Generation of a large synthetic dataset for learning physics-based optimal inference of 4D flow MRI

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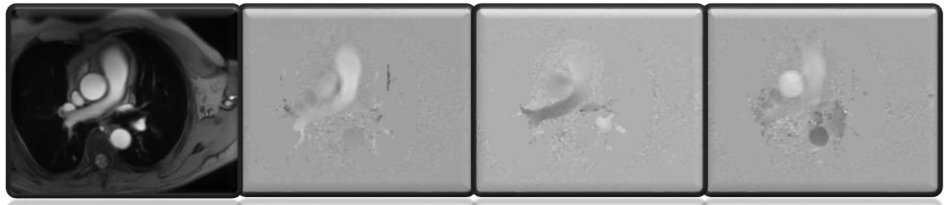
Pietro Dirix[1], Stefano Buoso[1], Gloria Wolkerstorfer[1], Michael Hansen[2] & Sebastian Kozerke[1]

Institute for Biomedical Engineering, University and ETH Zurich[1] and Microsoft Research[2]

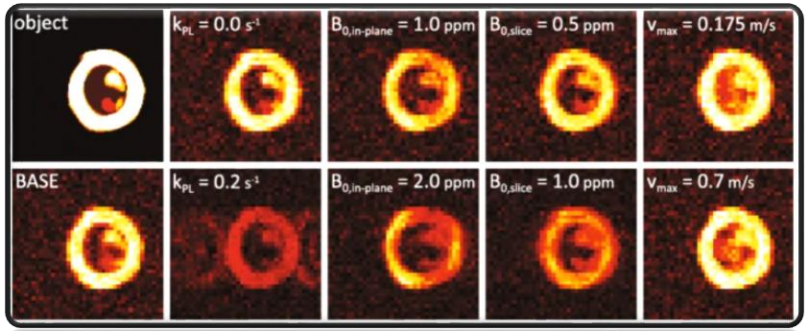
Cardiovascular Magnetic Resonance Group

Blood flow quantification



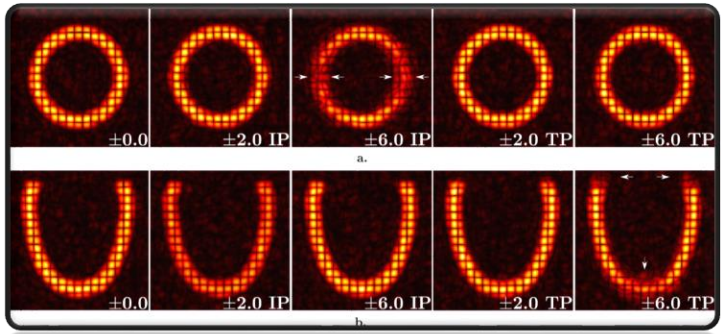
Perfusion Imaging

[Fluetterer et al. 2021]



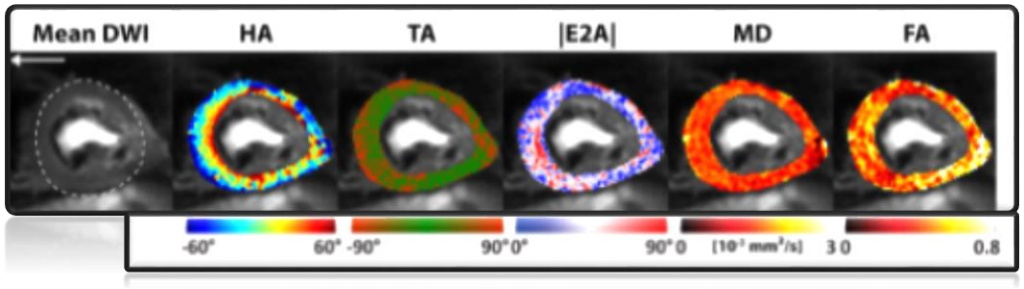
Motion and strain mapping

[Berberoglu et al. 2021]



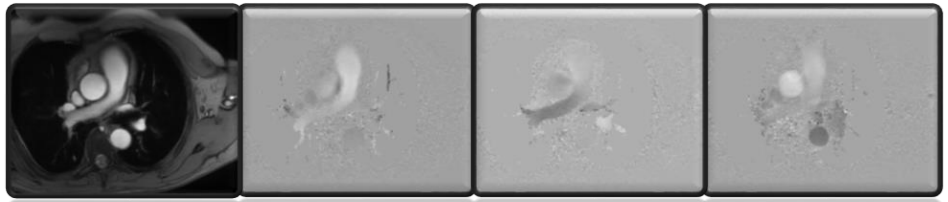
Diffusion tensor imaging

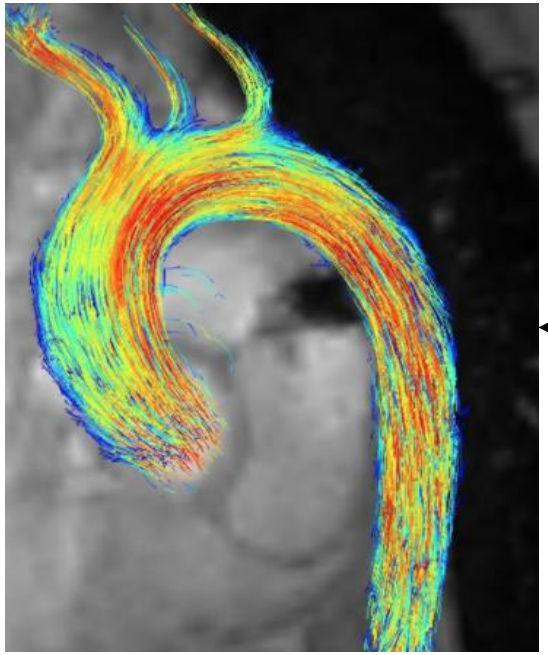
[van Gorkum et al. 2021]



