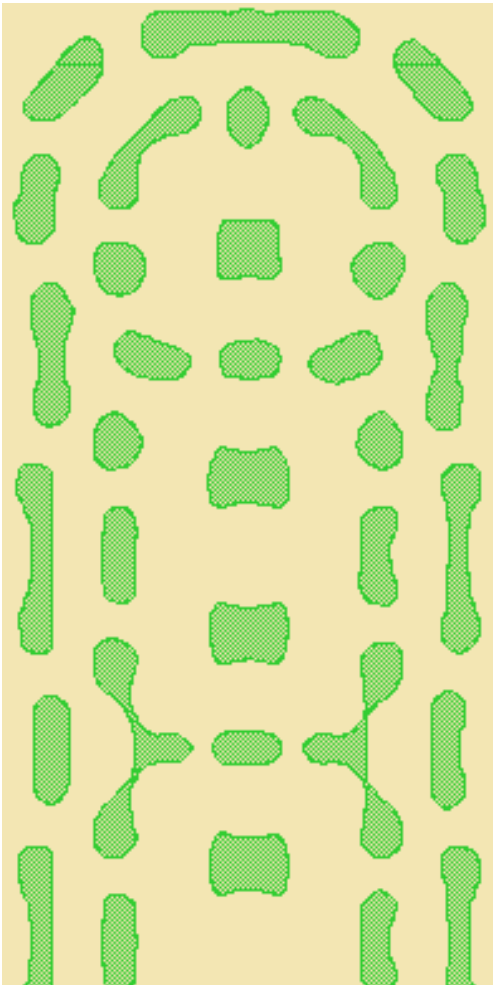
Simulation-Based MDP Verification for Leading Edge Masks

Bo Su, Oleg Syrel, Michael Pomerantsev, Kazuyuki Hagiwara, Ryan Pearman, Leo Pang and Aki Fujimura

D2S Patented Technology

GPU Accelerates Processing Complex Curvilinear Shapes

- Curvilinear mask shapes no longer can be ignored
- Verifying curvilinear mask shapes requires massive computation
- GPUs can accelerate processing of complex curvilinear shapes:
  - Created massively parallel versions of classic computational geometry algorithms;
  - Confirmed >10x speedup with GPU Acceleration
- GPU makes simulation-based MDP verification possible
  - Accurate physical mask model
  - GPU is required for simulation with overlapped shots and dose modulation

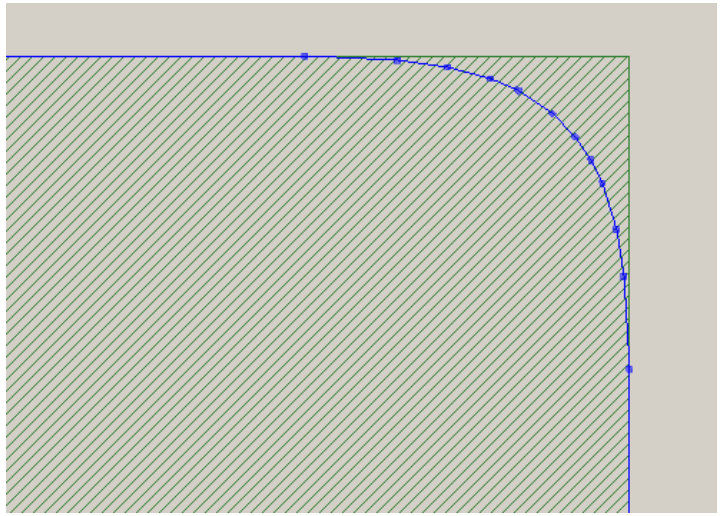


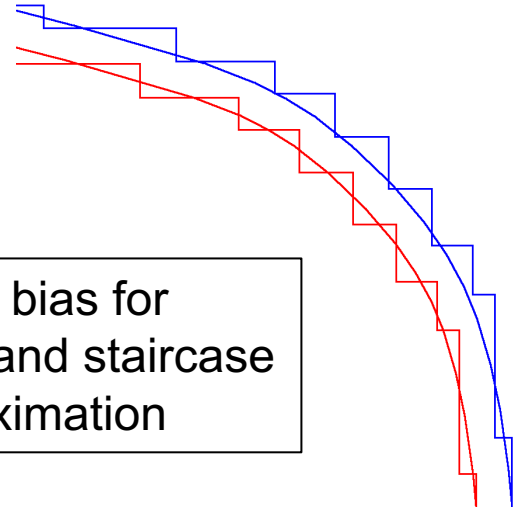
Shapes on Masks are all Curvilinear

- Regardless of OPC styles for mask writing:
  - Simulated mask shapes are curvilinear
  - Mask shapes from SEM images are curvilinear
  - Design can be curvilinear for ILT
- Curvilinear shapes consist of many little segments ***at all angles*** *with significant complexity increase*
- GPU accelerates curvilinear processing

