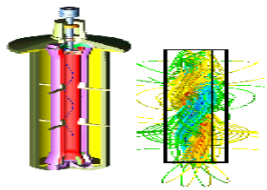
Sebastian Reinecke

Research on wastewater treatment for reducing pollution, preventing eutrophication, and ensuring sustainable water use.

Fluid Dynamics of Resource Technology Processes

Sascha Heitkam

Complex multiphase flows in resource technology processes such as froth flotation, electrolysis or extraction.



Magnetohydrodynamics in Geophysics and Astrophysics

Frank Stefani

Cosmic magnetic fields are generated by the hydro-magnetic dynamo effect and play a crucial role in cosmic structure formation.

Who we are?

Our Expertise

Model development for Eulerian multiphase method

- Morphology-adaptive MultiMorph model
- Validation database with > 700 cases
- (Closure) model development
- Numerical simulation with OpenFOAM Foundation Software

Software engineering

- DevOps within Helmholtz Codebase / Gitlab
- Workflow management with Snakemake
- Templated cases with Jinja

WHO WE ARE?

OUR DEVELOPMENT PILLARS

`Multiphase Code Repository`

Additional source code

- Morphology-adaptive Euler-Euler model (MultiMorph)
- (Closure) model for Euler-Euler
- Pre- and postprocessing utilities
- Tests & tutorials

📖 https:/doi.org/10.14278/rodare.767

`Multiphase Cases Repository`

Collection of simulation setups

- Validation cases (> 400) for Euler-Euler method
- MultiMorph validation & application cases
- Metadata & documentation

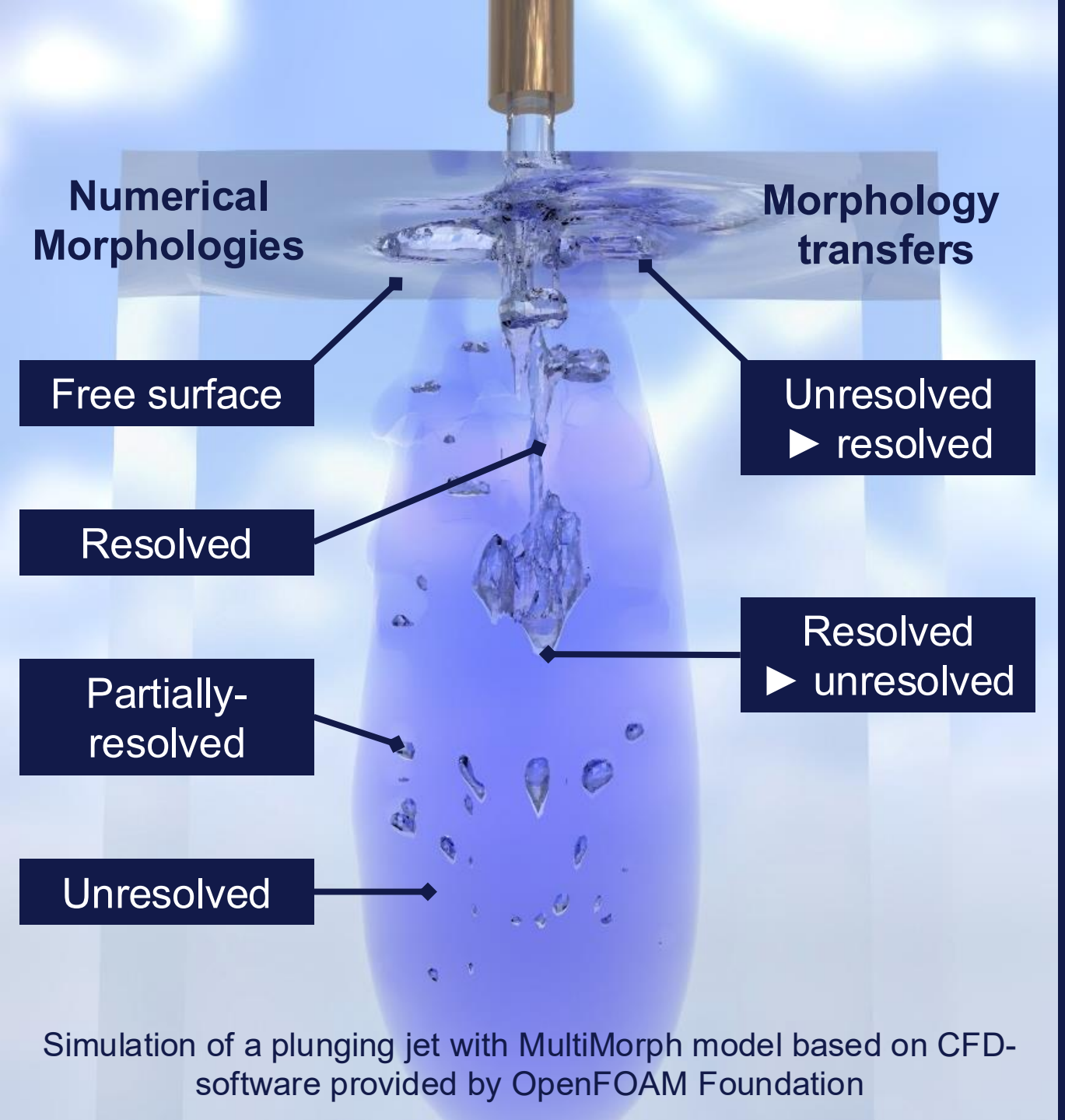
📖 https:/doi.org/10.14278/rodare.811

`Multiphase Python Repository`

User and working environment

- Utilities for data analysis
- Performance evaluation (Fuzzy logic)
- Snakemake workflow engine
- Copier template engine

