BGCE First Milestone Meeting

BGCE Project: CAD – Integrated Topology Optimization

S. Joshi, J.C. Medina, F. Menhorn, S. Reiz, *B. Rüth*, *E. Wannerberg*, A. Yurova

Technische Universität München

August 5, 2015

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Motivation

Current Design Process:

- Iterative and redundant
- Time consuming

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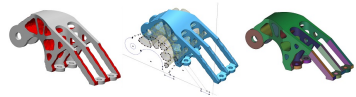**BGCE First Milestone Meeting, August 5, 2015**

2
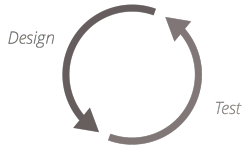
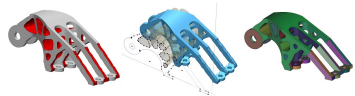# Motivation

Current Design Process:
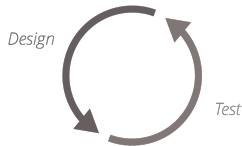
- Iterative and redundant
- Time consuming

Topology optimization

- Promoted by additive manufacturing

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Motivation

Current Design Process:

Topology optimization

- Iterative and redundant
- Time consuming

- Promoted by additive manufacturing

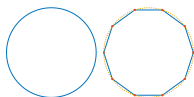**Focus**: Convert optimized geometry to **lightweight** and **scalable** CAD formats

Workflow Overview

CAD design

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ПЛП

Workflow Overview

STL Interface

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Workflow Overview

Voxelization

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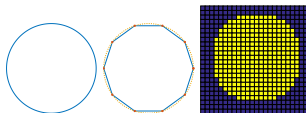
Workflow Overview

TPD input file - Specification of loads and fixtures

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TꓥM
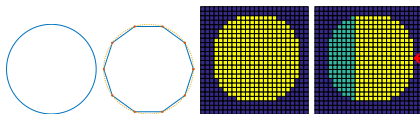
Workflow Overview

Topology optimization

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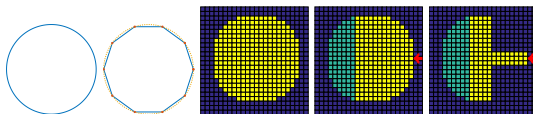
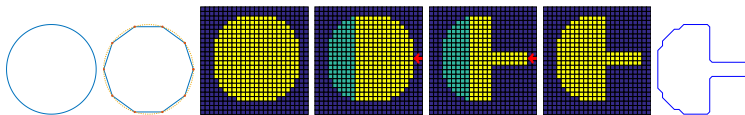# Workflow Overview

Optimized output geometry

ΤΛΠ
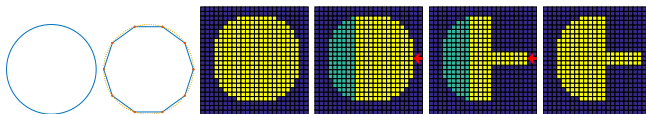
Workflow Overview
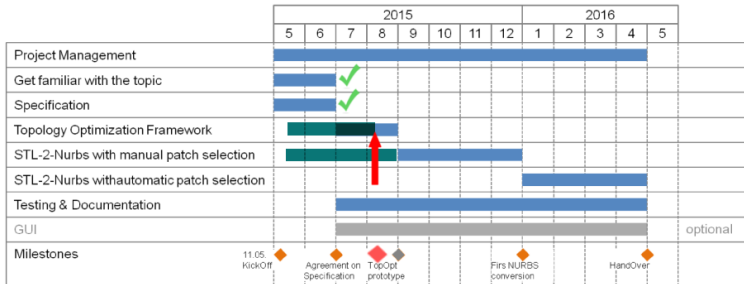
Post-processing: Parametrization, Feature recognition

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Schedule & Deadlines

Original schedule:

		2015								2016				
	5	6	7	8	9	10	11	12	1	2	3	4	5	
Project Management														
Get familiar with the topic														
Specification														
Topology Optimization Framework														
STL-2-Nurbs with manual patch selection														
STL-2-Nurbs with automatic patch selection														
Testing & Documentation														
GUI														optional
Milestones	11.05. KickOff	Agreement on Specification	TopOpt prototype				First NURBS conversion				HandOver			

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Schedule & Deadlines

Current state:

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CAD to STL

- Create original CAD geometry in CAD program
- Most CAD programs offer: Export to STL...

