



# CPS: Synergy: CNC Process Plan Simulation, Automation and Optimization

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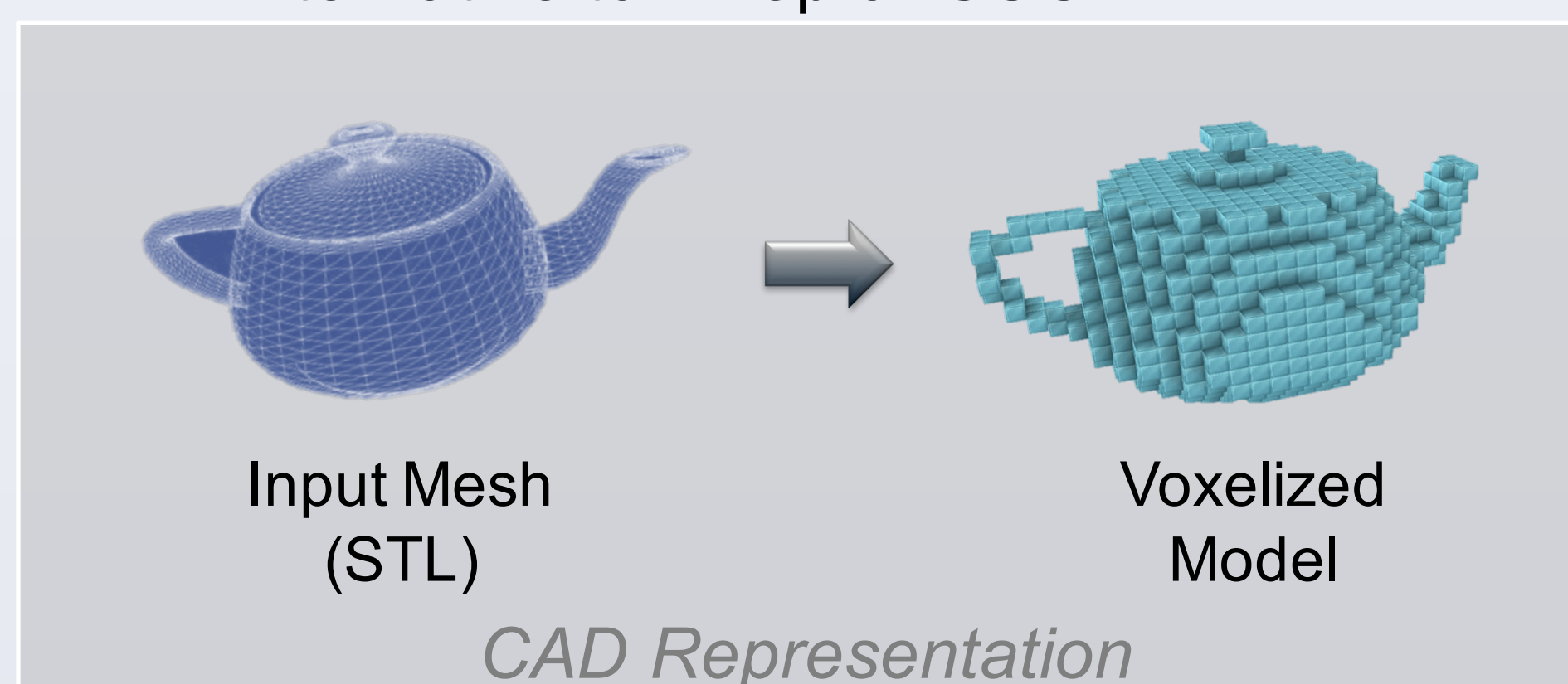
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## SculptPrint: The Print Button for 5-axis CNC Machining

CNC Toolpath Planning with the Ease of Programming of 3D Printing and Precision of Subtractive Manufacturing

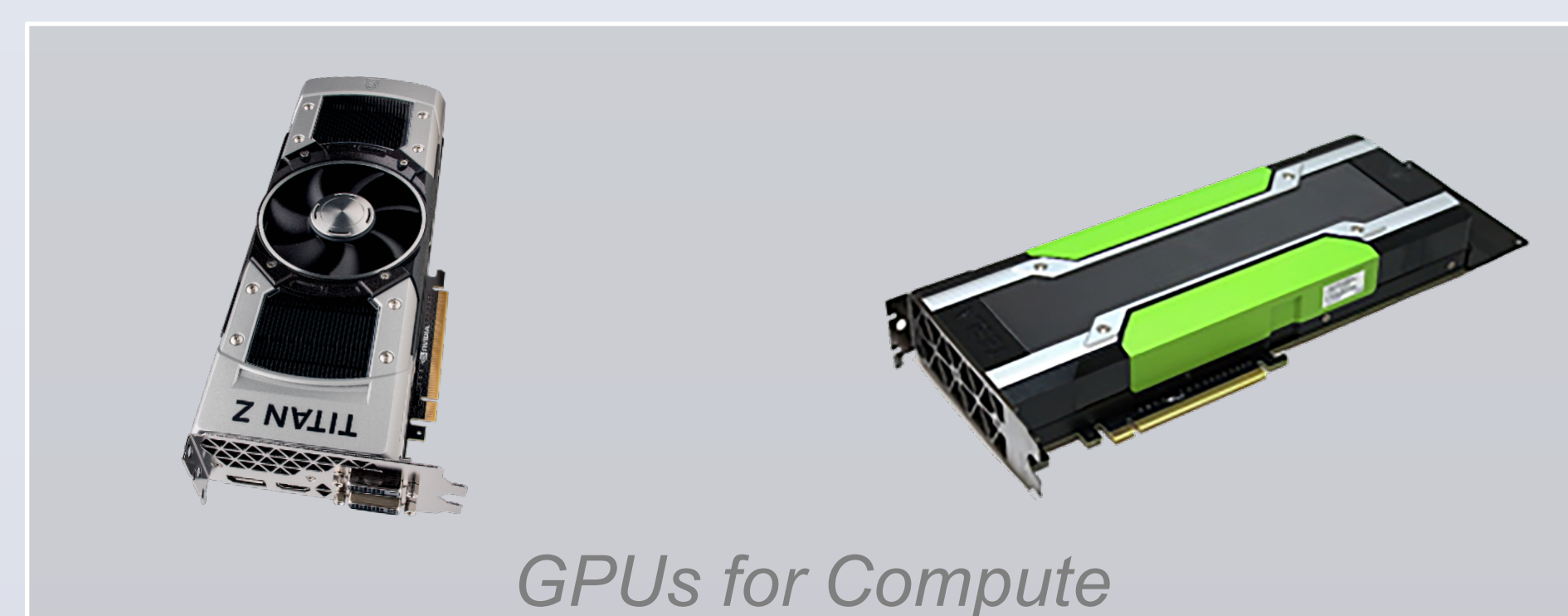
### Discrete Geometry Representation for Computer-Aided Manufacturing

