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Application of Optimization & CFD in Surgical Planning for Percutaneous Coronary Intervention

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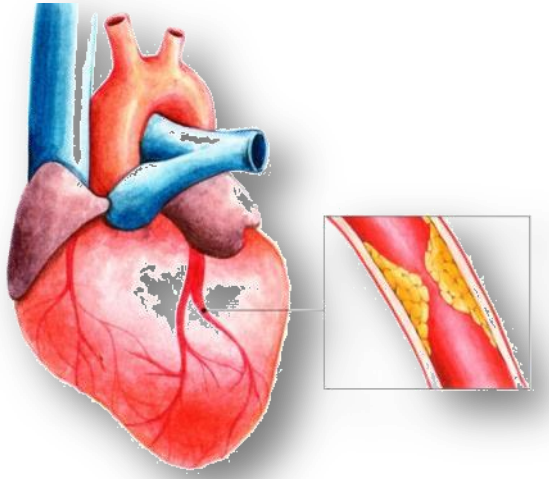
Problem description

- 1 in 4 Deaths in the USA are from heart disease
- Over 600,000 died from it last year alone
- Percutaneous Coronary Interventions (PCI's) work well, but there are problems and there has been relatively little fluid analysis on the procedure
- No surgical planning for PCI's

Myocardial Infarction (MI)

- Interruption of blood to an area of the heart
- Caused by an embolism (blockage)
- Most embolisms result from atherosclerotic plaque breaking free from vessel walls

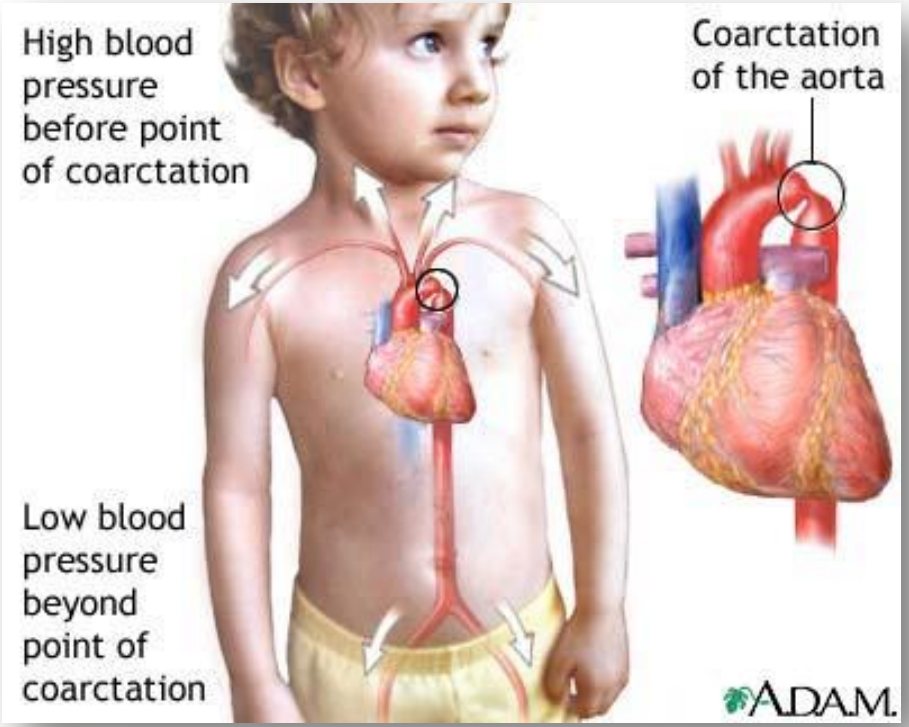


Current Solution

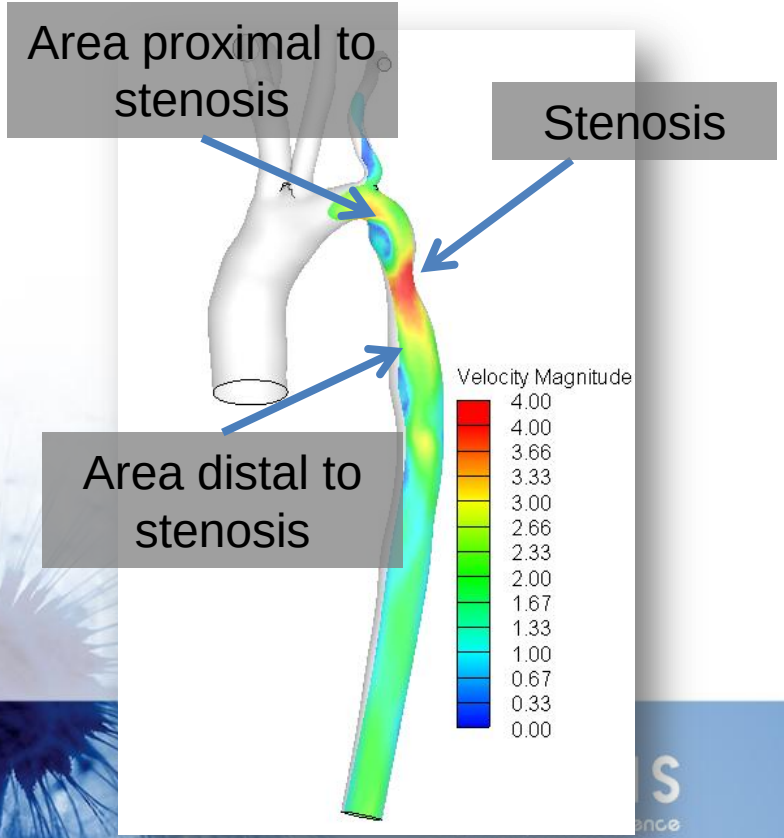
- Percutaneous Coronary Intervention
- Stenting
- Does not reduce expansion at the distal area

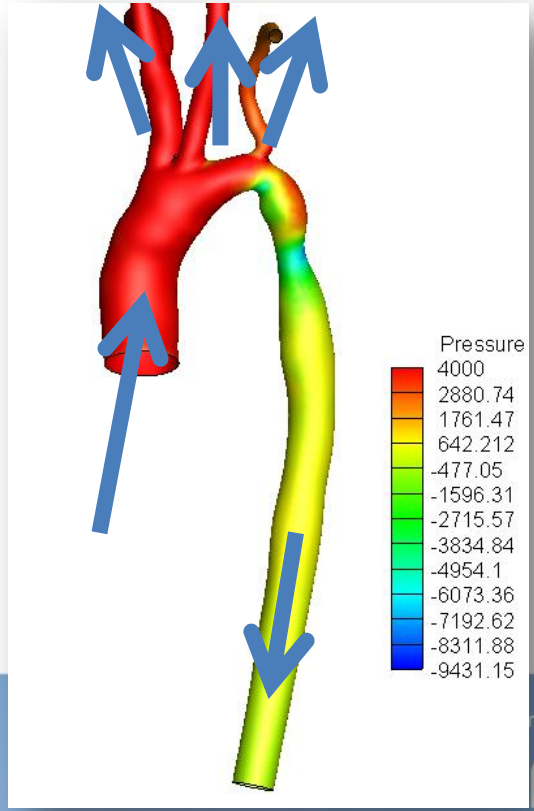
Model notes

- Model shown is an aortic coarctation
- Readily available
- High blood flows
- Same hemodynamic properties



