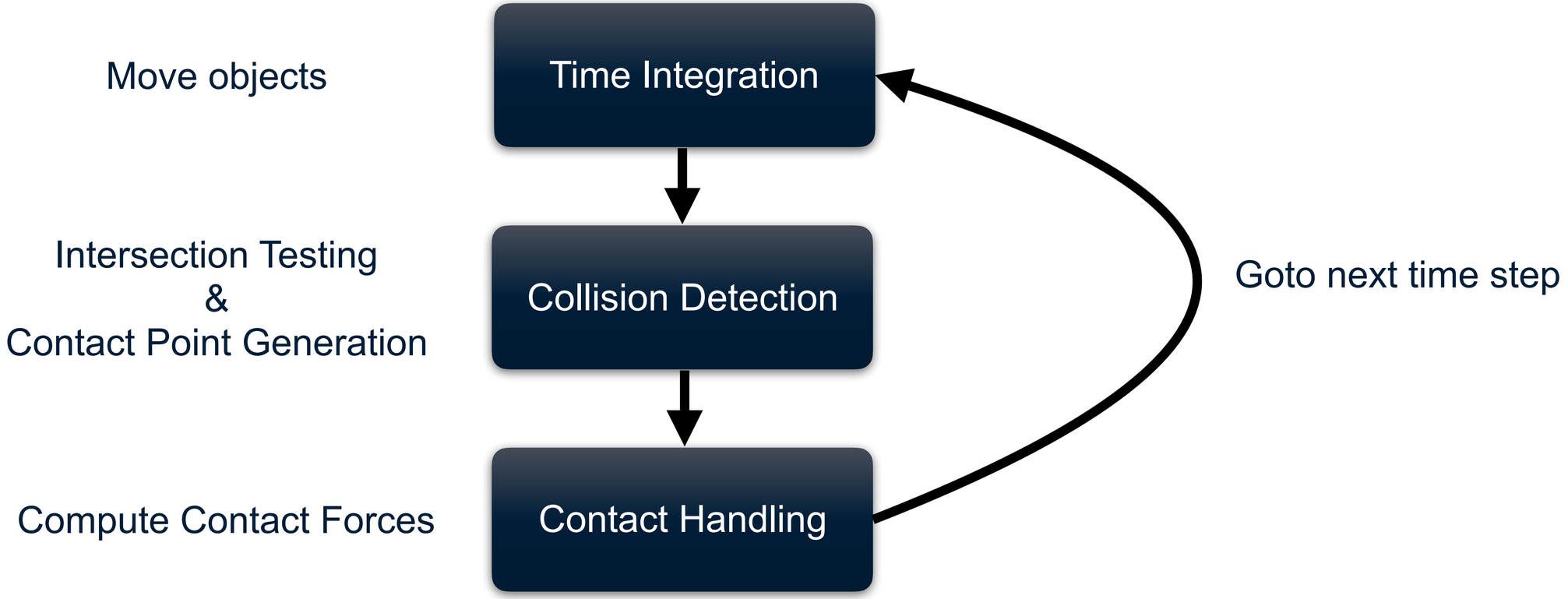
METHODOLOGY FOR ASSESSING MESH-BASED CONTACT POINT METHODS

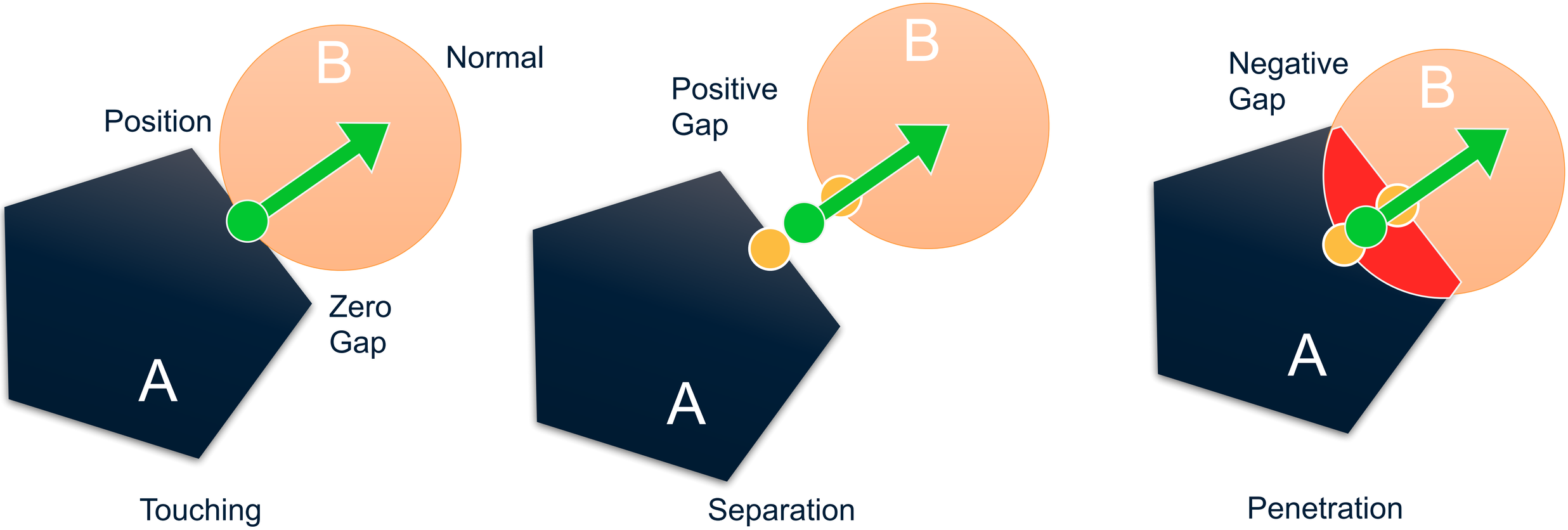
Kenny Erleben, University of Copenhagen

WHAT IS THE BIG DEAL?

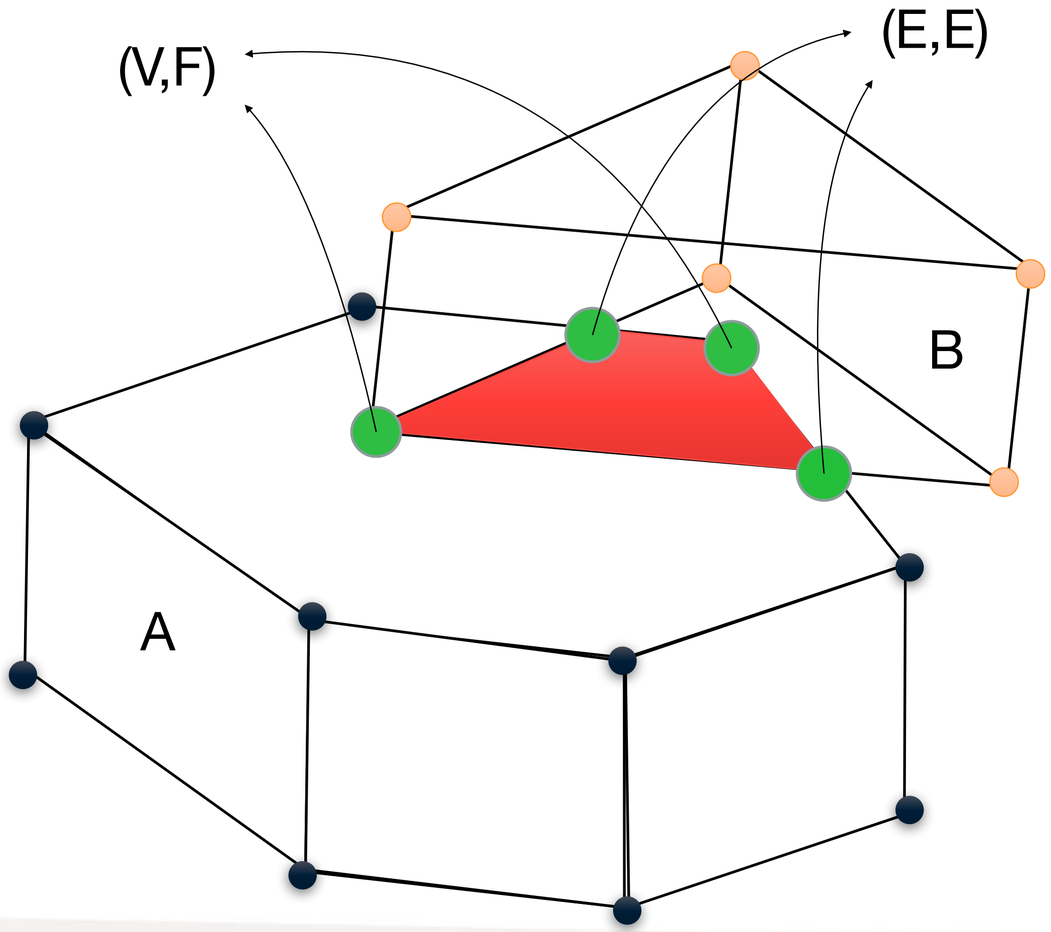
A TYPICAL SIMULATION LOOP



WHAT IS A CONTACT POINT?