Curvilinear Shapes Require Complex Geometry Algorithms

- Curvilinear shapes, geometry representation is much more complex:
  - Segment by segment at nm scale at all angles
- Higher requirement for robustness and complex algorithms
  - Staircase approximation is not good for etch bias—average 20% error for a rounded corner
  - direct curvilinear bias is more accurate





10 nm bias for curvilinear and staircase approximation

Mask Verification Needs Massive Computation

One example:

- Simulation to obtain mask contour from shots—The AEI contour generated, up to a full mask scale
- Etch Bias is calculated along the AEI curvilinear contour at every sampling point, using ***visible open area (VOA) calculation*** to approximate surrounding feature impact within search distance to get the corresponding ADI contour
- GPU-accelerated geometry engine for contour analysis with geometric algorithms

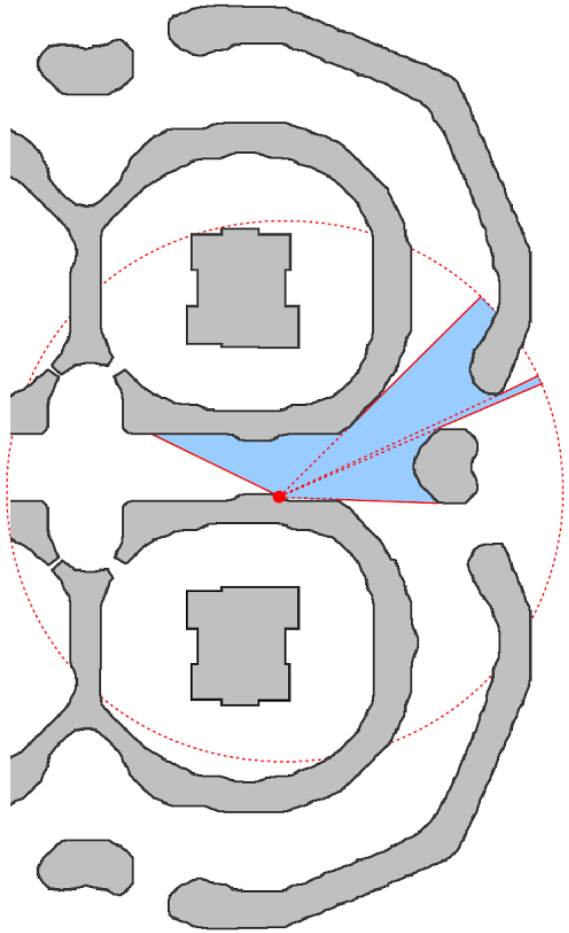
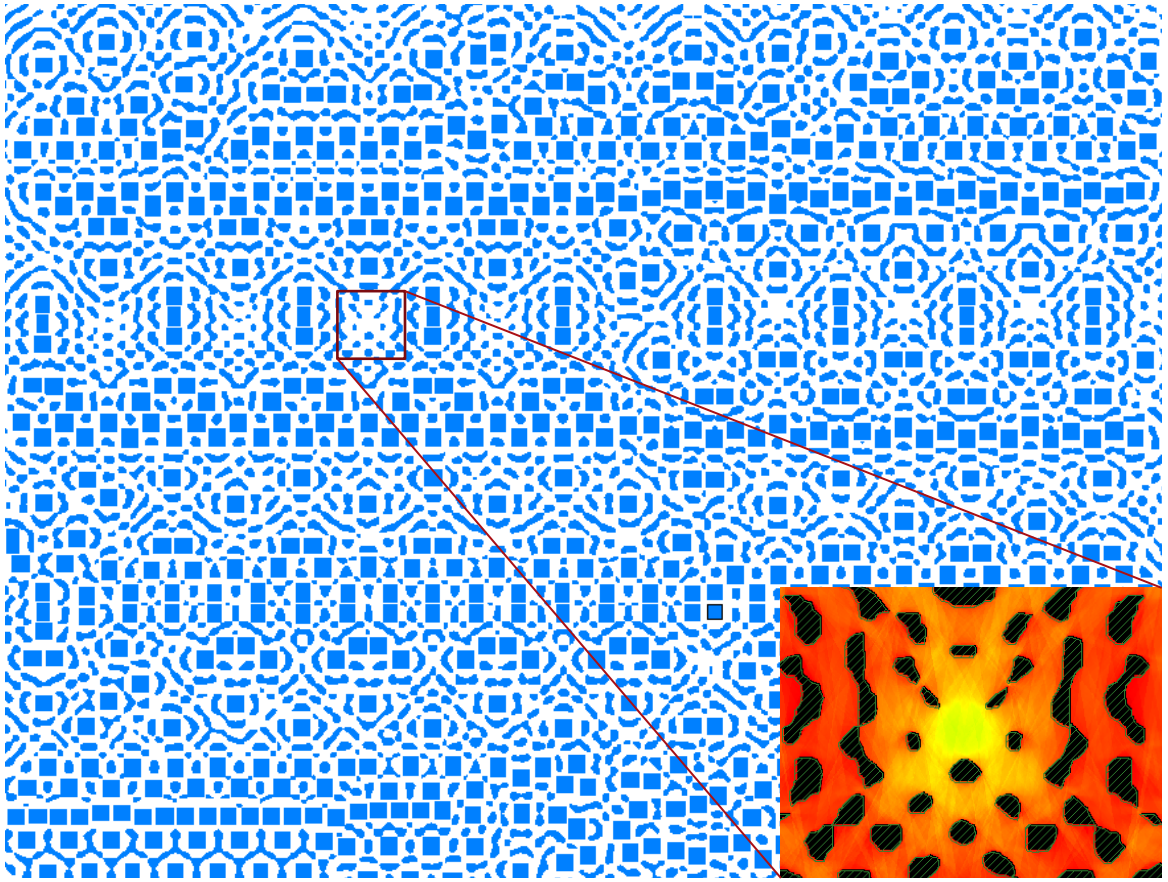