Picture

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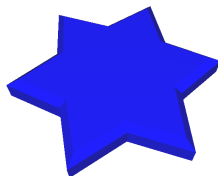**BGCE First Milestone Meeting, August 5, 2015**
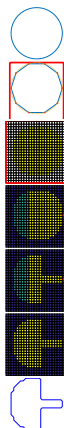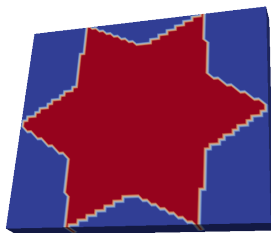
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From STL To Voxels

Tools:

- Common Versatile Multi-purpose Library for C++ (CVMLCPP)
  - Takes .stl file and returns a binary file with the given voxel size
- Custom script to read binary file and output it as ascii.vtk

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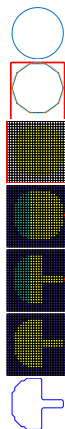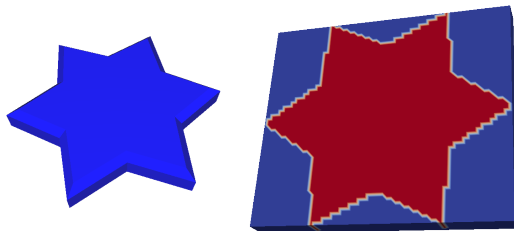
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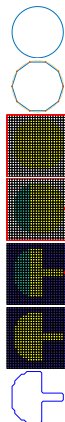
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Load and fixture specification

Boundary conditions required - how to specify?
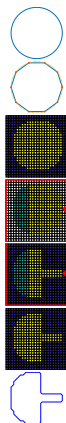
- Current state: Manual specification
- Idea 1: Metafile before Voxelization step

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Topology Optimization

Tools:

- ToPy for topology optimization
- Custom script for generating .tpd file
  - Takes binary output from CVMLCPP and generates ToPy input
  - Sets non-voxel cells to passive elements
  - Adds boundary conditions manually

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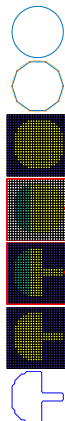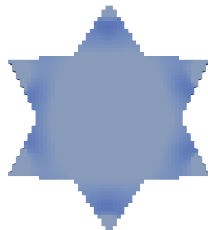
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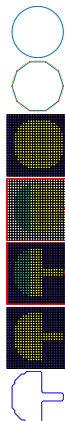
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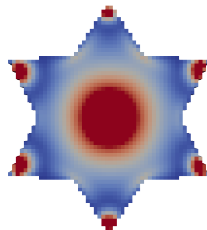 - Adds boundary conditions manually

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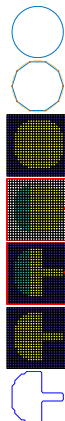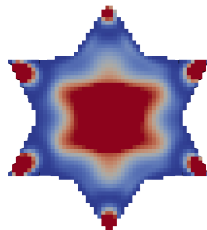
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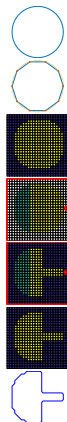 - Adds boundary conditions manually
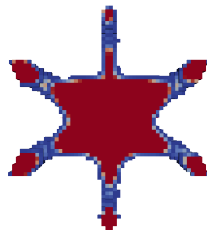
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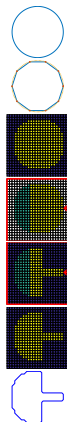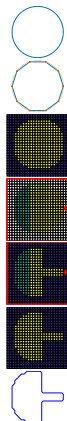
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From Voxel to Mesh Geometry