Cardiovascular Magnetic Resonance Group

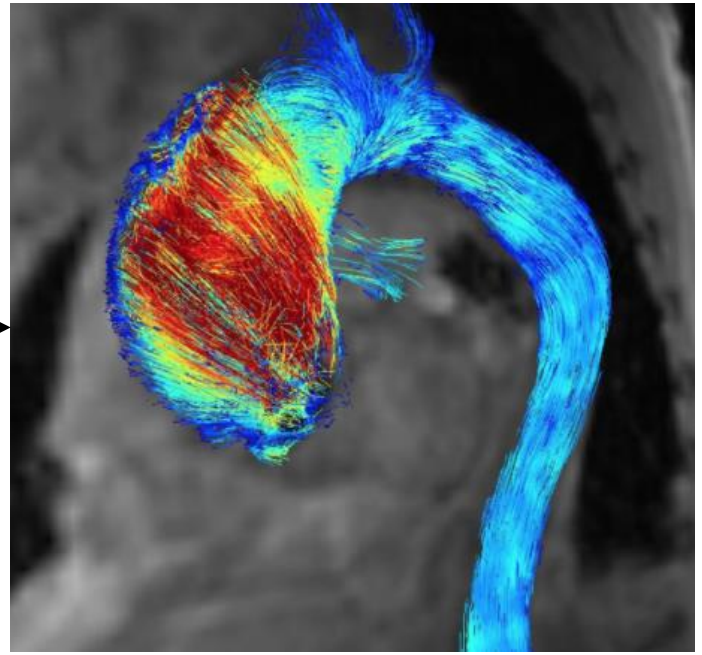
Blood flow quantification





4D flow MRI

[Markl et al, 2012]

