Deep 3D Surface Meshes

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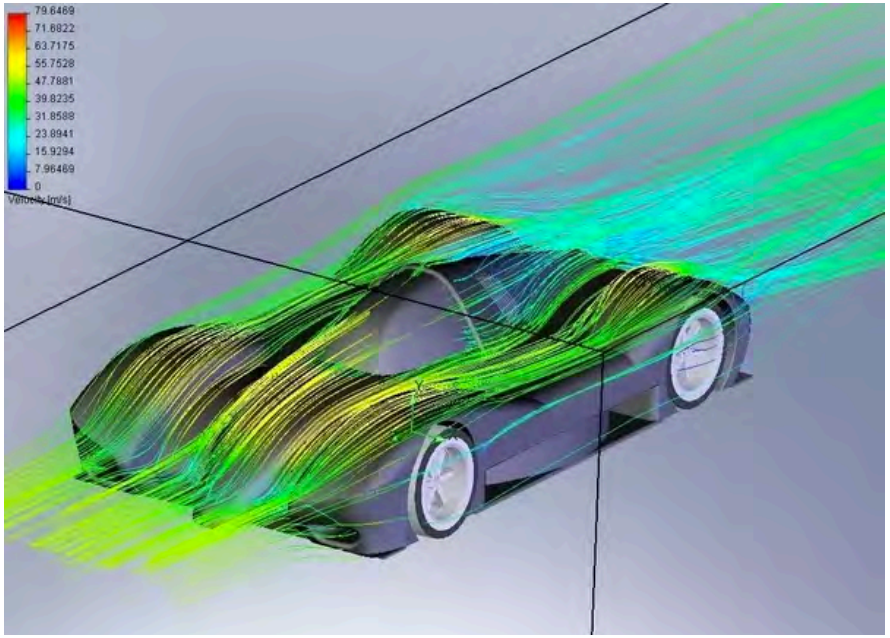
3D Shape Design

- Design a shape.
- Simulate its performance.
- Redesign.



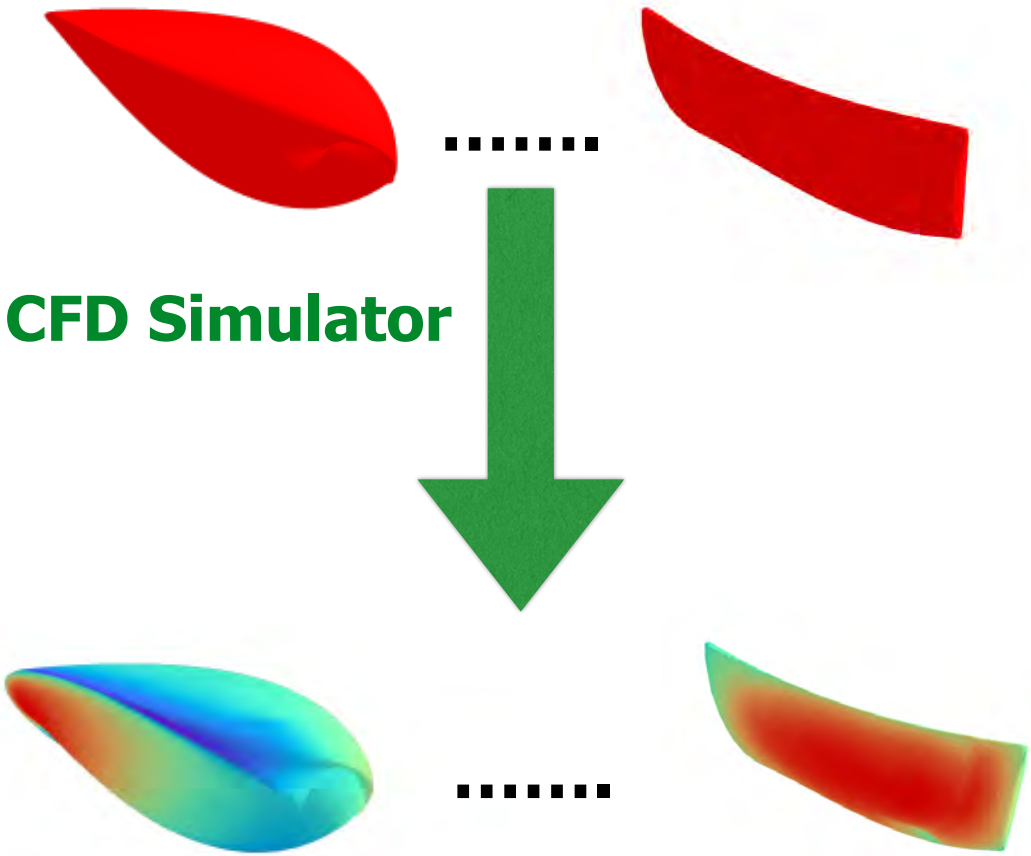
It works but:

It takes hours or days to produce a single simulation.

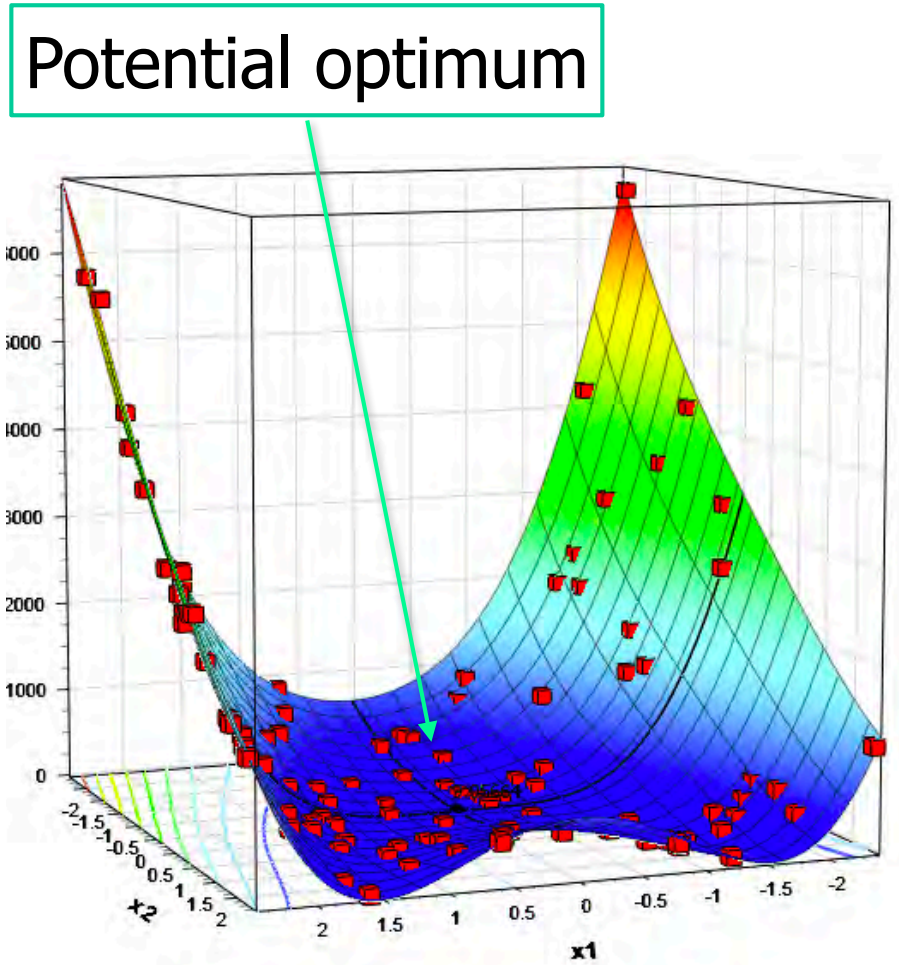
This constitutes a serious bottleneck in the exploration of the design space.

Designs are limited by humans' cognitive biases.

