TUHH
Technische Universität Hamburg

Simultaneous topology and fastener layout optimization of assemblies

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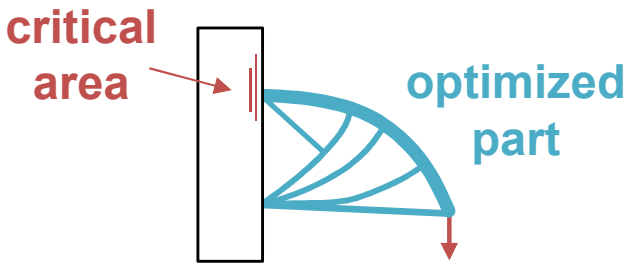
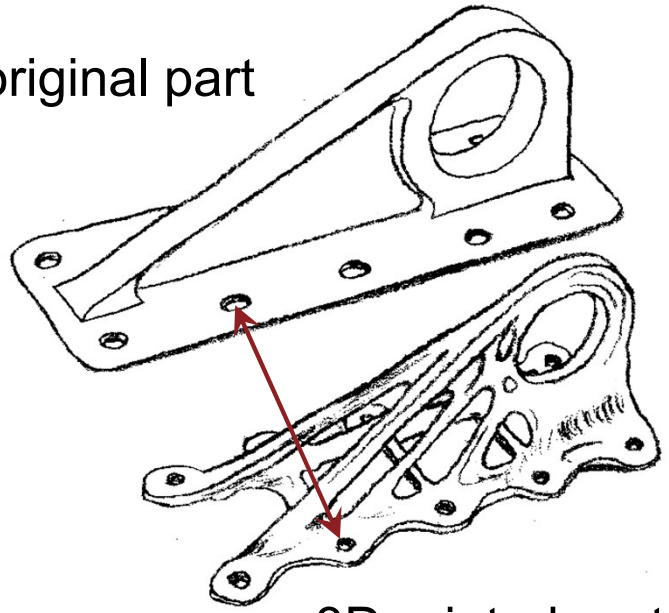
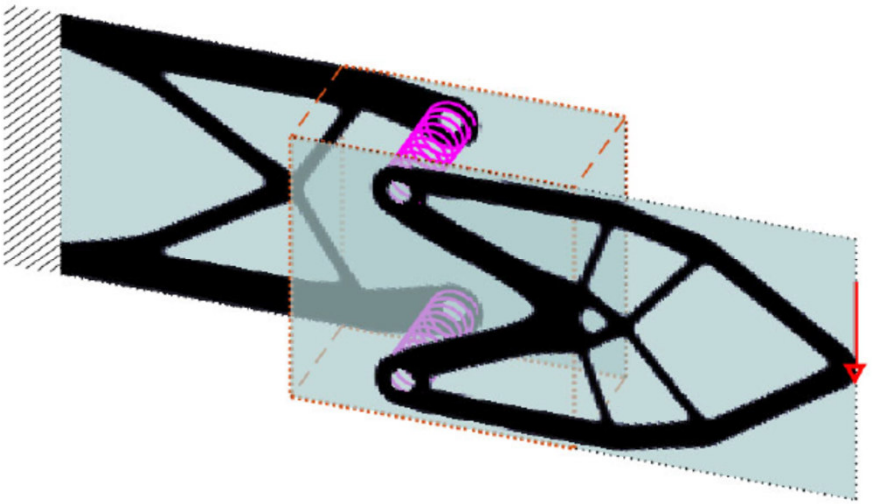
Motivation

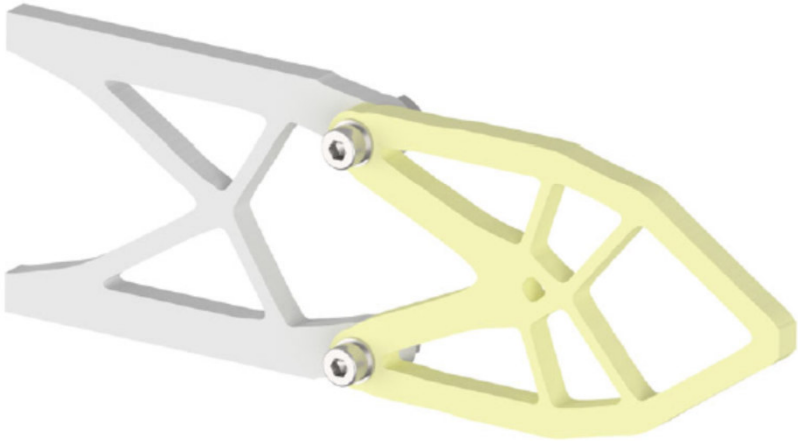
- part replacement with fixed connections
  - restricted optimization potential
  - risk: new design worse for connected part