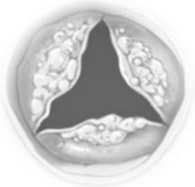


Healthy aorta

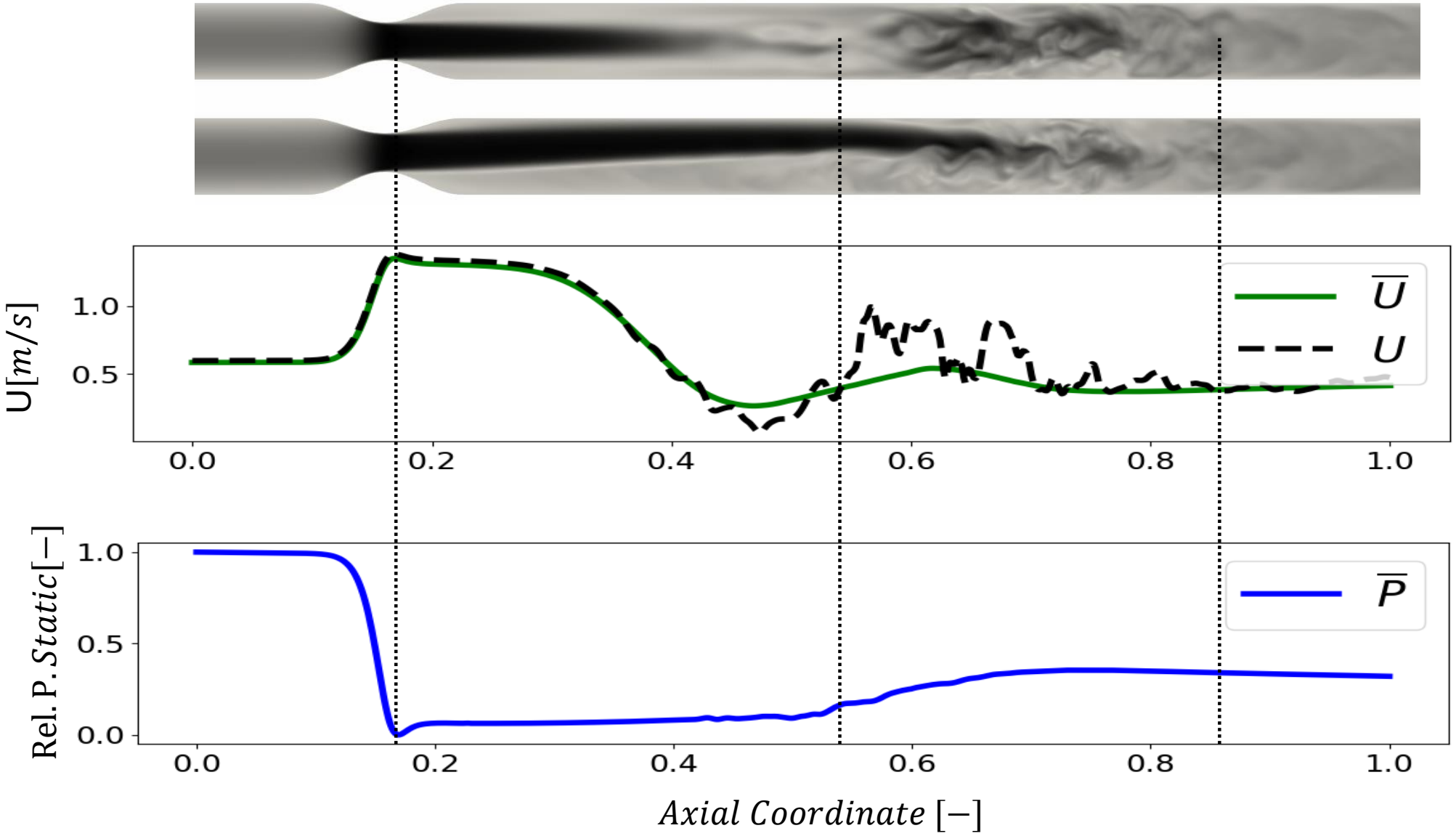
Stenotic dialated aorta

Calcific Aortic Valve Disease (CAVD)

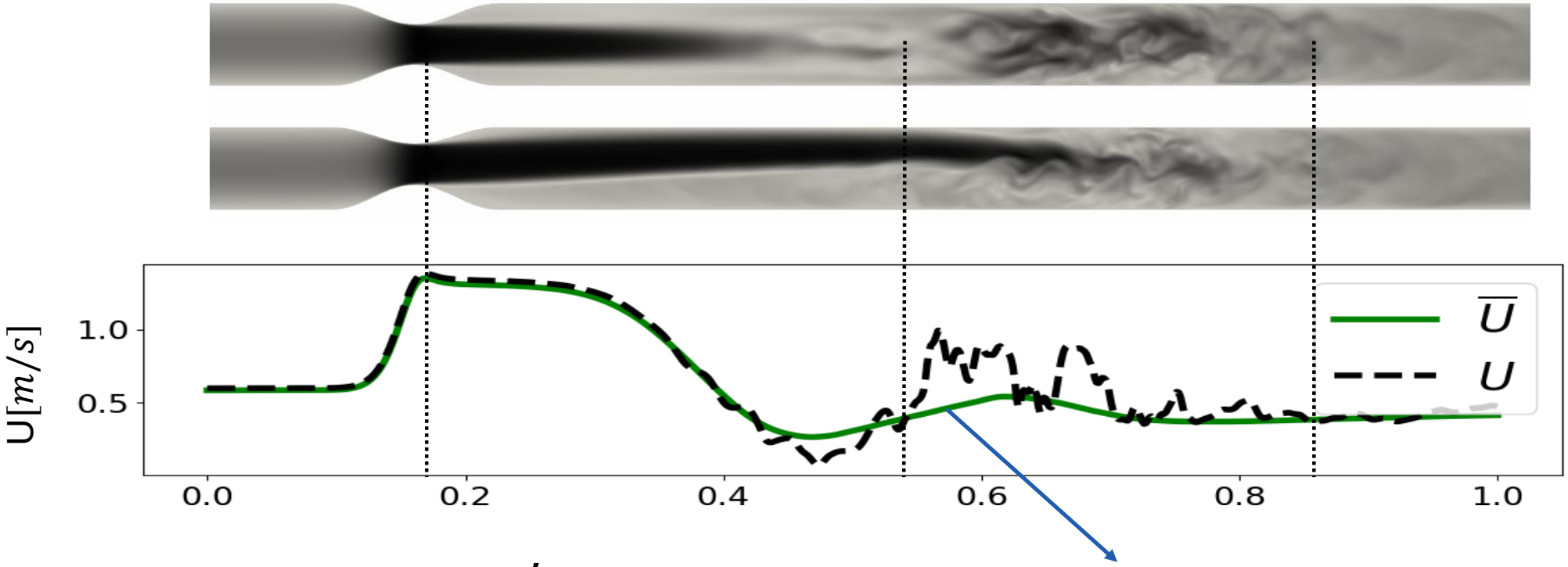
[Otto and Prendergast, 2014]

Normal leaflets	 At risk	• Risk valve morphology • Older age • Diabetes, Smoking, Hypertension…
Valvular sclerosis: 25% > 65y/o	 Disease initiation	• Shear stress • Inflammation • Slight leaflet calcification
Aortic stenosis (AS): 0.2% 50−59y/o 2.8% > 75y/o 9.8% > 80y/o	 Progressive disease	• Impaired aortic valve motion • Reduced aortic valve area
	 Valve obstruction	• Rate of death: 50% at 2y after symptoms

