

# Interactive Virtual Hands-on Manufacturing

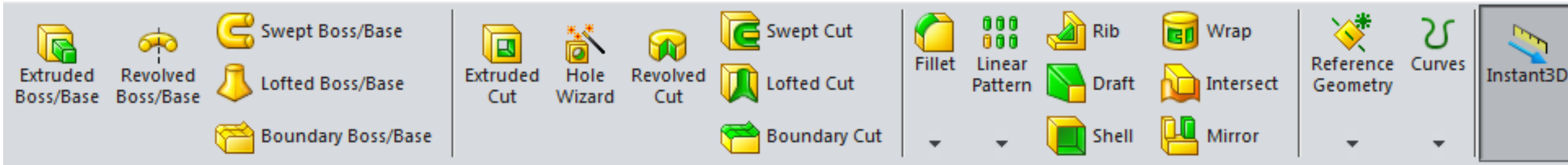
**Martin Jun<sup>1</sup> and Patrick Lee<sup>2</sup>**

<sup>1</sup>Associate Professor, Purdue University, West Lafayette, IN

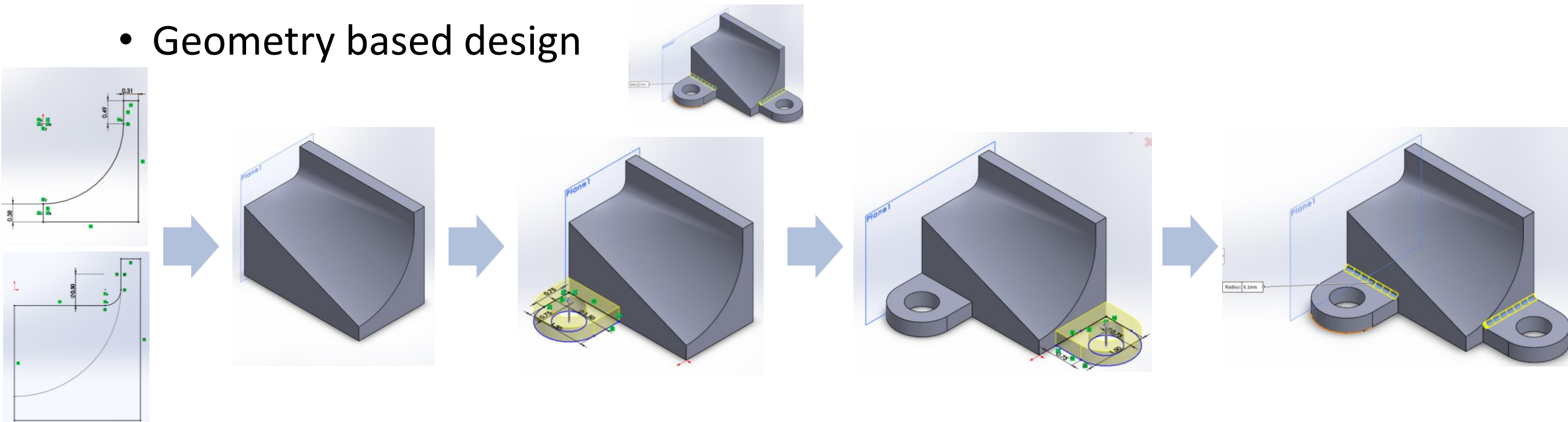
<sup>2</sup>Assistant Professor, University of Vermont, Burlington, VM

# Current CAD Software

- A series of features in sequence to represent a desired solid model

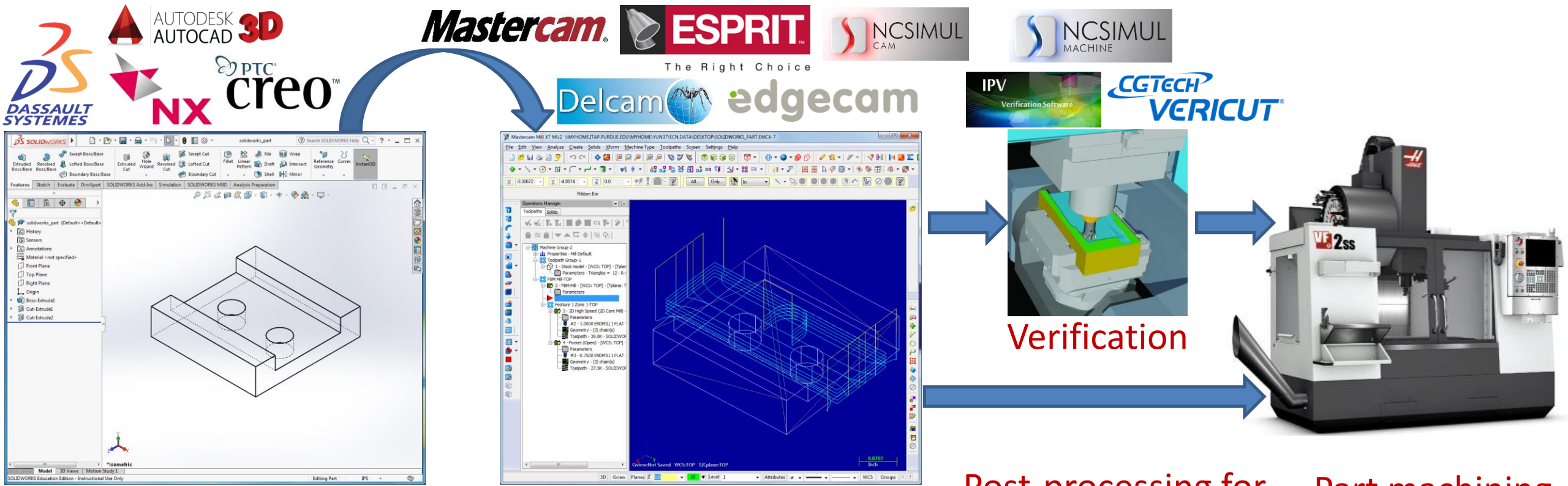


- Geometry based design



# Current Design and Manufacturing

- Current design and manufacturing approach for part generation
- Well established CAD/CAM and verification software products



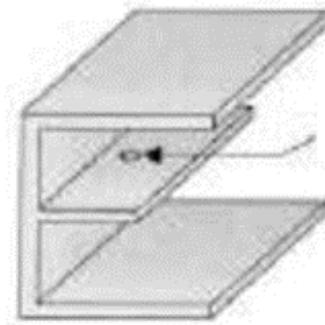
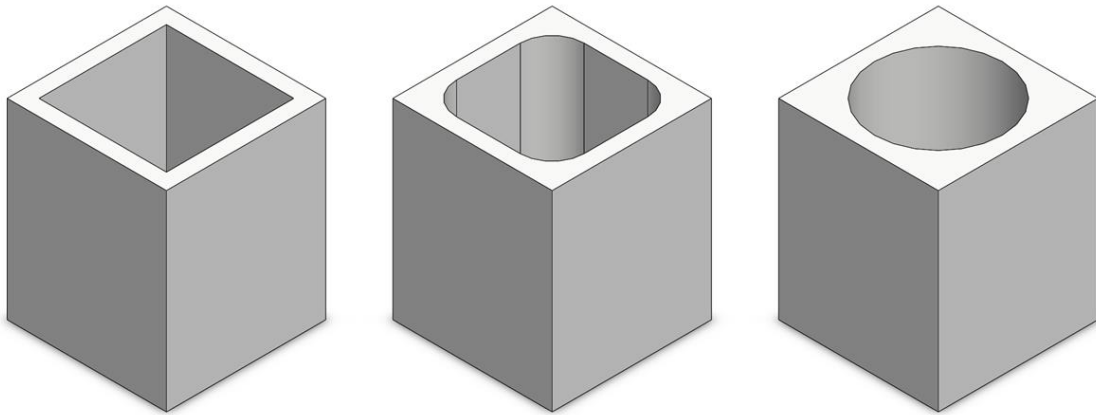
CAD

CAM

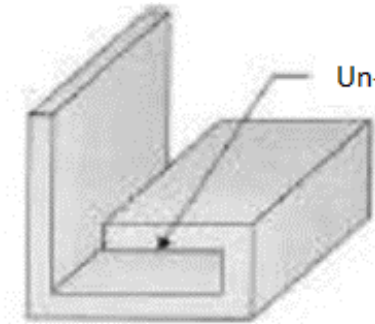
Post-processing for NC code generation

Part machining

- CAD software does not take manufacturing into consideration
- Difficult to learn design for manufacturing