Kriging

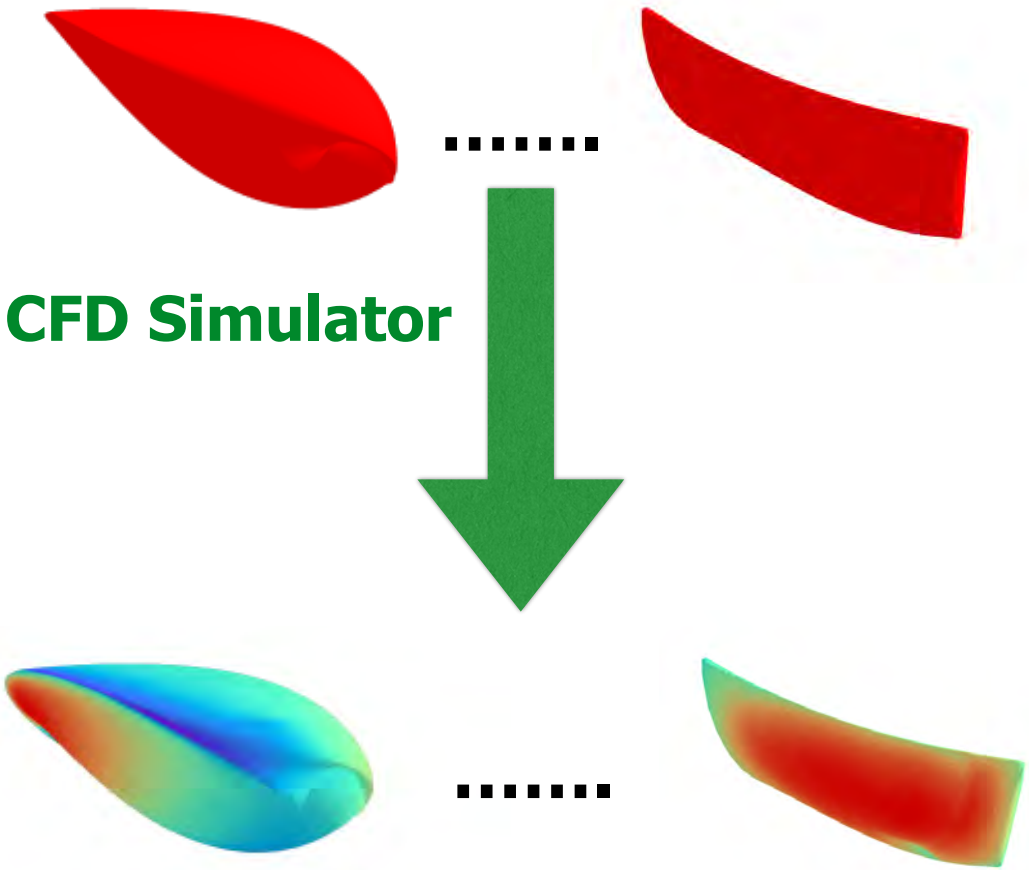


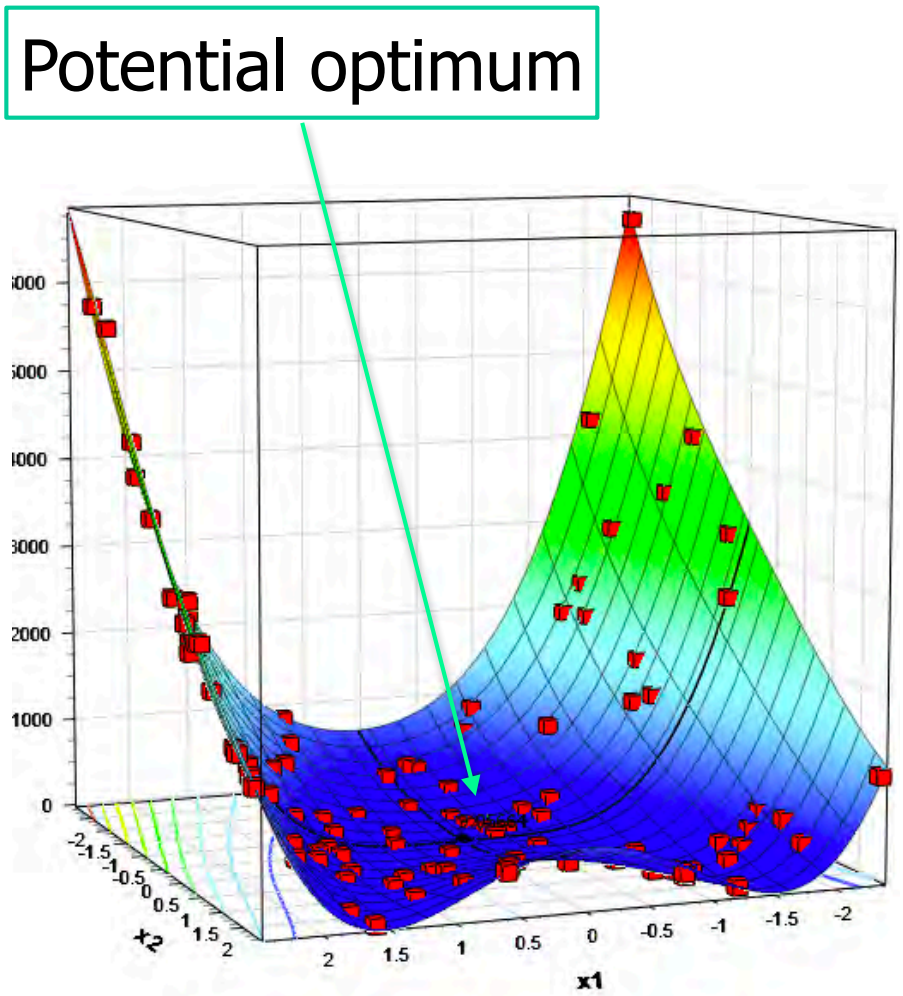
- Drag
- Pressure Coefficients
- Boundary Layer Velocities
- …



The response surface is approximated by a GP, which only works well when the model **has few parameters.**

Deep Surrogate Method



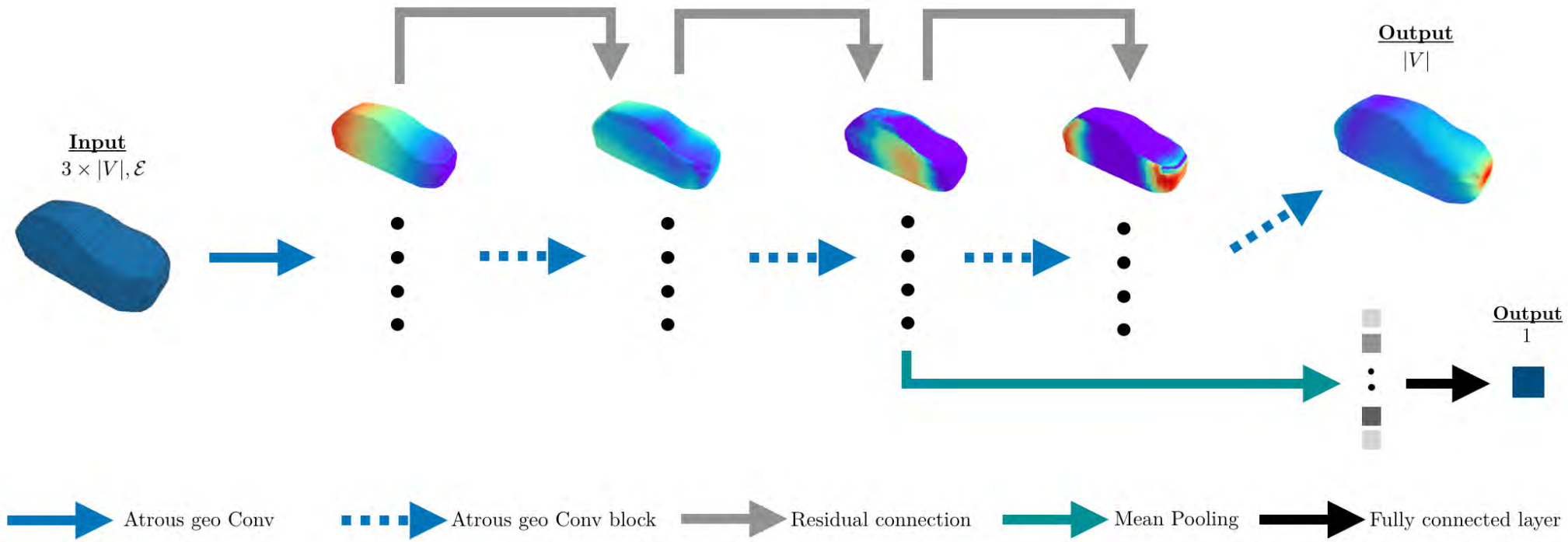


- Drag
- Pressure Coefficients
- Boundary Layer Velocities
- ...

The response surface can be approximated by a **GCNN** instead of a GP.