➔ simultaneous optimization of
  - parts (topology)
  - locations of joints

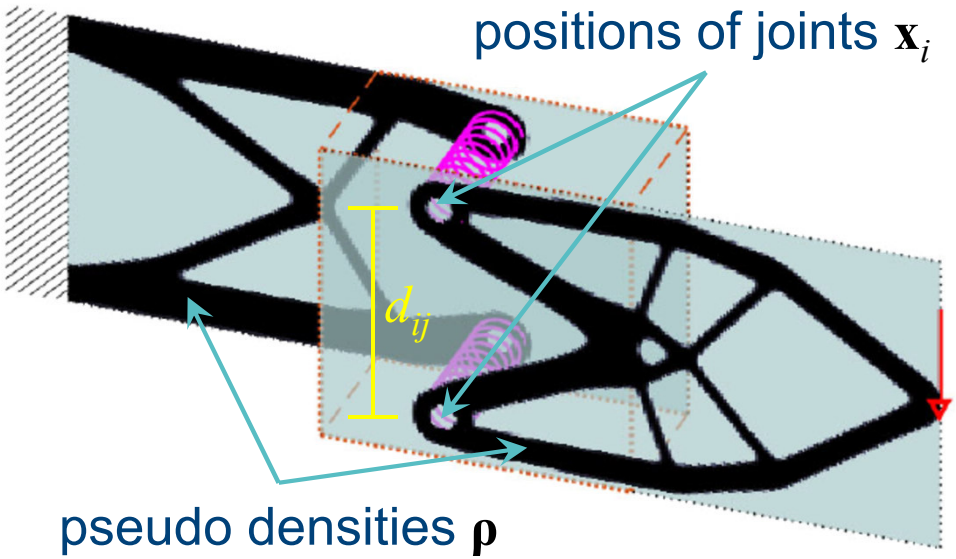








Optimization problem



fail-safe objective

$$\min_{\boldsymbol{\rho},\mathbf{x}} \max_{k} c_k \quad \text{for } k = 1,\ldots,n_J$$

~ KS function

$$\text{s.t.} \quad \mathbf{0} \le \boldsymbol{\rho} \le \mathbf{1}$$

$$\underline{\mathbf{x}} \le \mathbf{x}_i \le \overline{\mathbf{x}} \quad \text{for } i = 1,\ldots,n_J$$

$$\frac{V_P}{V_0} \le v_P$$ ← volume constraints per part

$$\tilde{\mathbf{K}}\,\tilde{\mathbf{u}} = \tilde{\mathbf{f}}$$

min distance of joints

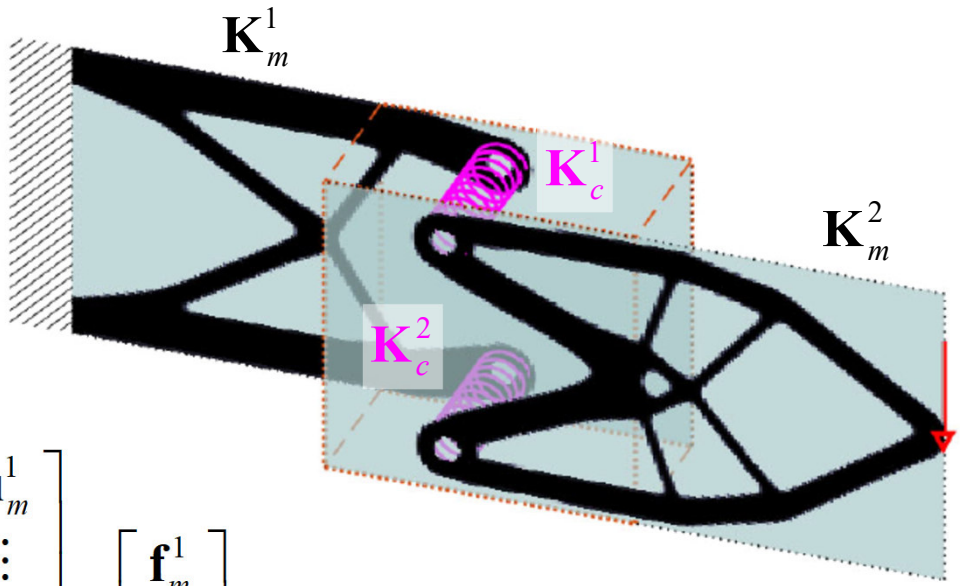
$$d_0 \le \min_{i \ne j} d_{ij} \quad \text{for } i, j = 1,\ldots,n_J$$

~ p-norm (reciprocal)

Equilibrium system

$$\tilde{\mathbf{K}}\,\tilde{\mathbf{u}} = \tilde{\mathbf{f}}$$

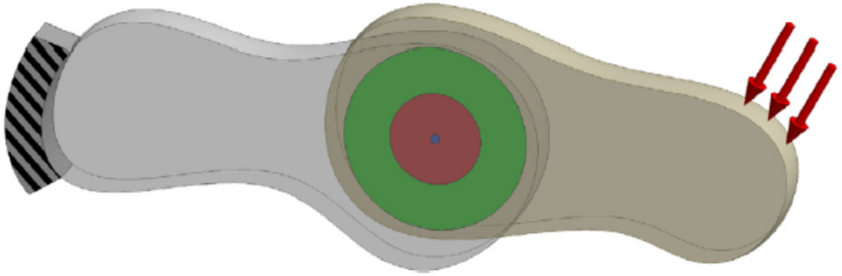
$$\left[\mathbf{K}_m\left(\boldsymbol{\rho},\mathbf{x}\right)+\mathbf{K}_c+\mathbf{G}\left(\mathbf{x}\right)\right]\tilde{\mathbf{u}} = \tilde{\mathbf{f}}$$