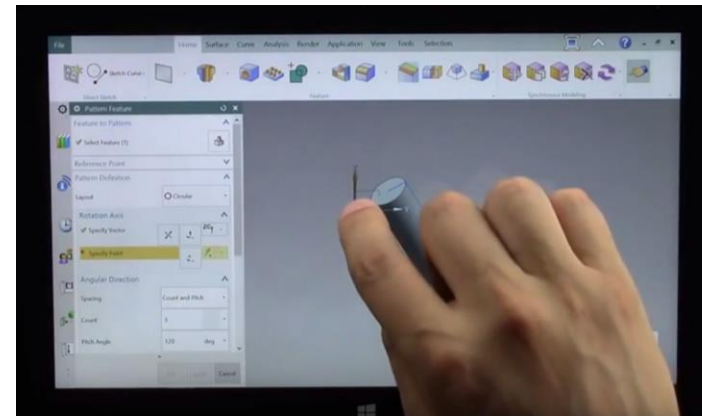
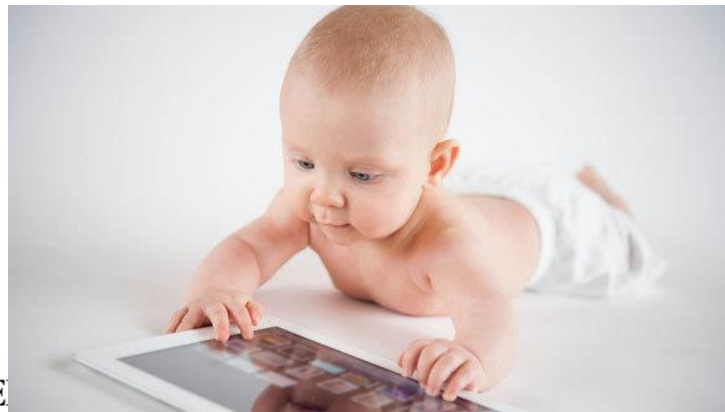


Un-drillable hole



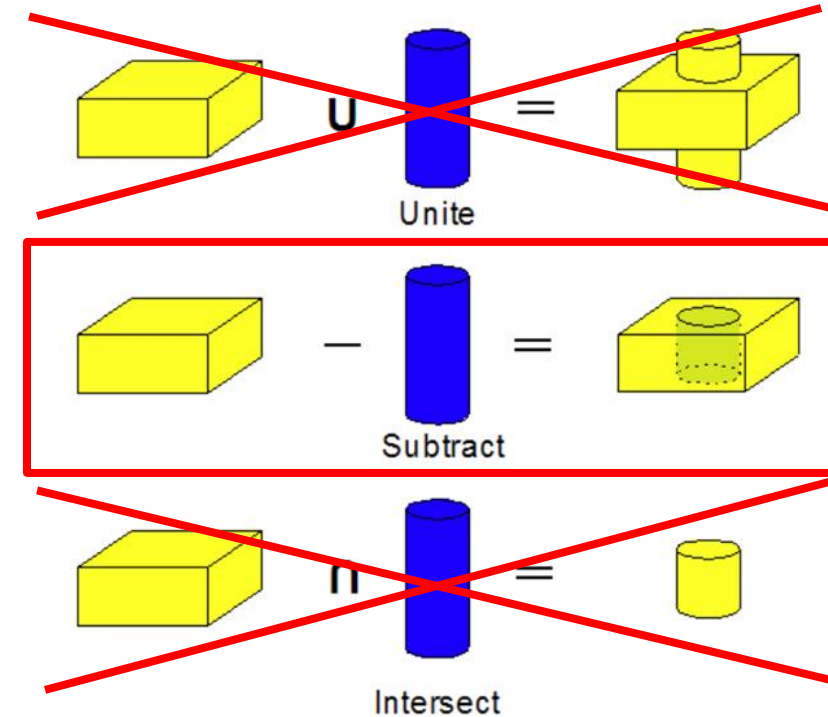
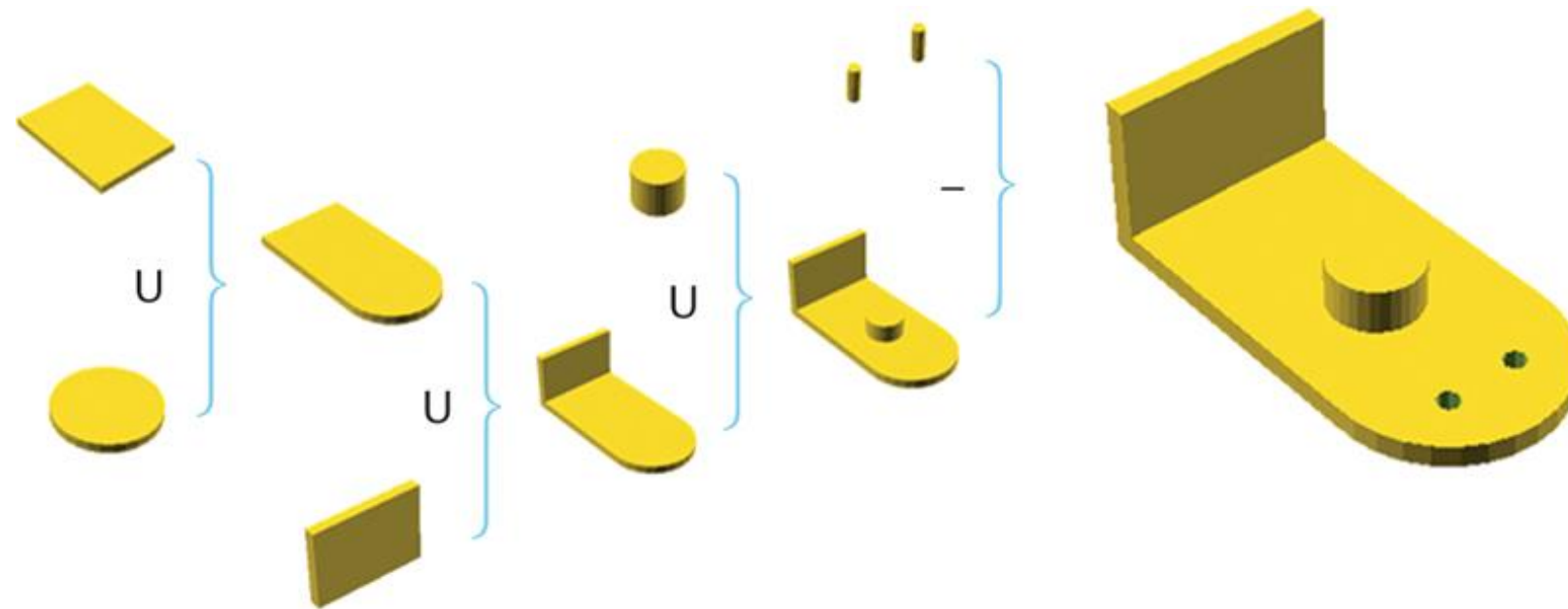
Un-machinable slot

- No environment for interactive manufacturing (not just touch capability)





- CAD software essentially uses a series of Boolean operations

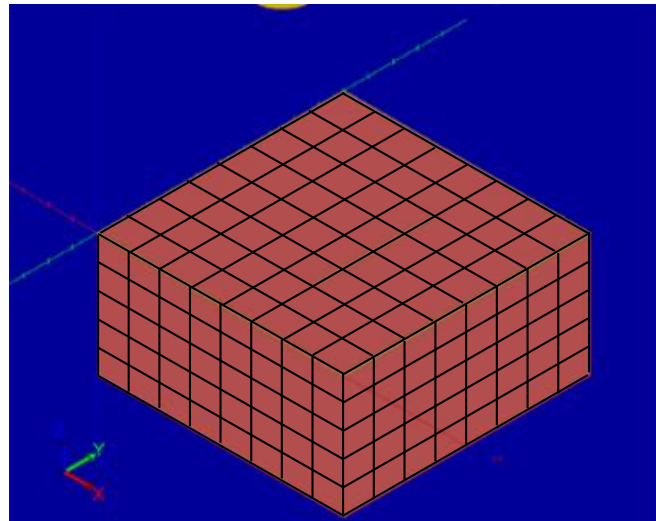


Can a part be generated using only Subtract Boolean operations?