- 3D Pixels
- Alternative to B-rep or CSG



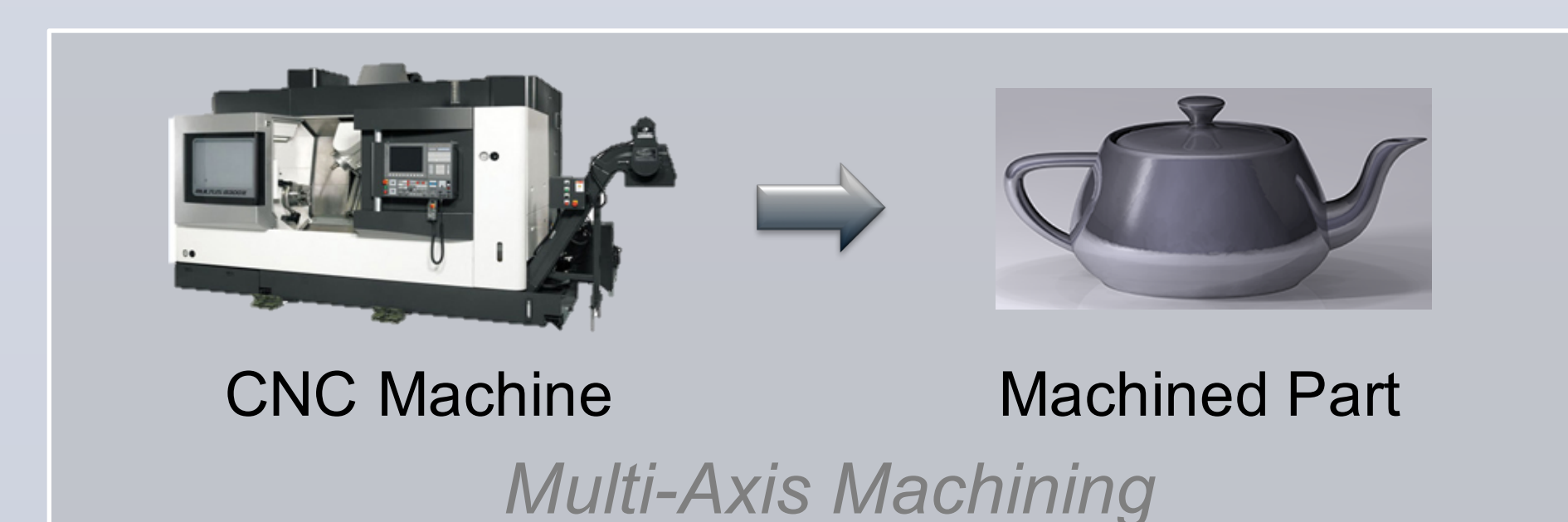
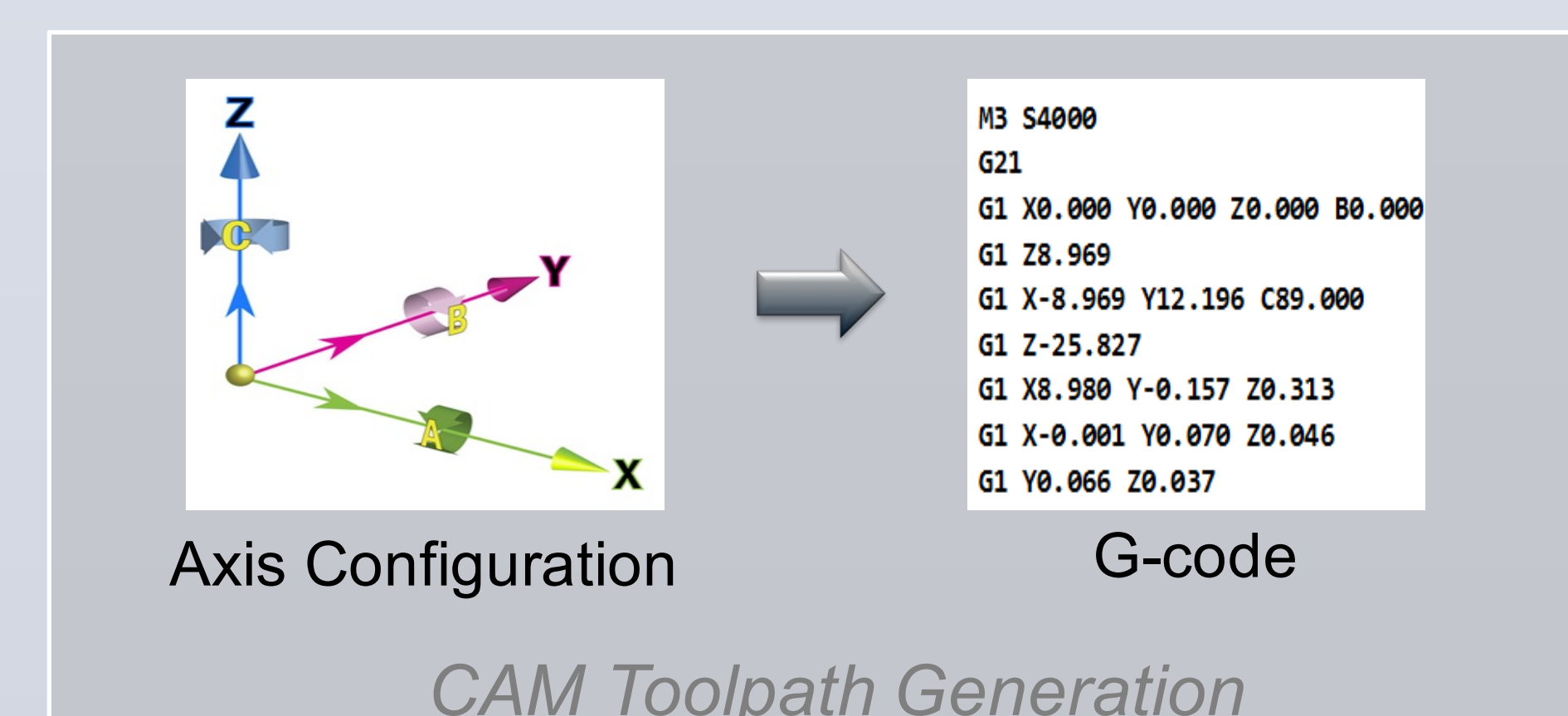
### Parallel Processing