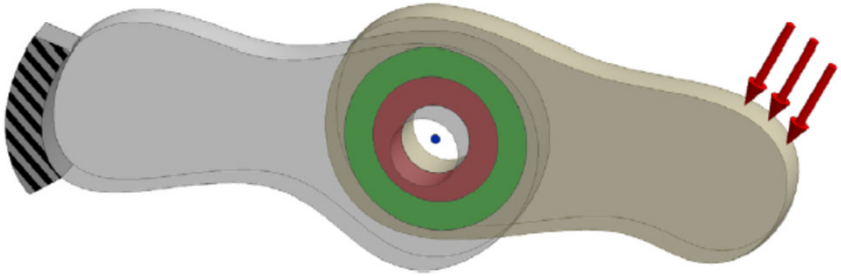
$$\begin{bmatrix} \begin{bmatrix} \mathbf{K}_m^1 & & \mathbf{0} \\ & \ddots & \\ \mathbf{0} & & \mathbf{K}_m^{n_P} \end{bmatrix} & & \mathbf{0} & \begin{bmatrix} \mathbf{G}^T \\ \mathbf{0} \end{bmatrix} \\ & \begin{bmatrix} \mathbf{K}_c^1 & & \mathbf{0} \\ & \ddots & \\ \mathbf{0} & & \mathbf{K}_c^{n_J} \end{bmatrix} & & \\ \begin{bmatrix} & & \mathbf{G} & & \end{bmatrix} & & & \end{bmatrix} \begin{bmatrix} \mathbf{u}_m^1 \\ \vdots \\ \mathbf{u}_m^{n_P} \\ \mathbf{u}_c^1 \\ \vdots \\ \mathbf{u}_c^{n_J} \\ \boldsymbol{\lambda}_c^1 \\ \vdots \\ \boldsymbol{\lambda}_c^{n_J} \end{bmatrix} = \begin{bmatrix} \mathbf{f}_m^1 \\ \vdots \\ \mathbf{f}_m^{n_P} \\ \mathbf{0} \\ \vdots \\ \vdots \\ \mathbf{0} \end{bmatrix}$$