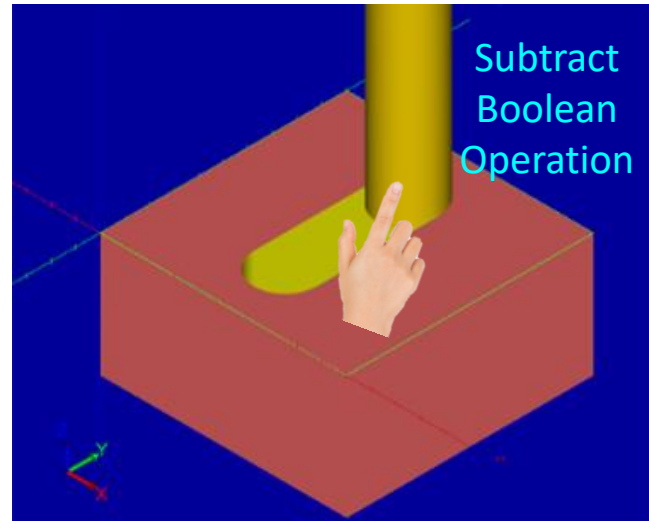
Can such Subtract Boolean operations be performed interactively by user?

# Proposed Approach

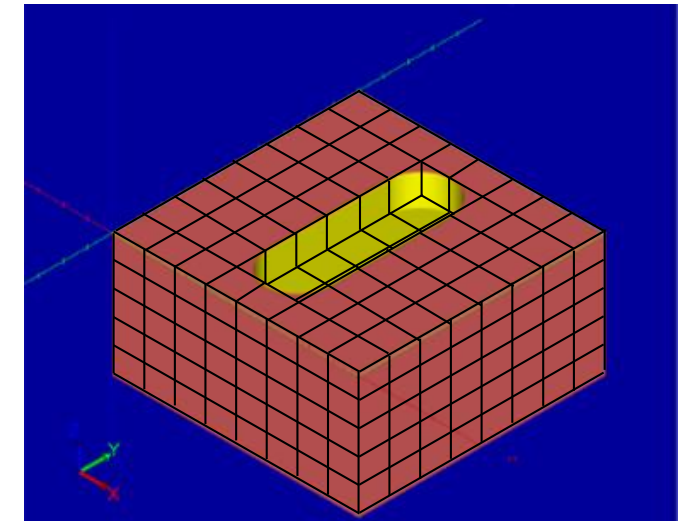
- Interactive virtual hands-on manufacturing
- Part design process is similar to manual machining process



Initial stock



Tool trajectory by user



Final design



NC code



# Software Interface Example

PURDUE UNIVERSITY  
Purdue Univ. User 1 Log out

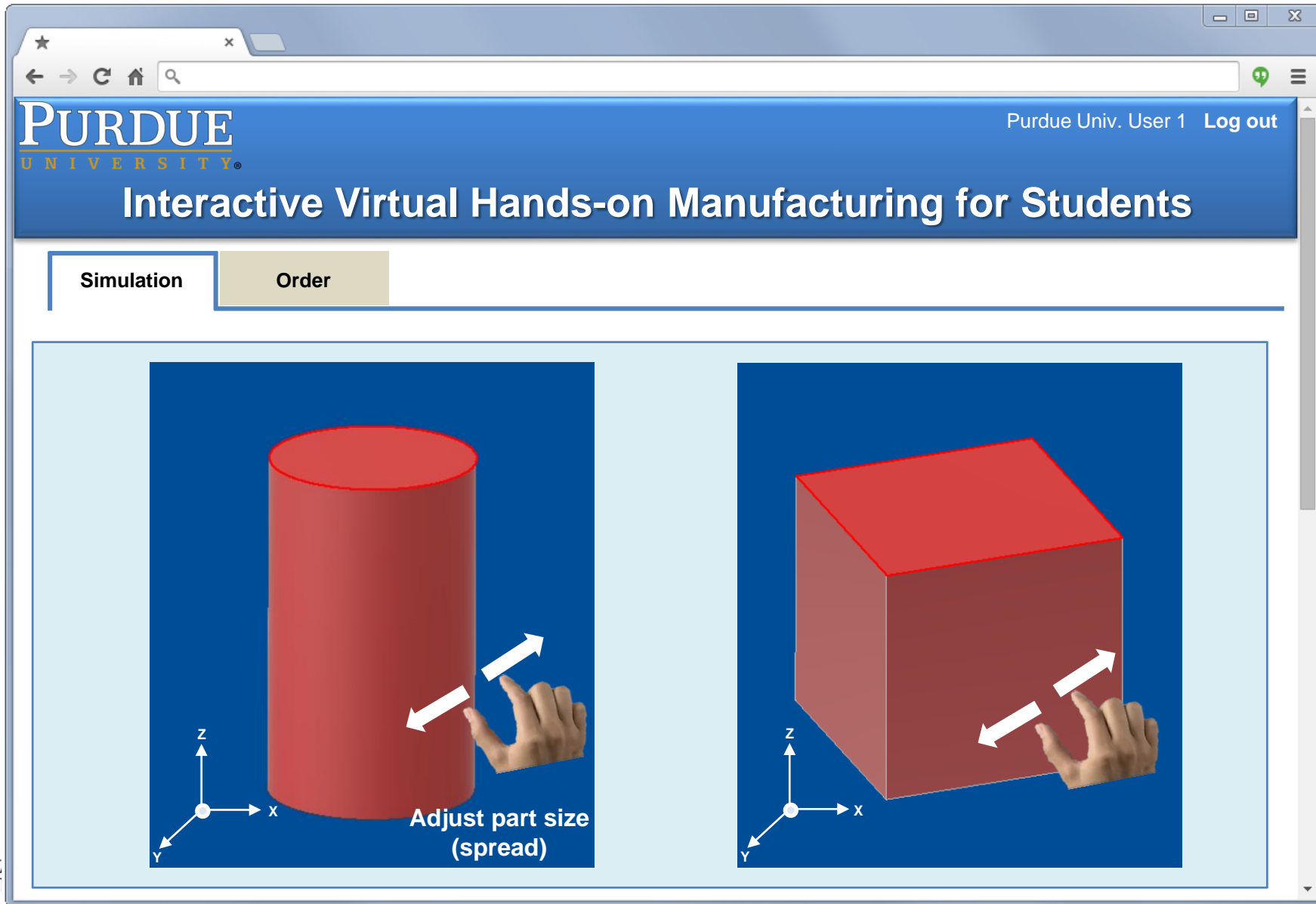
Interactive Virtual Hands-on Manufacturing for Students

Simulation Order

Cylinder shape

Square shape

# Software Interface Example





# Software Interface Example

The screenshot shows a web browser window displaying the Purdue University website. The page title is "Interactive Virtual Hands-on Manufacturing for Students". The user is logged in as "Purdue Univ. User 1".

The main interface is divided into several sections:

- Navigation:** "Simulation" (active) and "Order" tabs.
- Motion Control:** A 3D coordinate system (X, Y, Z) is shown. Below it are three sliders for X, Y, and Z movement, with values 09.30, 12.70, and 01.50 respectively.
- Shape Selection:** A "Shape" panel shows two yellow rectangular bars, one of which is highlighted with a red dashed box.
- 3D Workspace:** A red cube is shown with a green cylinder on top. A "Ref. axis" is indicated by a dashed line pointing to the cylinder's vertical axis.
- Position Data:** A box displays "Position X: 09.30, Y: 12.70, Z: 01.05".
- Subtract (Boolean):** A list of paths: "- path 1", "- path 2", "- path 3", "- path 4 (example)", and vertical dots.
- Modify:** A "Modify" button is located at the bottom right of the interface.

# Software Interface Example

The screenshot shows a web browser window displaying the Purdue University logo and the text 'PURDUE UNIVERSITY' and 'Interactive Virtual Hands-on Manufacturing for Students'. The user is logged in as 'Purdue Univ. User 1' with a 'Log out' link. Below the header, there are two tabs: 'Simulation' (selected) and 'Order'. The main interface is divided into several sections:

- Motion:** A 3D coordinate system with X, Y, and Z axes. Below it are three vertical sliders for X, Y, and Z. The X slider is at 00.00, the Y slider is labeled 'Hold', and the Z slider is at 00.30.
- Shape:** Two 3D models of a rectangular block. The second model is highlighted with a red dashed box.
- Position:** A box displaying 'Position X: 00.00 Z: 00.30'.
- Subtract (Boolean):** A list of paths: '- path 1', '- path 2', '- path 3', '- path 4 (example)', and three vertical dots. A 'Modify' button is located at the bottom right of this section.

In the center, a 3D visualization shows a red cylindrical object being cut by a yellow tool. Dotted lines indicate the X and Z axes relative to the tool's position.

# Operation Example: Straight Line

PURDUE UNIVERSITY

Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

Simulation Order

**Motion**

Z  
Y X

X Y Z

HOLD HOLD 00.00

**Shape**

Position  
X: 09.30  
Y: 12.70  
Z: 01.05

**Subtract (Boolean)**

-

Modify

# Operation Example: Straight Line

The screenshot shows a web browser window displaying the Purdue University website. The page title is "Interactive Virtual Hands-on Manufacturing for Students". The user is logged in as "Purdue Univ. User 1".

