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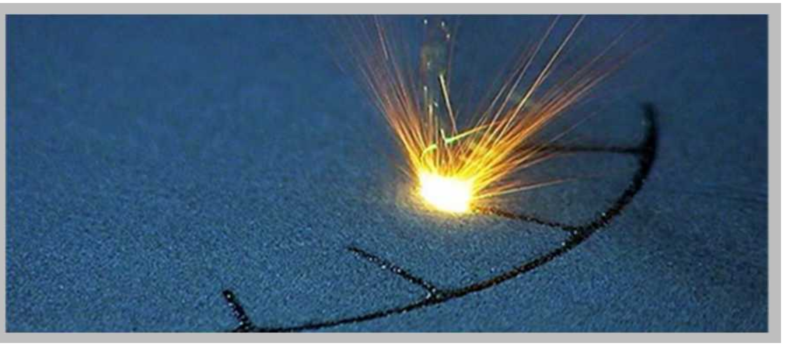

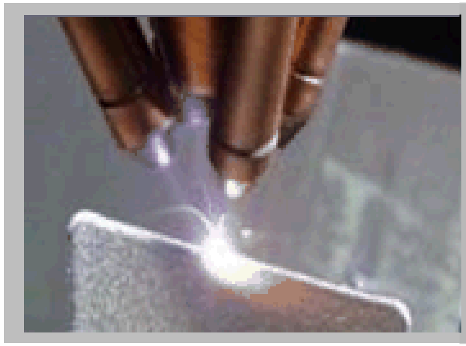

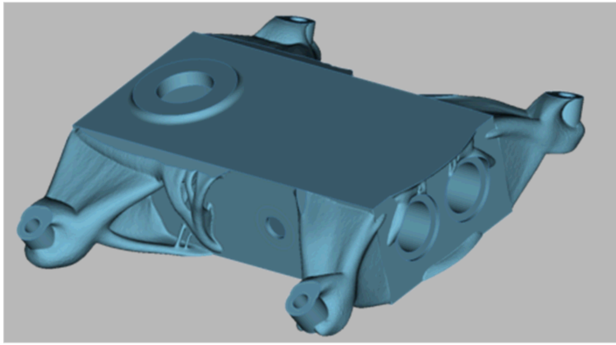

# Using a common geometry description to enable optimization-based design

Joshua Robbins

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration

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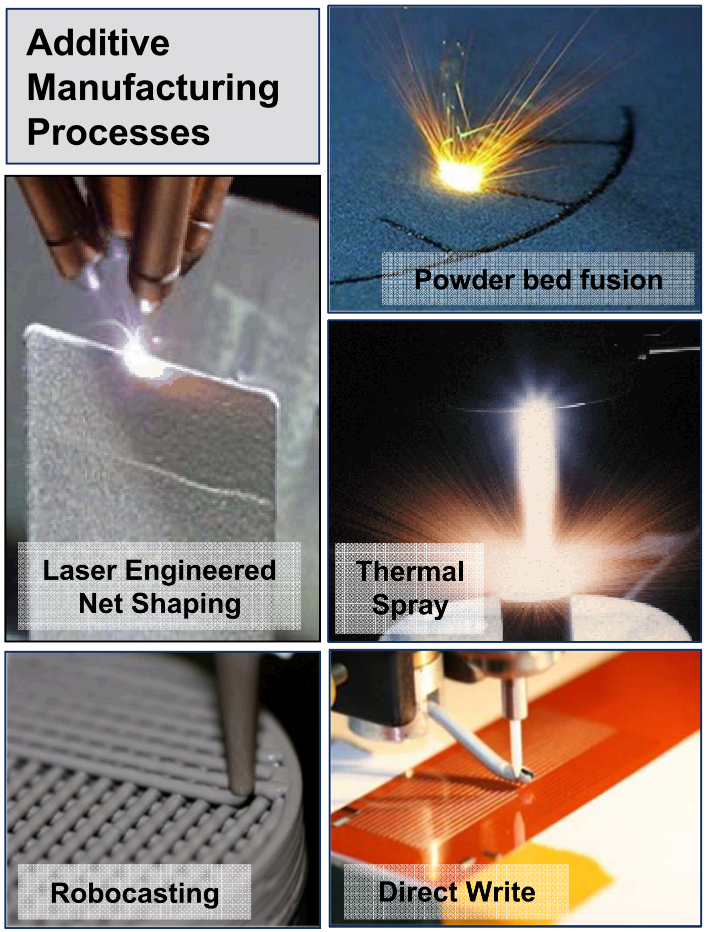
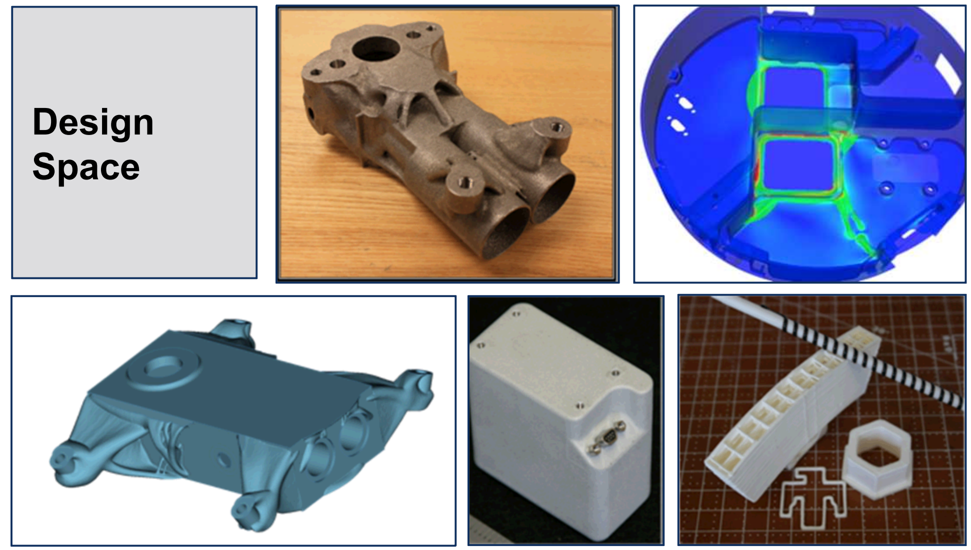
# Problem Statement




Two main challenges must be overcome:

- **Qualification**: assure quality
- **Design**: effectively utilize AM

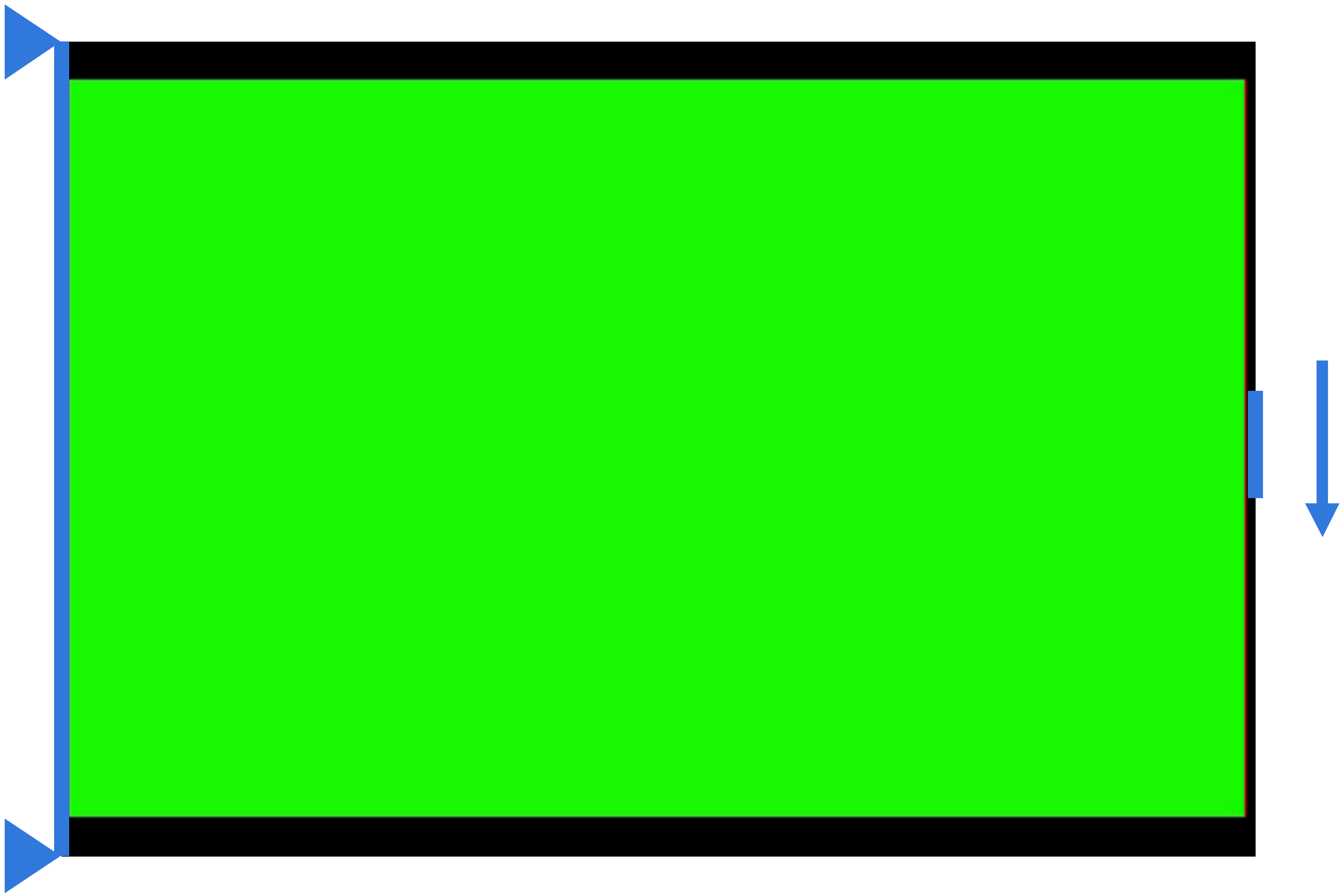
# Topology Optimization

**Forward Problem:**

Design + Materials → Response

**Inverse Problem:**

Design + Materials ← Response



Objective: optimal stiffness

Constraint: fixed mass

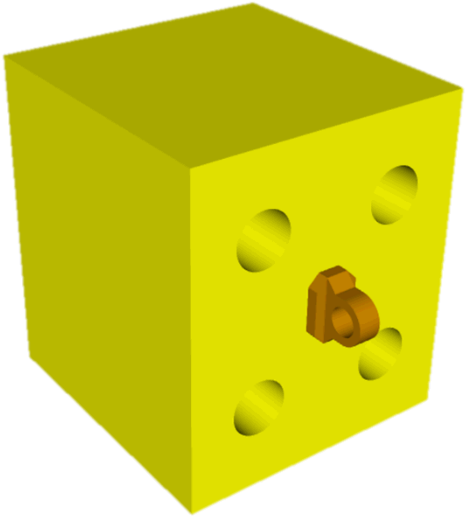
# Topology Optimization

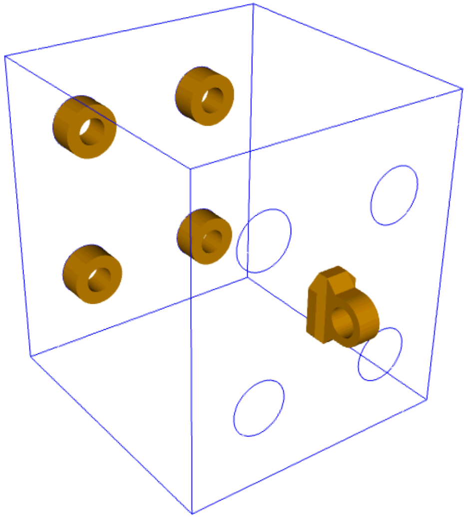
**Objective:** $\min_{z} \quad F\left(\mathbf{u}\left(\hat{\boldsymbol{z}}\right), \hat{\boldsymbol{z}}\right)$