Illustration of VOA calculation at a given point

Case Study: GPU Faster Than CPU in Bulk VOA Calculation

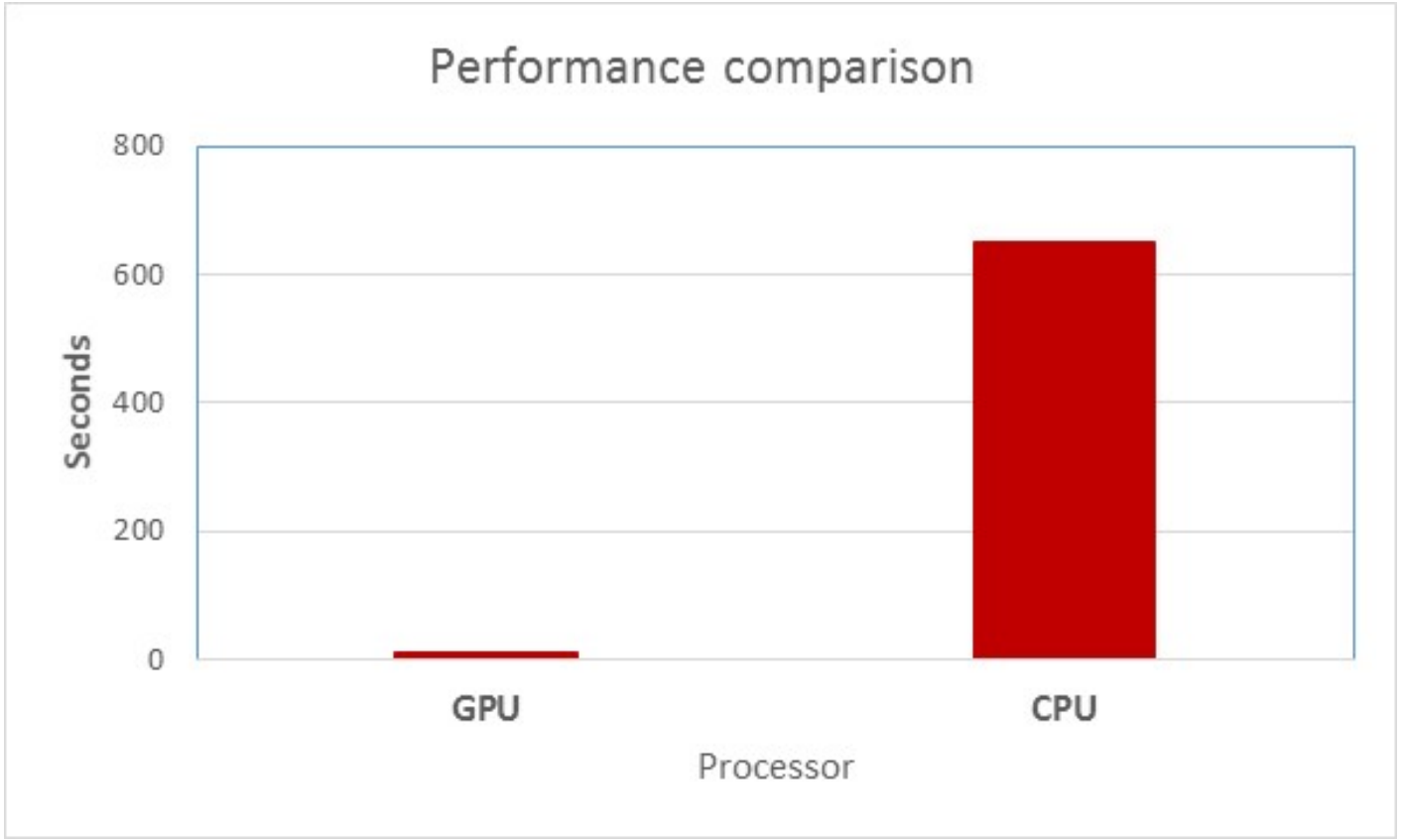
- GPU vs. CPU on **visible open area (VOA) calculation**:
  - Test case—**Manhattanized ILT**, 28x21um with *4nm sampling size* and 700nm search distance (Not realistic usage)
  - GPU=GeForce GTX 1080
  - CPU=4 core Intel Xeon E3-1220 v5 @ 3.00GHz