📖 https:/doi.org/10.14278/rodare.3093

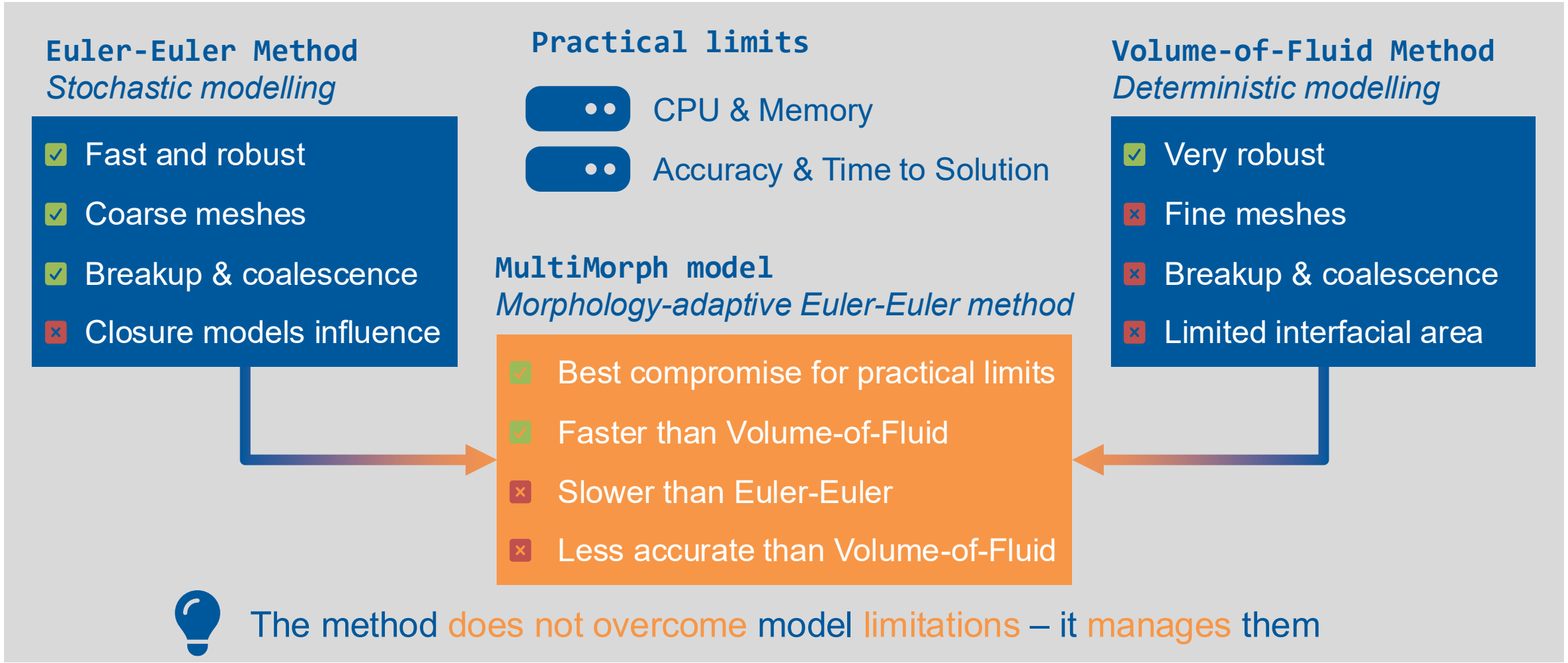


Simulation of a plunging jet with MultiMorph model based on CFD-software provided by OpenFOAM Foundation

WHAT IS MULTIMORPH?

What is MultiMorph?

The idea of multimorph



What is MultiMorph?

MultiMorph in a nutshell

General Concept

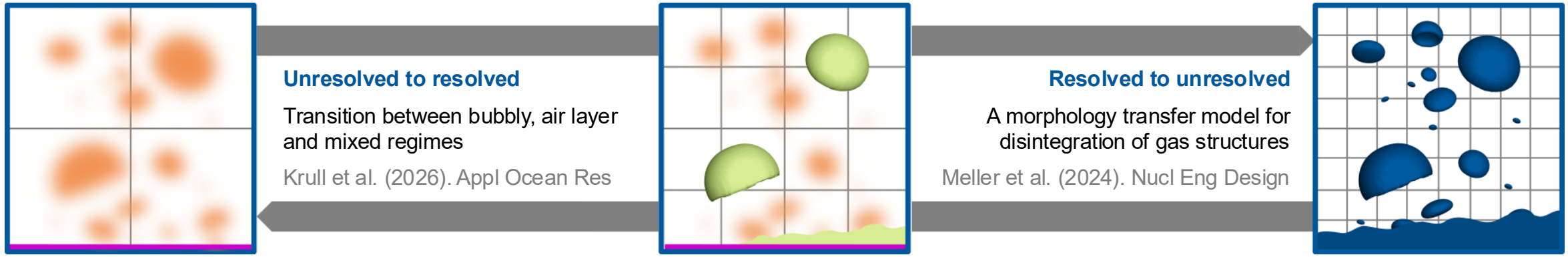
Design criteria for a morphology-adaptive Eulerian method

Schlegel et al. (2023). Nucl Sci Eng

Method homogenization

Review of morphology-adaptive Eulerian methods

Schlegel et al. (2026). Comp Fluids



Unresolved to resolved

Transition between bubbly, air layer and mixed regimes

Krull et al. (2026). Appl Ocean Res

Resolved to unresolved

A morphology transfer model for disintegration of gas structures

Meller et al. (2024). Nucl Eng Design

Unresolved morphology

Euler-Euler & Thin-film model

Krull et al. (2024). Chem Eng Sci

Partially-resolved morphology

A resolution-adaptive momentum exchange model

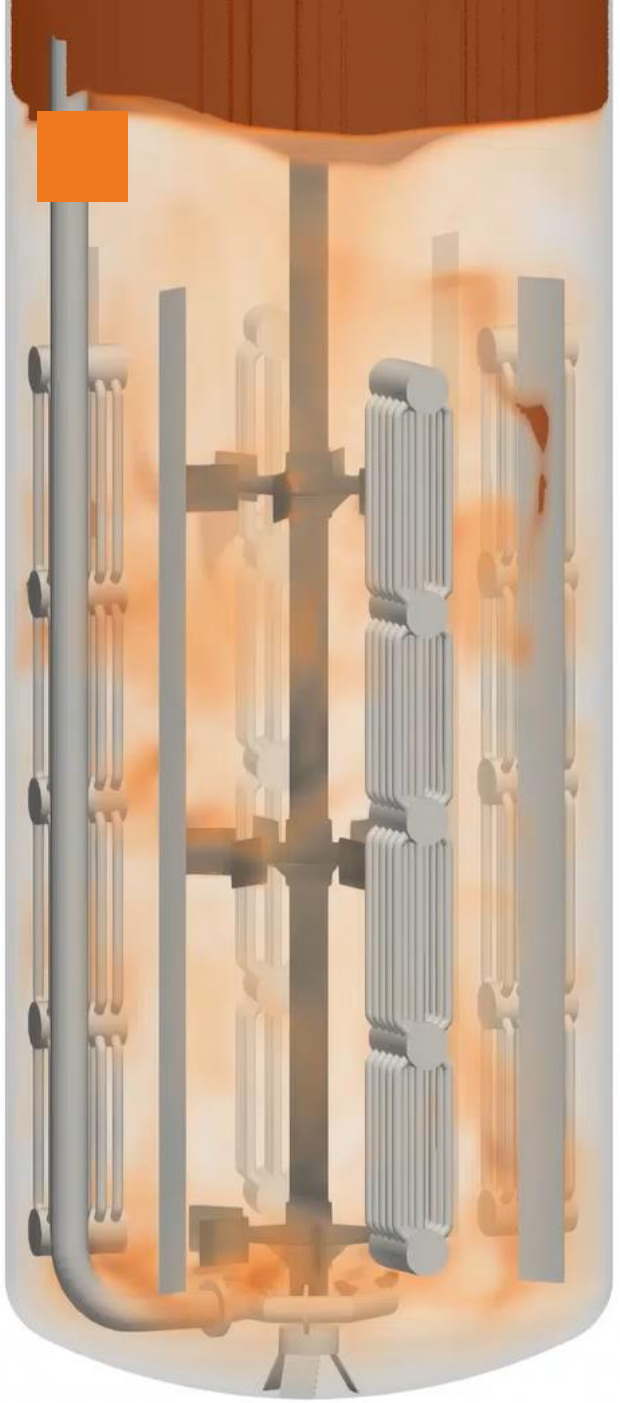
Meller et al. (2023). Int J Num Method Fluid