**Measure Constraint:** $s.t. \quad G\left(\hat{\boldsymbol{z}}\right) = M$

**PDE Constraint(s):** $H_i\left(\mathbf{u}\left(\hat{\boldsymbol{z}}\right), \hat{\boldsymbol{z}}\right) = 0, \;\; i = 1, \ldots, N$

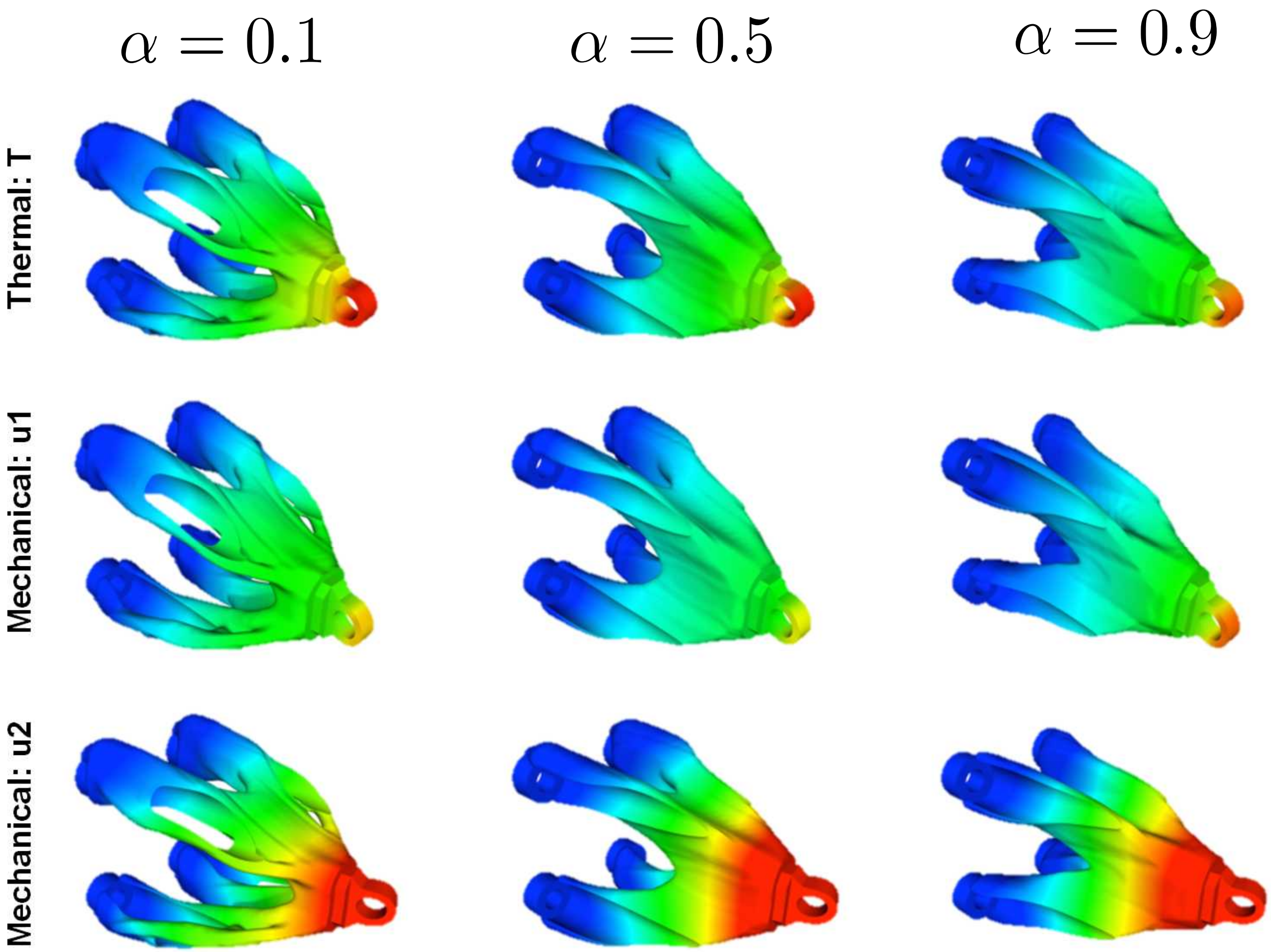
**Density Constraint:** $\hat{\boldsymbol{z}} = \left\{\hat{z}_1, \hat{z}_2, \ldots, \hat{z}_n\right\}, \hat{z}_i = P_i\left(z_i\right) \in [0, 1]$

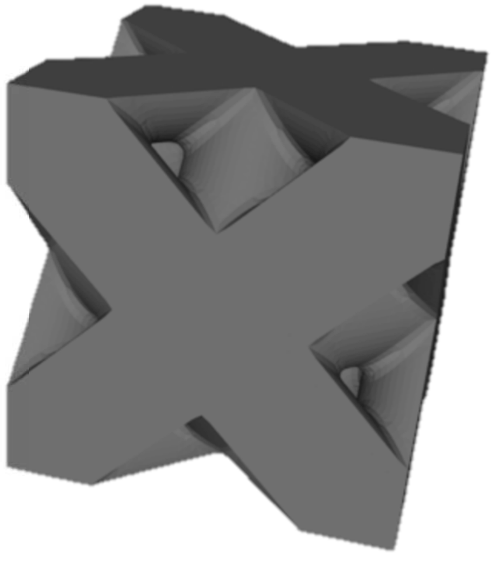




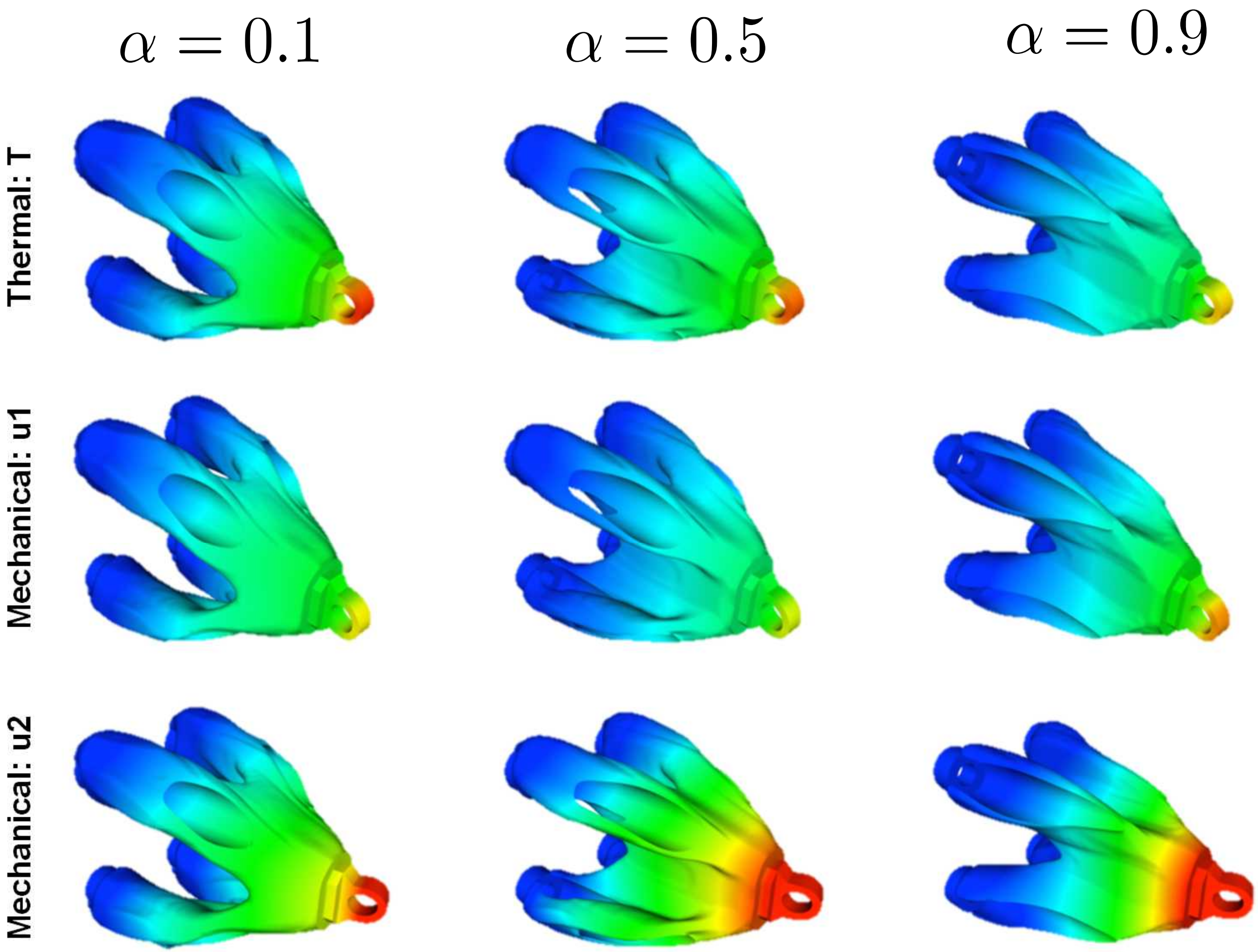
$$\min_{\rho} : \left( \frac{(1-\alpha)}{2} \int_{\partial\Omega_f} \mathbf{f_1} \cdot \mathbf{u_1}\left(\rho\right) dV + \frac{(1-\alpha)}{2} \int_{\partial\Omega_f} \mathbf{f_2} \cdot \mathbf{u_2}\left(\rho\right) dV + \alpha \int_{\partial\Omega_T} q \; T\left(\rho\right) dV \right)$$

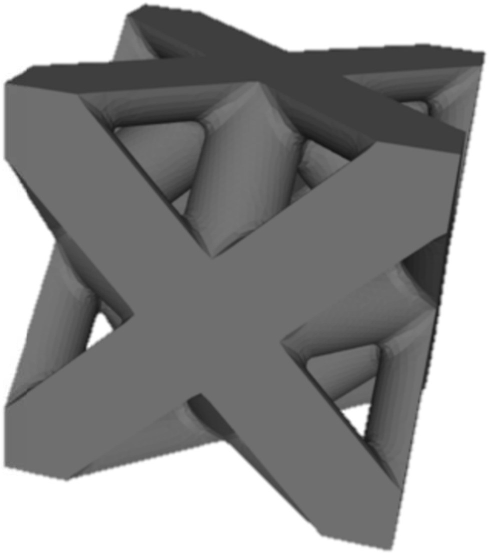
# Cellular (75% dense)



