technische universität dortmund

IANUS Simulation

Sim-a-a-S in the loop

Enhancing Rapid Prototyping of Complex Industrial Machines with Automatic Data Synthesis based on Numerical Simulation of Fluid Flow and Machine Learning

Markus Geveler, Stefan Turek, Tobias Herken – *CSAI 2021*

ZIM
Zentrales Innovationsprogramm Mittelstand

fakultät für mathematik

01. **Introduction**

Experiment vs Simulation of complex industrial machines

02. **Simulation-as-a-Service**

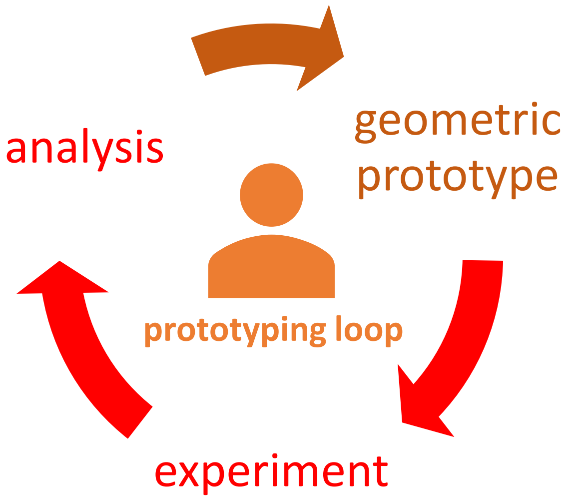
The engine that drives data synthesis

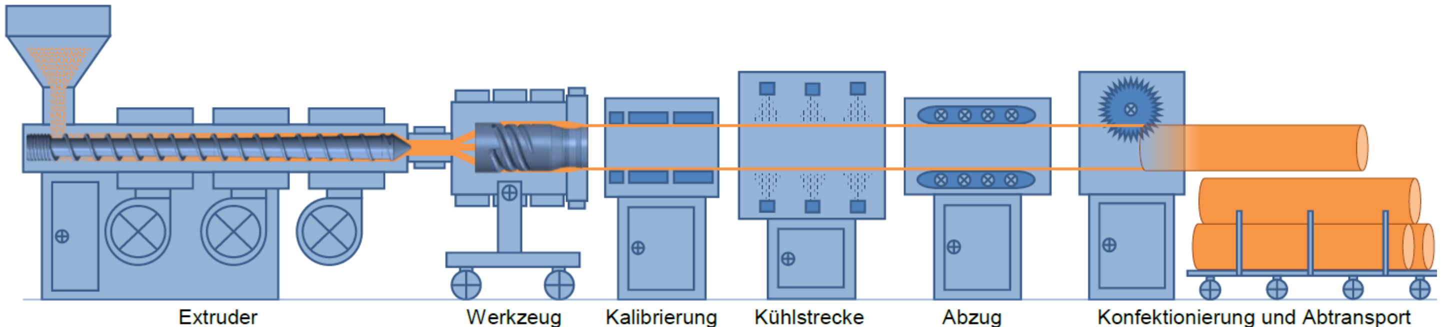
03. **AI assistants**

Machine Learning-driven assisting of Rapid Prototyping

Introduction

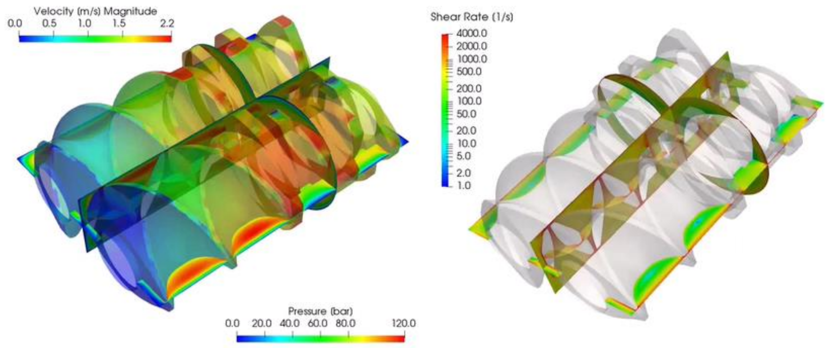
Experiment vs Simulation of complex industrial machines





Introduction

Rapid Prototyping based on simulation



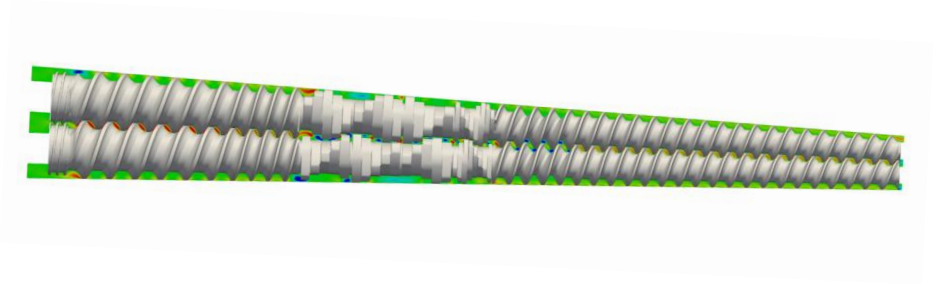
analyse simulation results

(batch of) geometric prototypes

rapid prototyping loop

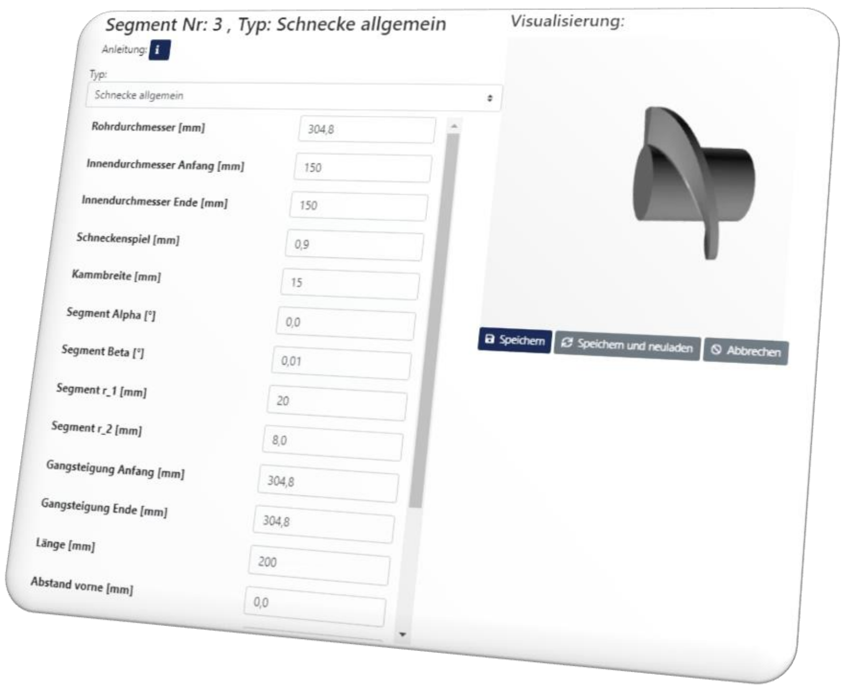
add (batch of) process data (sets)