Reynolds Decomposition



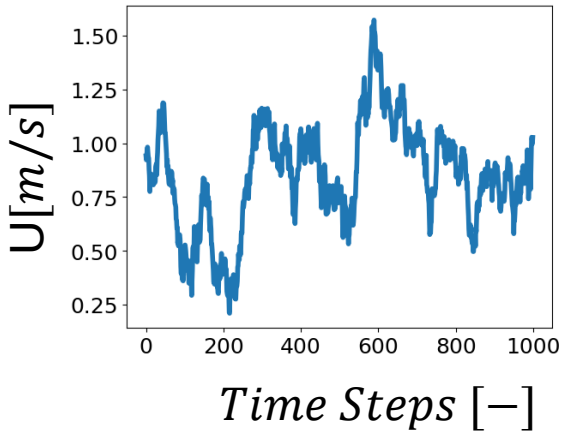
Reynolds Decomposition

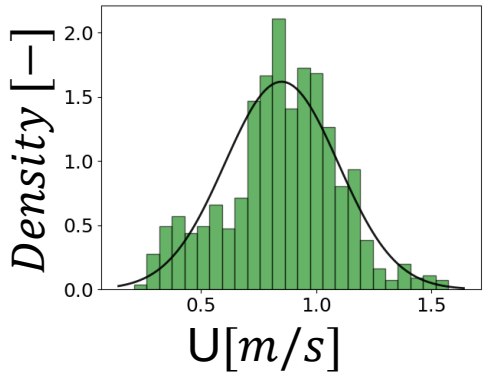


$$u_i = \overline{u_i} + u_i'$$

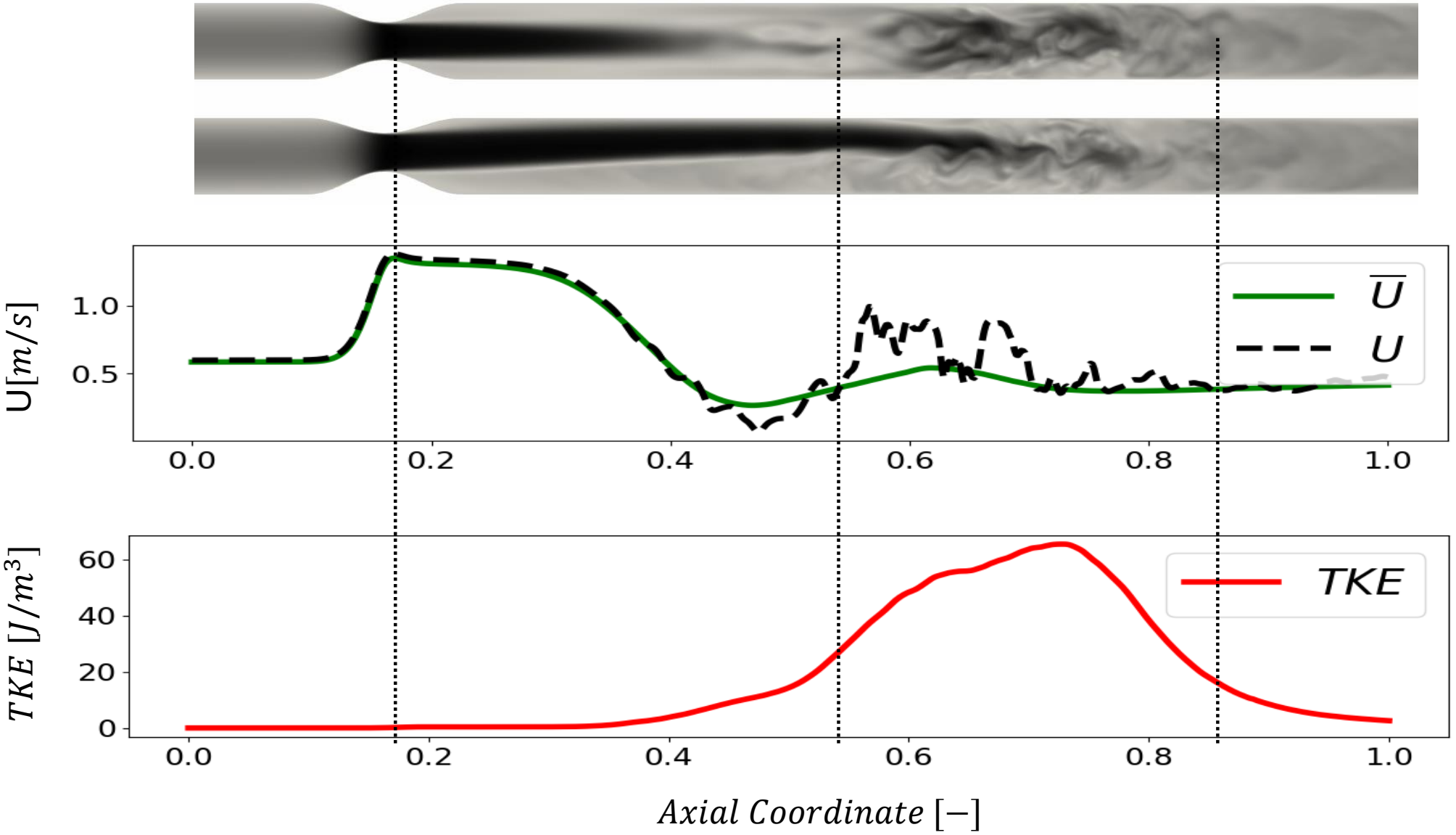
$$R_{ij} = \rho\overline{u_i' u_j'}$$

$$TKE = \frac{1}{2}(R_{11} + R_{22} + R_{33})$$





Reynolds Decomposition



4D Flow MRI

Fluctuations

Mean Velocity

$$S(\boldsymbol{k_v}) = S_0 e^{-\frac{\boldsymbol{k_v^T R k_v}}{2\rho}} e^{-i\boldsymbol{k_v}\bar{\boldsymbol{u}}}$$

[Walheim et al. 2019]