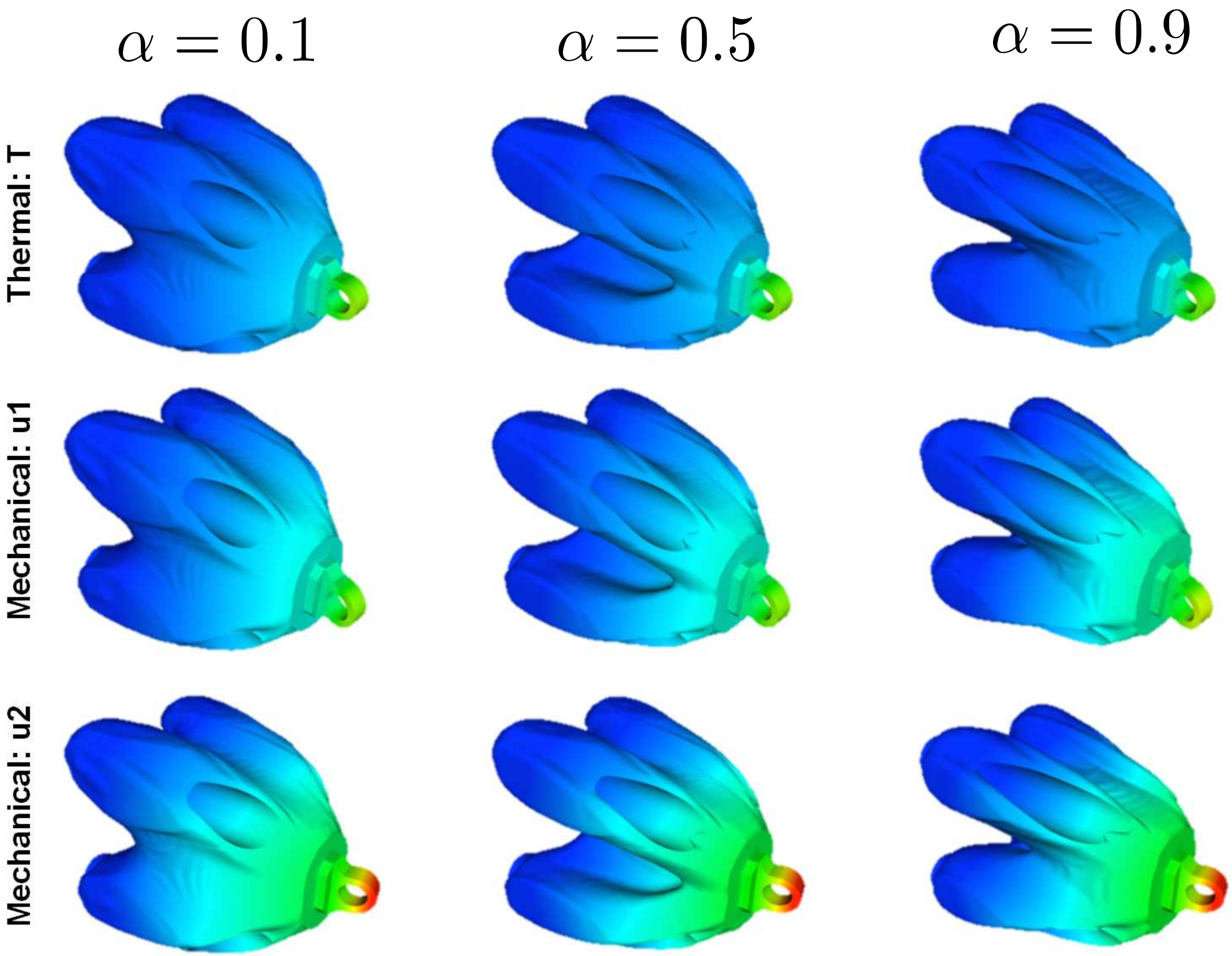



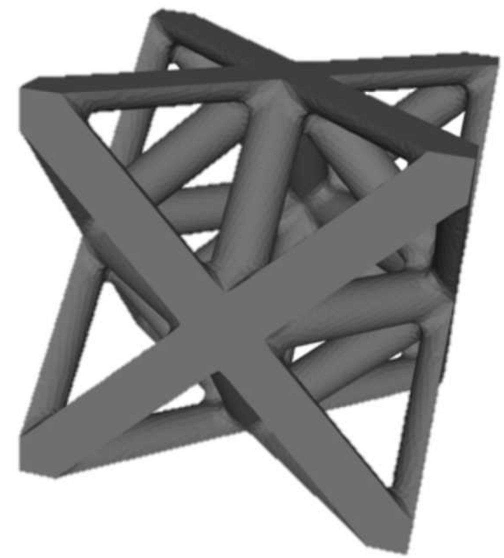
# Cellular (50% dense)



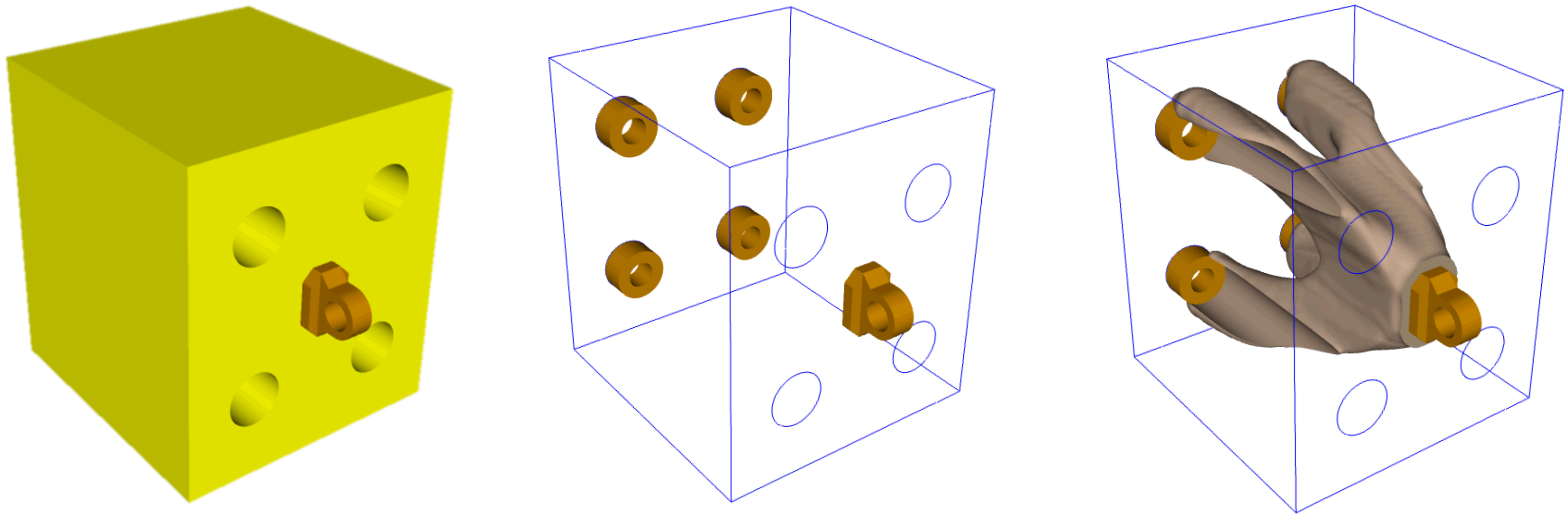



# Cellular (20% dense)



# Shape and Topology Optimization

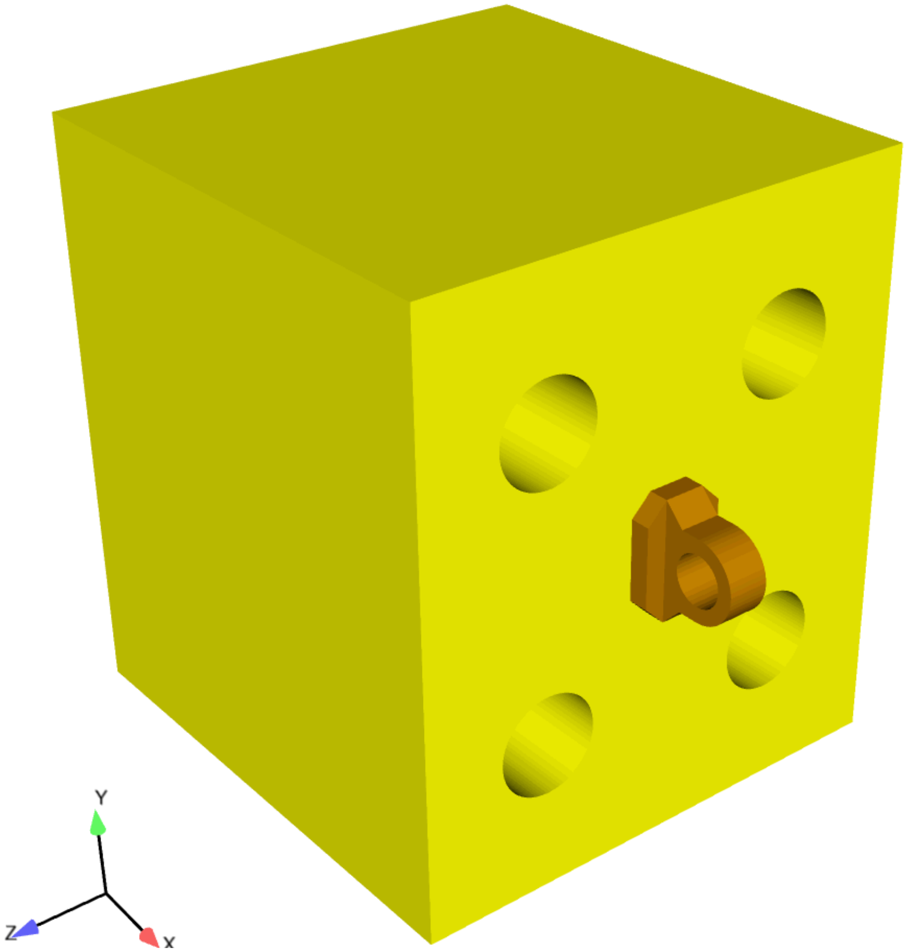


Are the mounts in the right place, the right size, shape?

Ideally, we'd optimize the shape (number, location, etc) and the topology, concurrently.