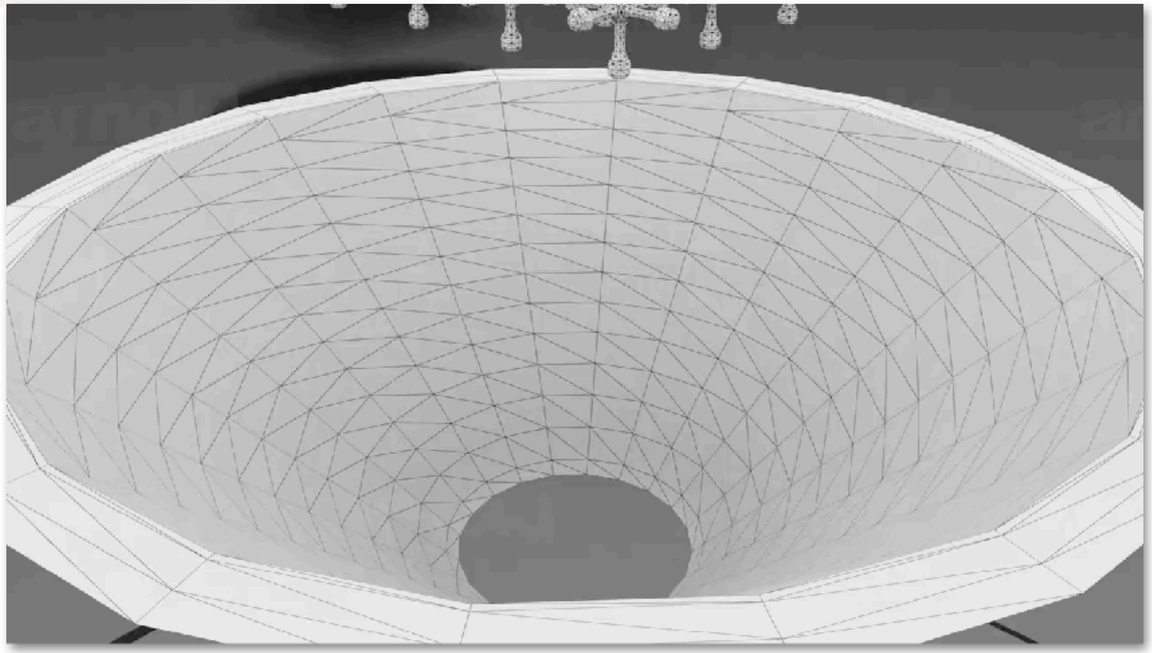
POLYGON MODELS

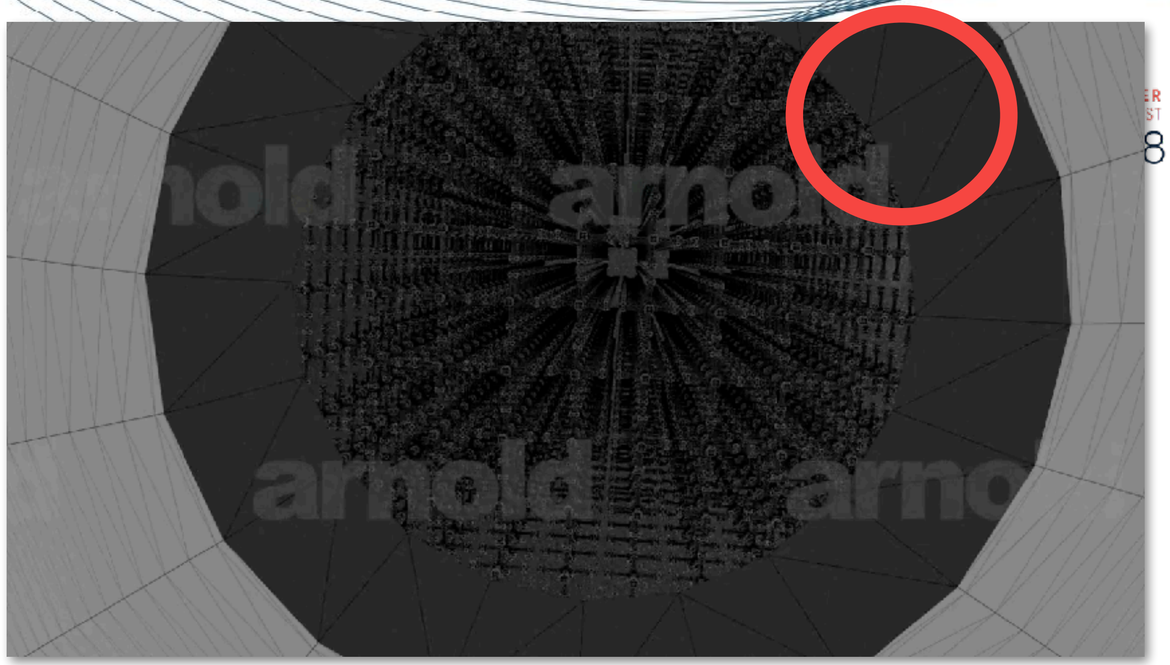


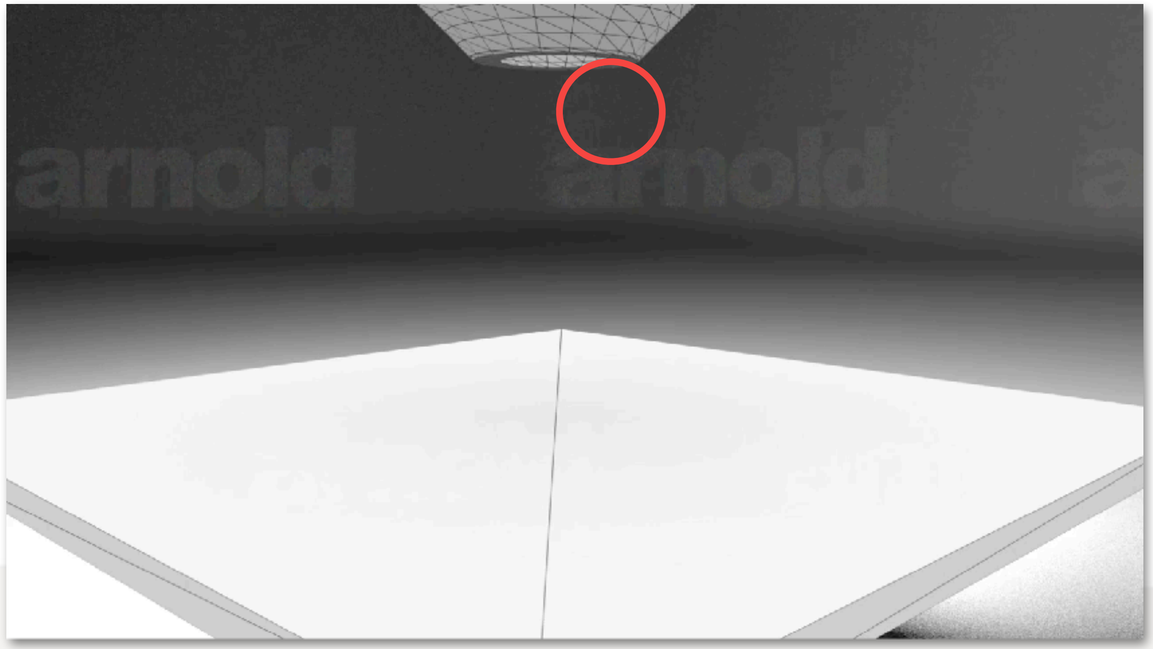
Contact points

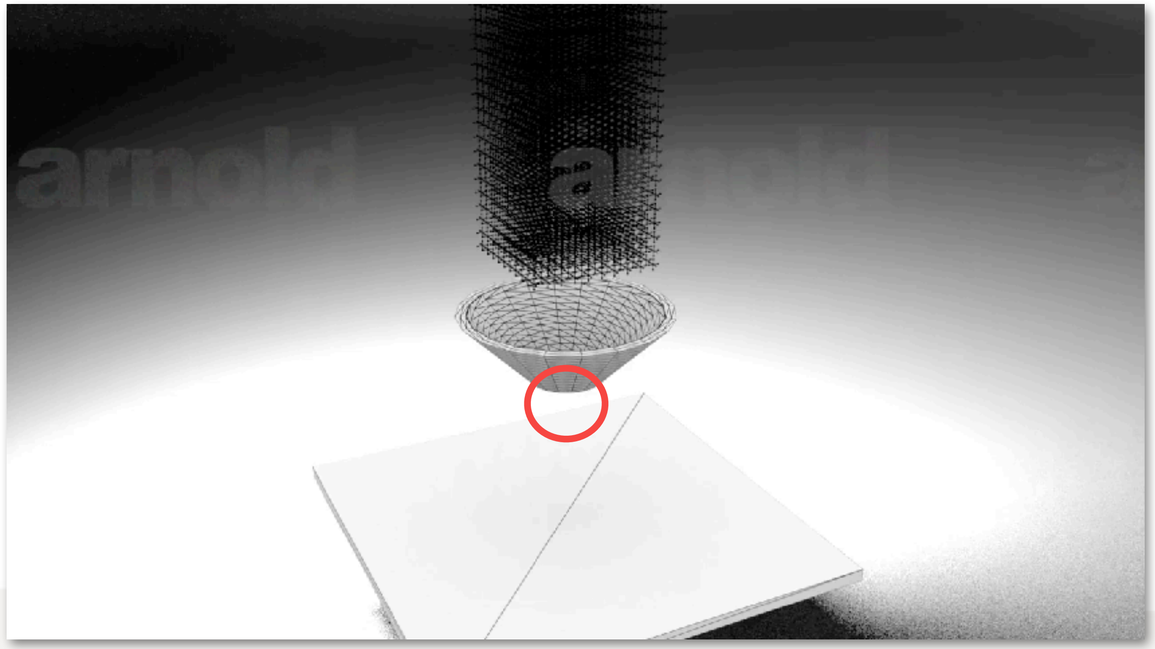
are

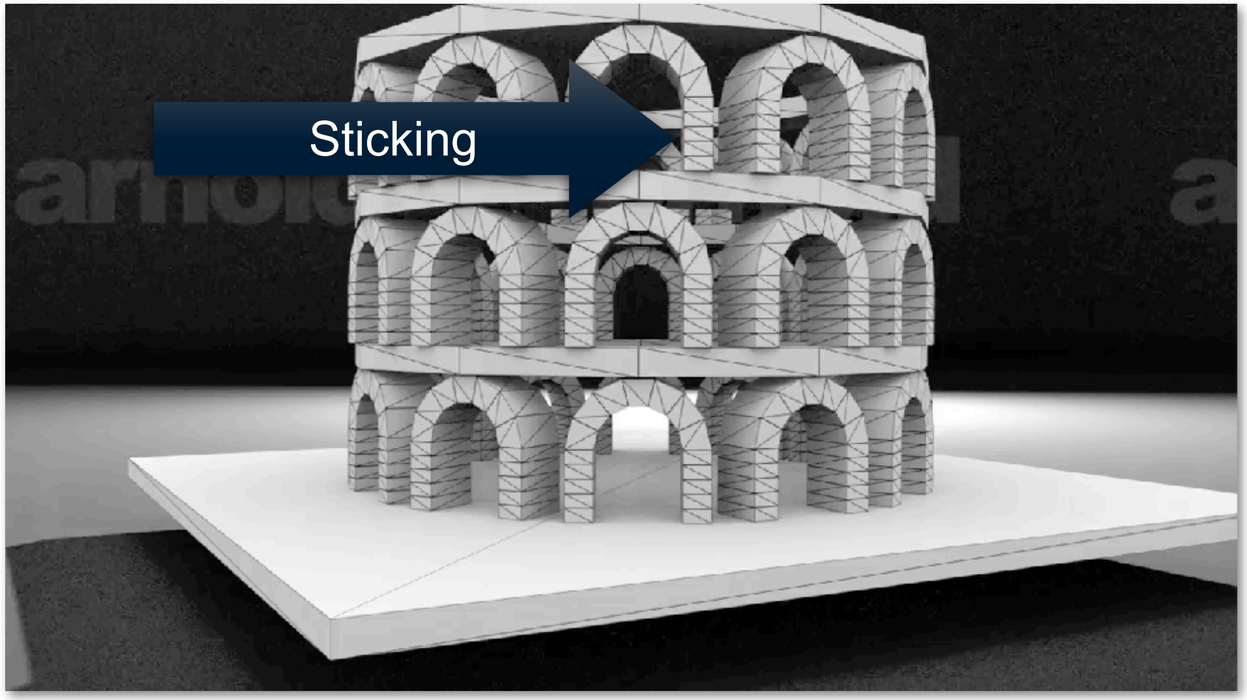
classified by mesh feature pairs

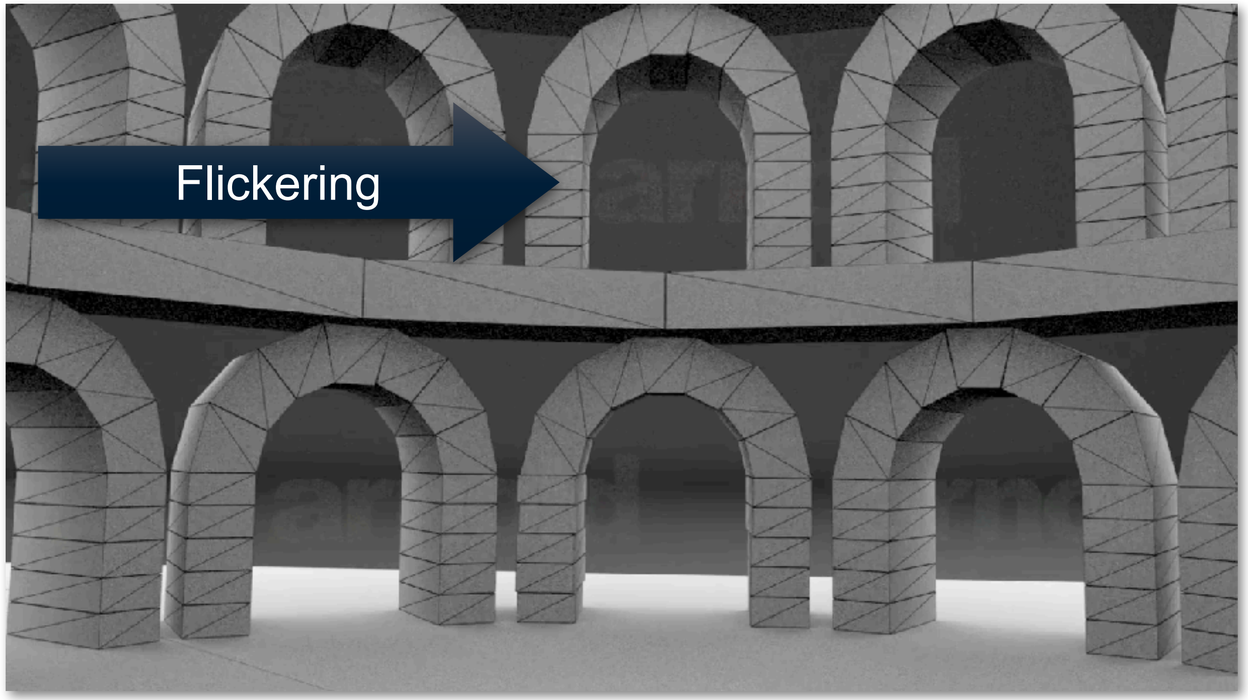









Sticking


Flickering

FULL SPECTRUM OF LOCAL METHODS

Method Name	Taxonomy Classification
Growth	Volume-based, exact geometry, normals from closest points, continuous.
Opposing	Volume-based, approximate geometry, normals from features, discrete.
Intersection	Surface-based testing, normals from feature types, discrete.
Closest points	Surface-based testing, normals from closest points, discrete.
Vertex only	Volume-based testing, approximate geometry, normals from volumetric elements/implicit fields, discrete.
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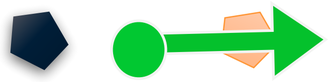

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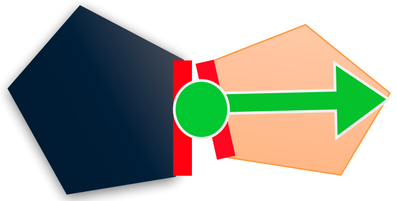