VOA zoom-in view in color code

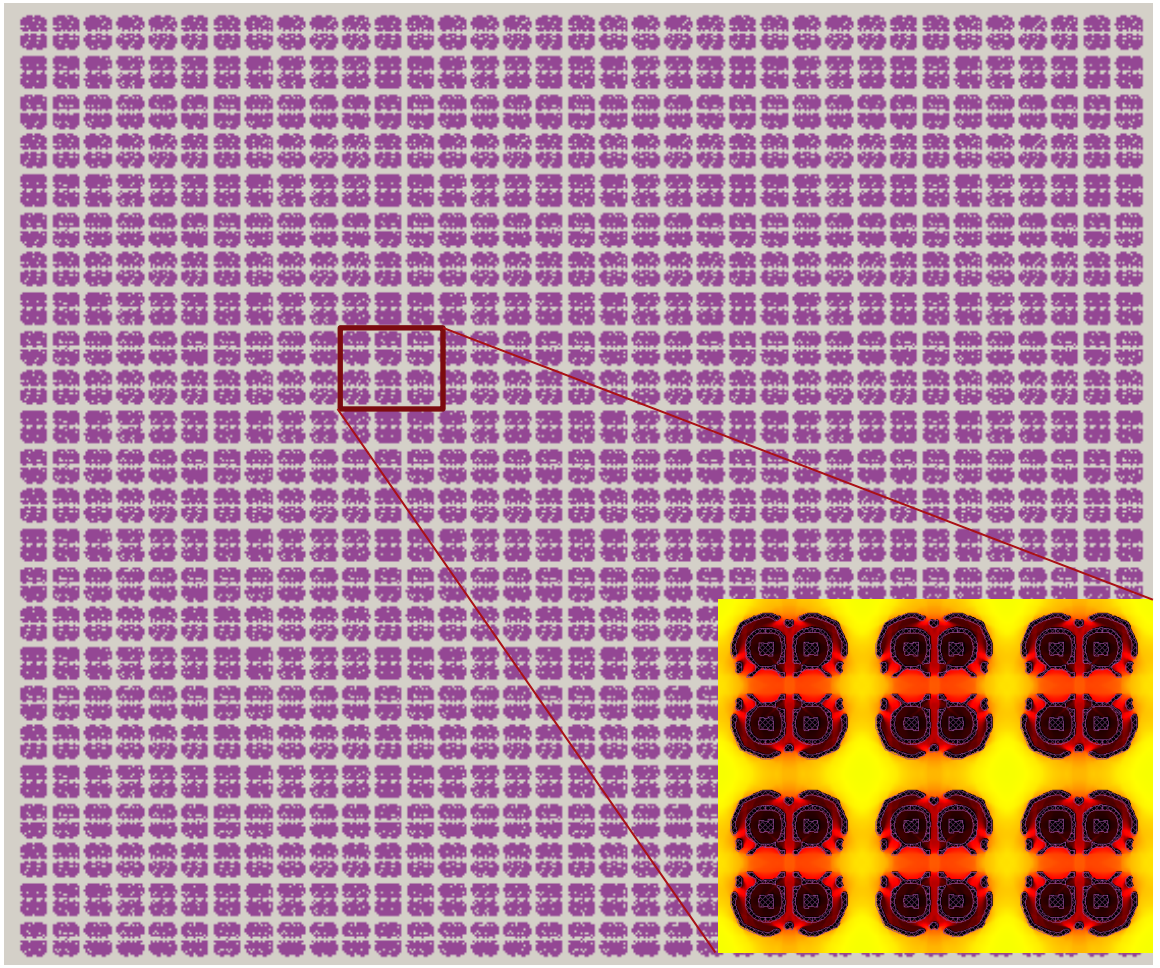
Test 1 Shows GPU is 54x Faster Than CPU

- With 4nm step size and 700nm search range:
  - GPU=12 seconds
  - CPU=650 seconds
- GPU is 54x faster than CPU



GPU vs. CPU in Test Case 2—ILT Design

