

Isogeometric Representation and Analysis

MS7 and MS9

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Presentations

MS 7 (Wednesday)

- **3:00-3:25 Challenges of Isogeometric Representation for CAD**
 - *Tor Dokken*, SINTEF, Norway
- **3:30-3:55 NURBS Volume Parameterizations for Blades**
 - *Elisabeth Pilgerstorfer*, Johannes Kepler University, Austria
- **4:00-4:25 Analysis-aware Modeling: Model Quality**
 - *Tom Lyche*, University of Oslo, Norway
- **4:30-4:55 Analysis-aware Modeling: Representing Shape and Volume**
 - *Elaine Cohen*, University of Utah

MS 9 (Thursday)

- **3:00-3:25 Isogeometric Analysis: Toward Integration of CAD and FEA**
 - Tom Hughes, *Scott Lipton*, and Mike Scott, University of Texas, Austin
- **Cancelled 3:30-3:55**
- **4:00-4:25 Advances in the Error Analysis for Isogeometric Discretization Techniques**
 - *Annalisa Buffa*, Consiglio Nazionale delle Ricerche, Italy;
- **4:30-4:55 Towards an Isogeometric Toolkit**
 - *Vibeke Skytt*, SINTEF, Norway

Challenges of Isogeometric Representation for CAD

Tor Dokken, SINTEF, Norway

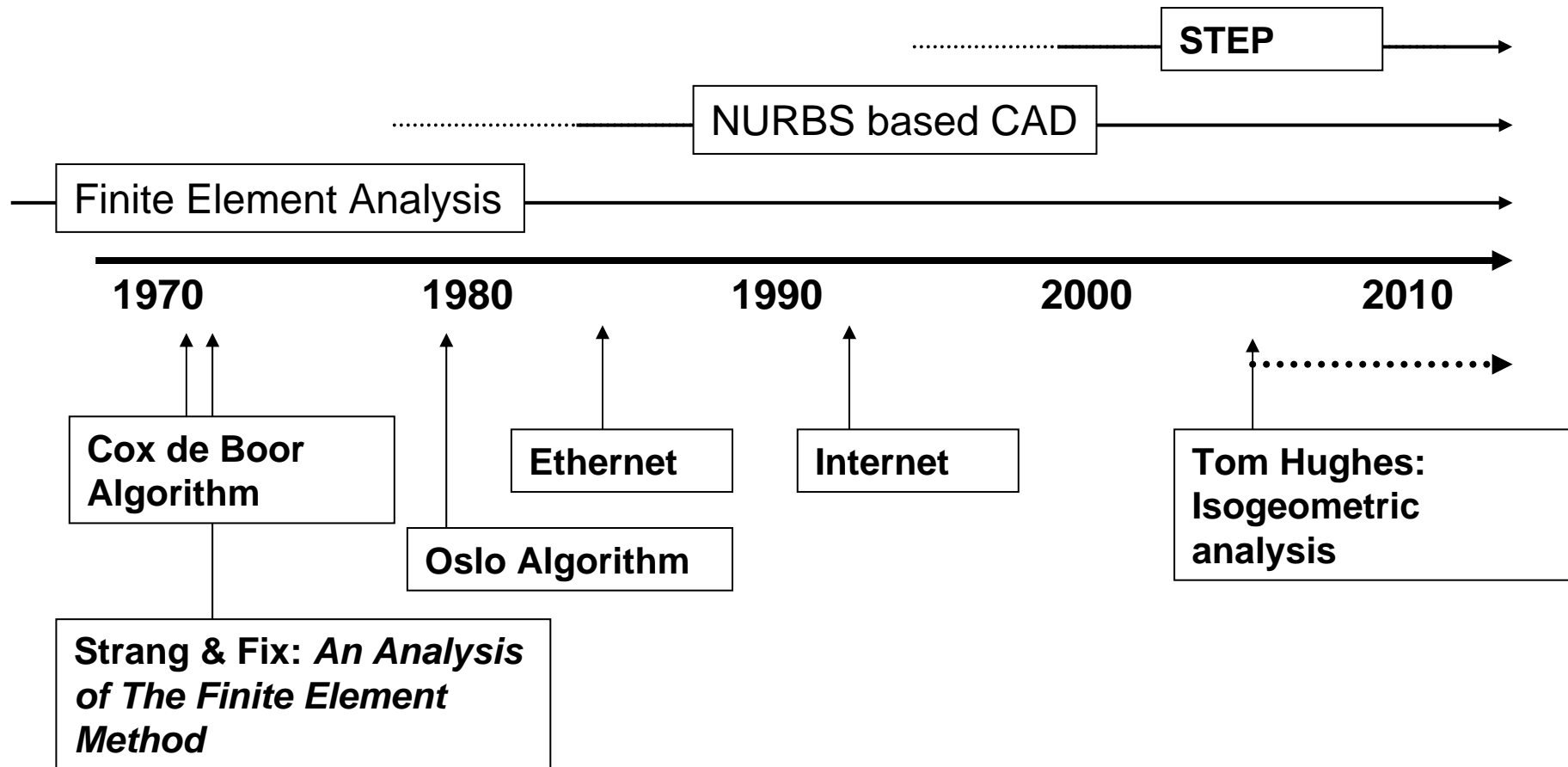
Independent evolution of CAD and FEM

- CAD (NURBS) and Finite Elements evolved in different communities before electronic data exchange
 - FEM developed to improve analysis in Engineering
 - CAD developed to improve the design process
 - Information exchange was drawing based, consequently the mathematical representation used posed no problems
 - Manual modelling of the element grid