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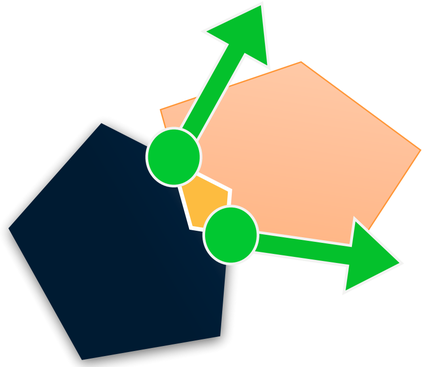

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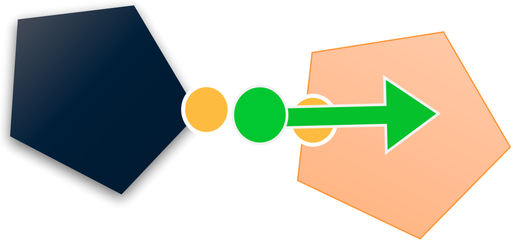

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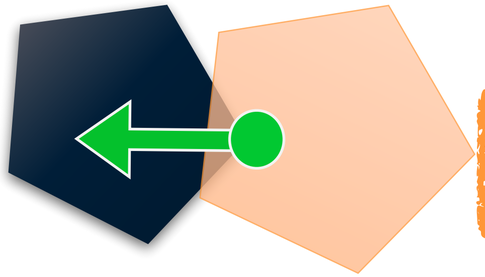

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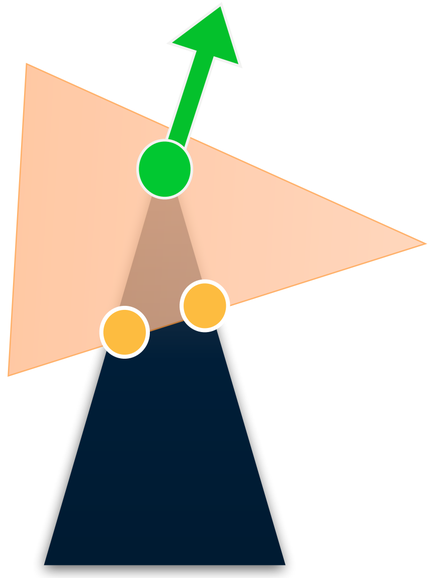

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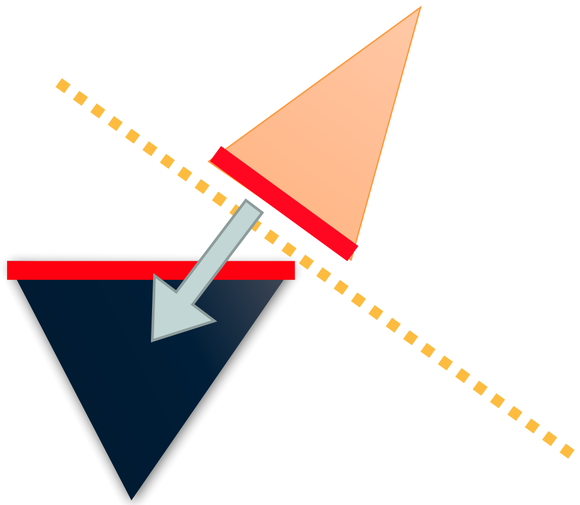

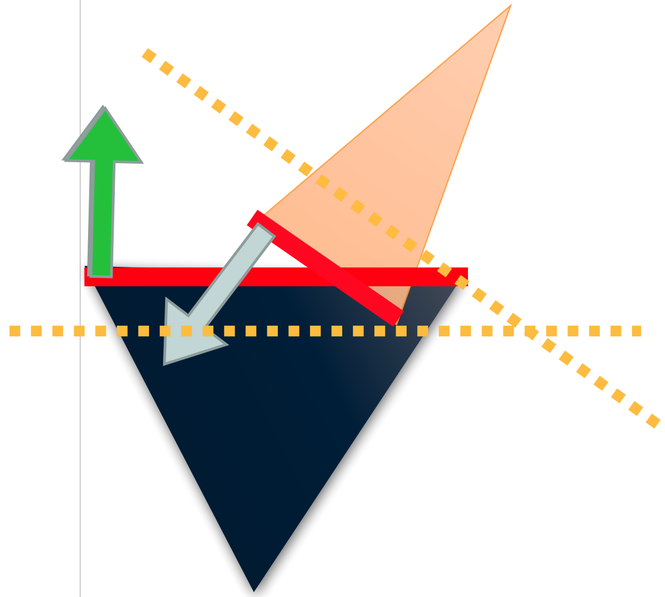

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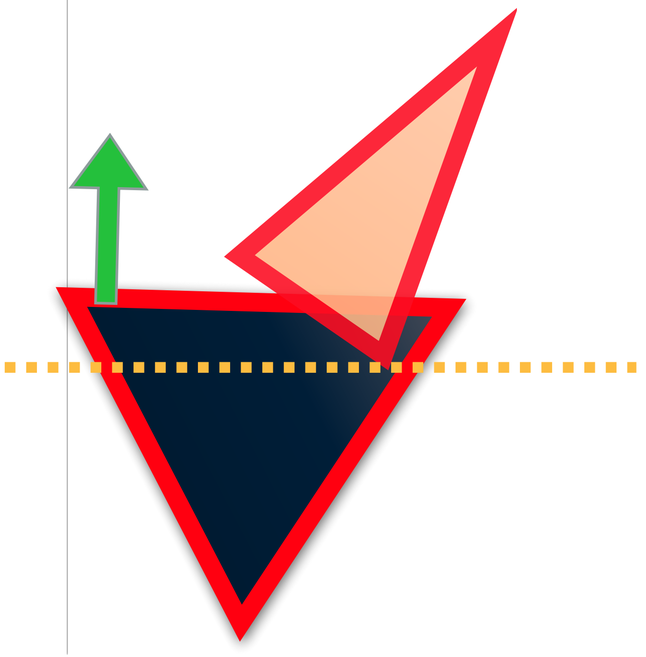
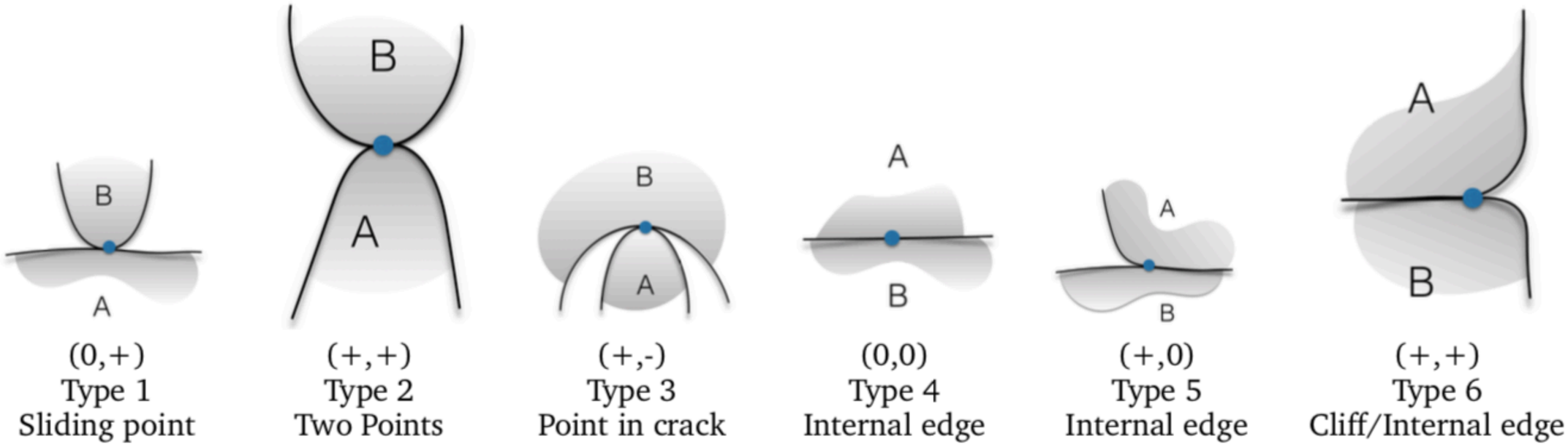
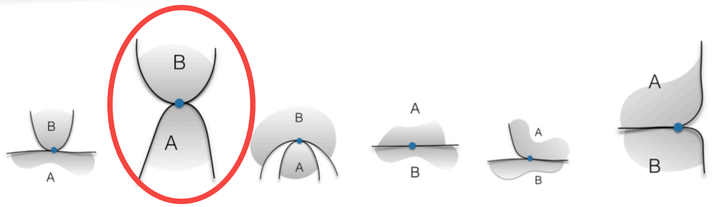


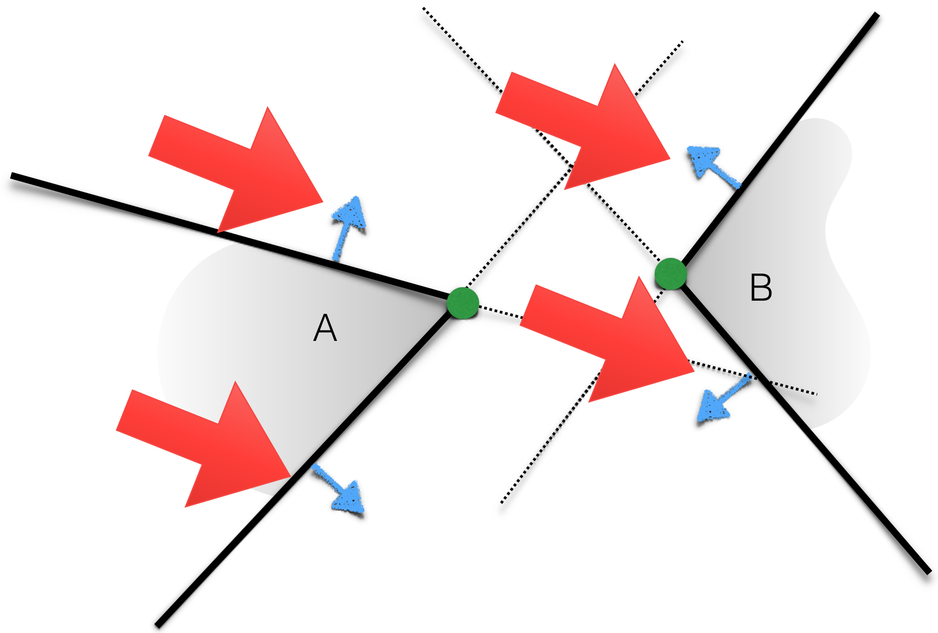
FUNDAMENTAL CASES

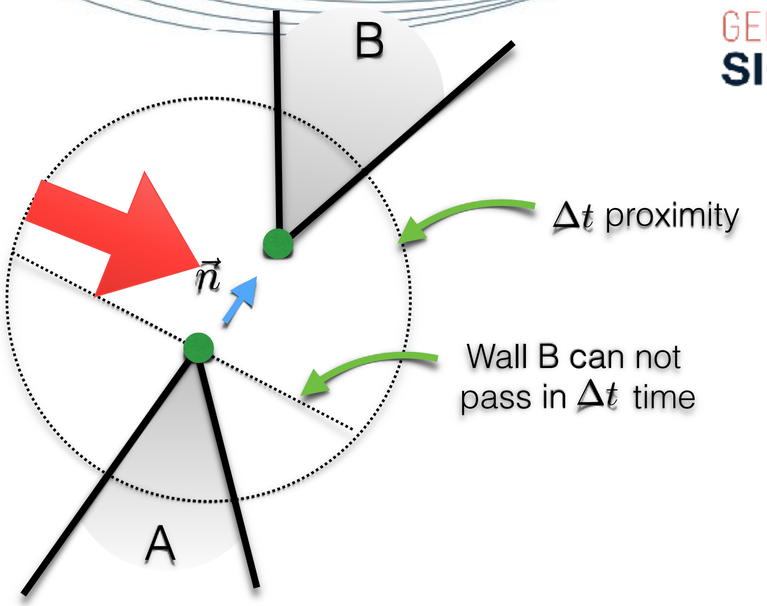
All possible curvature combinations in 2D