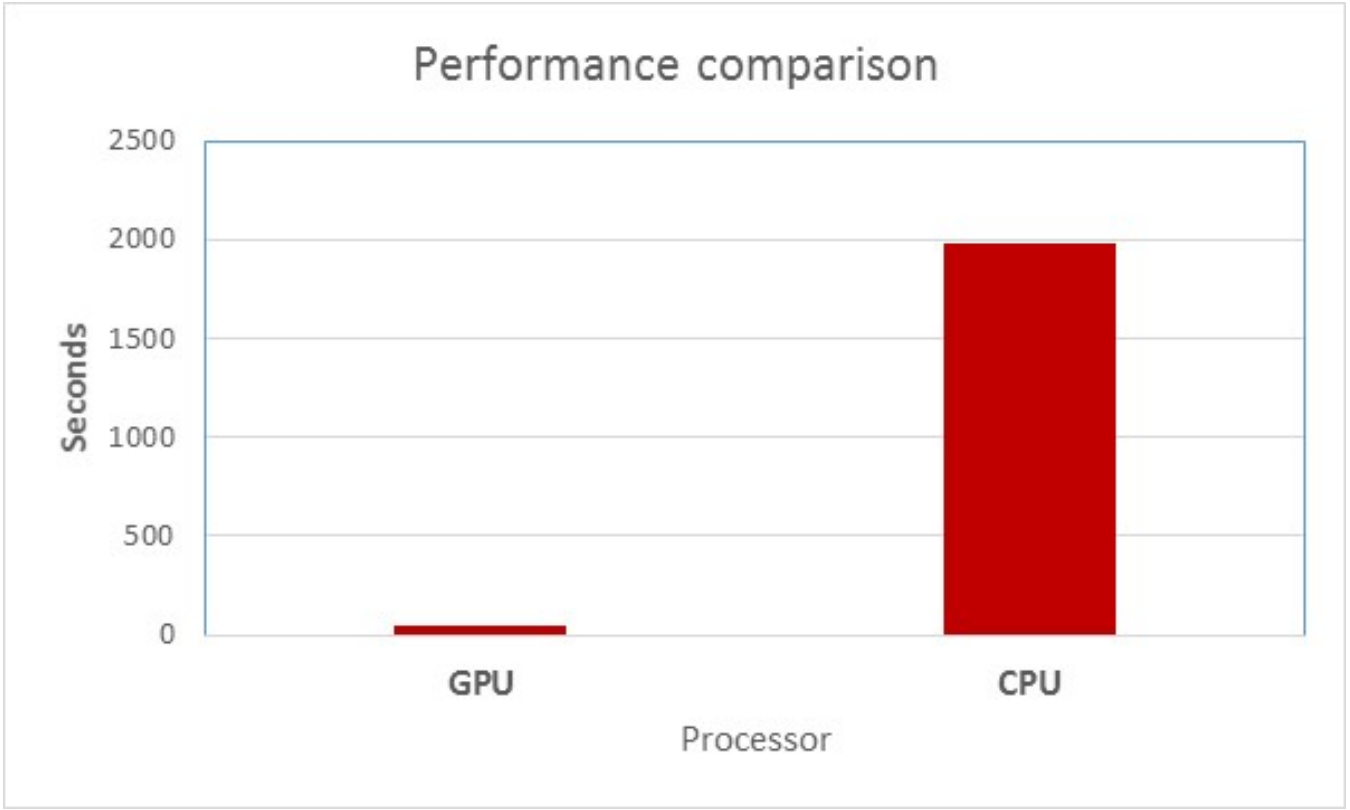
- GPU vs. CPU on **visible open area calculation** on a curvilinear ILT:
  - Test case—ILT design, 31x26um with 4nm sampling size and 500nm search distance
  - GPU=GeForce GTX 1080
  - CPU=4 core Intel Xeon E3-1220 v5 @ 3.00GHz