coupling terms: $\mathbf{G}$

Joint models

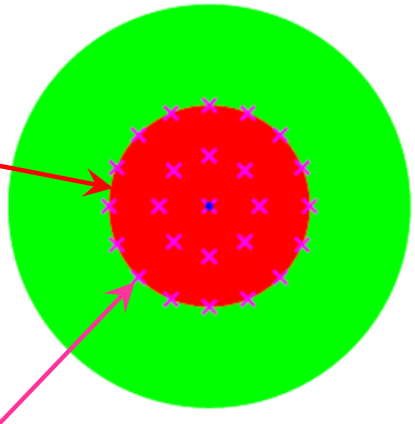


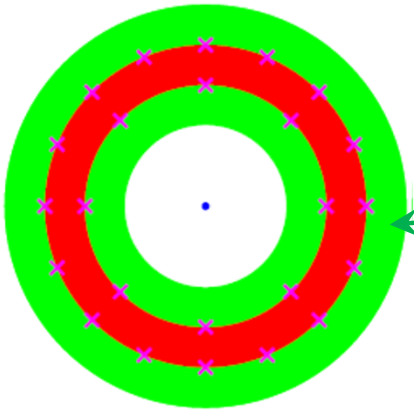
e.g. spot weld



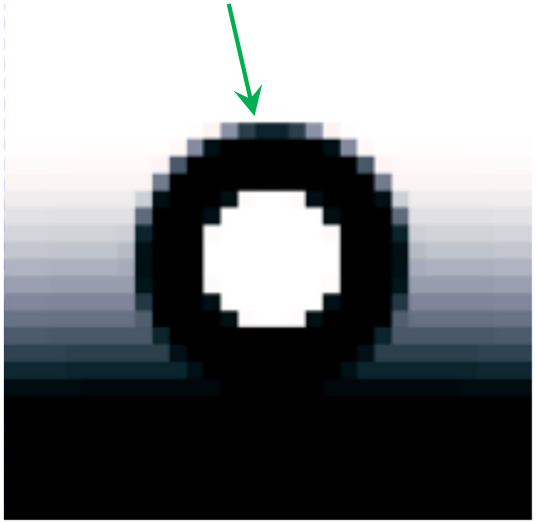
e.g. bolt

connection
to mesh



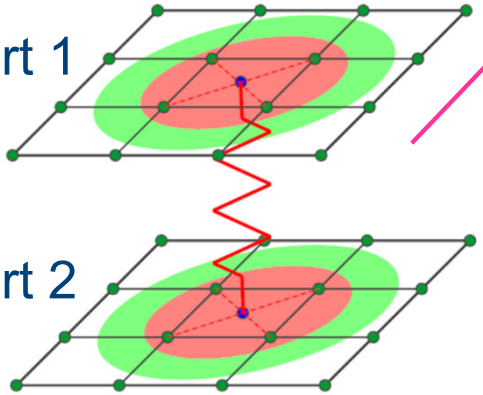


projection to
density field



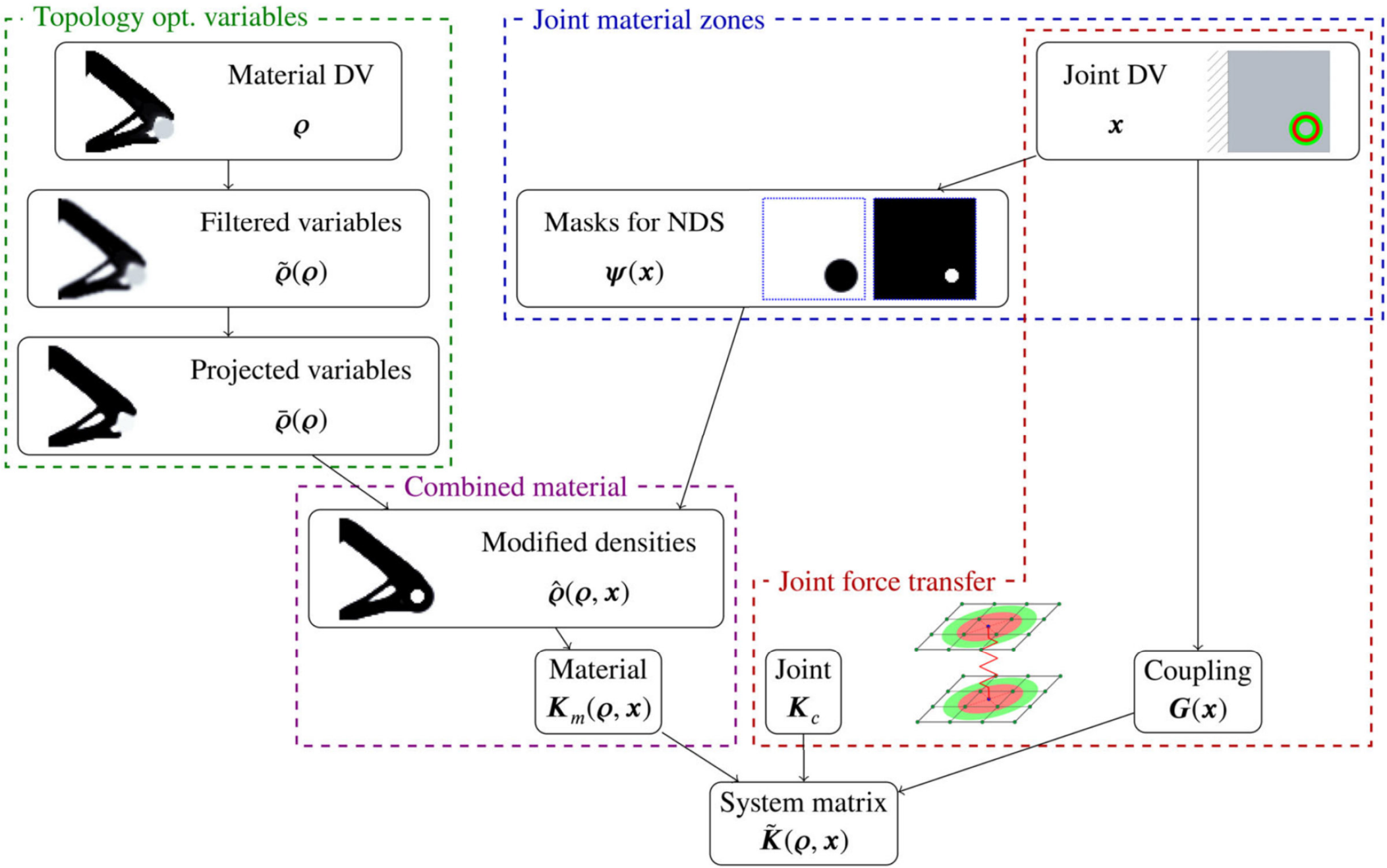
part 1

part 2