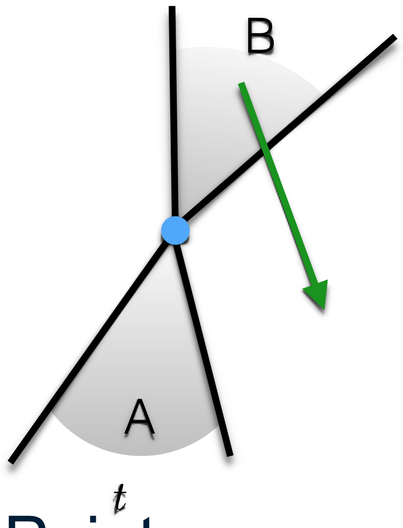


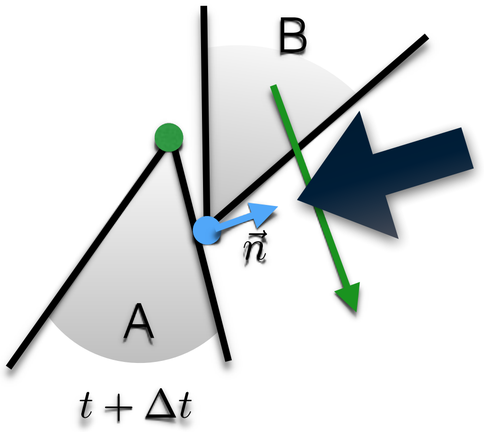
Results in necessary set of 3D counter cases


B
A
B
A
A
B
A
B
A
B

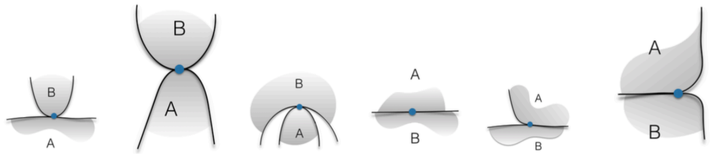

A
B

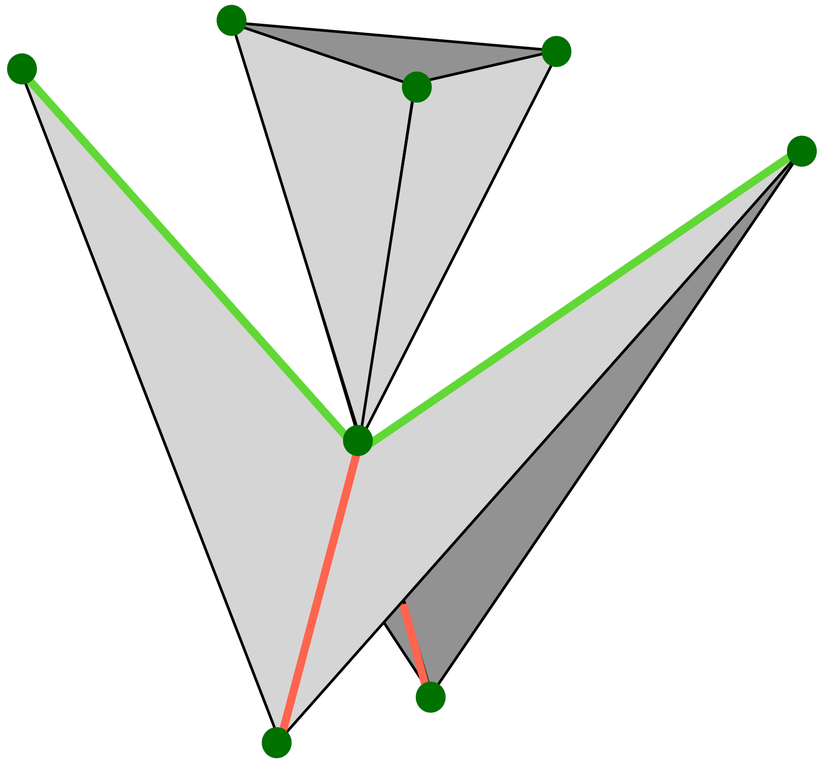

B
$\vec{n}$
Δt proximity
Wall B can not
pass in Δt time
A

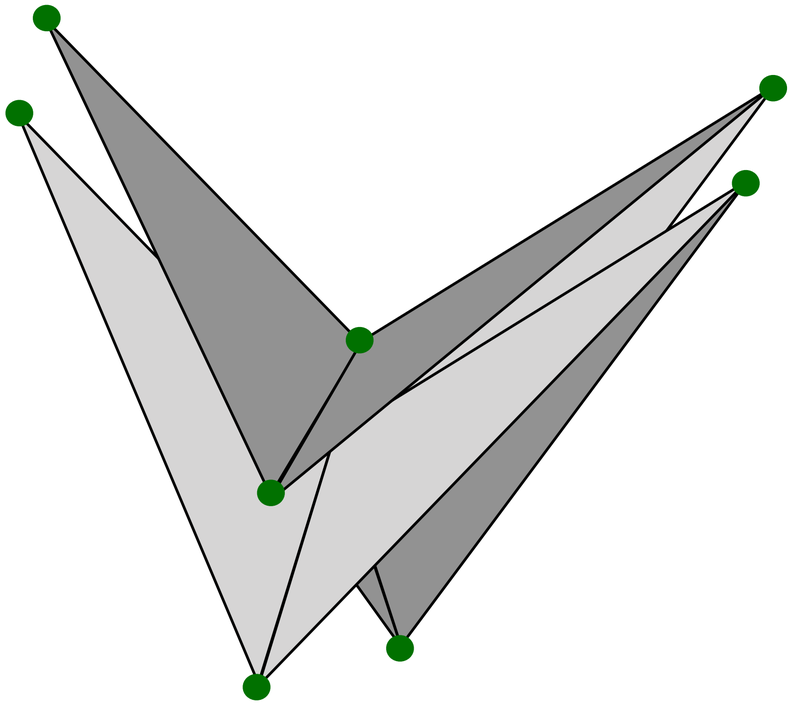

B
A
t


B
$\vec{n}$
A
$t + \Delta t$

Two Points

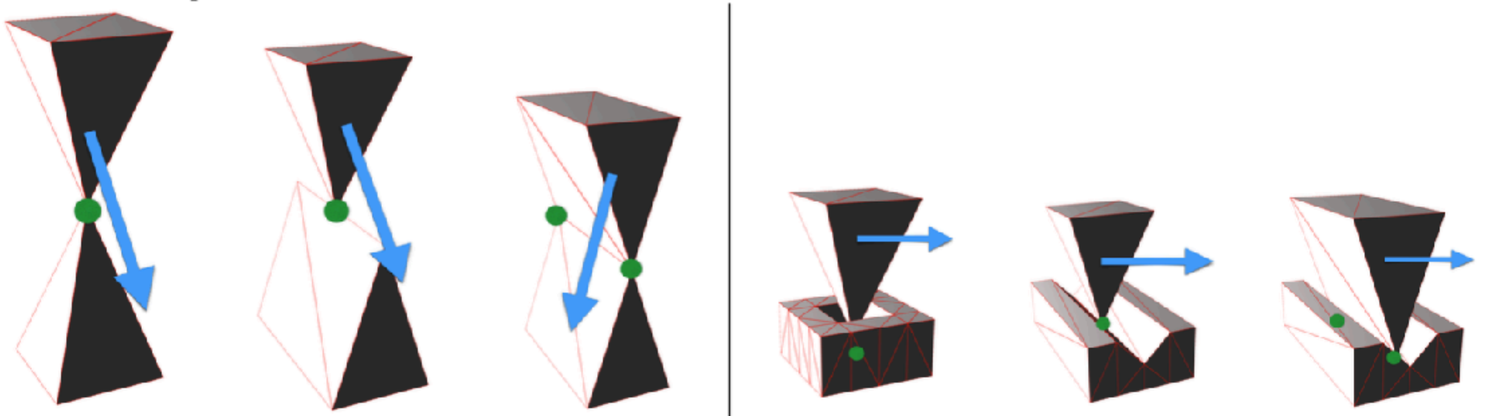






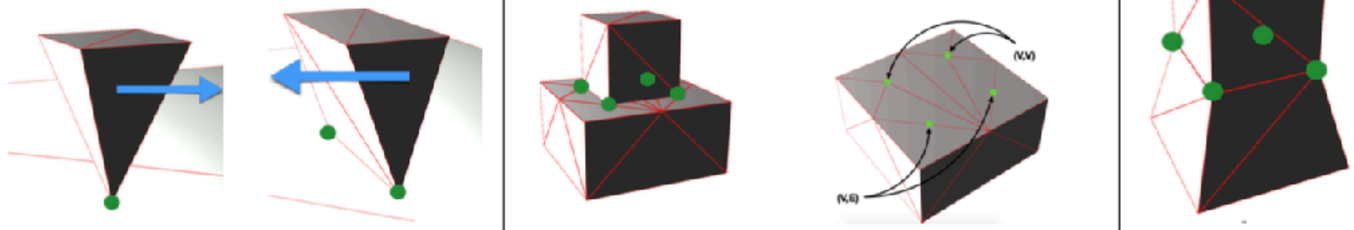
Mixed curvature cases in 3D are not covered

Two points (Strict convex cases) | Point in crack (Non-convex cases)



Spikes	Spike & wedge	Wedges	Spike in hole	Spike in crack	Wedge in crack
$(\gamma, \beta, 0)$ $(-\gamma, \beta, 0)^{\dagger}$ $(0, \gamma, \beta)^{\top}$ $(0, -\gamma, \beta)^{\dagger}$	$(\gamma, \beta, 0)$ $(-\gamma, \beta, 0)^{\dagger}$	$(-\gamma, \beta, 0)$ $(\gamma, \beta, 0)^{\dagger}$	$(0, \alpha, \alpha)$ $(0, \alpha, -\alpha)$ $(\alpha, \alpha, 0)$ $(-\alpha, \alpha, 0)$	$(\alpha, \alpha, 0)$ $(-\alpha, \alpha, 0)$	$(\alpha, \alpha, 0)$ $(-\alpha, \alpha, 0)$
1	1	2	4	2	4

Sliding point (Flat cases) | Internal edges | Cliff edges

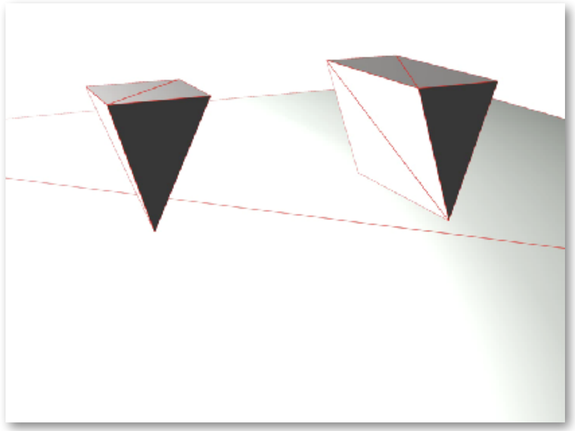


Sliding spike	Sliding wedge		Mesh Connectivity ‡	
$(0, 1, 0)$	$(0, 1, 0)$	$(0, 1, 0)$	$2 \times (V, V)$ & $2 \times (V, E)$	$(0, 1, 0)$
1	2	4		4

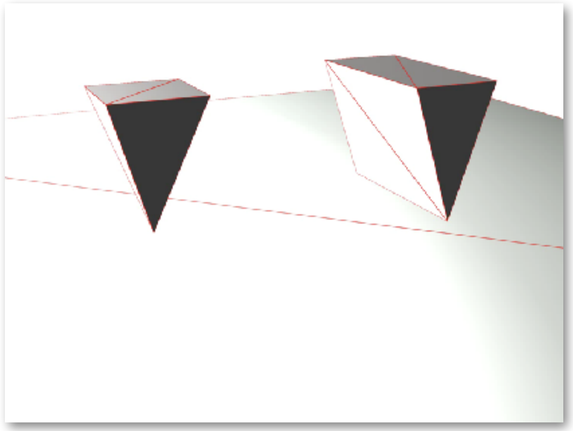
By construction we know minimal number of contacts and ideal normal directions