- Use of high performance computing (HPC) with GPUs to accelerate operations on voxel model
- GPGPU for sparse 3D matrices



### Toolpath Automation

- Automatic tool accessibility determination based on machine configuration
- G-Code generation

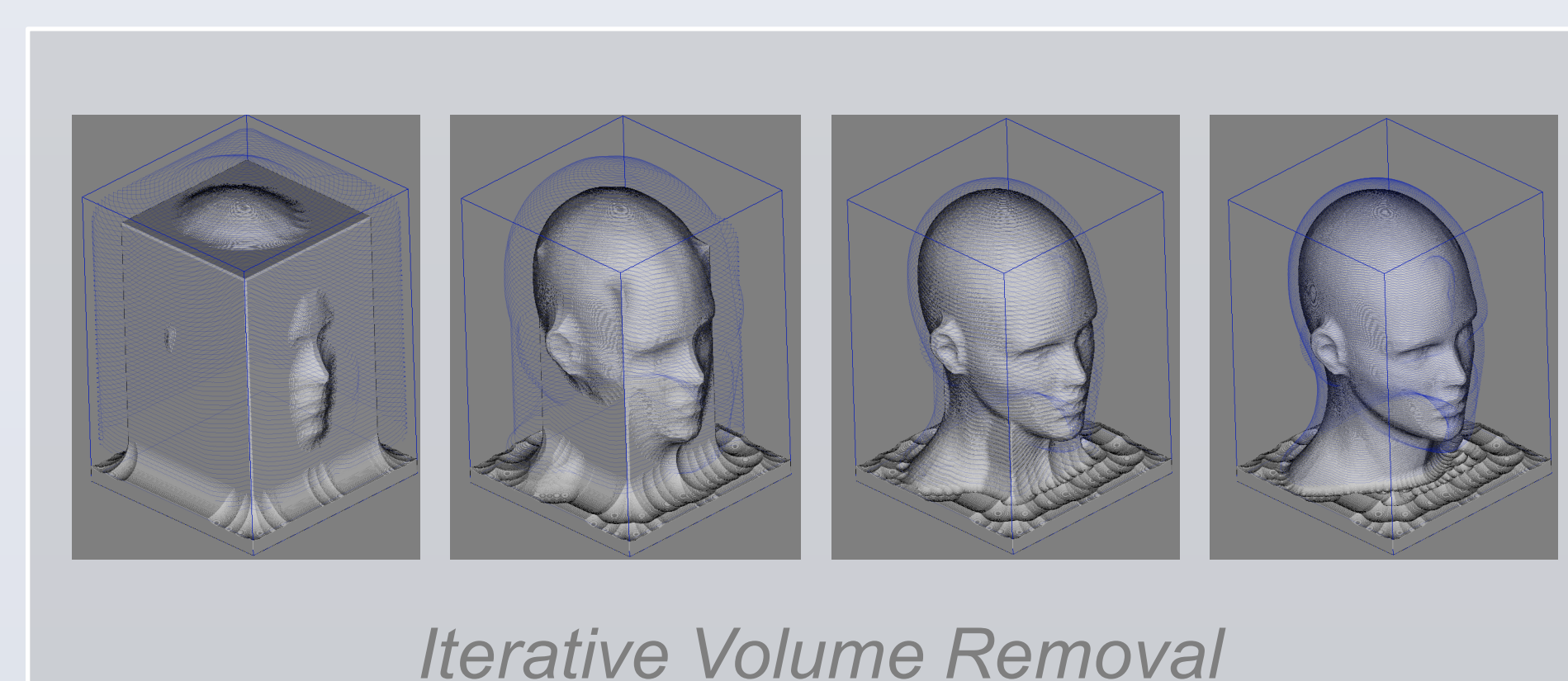
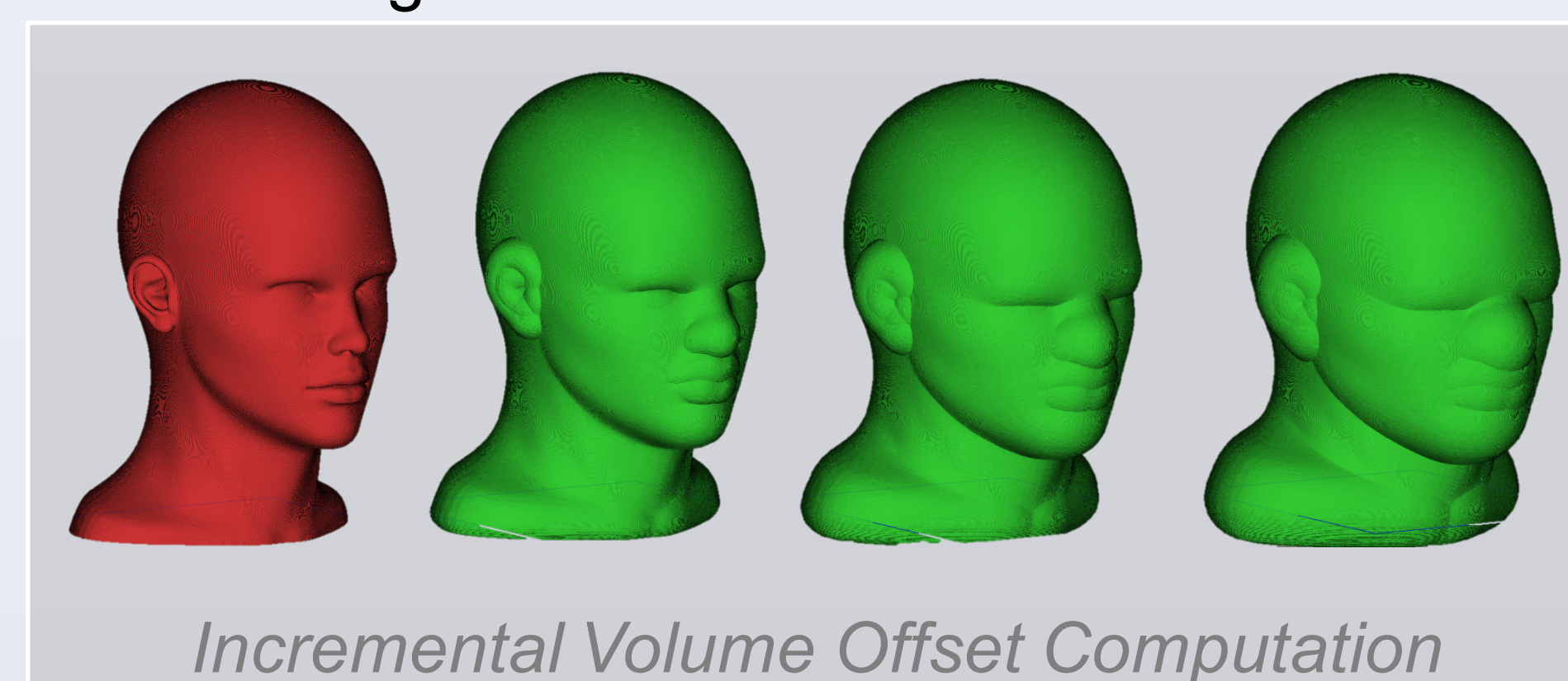


