Direct-to-Shape Printing of Complex Objects

Phil Collins, Director – Advanced R&D
Global Inkjet Systems Ltd

Dusseldorf – October 2018

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GIS – Company Overview

- **Leading provider of technology solutions to industrial inkjet systems builders**
- **Supported printhead manufacturers**
  - Fujifilm Dimatix, Konica Minolta, Kyocera, Ricoh, Toshiba Tec, Xaar
- **Founded November 2006**
  - Privately owned
- **Based in Cambridge, UK**
  - Technical support in UK, China and Japan
- **Employees 70**
- **Patent protected technology**
- **Supplier & partner to over 130 customers worldwide**






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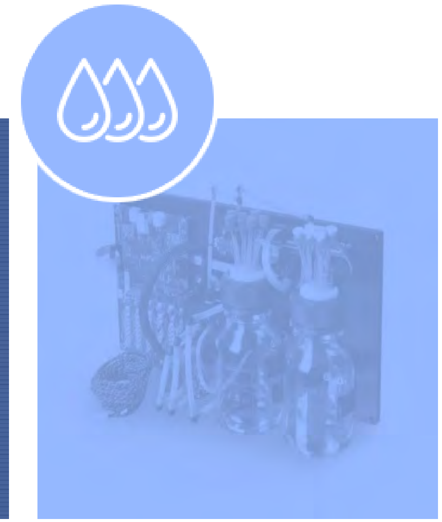
GIS – Products

DFE
Atlas® User Interface

Machine Control
Atlas® Server

Print Controllers
Drive Electronics



IDS
Ink Delivery Systems

Used in broad range of applications – textiles, labels, security printing, décor, spot varnish, product decoration, corrugated, ceramics, functional coatings, materials deposition, 3D, robotics and more

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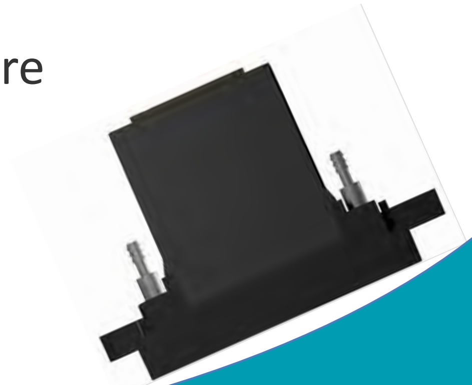
Agenda

- **Challenges**
  - What are the problems?
- **Tubes, cones & tubs**
  - Widely used, so experience exists
  - Assumptions of 2D printing start to break down
- **More complex shapes**
  - A generic approach, applied to a sphere
  - Some new challenges
  - From concept to reality



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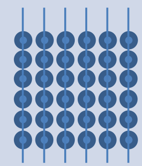
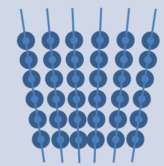
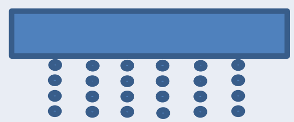
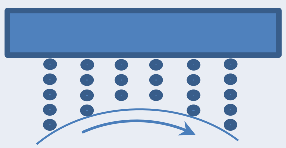
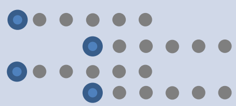
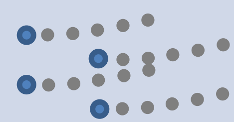
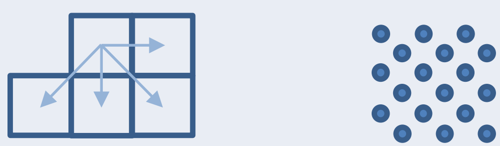
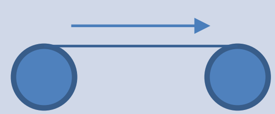
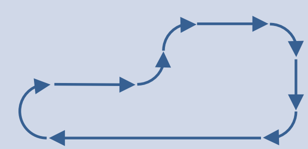
Challenges

	Flat Surfaces	Curved Surfaces
Density Correction		
Throw Distance & Flight Time		
Nozzle Alignment & Interleaving		
Screening		
Transport & Encoder Configuration		

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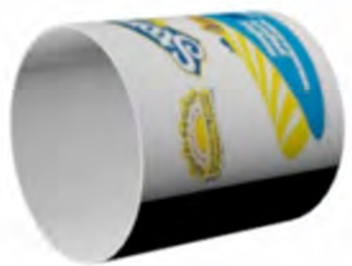
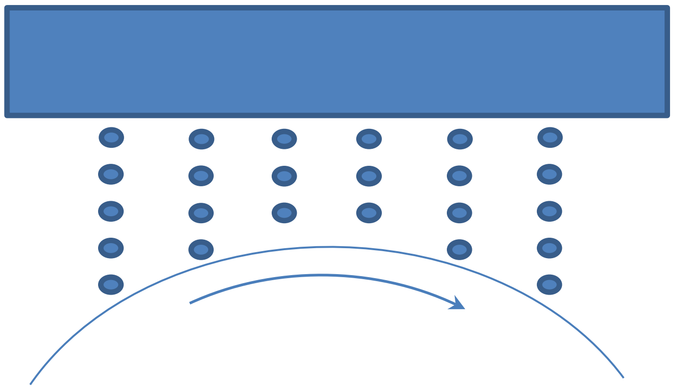
Tubes

- **Well established/well understood technology**
  - Fixed radius of curvature
  - Cylinder unwraps to a rectangle or square
- **But as print speed is increased, and/or radius of curvature decreased**
  - Throw distances vary
  - Flight time differences become significant for multi-column print heads





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Cones

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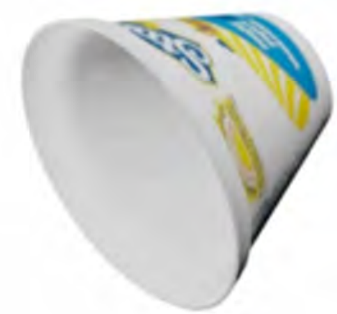
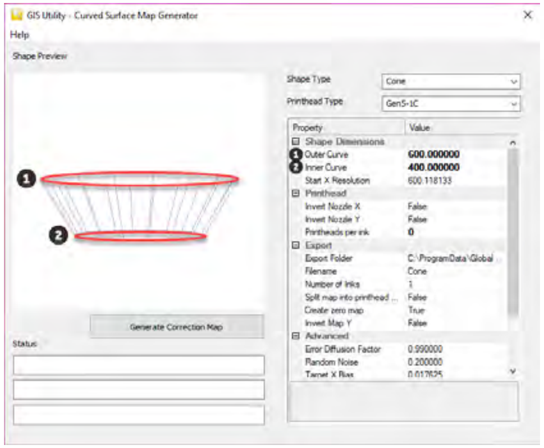
- **Cones or cone sections are useful for many applications**
  - Unfolds to an arced rectangle / section of a circle
  - Corrections are relatively simple, provided heads are narrow and mounted symmetrically
- **Challenges**
  - Nozzle alignment
  - Density correction
  - Dot gain management
  - Avoid screening artefacts