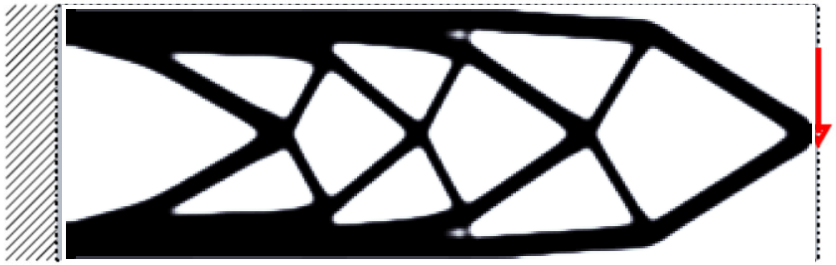


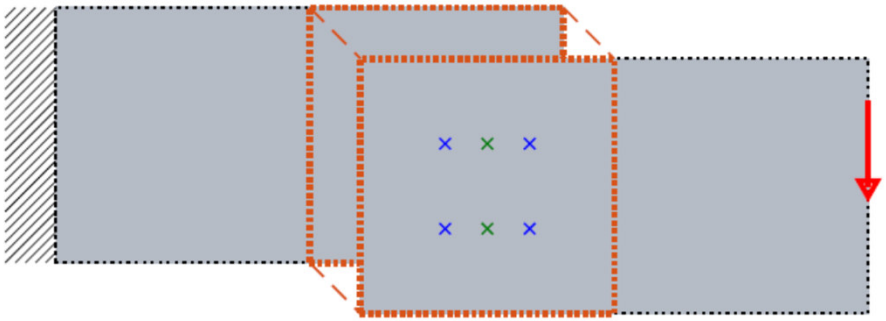
spring patterns

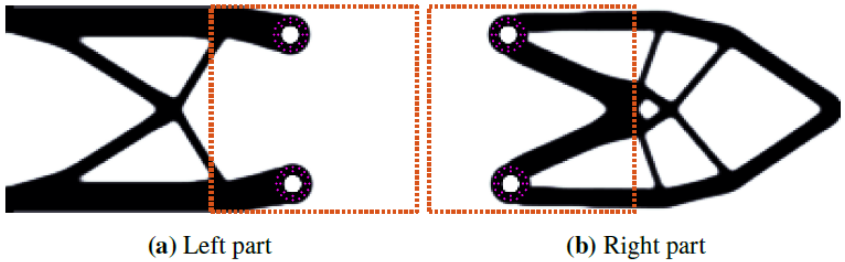
Overall approach



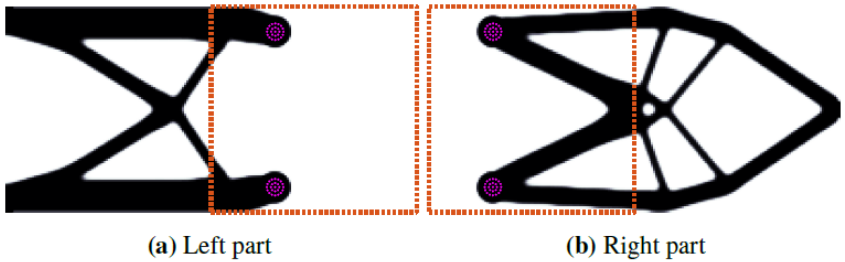
2D example – 2 joints



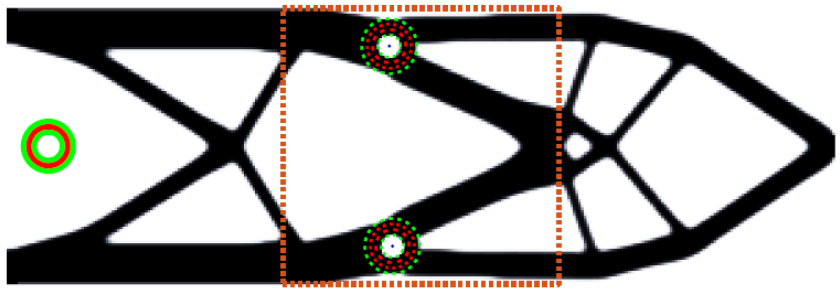




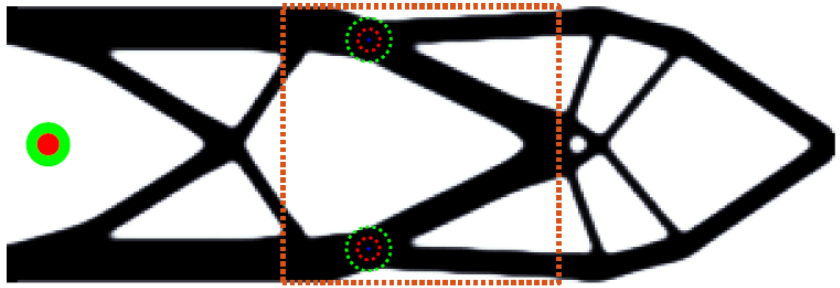
(a) Left part (b) Right part



(a) Left part (b) Right part