Resolved morphology

Volume-of-Fluid

Meller et al. (2021). Int J Num Method Fluid

Tekavčič et al. (2021). Nucl Eng Design



New **semi-implicit MULES** delivers speed-up up to a factor of 10

BASF
We create chemistry

WHO USES MULTIMORPH?

WHO USES MULTIMORPH?

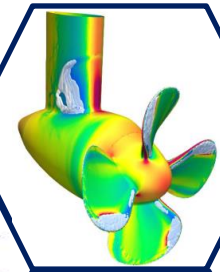
Aerated stirred-tanks

TECHNISCHE UNIVERSITÄT BERLIN

Parallel Vertical Risers

PEM electrolyzer cells

Air lubrication



Column trays

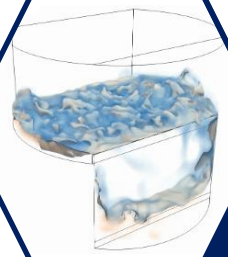
BASF We create chemistry

POLITECNICO MILANO 1863

UNIVERSIDADE FEDERAL DE SANTA CATARINA

VTT

Cavitation



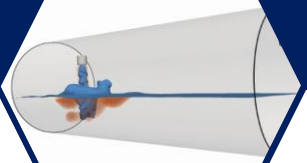
Rotating Packed Beds

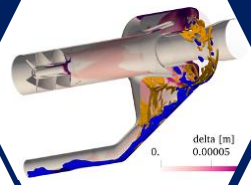
Continuous Flow Vessel

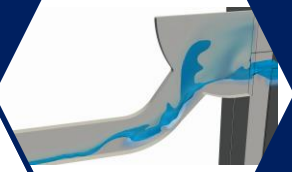
Droplet separators

Vane-type axial separator

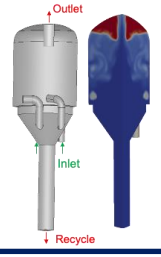
Gas-liquid separation in hydro-processors







uOttawa



sunfire

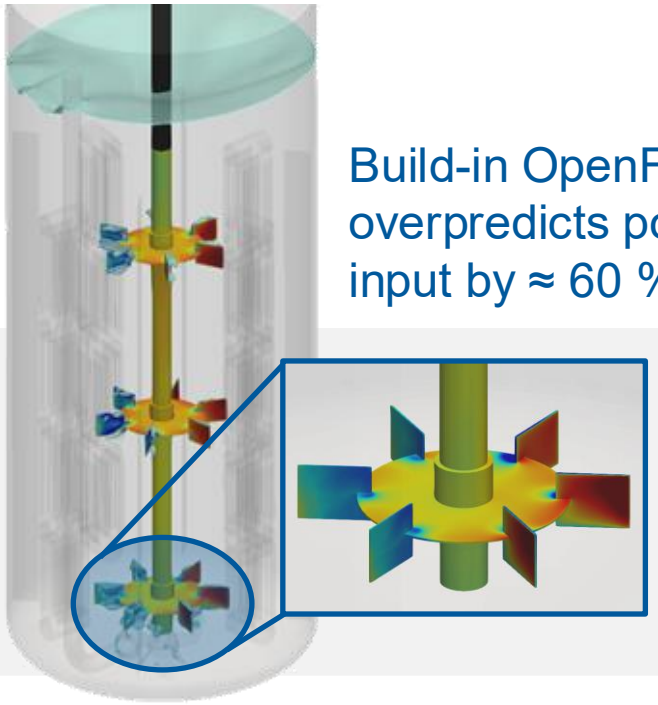
MAHLE

Nuclear Safety Analysis

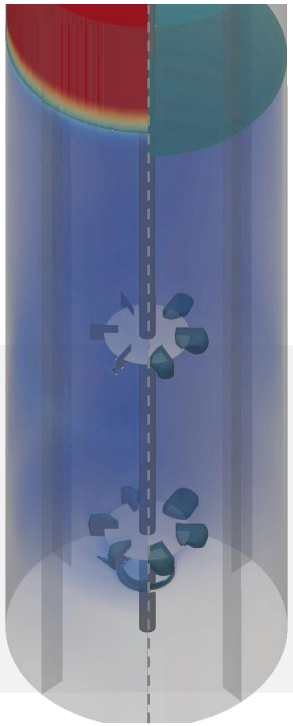
DRESDEN concept HZDR

WHO USES MULTIMORPH?