—> The model can have any number of parameters.

GCNN

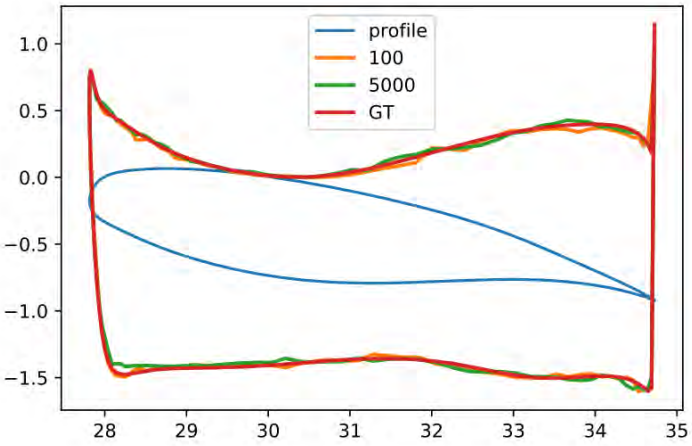


Operates directly on the mesh vertices.

Lift Prediction

Full Simulation (1 h)

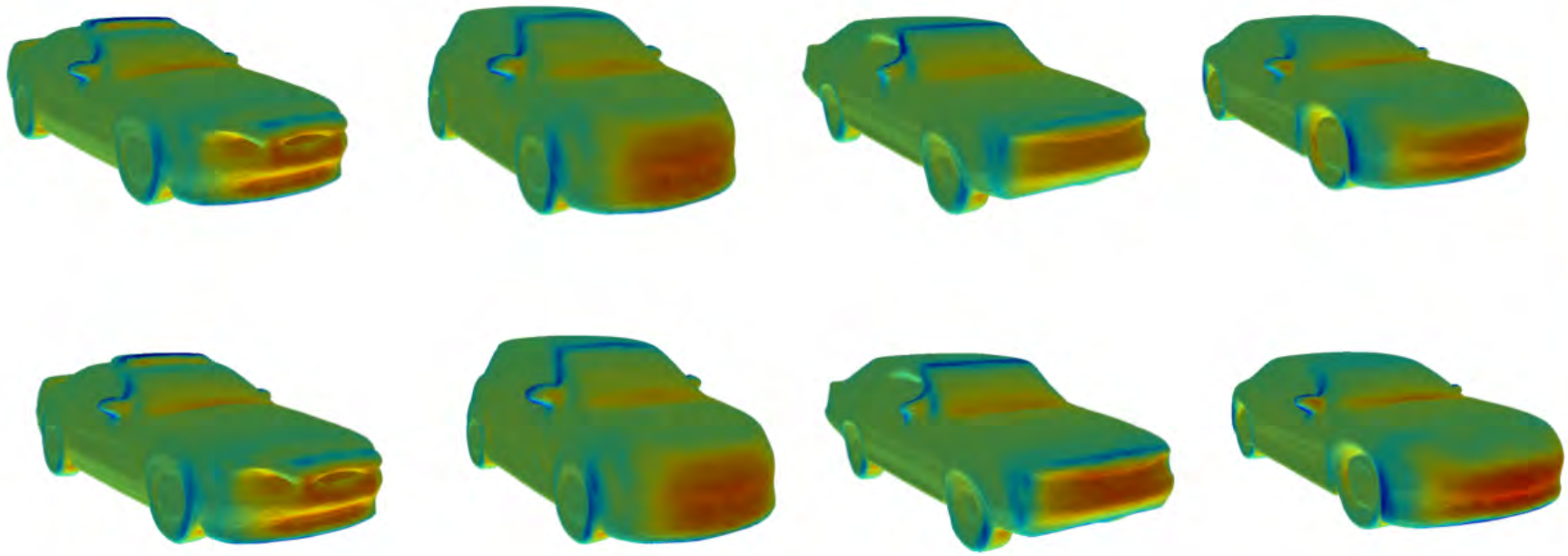
GCNN Prediction (30 ms)



Physics Type	External Aerodynamics
Dataset size	~1000 shapes
R2-accuracy	95 %

Drag Prediction

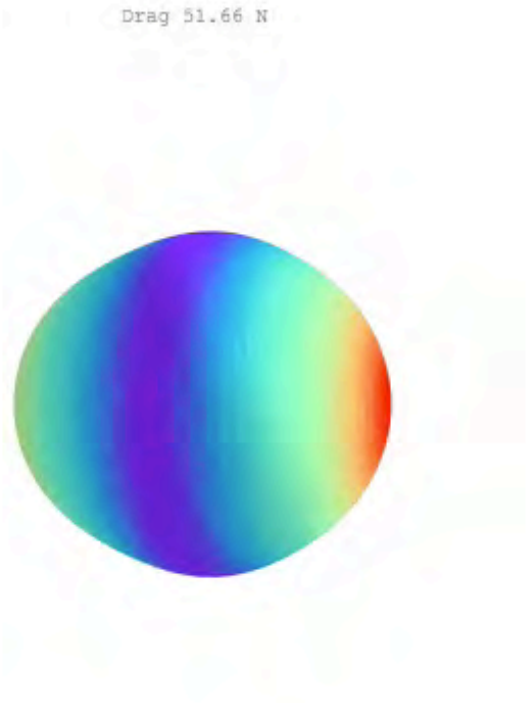
Simulated pressure fields

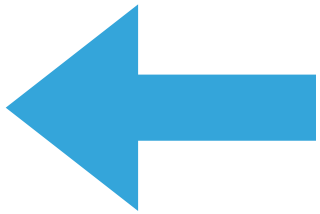


Predicted pressure fields

- The predicted results are very close to the simulated ones.
- The aerodynamic drag $\mathscr{D}$ can be estimated from these predictions.
- $\mathscr{D}$ is a differentiable function of the surface mesh vertices.

Minimizing Drag Under Constraints





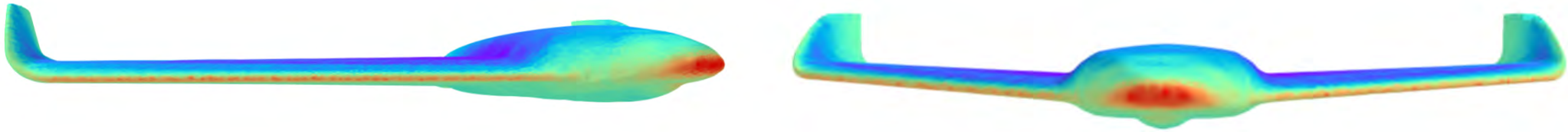
Wind

Minimizing drag while enclosing a sphere.

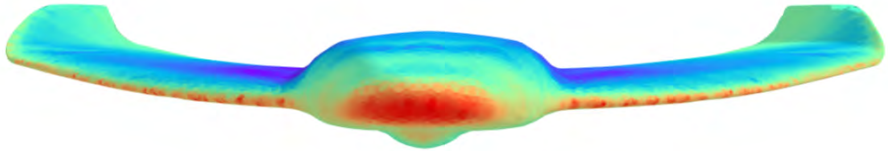
UAV Design

https://www.sensefly.com/

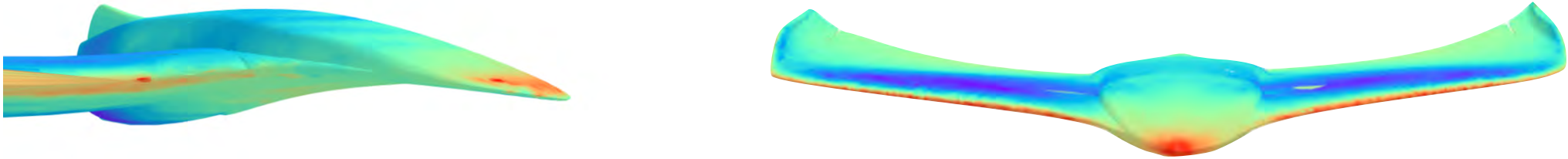
From UAV To Lifting Body



Sensefly drone (L/D 11.9)