 - Implementations used approaches that best exploited the limited computational resources and memory available.
- FEA was developed before the NURBS theory
 - FEA evolution started in the 1940s and was given a rigorous mathematical foundation in 1973 in [Strang](#) and [Fix's](#) *An Analysis of The Finite Element Method*
 - B-splines: 1972: DeBoor-Cox Calculation, 1980: Oslo Algorithm

From stand alone computers and systems to integrated information flows

- As long as communication between computers was hard, information exchange remained paper based
 - The Ethernet invented by Xerox Parc in 1973-1975,
 - ISO/IEEE 802/3 standard in 1984
 - Deployment in industry started, simple communication between computers
- CAD Data Exchange introduced
 - IGES Version 1.0 in 1980
 - STEP started in 1984 as a successor of IGES, SET and VDA-FS, Initial Release in 1994/1995, deployment started
- The Internet opened to all 1991
 - Start of deployment of data exchange between processes over the Internet

Timeline important events



What is isogeometric analysis?

- Introduced by Prof. Tom Hughes, University of Texas at Austin in 2005
 - Replace traditional Finite Elements by NURBS Elements
 - NURBS (NonUniform Rational B-splines) is used in CAD for representing free form curves and sculptured surfaces.
 - NURBS elements can represent the CAD-geometry exactly
 - Claim: NURBS elements have many advantages compared to traditional Finite Elements
 - Claim: Removes the bottleneck between CAD and analysis
 - Examples published show superior performance of isogeometric analysis compared to traditional FEA