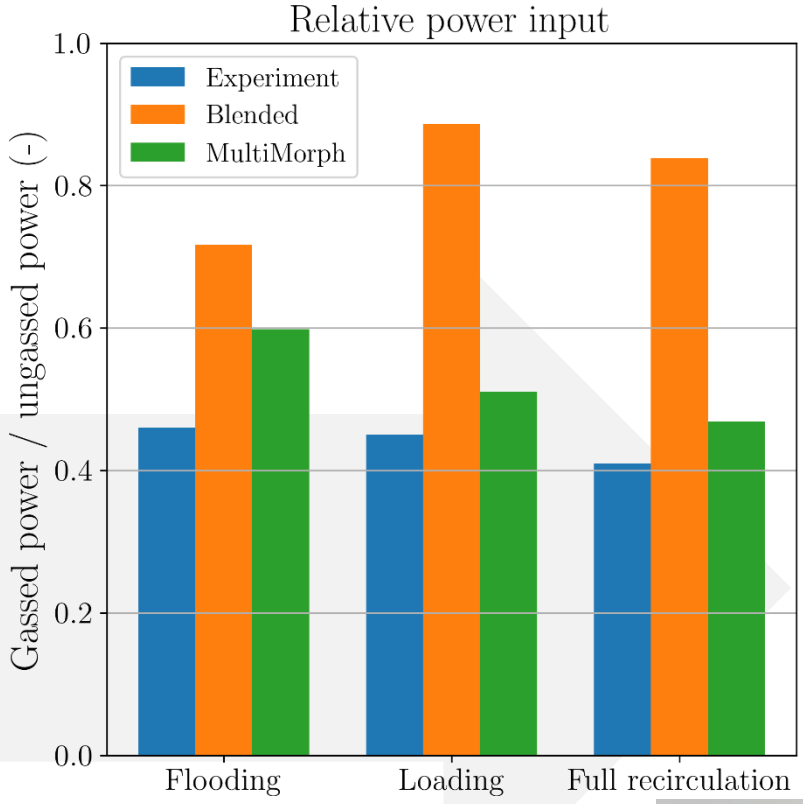
INDUSTRY-SCALE AERATED STIRRED TANK REACTOR



Build-in OpenFOAM overpredicts power input by ≈ 60 %



Loading regime



Advantages of MultiMorph

- Improves modelling of resolving gas pockets around blades
- Reduces numerical gas entrainment at free surface

Sebastian Meinicke
sebastian.meinicke@basf.com

WHO USES MULTIMORPH?

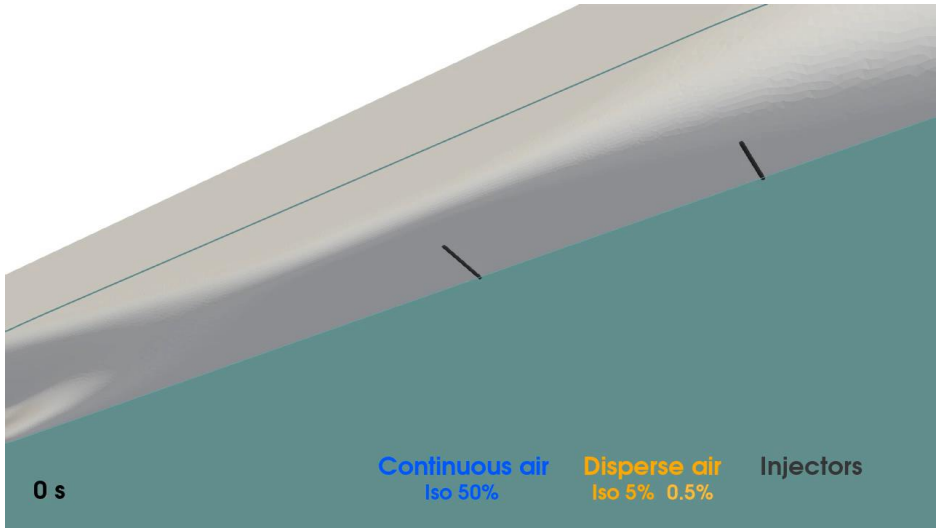
DRAG REDUCTION BY AIR LUBRICATION

Applications:

- Flat plate drag reduction by air lubrication
- Full scale ship hull air lubrication

Advantages of MultiMorph

- Captures both disperse (bubbly) and continuous (air layer) regime
- Allows for regime transitions



Air film formation beneath ship hull

📖 Krull et al. (2026). *Appl Ocean Res*, 166, 104892.

WHO USES MULTIMORPH?

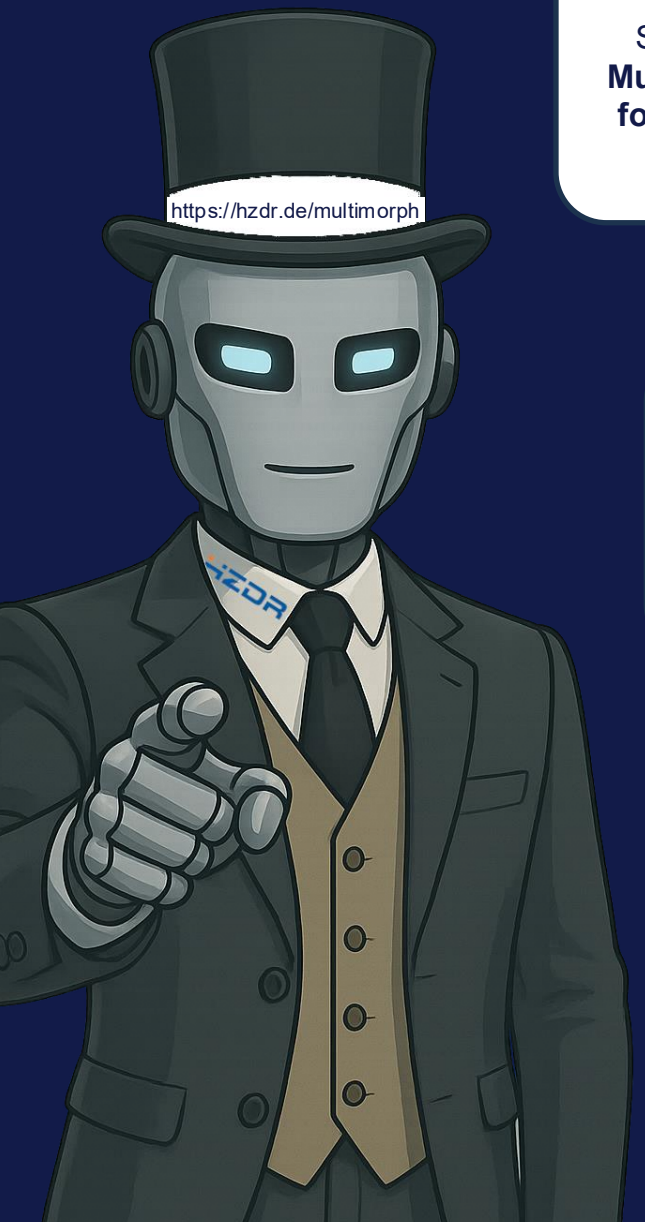
ACHIEVEMENTS AND FUTURE WORK

Achievements

- Robust framework supporting physically (empirical) and numerically (resolution-adaptive) motivated phase and morphology transfers
- Proof-of-concept simulations for various industrially relevant setups
- Proof-of-concept helped us to identify weak-points and development needs