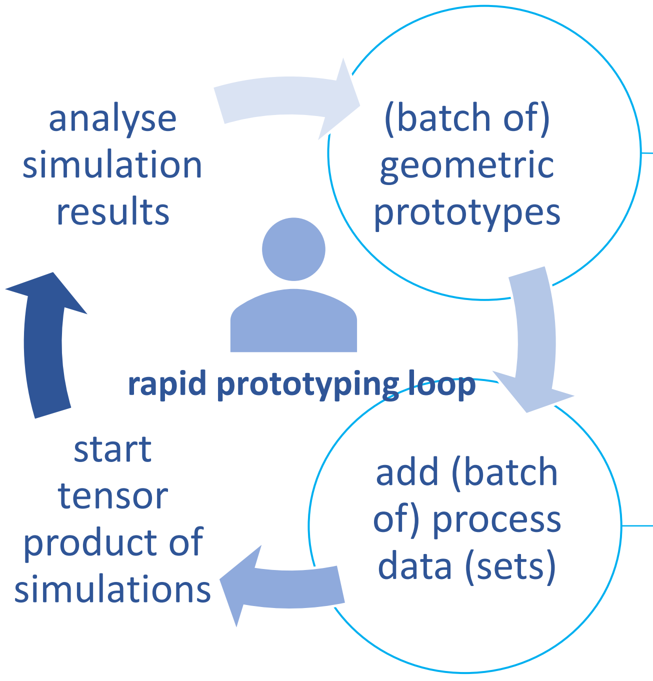
start tensor product of simulations

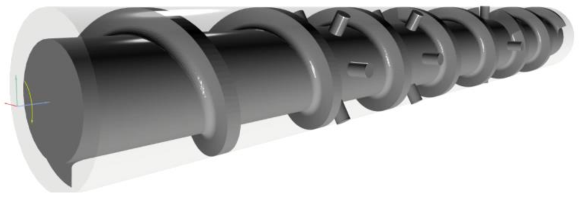


Digital Twin

Frontend and data layer





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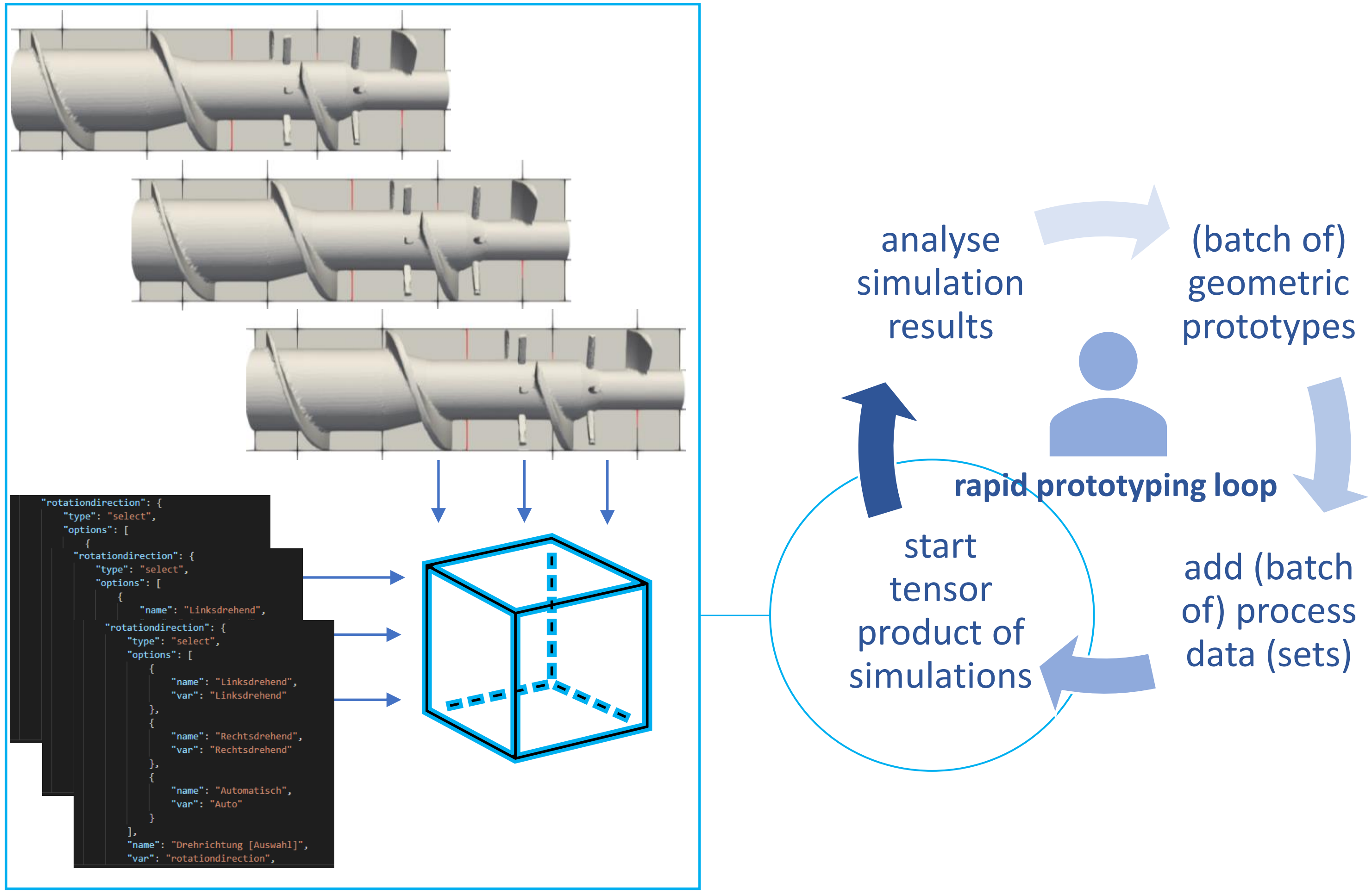
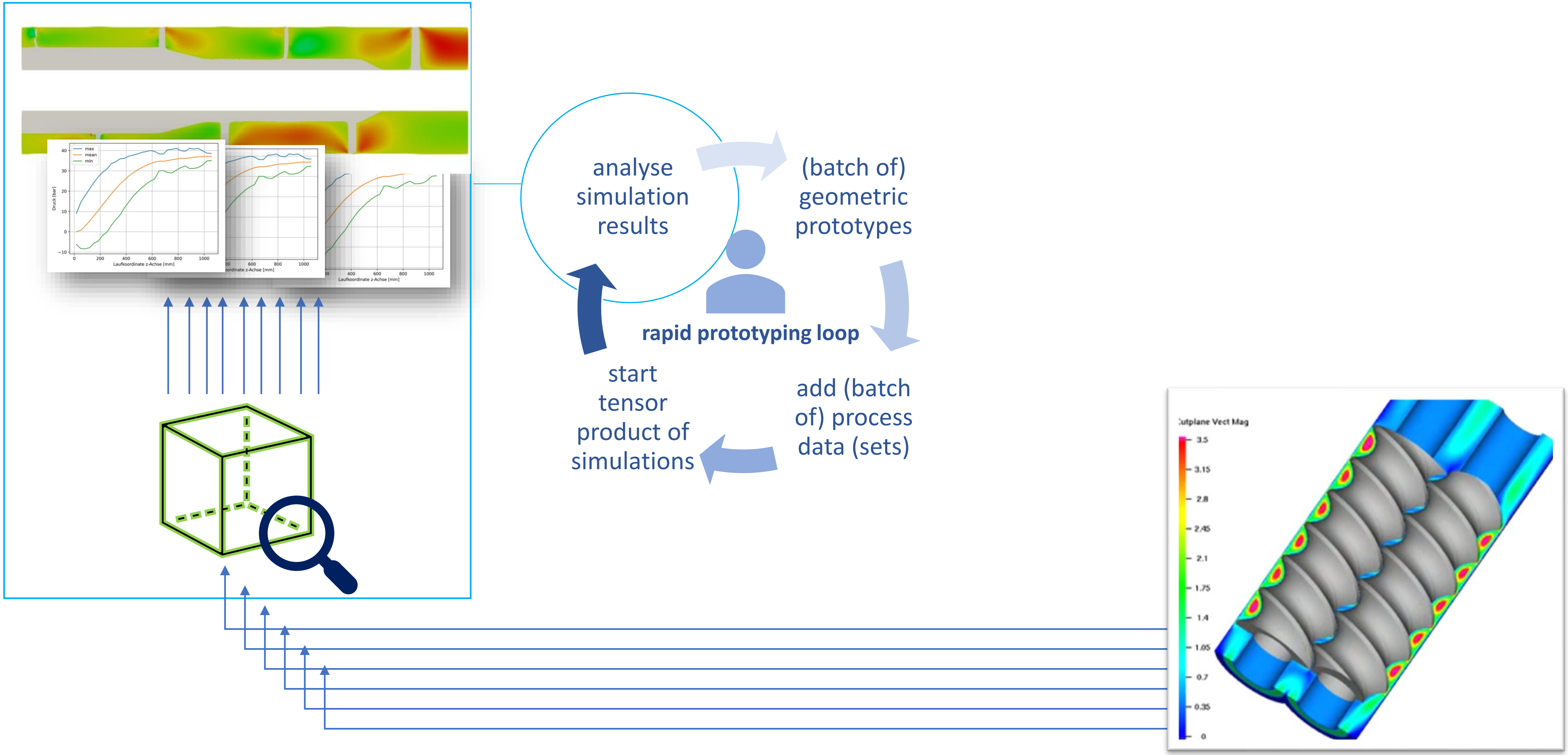
Simulation batch