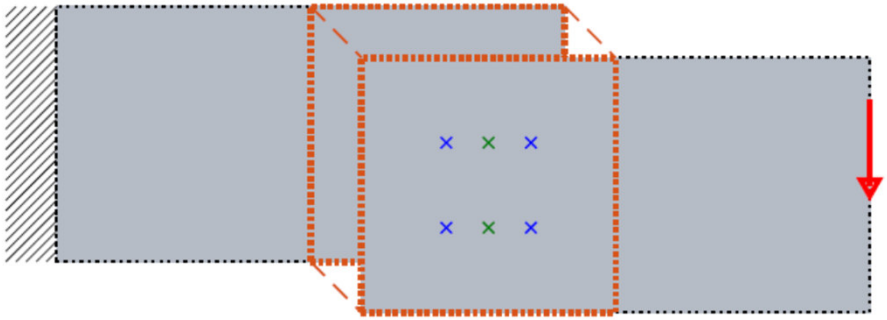


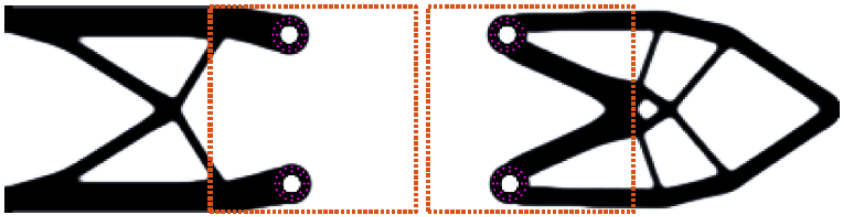
two bolt joints



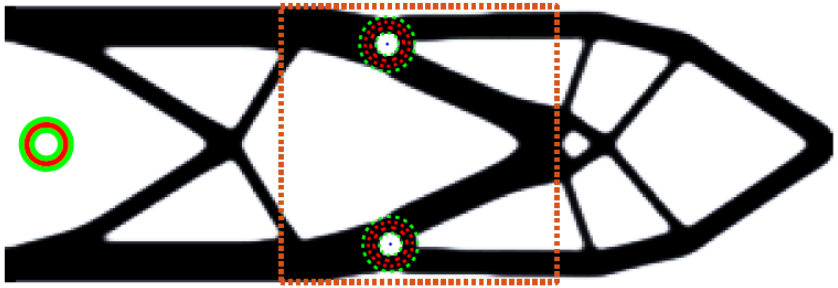
two spot joints

2D example – 2 vs 4 joints

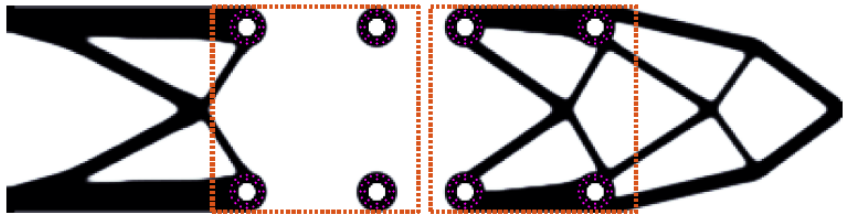




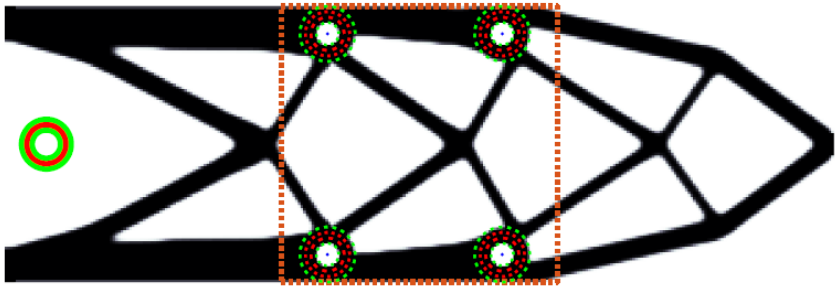
(a) Left part (b) Right part



two bolt joints
= four bolt design without min distance