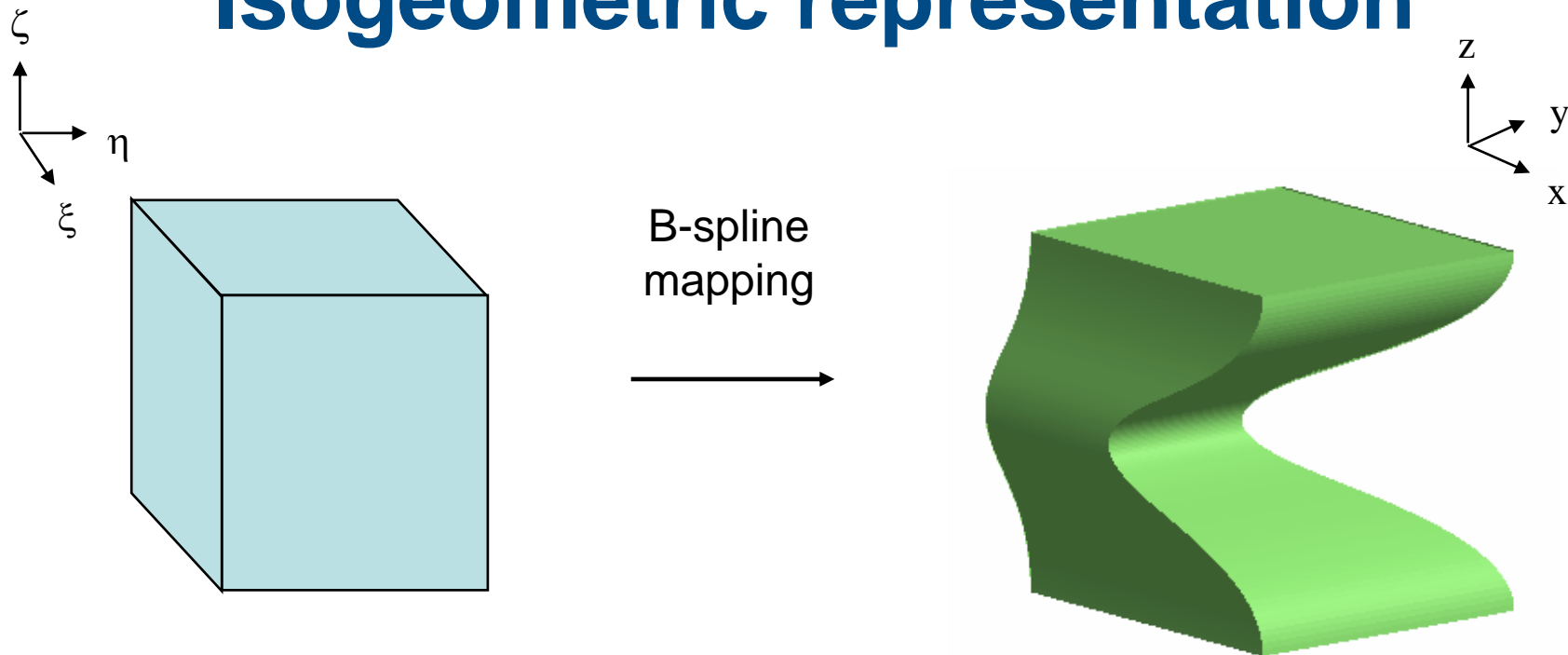
Why are splines important to isogeometric analysis?

- B-Splines are polynomial, same as Finite Elements
- B-Splines are very stable numerically
- B-splines represent regular piecewise polynomial structure in a more compact way than Finite Elements
- NonUniform rational B-splines can represent degree 2 algebraic curves and surfaces exactly. (circle, ellipse, cylinder, cone...)
- Efficient and stable methods exist for refining the piecewise polynomials represented by splines
 - Knot insertion (Oslo Algorithm, 1980)
 - B-spline has a rich set of refinement methods

Why have NURBS not been used in FEA?