Future Work

- Population balance modelling (class methods / method of moments)
- Additional film morphology based on Eulerian thin-film models
- Heat and mass transfer models
- Improve consistency of empirical and adaptive transfer models



MultiMorph Model

Schlegel et al. (2025, December 16).
Multiphase Code Repository by HZDR for OpenFOAM Foundation Software
(Version 13-s.1-hzdr.2). Rodare.
http://doi.org/10.14278/rodare.4195

Validation Database

Hänsch et al. (2025, December 16).
Multiphase Cases Repository by HZDR for OpenFOAM Foundation Software
(Version 13-s.1-hzdr.1-cases.1). Rodare.
http://doi.org/10.14278/rodare.4192

Workflow and User Environment

Schlegel et al. (2026, February 23).
Multiphase Python Repository by HZDR
(Version 2.11.0). Rodare.
http://doi.org/10.14278/rodare.4532

SUSTAINABLE **SOFTWARE** **DEVELOPMENT**

Sustainable Software Development

Our vision and needs for downstream development

- Create robust and efficient methods and models for simulating multiphase flows
- Build a validation database
- Foster transfer and collaboration with industry

- Long-term stable and manageable source code and simulation setups
- Collaboration platform
- Upstream contributions
- Portability

Sustainable Software Development

Active partnership with OpenFOAM Foundation

- **The downstream developers**
  - Maintenance plan
  - Support contract
  - Include core developers early on in project proposals
  - Respond quickly to testing requests
- **The core developers**
  - Take our needs into account when refactoring code
  - Faster and more productive in implementing new functionality

Sustainable Software Development

Our learning curve

Early Research

- First developments in `reactingTwoPhaseEulerFoam`, but got replaced by `reactingMultiphaseEulerFoam`
- `cipsaMultiphaseEulerFoam` to mitigate staggering issues
- Development of Population Balance Method (PBM) and contribution together with VTT

High complexity, limited scalability

Sustainable Development

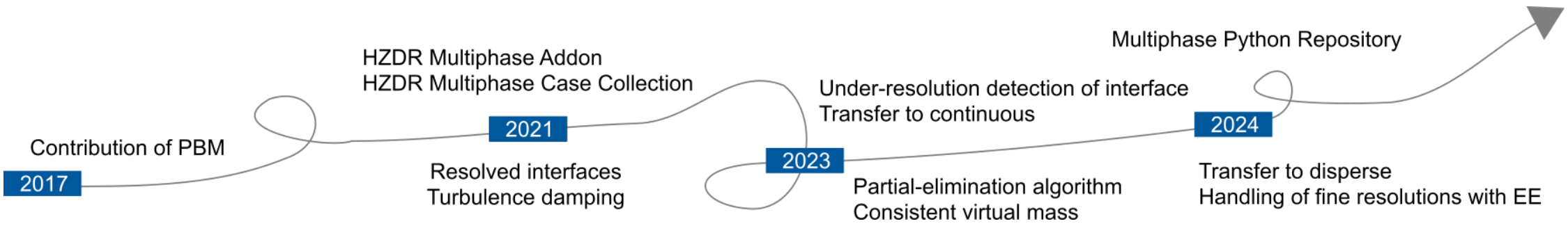
- Version control (SVN ► GitLab)
- Sprint-cycle based addon
- Establishment of case database
- Ensure release quality for code
- Integration into Helmholtz Codebase with HPC access

Need for reproducibility & structure

Automation & Scaling

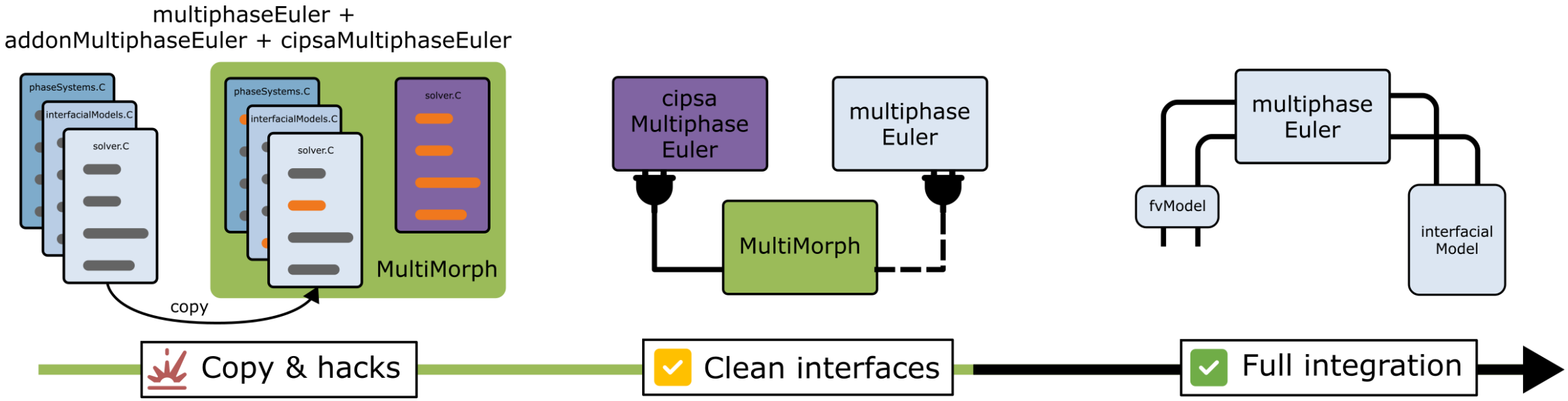
- CI/CD environment for OpenFOAM
- Automated batch-processing
- Metadata & quality measures
- Jinja-templated simulation setups
- Toolkit for reproducible multiphase CFD workflows (`multiphasepy`)
- Addon-based ► fork-based