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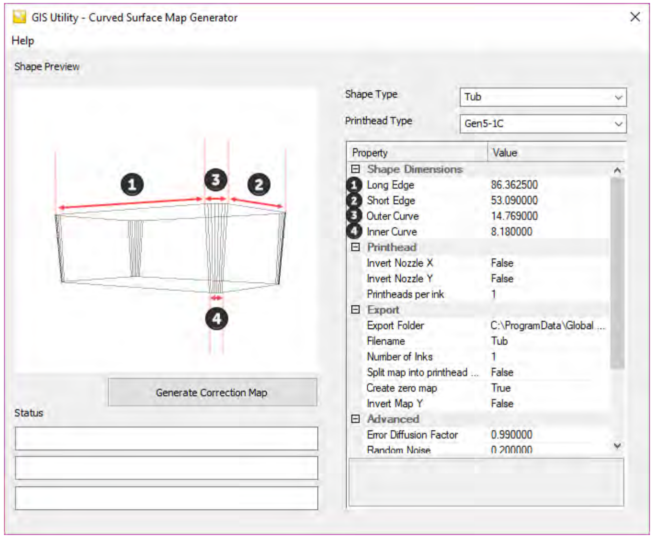
Tubs

- **Mixture of cone sections and flat surfaces**
- **Necessary corrections change during the print**
  - Often from pixel to pixel
- **Print system is more complex**
  - No longer rotating about a single axis
  - Transport design may require a synthetic encoder



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Agenda

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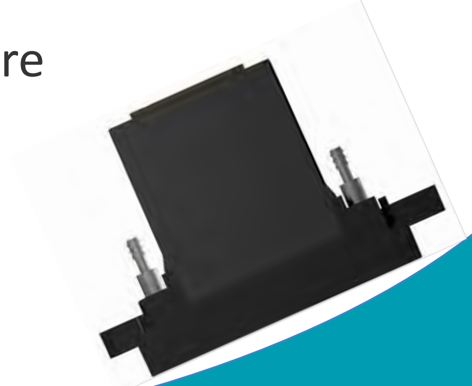

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More Complex Shapes

- **Strong demand in the market – particularly industrial**
  - Automotive parts; industrial components; aerospace; and much more….
  - Many projects underway – most long term and confidential
- **Automotive examples - using Heidelberg Omnifire 250/1000**
  - Mercedes Smart cars
    - Customisation of ventilation nozzles, instrument bezels
  - Borbet
    - Alloy rims

Images from InPrint Blog – review of IAA 2017, Frankfurt Motor Show

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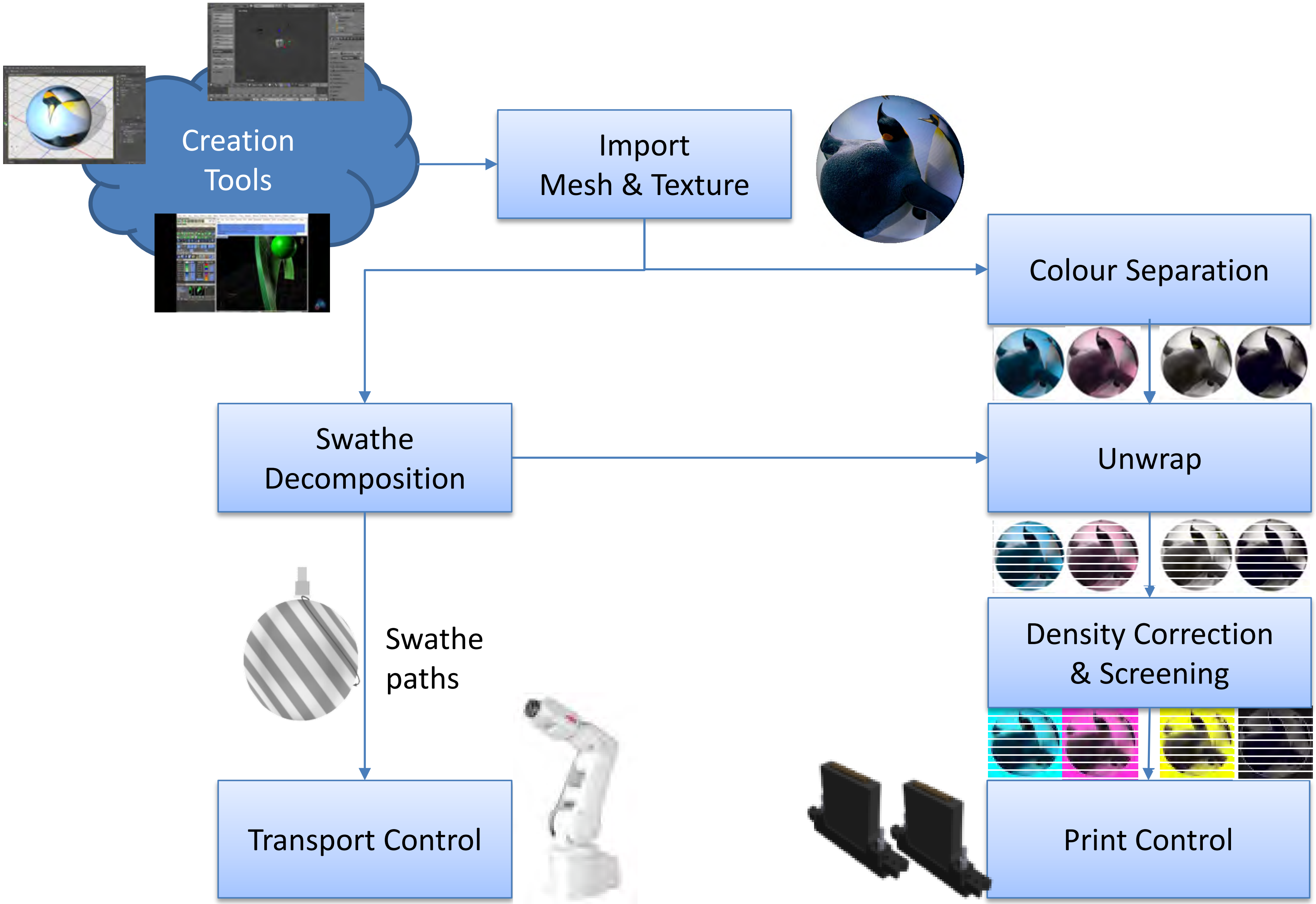
Generic Curved Surface Workflow