# Design Revisited: Volume based geometry

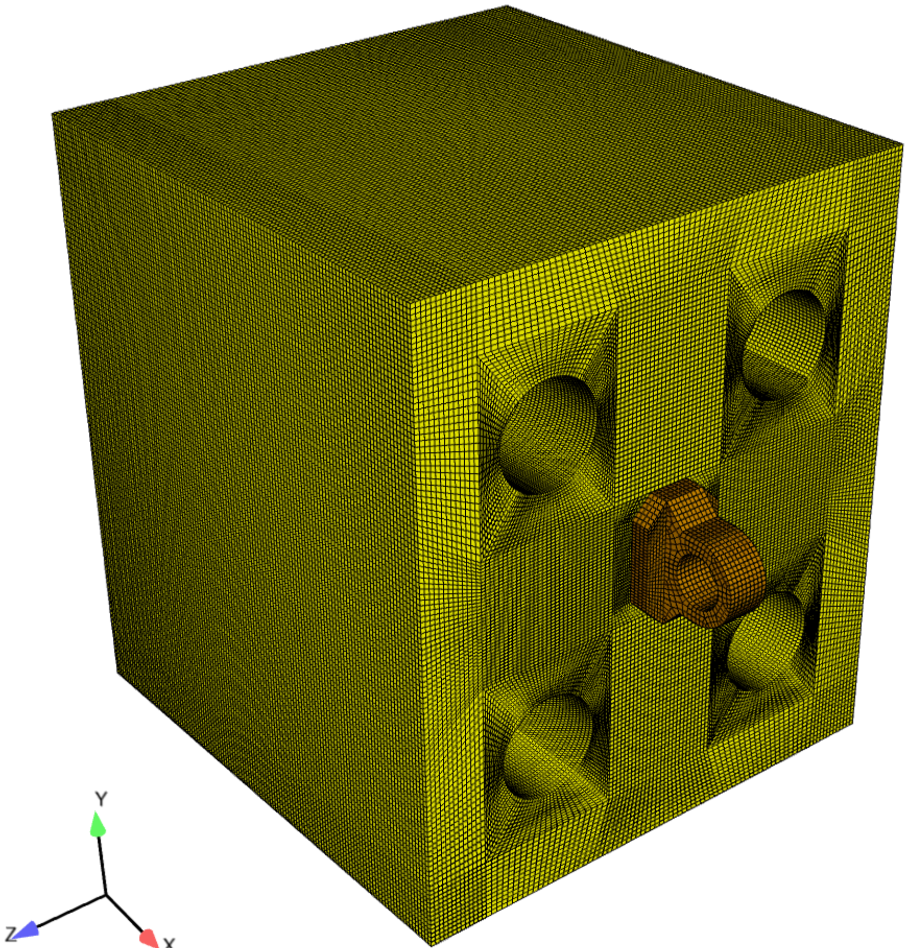
## Solid Modeling

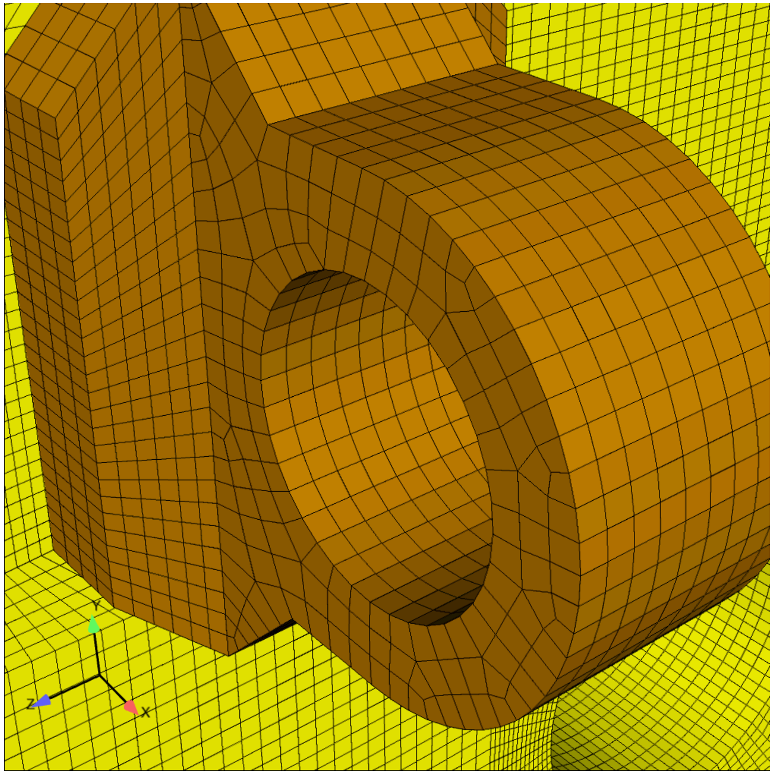



**Surface-based solid model**

# Design Revisited: Volume based geometry

## Simulation




**Discrete conformal volume-based solid model**

# Design Revisited:  Volume based geometry

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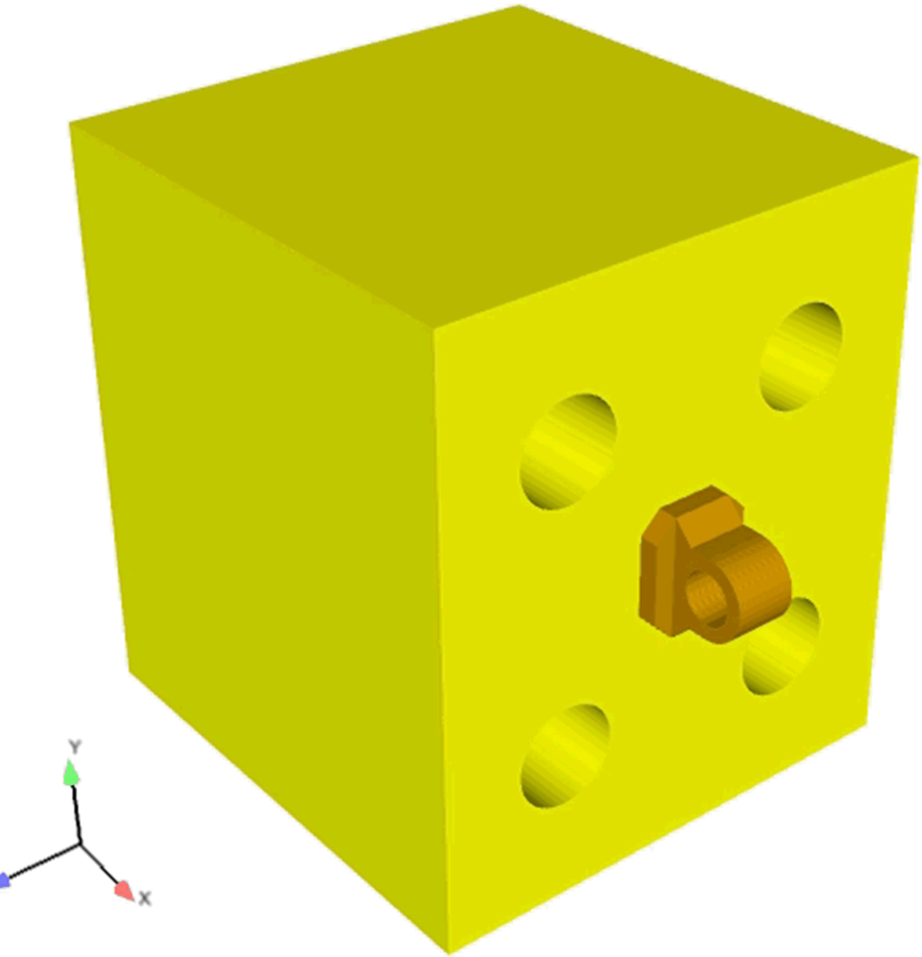
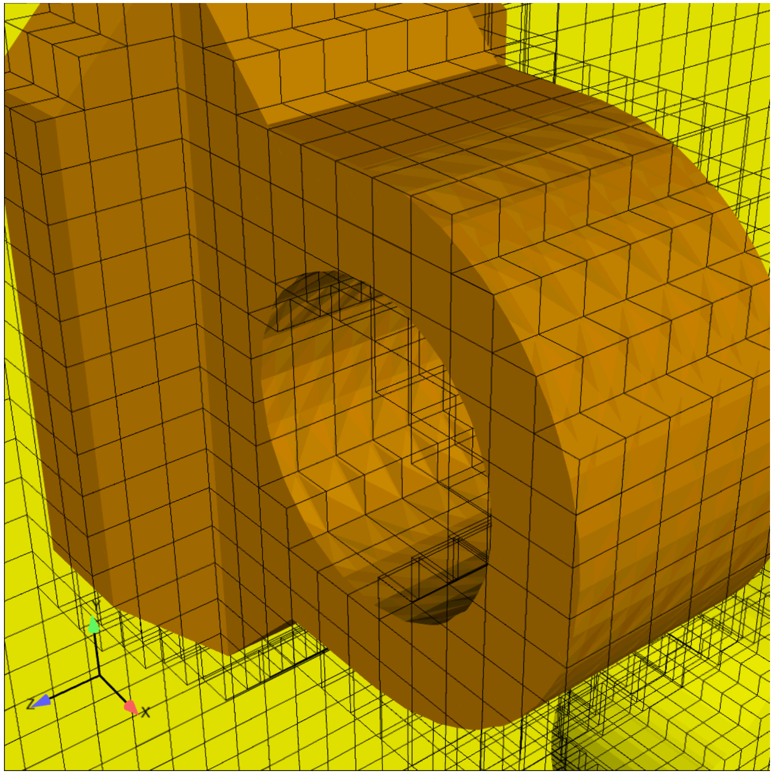
**Simulation**




**Discrete nonconformal volume-based solid model**

# Design Revisited:  Volume based geometry

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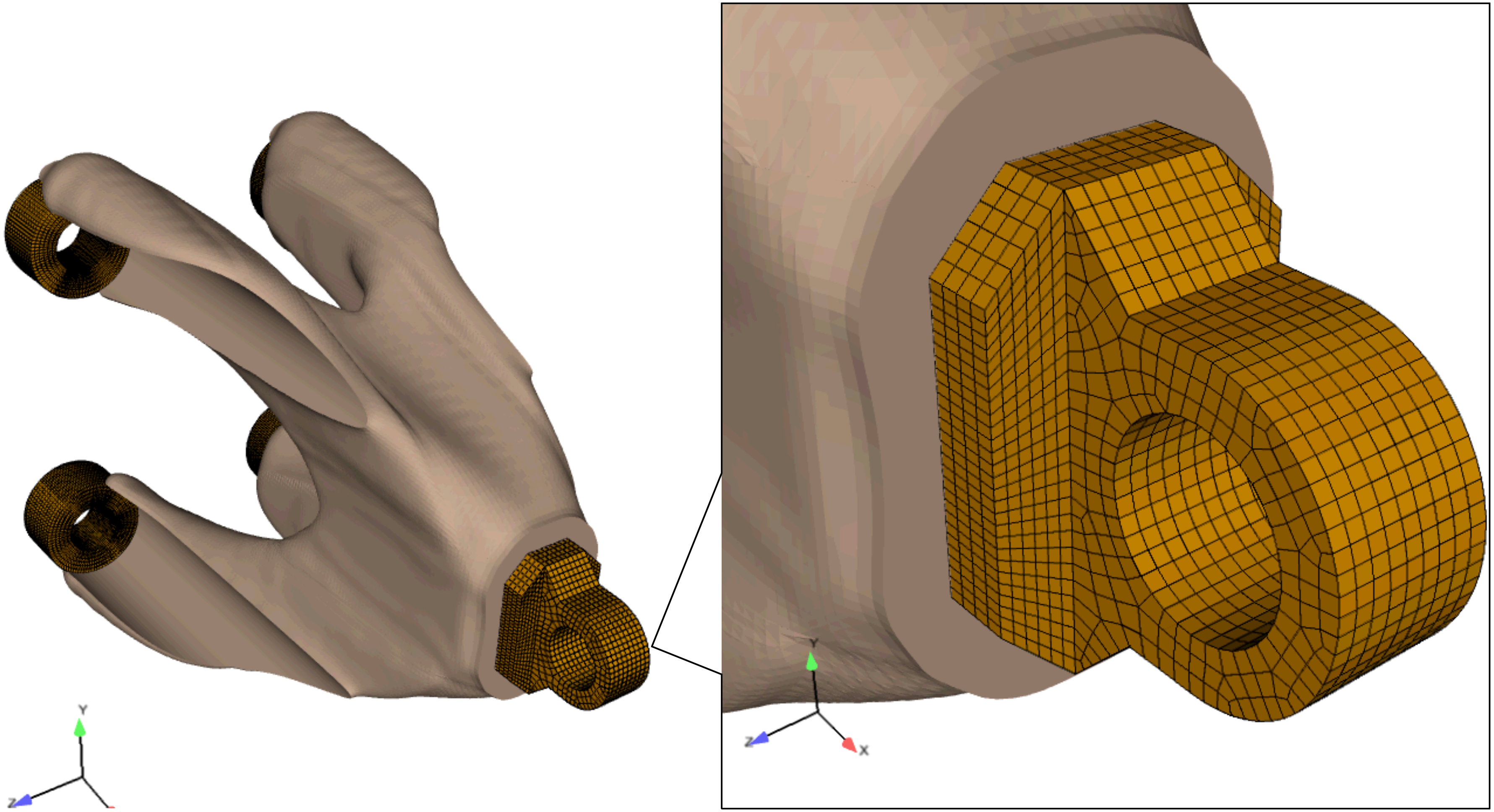
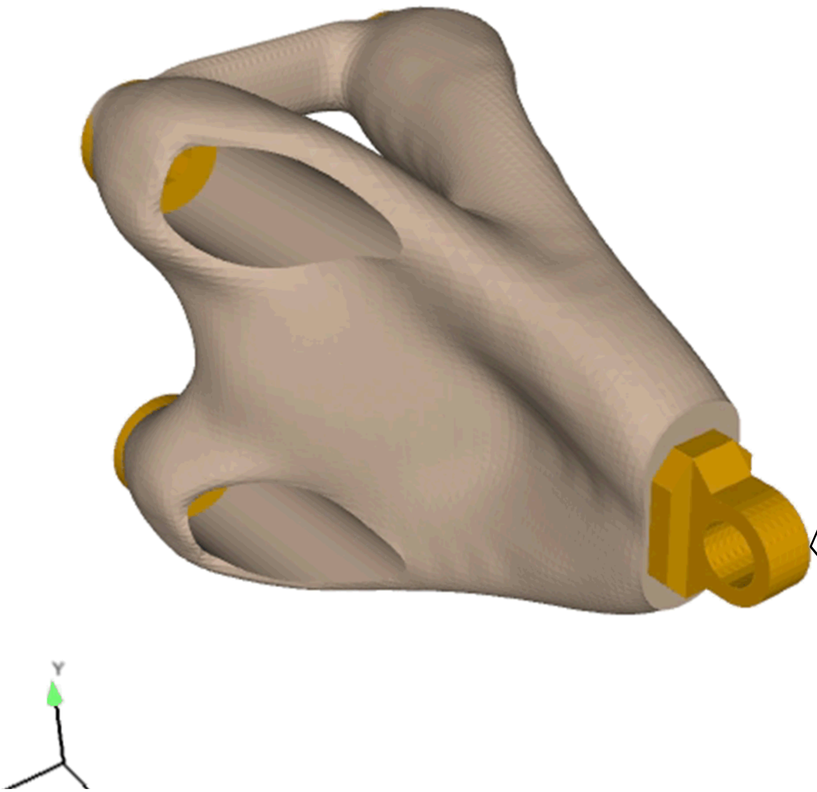
## Optimization-based design