Model notes


Area proximal to stenosis
Stenosis
Area distal to stenosis
Velocity Magnitude
4.00
4.00
3.66
3.33
3.00
2.66
2.33
2.00
1.67
1.33
1.00
0.67
0.33
0.00


Pressure
4000
2880.74
1761.47
642.212
-477.05
-1596.31
-2715.57
-3834.84
-4954.1
-6073.36
-7192.62
-8311.88
-9431.15

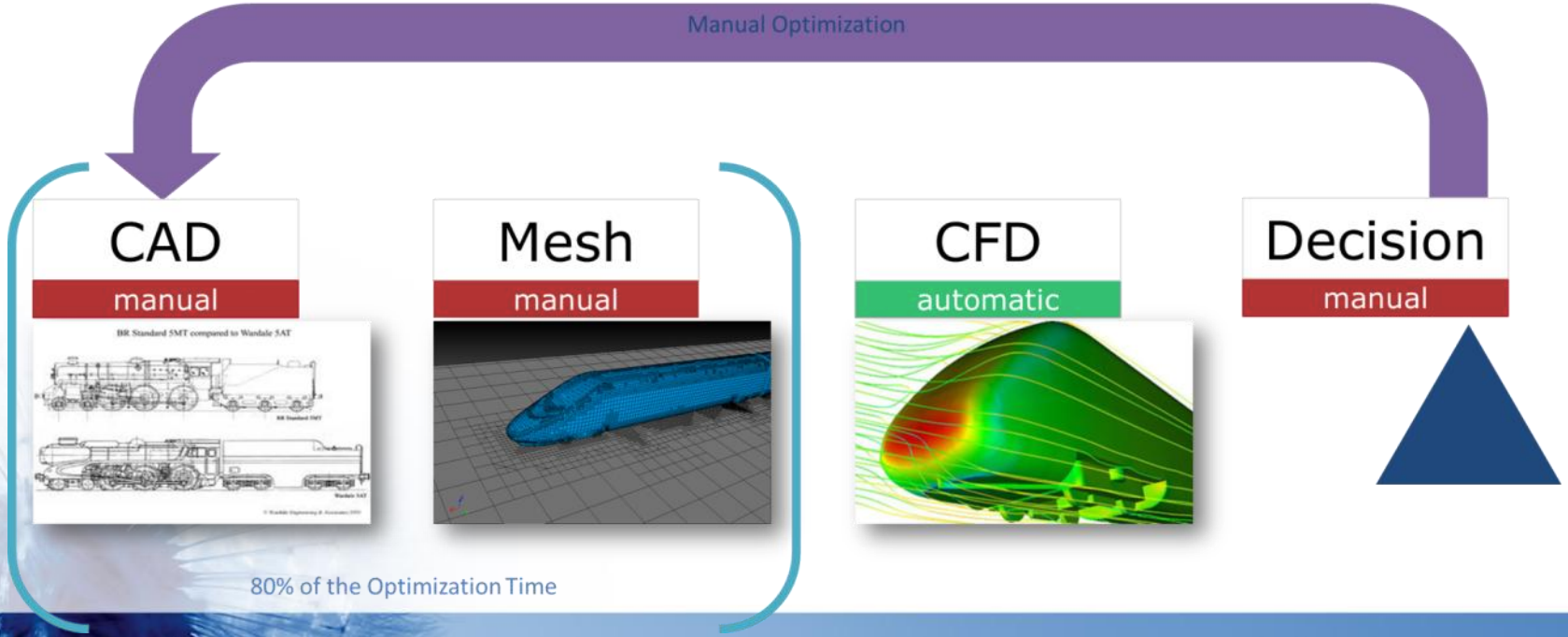
Proposed Solution

- Medical Planning for Optimal Shape
  - Reduce expansion in the distal region
- Provide doctor with quantitative results
- Optimus used to drive optimal design
- Minimize volume of artery
  - This ensures the minimization of expansion on proximal region

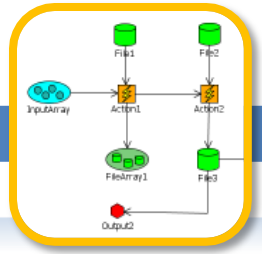
Challenges

- Models are non-CAD based
- CFD Models are large and require time-consuming simulations
- Changes should be organic using non-engineering parameters
- Highly technical tools to be used by overworked physicians

Barriers to optimizing in CFD

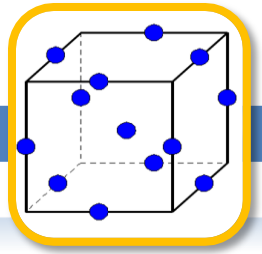


Optimus® **P**rocess **I**ntegration & **D**esign **O**ptimization



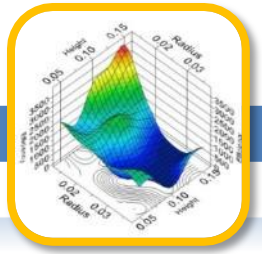
Process Integration

(PI)



Design of Experiments

(DOE)

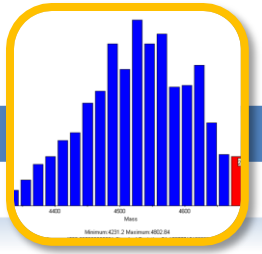


Response Surface Modeling

(RSM)

Multidisciplinary Design Optimization

(MDO)



Robust & Reliability-based Design Optimization

(RBDO)

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A leading software & services provider

… more than 15+ years & 100+ person-years experience in Simulation Process Automation & Design Optimization. The largest OEM provider of embedded optimization.

A strong worldwide presence

… sales offices across Europe, US and Asia realizing double-digit profit growth for 15+ years.