The interface features two tabs: "Simulation" (selected) and "Order".

On the left side, there are two panels:

- Motion:** A 3D coordinate system with X, Y, and Z axes. Arrows indicate movement directions.
- Shape:** Two 3D models of a straight line tool.

In the center, there are three vertical sliders for X, Y, and Z movement, each with a "HOLD" button. The Z slider is currently set to 02.50.

Below the sliders, the current position is displayed:

Position  
X: 09.30  
Y: 12.70  
Z: -1.10

The main simulation area consists of four views of a yellow tool cutting a red block:

- Top-left: 3D perspective view of the tool cutting the block.
- Top-right: Top-down view of the tool cutting the block.
- Bottom-left: Side view of the tool cutting the block.
- Bottom-right: Front view of the tool cutting the block.

On the right side, there is a panel titled "Subtract (Boolean)" with a text input field containing "- Path 1" and a "Modify" button.



# Operation Example: Straight Line

**PURDUE UNIVERSITY** Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

**Simulation** | **Order**

**Motion**

**Shape**

X Y Z

HOLD HOLD 02.50

**Position**  
X: 09.30  
Y: 12.70  
Z: -1.10

**Subtract (Boolean)**

- Path 1

**Modify**

# Operation Example: Straight Line

**PURDUE UNIVERSITY** Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

**Simulation** | **Order**

**Motion**

**Shape**

X Y Z

HOLD HOLD 02.50

**Subtract (Boolean)**

- Path 1

**Modify**

**Position**  
X: 09.30  
Y: 16.70  
Z: -1.10

# Operation Example: Curved Line

**PURDUE UNIVERSITY** Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

**Simulation** | Order

**Motion**

**Shape**

X Y Z

HOLD HOLD 00.00

Position  
X: 5.30  
Y: 9.70  
Z: 2.10

**Subtract (Boolean)**

-

**Modify**

# Operation Example: Curved Line

**PURDUE UNIVERSITY** Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

**Simulation** | **Order**

**Motion**

**Shape**

X Y Z

HOLD HOLD 00.00

**Position**  
X: 5.30  
Y: 9.70  
Z: -1.50

**Subtract (Boolean)**

- Path 1

**Modify**



# Operation Example: Curved Line

**PURDUE UNIVERSITY** Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

**Simulation** | Order

**Motion**

**Shape**

X Y Z

HOLD HOLD 03.00

**Position**  
X: 5.50  
Y: 9.90  
Z: -1.50

**Subtract (Boolean)**

- Path 1

**Modify**

# Operation Example: Curved Line

**PURDUE UNIVERSITY** Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

**Simulation** | Order

**Motion**

**Shape**

X Y Z

HOLD HOLD 03.00

Position  
X: 5.90  
Y: 11.90  
Z: -1.50

**Subtract (Boolean)**

- Path 1

**Modify**

# Operation Example: Curved Line

The screenshot shows a web browser window displaying the Purdue University website. The page title is "Interactive Virtual Hands-on Manufacturing for Students". The user is logged in as "Purdue Univ. User 1".

The interface features two tabs: "Simulation" (selected) and "Order".

**Motion Controls:** A 3D coordinate system (X, Y, Z) is shown. Below it are three vertical sliders for X, Y, and Z. The Z slider is currently set to 03.00. The X and Y sliders are labeled "HOLD".

**Shape Selection:** Two curved line shapes are displayed in a light green box.

**Position:** The current position is displayed as:  
 X: 7.90  
 Y: 14.90  
 Z: -1.50

**Simulation Area:** A 2x2 grid of views shows a yellow curved line being milled into a red block. The top-left view is a 3D perspective. The top-right view is a top-down view. The bottom-left view is a side view. The bottom-right view is a zoomed-in view of the curved line being milled.

**Boolean Operation:** A "Subtract (Boolean)" panel on the right shows "- Path 1" selected. A "Modify" button is at the bottom of this panel.

# Operation Example: Curved Line

**PURDUE UNIVERSITY** Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

**Simulation** | Order

**Motion**

**Shape**

X Y Z

HOLD HOLD 03.00

**Position**  
X: 9.40  
Y: 17.90  
Z: -1.50

**Subtract (Boolean)**

- Path 1

Modify



# Operation Example: Curved Line

The screenshot shows a web browser window displaying the Purdue University website. The page title is "Interactive Virtual Hands-on Manufacturing for Students". The user is logged in as "Purdue Univ. User 1".

The interface features two tabs: "Simulation" (selected) and "Order". The main simulation area is divided into several sections:

- Motion:** A 3D coordinate system with X, Y, and Z axes. Below it are three vertical sliders for X, Y, and Z movement. The Z slider is currently set to 03.00. The X and Y sliders are labeled "HOLD".
- Shape:** Two 3D models of curved lines, one straight and one curved.
- Position:** A text box displaying the current coordinates: X: 9.40, Y: 17.90, Z: 0.50.
- Operation View:** A 2x2 grid of views showing a yellow curved line being cut into a red block. The top-left view is a perspective view. The top-right view is a top-down view. The bottom-left view is a side view. The bottom-right view is a magnified view of the cutting process.
- Boolean Operation:** A section on the right titled "Subtract (Boolean)" with a dropdown menu showing "- Path 1".
- Modify:** A button at the bottom right of the Boolean section.

# Operation Example: Freeform

PURDUE UNIVERSITY

Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

Simulation Order

**Motion**

**Shape**

X Y Z

HOLD HOLD 00.00

**Subtract (Boolean)**

-

Modify

Position  
X: 3.40  
Y: -3.90  
Z: 1.50

# Operation Example: Freeform

PURDUE UNIVERSITY

Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

Simulation Order

**Motion**

Z  
Y X

X Y Z

HOLD HOLD 01.50

**Shape**

**Position**  
X: 3.40  
Y: -3.90  
Z: -0.50

**Subtract (Boolean)**

-

Modify

# Operation Example: Freeform

**PURDUE UNIVERSITY** Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

**Simulation** | **Order**

**Motion**

**Shape**

X Y Z

HOLD HOLD 03.00

**Position**  
X: 4.20  
Y: 0.40  
Z: -1.10

**Subtract (Boolean)**

- Path 1

**Modify**

# Operation Example: Freeform

**PURDUE UNIVERSITY** Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

**Simulation** | **Order**

**Motion**

**Shape**

X Y Z

HOLD HOLD 09.00

**Position**  
X: 6.50  
Y: 5.20  
Z: -3.70

**Subtract (Boolean)**

- Path 1

**Modify**

# Operation Example: Freeform

PURDUE UNIVERSITY

Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

Simulation Order

**Motion**

Z  
Y X

X Y Z

HOLD HOLD 03.00

**Shape**

Position  
X: 3.80  
Y: 9.80  
Z: -0.90

**Subtract (Boolean)**

- Path 1

Modify



# Operation Example: Freeform

**PURDUE UNIVERSITY** Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

**Simulation** | Order

**Motion**

**Shape**

X Y Z

HOLD HOLD 01.50

Position  
X: 2.70  
Y: 12.40  
Z: -0.20

**Subtract (Boolean)**

- Path 1

Modify

# Operation Example: Turning

The screenshot shows a web browser window displaying the Purdue University website for an interactive virtual manufacturing simulation. The page title is "Interactive Virtual Hands-on Manufacturing for Students". The user is logged in as "Purdue Univ. User 1".

The simulation interface is divided into several sections:

- Navigation:** "Simulation" and "Order" tabs.
- Motion Control:** A 3D coordinate system (X, Y, Z) with rotation arrows. Below it are three vertical sliders for X, Y, and Z, each with a "00.00" value and a "HOLD" button.
- Shape Selection:** Two 3D models of cylindrical shapes.
- 3D Workspace:** Four views of a red cylindrical part. The top-left view is an isometric view. The top-right view is a top-down view with a hand icon pointing to a feature. The bottom-left view is a front view showing a circular cross-section. The bottom-right view is a side view showing the cylindrical profile.
- Boolean Operations:** A panel on the right titled "Subtract (Boolean)" with a minus sign (-) in a text box and a "Modify" button at the bottom.

# Operation Example: Turning

The screenshot shows a web browser window displaying the Purdue University website for an interactive virtual manufacturing simulation. The page title is "Interactive Virtual Hands-on Manufacturing for Students". The user is logged in as "Purdue Univ. User 1".