The simulation data tensor



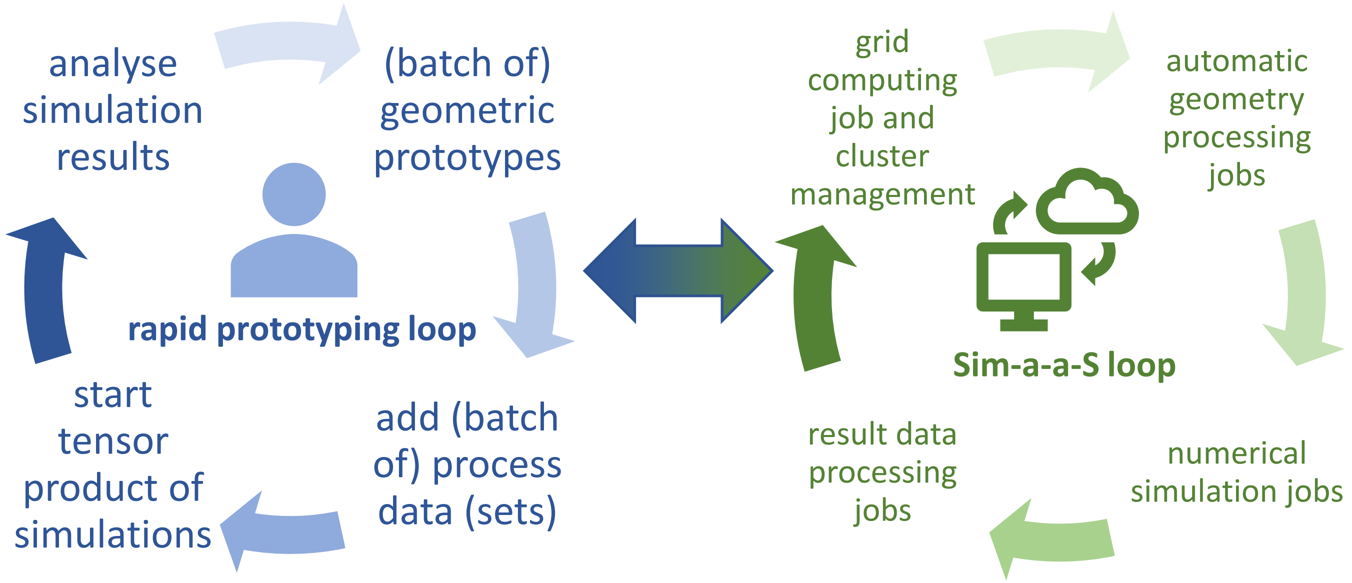
Results

The result data tensor



Simulation-as-a-Service

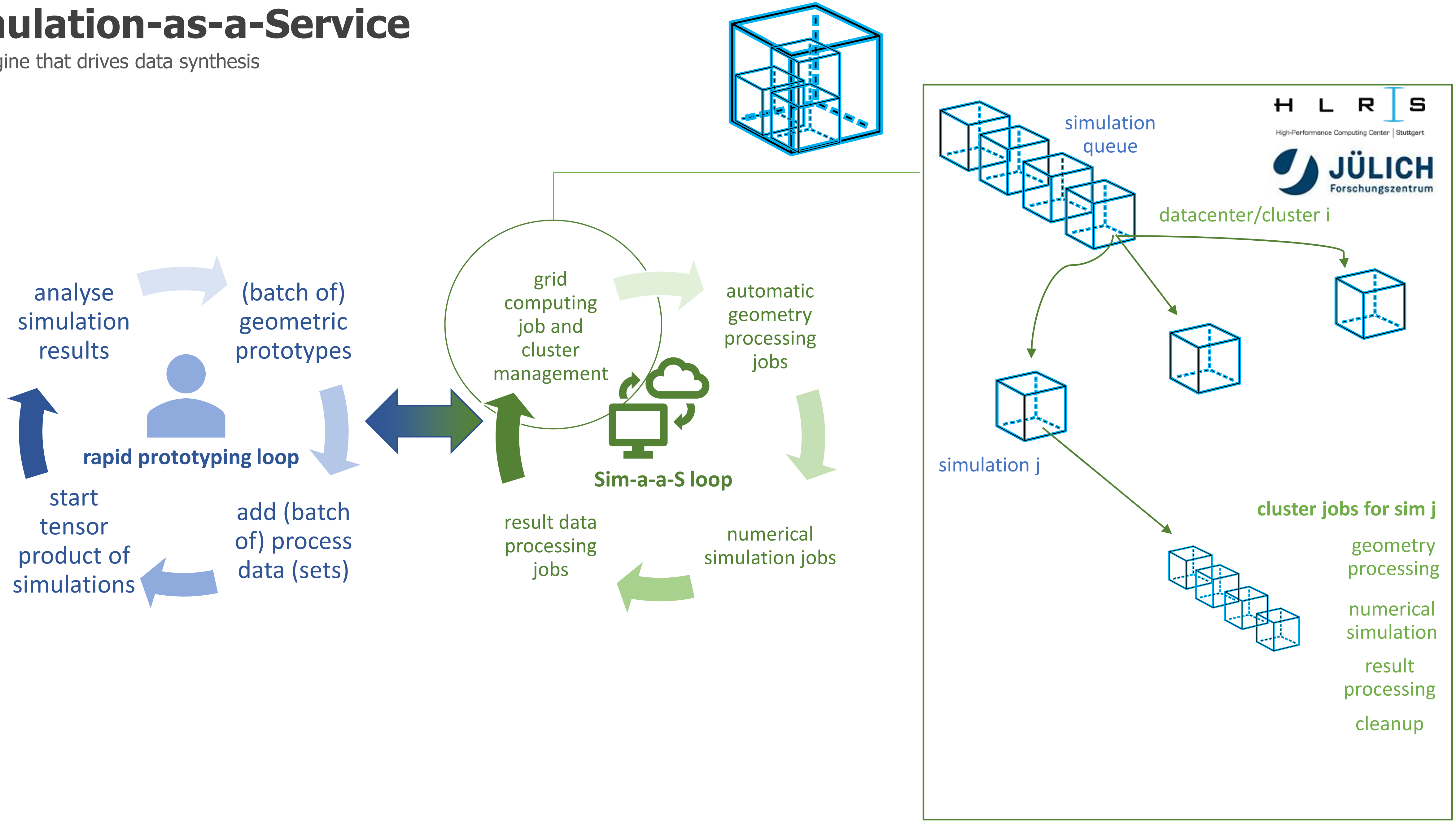
The engine that drives data synthesis: **Sim-a-a-S := I-a-a-S + S-a-a-S**



Geveler, M.; Turek, S.: *Fundamentals of a numerical cloud computing for applied sciences – Preparing cloud computing for Simulation-as-a-Service*, European Commission Workshop on Cloud Computing Research Innovation Challenges for WP 2018-2020, -, http://ec.europa.eu/digital-single-market/events/cf/public-consultation-on-cloud-computing-research-innovation-challenges-for-wp-2018-2020/stream-items.cfm?id=3, 2016