4D Flow MRI

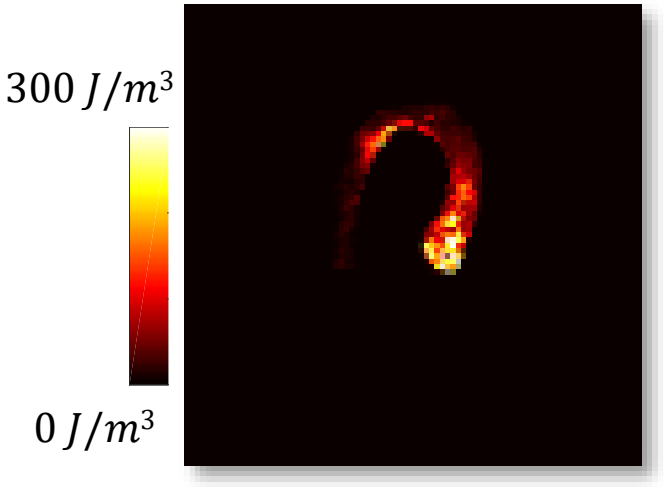
$$S(\boldsymbol{k_v}) = S_0 e^{-\frac{\boldsymbol{k_v^T R k_v}}{2\rho}} e^{-i\boldsymbol{k_v}\bar{\boldsymbol{u}}}$$

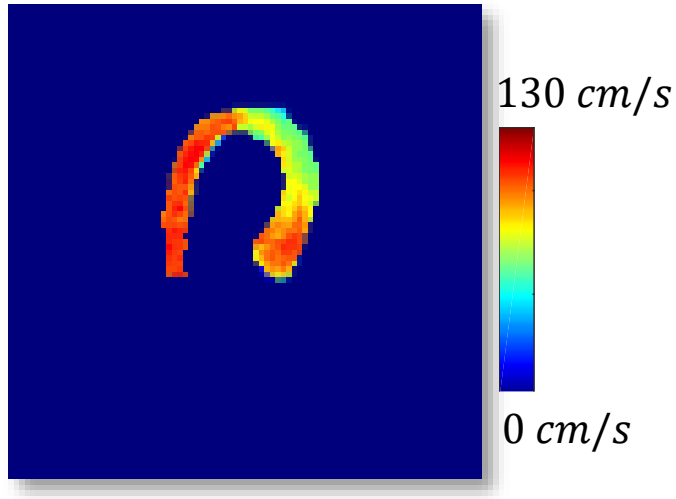
Large datasets?

Ground truth?

- Flow quantification
- Labeling/Segmentation
- Diagnosis
- Intervention decision

Automatic processing tools





[Walheim et al. 2019]