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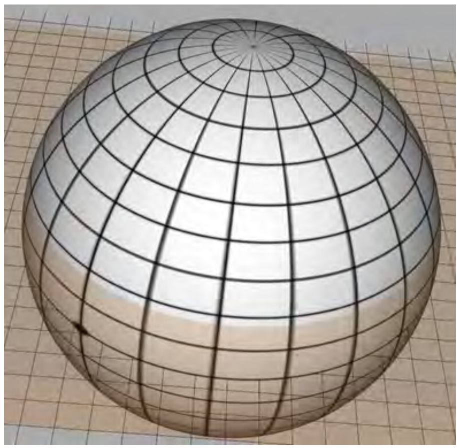
Wrapping a Sphere

3D Mesh



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Texture

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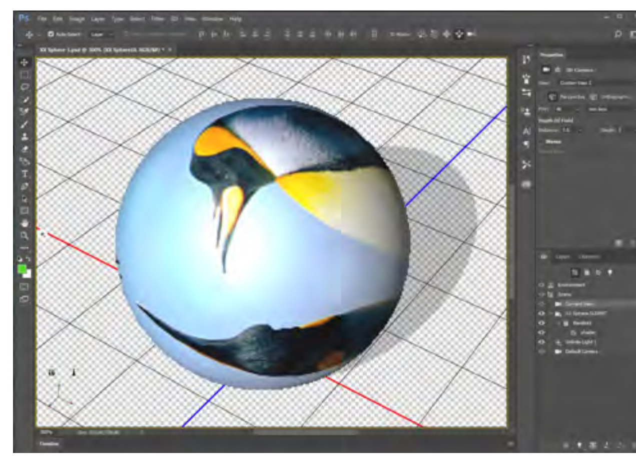
- **Many tools available for wrapping**
  - Well established technologies from gaming, augmented reality industries, etc.
  - Many different ways to wrap, edit directly on to 3D surfaces



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Unwrapping a Sphere

- **“Unwrap” the image and design a print path**
  - Taking into account the constraints of the object to be printed, inkjet printhead, capability of the robot
  - Currently we do this manually, which is appropriate for most manufacturing applications, but there is research towards automation

Latitude **Spiral** **Other**

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Simulated Print Sequence

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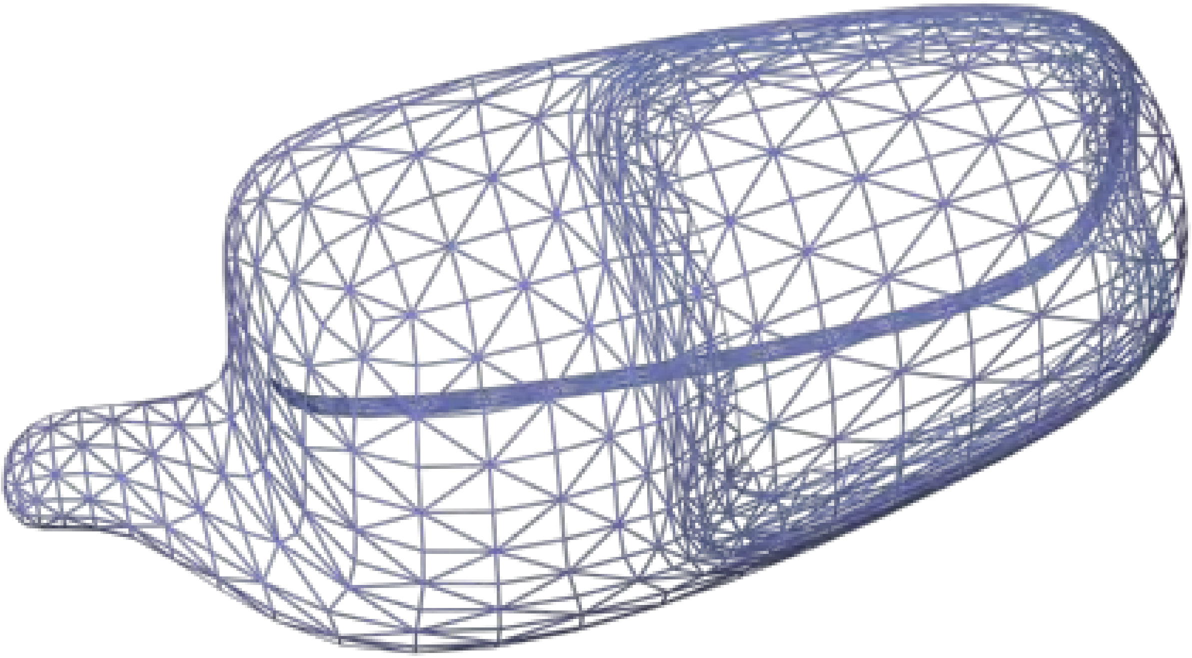

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Simulated Print Sequence

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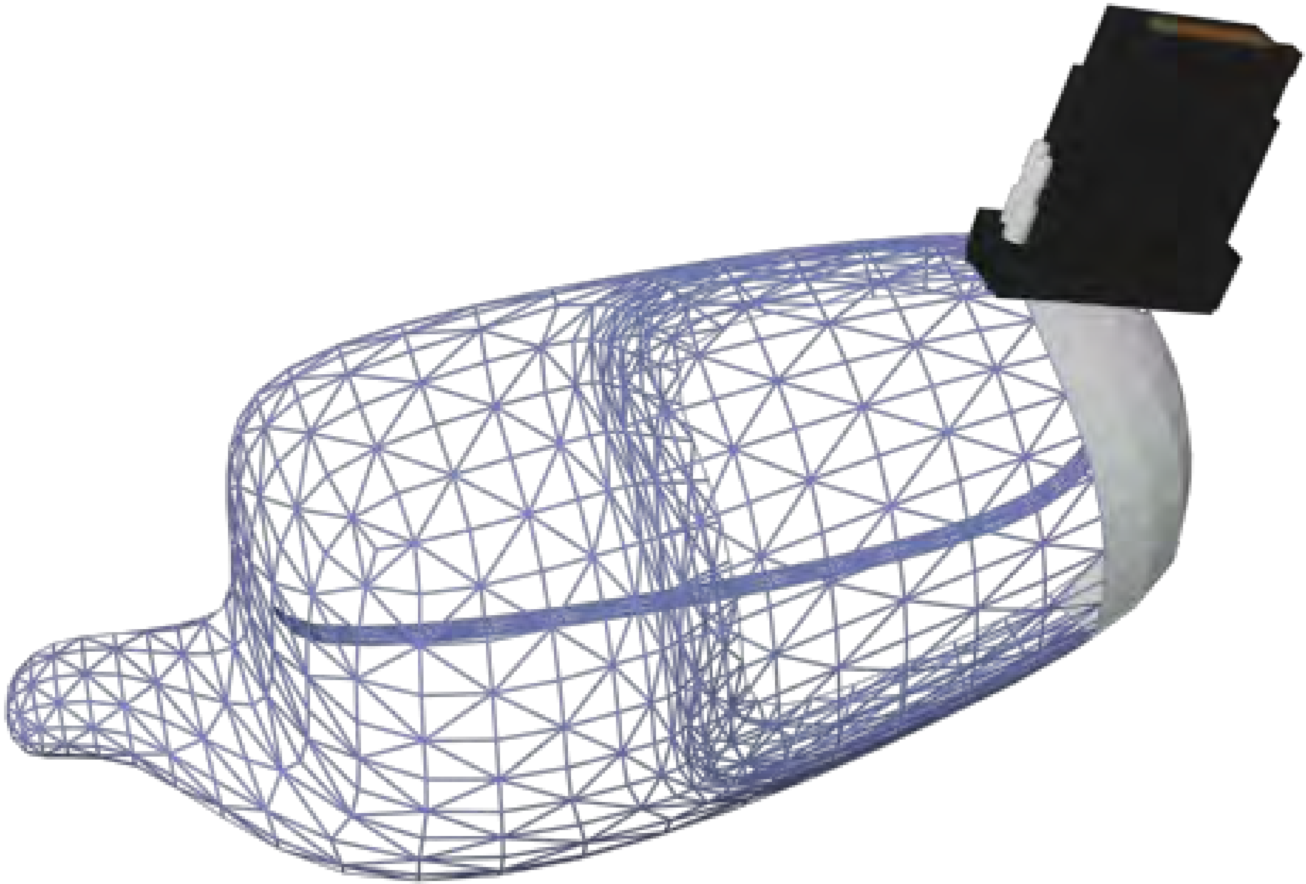