Optimus Workflow

Change Geometry

Perform Geometry Based Calculation

Export New Geometry

Calculate Mesh

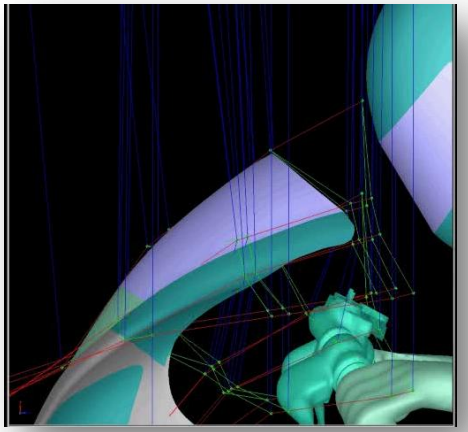
Decide on Analysis

Solve Model in Analysis

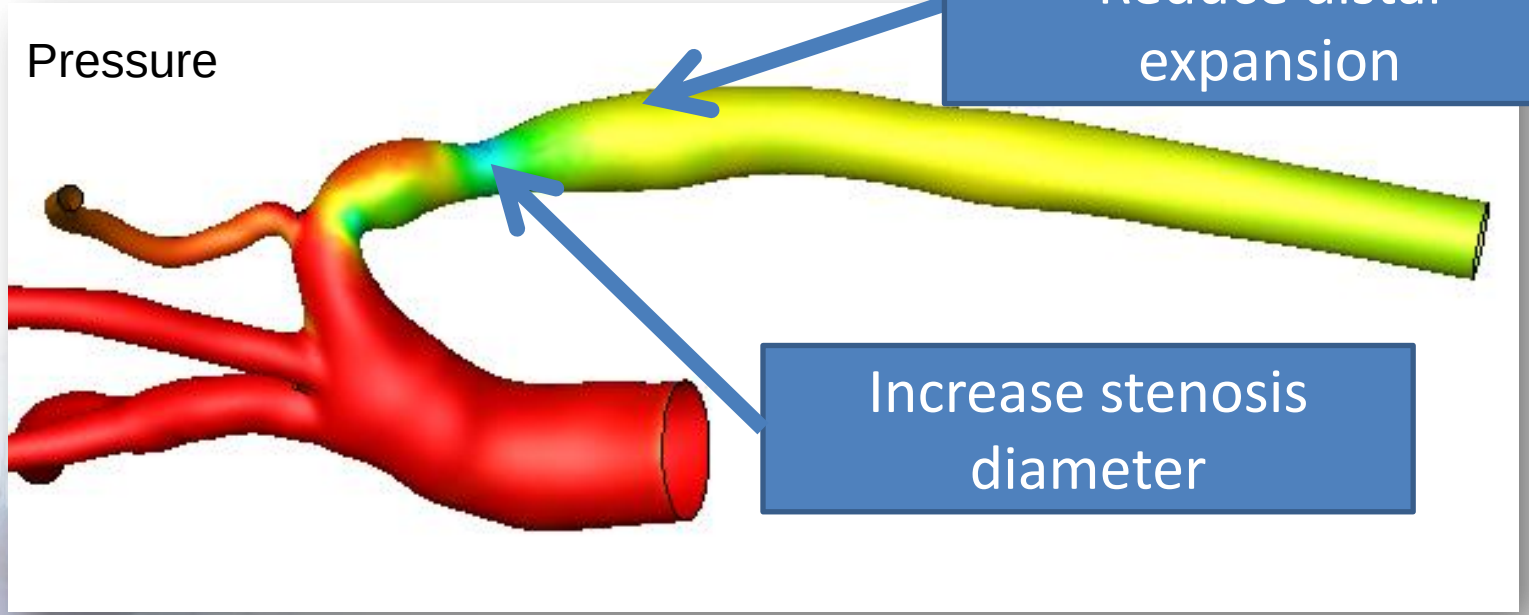
Extract Outputs from Reports

Mesh morphing to assist in optimization

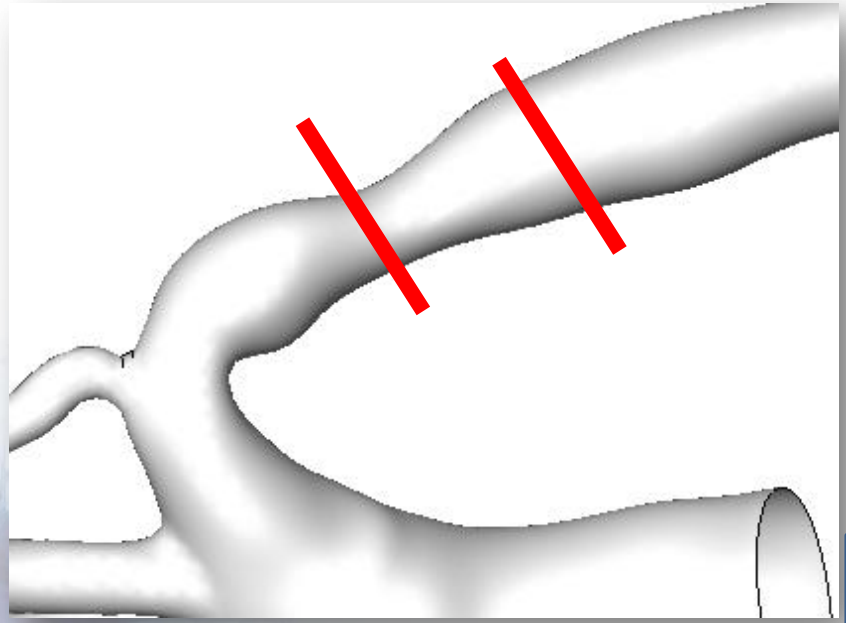
- No way to make changes to the model
- Remove the need to re-mesh each time
- Mesh morphing tool that utilizes Bezier volumes to morph nodes
- Arbitrary placement and deformation of Bezier nodes.
- Real time morphing