Image Synthesis

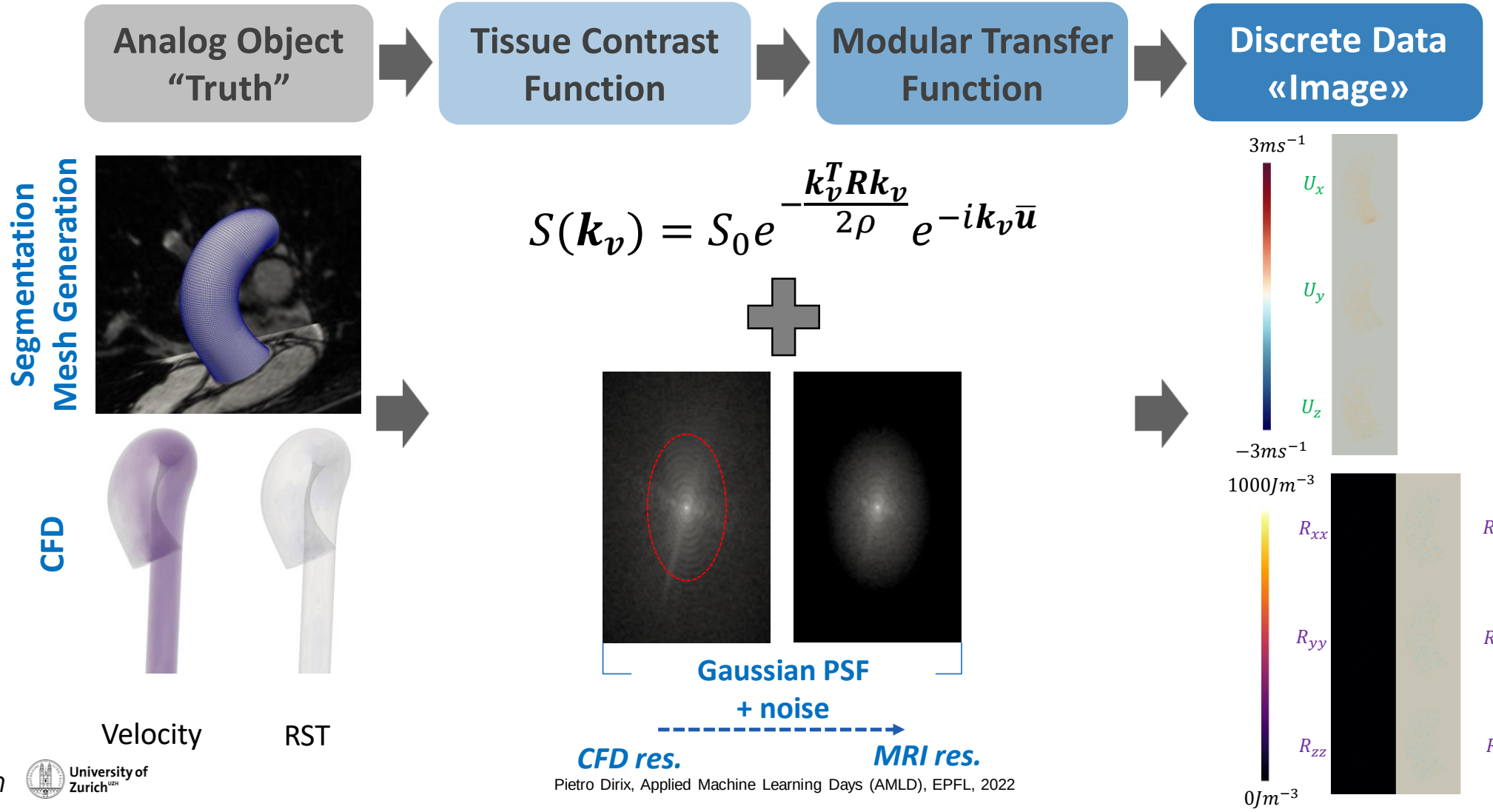
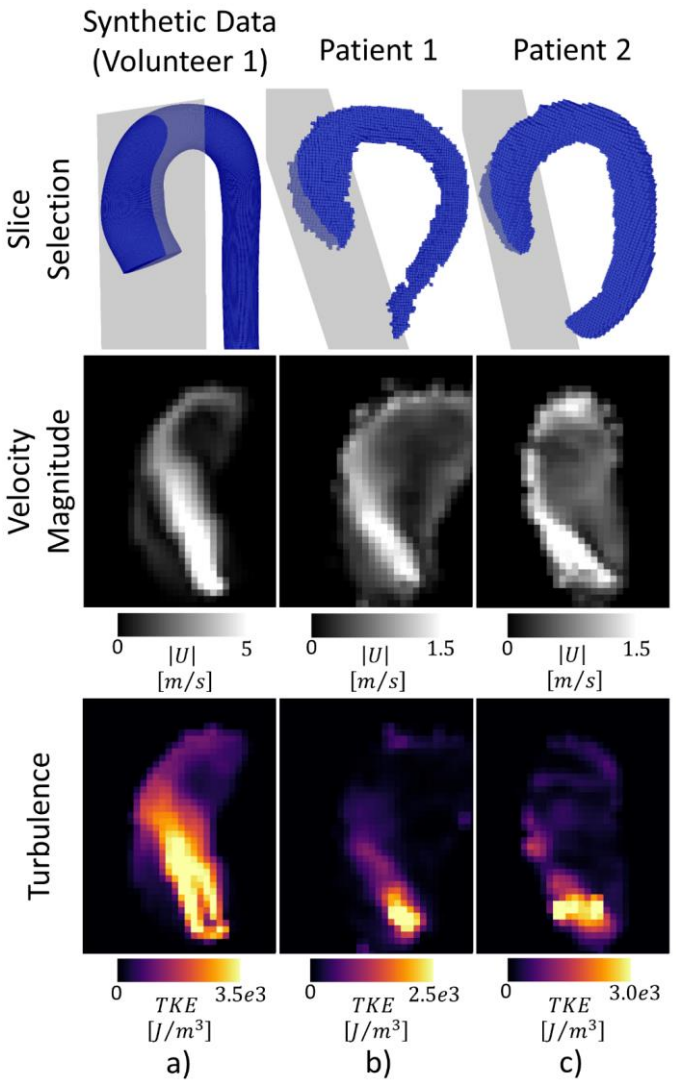