- FEA was developed before the NURBS theory
- NURBS and Finite Elements evolved in different communities before electronic data exchange
- Current computers have extreme performance compared to earlier computers. Allows more generic solutions.
 - Mathematical representation chosen based on what was computationally feasible.
- Heterogeneous multi-core processors require new algorithms and changes of existing codes
 - Most existing (CAD) program codes are sequential
 - Combine the introduction of NURBS in FEA and exploiting the performance of heterogeneous multi-core processors

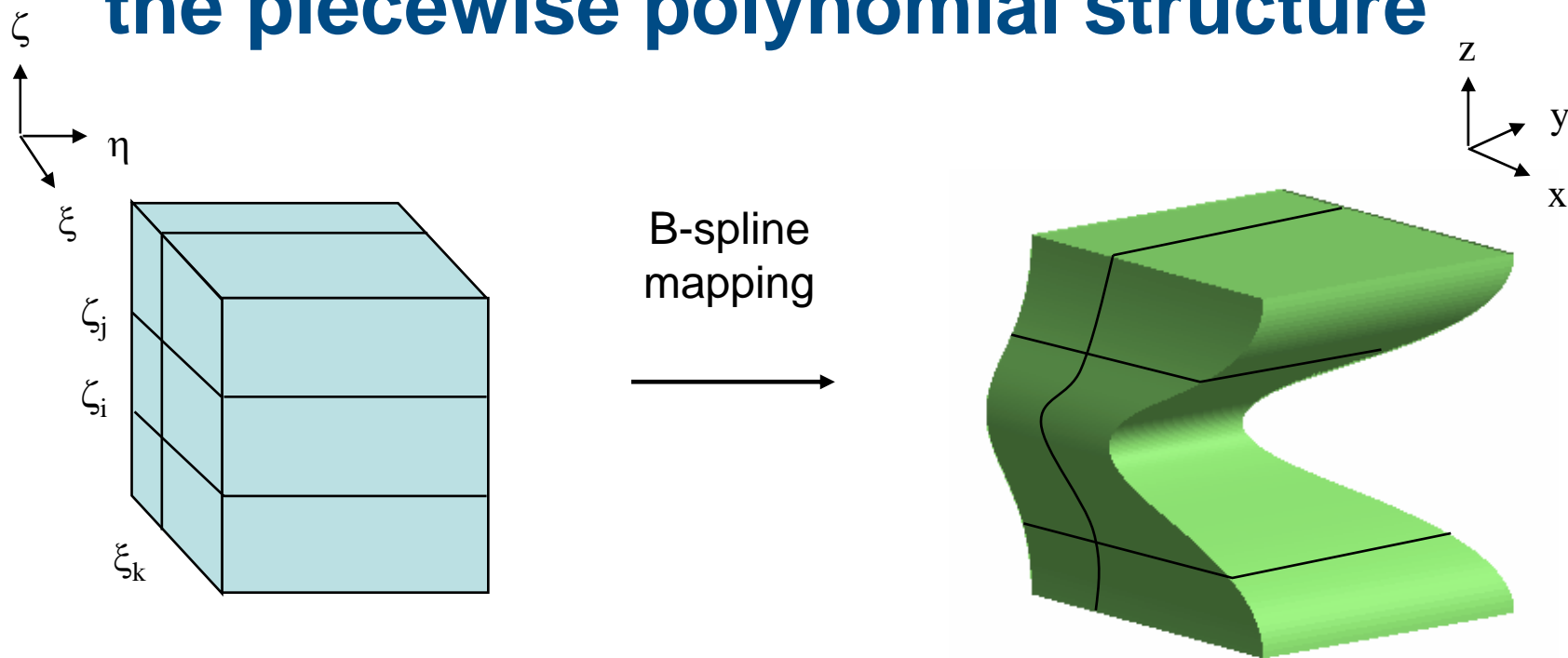
Isogeometric representation



Example by :
Tom Hughes

- The faces of the block reproduce the CAD-shape exactly

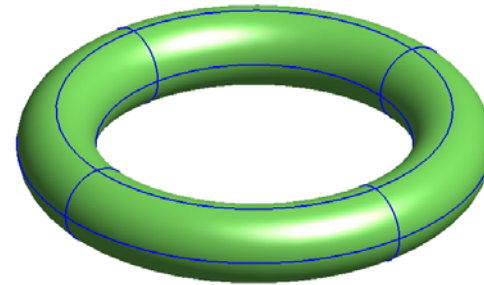
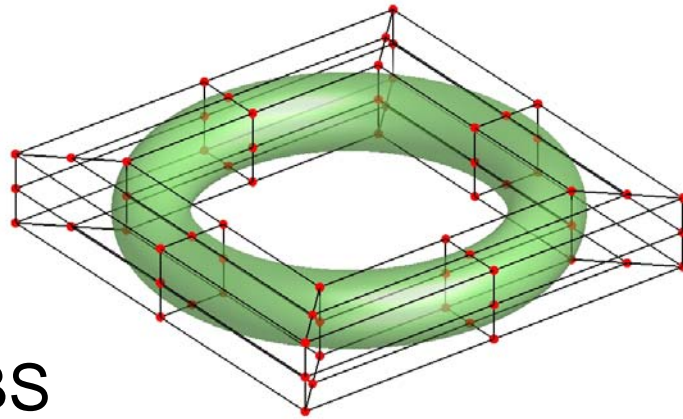
The description is refined by knots defining the piecewise polynomial structure



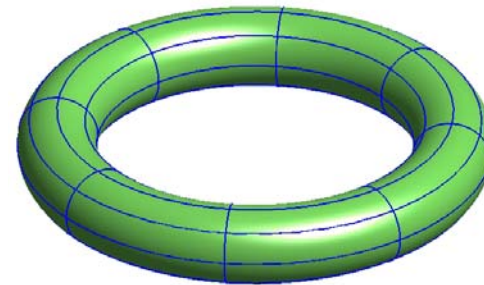
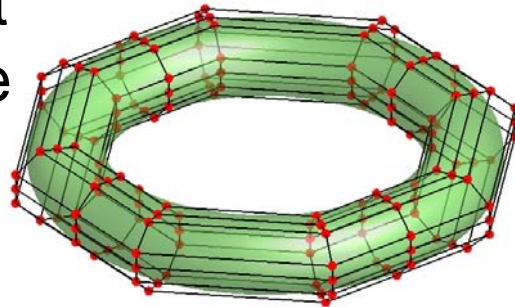
Example by :
Tom Hughes

- Knot insertion do not change the geometry, only the “element structure”

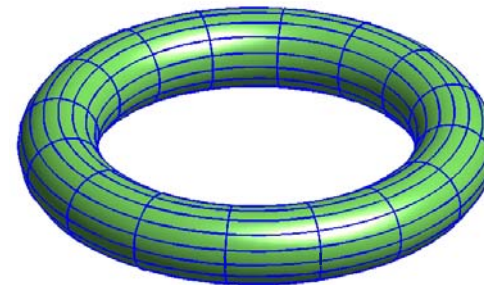
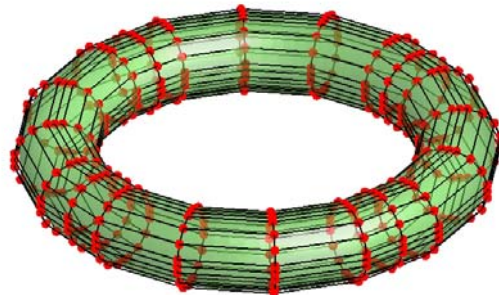
Knot insertion (h-refinement)