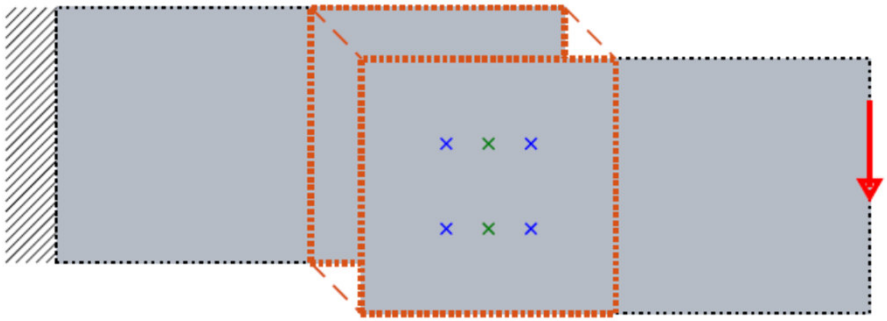


(a) Left part (b) Right part

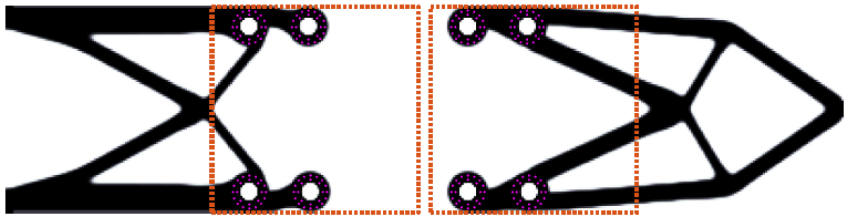


four bolt joints, with min distance

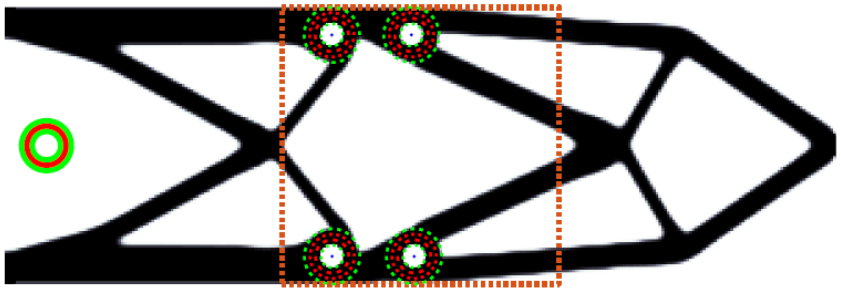
2D example – 4 joints – fail-safe



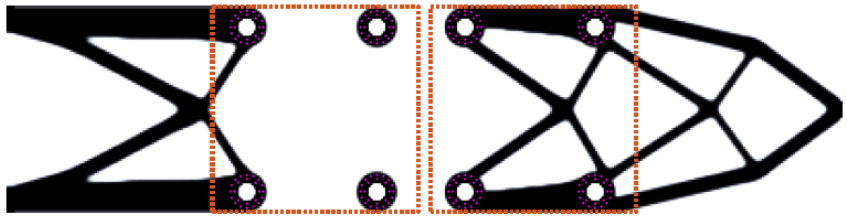
$$\min_{\boldsymbol{\rho},\mathbf{x}} \max_{k} c_k \quad \text{for } k = 1,\ldots,4$$