Fully automated, scalable CFD platform



Sustainable Software Development

MultiMorph transfer towards OpenFOAM Foundation release



Feasibility prototype

- Hard to maintain
- Interfacial closures, solution algorithms, phase transfers

Preliminary Product Prototype

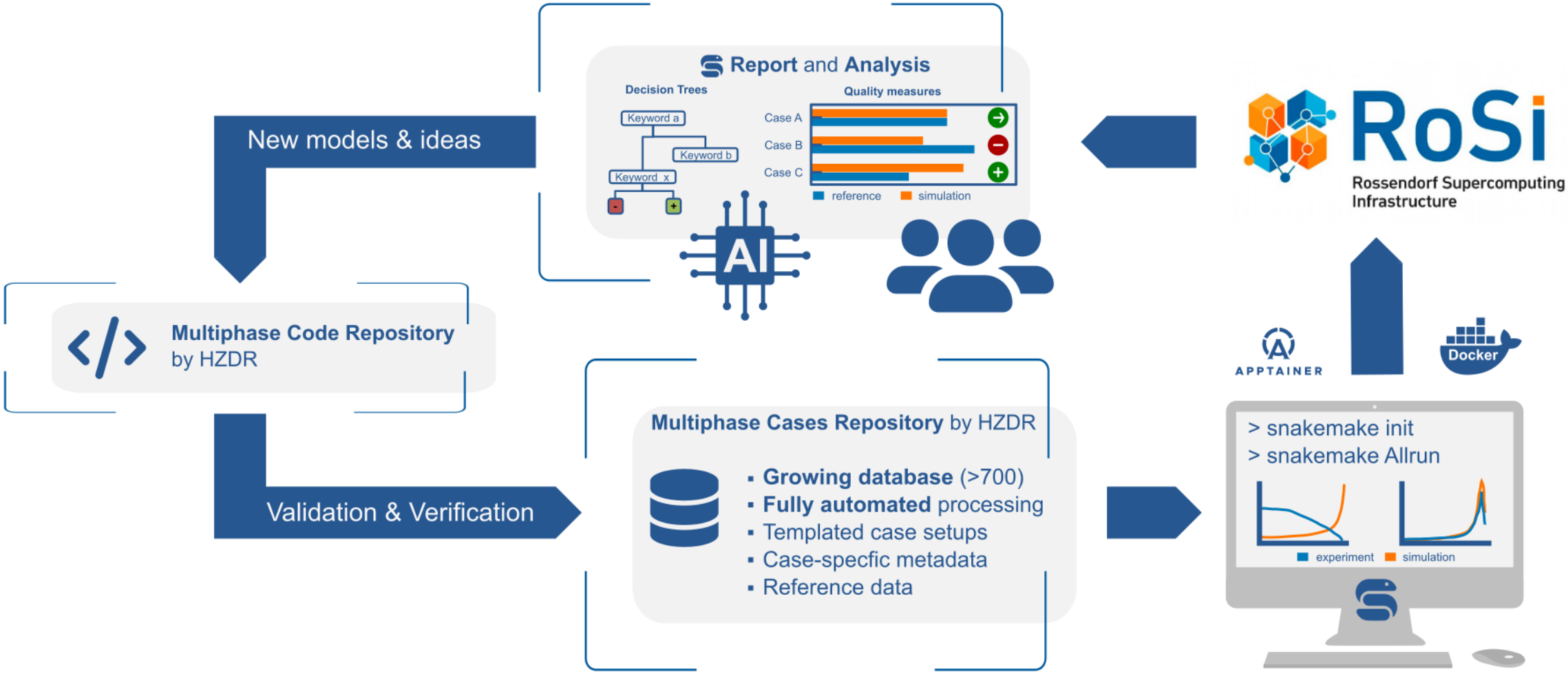
- Minimize extra code
- Contribute solution algorithms
- Easier to maintain

Demonstration Prototype

- Just a set of fvModels
- Easiest to maintain
- Successful transfer

Sustainable Software Development

Validation strategy for Eulerian multiphase CFD



DRESDEN concept HZDR

Sustainable Software Development

Case templating for efficient parameter studies

Error-prone

```
.
├── 3
│   ├── 0
│   ├── Allrun
│   ├── constant
│   └── system
├── 14
│   ├── 0
│   ├── Allrun
│   ├── constant
│   └── system
└── 15
    ├── 0
    ├── Allrun
    ├── constant
    └── system
```

Maintainable

```
.
├── 0
├── Allrun
├── caseParameterDict.jinja
├── caseParameterTable.ecsv
├── constant
└── system
```

```
FoamFile
{
    ...
}
// * * * * * * * * * * * * * * * * * * //

case            {{case}};

UsAir           {{UsAir}};
UsWater         {{UsWater}};
```

```
# %ECSV 0.9
# ---
# datatype:
# - {name: case}
# - {name: UsWater, unit: m / s, ...}
# - {name: UsAir, unit: m / s, ...}
case  UsWater  UsAir
3     0.102    0.0025
14    0.102    0.004
15    0.161    0.004
```

Avoid case duplication

Sustainable Software Development

Simulation batch-processing

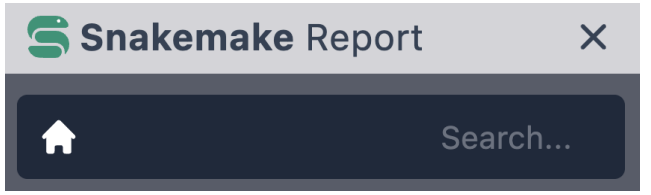
System requirements

- **Portability**
  Containerized software stack
  (OpenFOAM & dependencies)
- **Scalable**
  Single-core PC to multi-node HPC
- **Simple command sequence**
  No case-level batch scripts
- **Reporting**
  Results displayed in a compact and shareable format

snakemake

Apptainer/Singularity/Docker

```
snakemake init   -j <cores/jobs>
snakemake Allrun -j <cores/jobs>
snakemake --report report.html
```

