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# Trimmed NURBS Surface Tracking

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## Introduction

- Use of CAD has been long-standing goal within Sellafield Ltd and world-wide criticality/shielding community
- Many plant models are already available in 3D CAD formats
- Direct use of such models could potentially
  - Ease re-modelling burden on assessors
  - Reduce modelling time
  - Reduce re-modelling errors
- Allow use of codes in situations that are currently not practical
- Modellers could use most familiar CAD software
- Removes need to develop bespoke visual model builders

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## MC Calculations with CAD

- Develop IGES trimmed NURBS import software
- Convert NURBS surfaces and NURBS trimming curves into Bezier form
- Fix Bezier intersection method and develop working prototype
- Find some way of assigning material data to CAD model

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## Stage 1 - IGES Import

- IGES – Initial Graphics Exchange Specification
- Other standards available
  - Not as common
  - Know from Okino that IGES trimmed NURBS is standard method for transfering CAD data
- Import routines based on version 5.3
  - Large specification
  - Only need to worry about Trimmed NURBS subset
  - Subset still uses many elements of the specification
  - Often referred to as '144/142' format

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## Stage 1 - IGES Import status

- Working prototype has been developed
  - Based on IGES exports from Autodesk Inventor 11
- Individual module
  - Rest of code protected from changes if standard is updated
- Different 'flavours' of IGES are out there
  - Need to test with other CAD software
- Module has been used to import some very complex models
  - Note that some models contain errors (recursive definitions, redundant definitions) when exported

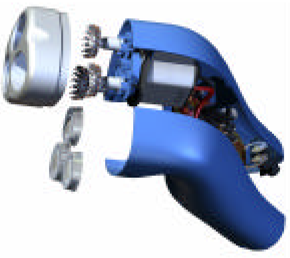


## Stage 1 - IGES Import Examples

Alloy Wheel
1 Unique solid
512 NURBS surfaces
2389 Trimming curves



## Stage 1 - IGES Import Examples



Shaver
32 Unique solids
4804 NURBS surfaces
27561 Trimming curves
68 Solid instances

## Stage 2 – NURBS to Bezier Conversion

- Why convert?
  - NURBS computationally expensive to evaluate
  - Bezier **much** quicker to evaluate
    - Use deCasteljau algorithm – Series of linear interpolations
- Surface evaluation is bottleneck in ray/surface intersection
- Can represent any NURBS surface with Bezier Patches
  - Hence conversion is good idea
- Conversion is performed once as pre-processing step
  - Trimming curves also converted to Bezier form



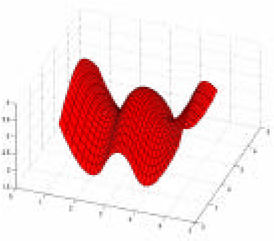
## Stage 2 – NURBS to Bezier Conversion Status

- Theory is relatively straightforward
  - Conversion consists of series of knot insertions
- Seems to be very robust
  - No failures detected so far
- Alloy wheel converted to
  - 6853 Bezier patches
  - 12110 Bezier trimming curves
- Shaver model converted to
  - 42591 Bezier patches
  - 101143 Bezier trimming curves

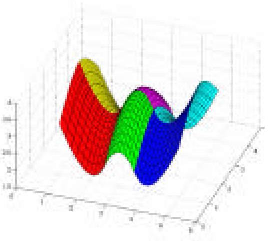


## Stage 2 – NURBS to Bezier Conversion Example

NURBS Surface



Bezier Patches



## Stage 3 – Bezier Intersection

- Need to find all intersections for CSG operations
- Sub-millimetre accuracy, numerical stability, quick evaluation required
- 'Bezier Clipping' seems most suitable
  - Relies on fact that patch is entirely enclosed within convex hull of control points
  - Has been used by several groups for Bezier visualisation
  - Standard method for 2D line-curve/curve-curve intersections

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## Stage 3 – Bezier Intersection Status

- Have working prototype
- Method is fully documented
- Several problems
  - Intersection failures, mainly due to CAD models
  - Relatively slow, computationally expensive.
- Incorporated into Decode, not MONK or MCBEND
  - Work is ongoing

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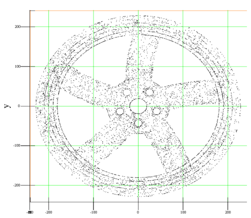
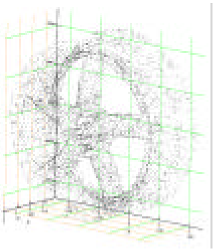
## Stage 3 – Bezier Intersection Example





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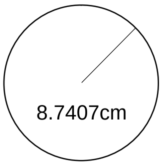
## Stage 4 – Material Assignment

- Turns out to be very simple
- Depends on number of parts in model
  - For multiple parts, include material number in CAD part names
    - 'shiphull_1' , Part named 'shiphull' is made of material 1
    - CAD assemblies, don't include material number
  - For single parts, include material number in CAD filename
    - 'godiva_1.igs', model 'godiva' is made of material 1
- Existing CAD models need editing to adhere to this convention



## Criticality Benchmark Example

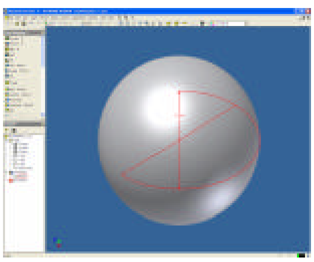
- Benchmark model created in Inventor
  - Spherical 93.71% U system, Godiva
  - MONK validation case9.01
  - BINGO-in-MONK $k_{eff}$=0.9958, s =0.0014
- Model also created using standard primitives in Decode






## Criticality Benchmark Example - Results

- Benchmark $k_{eff}$:
- Decode/Primitives
  - $k_{eff}$=0.9972
  - s =0.0021
  - Runtime:4m52.0s
- Decode/NURBS
  - $k_{eff}$=0.9909
  - s =0.0031
  - Runtime:21m4.9s
- 4.3 times slower



## Remaining Work

- Increase intersection calculation speed
- Any way to prevent intersection errors?
  - Scale of problem increases as model complexity increases
  - Currently dealt with by re-sampling for neutron direction
- Hole tracking
  - Theory has been developed, not yet implemented
  - Seems computationally expensive but might be faster!

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## Conclusion

- CAD importing for MC calculations now possible
  - There are problems, but not insurmountable
  - Problems mostly relate to modelling errors
- Survey calculations possible
  - Need to split the 'survey geometry' from NURBS geometry
- Process not a magic bullet, but worthy functionality

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