Optimizing Electron Beam Lithography for 15-mm Metalens: A Pattern Conversion Approach using Beamer

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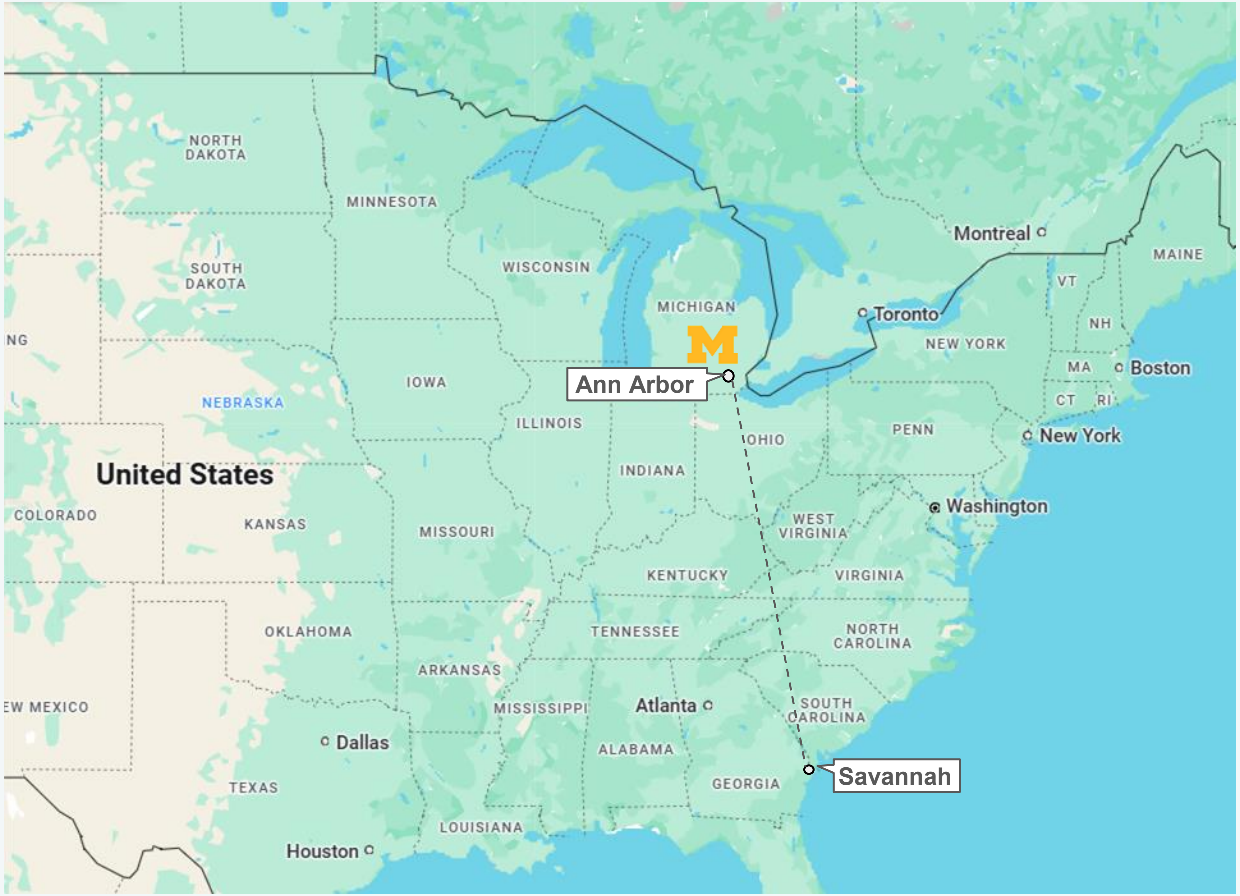
EIPBN 2025
May 27-30th | Savannah, GA

Introduction



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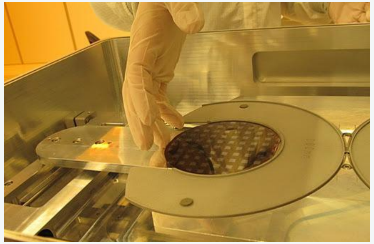
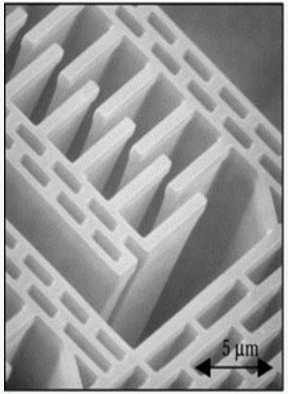
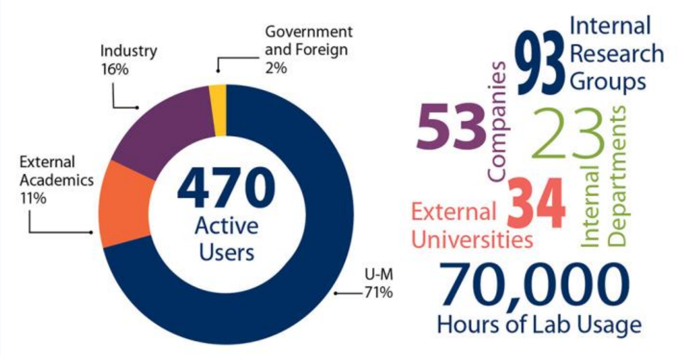
Introduction

The Lurie Nanofabrication Facility serves technology educators and creators through broad access to advanced nanofabrication equipment and staff expertise in a safe, collaborative environment

- Class 10+ cleanroom with 13,500 sq.ft. under filter, open 24/7/365
- 135+ fab tools with comprehensive deposition, lithography, dry/wet etch, metrology, packaging capabilities
- Applications in Si and compound semiconductors for MEMS, memory, power, opto/photonic devices, metamaterials, packaging
- 20 staff members with dedicated User Services team
- Independent onsite work, staff process services, or work can be done by 3rd party contractors (fee-for-service)