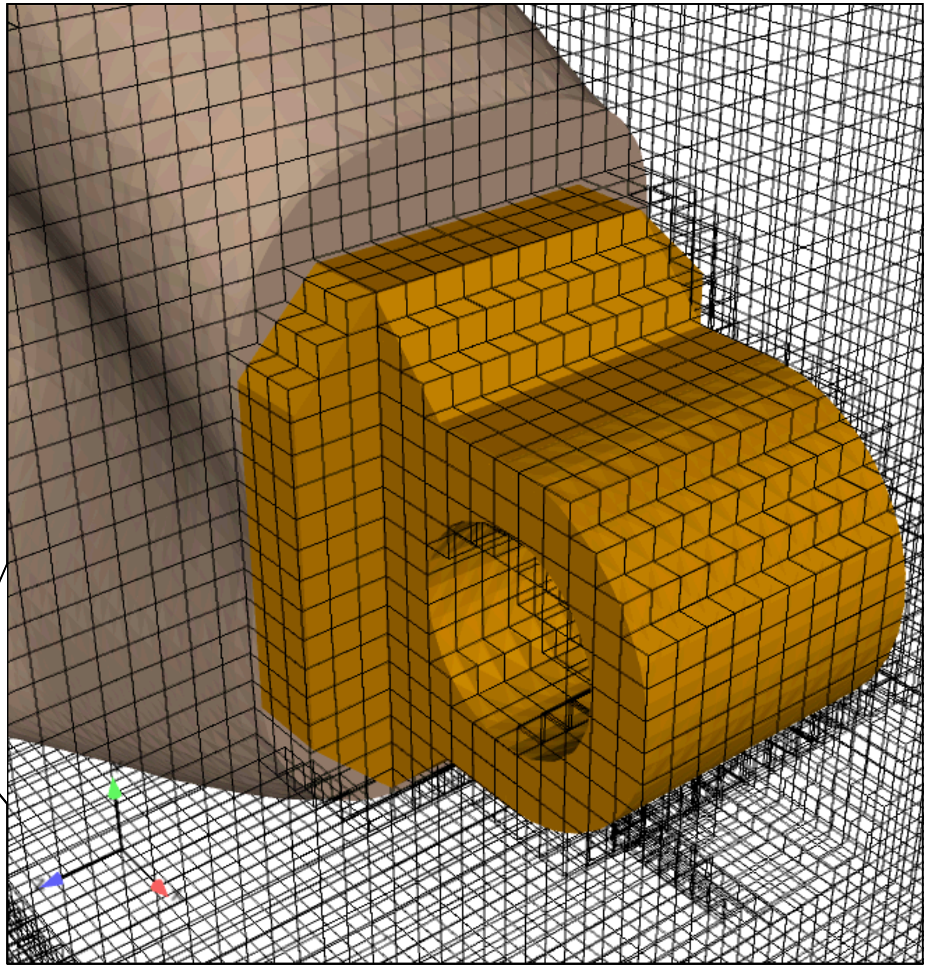



**Discrete nonconformal volume-based solid model**

# Design Revisited: Volume based geometry

## Optimization-based design

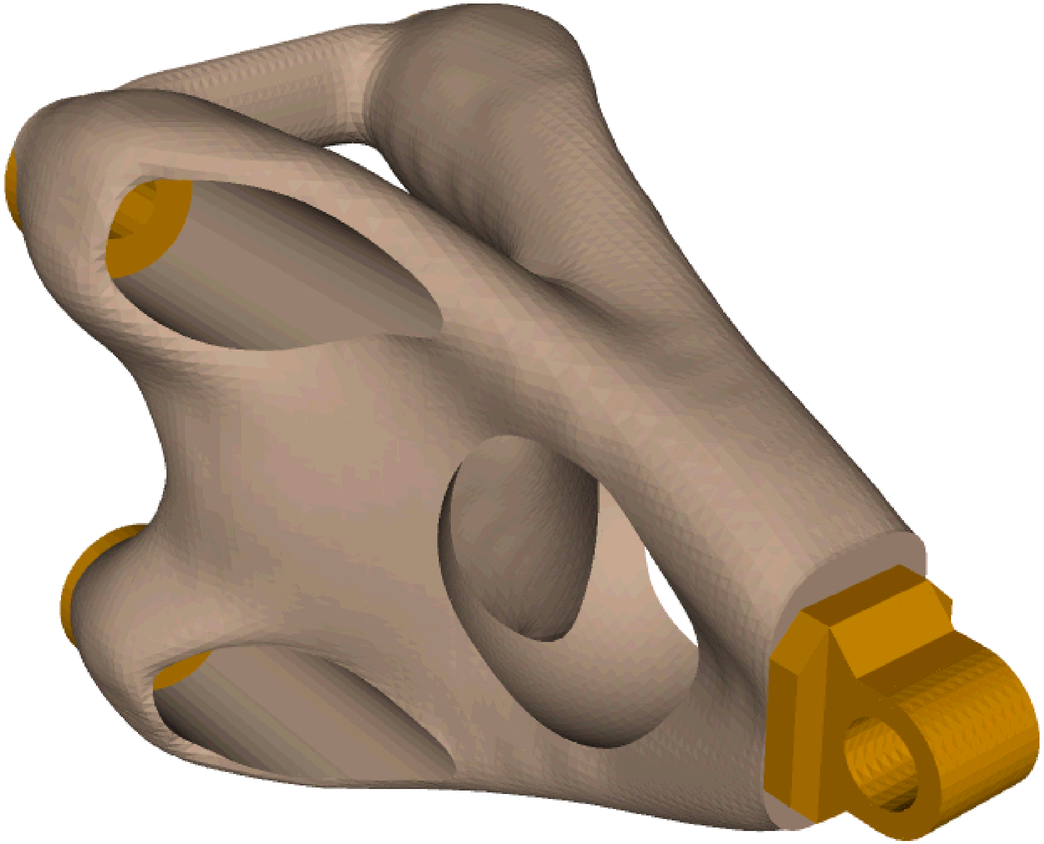




**Discrete nonconformal volume-based solid model**

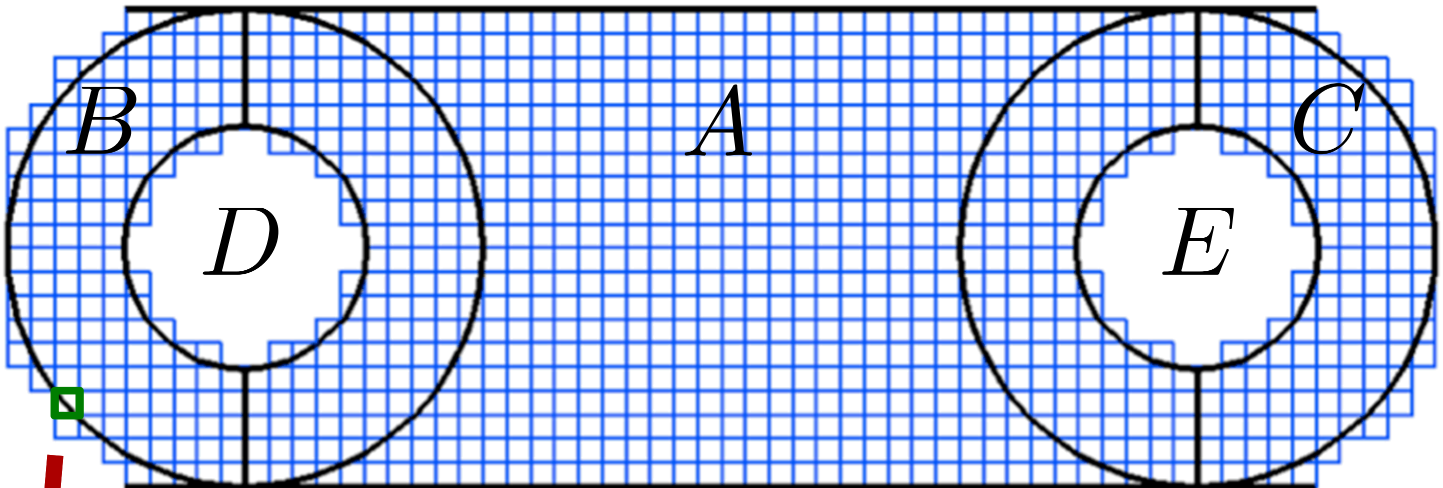
# Design Revisited: Volume based geometry