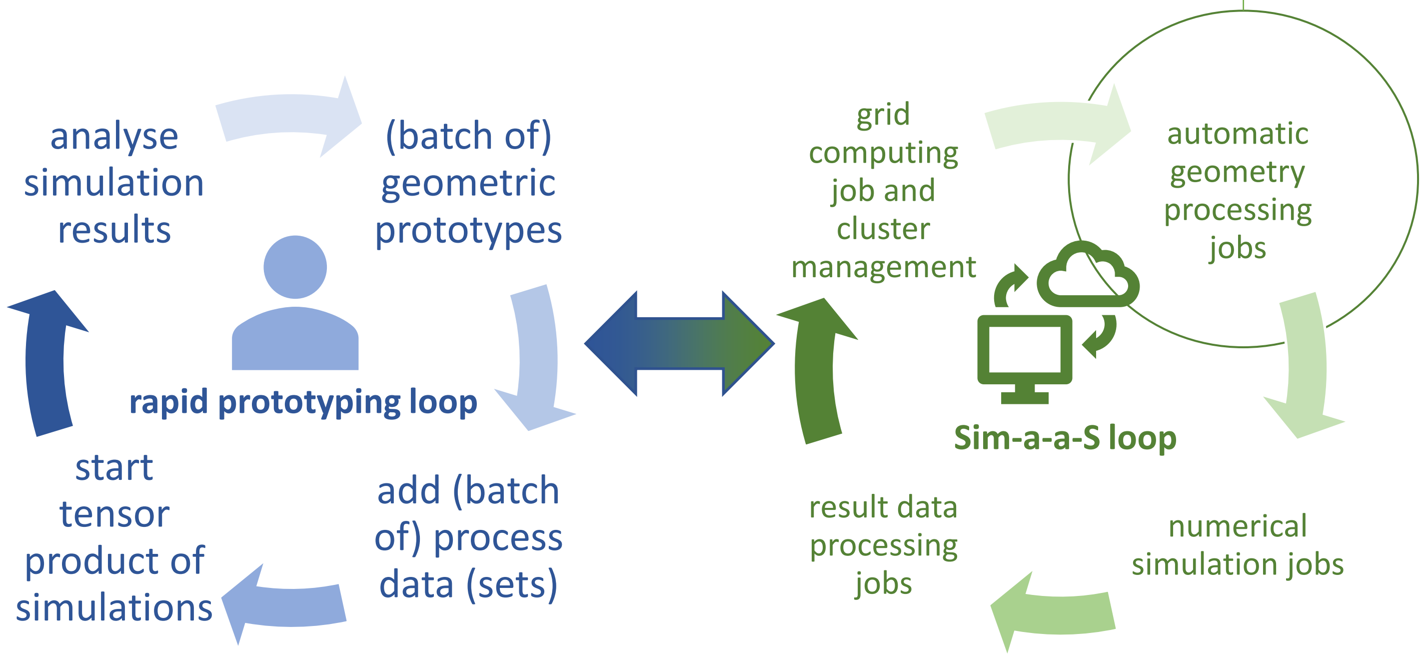
Simulation-as-a-Service

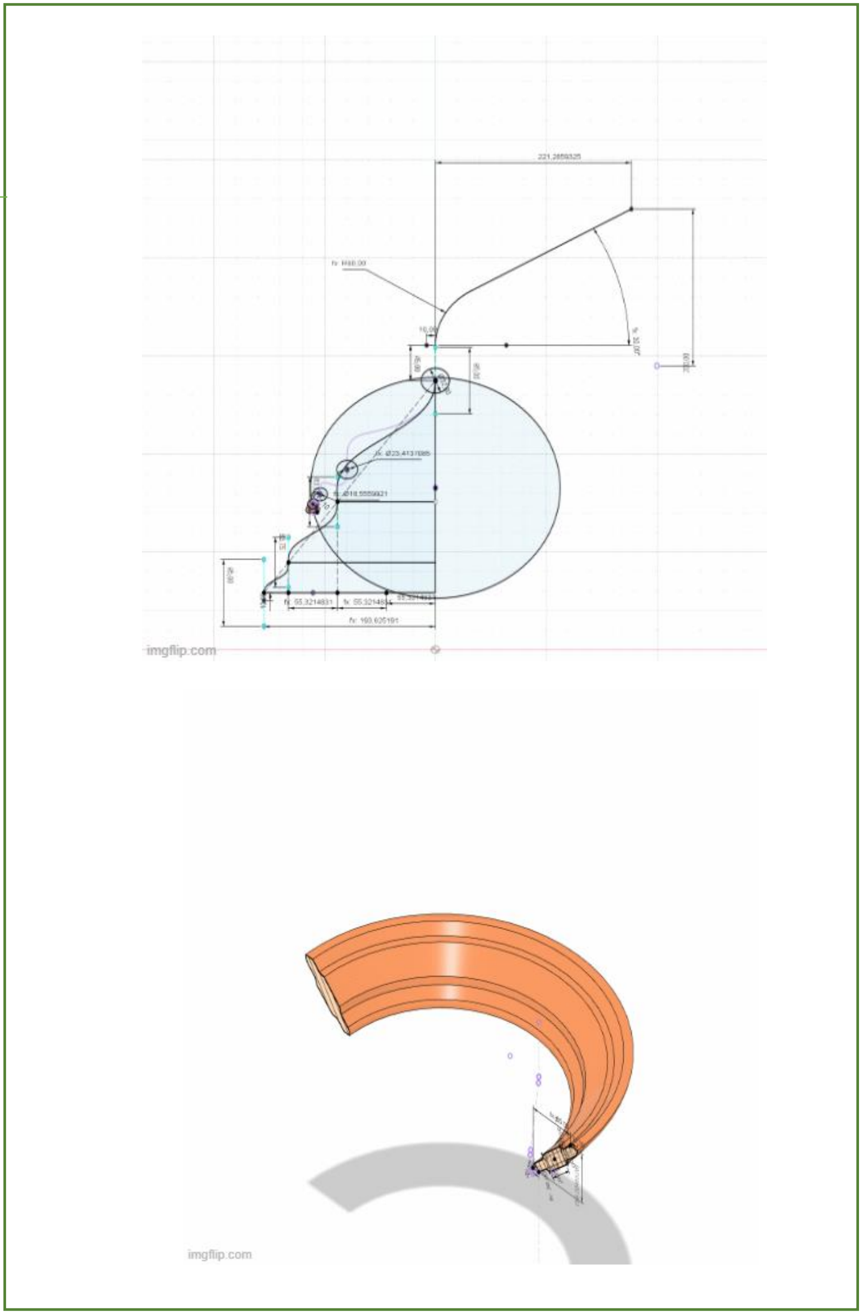
The engine that drives data synthesis



Digital Twin

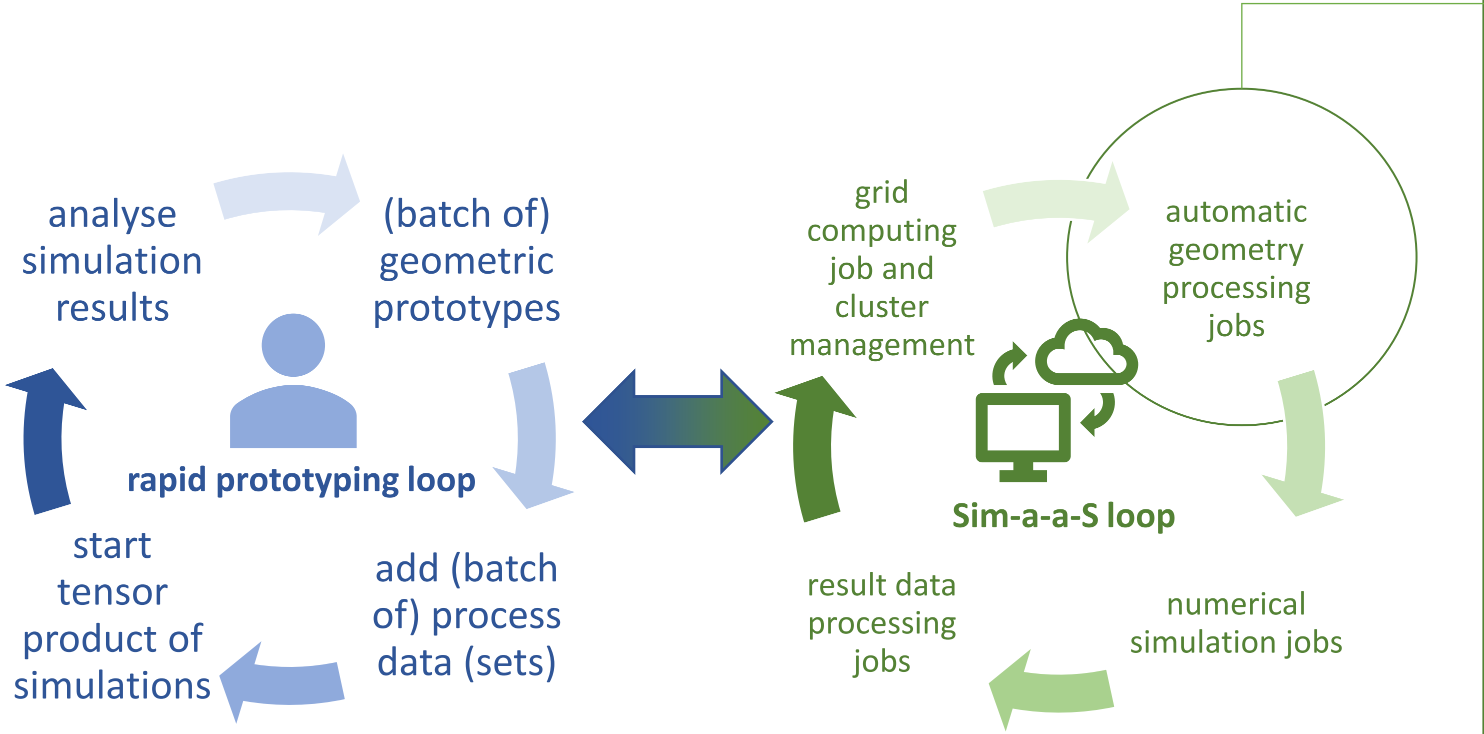
Geometric layer: Automatic geometry processing I

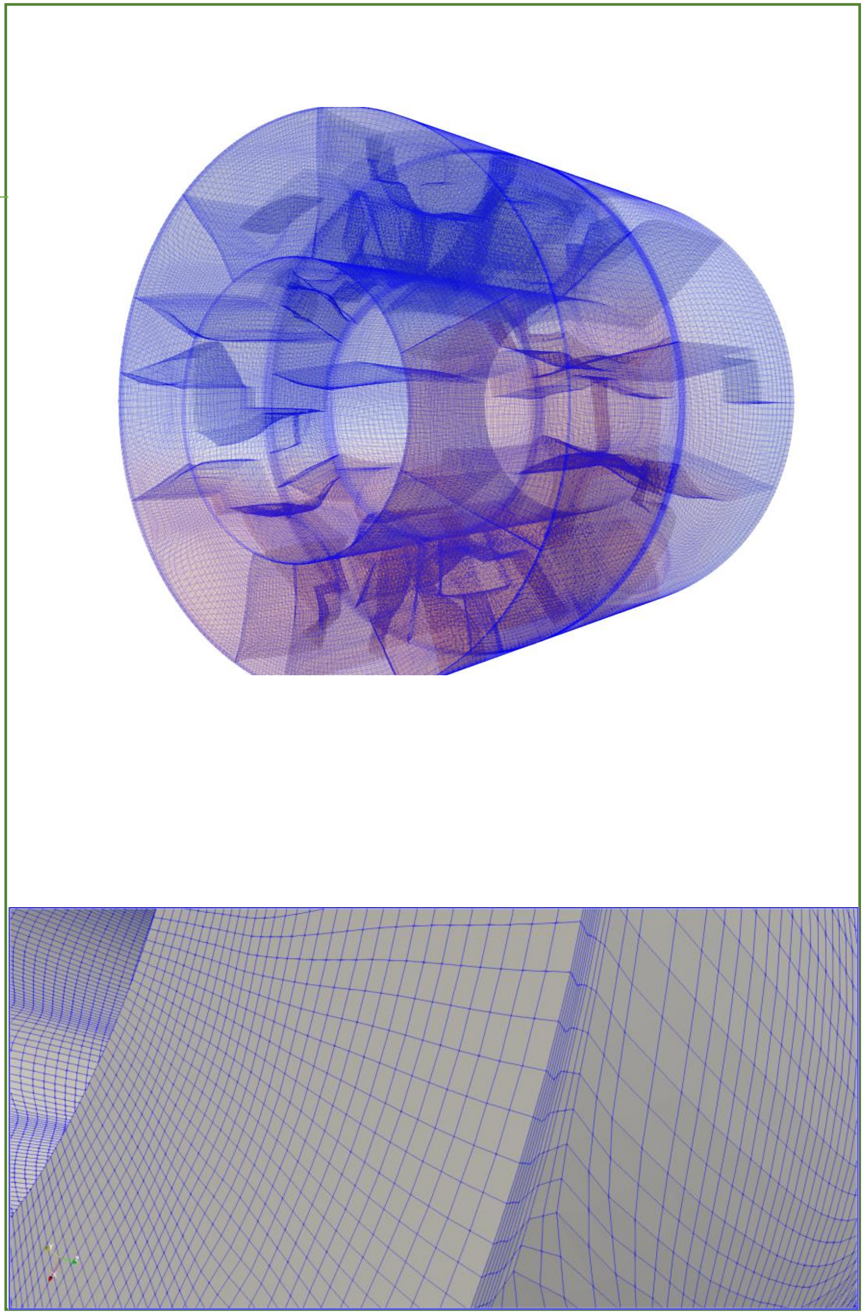




Digital Twin

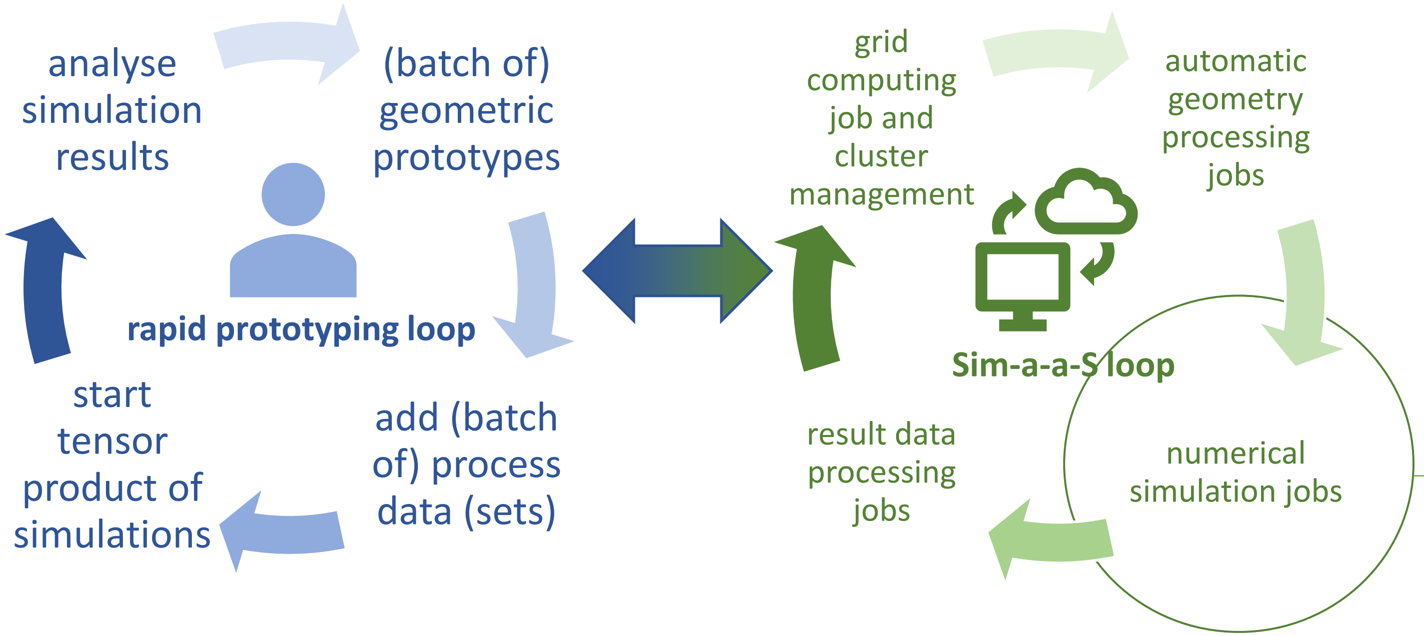
Geometric layer: Automatic geometry processing II





Sim-a-a-S

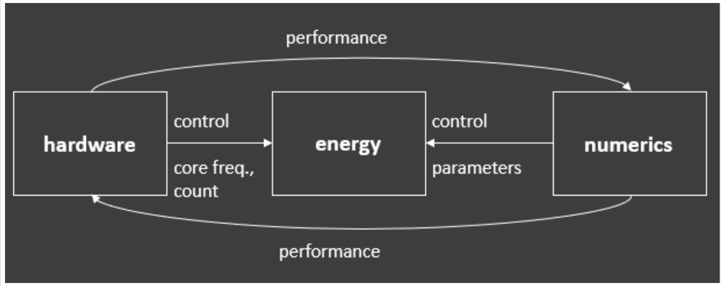
Numerical simulation of fluid flow: the behavioural layer of the Digital Twin



Solve NSEs efficiently

$$
\begin{aligned}
u_t - \nu \Delta u + u \cdot \nabla u + \nabla p &= f, \\
-\nabla \cdot u &= 0
\end{aligned}
$$