The simulation interface is divided into several sections:

- Navigation:** "Simulation" and "Order" tabs.
- Motion Control:** A 3D coordinate system (X, Y, Z) with rotation arrows. Below it are three sliders for X, Y, and Z movement, with values 08.00, 01.50, and HOLD respectively.
- Shape Selection:** Two 3D models of cylindrical shapes.
- 3D View Area:** Four perspective views of a yellow and red cylindrical part. The top-right view shows a hand interacting with the part, and a blue arrow indicates a cutting path.
- Boolean Operations:** A panel on the right titled "Subtract (Boolean)" with a dropdown menu showing "- Path 1" and a "Modify" button.

# Operation Example: Turning

The screenshot shows a web browser window displaying the Purdue University website. The page title is "Interactive Virtual Hands-on Manufacturing for Students". The user is logged in as "Purdue Univ. User 1". There are two tabs: "Simulation" (active) and "Order".

The simulation interface includes:

- Motion:** A 3D coordinate system with X, Y, and Z axes. Below it are three vertical sliders for X, Y, and Z, with values 00.00, 01.50, and HOLD respectively.
- Shape:** Two 3D models of a lathe tool bit.
- 3D Views:** Four panels showing different views of a yellow cylindrical workpiece being machined by a red tool bit. The top-left view is an isometric view. The top-right view shows the tool bit cutting into the cylinder. The bottom-left view is a top-down view of the cylinder. The bottom-right view is a side view of the cylinder.
- Boolean Operation:** A panel on the right titled "Subtract (Boolean)" with a dropdown menu showing "- Path 1".
- Modify:** A button at the bottom right of the Boolean panel.

# Operation Example: Turning

The screenshot shows a web browser window displaying the Purdue University website. The page title is "Interactive Virtual Hands-on Manufacturing for Students". The user is logged in as "Purdue Univ. User 1". The interface has two tabs: "Simulation" (active) and "Order".

**Motion** section includes a 3D coordinate system with X, Y, and Z axes. Below it are three sliders for X, Y, and Z movement. The X slider is set to 06.00, the Y slider to 05.50, and the Z slider is labeled "HOLD".

**Shape** section shows two brown rectangular blocks representing tool shapes.

The central area contains four 3D views of a yellow part being turned on a lathe. The top-left view is an isometric view. The top-right view shows a hand interacting with a control panel. The bottom-left view is a top-down view of the part. The bottom-right view is a side view of the part.

**Subtract (Boolean)** section contains a list of paths:

- Path 1
- Path 2
- Path 3
- Path 4
- Path 5
- Path 6
- Path 7

A "Modify" button is located at the bottom right of the interface.

# Operation Example: Turning

PURDUE UNIVERSITY

Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

Simulation Order

**Motion**

**Shape**

X Y Z

00.00 05.50 HOLD

**Subtract (Boolean)**

- Path 23
- Path 24
- Path 25
- Path 26
- Path 27

Modify



# Operation Example: Turning

PURDUE UNIVERSITY

Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

Simulation Order

**Motion**

**Shape**

X Y Z

03.00 06.00 HOLD

**Subtract (Boolean)**

- Path 23
- Path 24
- Path 25
- Path 26
- Path 27
- Path 28
- Path 29
- Path 30
- Path 31
- Path 32
- Path 33

Modify

# Operation Example: Turning

PURDUE UNIVERSITY

Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

Simulation Order

**Motion**

**Shape**

X Y Z

00.00 06.00 HOLD

**Subtract (Boolean)**

- Path 23
- Path 24
- Path 25
- Path 26
- Path 27
- Path 28
- Path 29
- Path 30
- Path 31
- Path 32
- Path 33

Modify

# Operation Example: Turning

The screenshot shows a web browser window displaying the Purdue University website for an interactive virtual manufacturing simulation. The page title is "Interactive Virtual Hands-on Manufacturing for Students". The user is logged in as "Purdue Univ. User 1".

The interface is divided into several sections:

- Navigation:** "Simulation" and "Order" tabs.
- Motion:** A 3D coordinate system (X, Y, Z) with rotation arrows and three sliders for X (04.50), Y (03.00), and Z (HOLD).
- Shape:** Two 3D models of a lathe tool bit.
- Simulation Area:** Four viewports showing the turning process:
  - Top-left: 3D perspective view of the yellow workpiece and red tool bit.
  - Top-right: Top-down view showing the tool bit cutting into the workpiece.
  - Bottom-left: Front view of the workpiece showing the circular cross-section.
  - Bottom-right: Side view of the workpiece showing the turned profile.
- Boolean Operations:** A "Subtract (Boolean)" panel with a list:
  - Path 56
  - Path 57
  - Path 58
  - Path 59
  - Path 60
- Modify:** A button at the bottom right of the Boolean panel.

# Operation Example: Turning

PURDUE UNIVERSITY

Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

Simulation Order

**Motion**

**Shape**

X Y Z

03.00 00.50 HOLD

**Subtract (Boolean)**

- Path 70
- Path 71
- Path 72
- Path 73
- Path 74
- Path 75

Modify

# Part Generation Example

PURDUE UNIVERSITY

Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

Simulation Order #0. Rectangular stock

**Motion**

**Shape**

**Subtract (Boolean)**

-

Modify

# Operation Example: Turning

The screenshot shows a web browser window displaying a Purdue University page titled "Interactive Virtual Hands-on Manufacturing for Students". The page is for a simulation titled "#1. Rough contouring".

At the top of the page, there is a navigation bar with the Purdue University logo on the left, the text "Purdue Univ. User 1" and a "Log out" link on the right, and the main title "Interactive Virtual Hands-on Manufacturing for Students" in the center.

Below the navigation bar, there are two tabs: "Simulation" (which is active) and "Order".

The main content area is divided into three vertical panels:

- Left Panel:** Contains a "Motion" section with a 3D coordinate system showing X, Y, and Z axes and arrows indicating movement. Below it is a "Shape" section with two 3D models of rectangular bars.
- Center Panel:** A large 3D visualization of a yellow workpiece being turned on a lathe. A purple cylindrical tool is positioned against the workpiece. A hand icon is shown interacting with the tool. The workpiece has a red top surface and a curved bottom surface.
- Right Panel:** Contains a "Subtract (Boolean)" section with a list of three items: "- Path 1", "- Path 2", and "- Path 3". At the bottom of this panel is a "Modify" button.



# Operation Example: Turning

PURDUE UNIVERSITY

Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

Simulation Order #2. Drilling

**Motion**

**Shape**

**Subtract (Boolean)**

- Path 1
- Path 2
- Path 3
- Path 4
- Path 5
- Path 6

Modify

# Operation Example: Turning

PURDUE UNIVERSITY

Purdue Univ. User 1 Log out

## Interactive Virtual Hands-on Manufacturing for Students

Simulation Order #3. Fine contouring

**Motion**

Z  
Y X

**Shape**

**Subtract (Boolean)**

- Path 1
- Path 2
- Path 3
- Path 4
- Path 5
- Path 6
- Path 7

Modify

# Operation Example: Turning

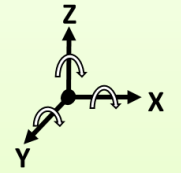
PURDUE UNIVERSITY

Purdue Univ. User 1 Log out

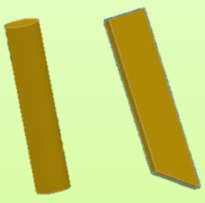
## Interactive Virtual Hands-on Manufacturing for Students

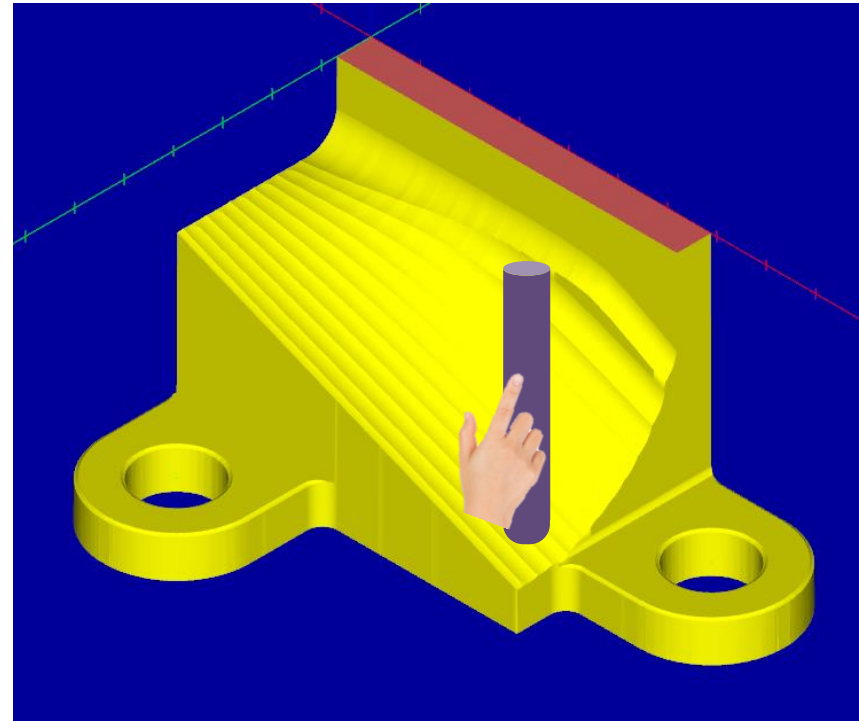
Simulation Order #4. Freeform contouring