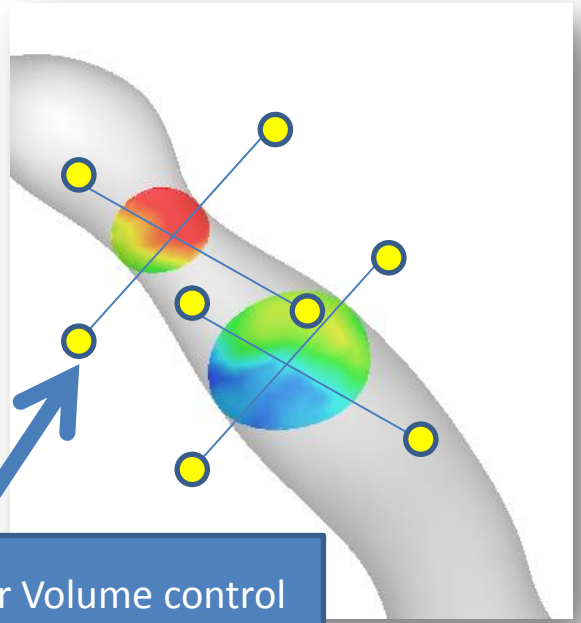


The Initial CFD Model



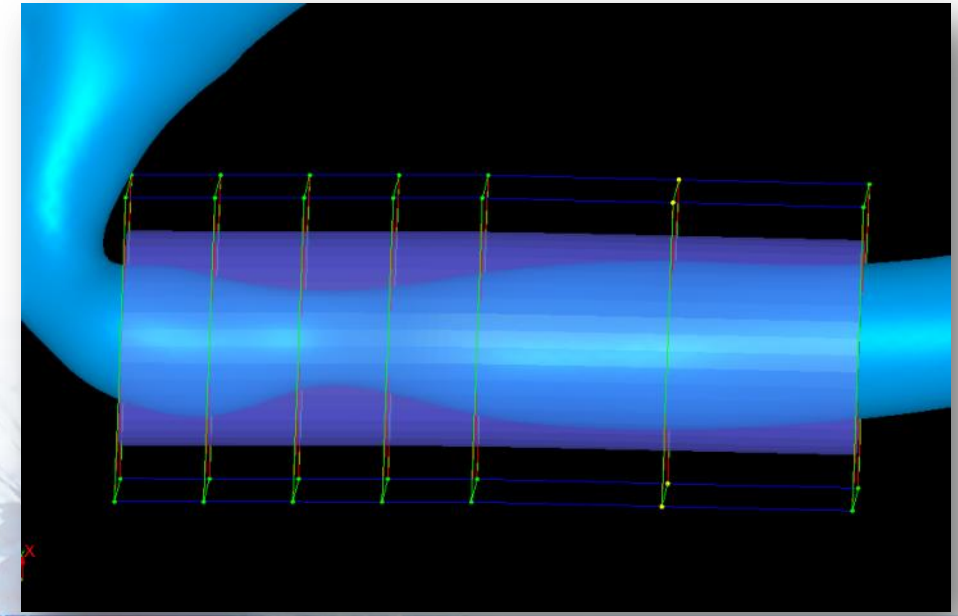
Preparing the Model for Morphing Deformation Areas