VOA zoom-in view in color code

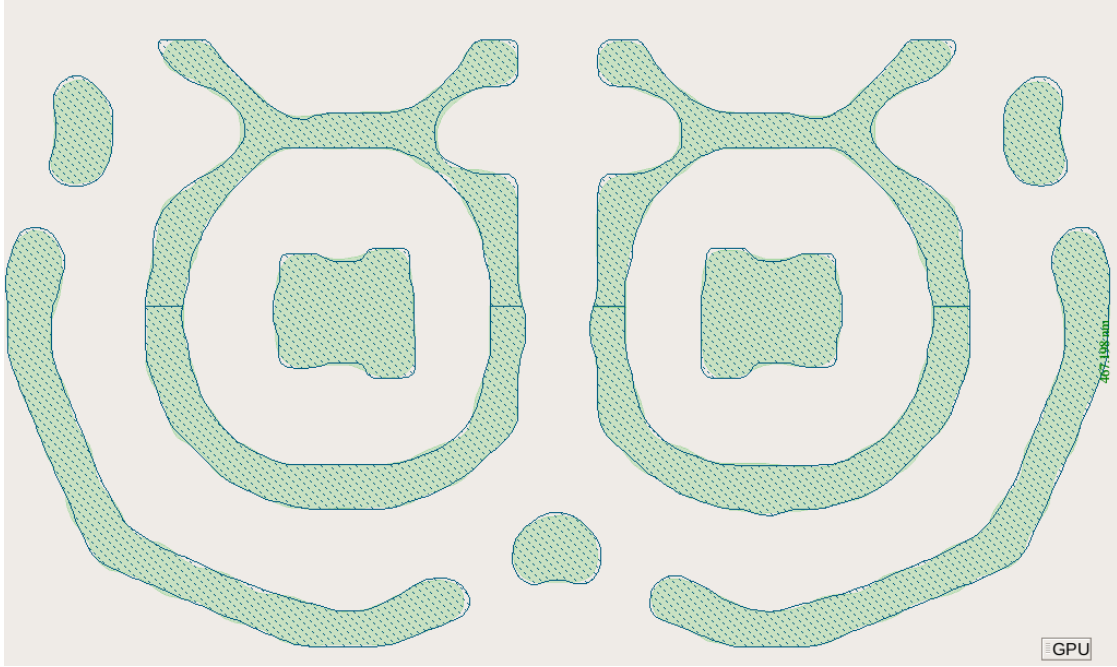
Test Case 2 Shows GPU is 44x Faster Than CPU

- With 4nm step size and 500nm search range:
  - GPU=45 seconds
  - CPU=1980 seconds
- GPU is 44x faster than CPU



GPU vs. CPU in Contour Simulation—Real Apps

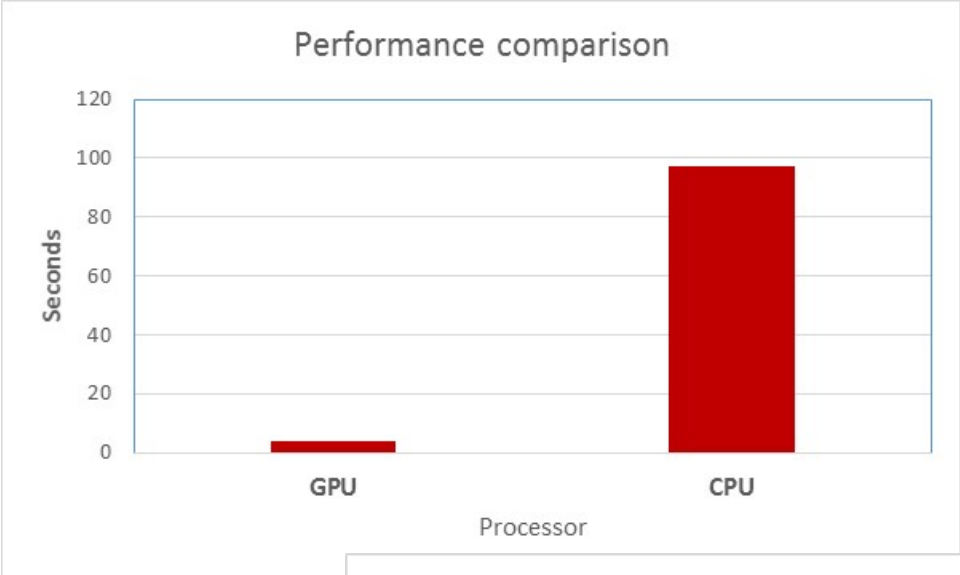
- GPU vs. CPU in real contour simulation, same as Test 2:
  - With a real mask model
  - 31x26um
  - GPU=GeForce GTX 1080
  - CPU=4 core Intel Xeon E3-1220 v5 @ 3.00GHz
- **In more accurate simulation mode, as shown**