## Automation in Toolpath Planning

Offsetting and Tool Accessibility Analysis

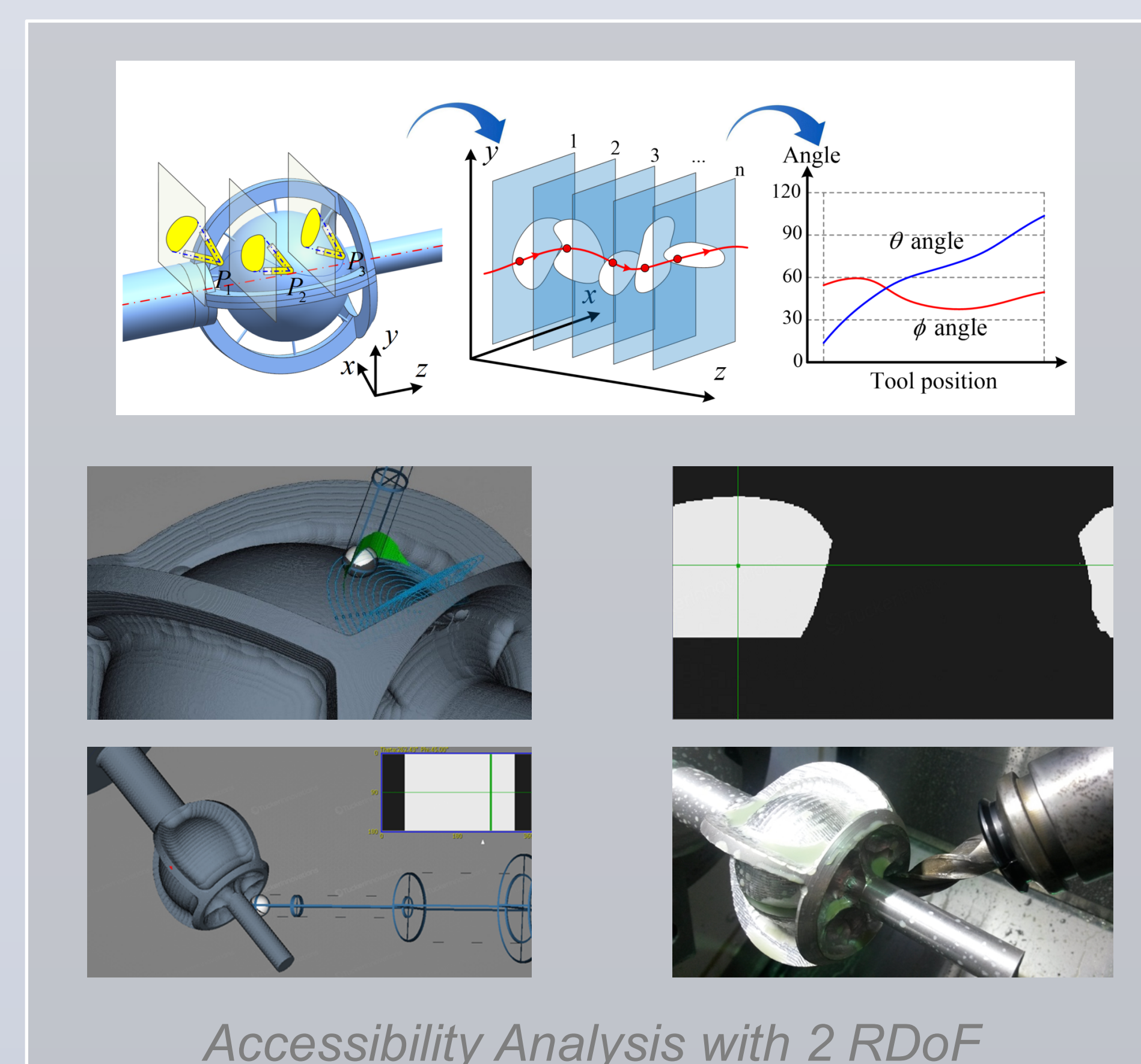
### Contact Volume Generation

- Discrete surface offsetting using CUDA
- Contact volumes provide the surfaces where a tool of a certain radius can reside without cutting too deeply
- Successive offsets provide XYZ points for the cutting tool



### Tool Accessibility Analysis

- A tool positioned on the offset volume must assume an orientation that avoids collisions
- An "accessibility map" provides allowable orientations for the tool.
- Stacked in sequence, the accessibility maps form an accessibility space.