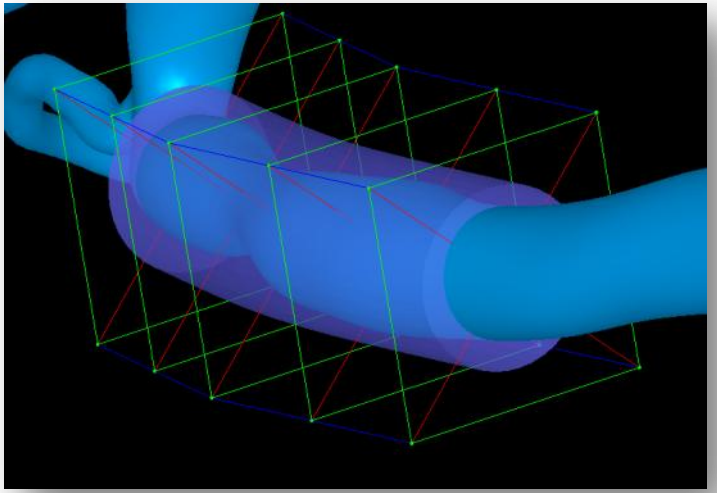


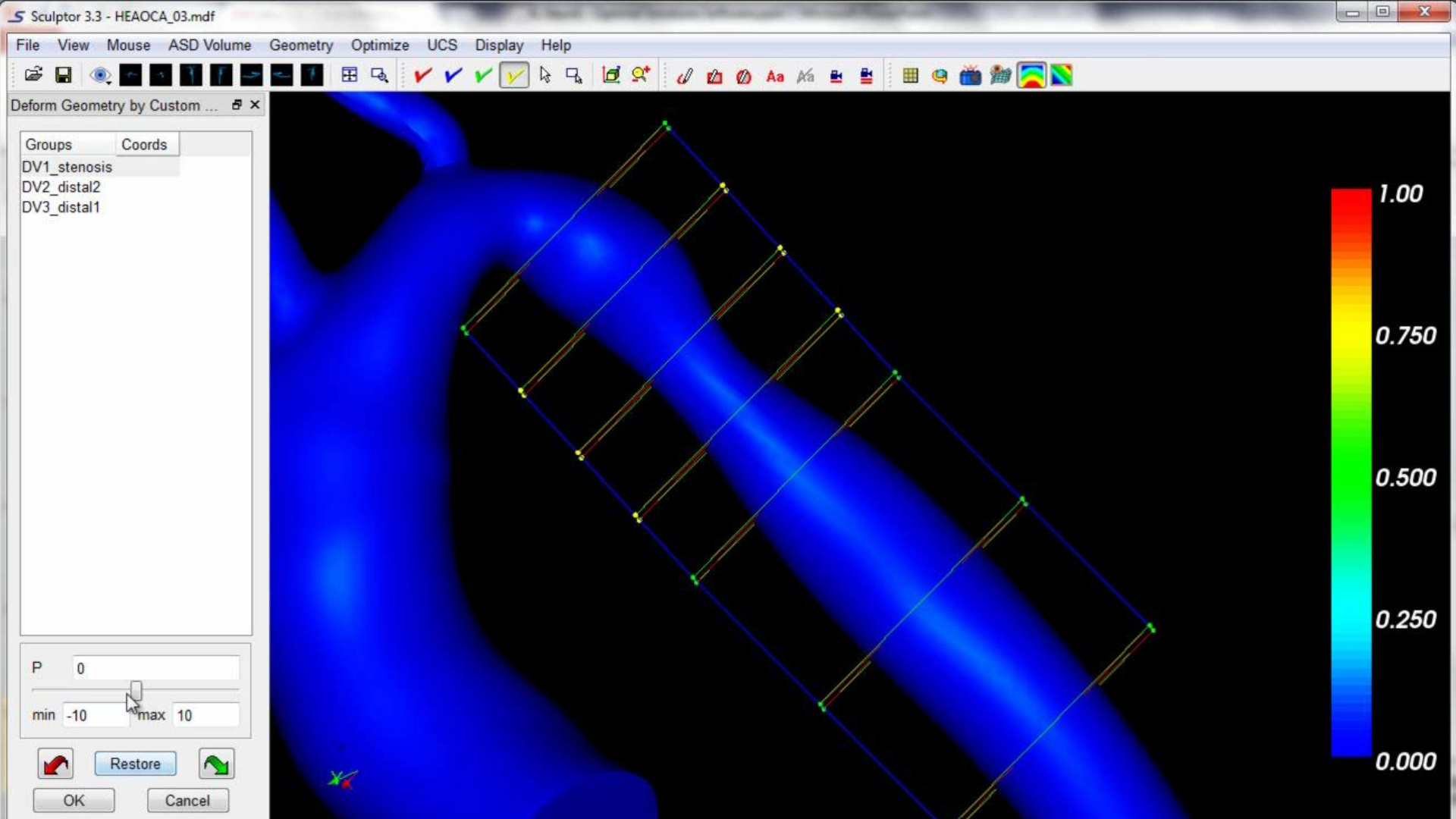


Bezier Volume control point location

Creating Bezier Control Volume

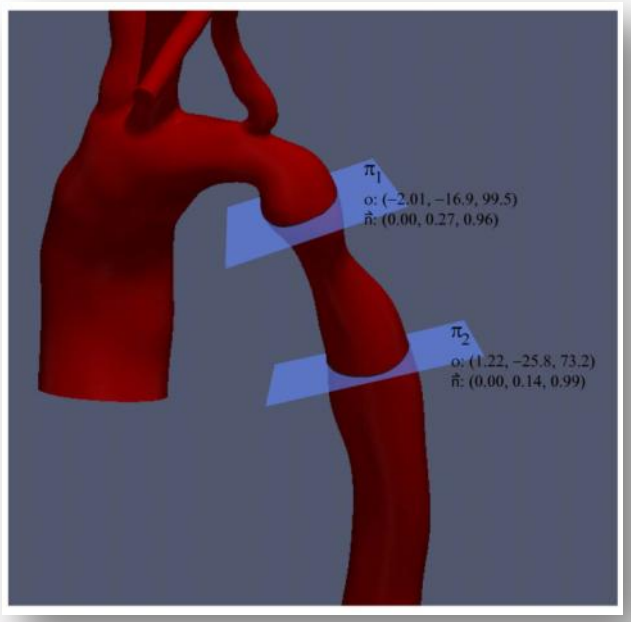





Sculptor 3.3 - HEAOCA_03.mdf
File
View
Mouse
ASD Volume
Geometry
Optimize
UCS
Display
Help
Deform Geometry by Custom ...
Groups
Coords
DV1_stenosis
DV2_distal2
DV3_distal1
P
0
min
-10
max
10
Restore
OK
Cancel
1.00
0.750
0.500
0.250
0.000

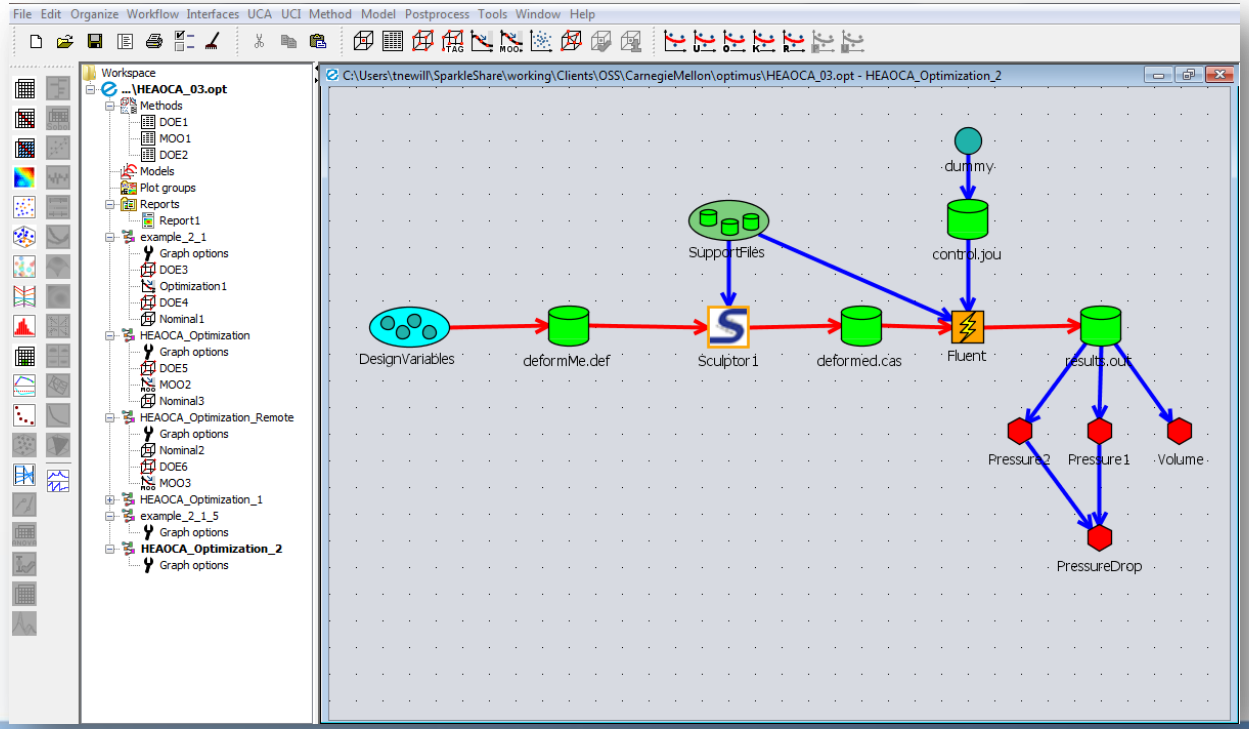
Optimization Goal

- Minimize the pressure drop across the two planes shown
- Minimize Volume of mesh
- Reduce velocity gradient at stenosis
- Reduce pressure on distal region