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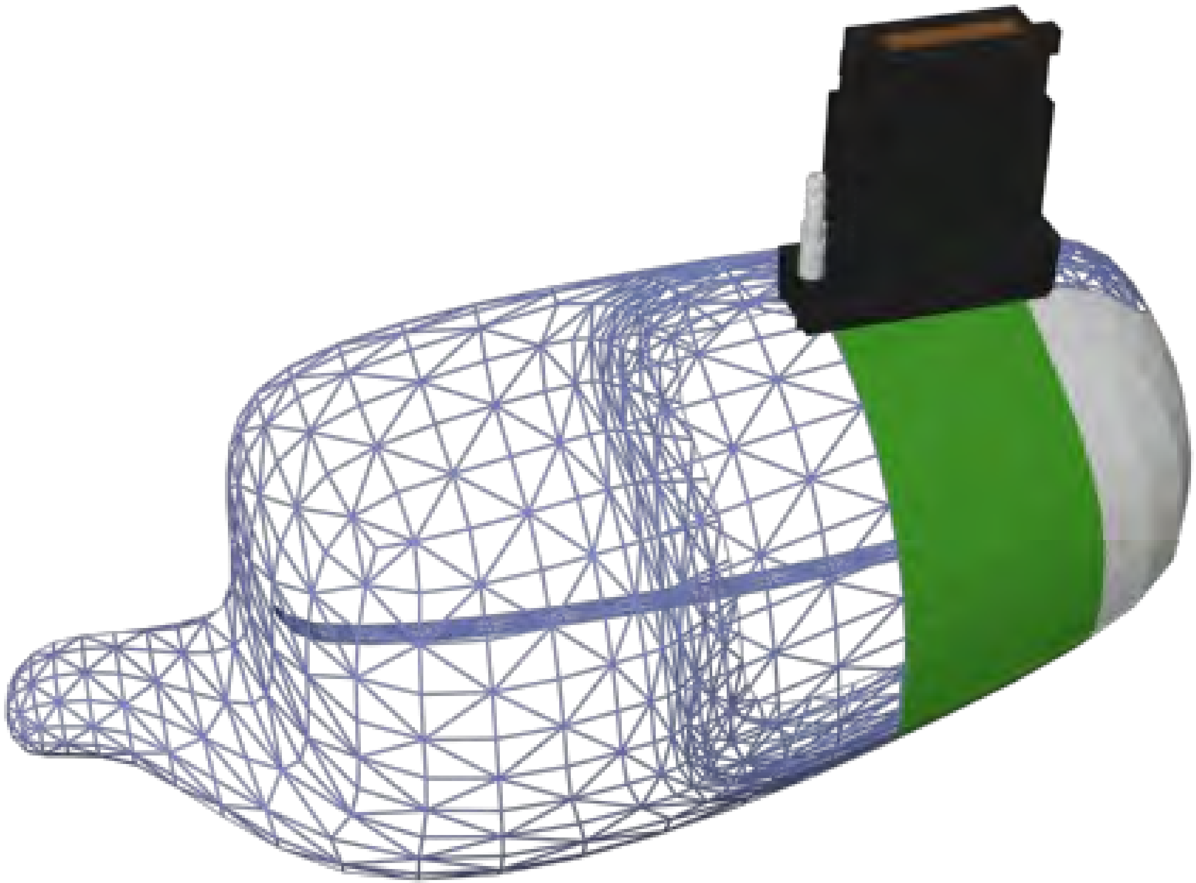

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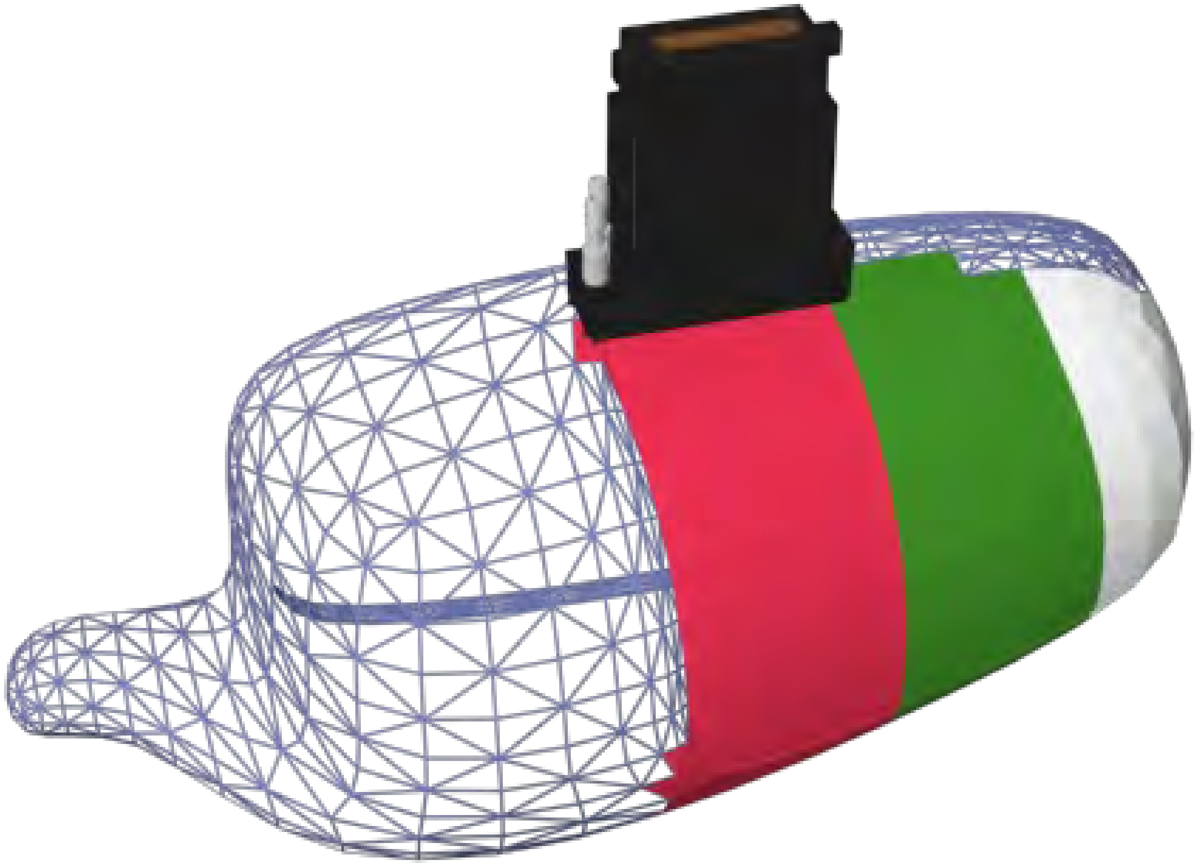