- recursive domain decomposition Newton-Krylov-***multigrid schemes***
- local **geometric multigrid** highly hardware-optimised and accelerated with GPUs or similar
- **smoother** determines overall efficiency



Sim-a-a-S

Numerical simulation of fluid flow: the behavioural layer of the Digital Twin: FEAT family

Sim-a-a-S loop

weak form

$$\int_\Omega \partial_t u \ v \ dx + \int_\Omega (u \cdot \nabla u) \ v \ dx - \nu \int_\Omega \Delta u \ v \ dx + \int_\Omega \nabla p \ v \ dx \ = \int_\Omega f \ v \ dx$$

$$\int_\Omega (\nabla \cdot u) \ q \ dx \qquad = 0$$

FEM

$$\begin{aligned} (\partial_t u_h, v_h) + (u_h \cdot \nabla u_h, v_h) + \nu(\nabla u_h, \nabla v_h) - (p_h, \nabla \cdot v_h) &= \quad (f, v_h) \\ -(q_h, \nabla \cdot u_h) &= \quad 0 \end{aligned}$$

matrix form

$$\begin{bmatrix} M & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \partial_t u \\ 0 \end{bmatrix} + \begin{bmatrix} K(u) + \nu L & B \\ -B^T & 0 \end{bmatrix} \begin{bmatrix} u \\ p \end{bmatrix} = \begin{bmatrix} F \\ 0 \end{bmatrix}$$

theta scheme

$$S(u) = \alpha M + \theta \Delta t (K(u) + \nu L)$$

$$g = [M - (1-\theta)\Delta t (K(u) + \nu L)] \cdot u^n + \theta \Delta t F^{n+1} + (1-\theta) \Delta t F^n.$$

$$\begin{bmatrix} S(u) & B \\ -B^T & 0 \end{bmatrix} \begin{bmatrix} u^{n+1} \\ p^{n+1} \end{bmatrix} = \begin{bmatrix} g \\ 0 \end{bmatrix}$$

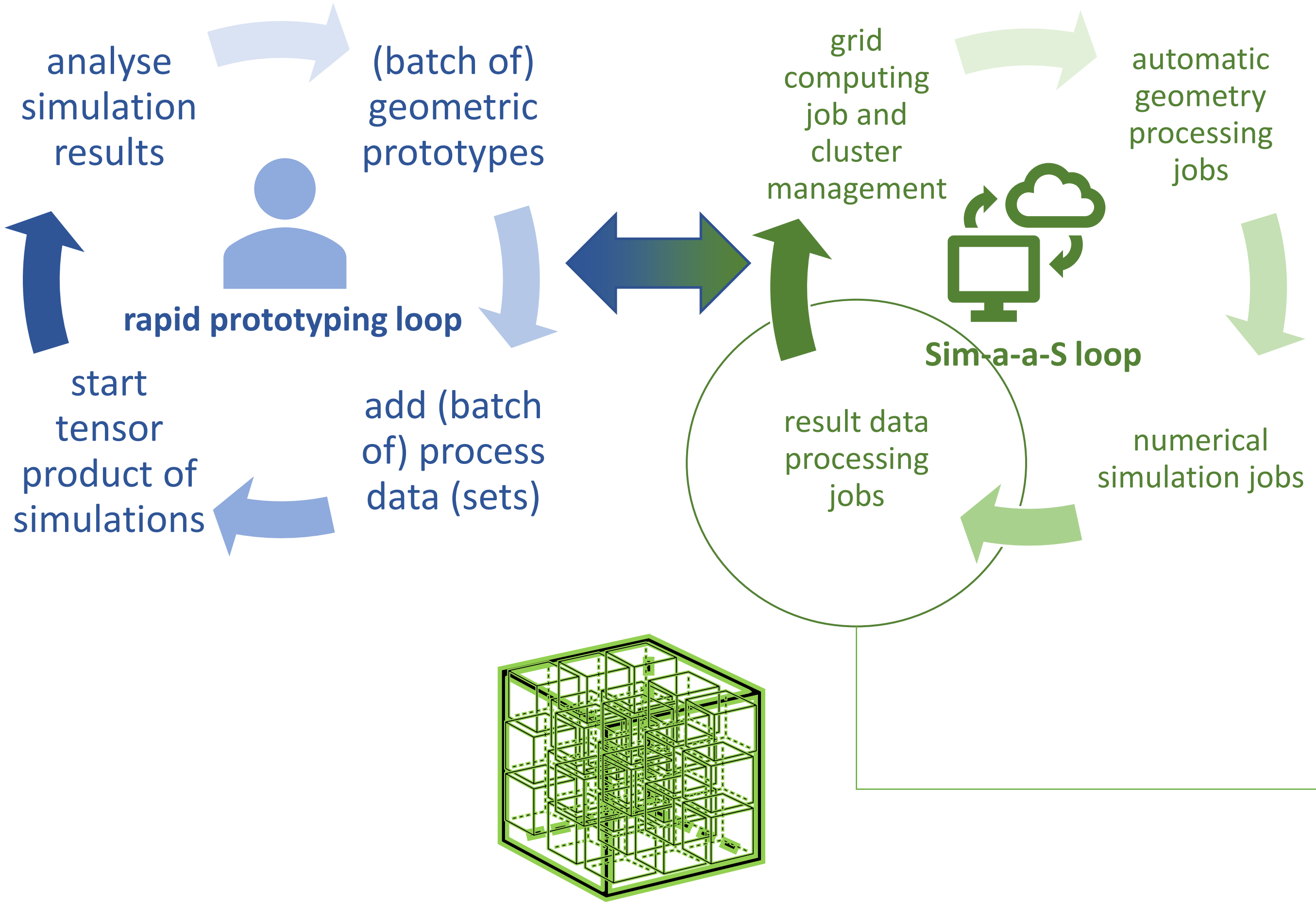
decouple
+ some magic

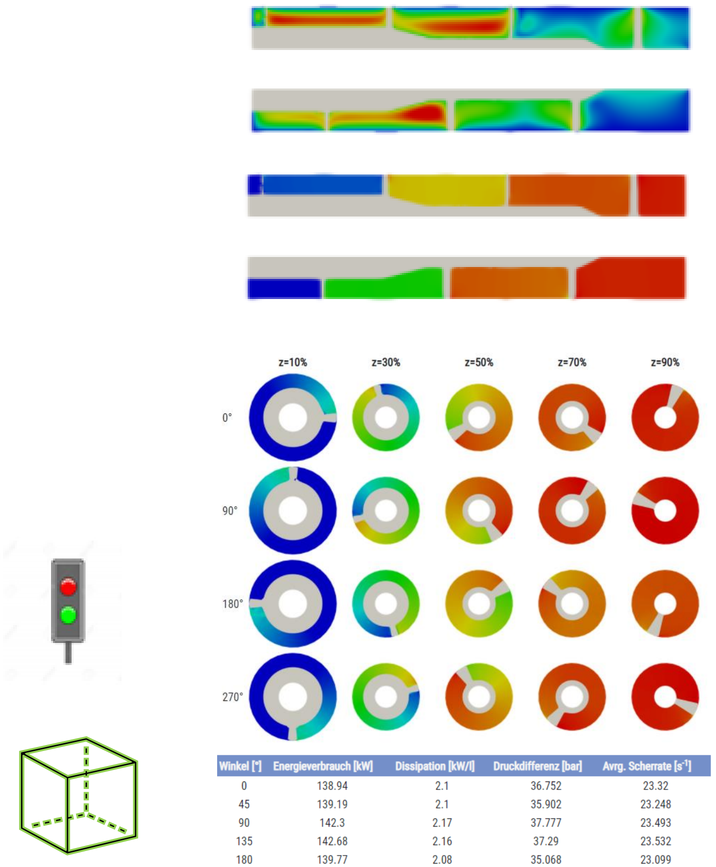
$$\boxed{\begin{aligned} S(\tilde{u}) \cdot \tilde{u} &= f_{FP} \\ P \cdot q &= \frac{1}{\Delta t} B^T \cdot u \end{aligned}}$$

- Pressure Poisson Problem Consumes most of the time
- Recursive Domain Decomposition Newton-Krylov-***Multigrid schemes***
- Local **geometric multigrid** highly hardware-optimised and accelerated with GPUs or similar
- **smoother** determines overall efficiency