**Motion**



**Shape**





**Subtract (Boolean)**

- Path 8
- Path 9
- Path 10
- Path 11
- Path 12
- Path 13
- Path 14
- Path 15
- Path 16
- Path 17
- Path 18
- Path 19

**Modify**

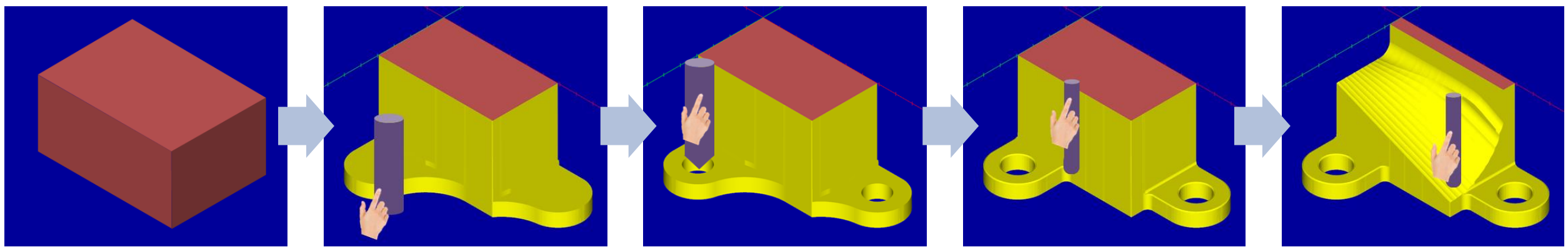
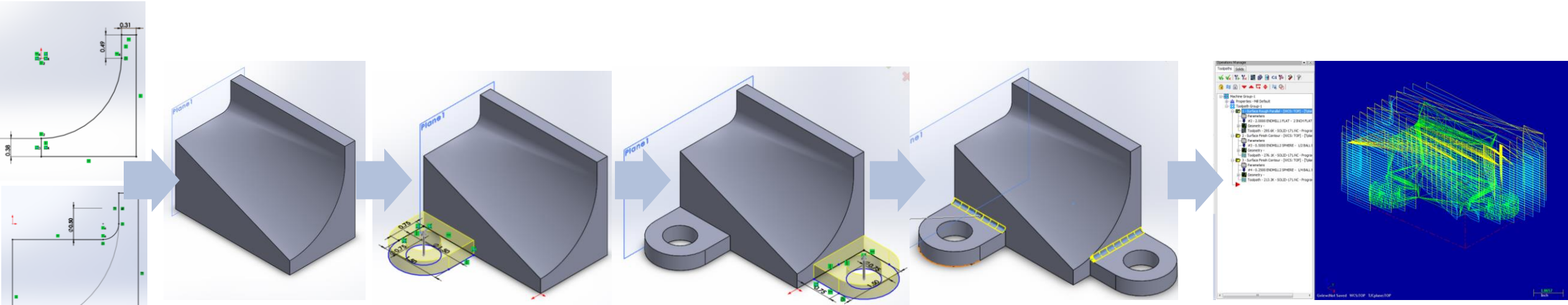
1. Select tool paths

3. Modify tool diameter (Φ3/4→1 in.)

# Operation Example: Turning

The screenshot shows a web browser window displaying a simulation interface. At the top, the Purdue University logo is on the left, and 'Purdue Univ. User 1 Log out' is on the right. The main title is 'Interactive Virtual Hands-on Manufacturing for Students'. Below this, there are two tabs: 'Simulation' (selected) and 'Order'. The current operation is '#5. Parametrization 2'. The central area shows a 3D model of a yellow part with a turning operation being performed, indicated by a red cutting tool path and a green axis. To the left, there is a 'Motion' section with a 3D coordinate system (X, Y, Z) and a 'Shape' section with two brown rectangular blocks. To the right, there is a 'Subtract (Boolean)' section with a list of paths from Path 8 to Path 19, and a 'Modify' button at the bottom.