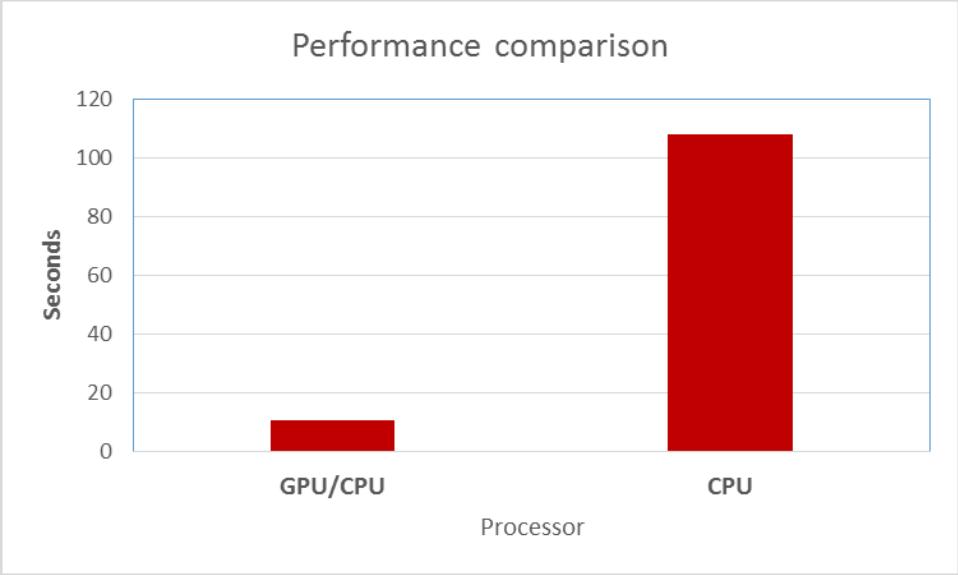


Simulated contour in more accurate mode

GPU+CPU is 10x Faster Than CPU in Etch Bias Simulation

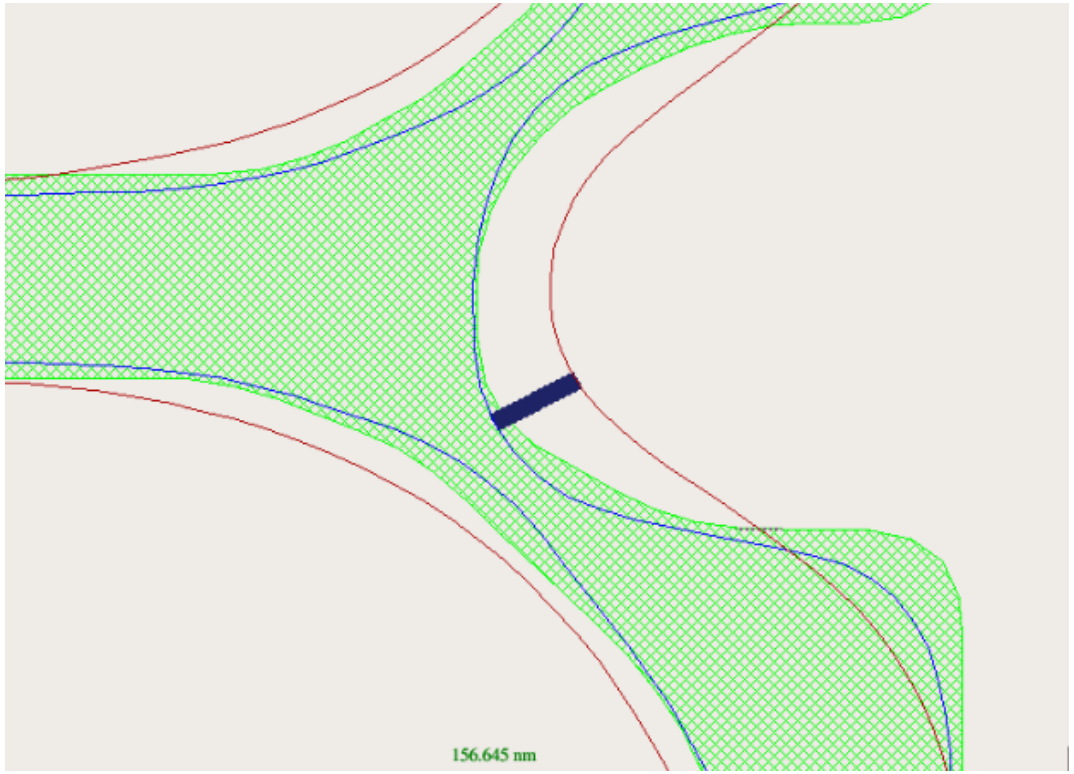
- In contour simulation—in geometry calculation only:
  - GPU=4 seconds
  - CPU=97 seconds
- Considering everything else (all other steps):
  - GPU+CPU=11 seconds
  - CPU=108 seconds