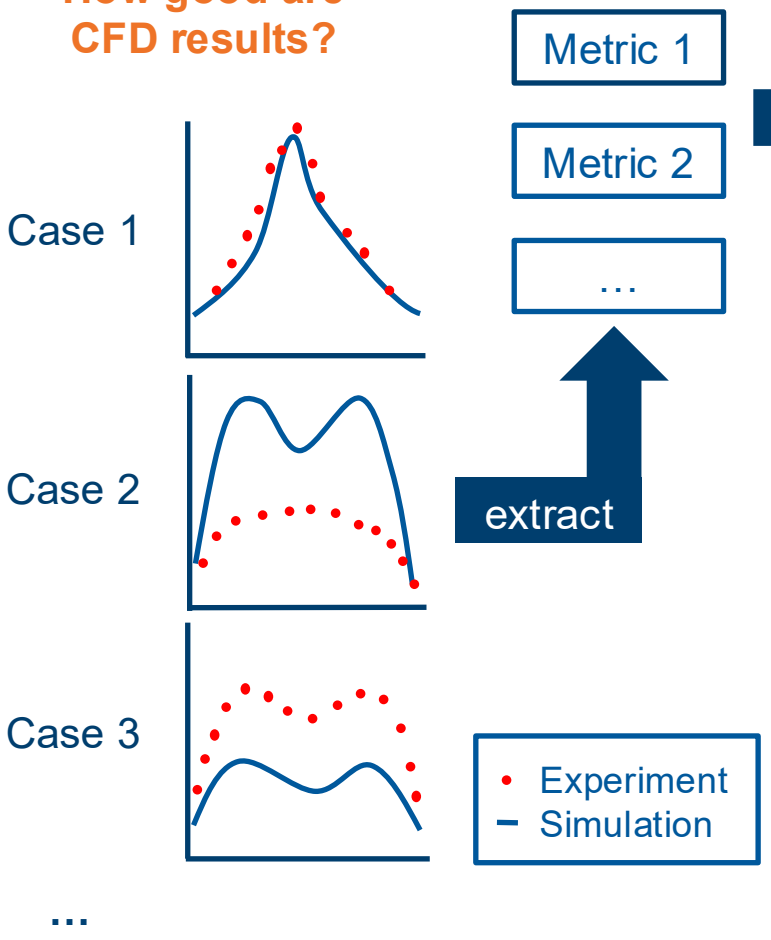


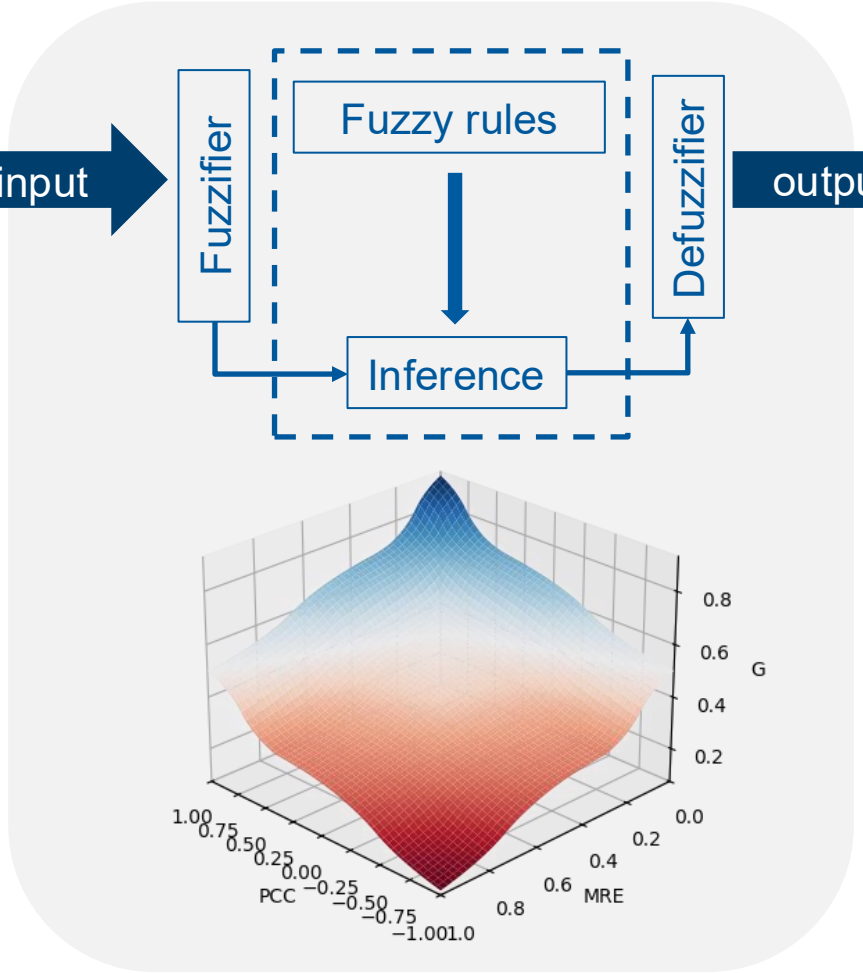
DRESDEN concept HZDR

SUSTAINABLE SOFTWARE DEVELOPMENT

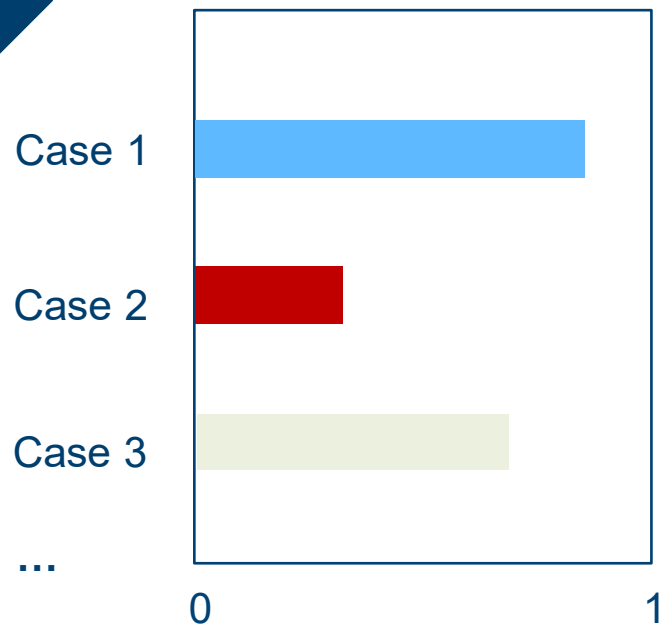
QUALITY MEASURES

How good are CFD results?