NURBS
control net
around the
shape

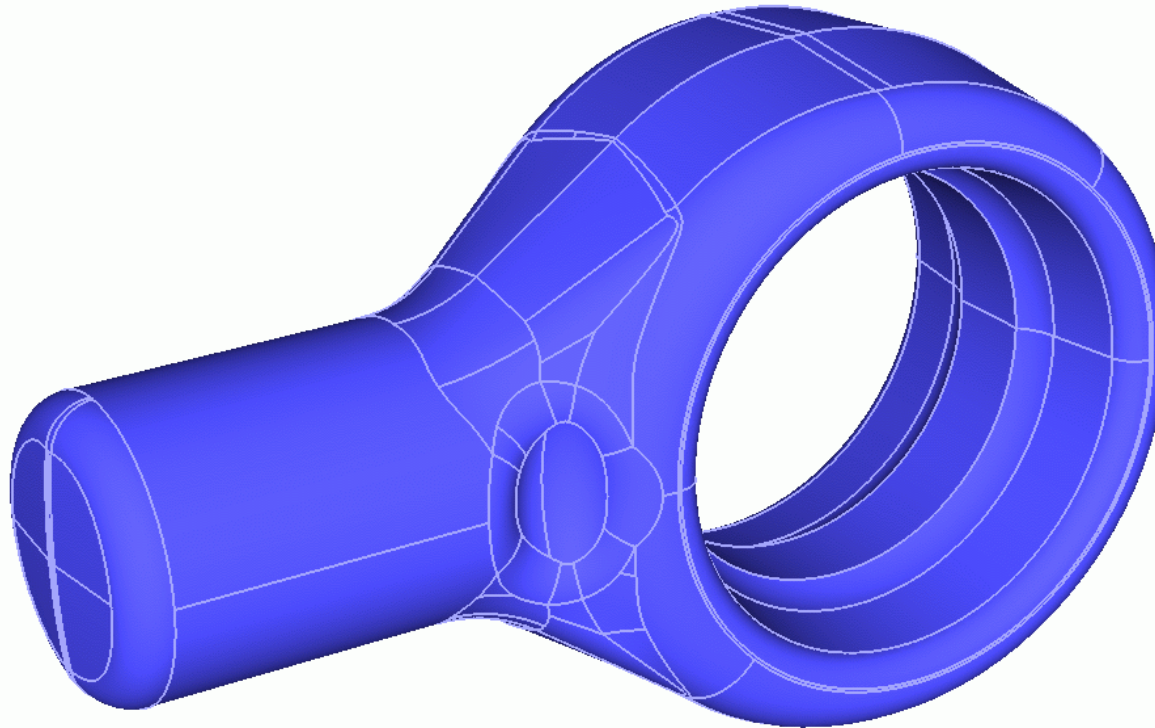


Mesh on
the shape



Example by :
Tom Hughes

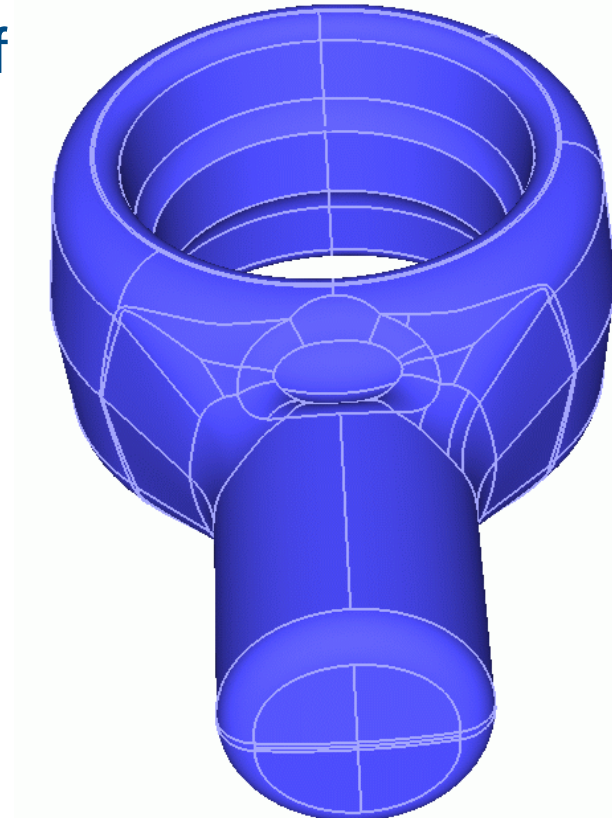
CAD has to change to support isogeometric analysis