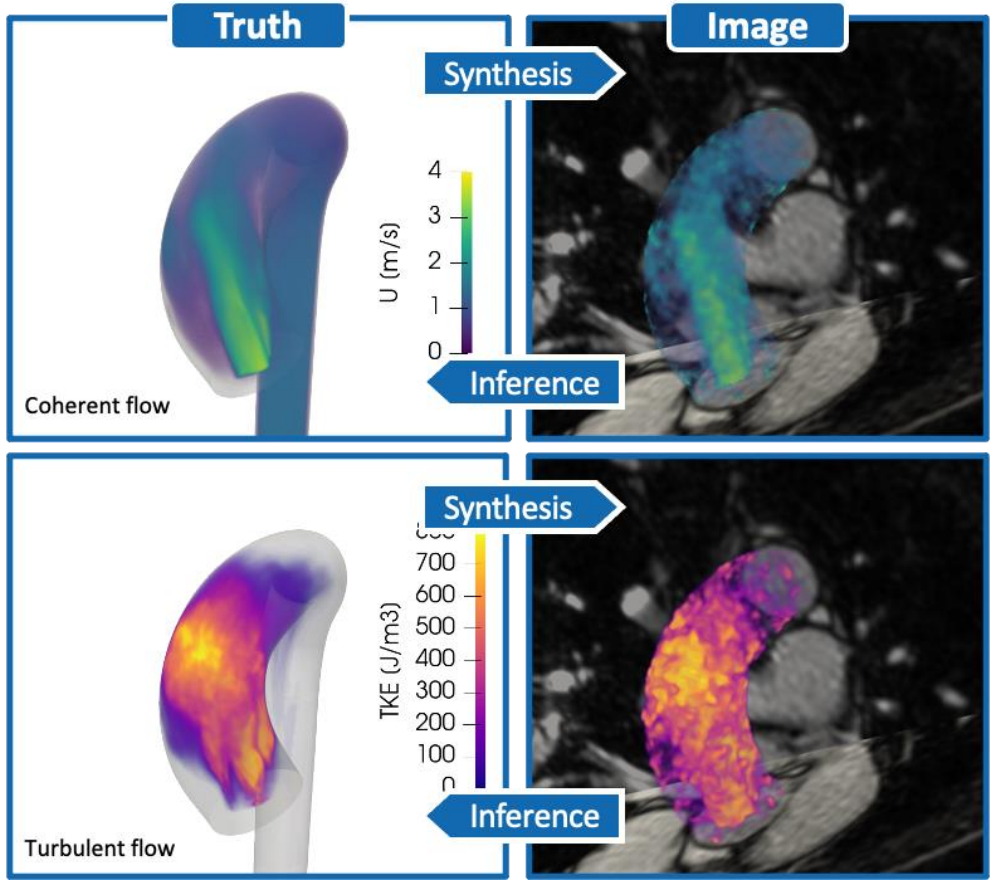
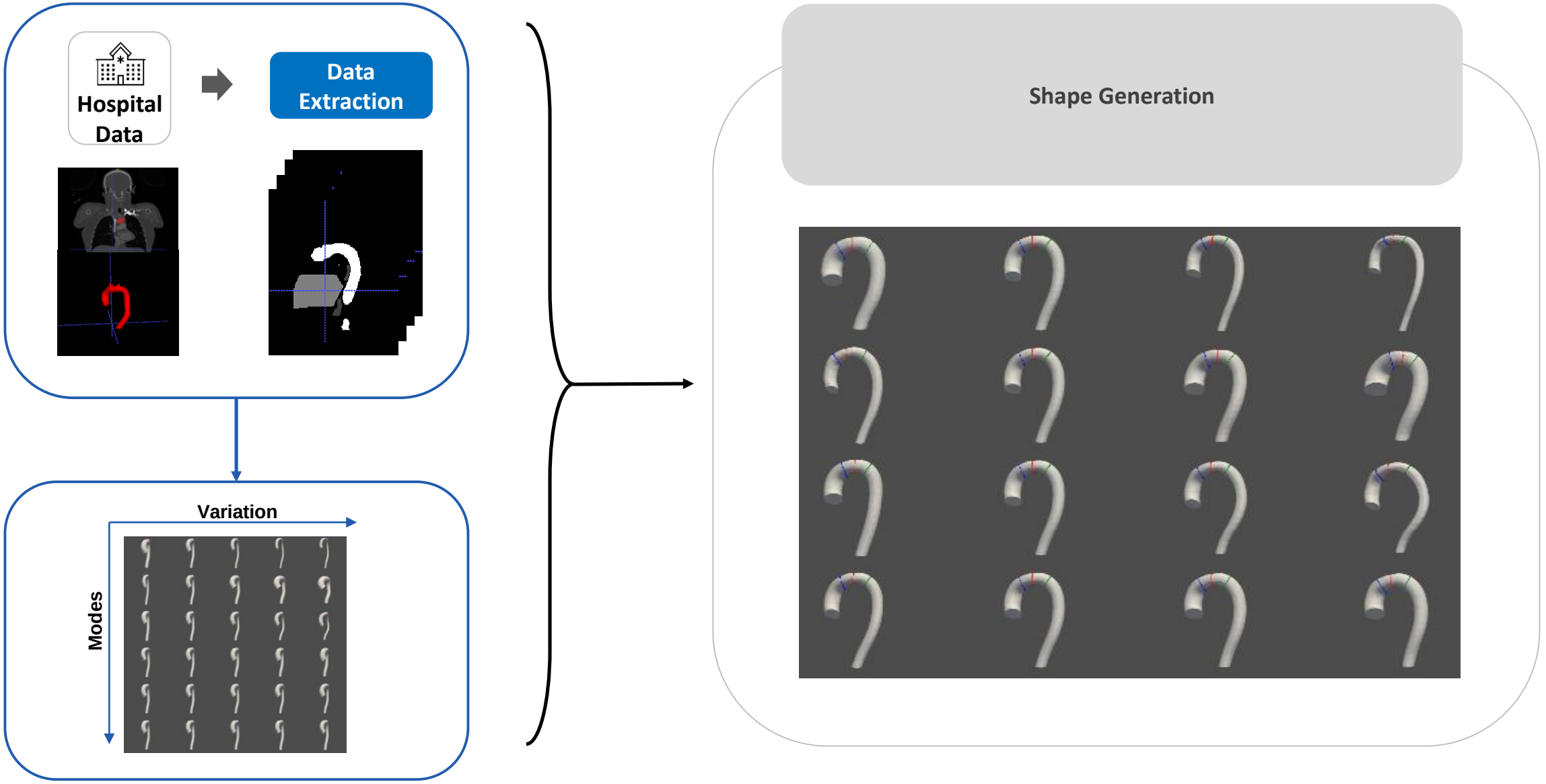