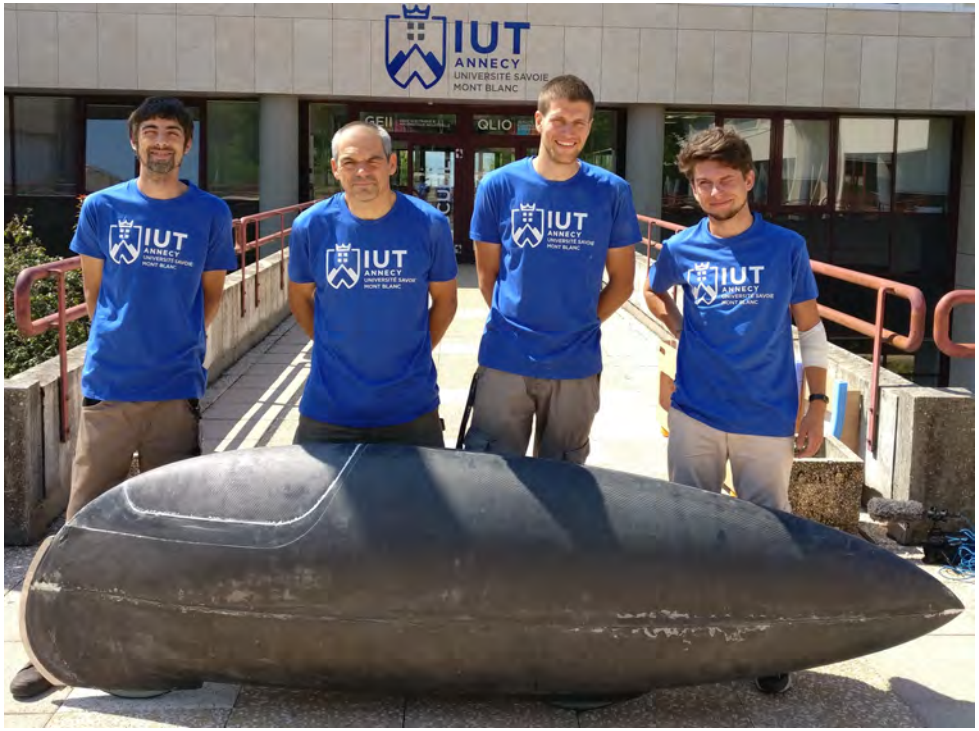


Optimize the wings (L/D 13.7)