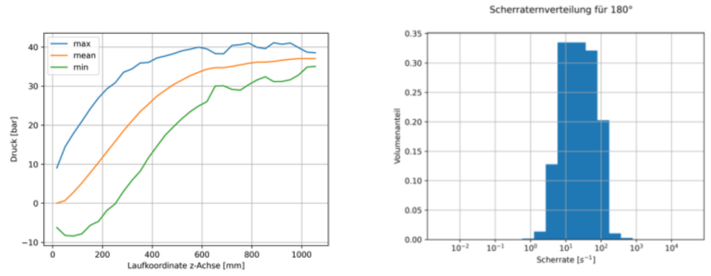
Sim-a-a-S

Data visualisation and -derivatives



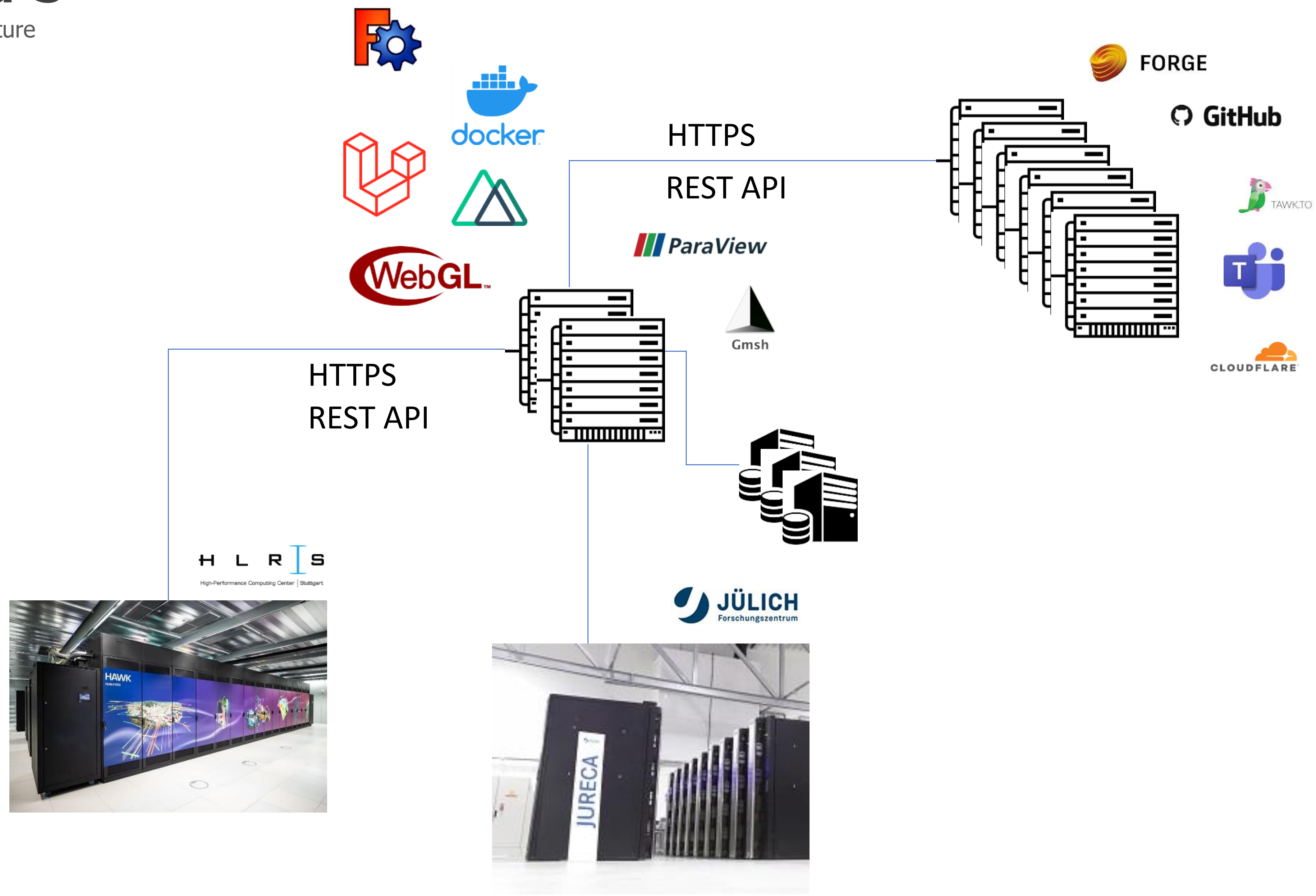


Winkel [°]	Energieverbrauch [kW]	Dissipation [kW/l]	Druckdifferenz [bar]	Avrg. Scherrate [s^{-1}]
0	138.94	2.1	36.752	23.32
45	139.19	2.1	35.902	23.248
90	142.3	2.17	37.777	23.493
135	142.68	2.16	37.29	23.532
180	139.77	2.08	35.068	23.099
225	141.1	2.13	36.746	23.264
270	140.81	2.15	37.313	23.469
315	142.3	2.18	38.244	23.723
Avg	140.89	2.13	36.89	23.39
Std	1.38	0.03	0.95	0.18



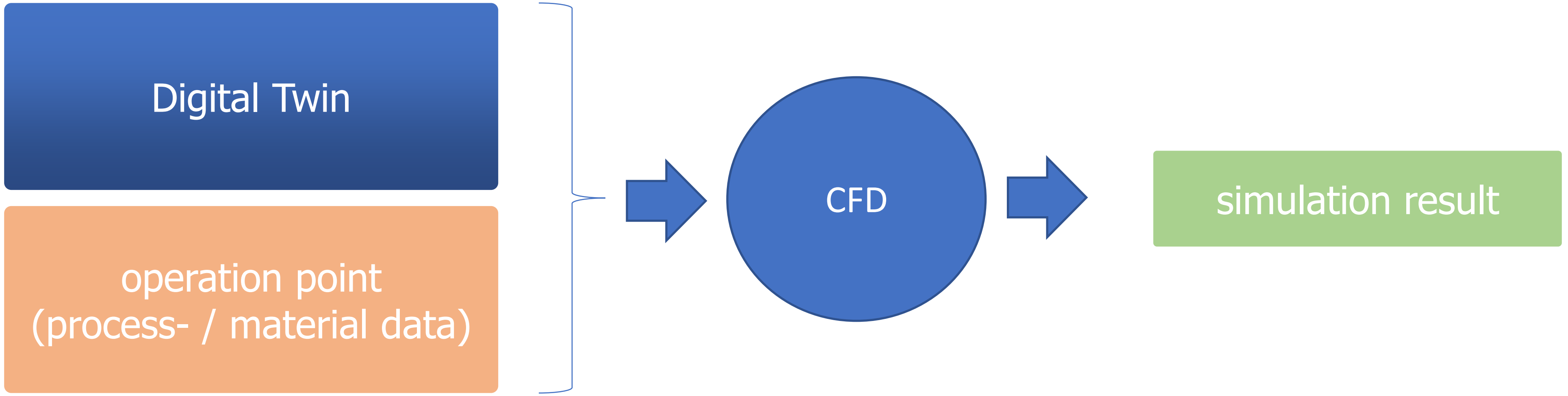
Sim-a-a-S

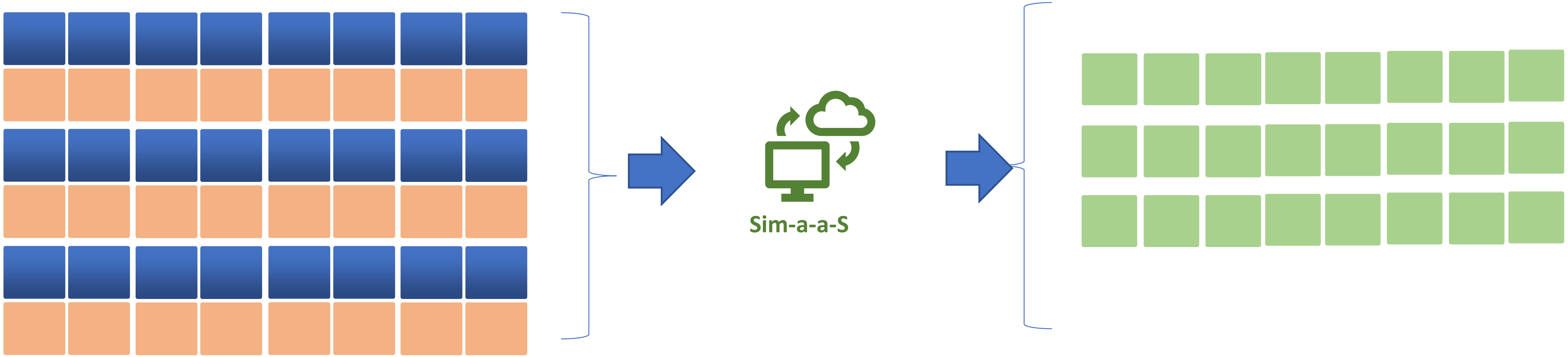
System Architecture



AI-based assistance systems

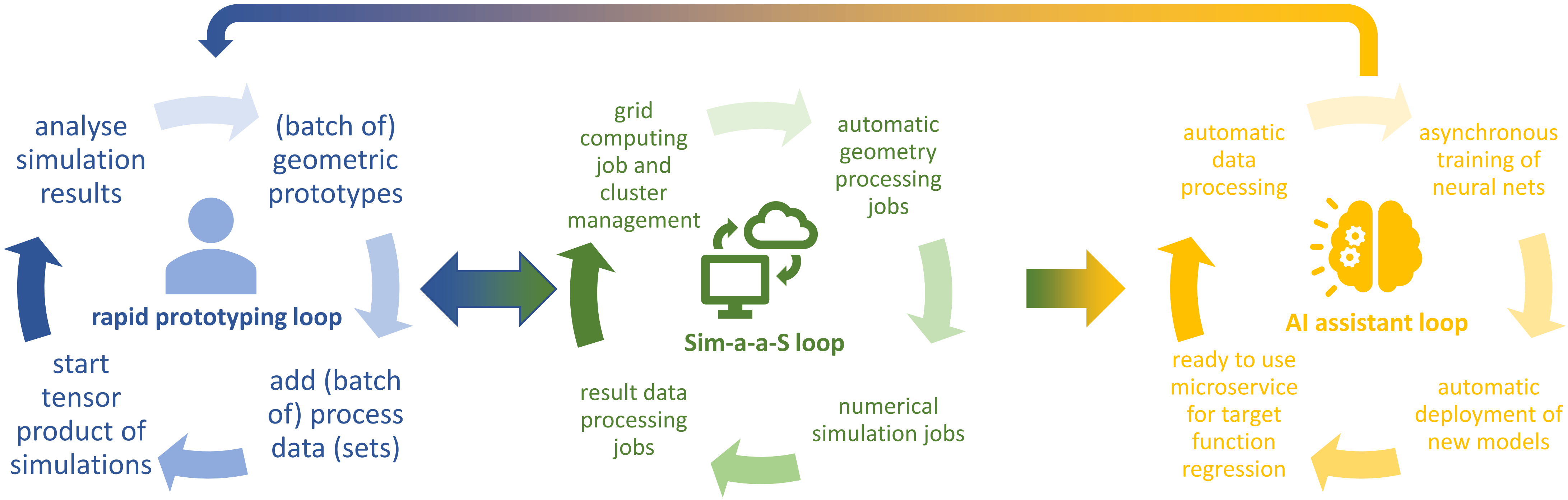
Sim-a-a-S increases simulation throughput and allows for fast data synthesis **+ standardized data**