- Extract isosurface from voxel information

- Algorithms: Marching Cubes, Dual Contouring, Extended Models

MC

Dual method

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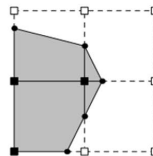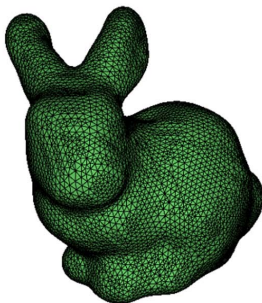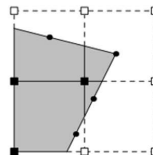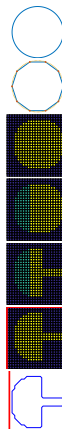
Surface Extraction

Contour Filtering using Implicit Modelling
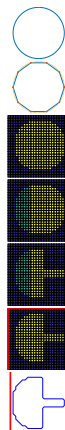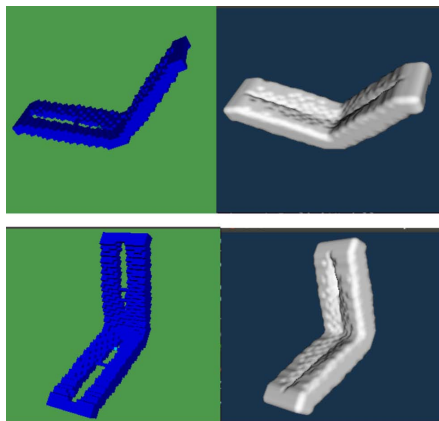
Problem: Holes are not taken into account

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Decimation

- Fine mesh to a coarser mesh through Decimation- Reduction of number of triangles. (Upper: 50% Lower: 90%)

- Smoothing step is needed in between

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Current status

- What do we have so far?

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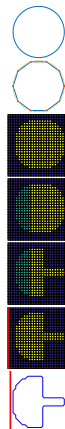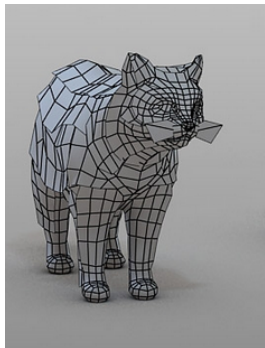
Current status

- What do we have so far?   • What if we try to pass it to an engineer?

But I wanted CAD, not CAT!
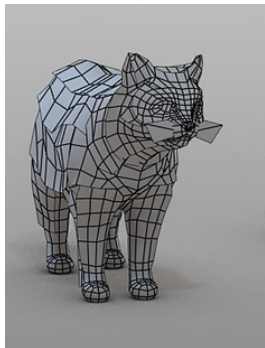
How to make CAD understand our data?

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B–Spline

$$\vec{S}(u, v) = \sum_{i,j=1}^{n,m} \vec{C}_{i,j} N_i^p(u) N_j^p(v),$$

where p – degree of the B–Spline surface and n, m – number of control points in each direction.