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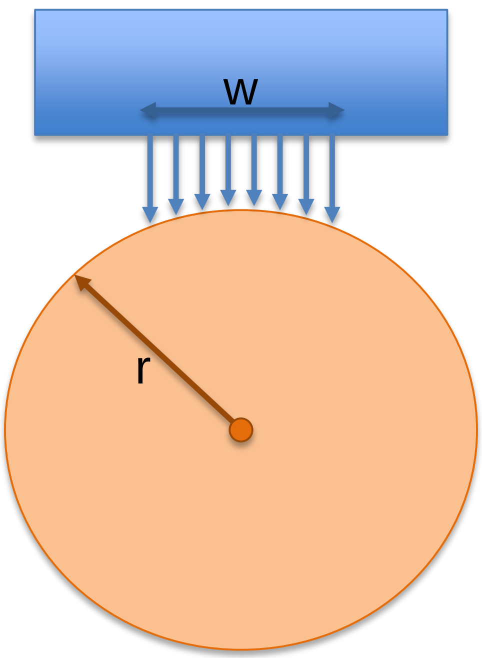
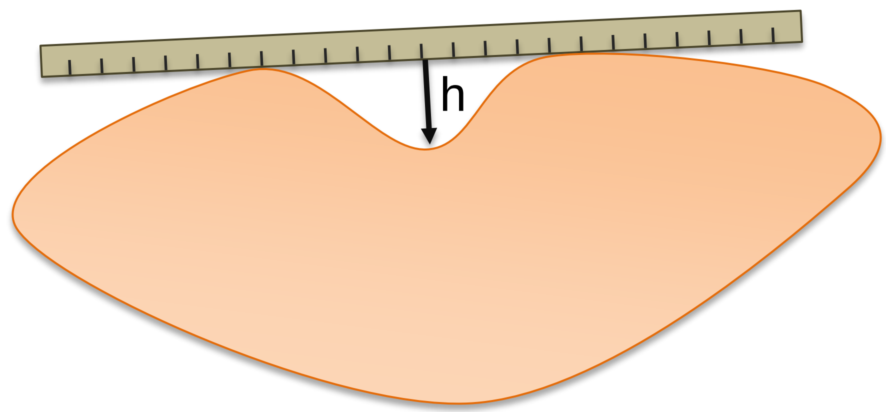
Where Can We Print?

At printhead scale and below: convex or near-convex shapes



Convex
r >≈ w



Near-convex
$h < h_{max}$

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Where Can We Print?

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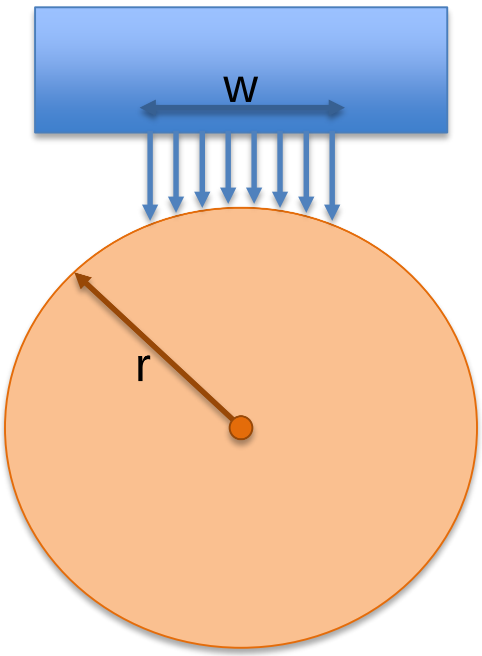
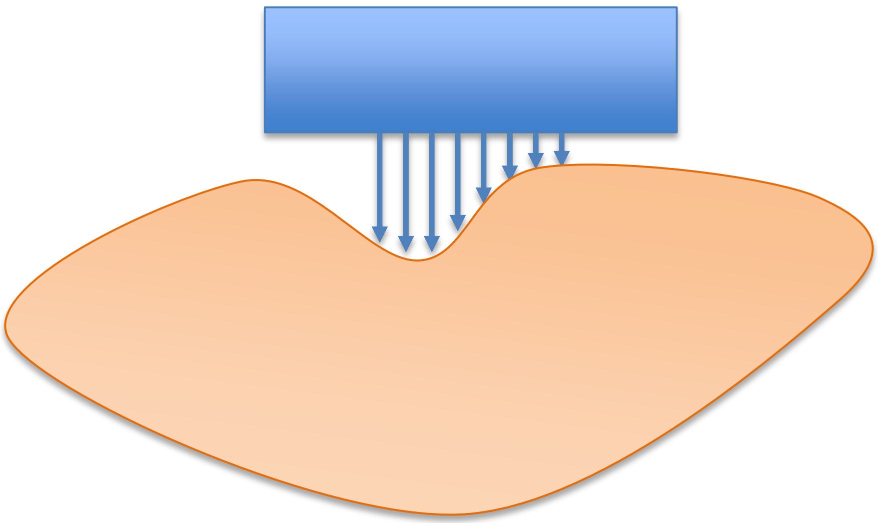
At printhead scale and below: convex or near-convex shapes