SLIDING POINT

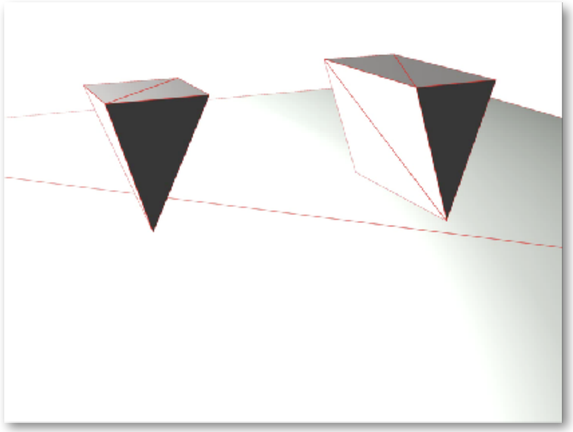
Closest points



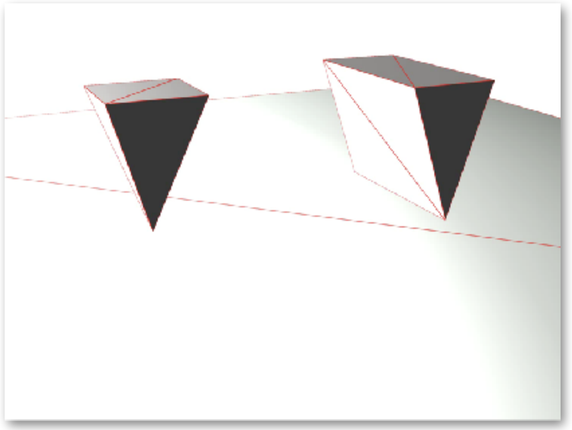
Consistent vertex

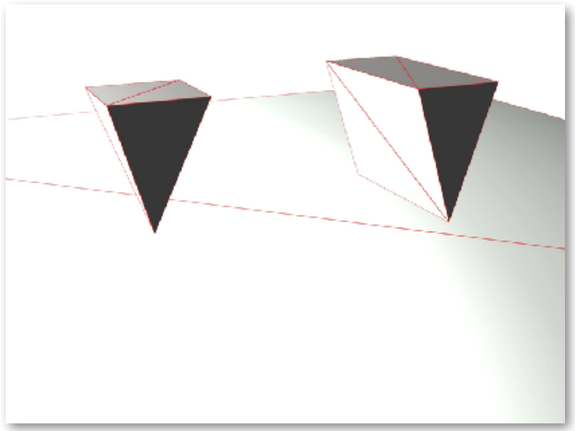


Growth

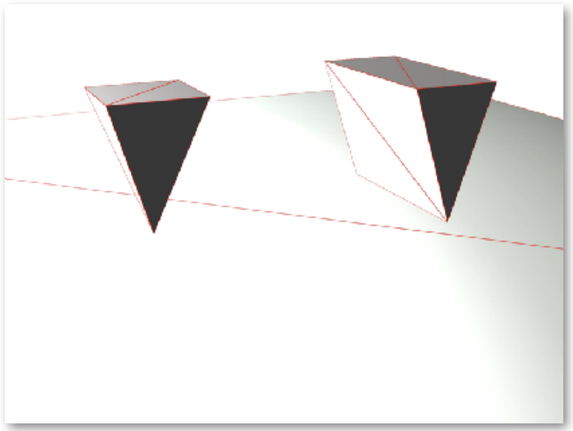


Intersection

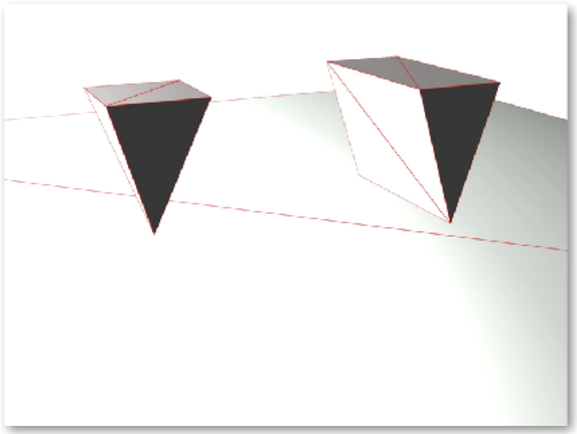




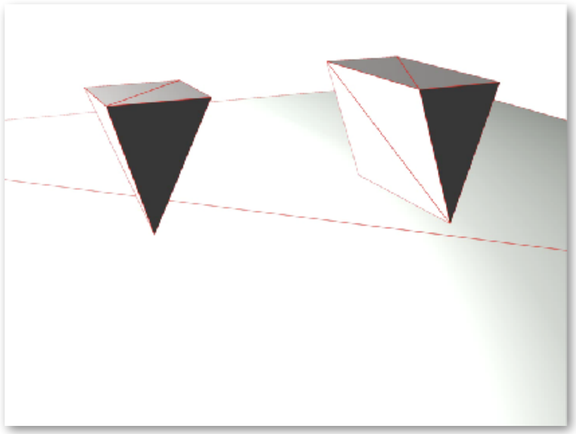
Opposing



Surface SAT



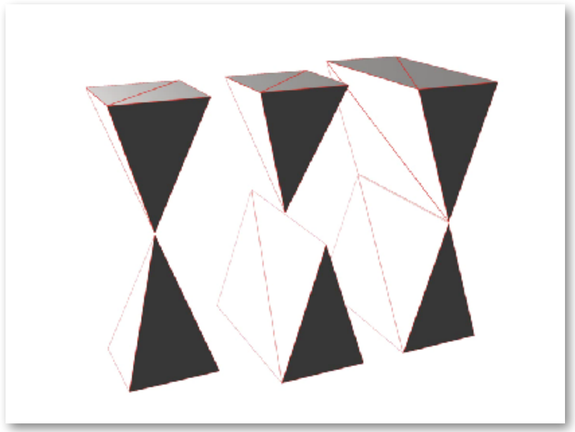
Vertex only



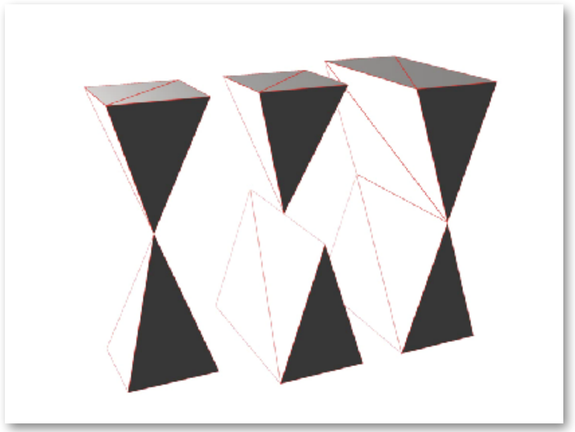
Volume SAT

TWO POINTS

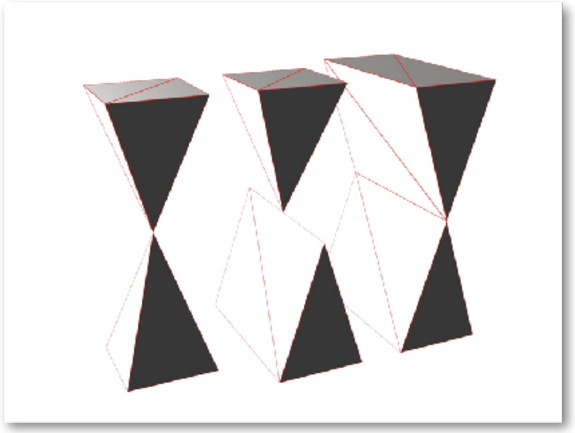
Closest points



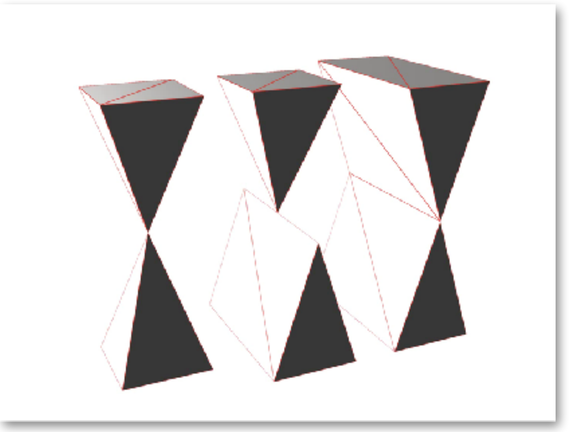
Consistent vertex

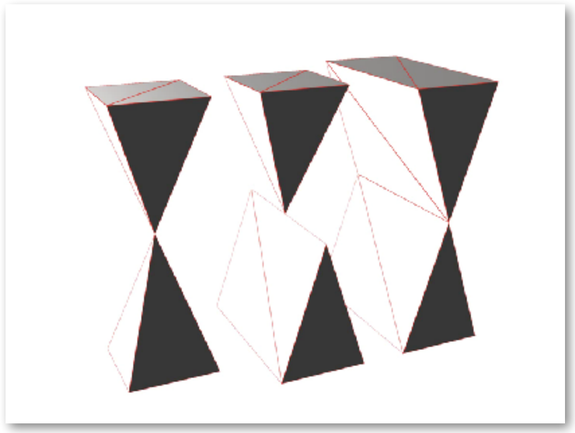


Growth

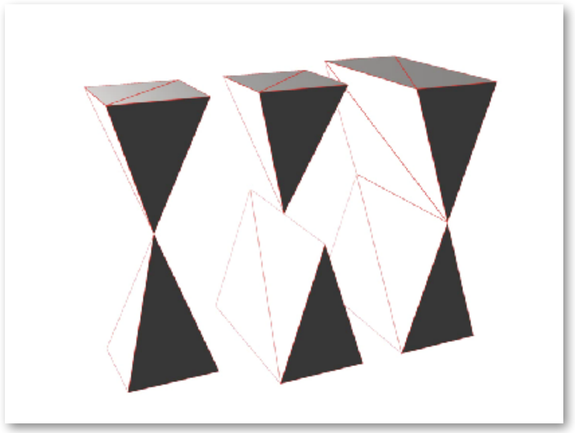


Intersection

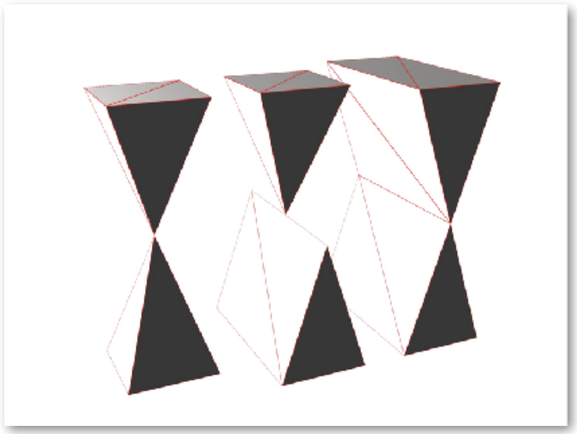




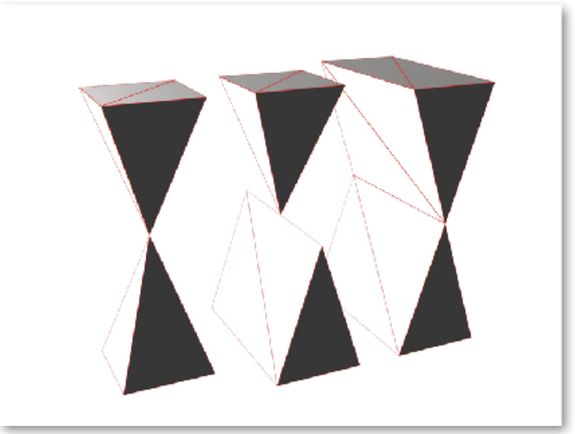
Opposing



Surface SAT



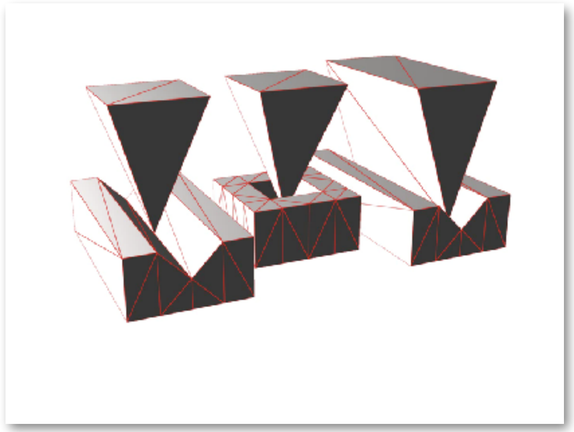
Vertex only



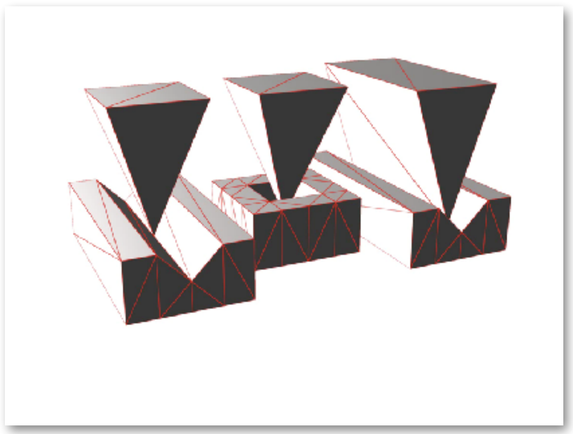
Volume SAT

POINT IN CRACK

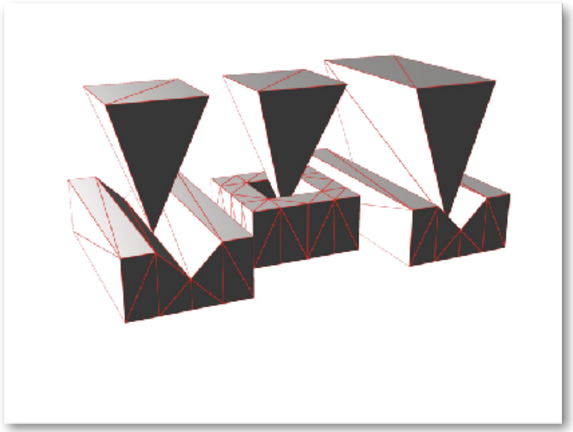
Closest points



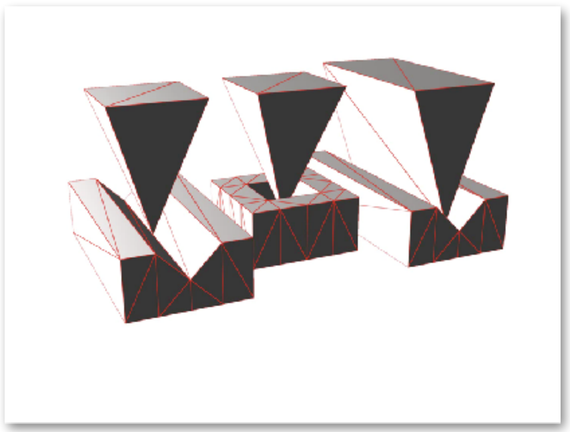
Consistent vertex

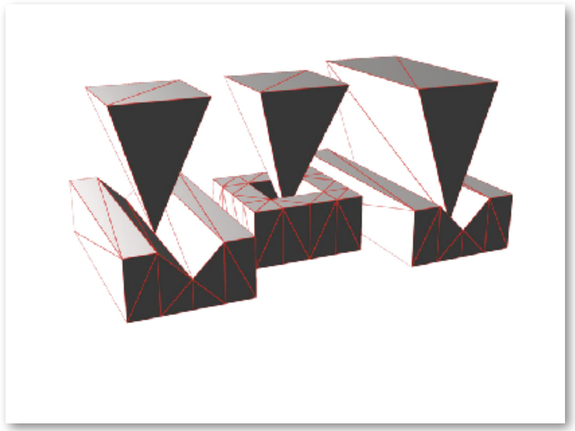


Growth

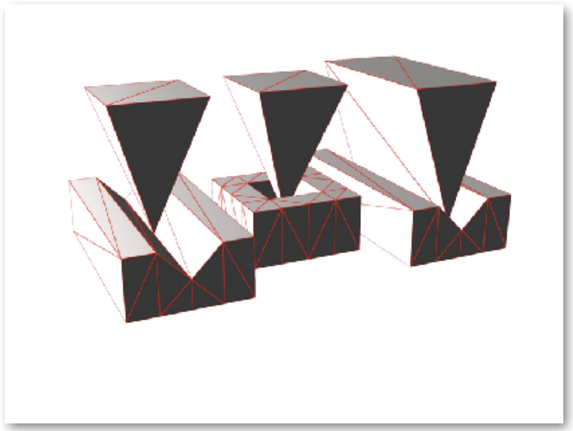


Intersection

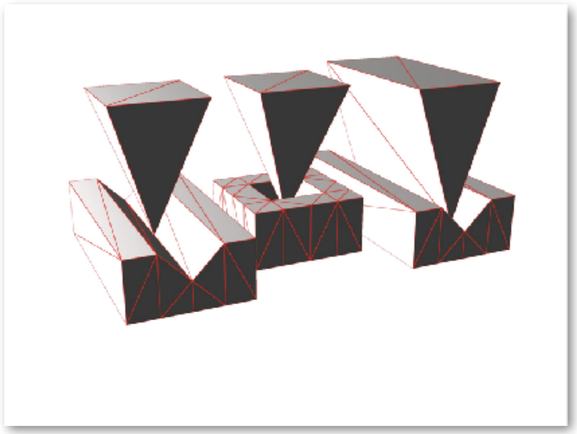




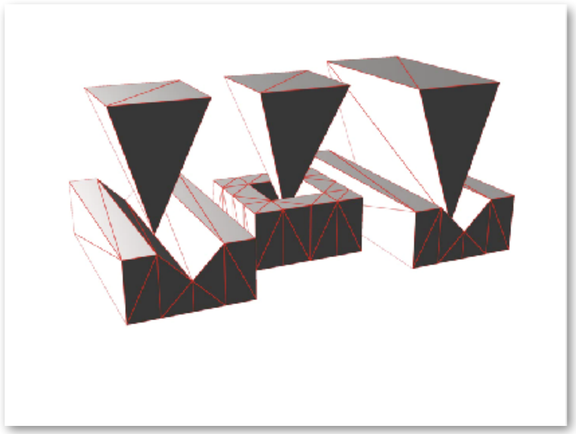
Opposing



Surface SAT



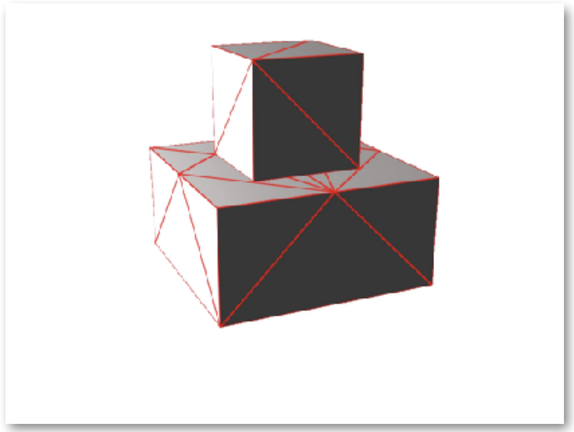
Vertex only



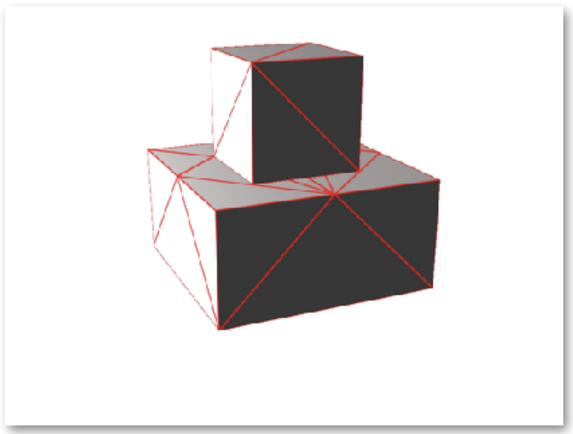