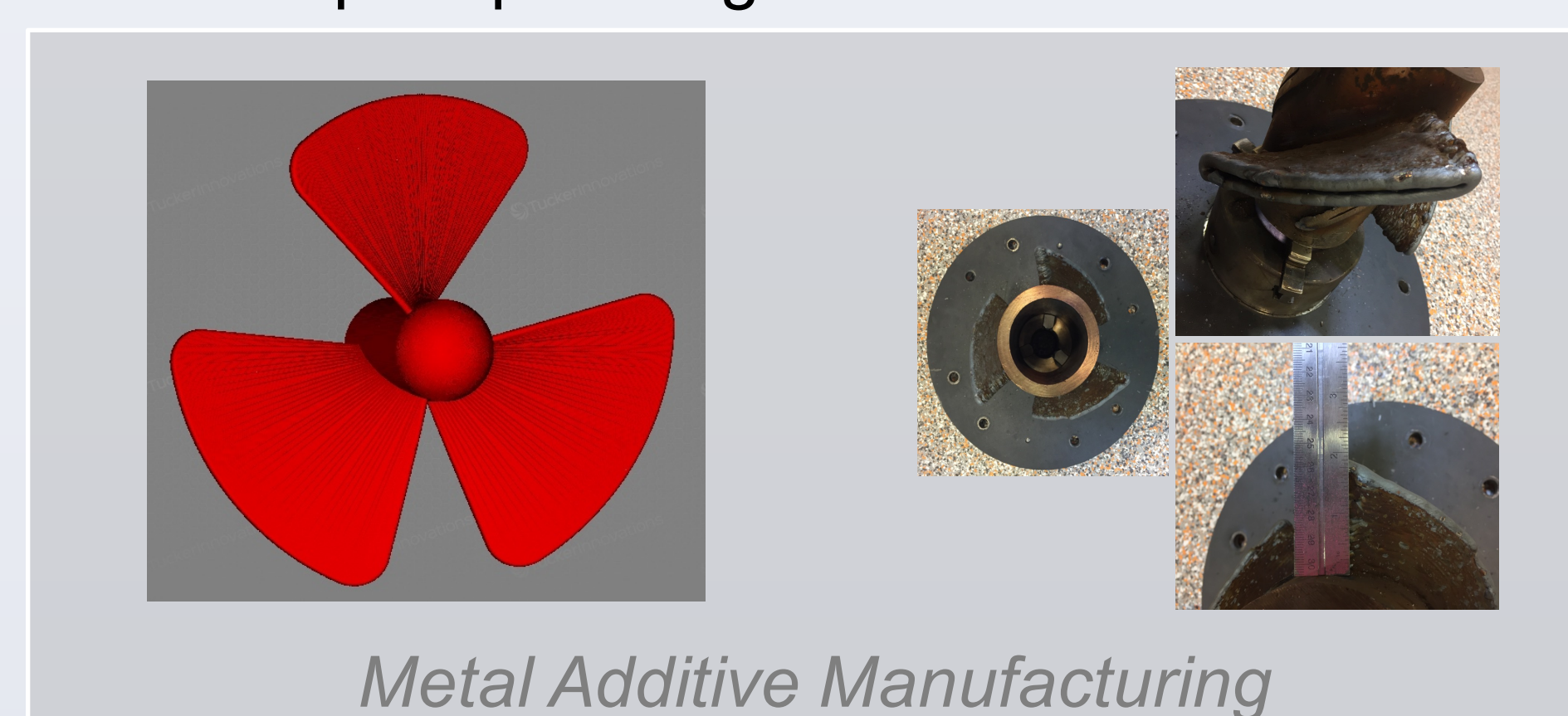


## Multi-Process Capability and Advanced CAM Functionality

Hybrid Manufacturing, Reverse Engineering and Process Analysis

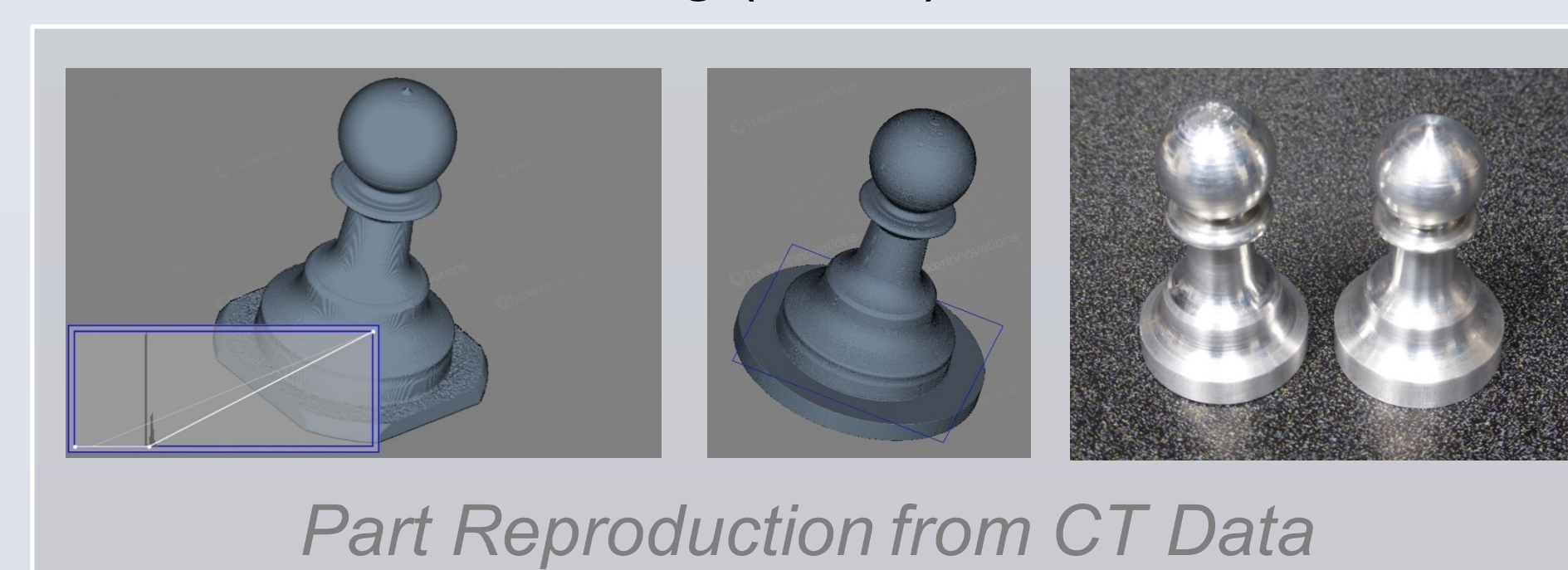
### Additive, Subtractive and Hybrid Manufacturing Operations

- CNC machining complements low resolution steel deposition
- Addresses gap in nonplanar deposition toolpath planning