Convex
$r \gtrapprox w$



Near-convex
$h < h_{max}$

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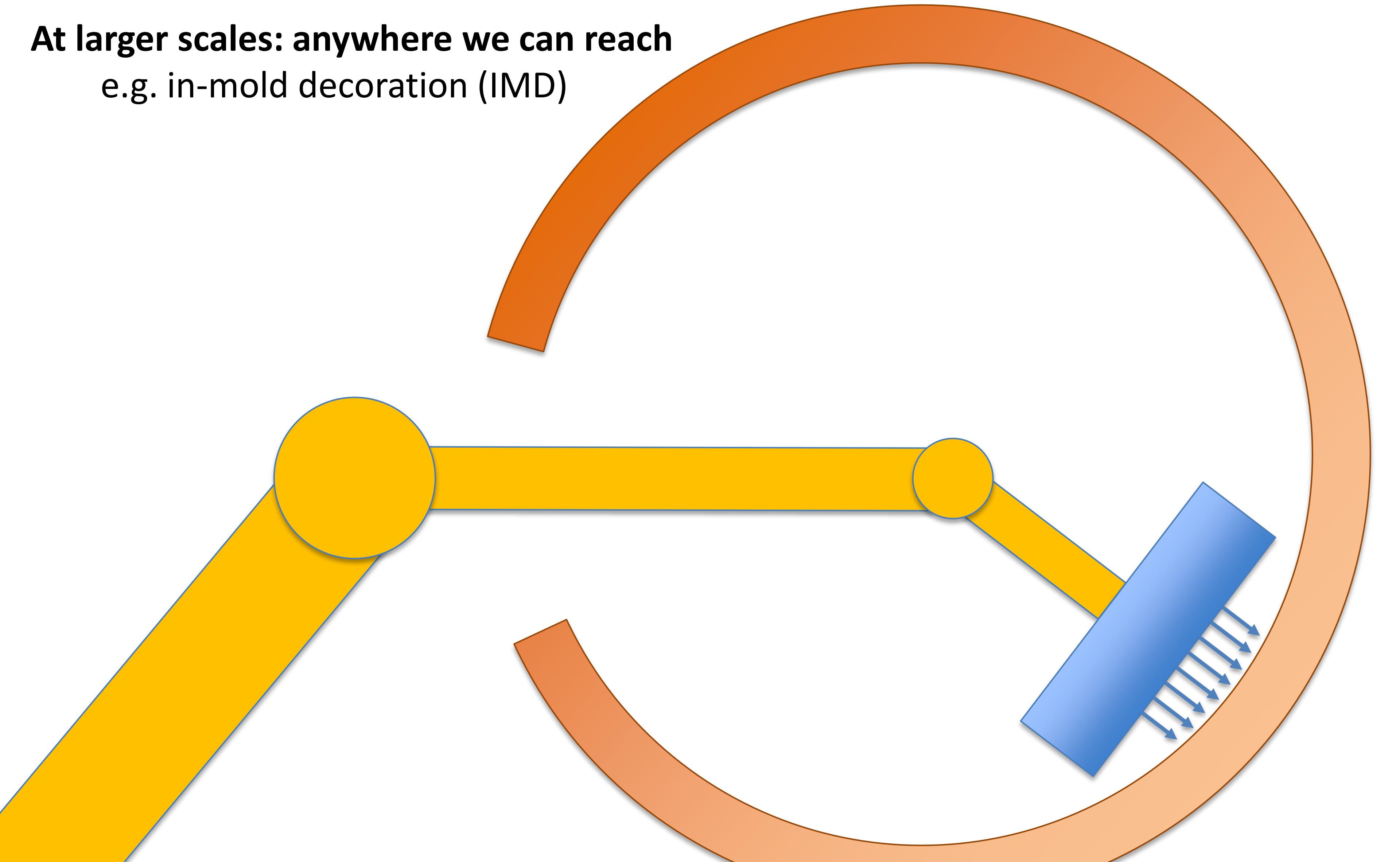
Where Can We Print?

At larger scales: anywhere we can reach

e.g. in-mold decoration (IMD)



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Positioning Accuracy

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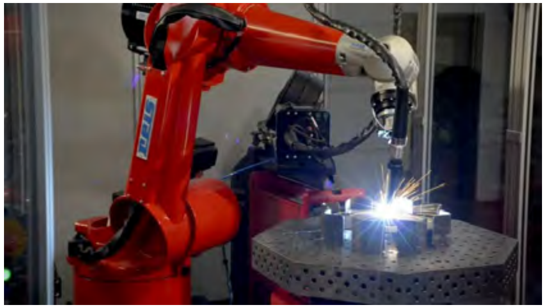
Industrial robots have excellent accuracy for many industrial applications …



… but printing requirements are tight

- Typical industrial robots have absolute accuracy of 200-500 µm
- Inkjet printing requirements are typically 10x finer
- Robot repeatability is better than absolute accuracy, so calibration is possible

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Transport Mechanisms

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	General Purpose Robots	Custom Mechatronics
Advantages	• Available off-the-shelf • Many specifications • Well supported	• Specific to application • Implementation efficiency
Disadvantages	• Positioning accuracy • Under utilisation of standard feature sets • Encoders not included	• One-off design, build and debug costs • Timescale
Suitability	Fast development, short run systems that fit available specifications	Longer production runs Systems with special requirements

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Encoders

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- **Very useful when printing on flat or regular curved surfaces**
  - Jetting precision 1 µm (<5% pixel pitch @ 1200 dpi) possible
  - Harder to apply to complex print paths
- **Not standard on industrial 6-axis robots**
  - But can be added
- **Hybrid techniques**
  - Combine robot handling for shape orientation with linear transport plus encoder
  - Synthetic encoders: combine multiple encoder inputs into one