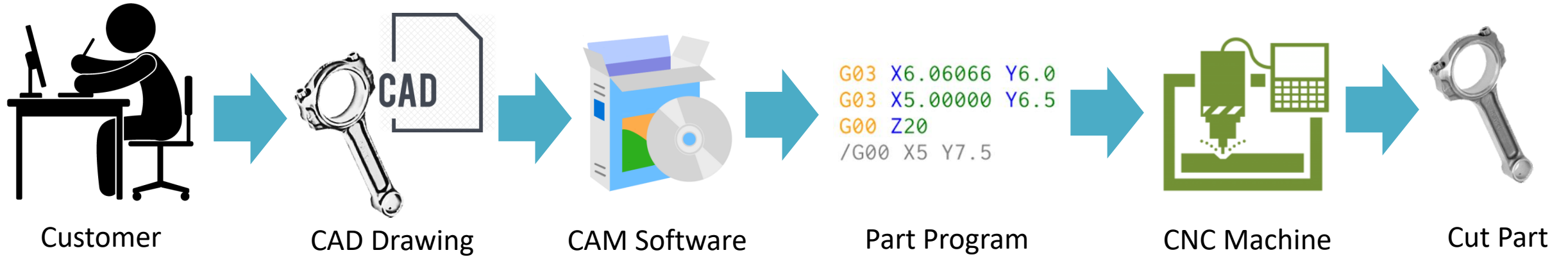
# New Approach for CAD/CAM



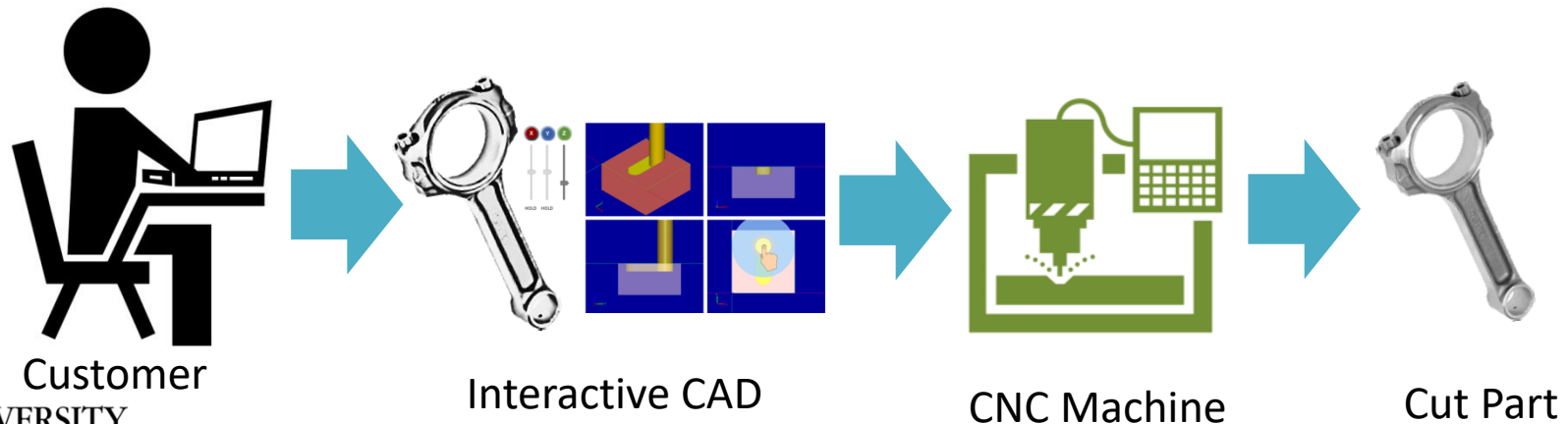


# Manufacturing Workflow

## Conventional Design-to-Manufacture Workflow

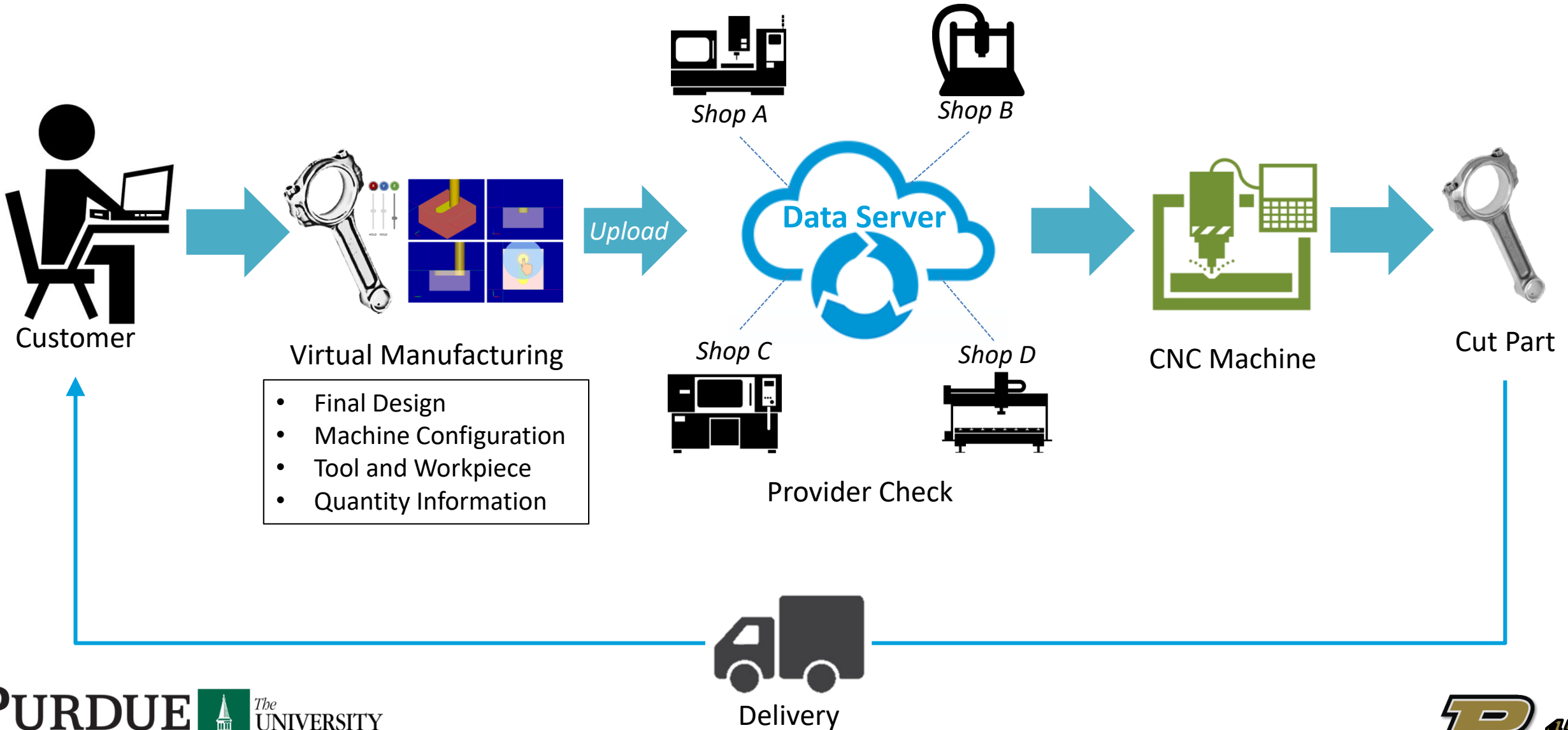


## Streamlined Virtual Manufacturing Workflow

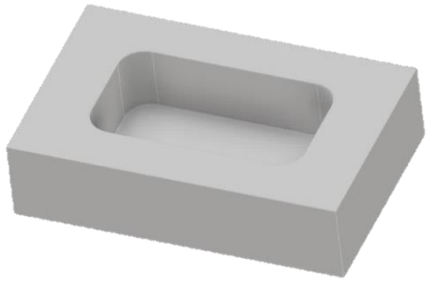




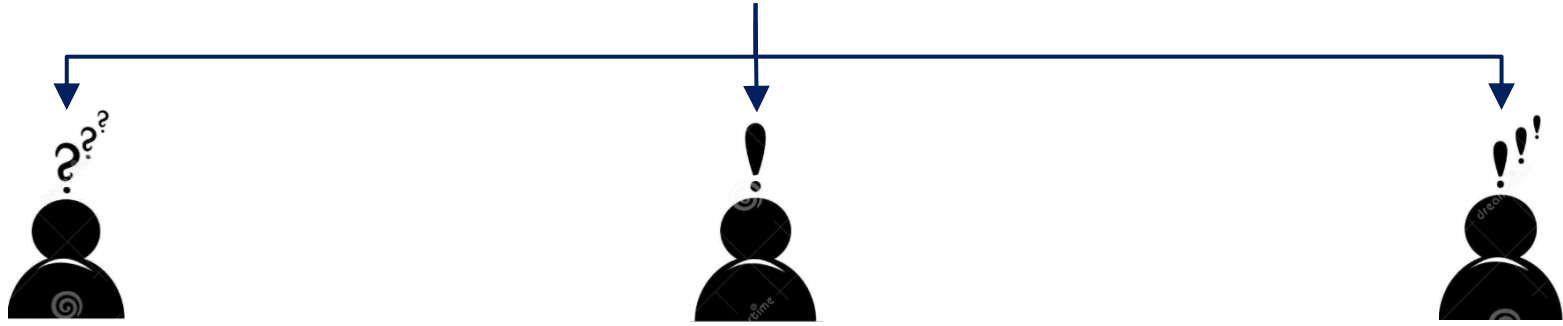
# Cybermanufacturing



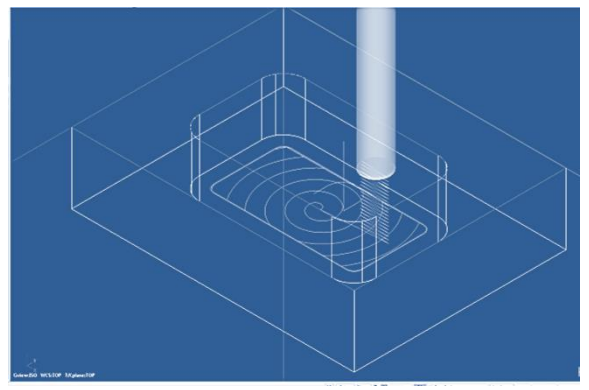
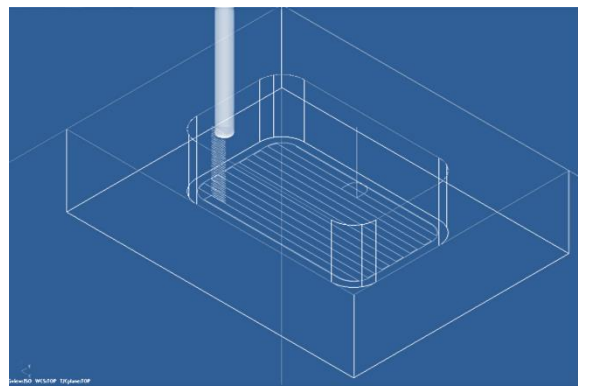
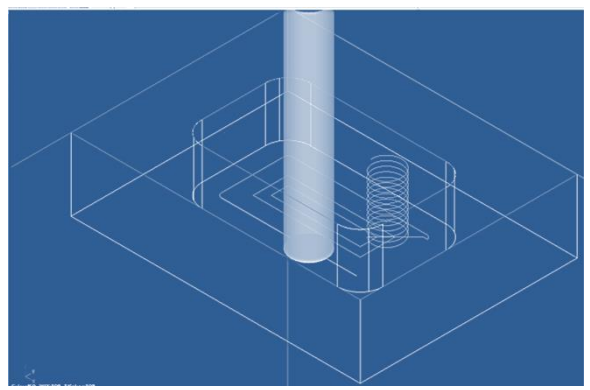
# Good Manufacturing Designer