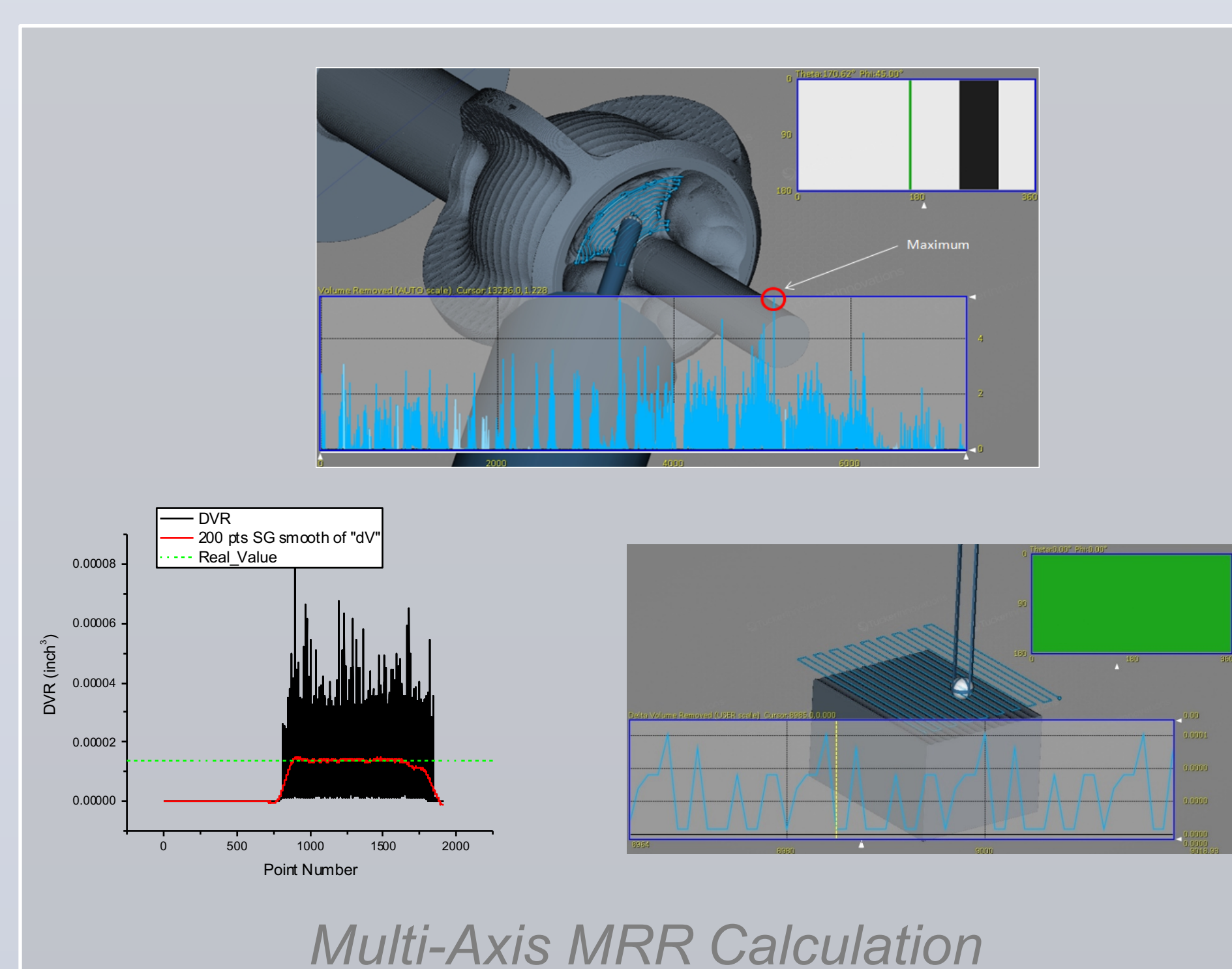
### Micro Computed Tomography X-Ray Scanning

- Volumetric scanning to voxel model
- SculptPrint toolpath generation for additive or subtractive manufacturing
- No CAD model needed to fabricate part: model-free manufacturing (MFM)