Image source: Renishaw

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Shape Accuracy

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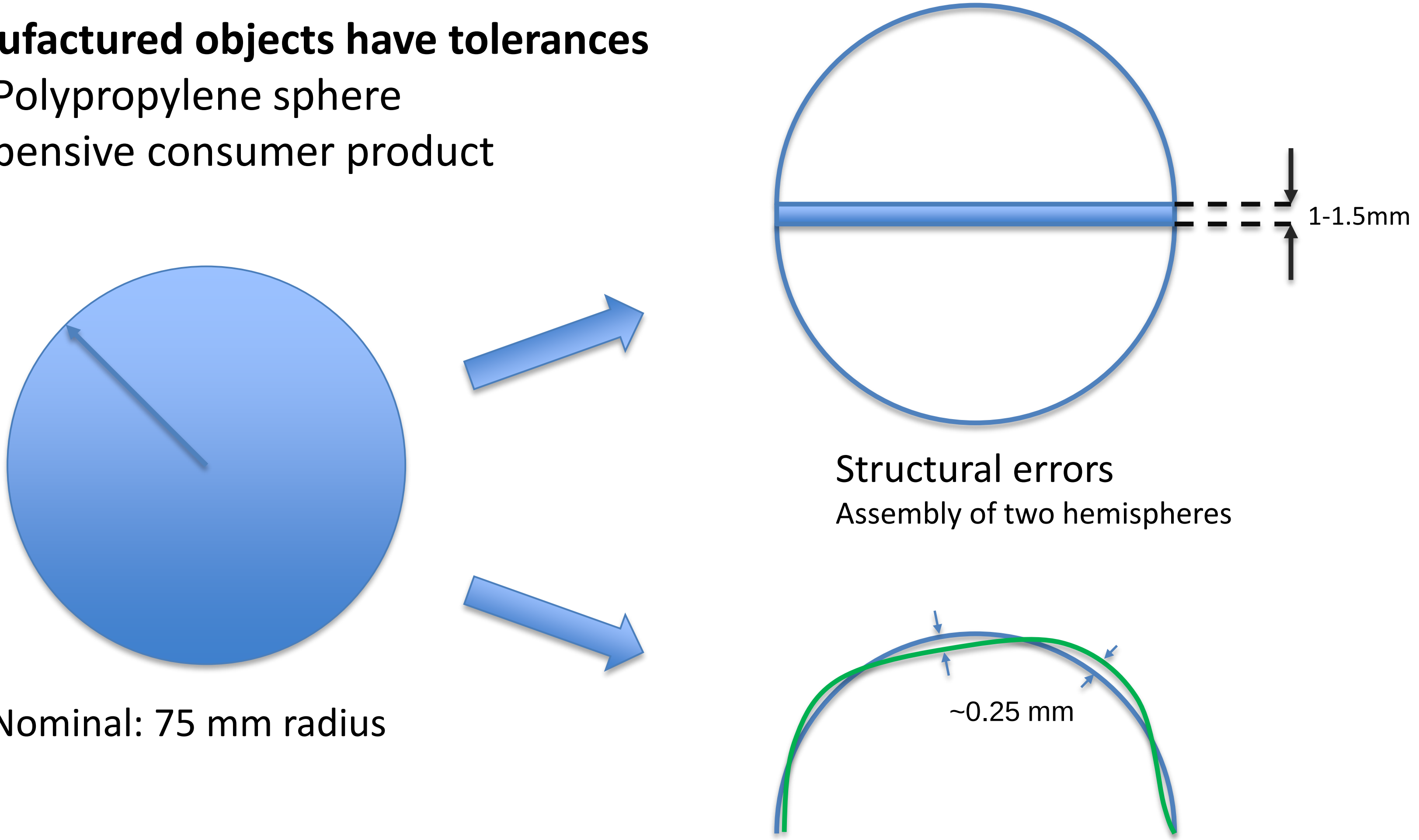
All manufactured objects have tolerances

- E.g. Polypropylene sphere
- Inexpensive consumer product



Nominal: 75 mm radius

Structural errors
Assembly of two hemispheres

Precision errors
Limitations of process

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Shape Accuracy Compensation

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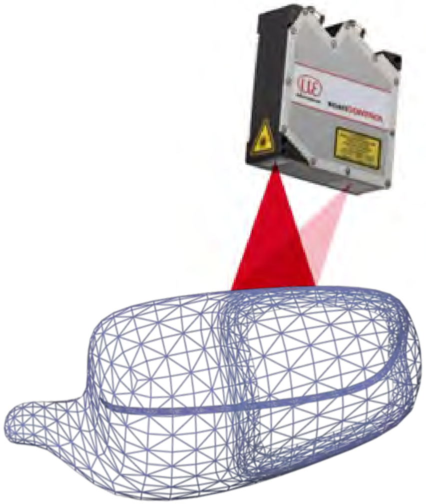
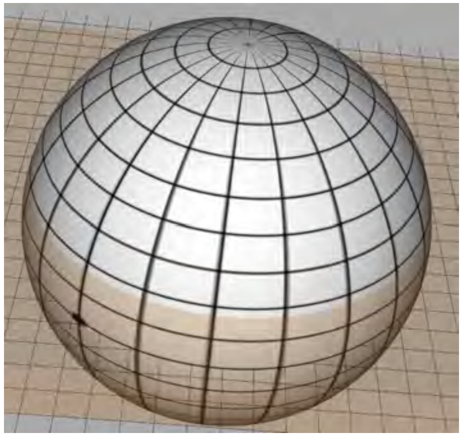


- **Measure the target shape accurately**
  - Mechanical profile gauges
    - Adequate, but rather slow
    - Contact with target shape may be a problem
  - Laser triangulation sensors
    - Resolutions down to ~1 µm, sample rates 1-100kHz
    - Non-contact
- **Apply measurements as corrections to the mesh model**
  - For per unit variations this can be done as a late stage delta
  - Output adjusted swathe data



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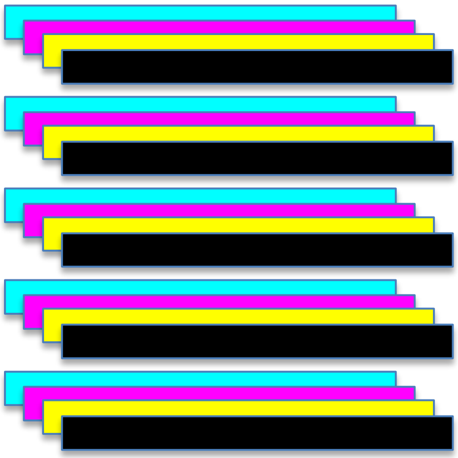

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Stitching

- **Stitching is a key area where inaccuracies will show**
  - Positioning errors cause gaps or overlaps, familiar from 2D printing

- **Careful control is required of multiple factors:**
  - Accuracy of transport, especially robots near to singularities
  - Print synchronisation
  - Variation of the target shape from nominal dimensions

Image source: GIS

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From Concept to Reality

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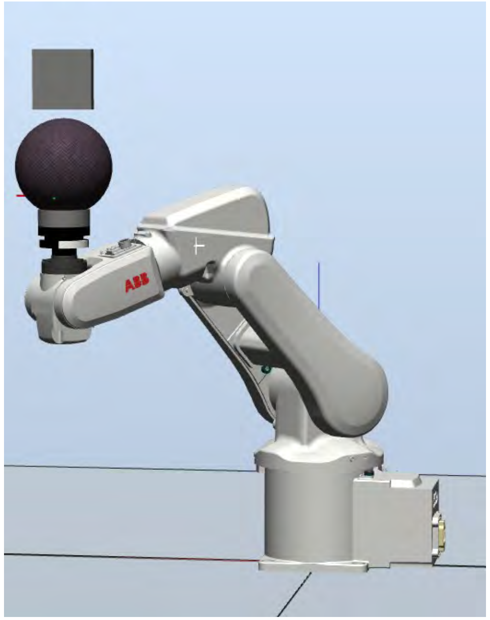
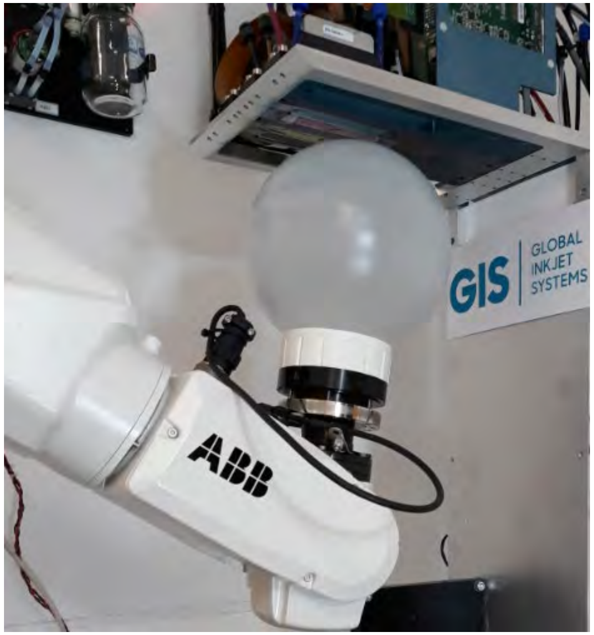
- Starting with a sphere
- Using a robot to position the shape under the printheads
- We built a test print rig