## Interaction / Modification

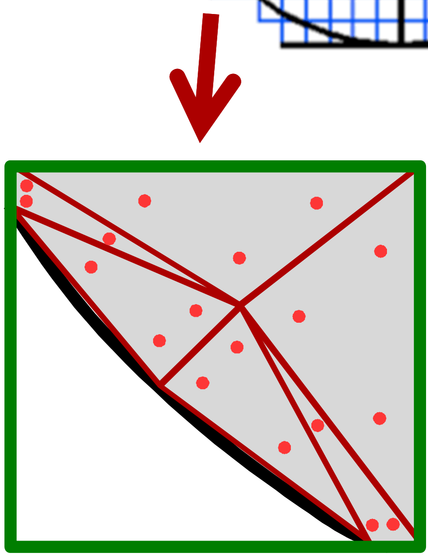


**Discrete nonconformal volume-based solid model**

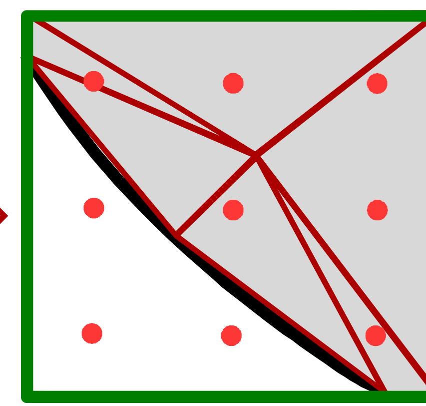
# Shape and topology optimization



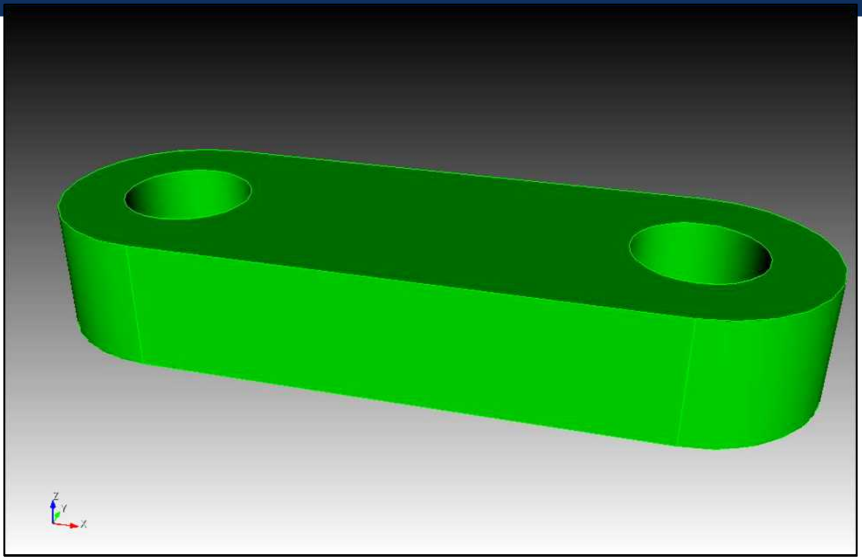

$$(A \vee B \vee C) \wedge \neg(D \vee E)$$

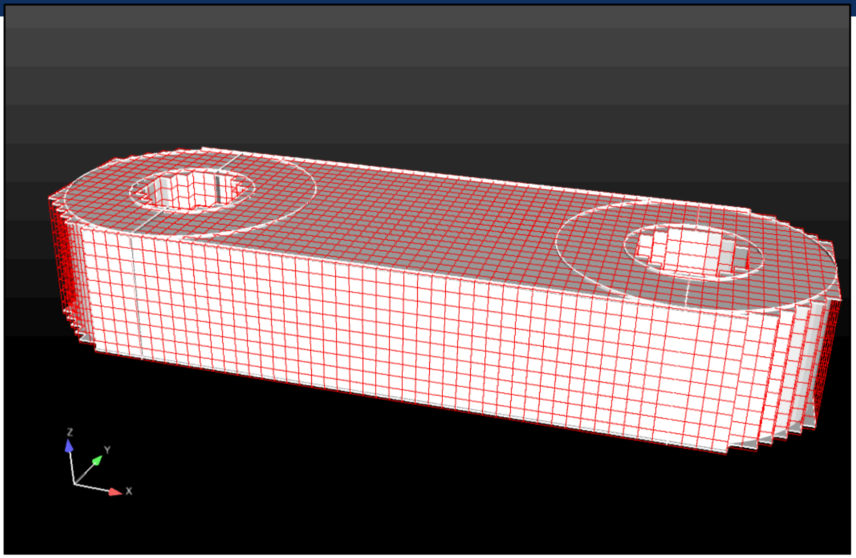


$$\int_{\Omega} g_j(\mathbf{x})\, d\Omega = \sum_i \omega_i \; g_j(\xi_i) det J_{\mathbf{x}\xi}(\xi_i)$$



# Common Geometry Representation



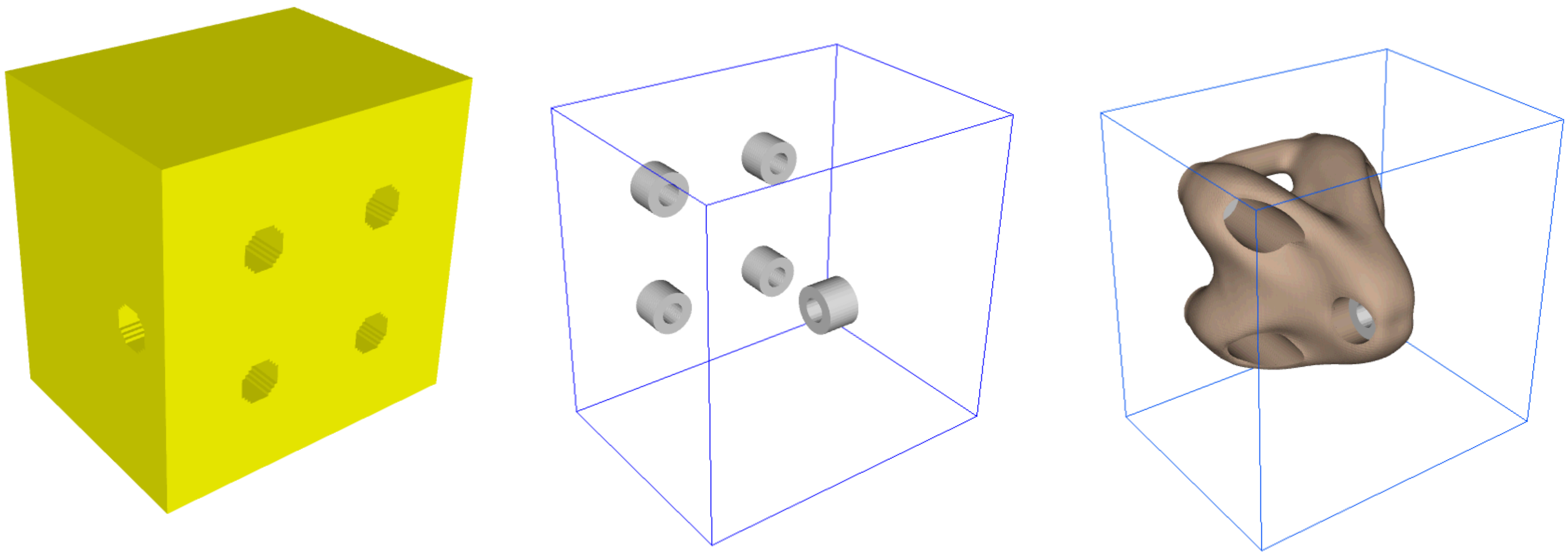


```
create brick x 2 y 1 z 0.5
create cylinder height 0.5 radius 0.5
move volume 2 x 1
unite volume 1 2
create cylinder height 0.5 radius 0.5
move volume 3 x -1
unite volume 1 3
create cylinder height 0.5 radius 0.25
move volume 4 x 1
subtract volume 4 from volume 1
create cylinder height 0.5 radius 0.25
move volume 5 x -1
subtract volume 5 from volume 1
```

```
body = GMeshTools.Body()
brick = GMeshTools.Brick(2.0, 1.0, 0.5)
body.Add(brick)
cylinder = GMeshTools.Cylinder(0.5,0.5,[1,0,0])
body.Add(cylinder)
cylinder = GMeshTools.Cylinder(0.5,0.5,[-1,0,0])
body.Add(cylinder)
cylinder = GMeshTools.Cylinder(0.5,0.25,[1,0,0])
body.Subtract(cylinder)
cylinder = GMeshTools.Cylinder(0.5,0.25,[-1,0,0])
body.Subtract(cylinder)
gmesh.Imprint(body)
```

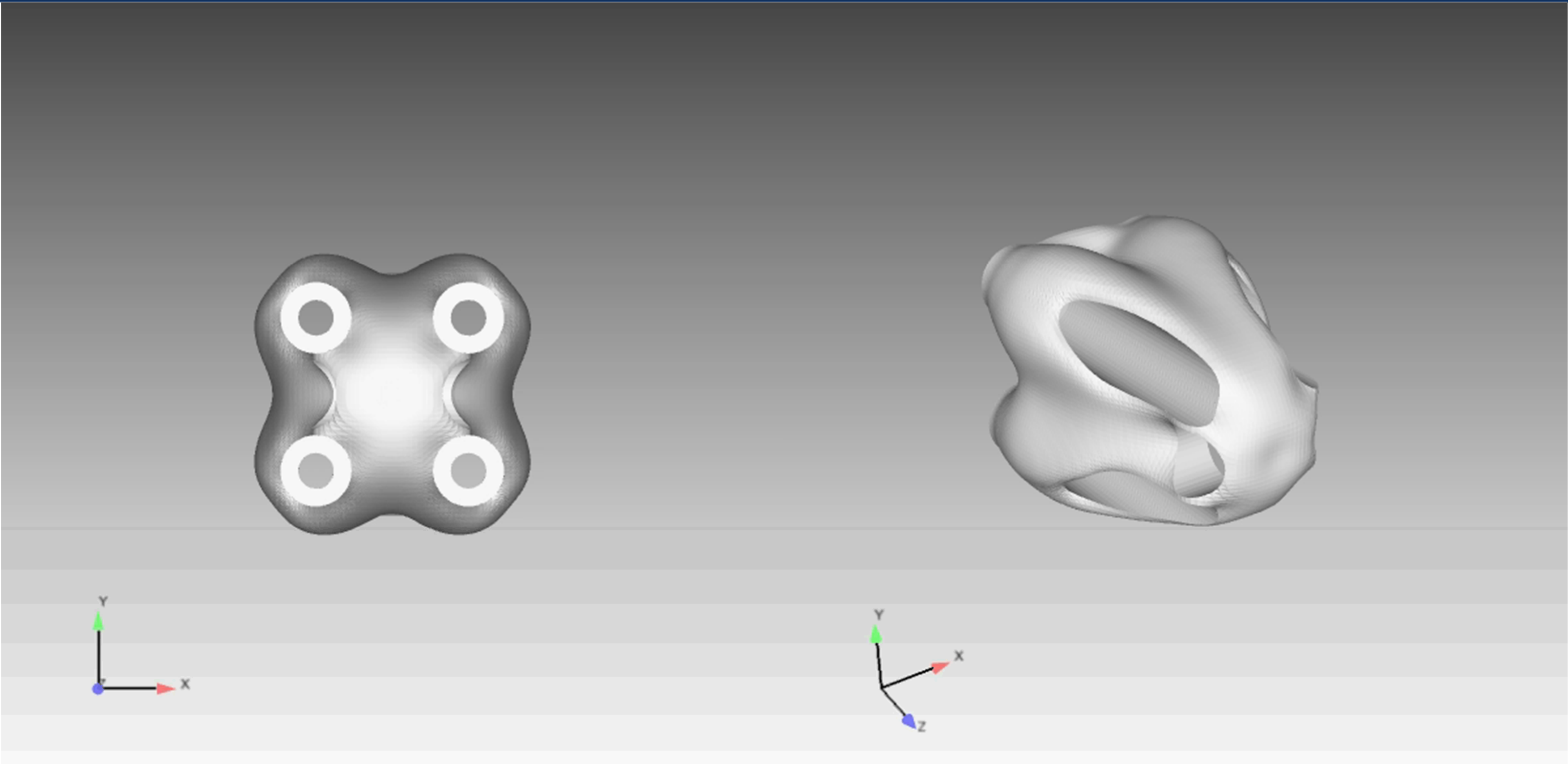
Goal is to implement geometry creation utilities in a stand-alone library (Cogent) that is used by **the design tool, the mod/sim/STMO code, and the post-processor.**

# Topology Optimization with Shape Parameter Study



$$\min_{\rho} : \left( \frac{(1-\alpha)}{2} \int_{\partial\Omega_f} \mathbf{f_1} \cdot \mathbf{u_1}(\rho)\, dV + \frac{(1-\alpha)}{2} \int_{\partial\Omega_f} \mathbf{f_2} \cdot \mathbf{u_2}(\rho)\, dV + \alpha \int_{\partial\Omega_T} q\ T(\rho)\, dV \right)$$

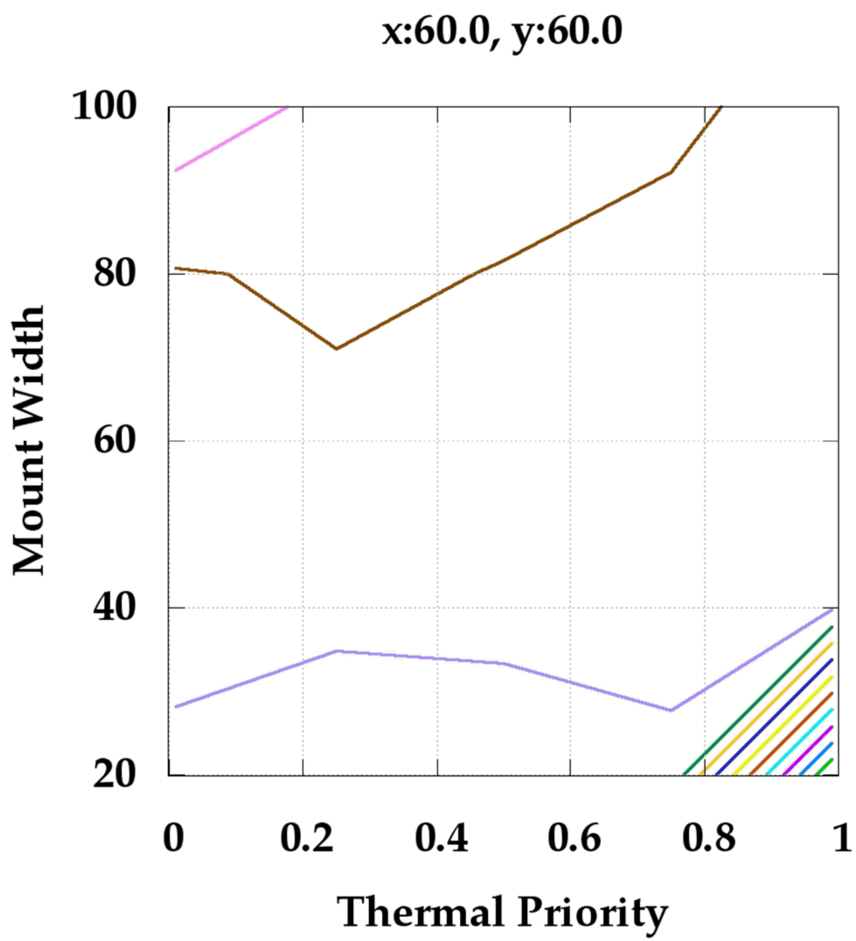
# Topology Optimization with Shape Parameter Study