### Discrete Material Removal Rate (MRR) Analysis and Optimization

- Sum of voxels over time
- Digital filtering and validation

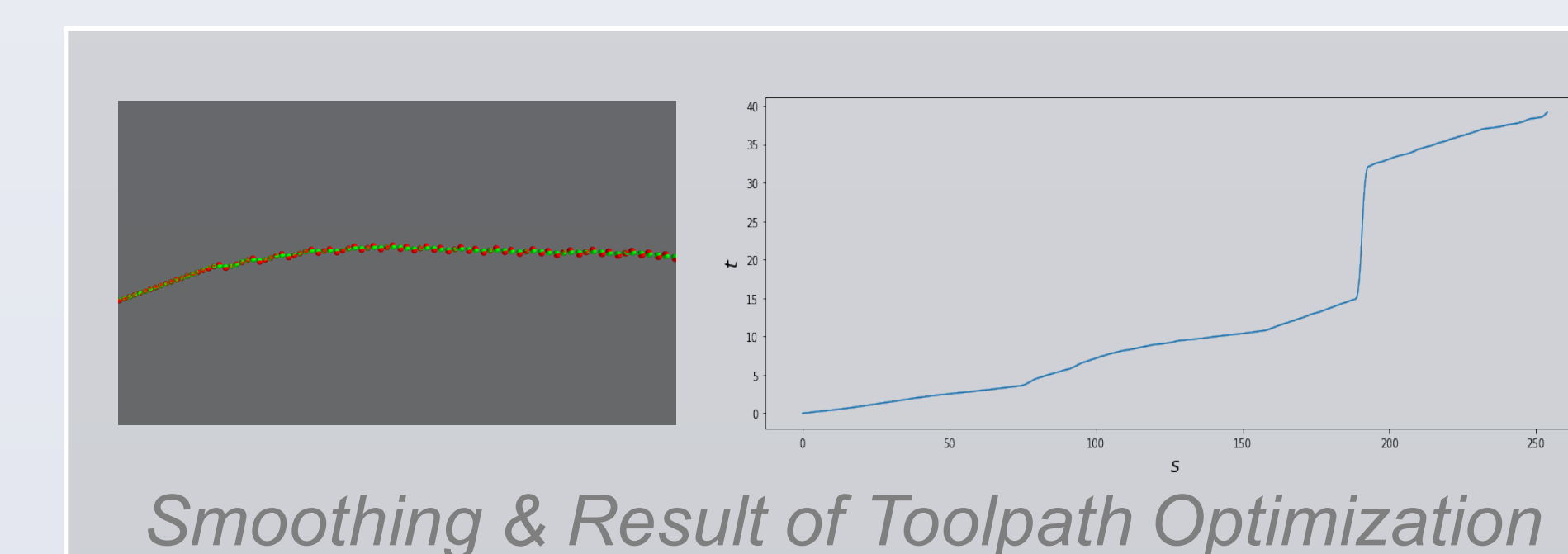


## Trajectory Planning

Dynamic Modeling of Machine Motion for Cutting Time Reduction

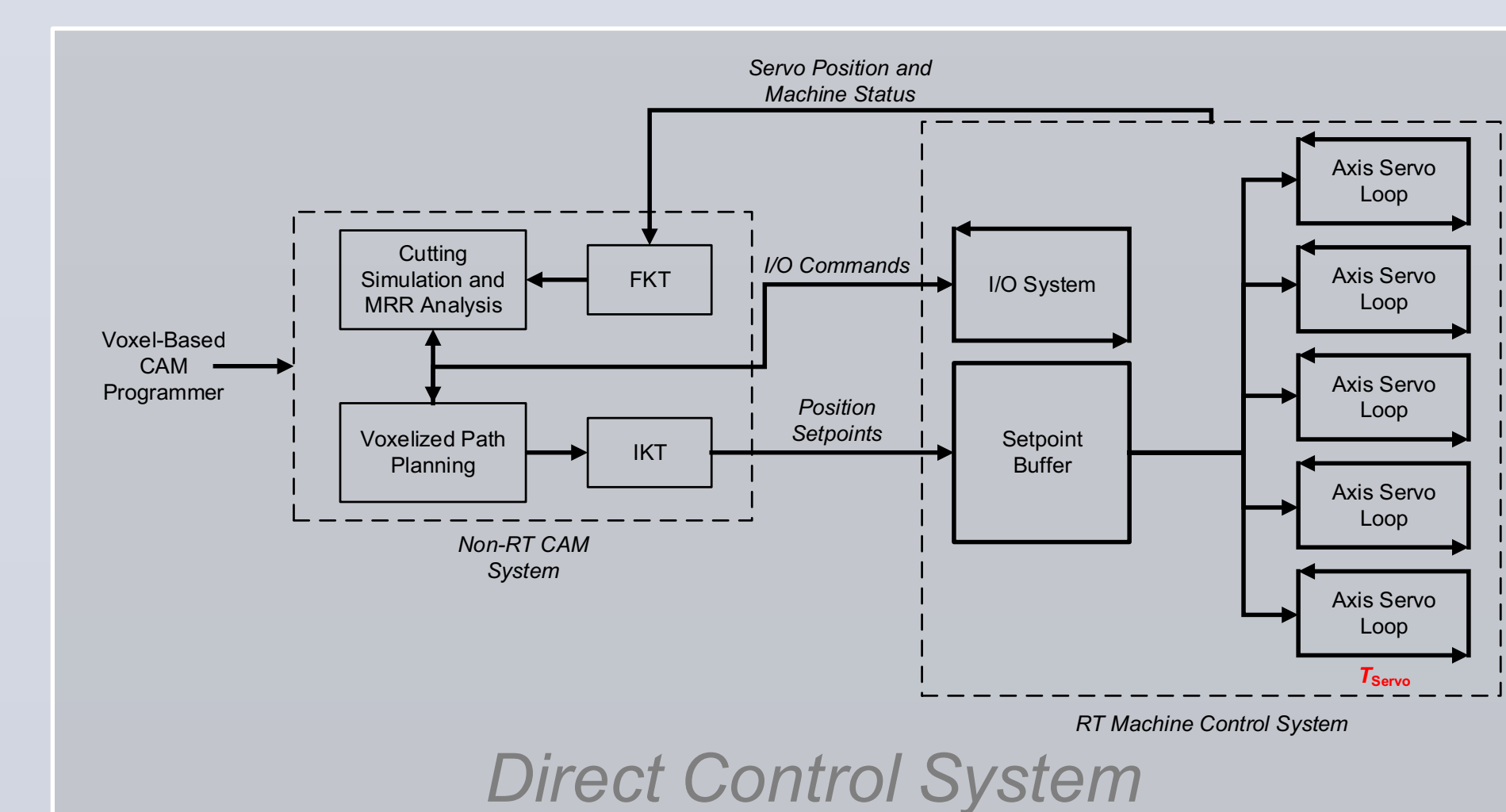
### Toolpath Optimization

- Discrete position samples converted to motion (time parameterized paths) using B-Splines
- Travel time minimization, subject to material removal and machine kinematic constraints
- Smoothing of angular positions in accessible space
- s and t values give improvement comparison for original and optimized path



### Open-Source 5-Axis CNC Development

- Modification of Machinekit for direct read and write of servo loop feedback and setpoint
- Instrumentation of machine tool
- Network control of machine tool using TCP/IP
- Interactive realtime plotting in HMI



## Acknowledgements

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