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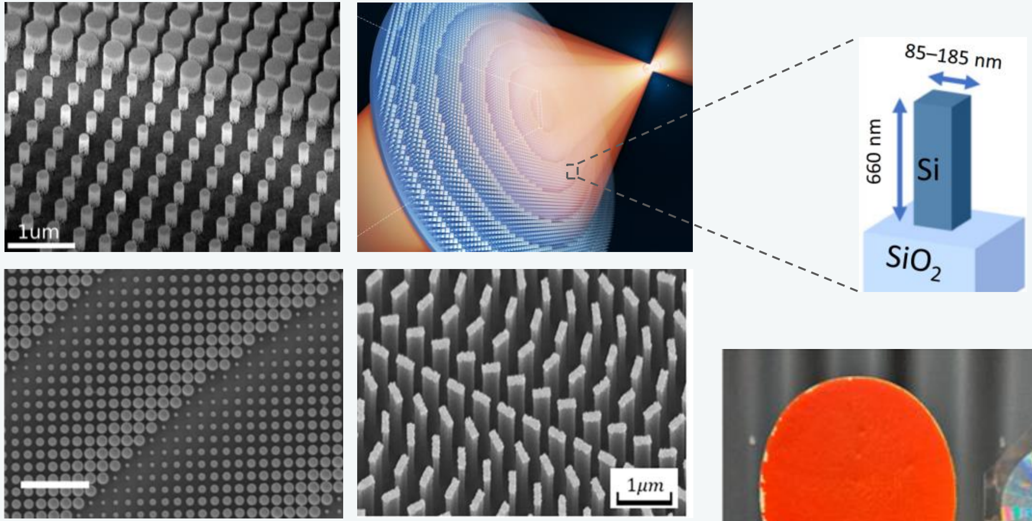
Process Request Case Study: Metalens Fabrication

Applications of metasurfaces:
imaging, sensing, light sources, displays, quantum optics

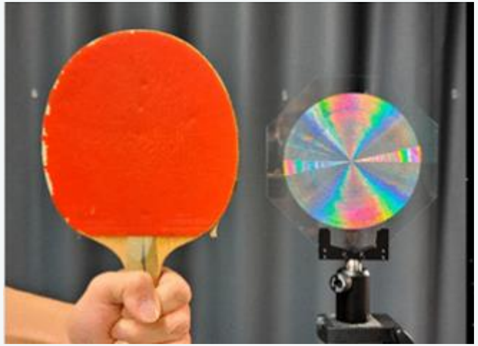


SEM images of metalenses

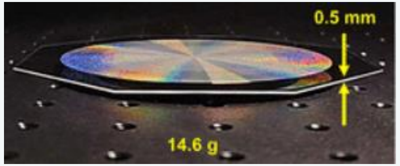
Khorasaninejad et al.*Nano Lett.* (2016)
TW Hsu et al, *PRX Quantum* (2022)
Johansen et al, *Comm Phys* (2024)
SW Moon et al, *L&PR* (2024)

Challenges:

- ➢ Nanoscale precision
- ➢ Shape imperfections
- ➢ High-throughput at low cost

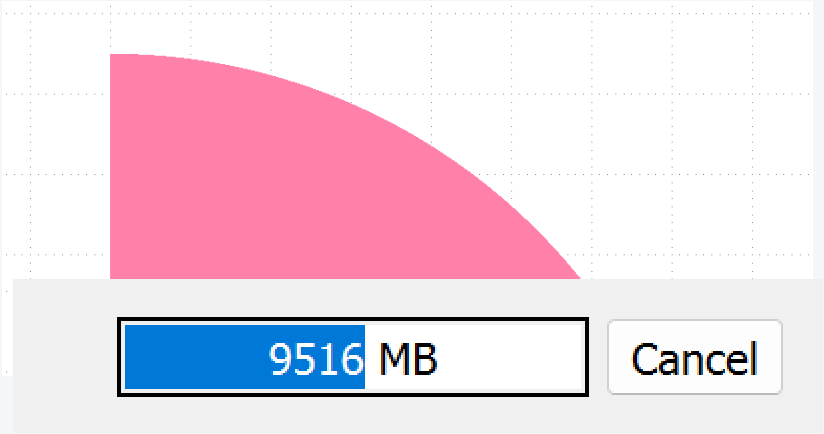


An all-glass 100 mm diameter metalens
~ 18.7 billion nanopillars
operates in the visible spectrum
patterned with DUV stepper



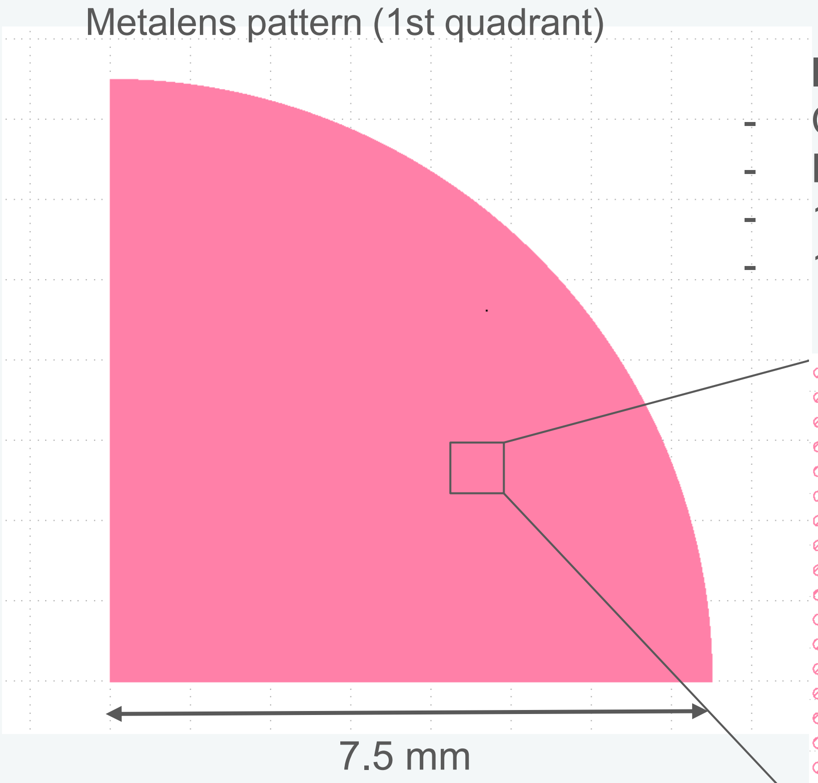
JS Park et al. *ACS Nano* (2024)

Provided pattern:



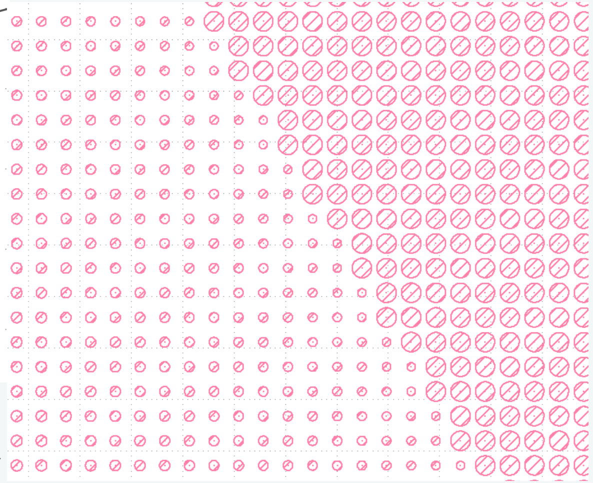
Loading file, please wait…

Provided pattern:



Input data:

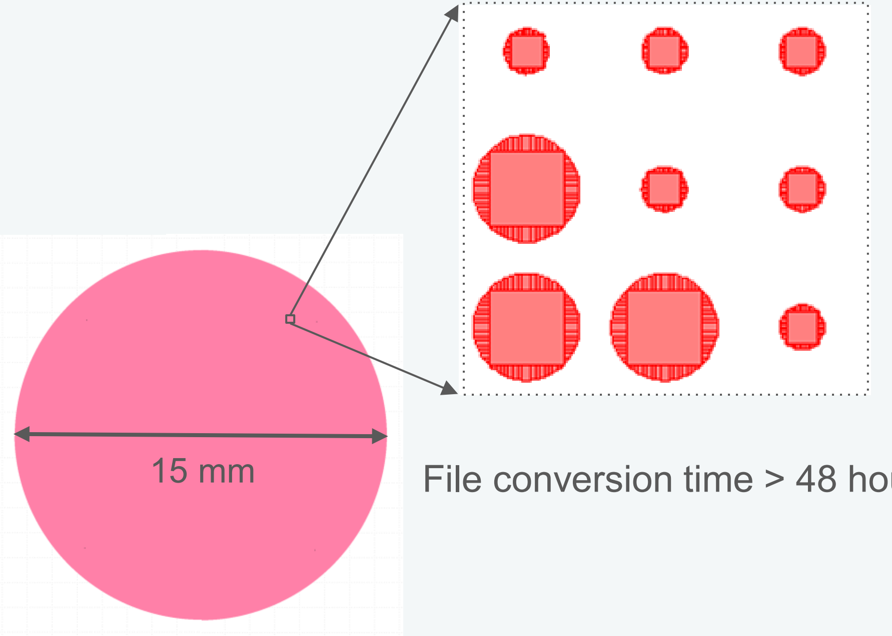
- Circle shapes are path elements
- File with no hierarchy (no layers, no cells)
- 10 GB file consists of ~192 millions elements
- 1st quarter of the lens to be copied and rotated 3 times



When we realized it was not just an Import-Export flow…

EBL system: JEOL JBX6300FS
100 kV, 20nA current

Data input - only trapezoids & lines



File conversion time > 48 hours !

Let’s minimize number of polygons

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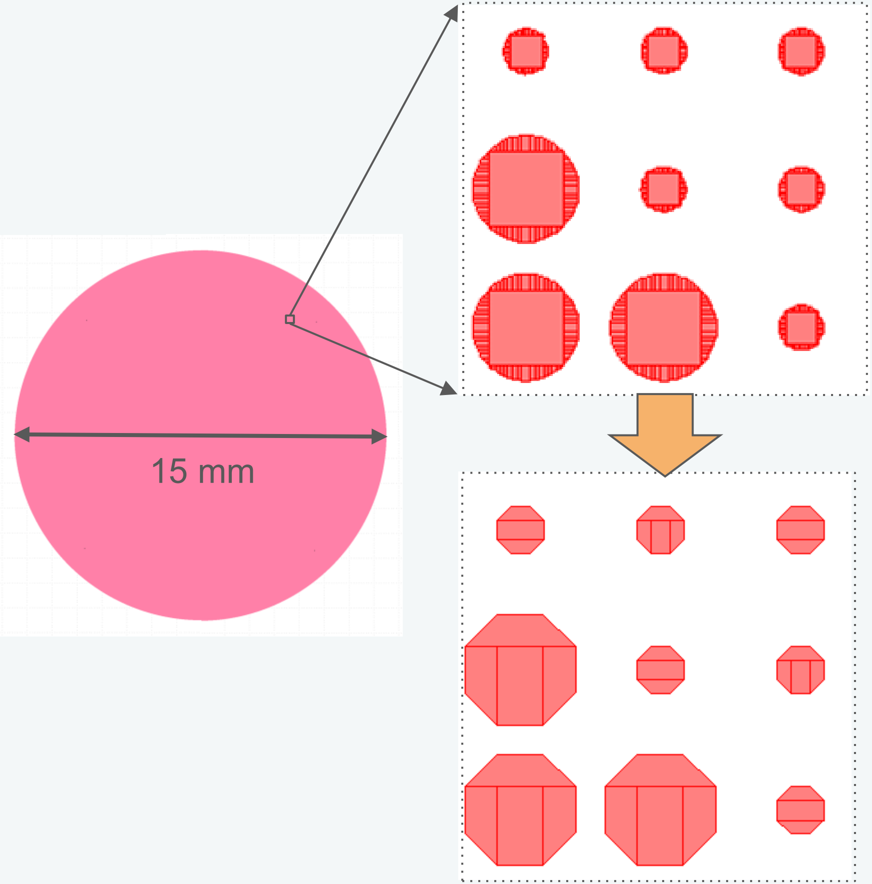
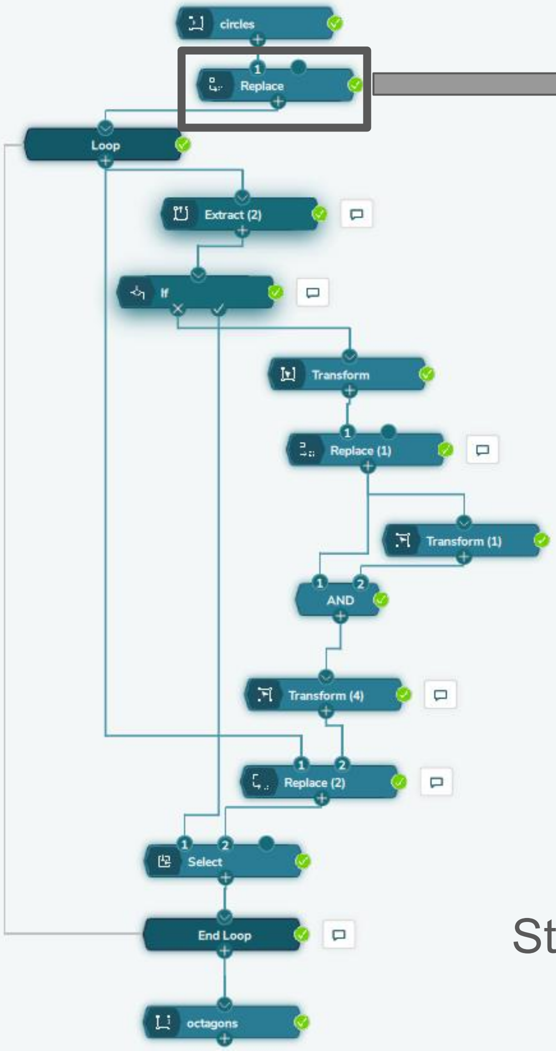
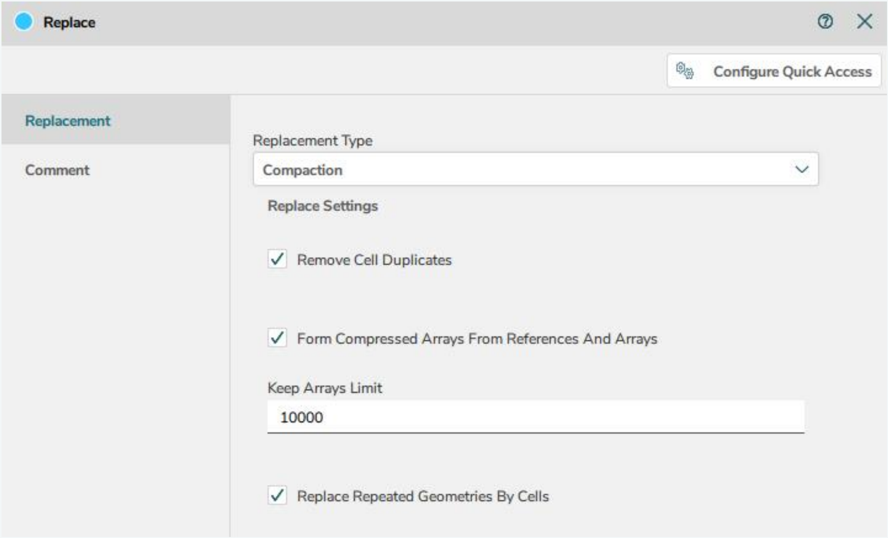
100 kV, 20nA current