B–Splines

- offer great flexibility for handling arbitrary shapes
- are CAD–standard

Engineers are working with CAD

$* \ \vec{C}_i$ ——— $\vec{S}(u)$

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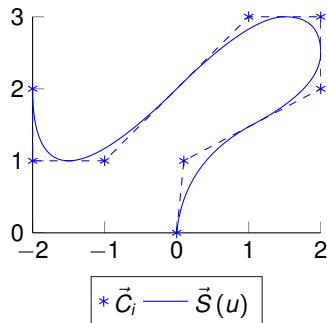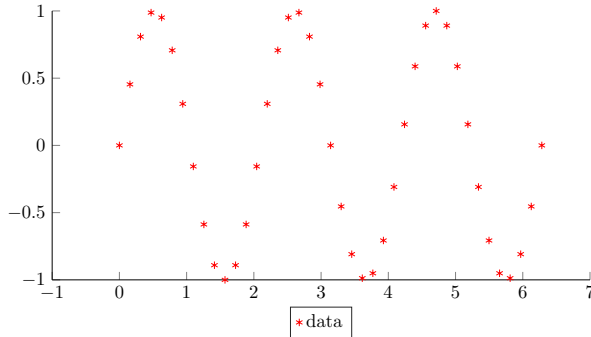
B–Spline Fitting

Goal:

Find B–Spline representation of our data!

$$\vec{S}(u_\alpha, v_\alpha) \approx \vec{P}_\alpha$$

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B–Spline Fitting

* data * control pt. ——— BSpline

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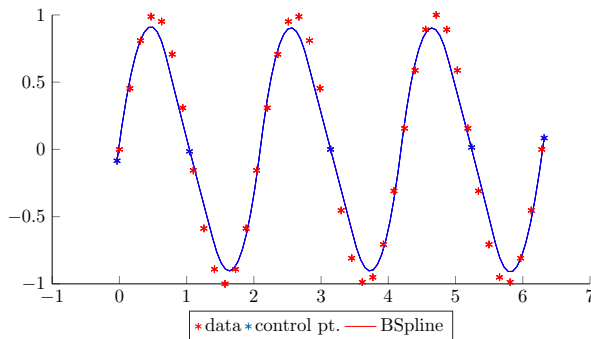
B–spline fitting: Least squares

The task:

Find control points $C_{i,j}$, such that the B–Spline surface

$$\vec{S}(u,v) = \sum_{i,j=1}^{n,m} \vec{C}_{i,j} N_i^p(u) N_j^p(v)$$

approximates our dataset of points $\left\{\vec{P}_\alpha\right\}$.

This leads to *minimization problem*:

$$\vec{S}(u_\alpha, v_\alpha) \approx \vec{P}_\alpha \, \forall \alpha \leftrightarrow \min_{\vec{C}_{i,j} \in \mathbb{R}^3} \sum_\alpha \| \vec{P}_\alpha - \vec{S}(u_\alpha, v_\alpha) \|_2$$

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B–spline fitting: Least squares (cont.)

Resulting system looks like:

$$\sum_{i,j=1}^{n,m} \vec{C}_{i,j} N_i^p(u_\alpha) N_j^p(v_\alpha) \approx \vec{P}_\alpha \quad \forall \alpha$$

Or, in matrix–vector form:

$$AC \approx P$$

Our system matrix A depends on $\{u_\alpha, v_\alpha\}$

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B–Spline Fitting pipeline according to Becker, Schäfer, Jameson

How to deal with a complex shape?
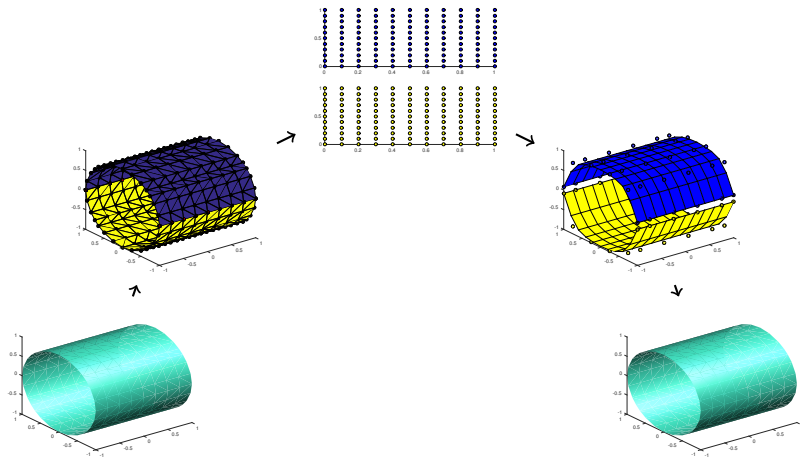
B–Spline Fitting: Open questions

- How to distribute our data into patches?
- How to parameterize obtained patches?
- How to connect several patches after fitting?