Simulation-Based MDP Verification Engine was Developed

- GPU-accelerated simulation engine
- Curvilinear geometry analysis
  - EPEs in 1D and 2D regions—EPEs between two curvilinear contours: the target and the mask
  - Dose margin check (hotspot detection)—flag regions with large EPE change with a fixed dose variation

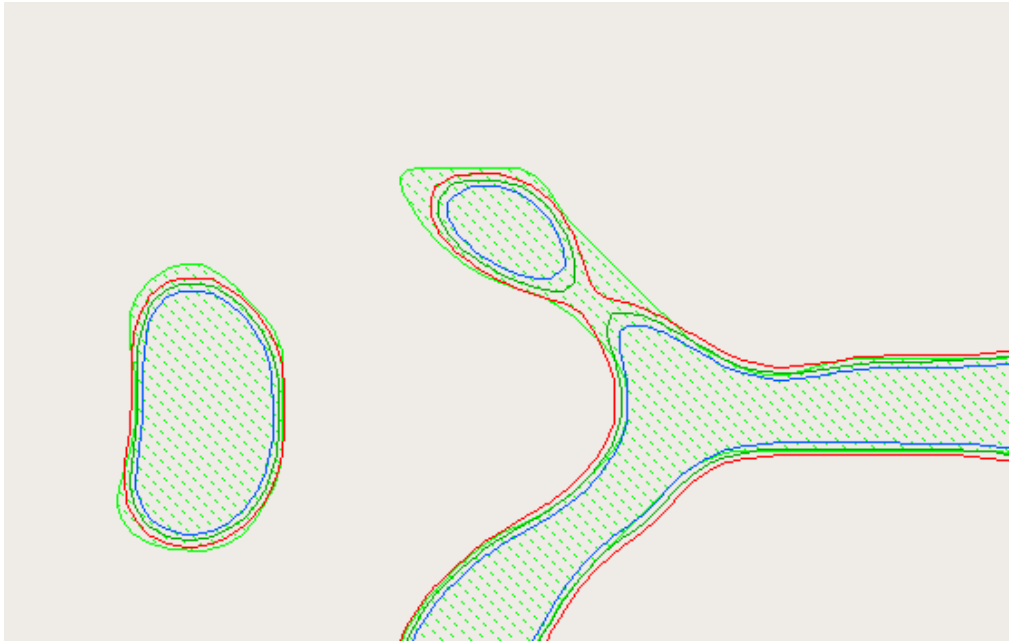


An example of a 2D EPE error.

Real Simulation-Based Verification Runs…

- Layout area=14.2mm^2 (M), ILT style design
- Runtime:

Phase	Time
Import	0d:00:00:26
Verification	0d:00:10:04
Total	0d:00:10:30



- Translates to <4 hours for 48x48mm^2 mask scale on 5th Generation CDP

GPU is Good for Curvilinear Shape Processing

- Mask shapes are curvilinear and GPU accelerates curvilinear shape processing
- Our visible open area calculation tests show that GPU is 50x faster than CPU in curvilinear geometry shapes
- In etch bias simulation case, GPU+CPU is 10x faster than CPU
- GPU acceleration enables simulation-based mask verification
  - provides a quality check for MB-MDP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