Volume SAT

INTERNAL EDGES

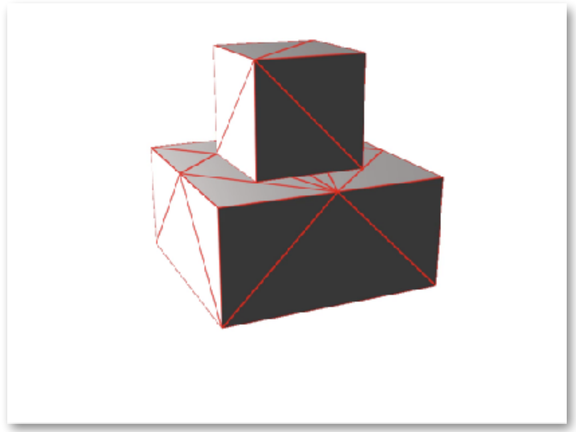
Closest points



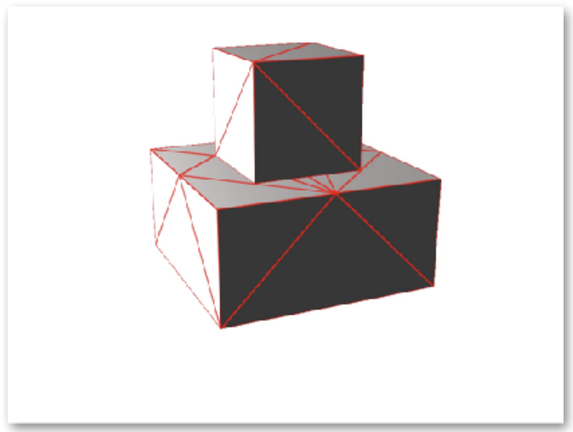
Consistent vertex

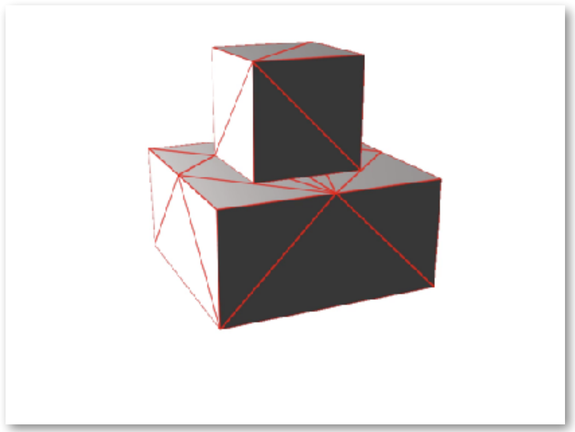


Growth

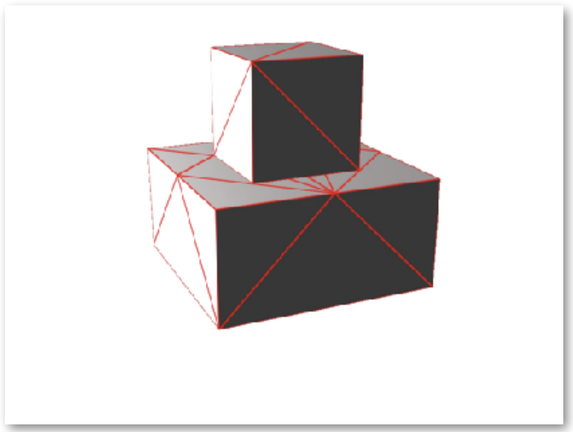


Intersection

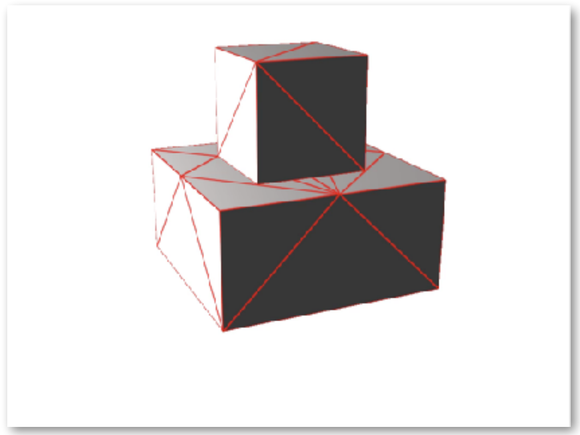




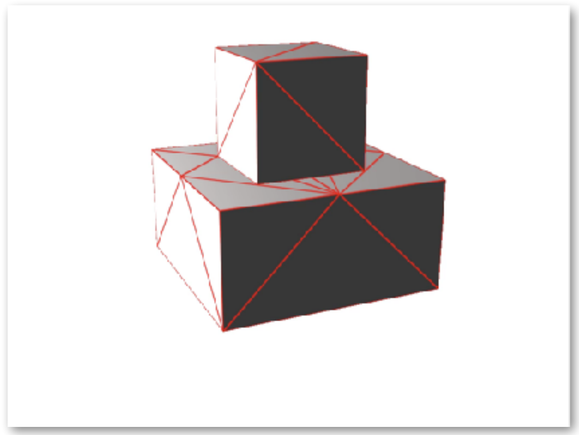
Opposing



Surface SAT



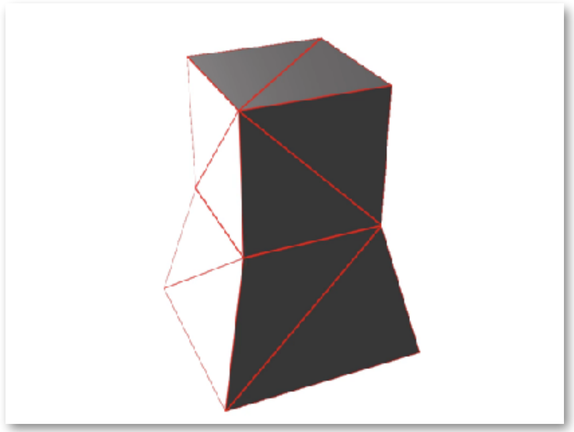
Vertex only



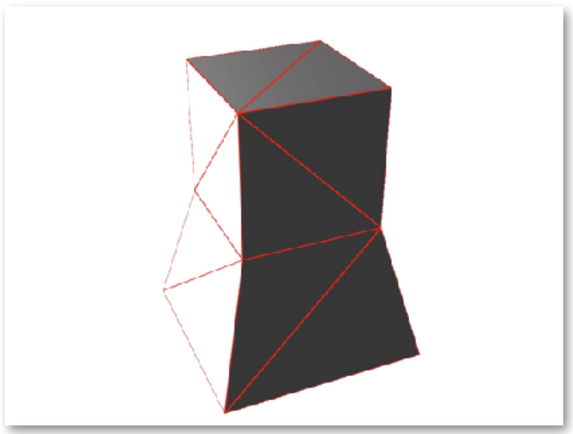
Volume SAT

CLIFF EDGES

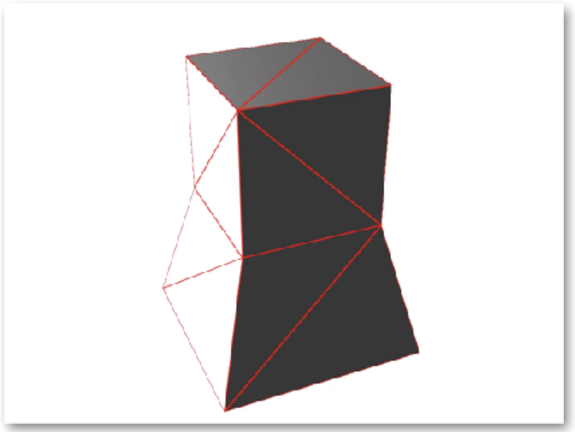
Closest points



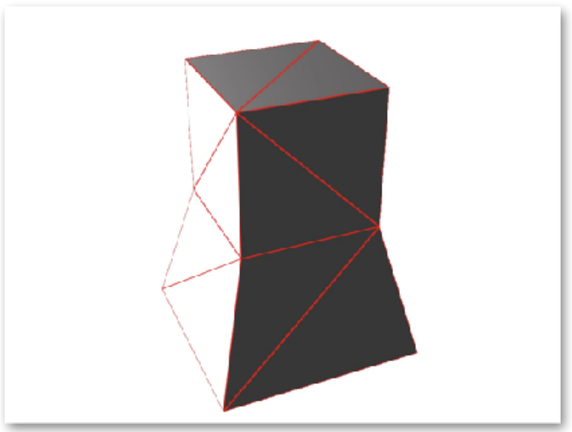
Consistent vertex

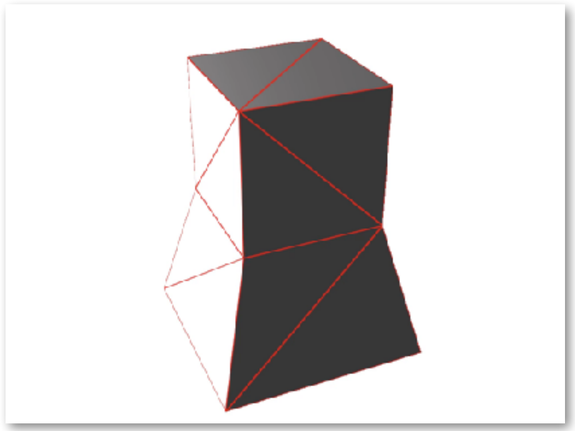


Growth

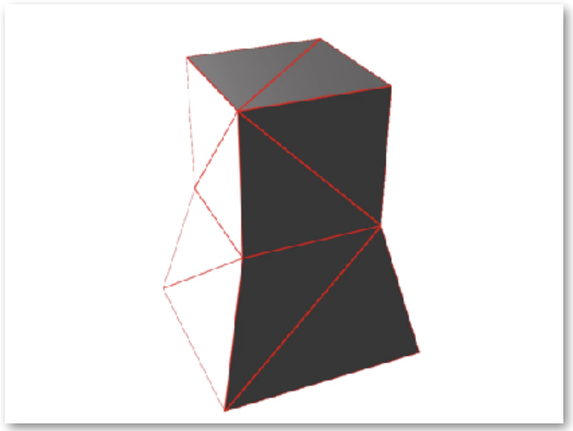


Intersection

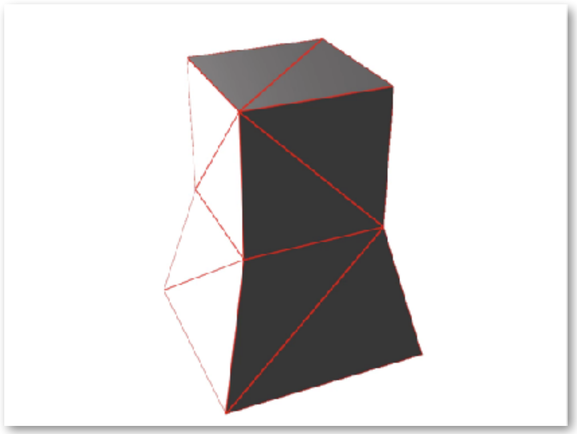




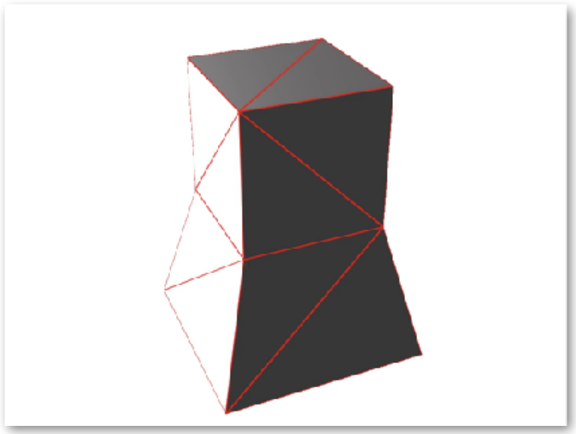
Opposing



Surface SAT



Vertex only



Volume SAT

Method Name	Spike in crack	Spike in hole	Wedge in crack	Sliding spike	Sliding wedge	Spikes	Spike and wedge	Wedges	Cliff edges	Internal edges
					Coverage (%)					
Closest points	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	100.0	100.0
Intersection	0.0	0.0	0.0	0.0	0.0	100.0	100.0	0.0	100.0	100.0
Vertex only	50.0	0.0	50.0	100.0	100.0	0.0	0.0	0.0	100.0	100.0
Consistent vertex	50.0	0.0	50.0	100.0	100.0	0.0	100.0	100.0	100.0	100.0
Volume-SAT	50.0	25.0	50.0	100.0	100.0	0.0	0.0	0.0	100.0	100.0