Data input - only trapezoids & lines



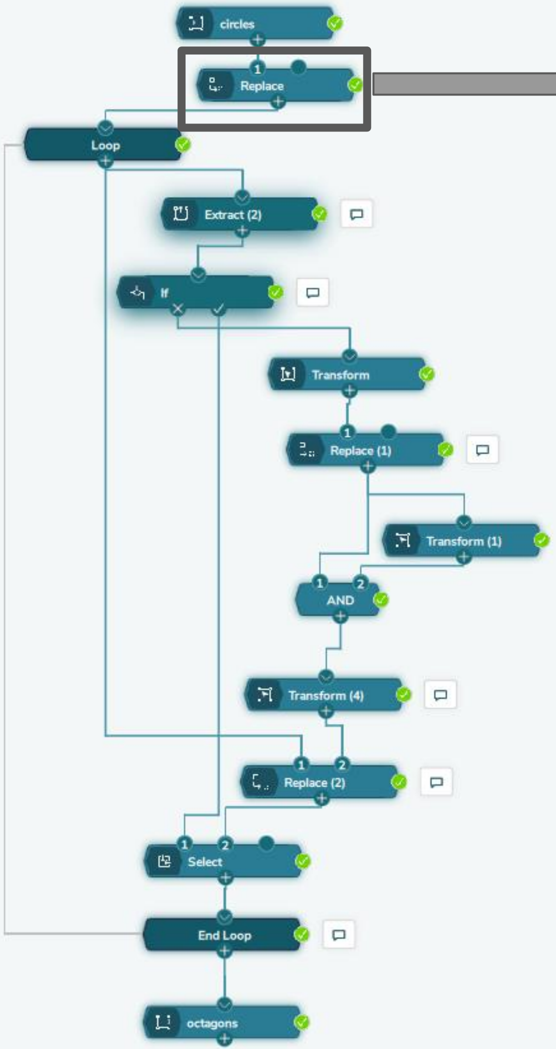
BEAMER flow:

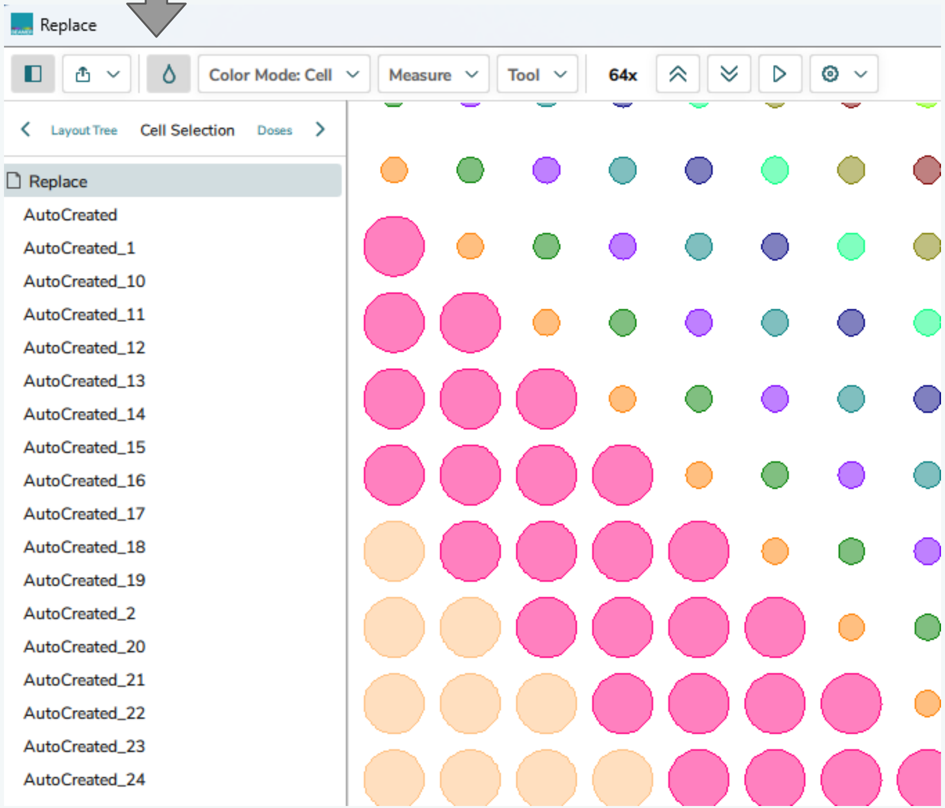




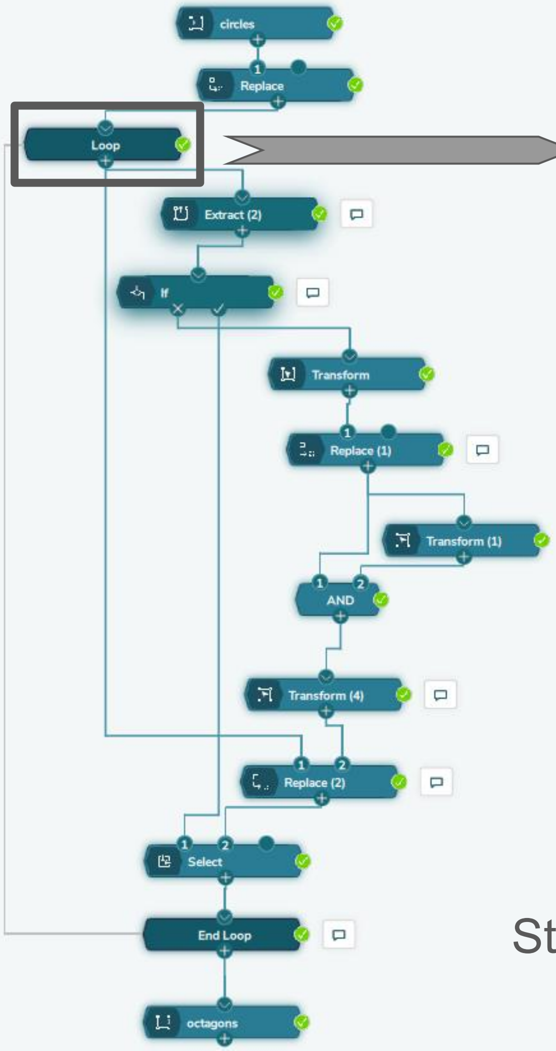
Step 1: Restore Cells hierarchy for circles of the same size

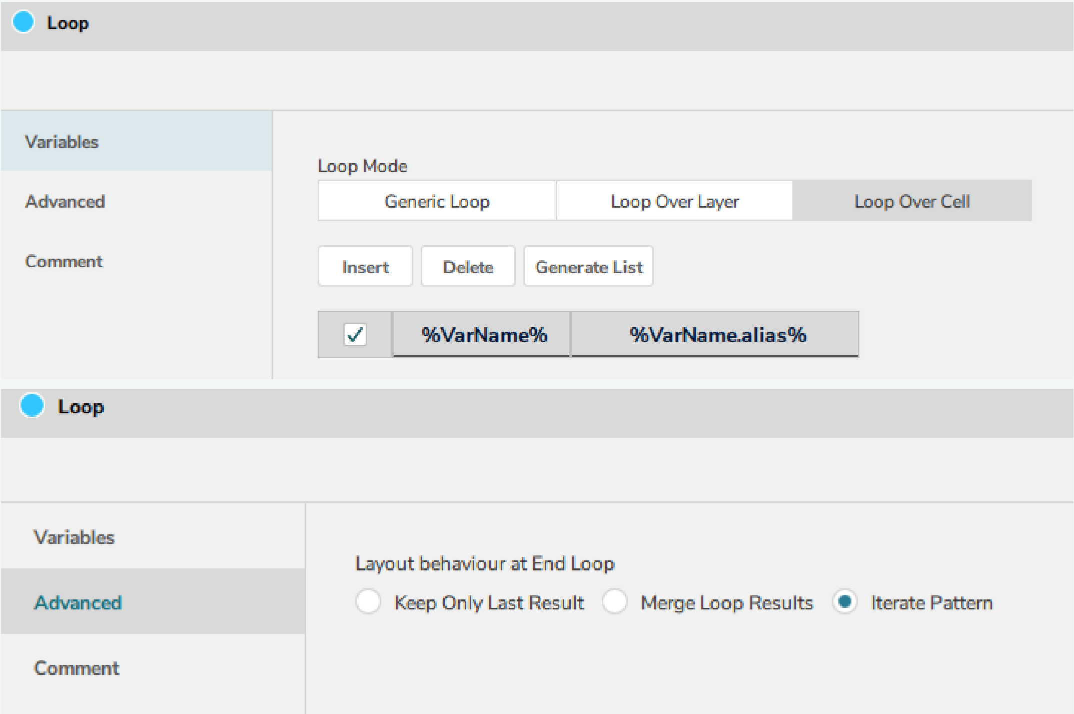
BEAMER flow:


circles
Replace
Loop
Extract (2)
If
Transform
Replace (1)
Transform (1)
AND
Transform (4)
Replace (2)
Select
End Loop
octagons


Replace
Color Mode: Cell
Measure
Tool
64x
Layout Tree
Cell Selection
Doses
Replace
AutoCreated
AutoCreated_1
AutoCreated_10
AutoCreated_11
AutoCreated_12
AutoCreated_13
AutoCreated_14
AutoCreated_15
AutoCreated_16
AutoCreated_17
AutoCreated_18
AutoCreated_19
AutoCreated_2
AutoCreated_20
AutoCreated_21
AutoCreated_22
AutoCreated_23
AutoCreated_24

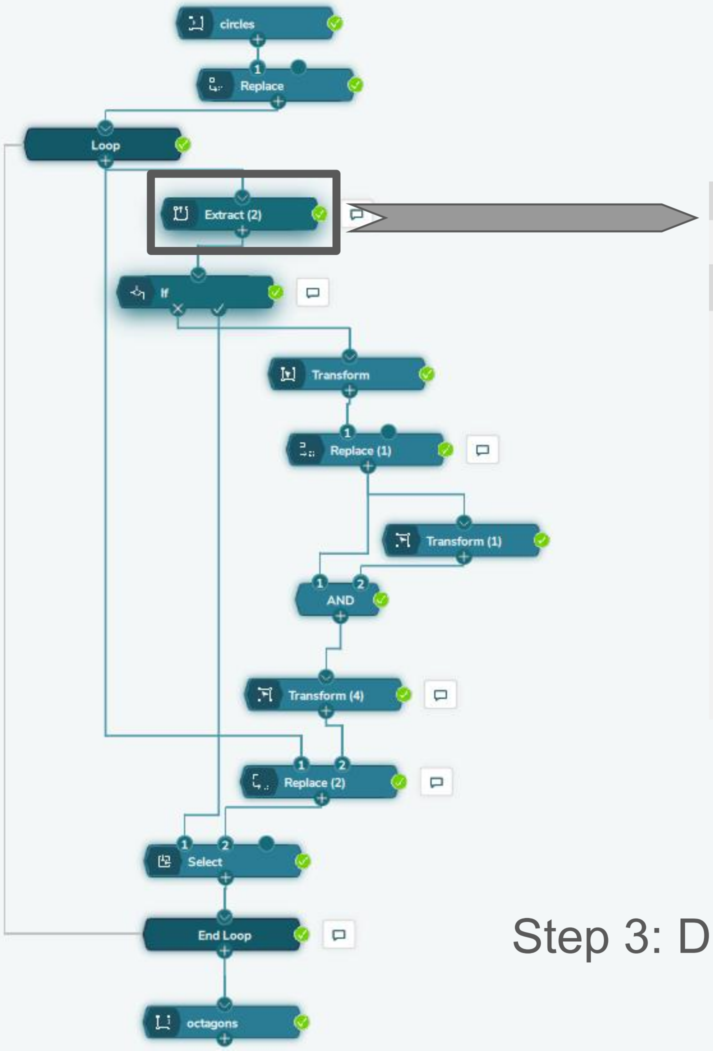
BEAMER flow:

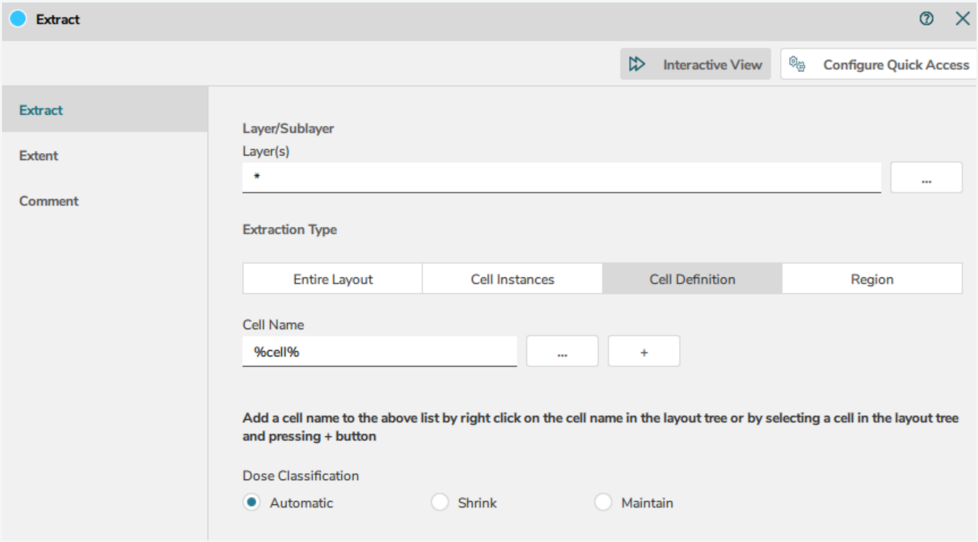




Step 2: Modify pattern iteratively over cells using Loop

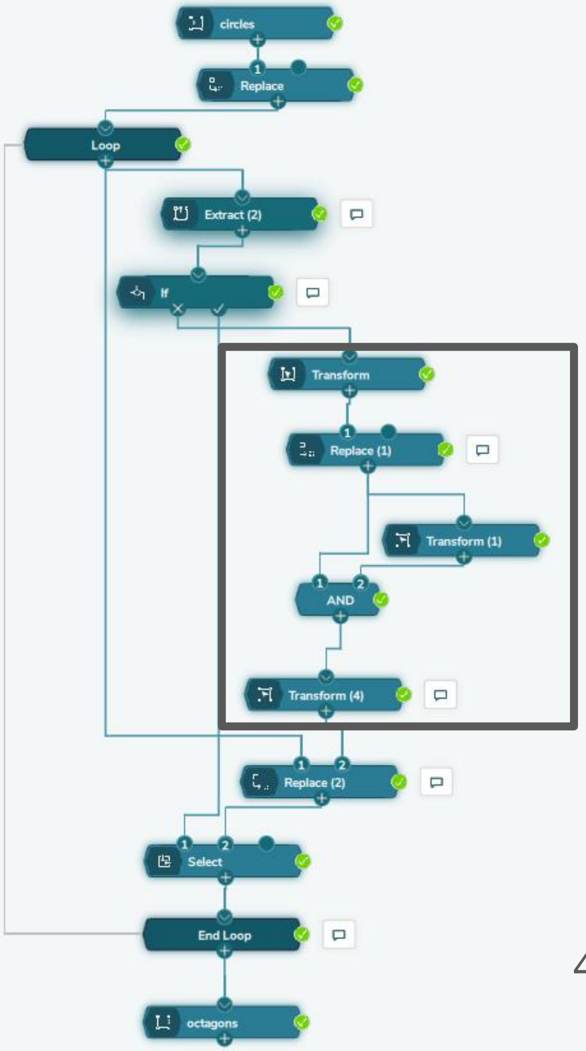
BEAMER flow:

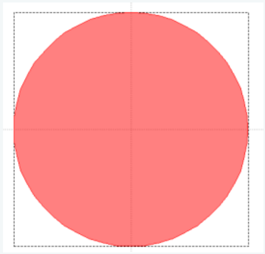




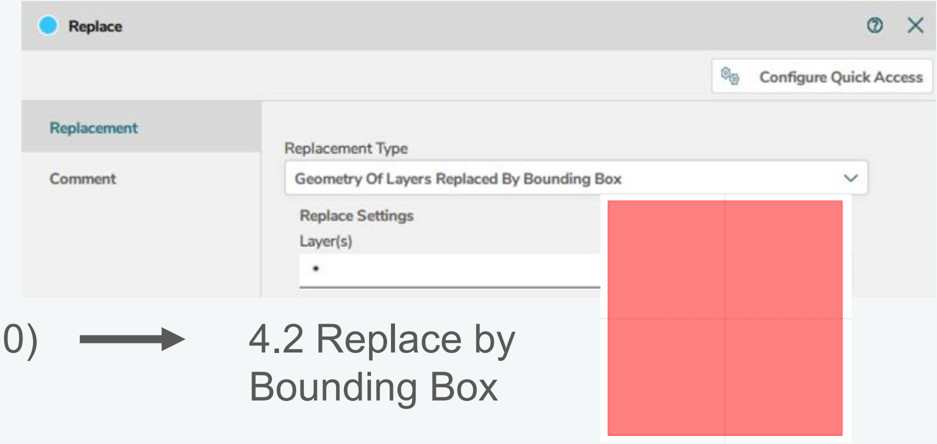
Step 3: Define a cell as a variable %cell%

BEAMER flow:

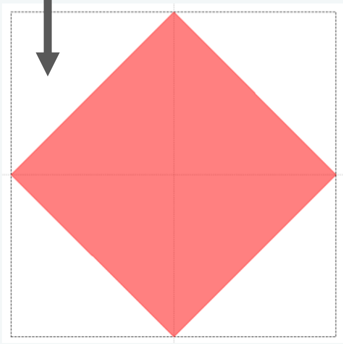




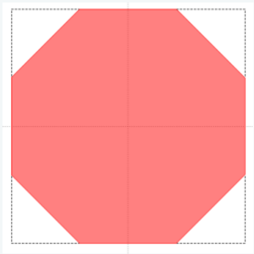
4.1 Center to (0,0)



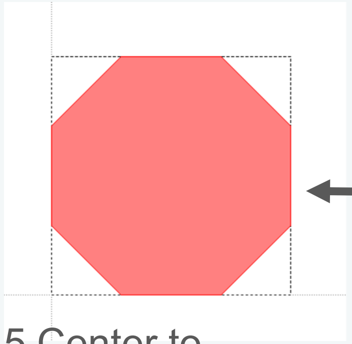
4.2 Replace by Bounding Box



4.3 Rotate

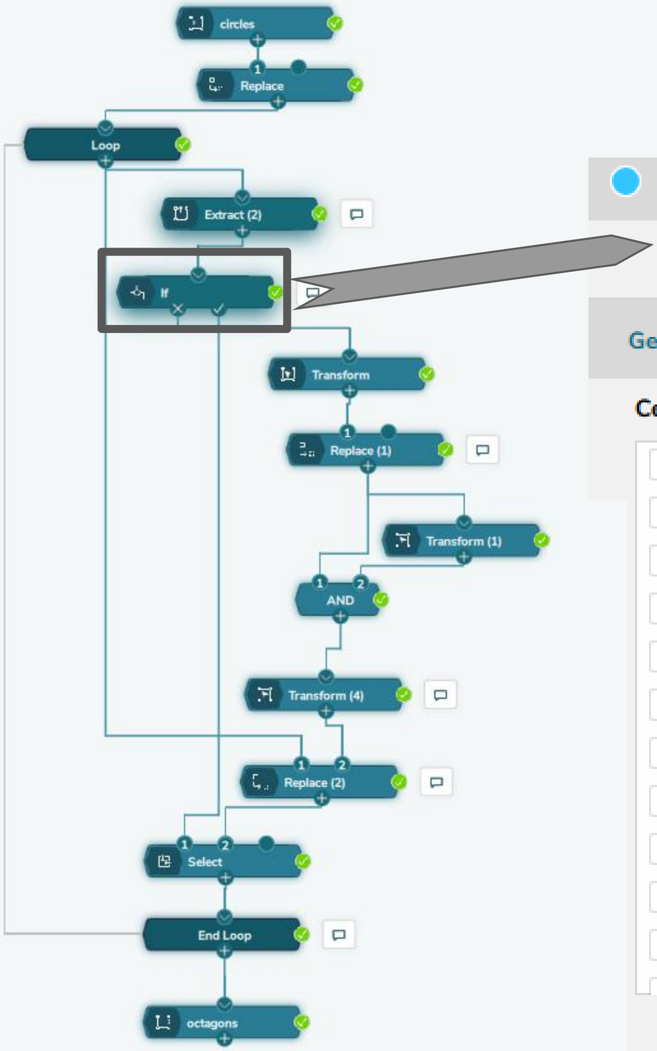


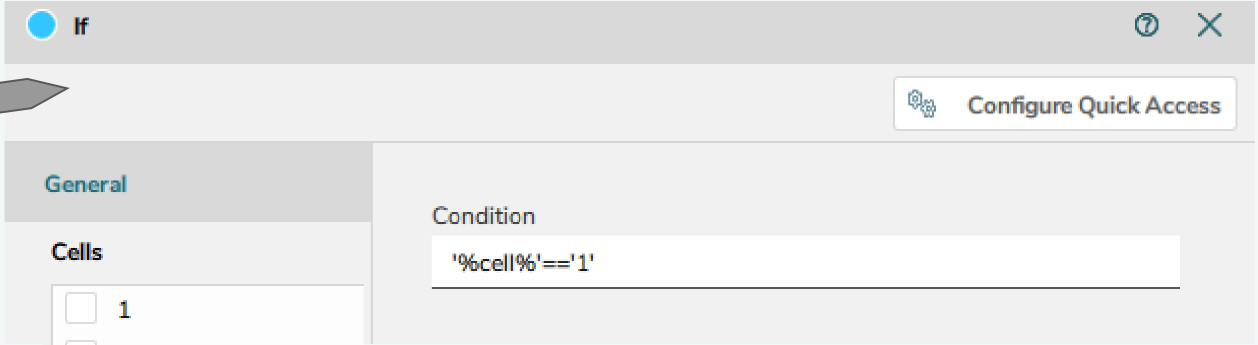
4.4 AND

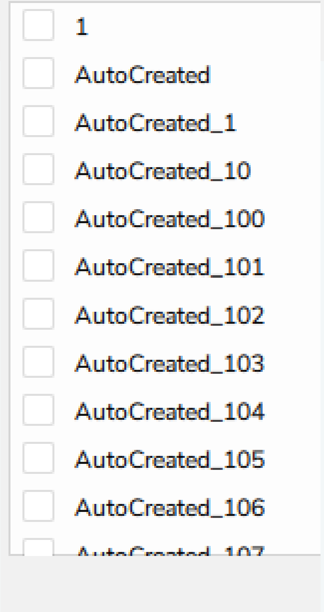


4.5 Center to Left bottom corner

BEAMER flow:

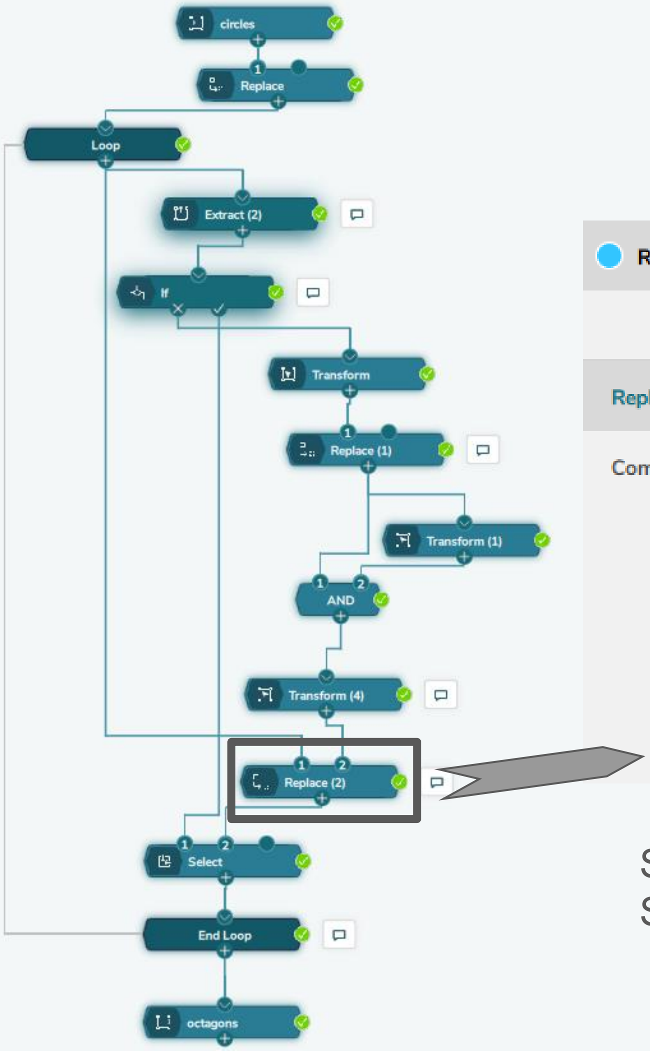


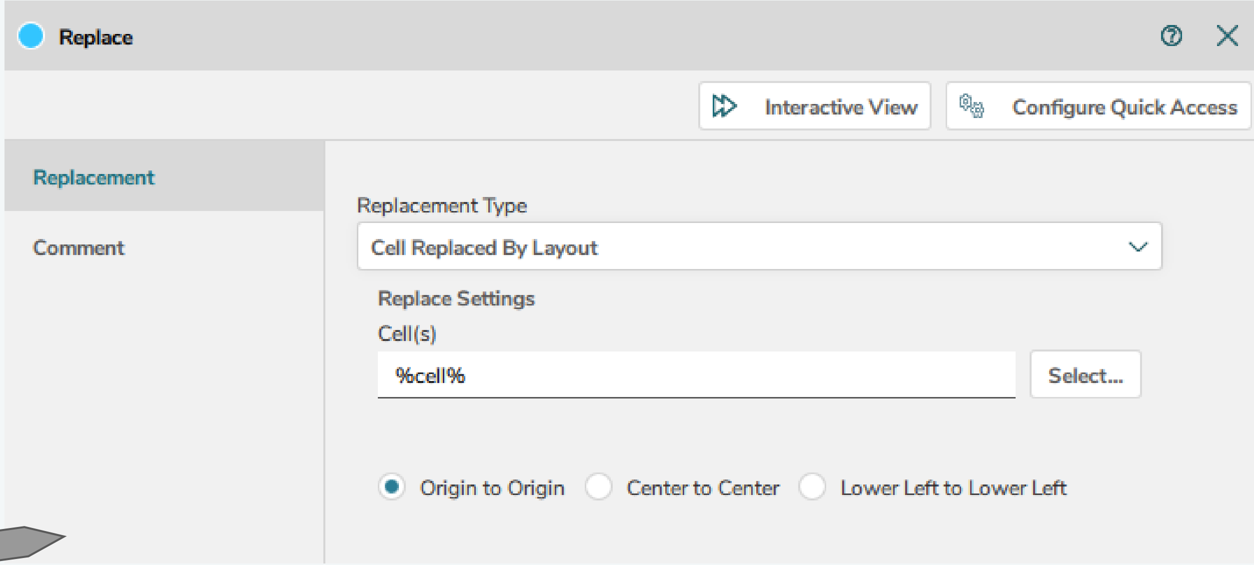




Step 5: Use IF operator to remove the top cell from the pattern

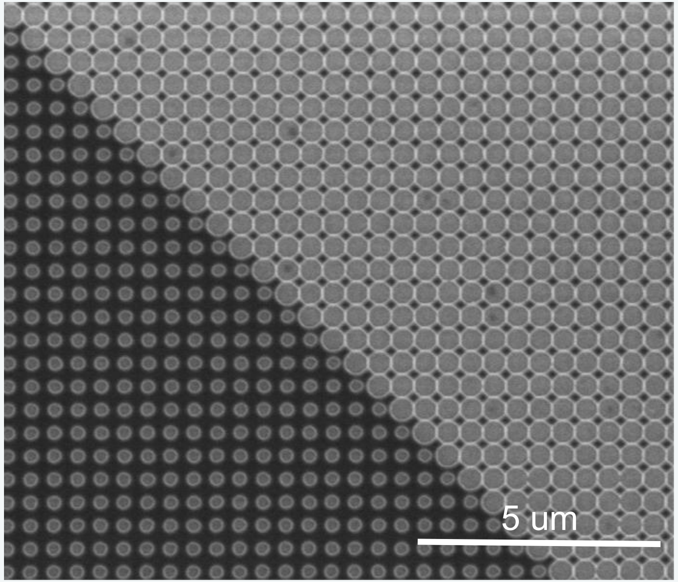
BEAMER flow:





Step 6: Replace each original cell with the created octagon
Step 7: End of loop – all cells have been replaced with octagons of the same size

Our results:



SEM image of the pattern replaced
by octagons in PMMA after development

- 18 hours to process one quadrant using BEAMER
- Output file size: 14.8 GB, containing ~671 million shapes
- After 30 hours of EBL exposure.. only 20% of the pattern was completed

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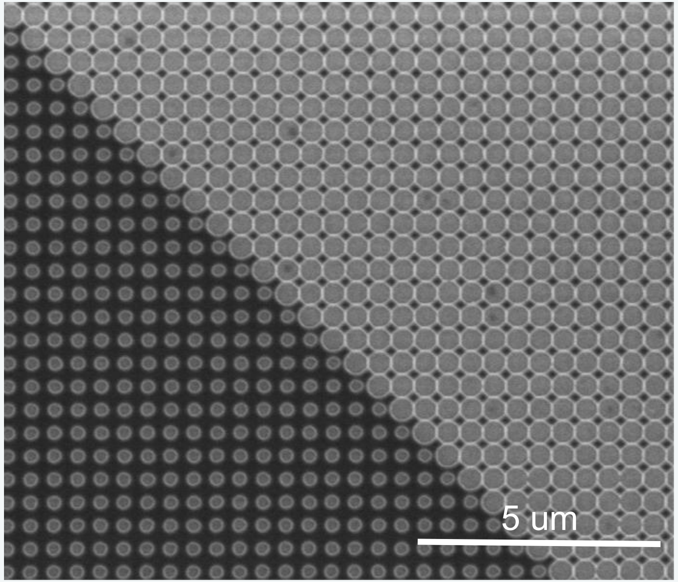

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Thank you for attention!