Image Synthesis

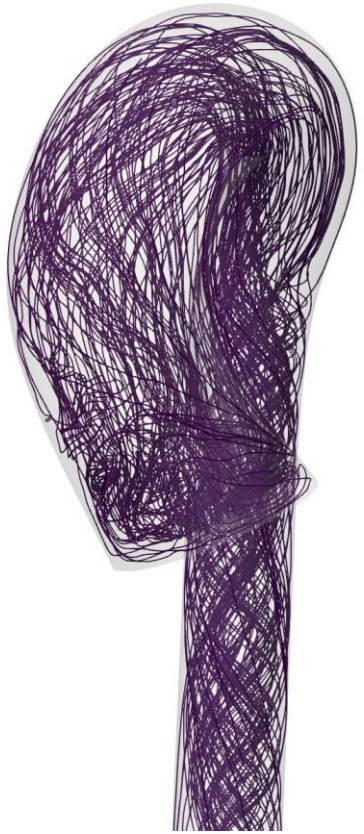




Generation of synthetic aortic shapes

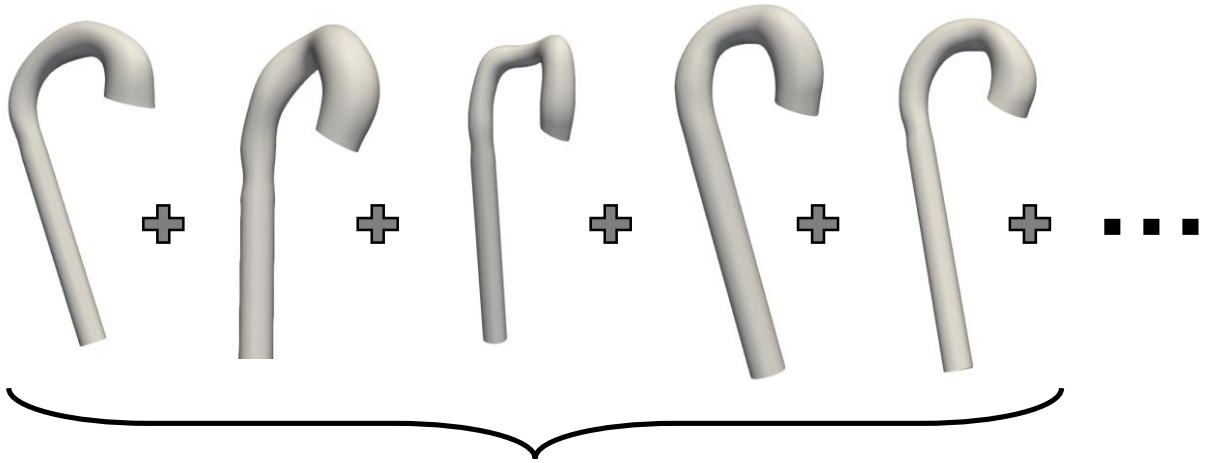


Simulation Run Time



~288-480 cpu/hours/cycle

x100 geometries



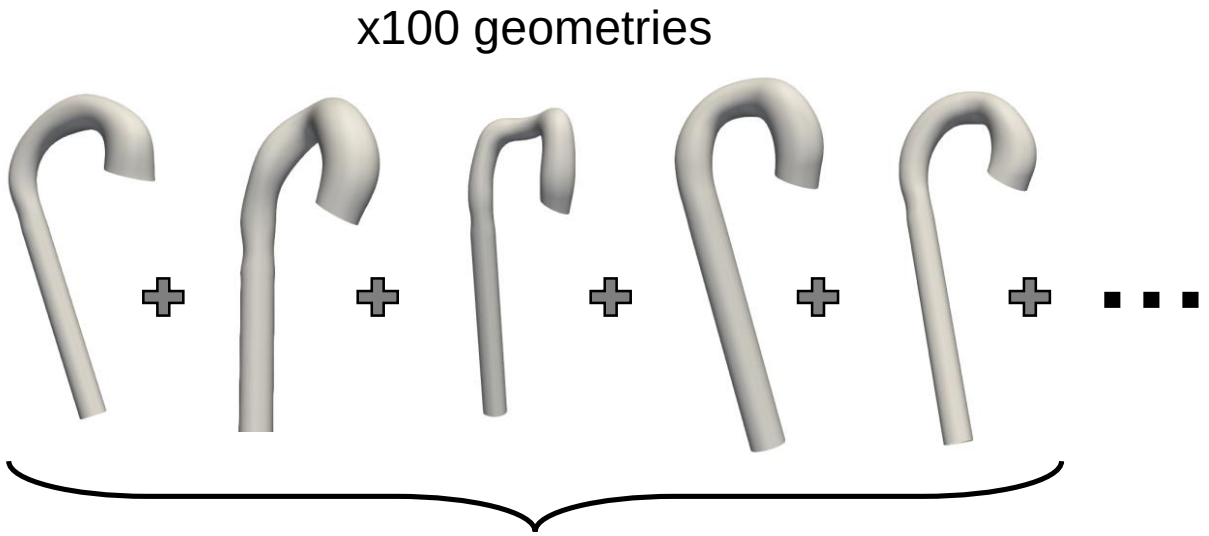
10 cardiac cycles

Data curation

4D flow MRI synthesis

~288k-480k cpu/hours

Simulation Run Time



10 cardiac cycles

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4D flow MRI synthesis

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Dirix Pietro

Doctorate at D-ITET

dirix@biomed.ee.ethz.ch

ETH and University Zürich

ETZ F 61.2

Gloriastrasse 35

8092 Zürich

www.biomed.ee.ethz.ch
www.cmr.ethz.ch