Surface-SAT	50.0	25.0	50.0	100.0	100.0	0.0	0.0	0.0	100.0	100.0
Growth	50.0	25.0	50.0	100.0	100.0	0.0	0.0	0.0	100.0	100.0
Opposing	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
					Quality (%)					
Closest points	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	62.5	58.3
Intersection	0.0	0.0	0.0	0.0	0.0	10.0	33.3	0.0	55.6	50.0
Vertex only	100.0	0.0	100.0	100.0	100.0	0.0	0.0	0.0	60.0	83.3
Consistent vertex	100.0	0.0	100.0	100.0	100.0	0.0	50.0	25.0	50.0	100.0
Volume-SAT	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	61.5	65.2
Surface-SAT	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	70.0	83.3
Growth	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	37.5	63.0
Opposing	0.0	0.0	0.0	100.0	100.0	22.2	55.6	47.4	73.5.0	93.3
					Excess (%)					
Closest points	1.0	1.0	1.0	1.0	1.0	10.0	3.0	3.5	2.0	3.0
Intersection	0.5	1.2	1.5	3.0	0.5	20.0	6.0	3.5	2.2	3.0
Vertex only	0.5	(*)	0.5	1.0	0.5	2.0	1.0	1.0	1.2	1.5
Consistent vertex	0.5	(*)	0.5	1.0	0.5	4.0	2.0	2.0	1.5	1.0
Volume-SAT	2.0	1.8	2.2	5.0	1.0	14.0	9.0	8.5	3.2	5.8
Surface-SAT	2.0	1.8	2.2	5.0	1.0	14.0	9.0	9.0	2.5	4.5
Growth	2.0	2.2	1.5	5.0	1.0	15.0	11.0	10.5	6.0	6.8
Opposing	3.0	2.2	1.8	5.0	1.0	18.0	9.0	9.5	8.5	3.8

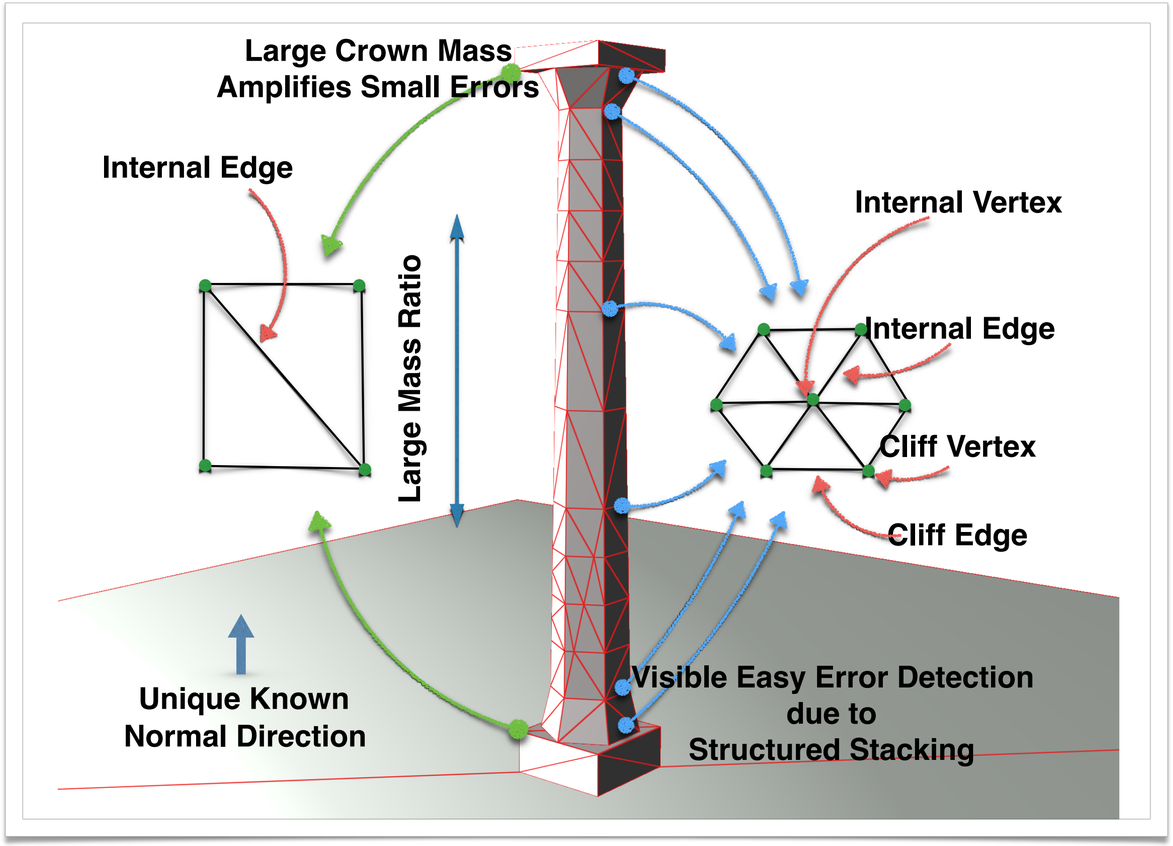
Results show no clear winner

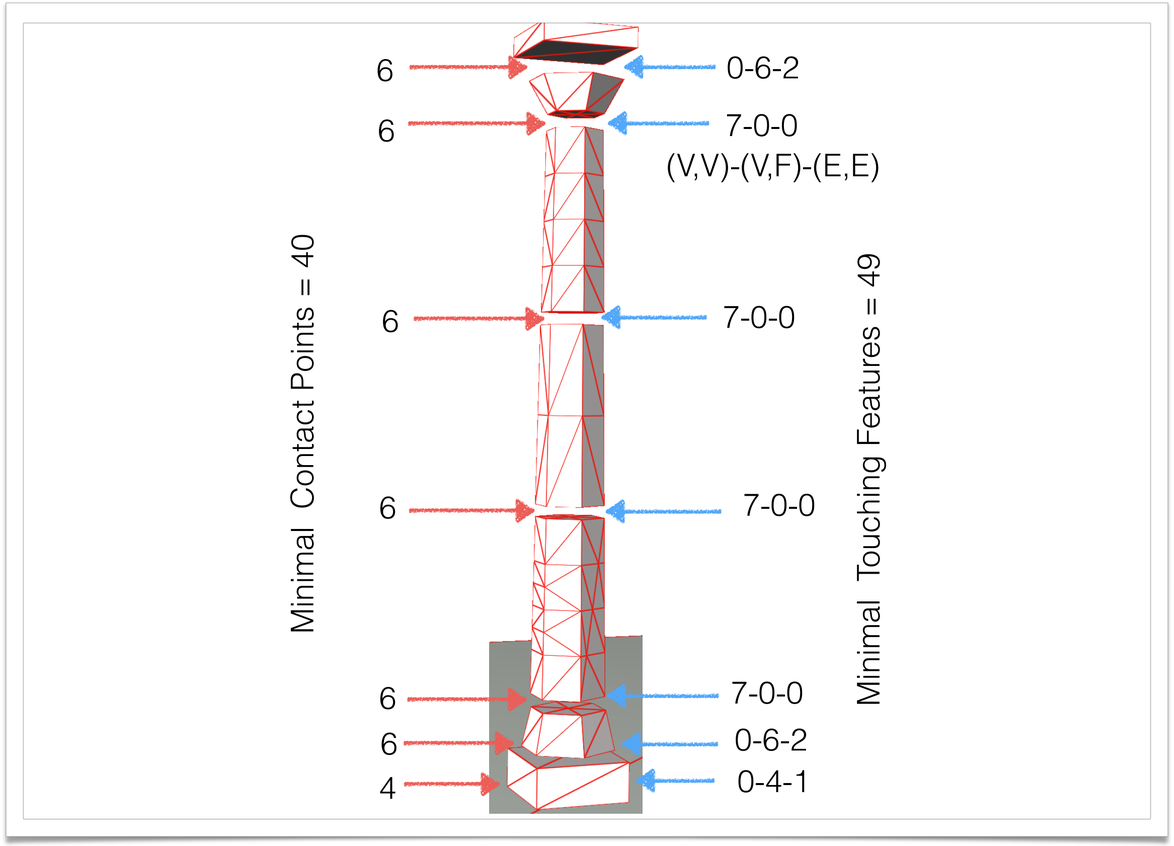
Closest points and Opposing have best coverage but are not perfect