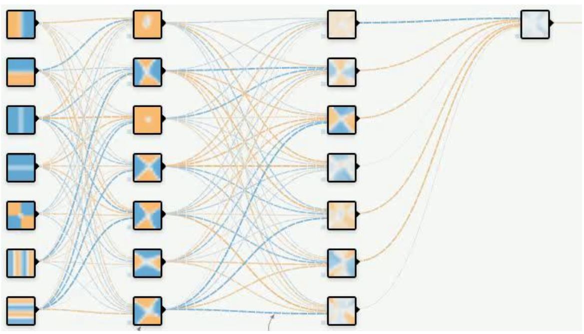
AI-based assistance systems

Connected to Sim-a-a-S

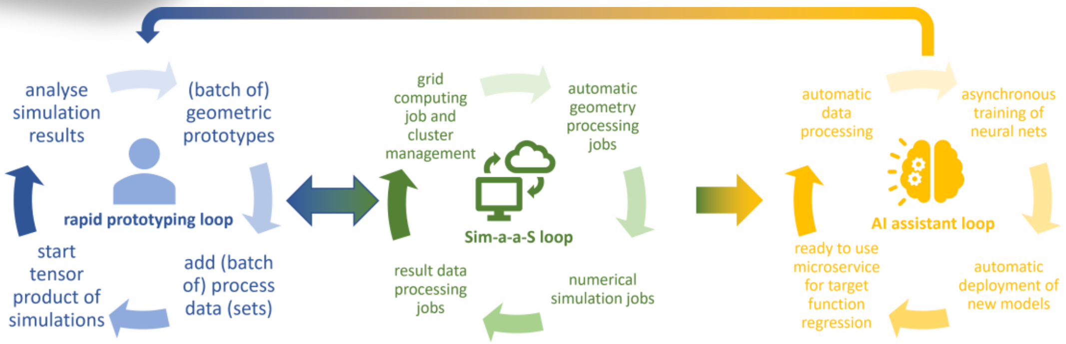


AI-based assistance systems

Connected to Sim-a-a-S



readily trained neural net
=
instant response model for simple answer



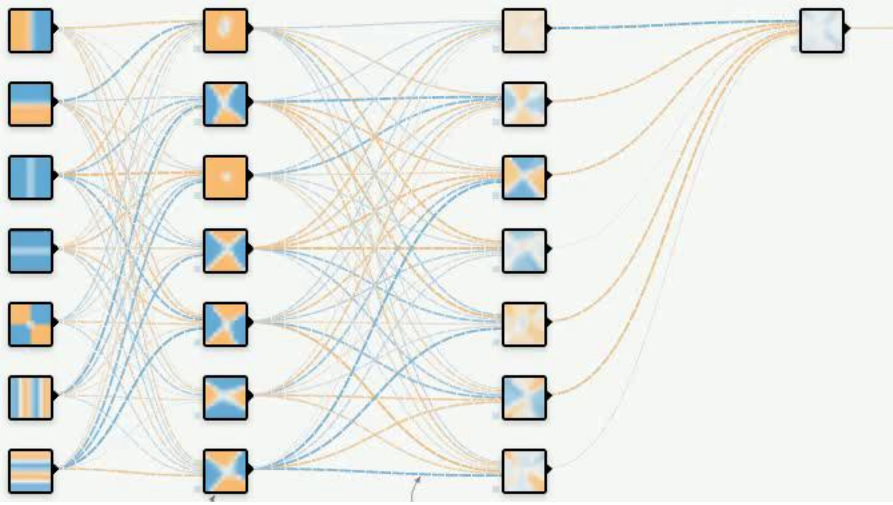
AI-based assistance systems

Connected to Sim-a-a-S

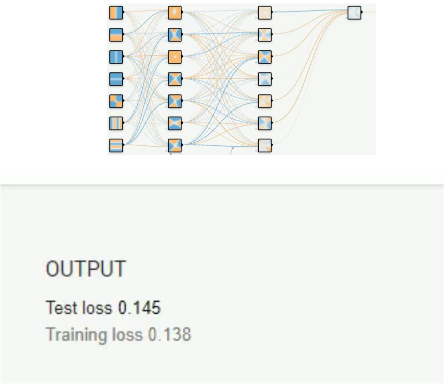
max temperature gradient,
min washing time,
pressure estimate in axial direction,
„go!“, …

Digital Twin (parametric)

operation point

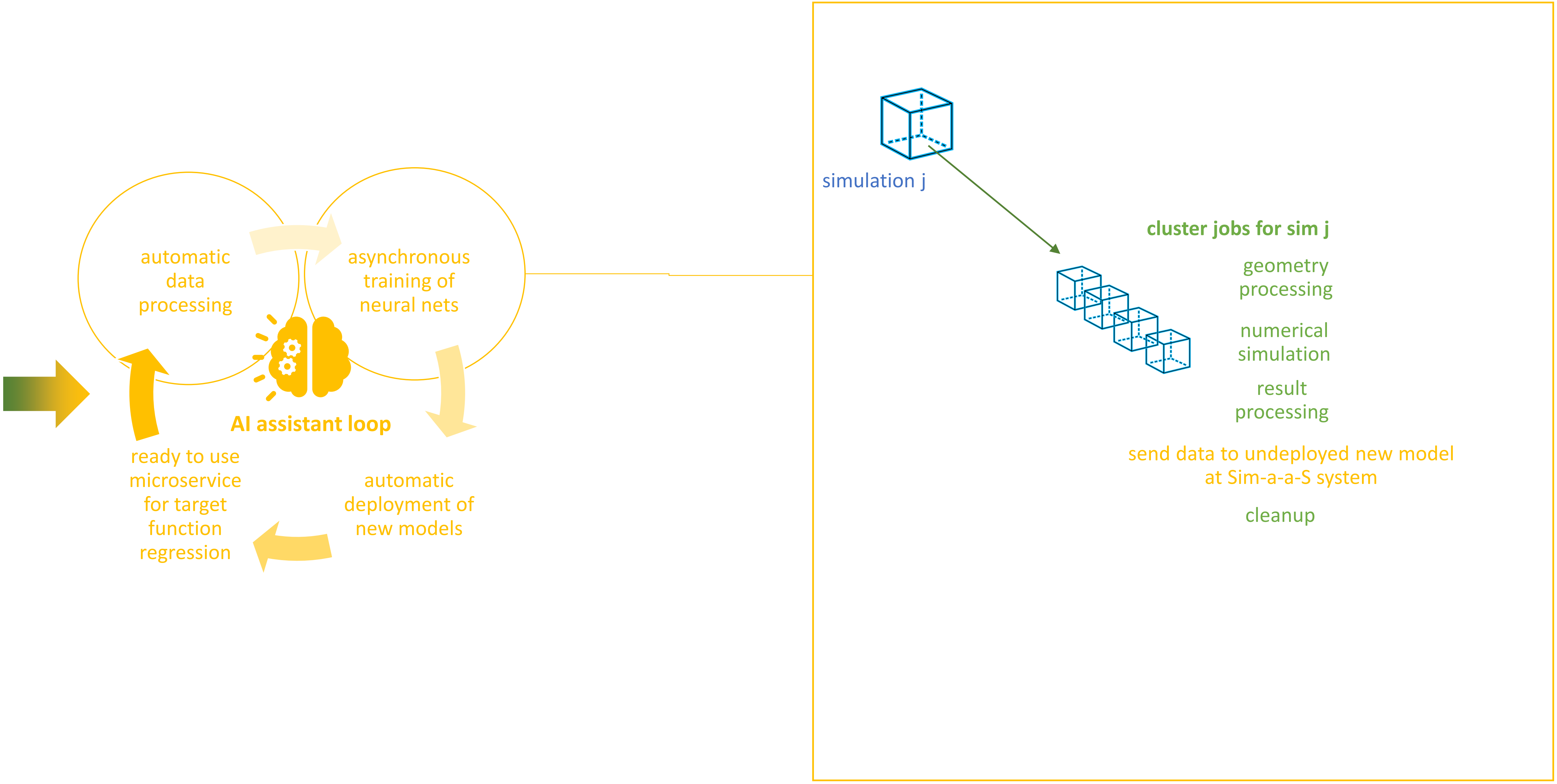


simple target function value(s) e.g. scalar quality-metrics, go/nogo, simple discrete representations



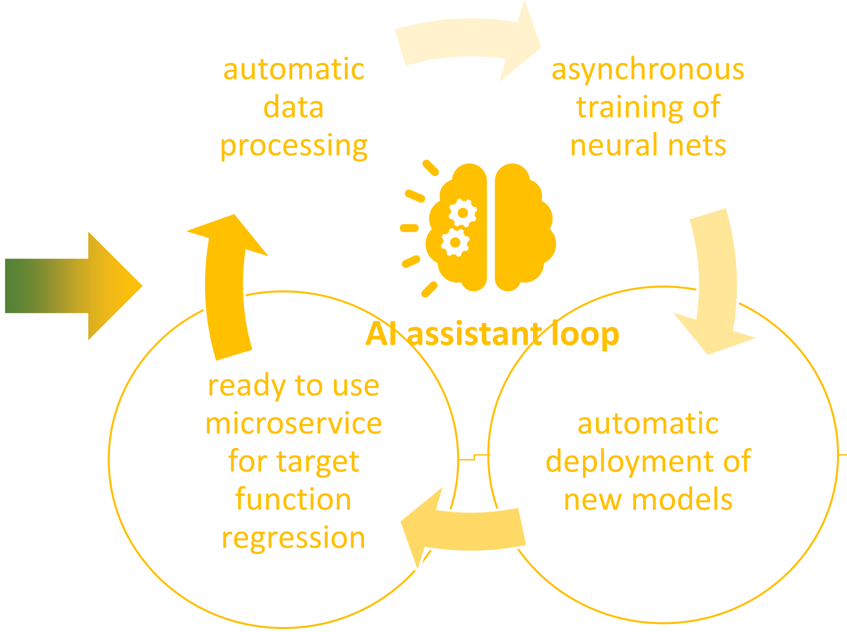
AI-based assistance systems

Connected to Sim-a-a-S



AI-based assistance systems

Connected to Sim-a-a-S



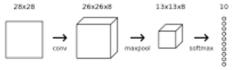
1) incremental training at the Sim-a-a-S gateway system

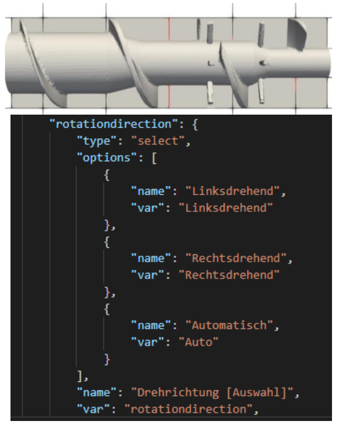
2) re-training starting at data saturation point or nightly

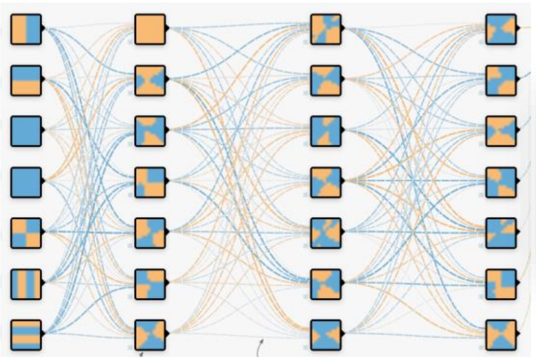
3) readily trained models generate pull request