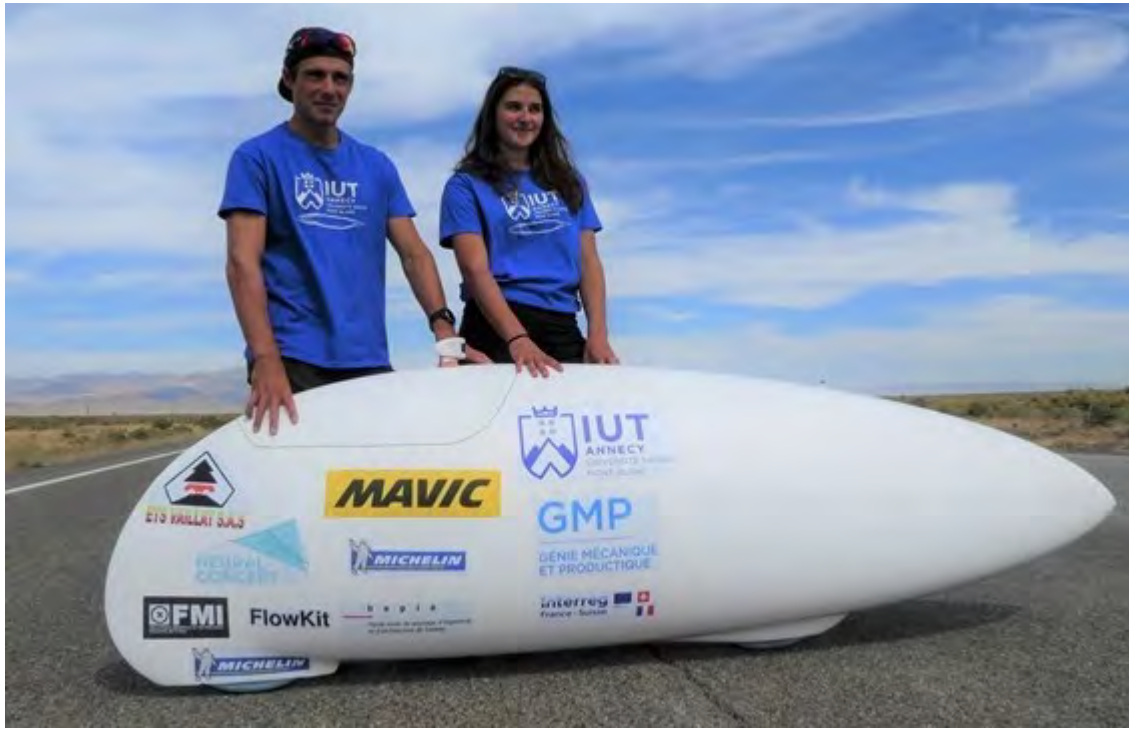


Optimize the fuselage as well

Bicycle Shell



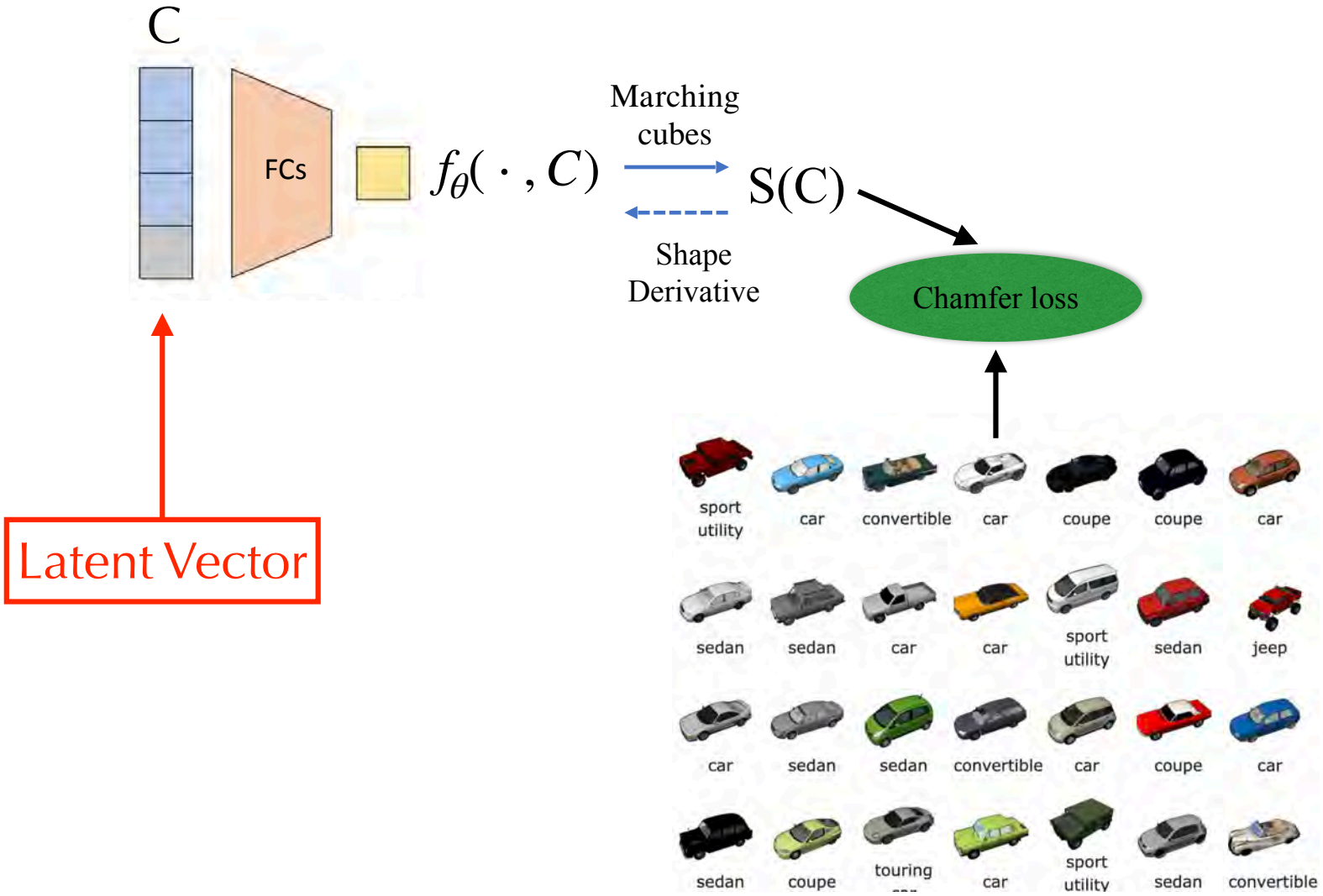
Altair 6, IUT Annecy, 2018



World Human Powered Speed Challenge
Battle Mountain Nevada, 2019

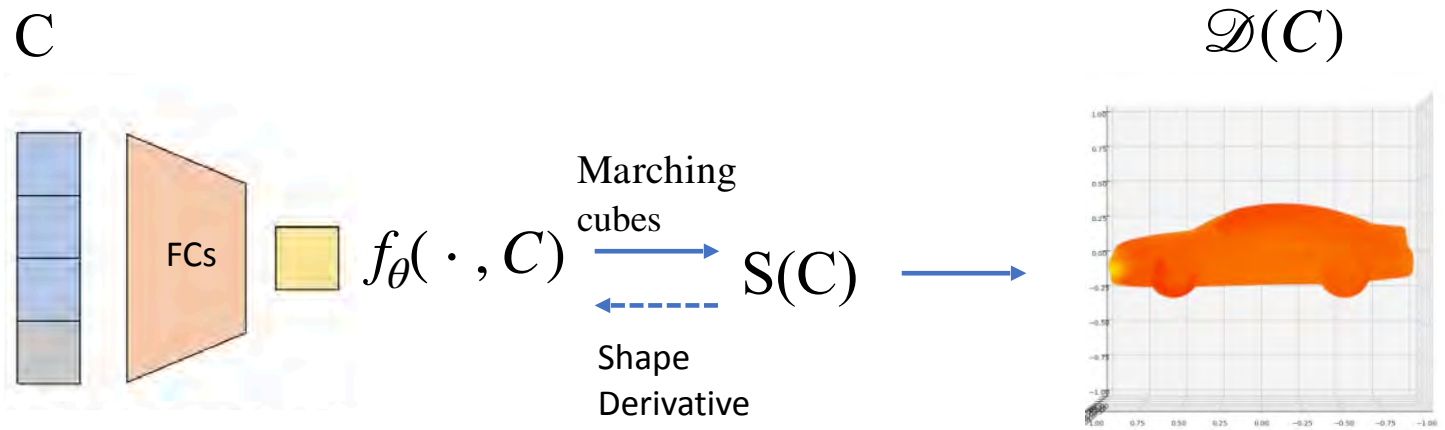
Women world record: 126,48 km/h
Men student world record: 136.74 km/h

Introducing Priors



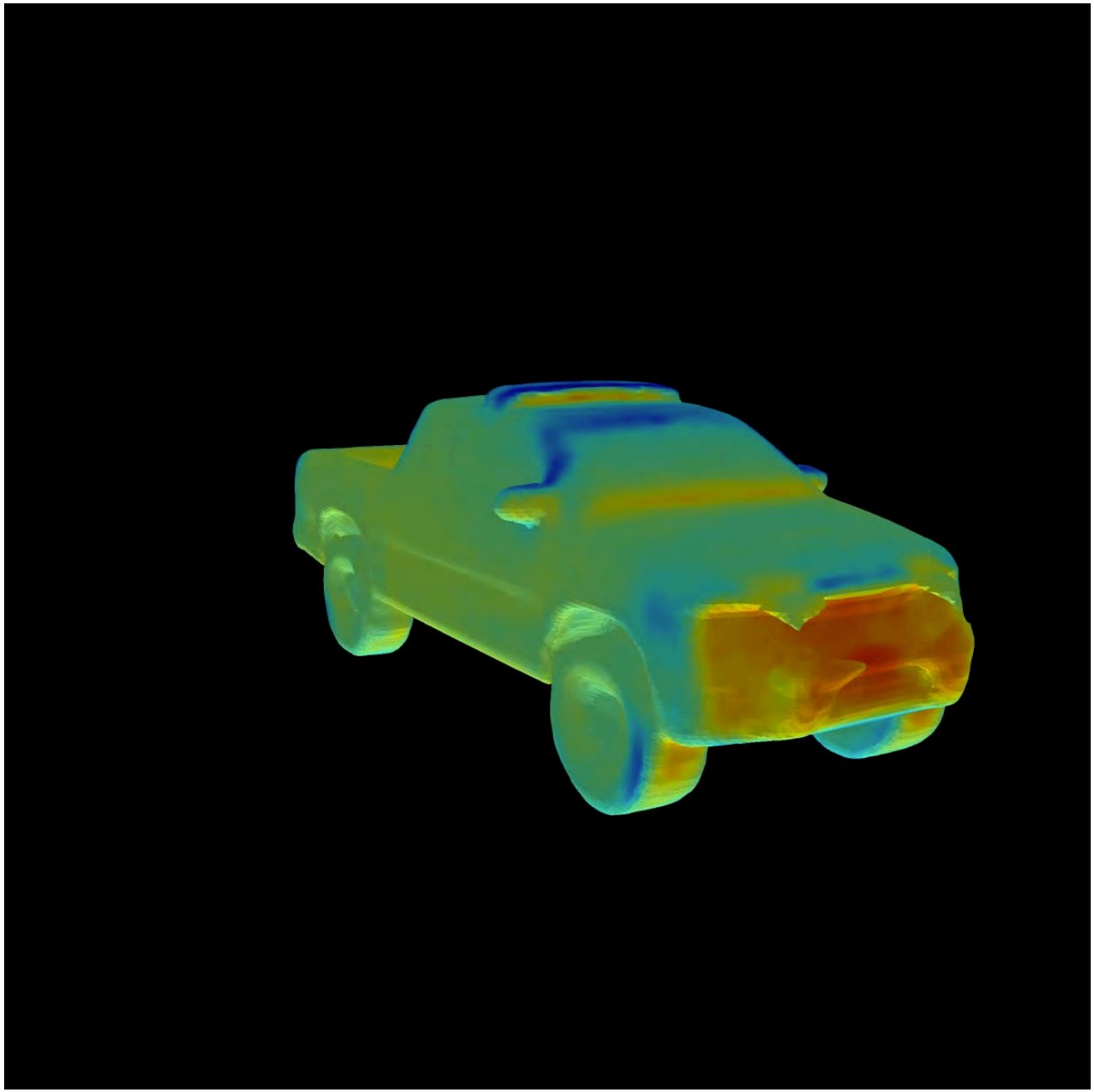
Train an auto-decoder using ShapeNet cars.