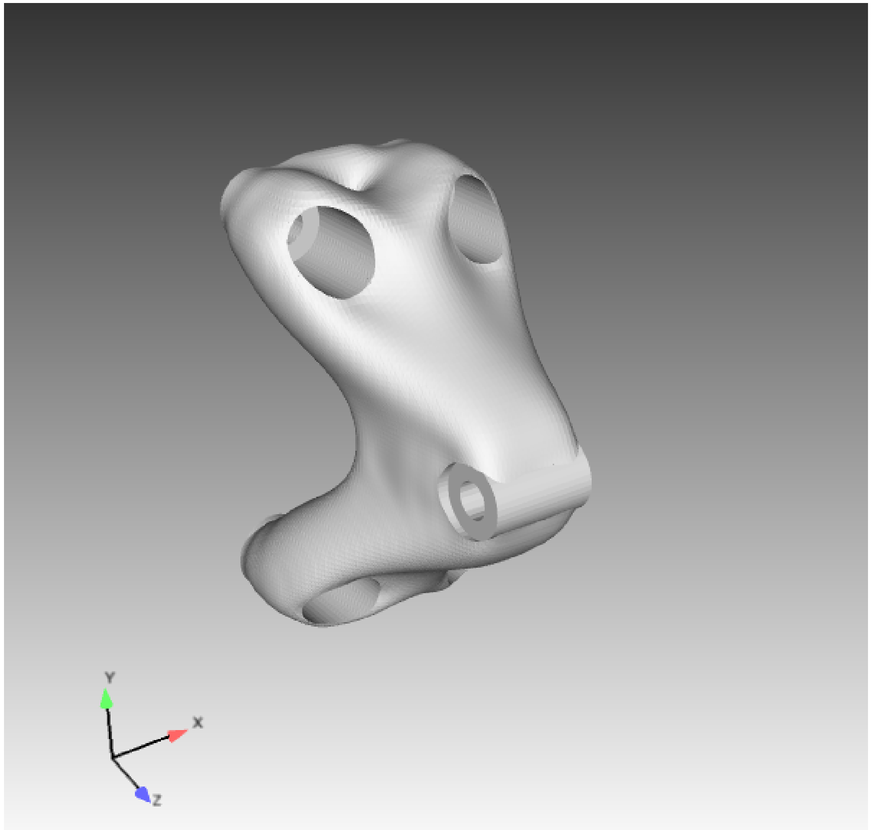



$$\min_{\rho} : \left( \frac{(1-\alpha)}{2} \int_{\partial\Omega_f} \mathbf{f_1} \cdot \mathbf{u_1}\,(\rho)\, dV + \frac{(1-\alpha)}{2} \int_{\partial\Omega_f} \mathbf{f_2} \cdot \mathbf{u_2}\,(\rho)\, dV + \alpha \int_{\partial\Omega_T} q\ T\,(\rho)\, dV \right)$$