Optimus Workflow

- 3 Inputs
- 3 Outputs



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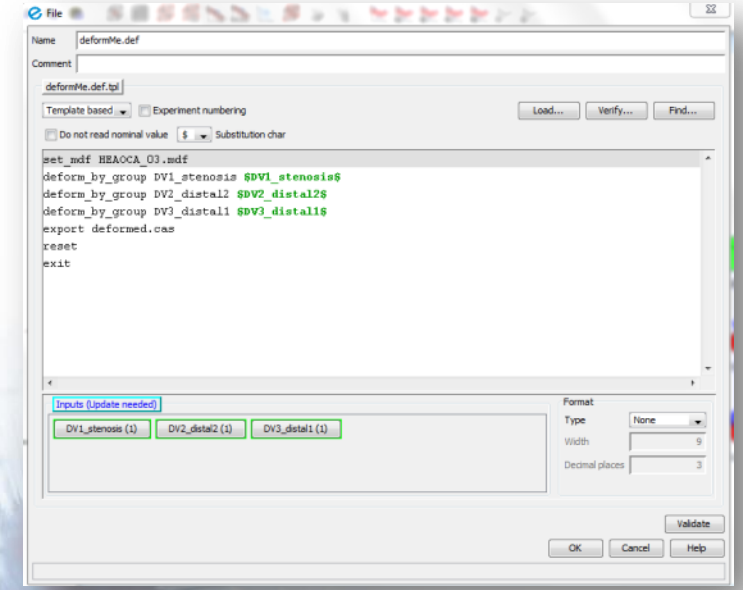
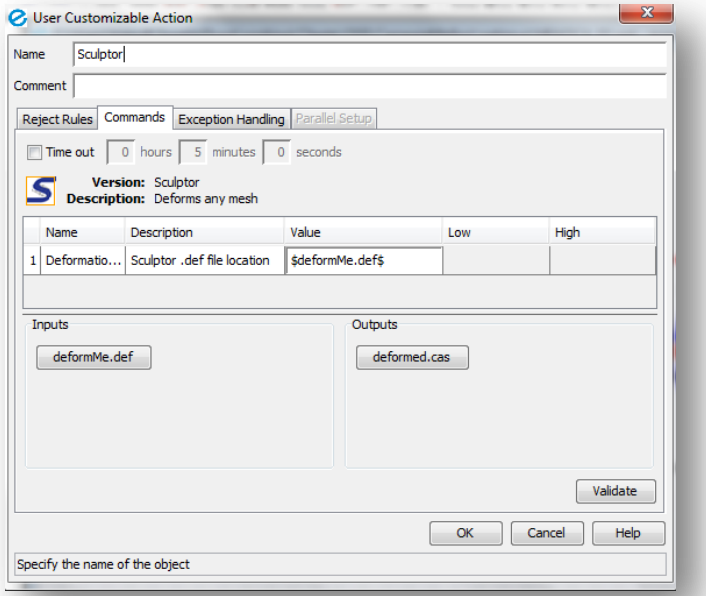
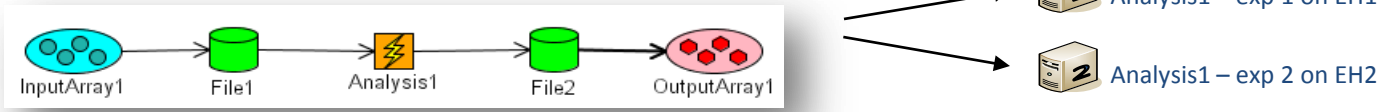
Automation Setup



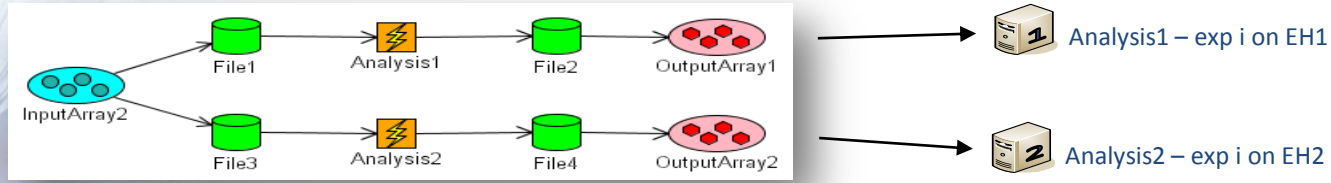


2 types of parallel execution

- **Experiment level**: For every single independent analysis of the sequence, several execution can be performed simultaneously for the different design alternatives



- **Workflow level**: 2 or more analyses of a same workflow are independent and can be execute “in parallel” for the same experiment



Parallel & HPC

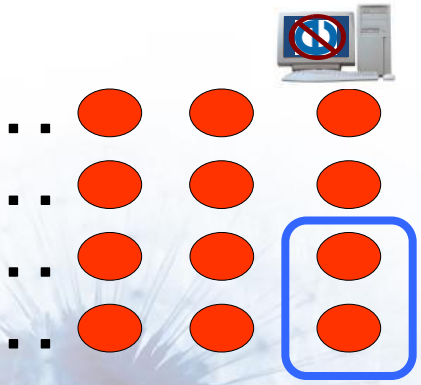
- Optimus can manage each job separately
- All methods and optimizers can take real advantage of parallelization
- Takes advantage of **heterogeneous** networks (and GPU)
- Unique capability

Parallelization Example

Only Experiment level

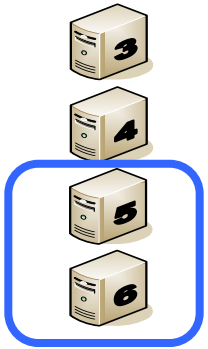
1 Experiment

Other Optimizer



Sculptor (< 1min)

Fluent (25 min)



Time

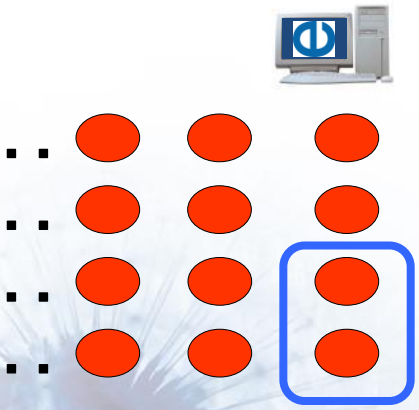
1000 run*(1min+25min)/2=13000min
13000min / 60min = 217h
217h = 9 **days**

Dependencies Example

Experiment level & Workflow level

1 Experiment

OPTIMUS



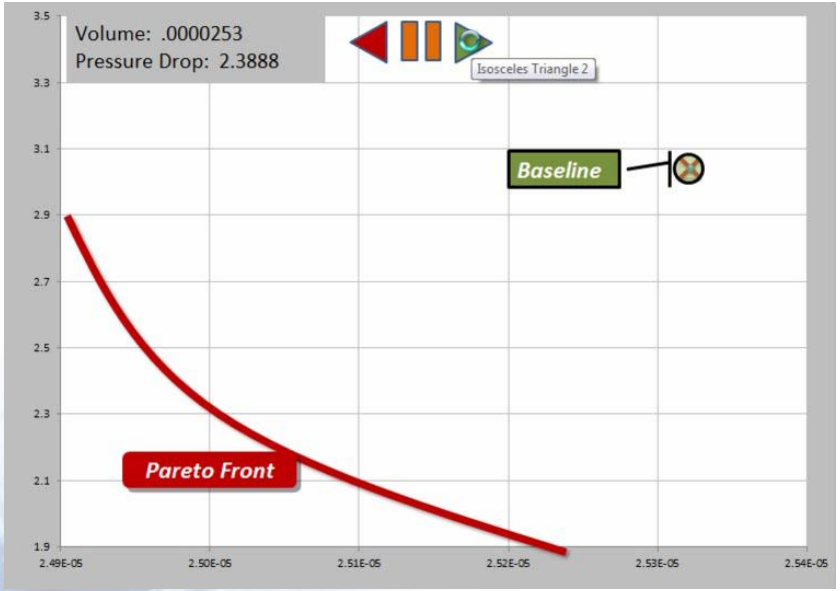
Sculptor (<1 min)