Drag Minimization

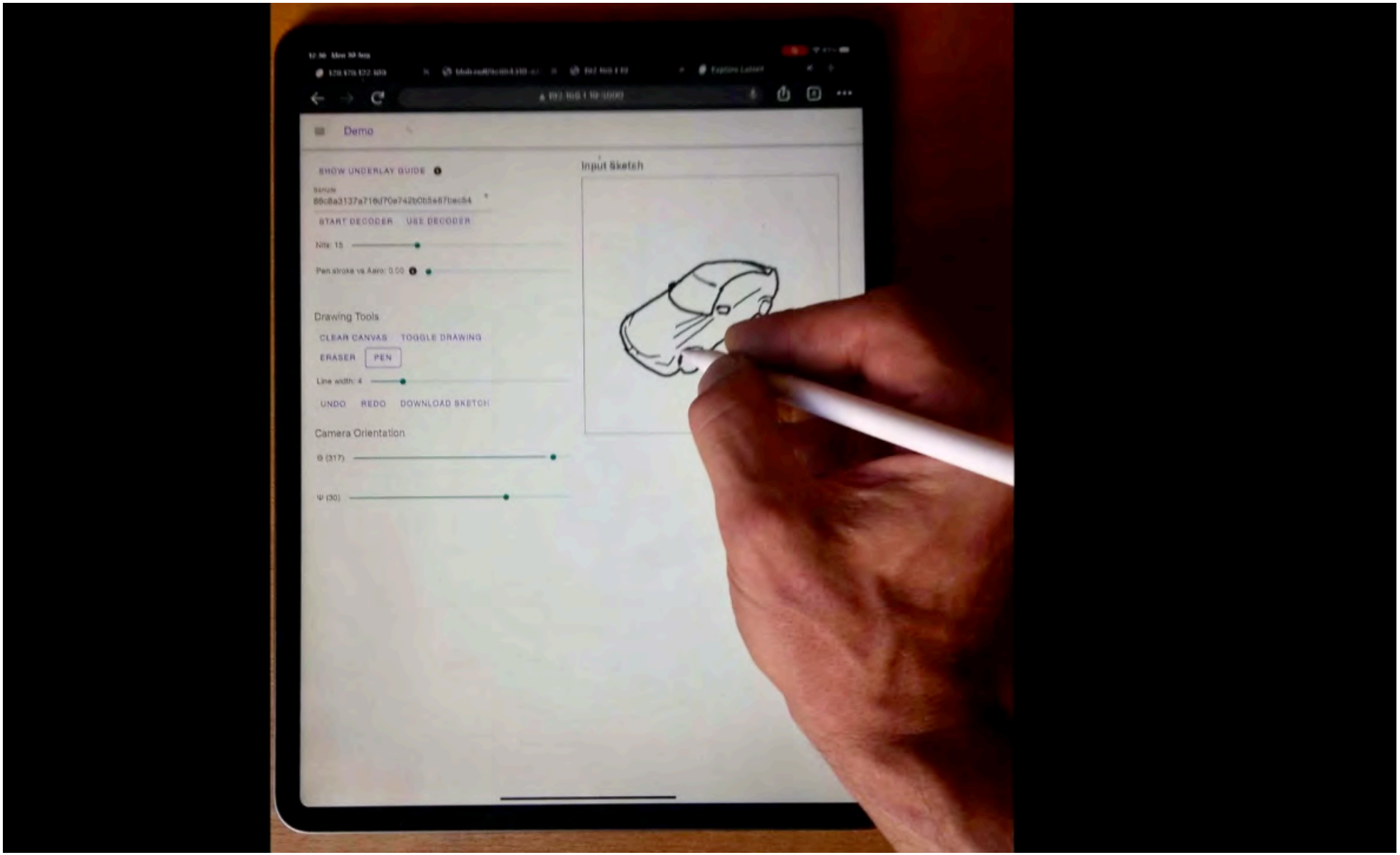


Minimize $\mathscr{D}(C)$ with respect to C under constraint.

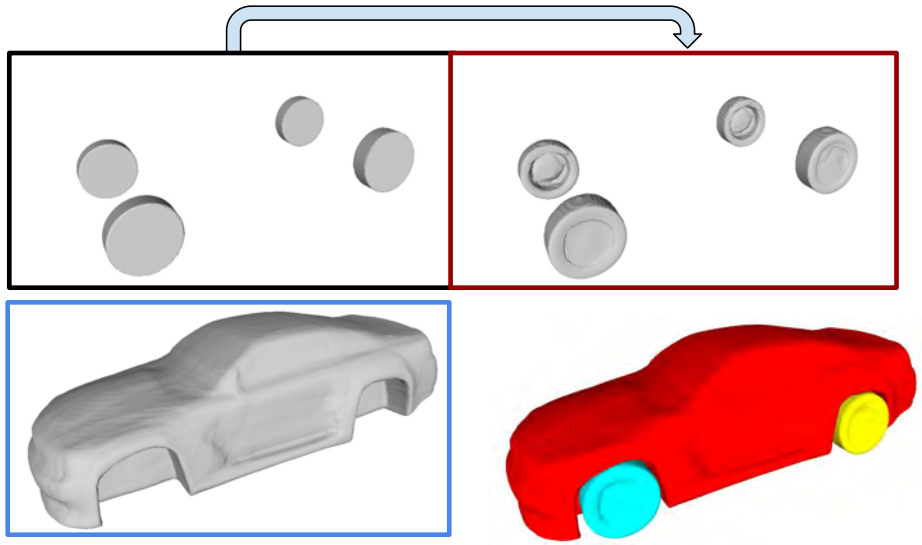
From Pickup-Truck to Sports Car



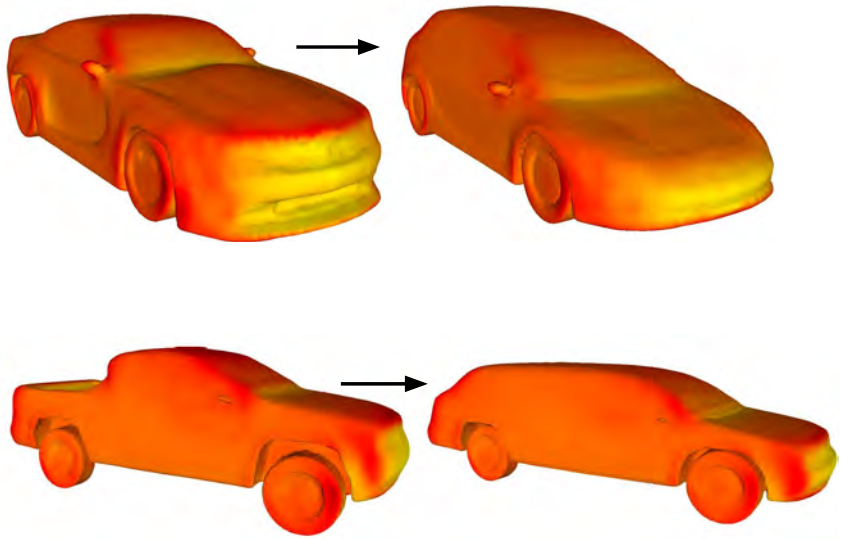
Interactive Design



Hybrid Shape Representation



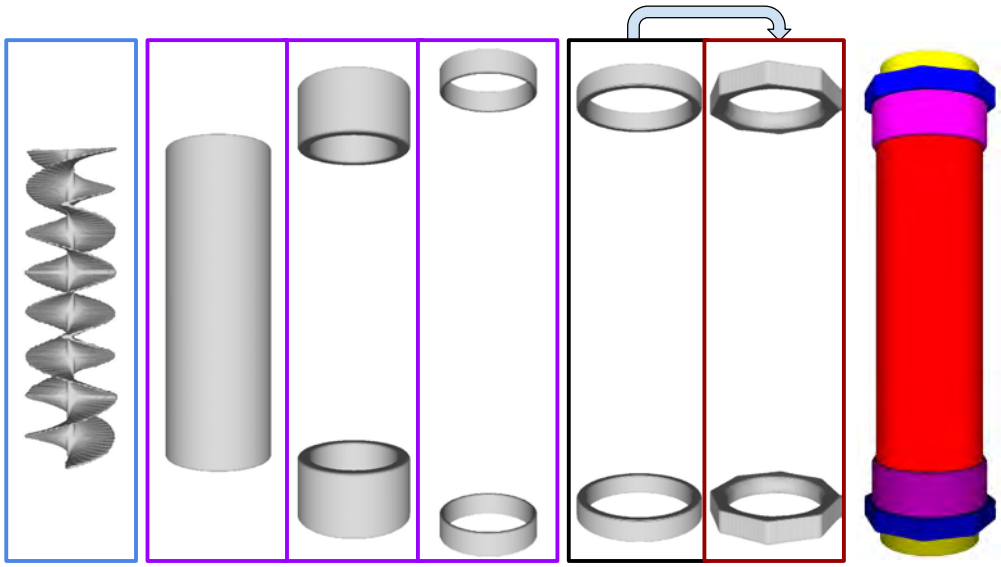
Different types of primitives



Optimization results

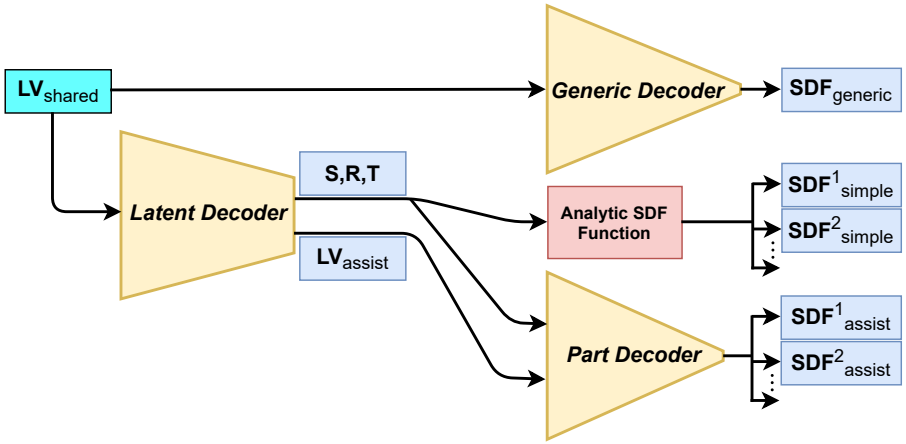
—> Individual parts adapt to each other.