# Topology Optimization with Shape Parameter Study

## Vertical Displacement:

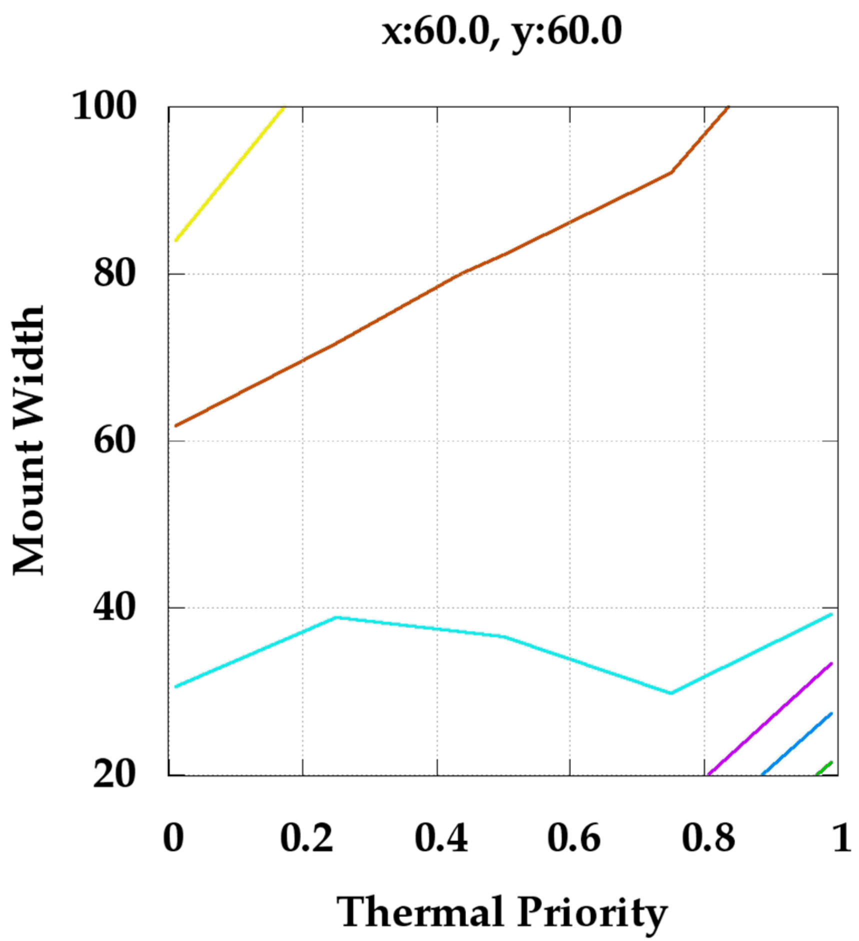


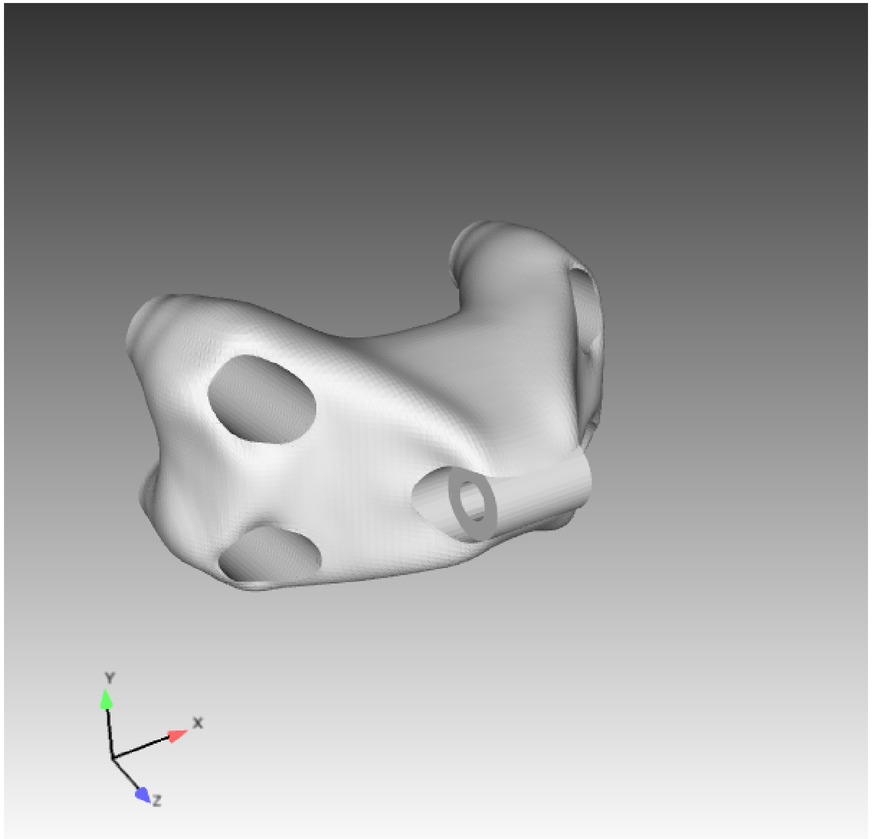




X:60.0, Y:140, Mount width: 40.0

# Topology Optimization with Shape Parameter Study

## Lateral Displacement:

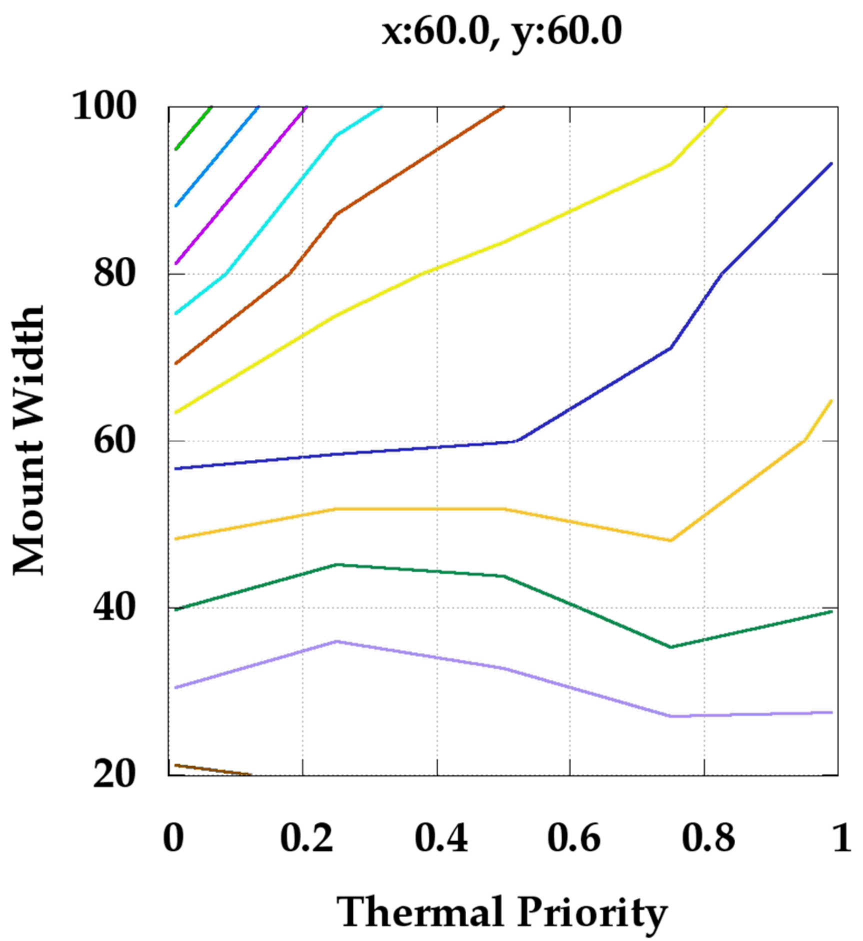


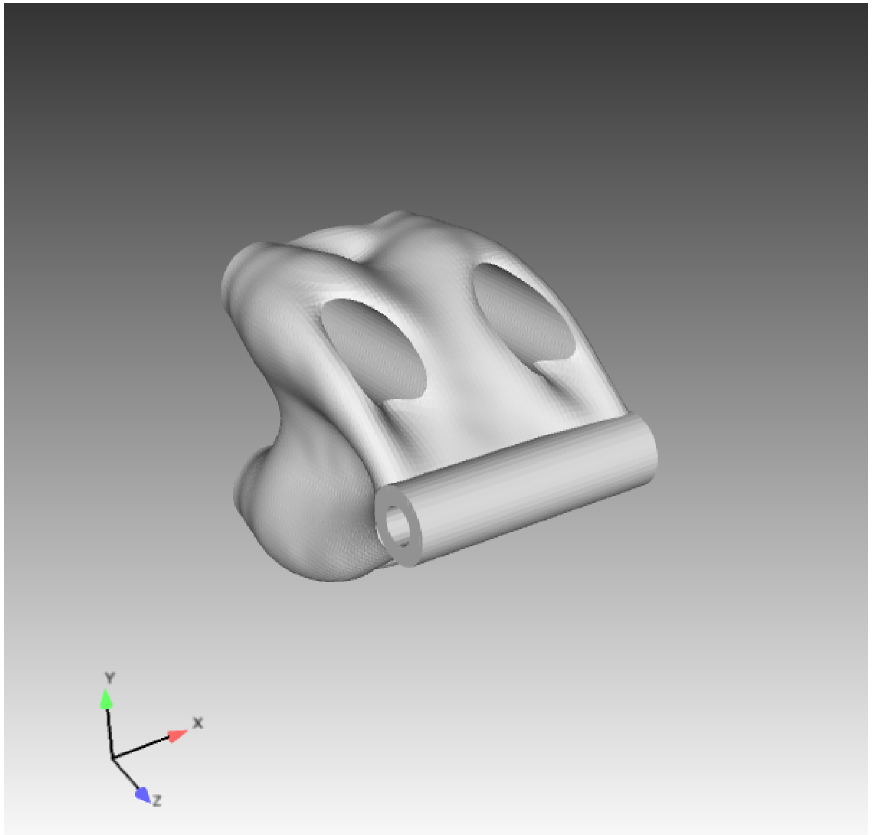




X:140.0, Y:60, Mount width: 40.0

# Topology Optimization with Shape Parameter Study

## Temperature Difference:

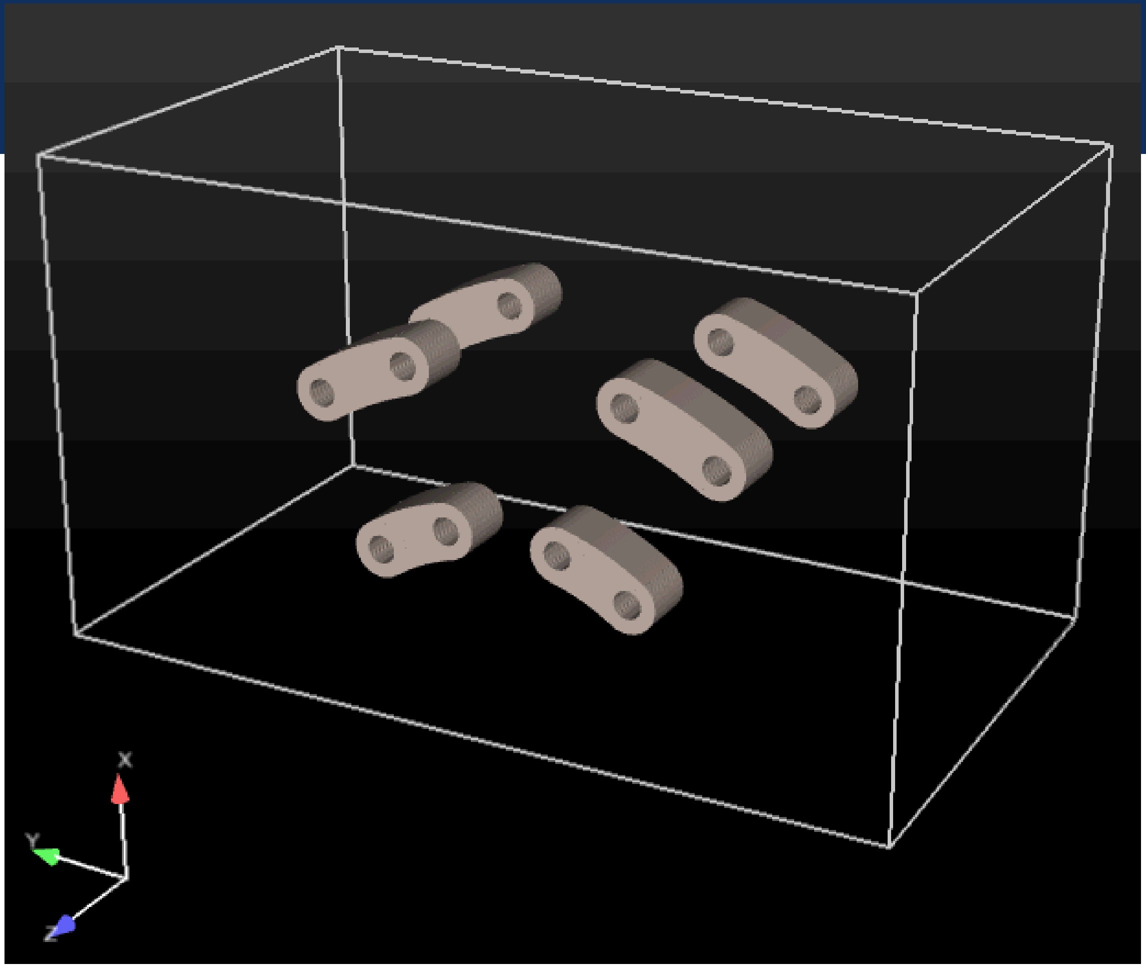


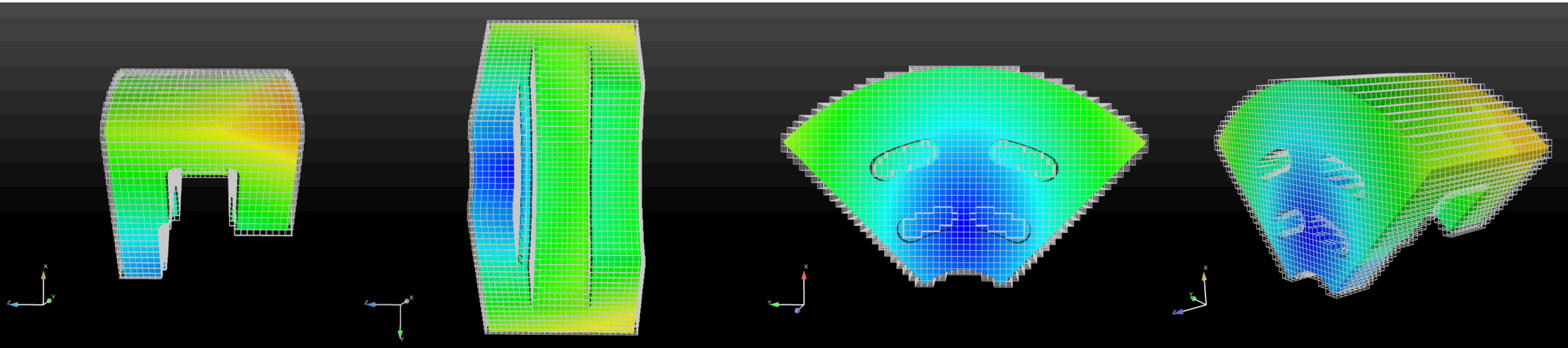




X:60.0, Y:80, Mount width: 100.0

# Case Study

**Objective:** conduction and stiffness
**Constraint:** volume
**Shape parameters:** ~20



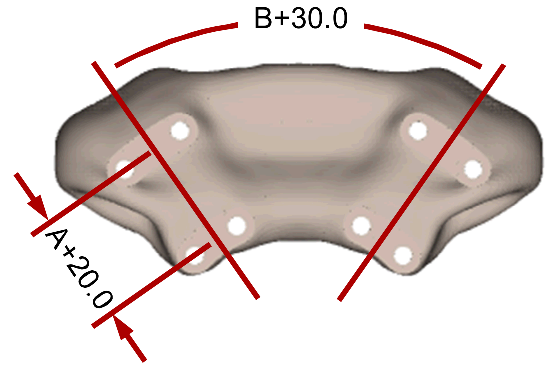


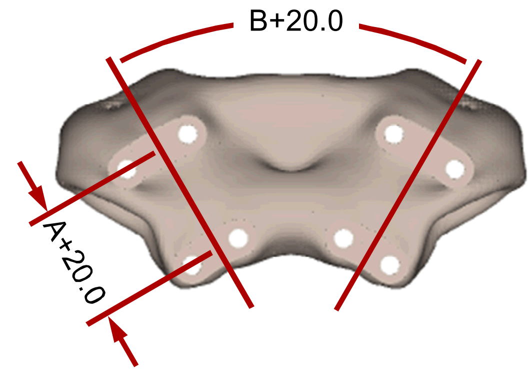
# Topology Optimization Case Study

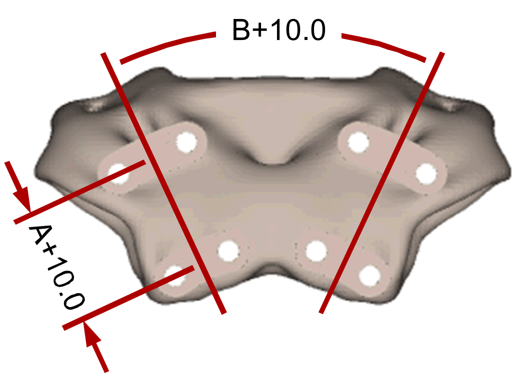
- Parameter space is too large for brute force approach
- Gradient based approach is under development:

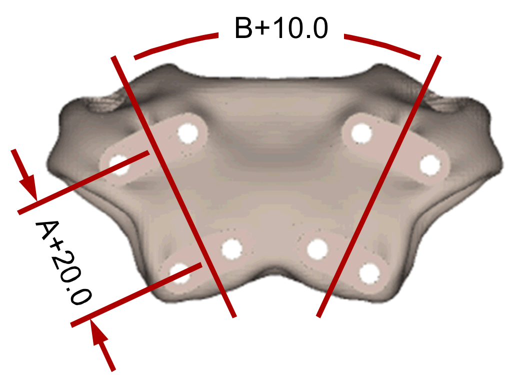
$$\frac{dF}{dw_j} = \frac{dF}{d\hat{z}_k}\frac{d\hat{z}_k}{dw_j}$$

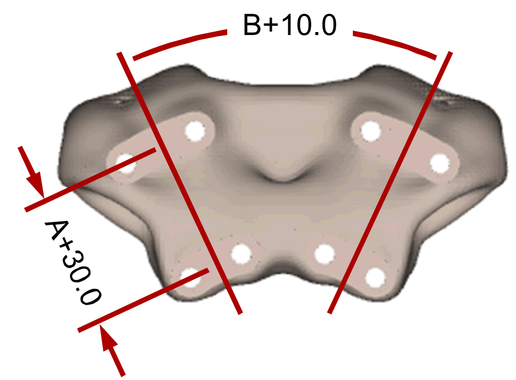
  - Sensitivities computed via adjoint method
  - Derivatives wrt shape parameters via AD
- Gradient based approach enables nested or concurrent shape and topology optimization



# Concluding Remarks

**Fully non-conformal geometry:**

- greatly simplifies concurrent treatment of shape and topology
- eliminates (separate) meshing step
- eliminates “un-meshing” step
- simplifies modification of computed designs
- is proving robust even for complicated models
- creates interesting possibilities for computational efficiency, geometric multi-level, automatic distributed meshing, and ?
- seamlessly integrates modeling and simulation

**Ongoing and future work:**

- Robust preconditioners
- Gradient based shape optimization
- General-use constraints
- Tools for pre and post

# Thank you