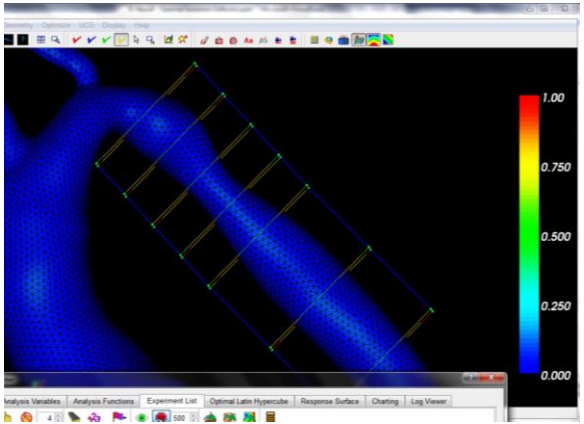
Fluent (25min)

Time

6250min = 104h = 4.3 days

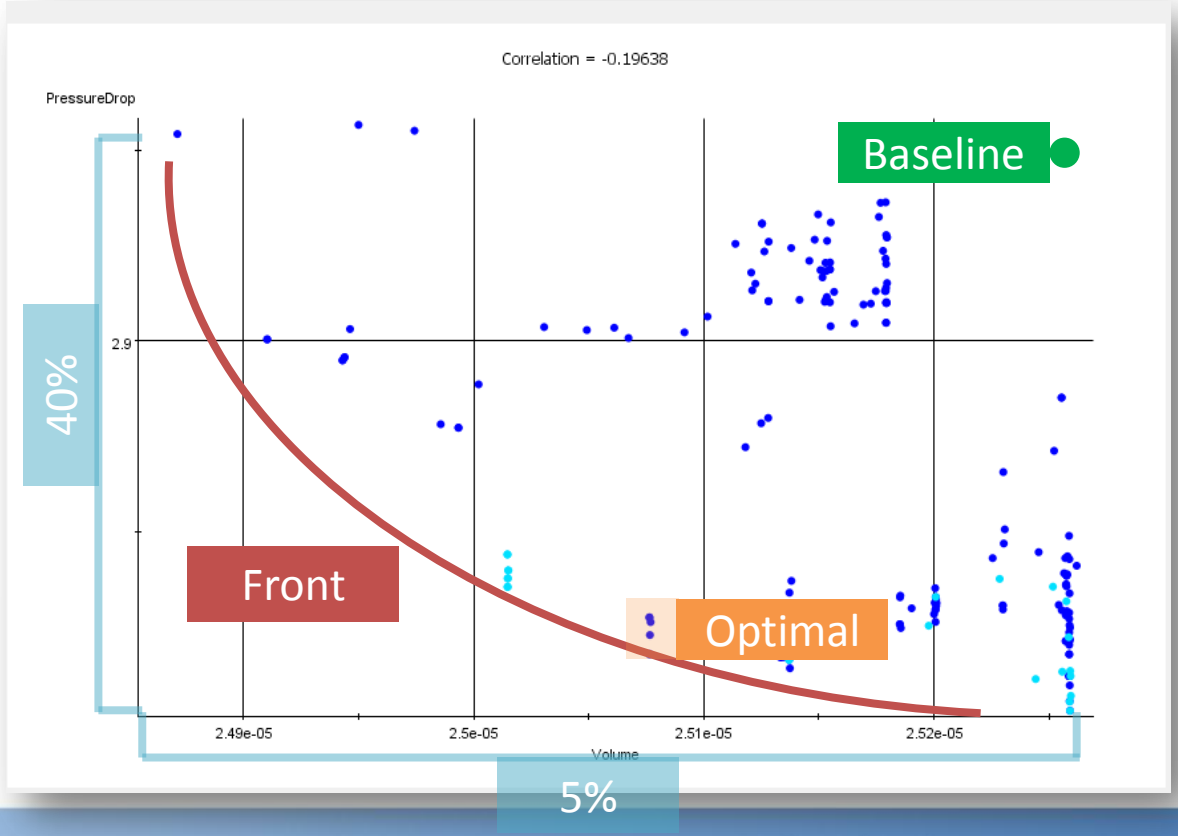
Optimization Process





Results

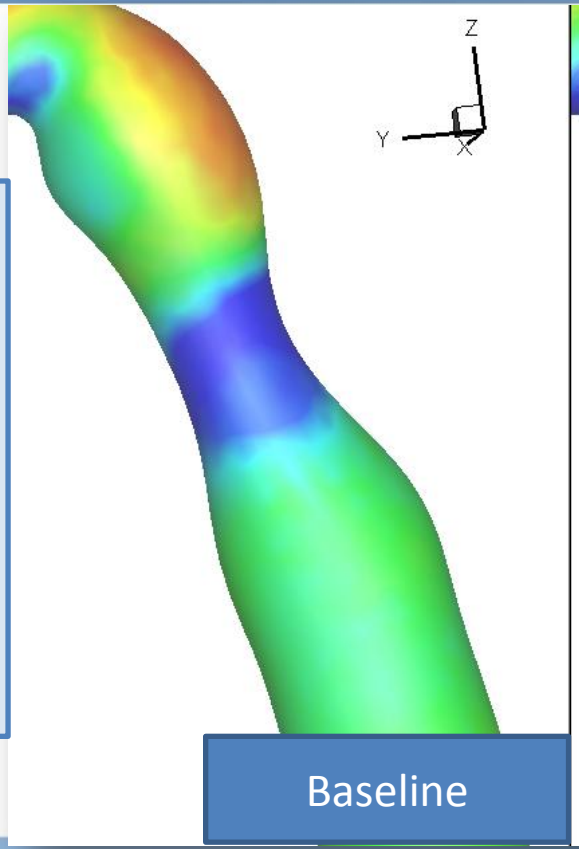
- The chart displays a shallow Pareto front
- Weight pressure drop more than volume