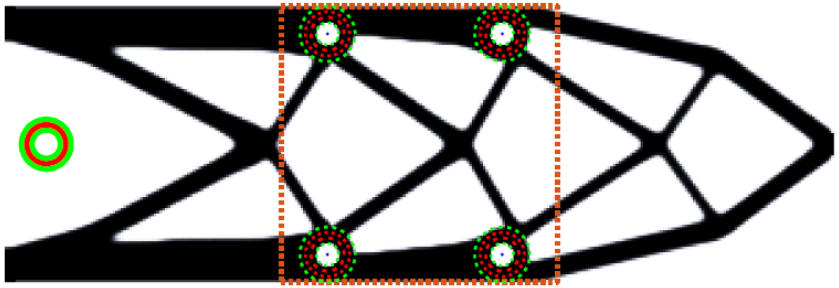
(a) Left part (b) Right part



four bolts, fail-safe

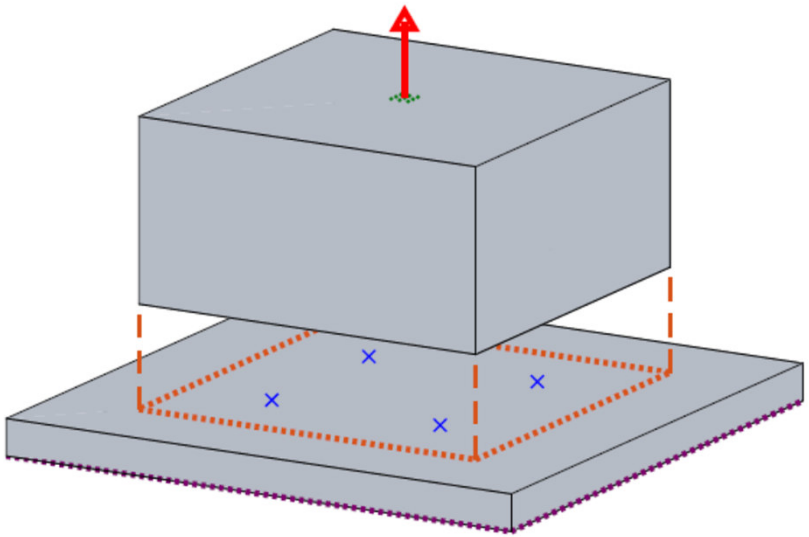


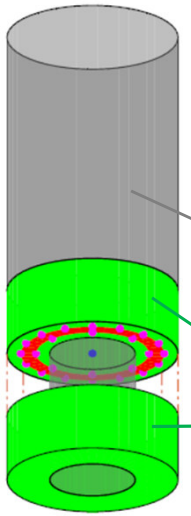
(a) Left part (b) Right part

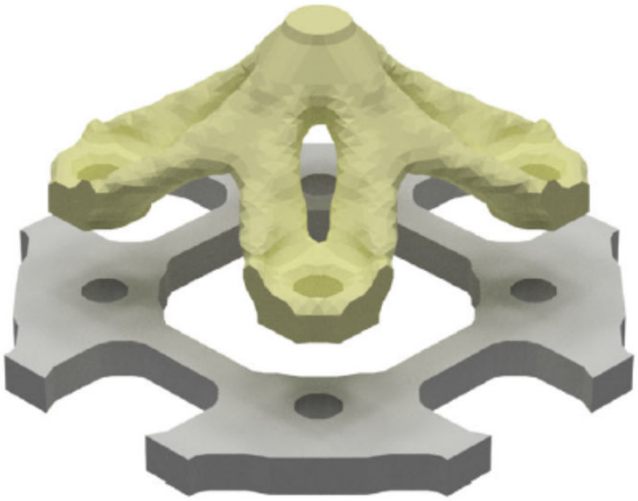


four bolt joints, with min distance

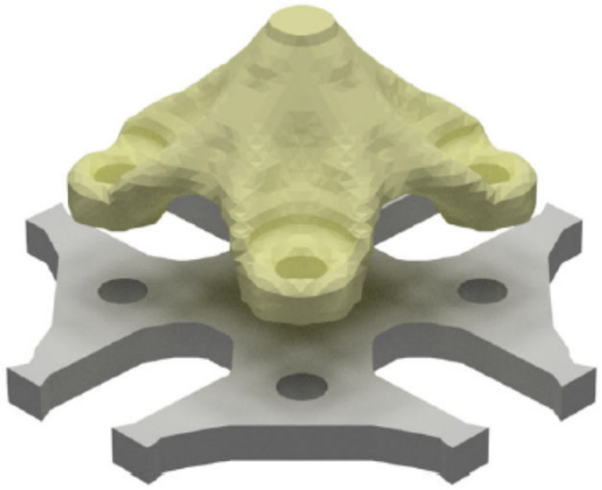
3D example







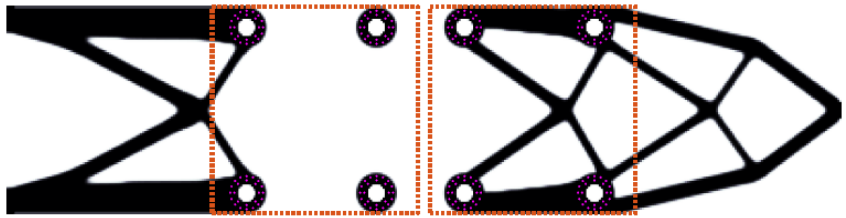
four-bolt design



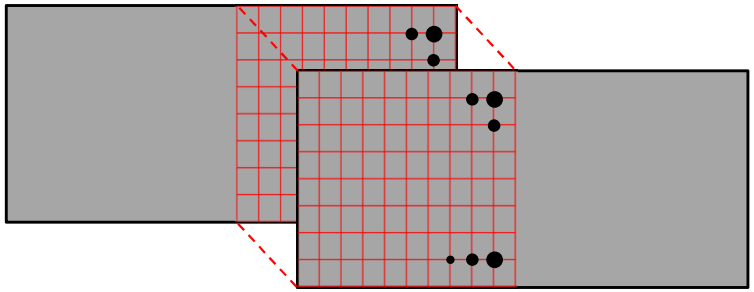
fail-safe design

Concluding remarks

- number of joints prescribed, but maybe not load carrying

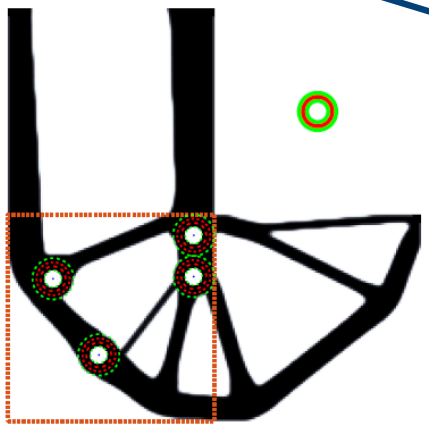


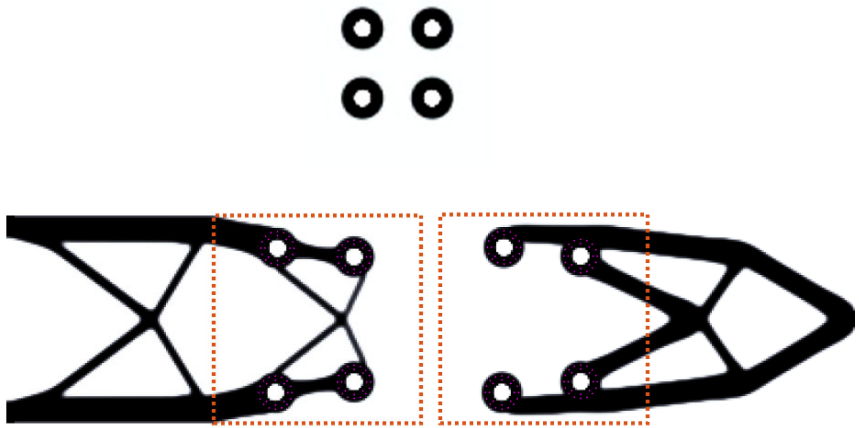
- number of joints design variable
  ➔ half joints



- extension to
  - strength
  - max joint force

- L-bracket example
  ➔ see paper





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Thank you for your attention!

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