From Latent Vector to Primitives

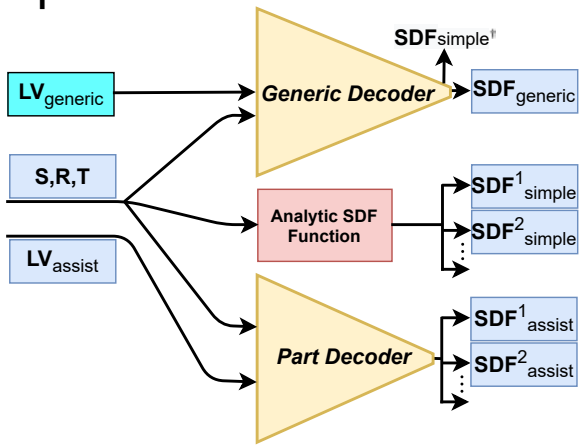


We use SDFs to represent:

- Simple geometric primitives, such as spheres and cylinders.
- Primitives that bear a close resemblance to the simple ones but can deviate from them.
- Free form primitives that have arbitrarily complex shapes.

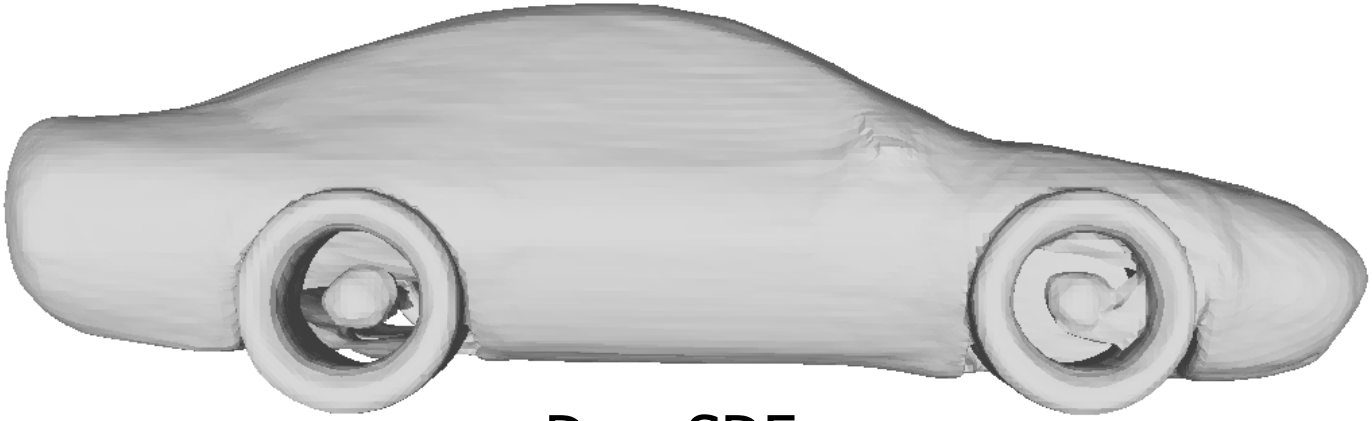


Shared Latent Vector

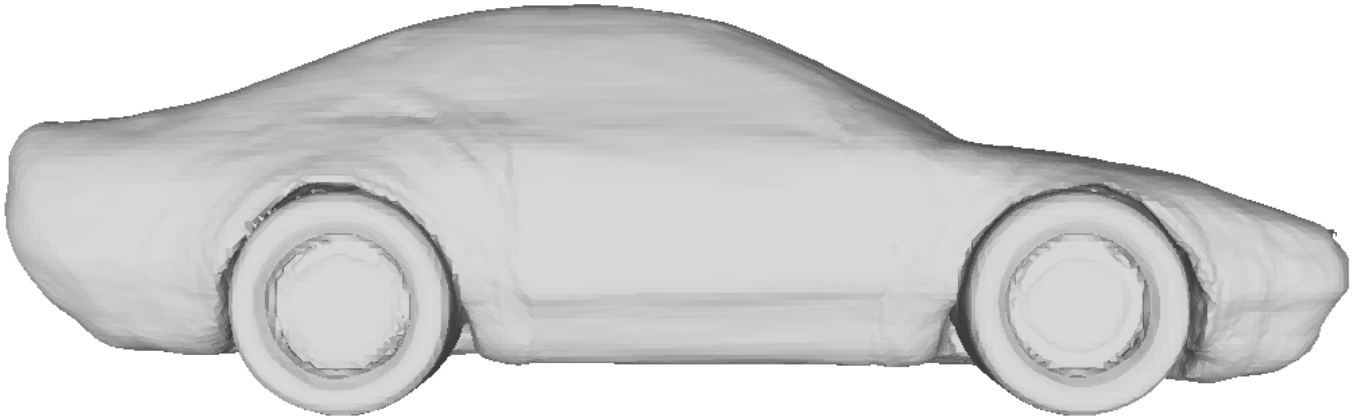


Disentangled Latent Vector

Car Wheels



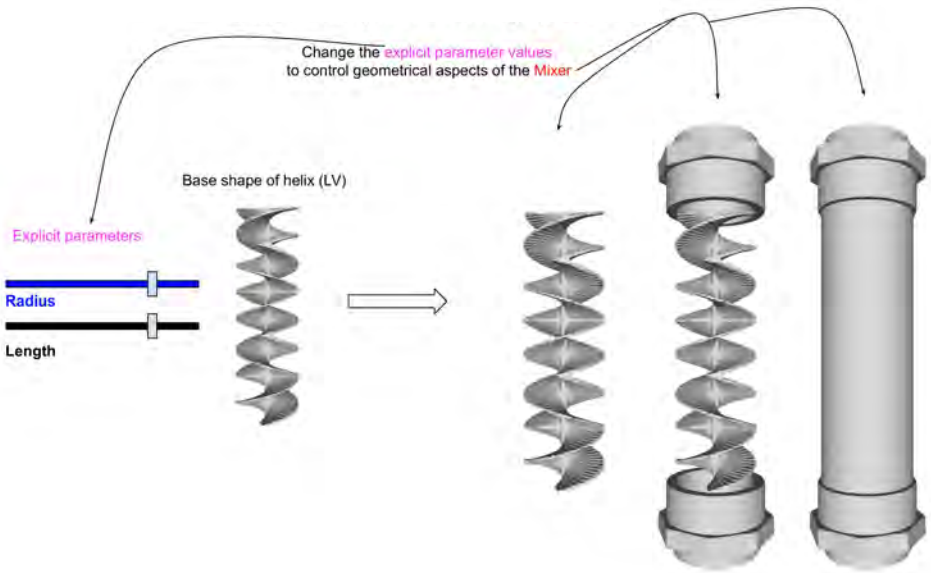
DeepSDF



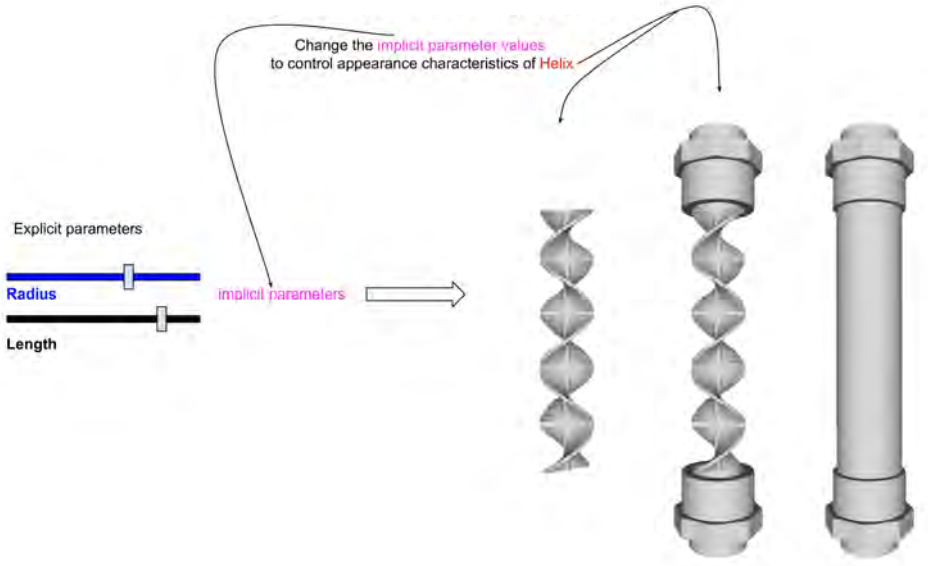
HybridSDF

The wheels are better separated from the car body.