- Example: Patch structure of a fairly simple CAD-object
 - Object designed patch by patch to match the desired shape
 - Shape designed for production

CAD patch structure not an obvious guide to NURBS block structure

- We would like considerably fewer NURBS blocks than the number of surfaces patches
- The object has three main parts
 - The “torus” like part
 - The “cylindrical” handle
 - The transition between these
- Not obvious how this can be represented as a composition of NURBS blocks
 - Acute angles
 - Extraordinary points
 - Singular points



Current CAD technology is here to stay

- The major part of revenue of CAD vendors comes from industries that don't suffer from the CAD to analysis bottleneck.
- Current CAD is standardized in ISO STEP (ISO 10303)
- The driving force for isogeometric CAD has to be industries that has the most to gain from the novel approach, e.g.,
 - aeronautics, defense, space and automotive industries
- Iso geometric CAD: A next natural step in CAD evolution?
- ISO STEP should also encompass isogeometric CAD

Two approaches to isogeometric CAD

1. Build the block structure one block at the time
 - User responsible for block interfaces and interfaces to outer and inner hulls.
 - Similar to surface modeling without trimming
 2. Design the trivariate block structure in an already existing ISO STEP type CAD model
 - The user controls the block structure. The blocks snap together and to outer and inner hulls.
 - Similar to designing surfaces into a point cloud in reverse engineering
- We believe that starting with approach 2 and then gradually introduce approach 1 is the best approach

Tensor product NURBS lacks local refinement

- The regular structure of tensor product NURBS does not allow local refinement
- Local refinement is the aim of hierarchal B-splines
 - Isogeometric analysis needs to have a one-level coding
- T-splines has a one level coding of hierarchal B-splines
 - However, T-spline theory is developed only? for surfaces,
- Alternative: **Locally Refined Splines**, where selected tensor product B-spline basis functions are refined.
 - The splines space is be a space of tensor product B-spline basis functions with refinement at different levels.
 - The spline space will be globally linearly independent, but in refined interval there will be linear dependencies.
 - SINTEF is now addressing the potential of LR-Splines

SINTEF Activities with isogeometric representation and analysis

- Isogeometry. Norwegian project for improving the mathematics used in the processes between CAD and FEM. (2008-2011) (SINTEF + 2 industrial partners).
- ICADA. Norwegian project looking at the use of splines elements (mathematics of CAD) in FEM. (2008-2013) (SINTEF + 3 industrial partners).
- Exciting. EU-project looking at the use of isogeometric analysis within the transport sector. (2008-2011) (3 Universities, 2 R&D Institutes, 4 industrial partners)
 - Coordinator: Prof. Bert Jüttler

Work so far at SINTEF

- **Isogeometry:** Focus on CAD-model qualities necessary for modeling of NURBS-volumes into CAD-structures
 - Preparatory work within quality control and repair of CAD-models
- **ICADA:** Focus on direct modeling of NURBS volumes by basic operations such as generating NURBS volumes:
 - Surface sweeping
 - Surface rotation
 - Lofting through surface

Provide good NURBS volumes for isogeometric analysis

- **Exciting:** The **Isogeometric Toolkit** with NURBS functionality for curves, surfaces and volumes, and provide complementary software, e.g., quadratur formulas
 - For information see http://www.sintef.no/math_software.

Conclusion

- Isogeometric representation has the potential of introducing close integration of CAD and FEA, and to improve the quality of FEA
 - FEA has to be changed
 - CAD has to be changed
 - ISO STEP has to be extended
 - More exact models will improve the quality of long term archival
- The driving force for isogeometric CAD has to be research and industries in need of removing the bottlenecks between CAD and FEA
- Growing interest for the approach in US and Europe
 - An isogeometric toolkit is under development
- Heterogeneous multi-core processors demands changes of many software codes
 - This is an opportunity also to readdress established solutions