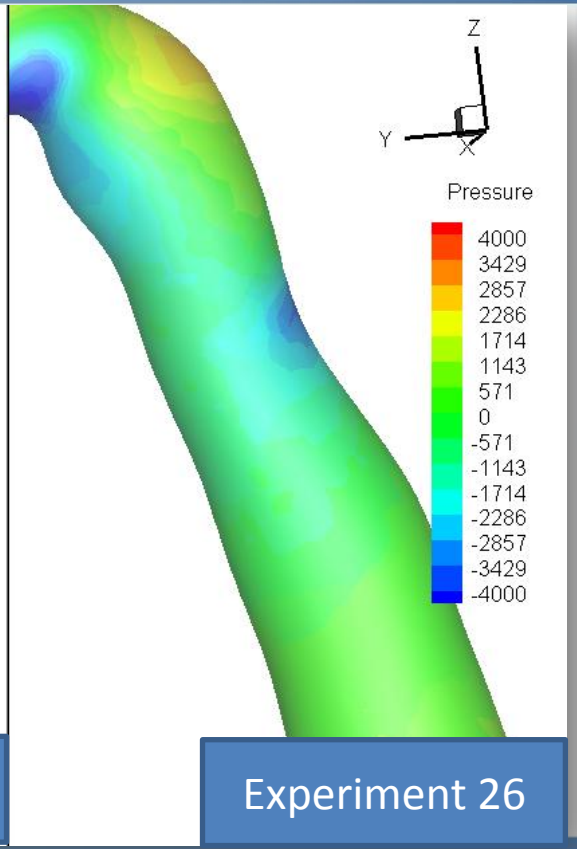
Results

Pressure

- Pressure drop reduced by 28%
- The low pressure region in the area proximal to the stenosis was increased by 37%
- The high pressure region in the distal area was reduced by 26%



Baseline



Experiment 26

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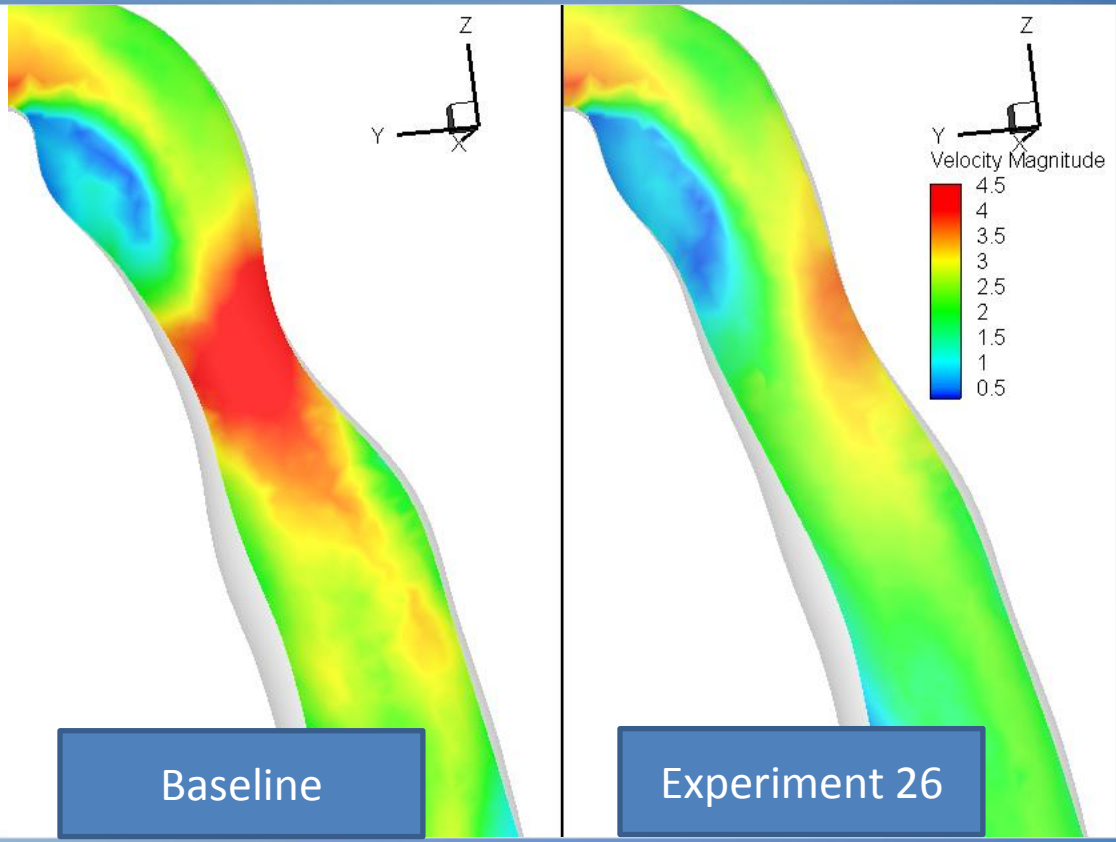
Results

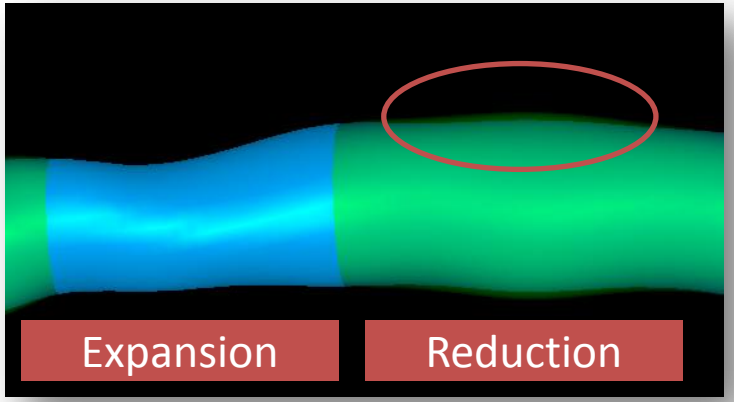
Velocity Magnitude

- Reduced flow variability
- Hemodynamic flow velocity was decreased through the medial area by 22%



Results – Volume

- Subtle volume changes, 1.1% decrease
- Increase in medial area volume disguised changes in distal area volume



Results

Experiment	Pressure Drop	Delta	Volume	Delta	Velocity	Delta
Baseline	3.0406		2.532E-05		4.4280	
Experiment26	2.1835	**-28.19%**	2.501E-05	**-1.23%**	3.4617	**-21.82%**

Conclusion & Future Work

- The method proved to be a success
  - Reduce expansion in the distal region
  - Provide doctor with quantitative procedure feedback
  - Optimus used to drive optimal design
- The method was “easy enough a Doctor could do it”
- The method can be even easier using Optimus API to integrate all this in Excel or a browser
- Future work: including robustness and stochasticity in the process

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Thank You

Special thanks to: Carnegie Mellon University, Riverview Medical Center, Indianapolis, Indiana

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