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Apply the Workflow

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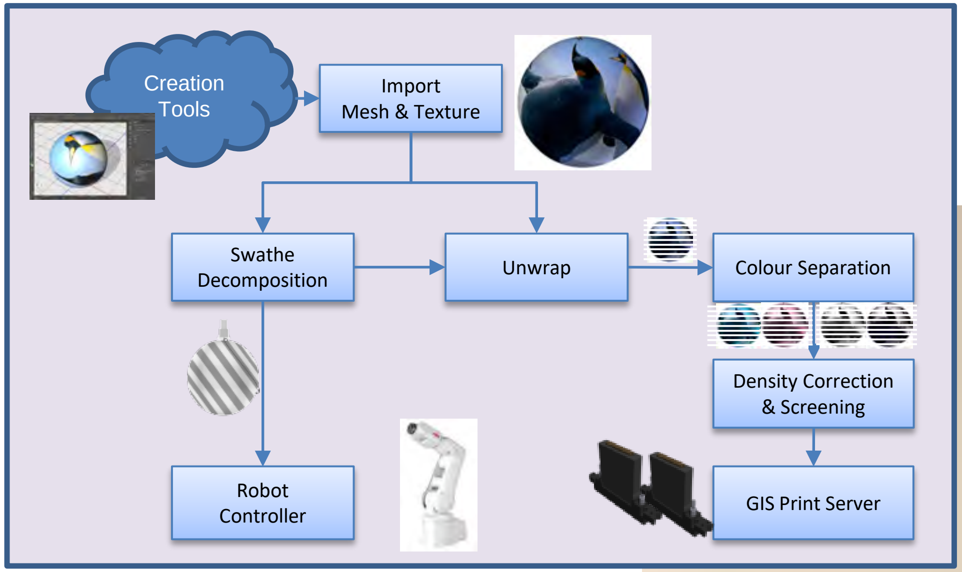

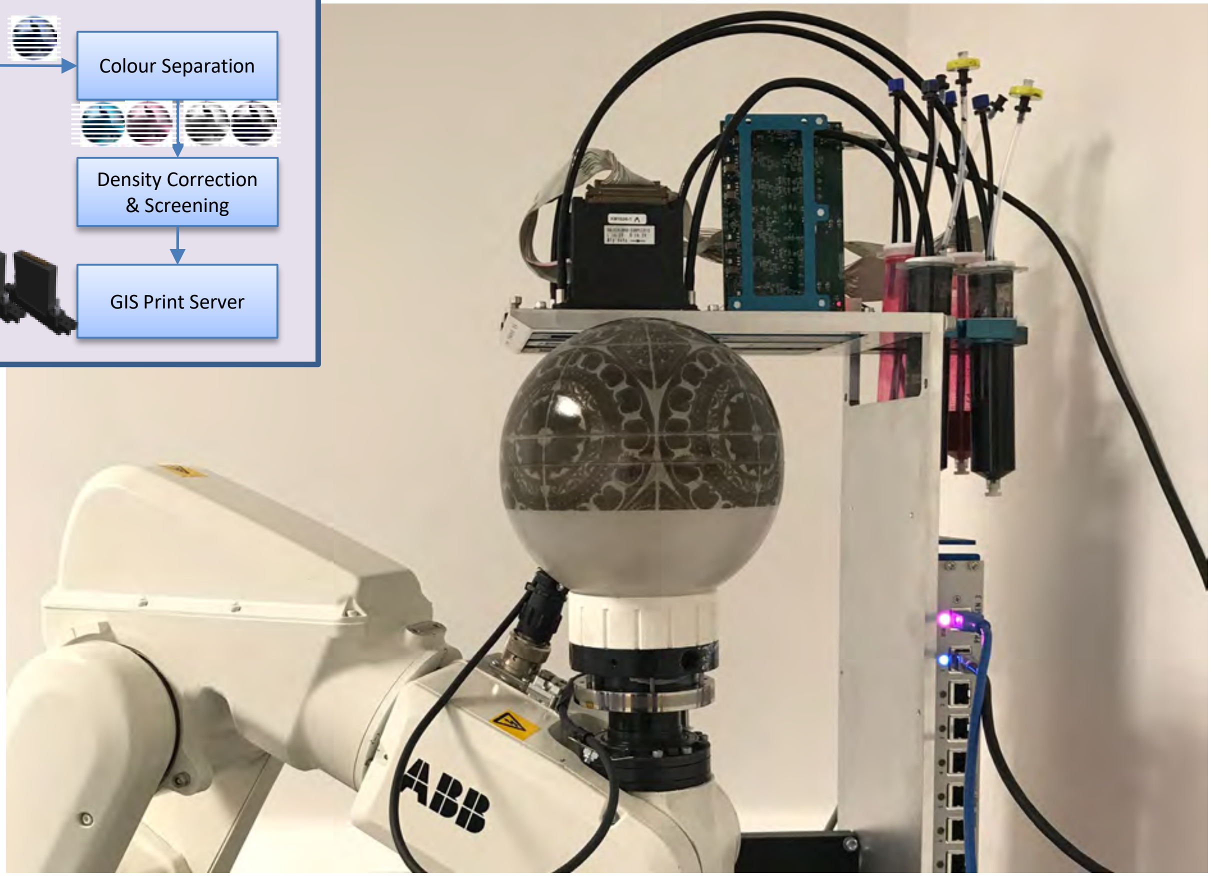

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From Concept to Reality

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Result: a printed polypropylene spheroid

- CMYK 1200 dpi
- Latitude swathes, 18^{o} high
- 300dpi native; x 4 interleave

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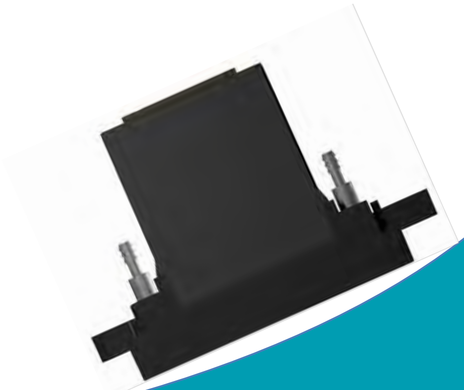
Key Points to Take Away

- **Inkjet printing of complex irregular shapes is possible today**
- **Precision positioning is vital, and more complex than for 2D**
- **Industrial robots are very useful, but not the whole solution**



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