Shape Manipulation

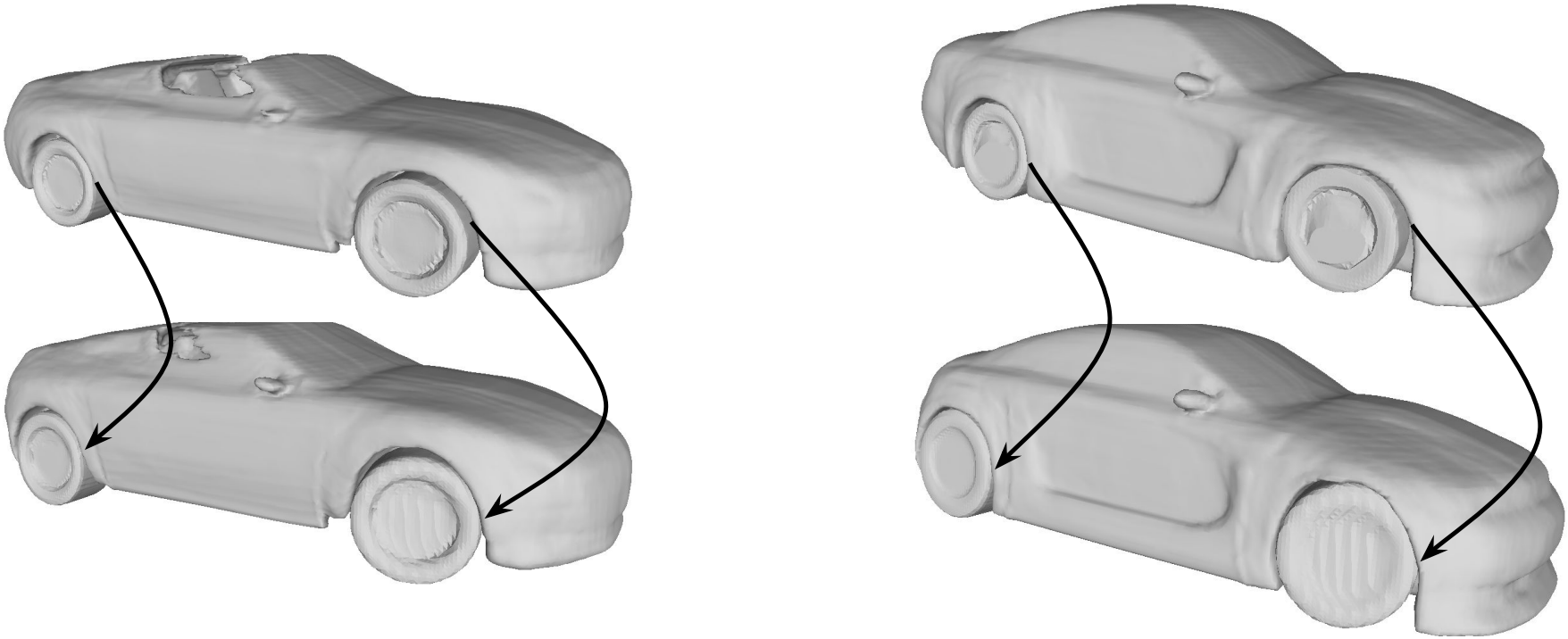


Changing the explicit parameters



Changing the implicit parameters

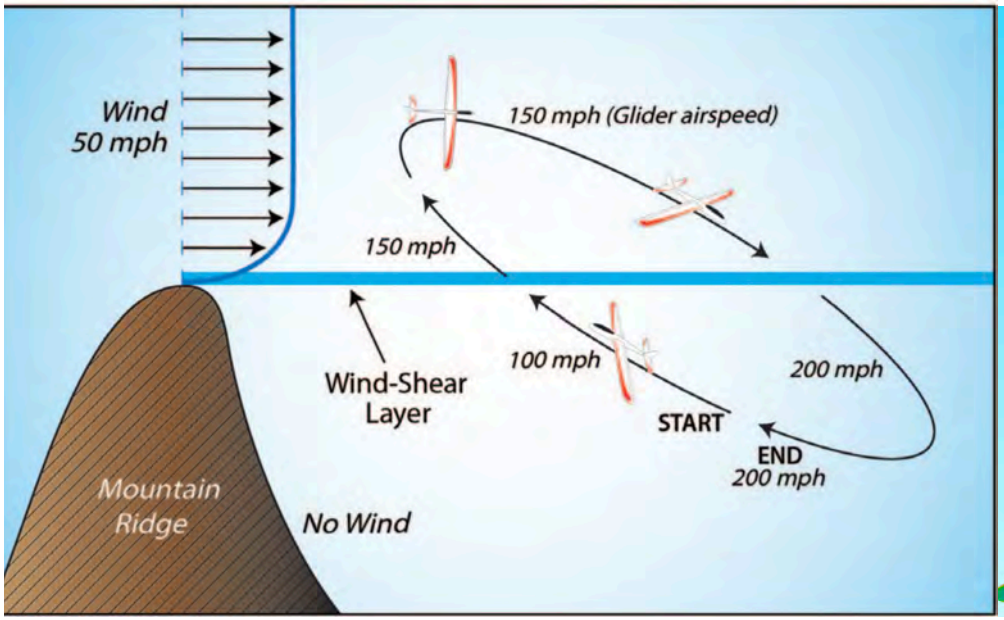
Interactive Shape Manipulation

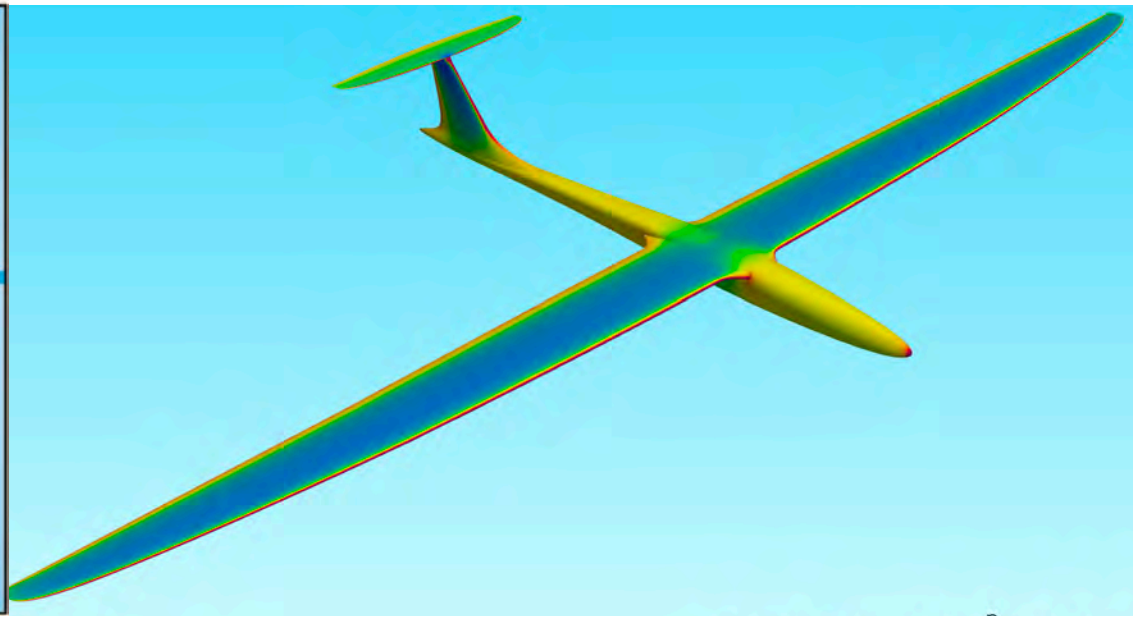


Changing the wheels

[Vasu et al., ArXiv'21]

Dynamic Soaring





- We plan to design for ease of control.
- We will use dynamic soaring to prove the concept.

Conclusion

- Combining explicit and implicit representations early makes it possible to exploit the strength of both representations.

- Deep Signed Distance Functions can be used to implement 3D surface meshes that can change their topology while preserving end-to-end differentiability.

—> This opens the door for new applications in fields as diverse as Computer Assisted Design and Medical Imaging.