CFD performance for a closure model

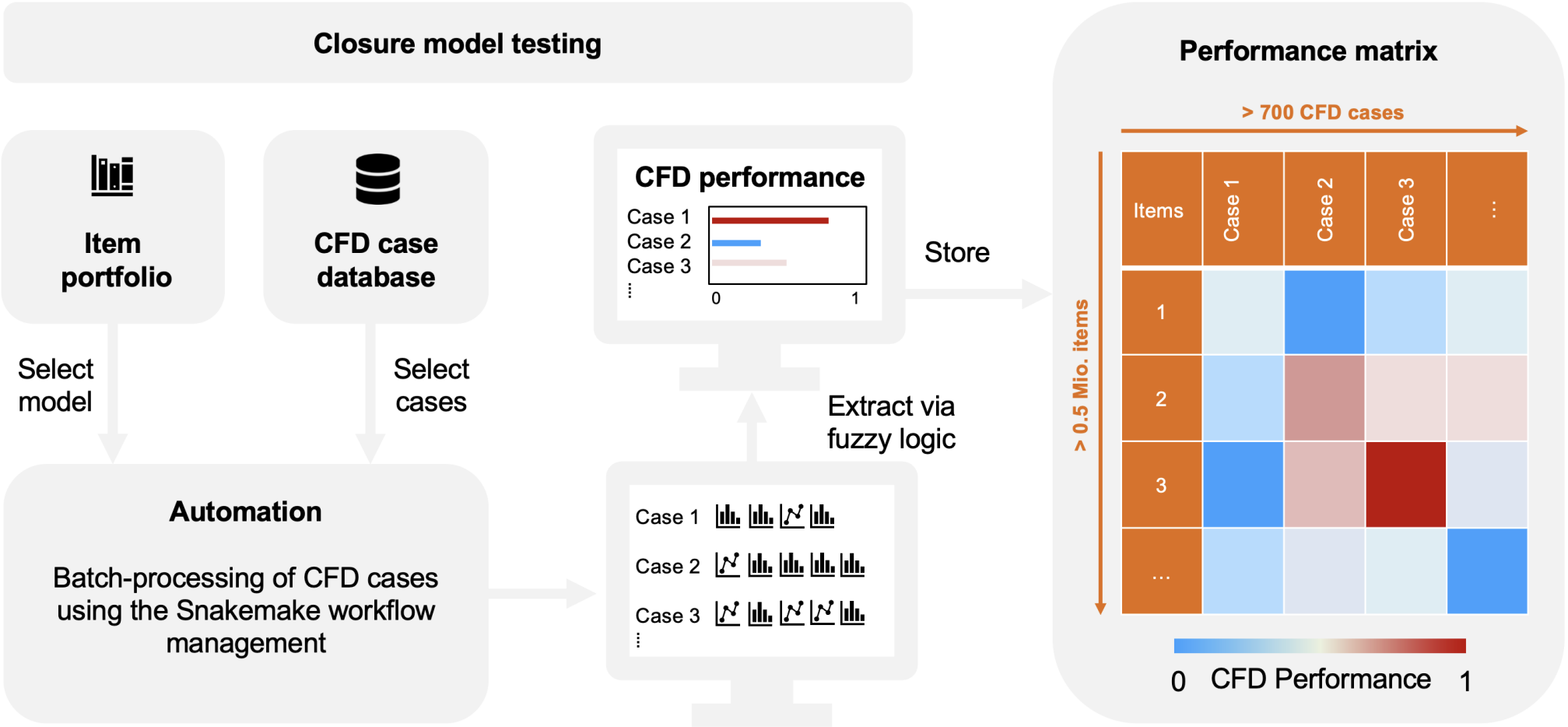


Hänsch et al. (2021). Chem. Eng. Science

SUSTAINABLE SOFTWARE DEVELOPMENT

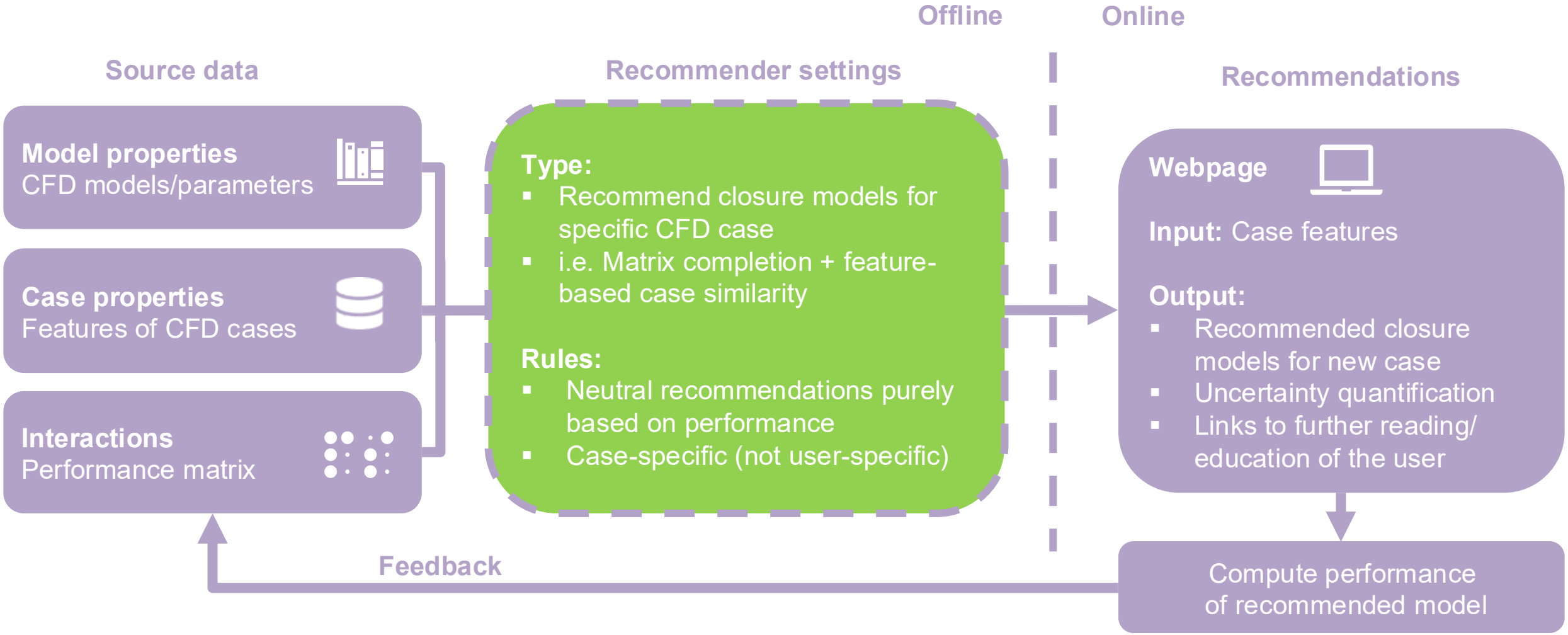
AI-SUPPORTED MODELLING

Hänsch et al. (2025). AI Thermal Fluids



SUSTAINABLE SOFTWARE DEVELOPMENT

AI-SUPPORTED MODELLING



Learn more about multiphase CFD at our

22nd Multiphase Flow Conference & Short Course: Modelling, Simulation, Experiment and Application

November 02 – 06, 2026, Dresden, www.hzdr.de/multiphase