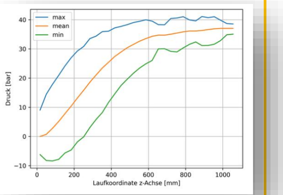
4) new models go to new Sim-a-a-S system version at update time (2-weekly)

Keras TensorFlow Flask

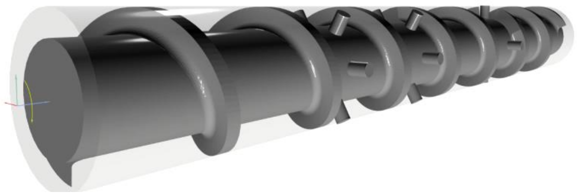




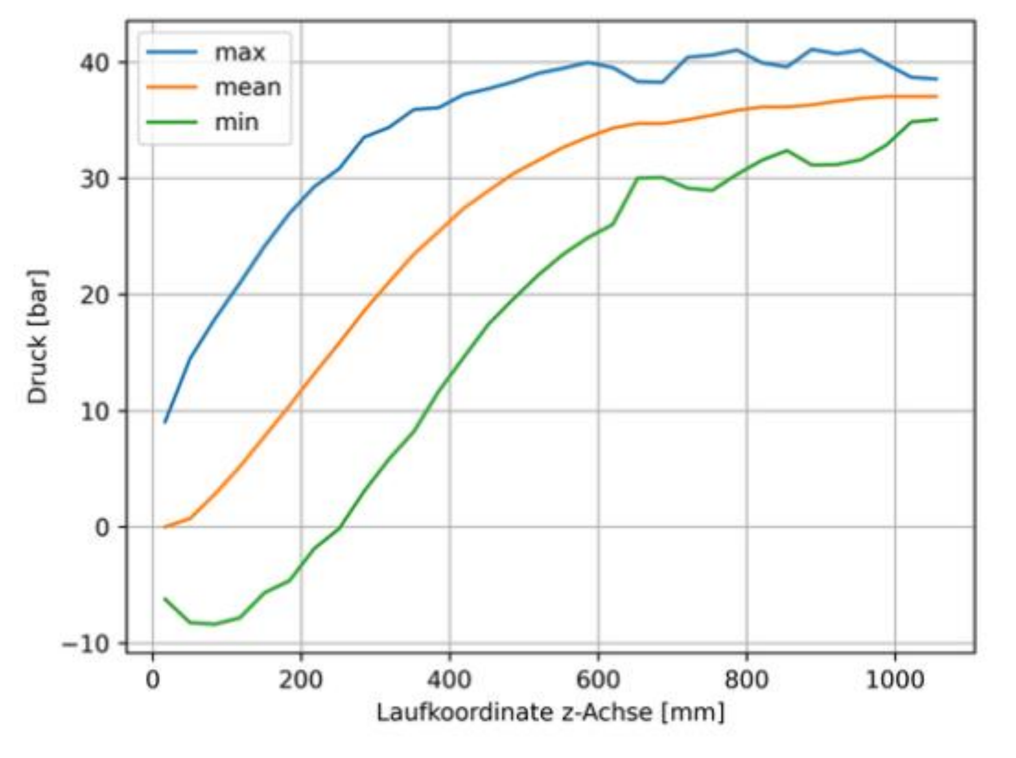




Results



First alpha assistants predict simple indicators at high accuracy



Automatic Simulation ready for

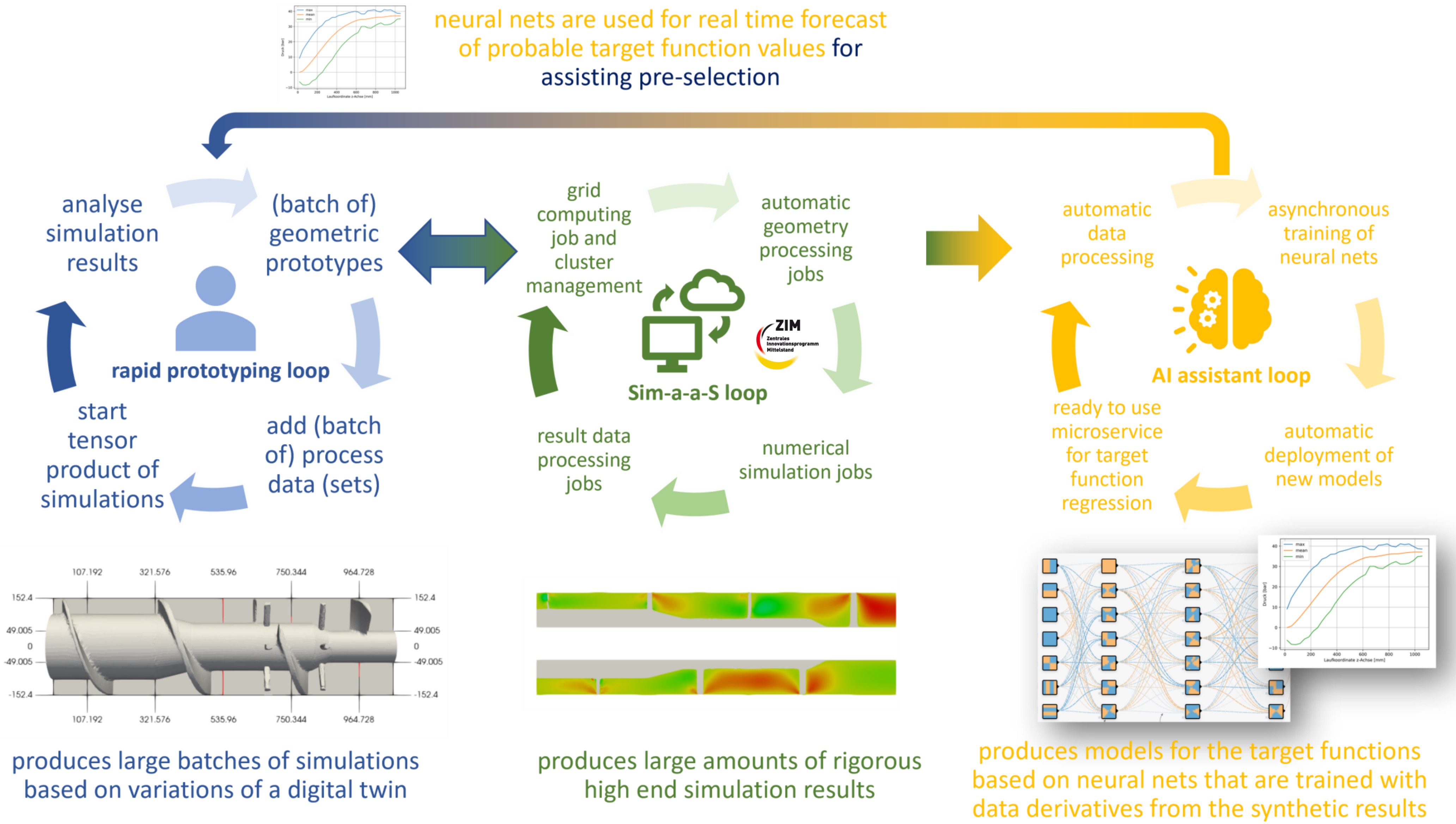
- Extrusion Dies
- Single Screw Extruders
- Hotrunner systems
- Excenterscrewpumps

- Twin Screw Extruders BETA
- Centrifugal pumps BETA
- Blow Mold ALPHA

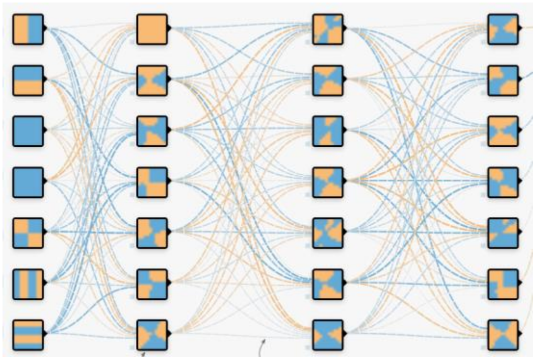
AI Assistants in ALPHA for

- Extrusion Dies
- Single Screw Extruders
- Blow Mold

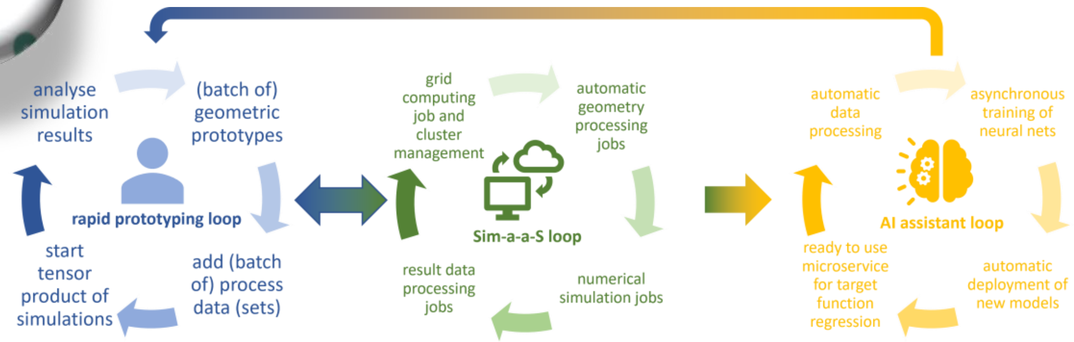
Summary


neural nets are used for real time forecast of probable target function values for assisting pre-selection
analyse simulation results
(batch of) geometric prototypes
rapid prototyping loop
start tensor product of simulations
add (batch of) process data (sets)
grid computing job and cluster management
automatic geometry processing jobs
ZIM
Zentrales Innovationsprogramm Mittelstand
Sim-a-a-S loop
result data processing jobs
numerical simulation jobs
automatic data processing
asynchronous training of neural nets
AI assistant loop
ready to use microservice for target function regression
automatic deployment of new models
107.192
321.576
535.96
750.344
964.728
152.4
49.005
0
-49.005
-152.4
produces large batches of simulations based on variations of a digital twin
produces large amounts of rigorous high end simulation results
produces models for the target functions based on neural nets that are trained with data derivatives from the synthetic results

Outlook



Construction parameter proposal



Thank you

https://ianus-simulation.de/en/stroemungsraum/