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B–Spline Fitting pipeline according to M. Eck & H. Hoppe

(a) Input: 4000 unorganized points P

(b) Step 1: Reconstructed mesh M_0

(c) Step 2a: Voronoi partition of M_0

(d) Step 2b: Delaunay triangulation of M_0

(e) Step 2c: Triangular base complex K_Δ

(f) Step 3: Quadrilateral base complex $K_\square$

(g) Step 4: Optimized control mesh M_c

(h) Step 4: B-spline control net $d_{r,s}$

(i) Step 4: B-spline surface S
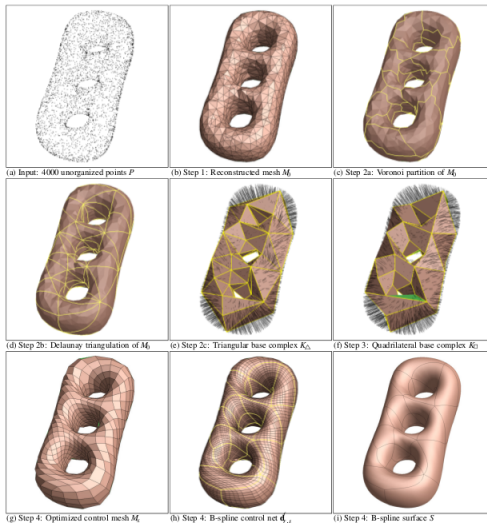
B–Spline Fitting: Parameter correction

The task:

For *fixed* control points $C_{i,j}$, find an optimal parametrization $\{u_\alpha, v_\alpha\}$.

fit

parameter space

$* \vec{P}_\alpha$ —— first —— last

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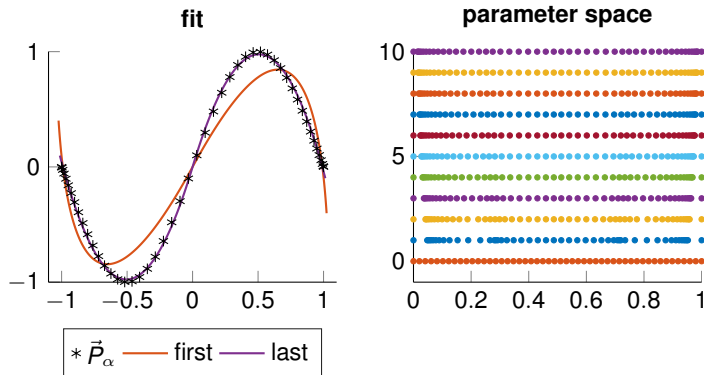
What is done?

- First part of the pipeline from CAD model to optimized voxel model:
    - ✓ CAD to STL with e.g. FreeCAD
    - ✓ STL to Voxels with CVMLCPP
    - ✓ Voxels to ToPy input with custom script
    - ✓ Topology optimized geometry with ToPy
    - 🕐 Surface reconstruction with VTKToolbox
- B–spline fitting
    - ✗ Automatic patch selection
    - ✗ Parametrization of obtained patches
    - ✓ B–spline fitting using least squares
    - 🕐 Smooth connection of patches
    - ✗ Conversion back to CAD

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What is next?

- Automation of the first part of the pipeline
- Integration of boundary conditions handling
- Implementation of remaining B–spline fitting steps (based on work of M.Eck & H.Hoppe)
- Further research on algorithms considering voxel geometry

Thank you for your attention!

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