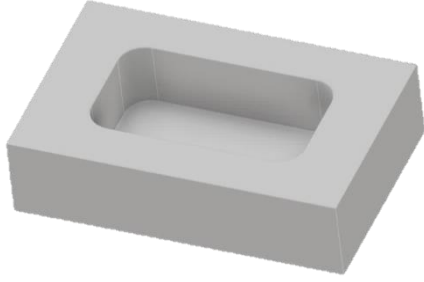
Target Part



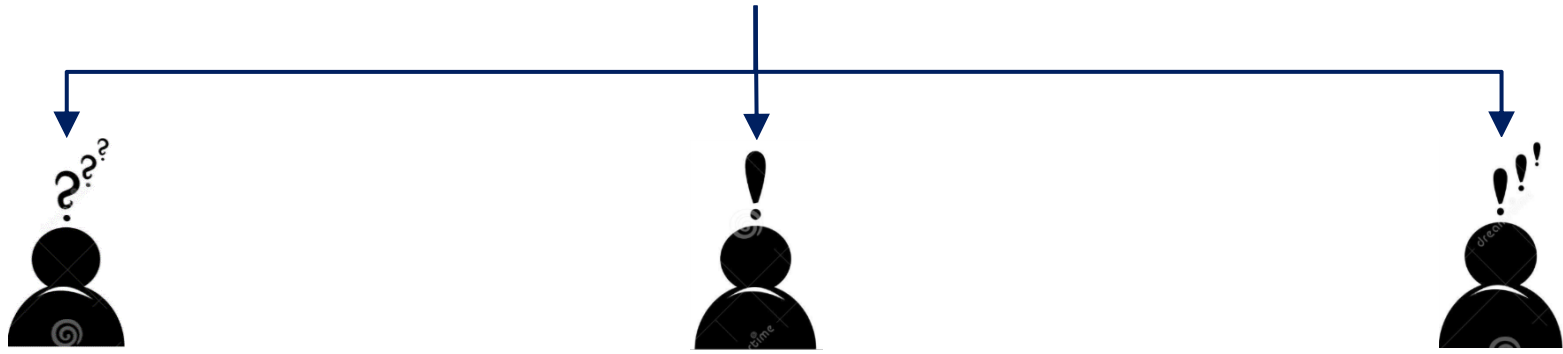
Idea for parts



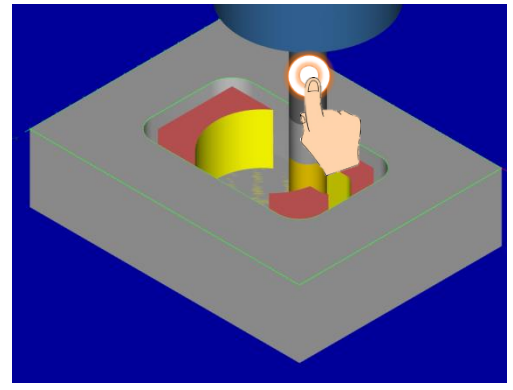
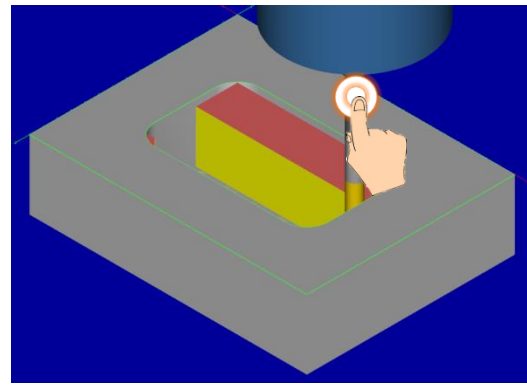
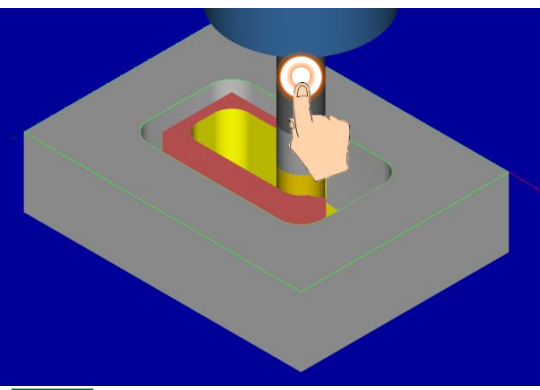
# Good Manufacturing Designer



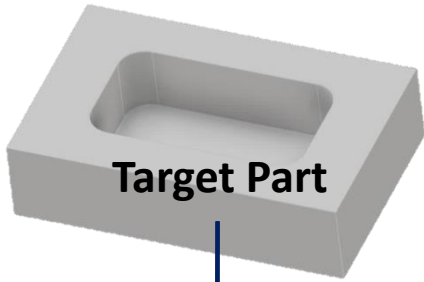
Target Part



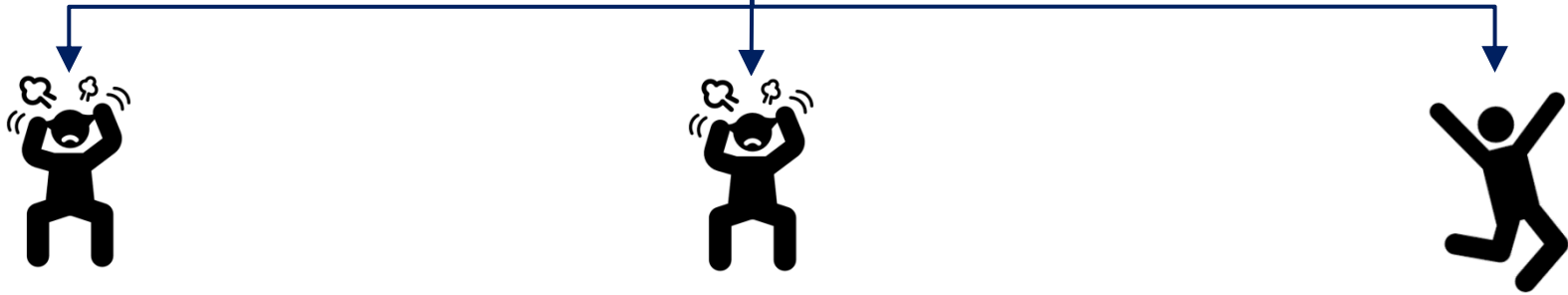
Virtual  
Manufacturing



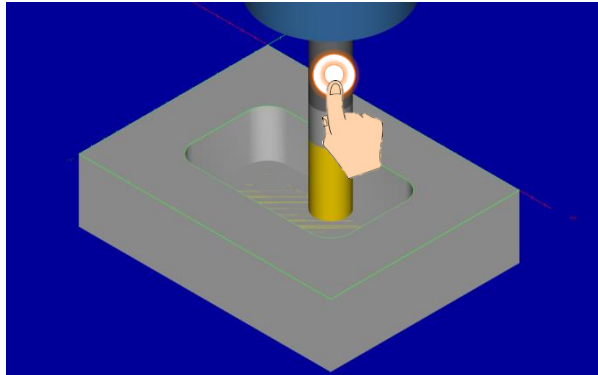
# Good Manufacturing Designer



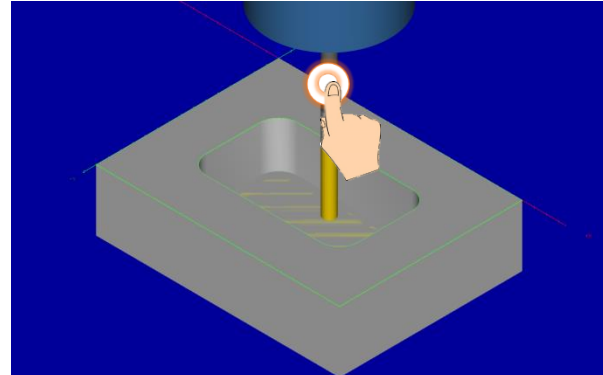
Target Part



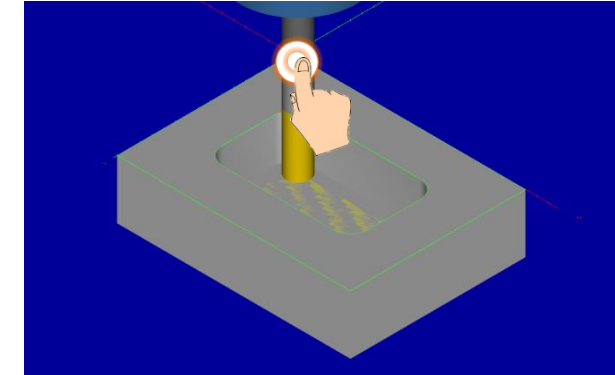
Virtual  
Manufacturing  
Results



Machining time : 39.0 sec  
Part shape : Good



Machining time : 42.3 sec  
Part shape : Normal



Machining time : 25.7 sec  
Part shape : Good

# Conclusion

- If the design process is similar to manufacturing, manufacturable parts can be readily designed
- Learning of manufacturing processes can be naturally obtained
- It provides a platform that allows innovative human inputs to manufacturing during the design process
- It can be a great tool for education and cybermanufacturing