Closest points, SATs, and Growth have best normal quality but are not perfect

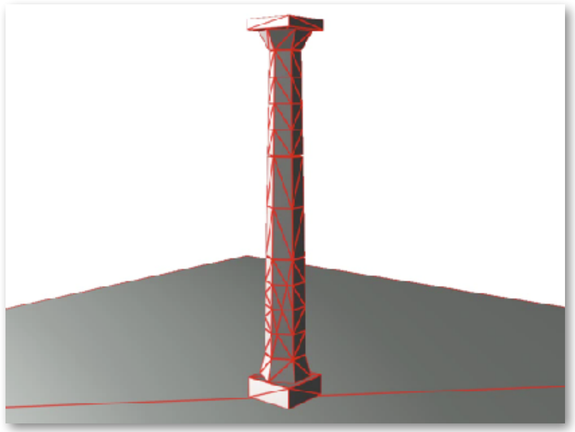
Closest points has best excess, Growth and Opposing can have large excess.

THE PILLAR EXAMPLE

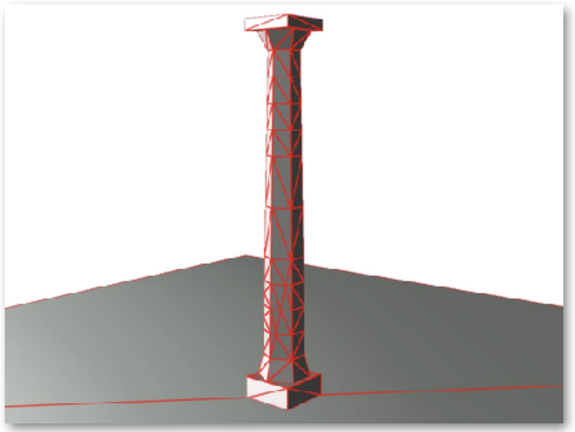

Large Crown Mass
Amplifies Small Errors
Internal Edge
Large Mass Ratio
Internal Vertex
Internal Edge
Cliff Vertex
Cliff Edge
Unique Known
Normal Direction
Visible Easy Error Detection
due to
Structured Stacking


6
6
6
6
6
6
4
0-6-2
7-0-0
(V,V)-(V,F)-(E,E)
7-0-0
7-0-0
7-0-0
0-6-2
0-4-1
Minimal Contact Points = 40
Minimal Touching Features = 49

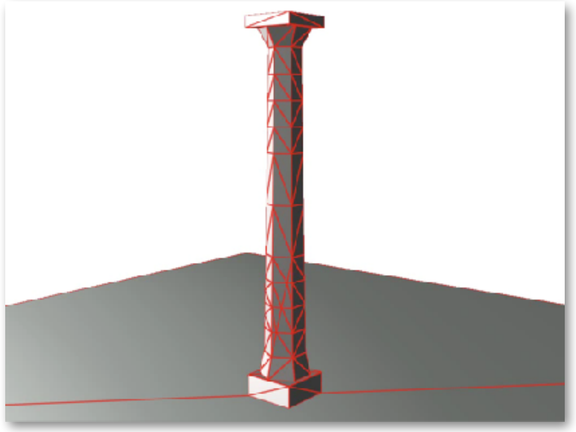
Closest points



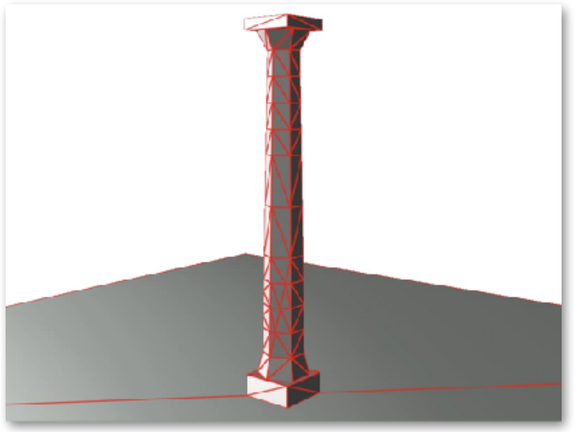
Consistent vertex

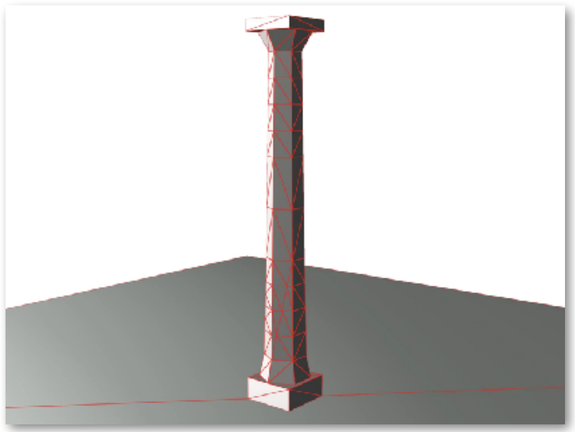


Growth

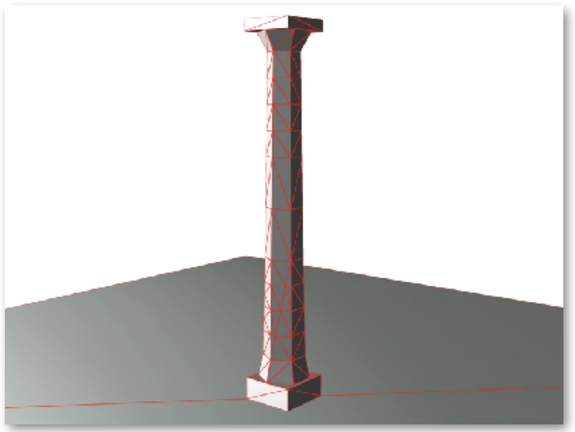


Intersection

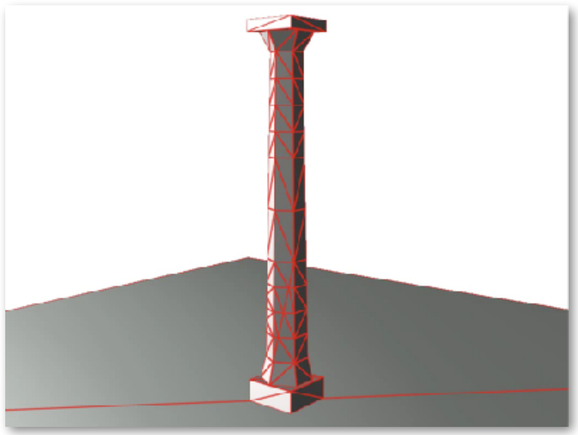




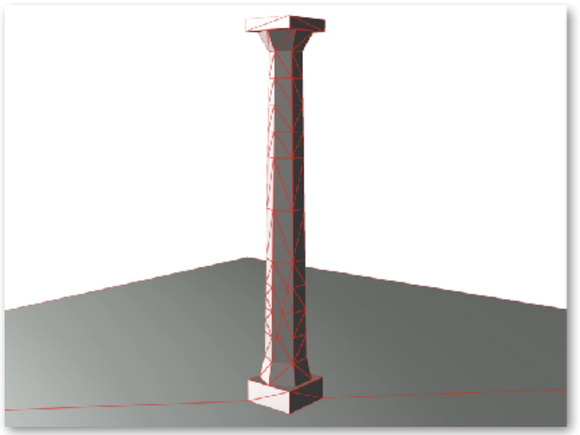
Opposing



Surface SAT

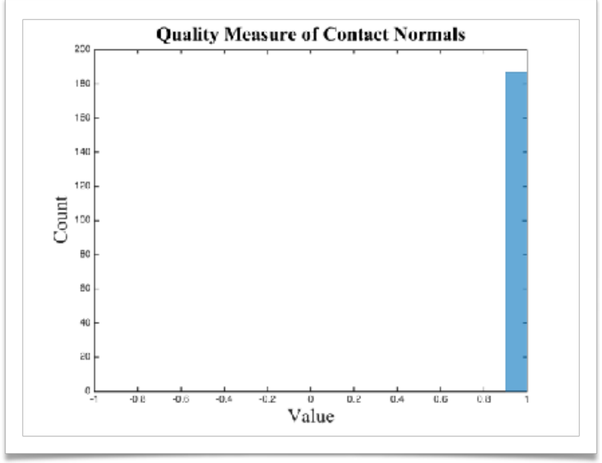


Vertex only

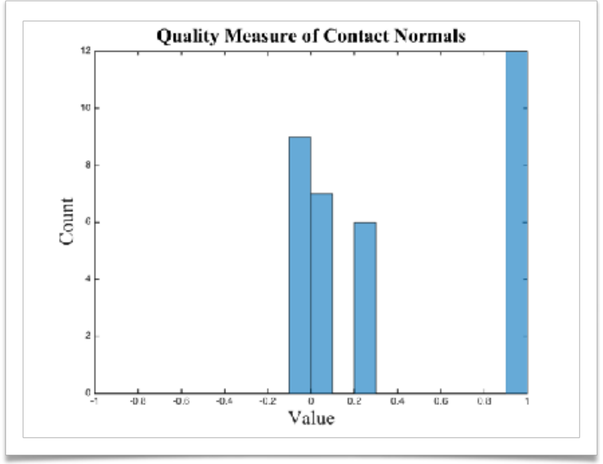


Volume SAT

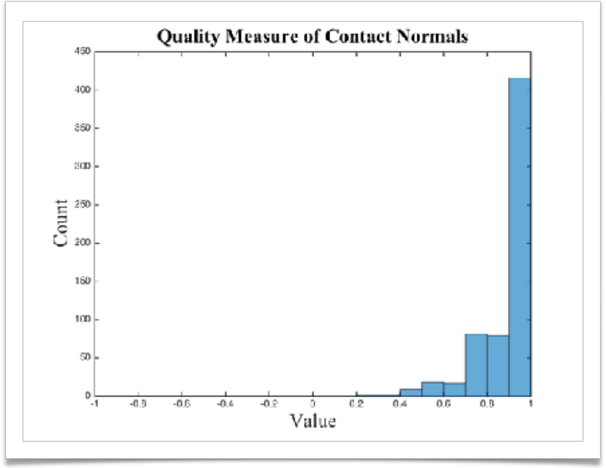
Closest points



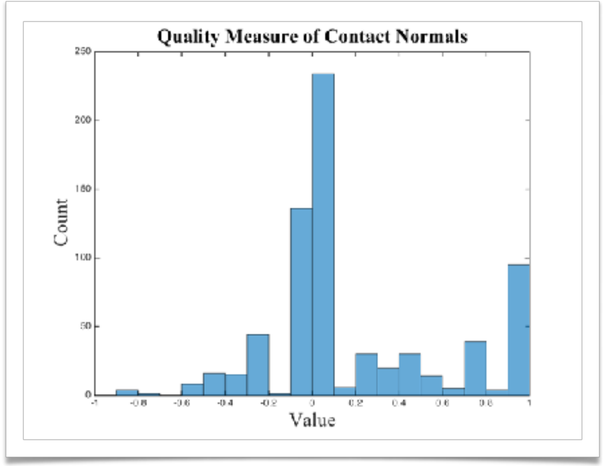
Consistent vertex

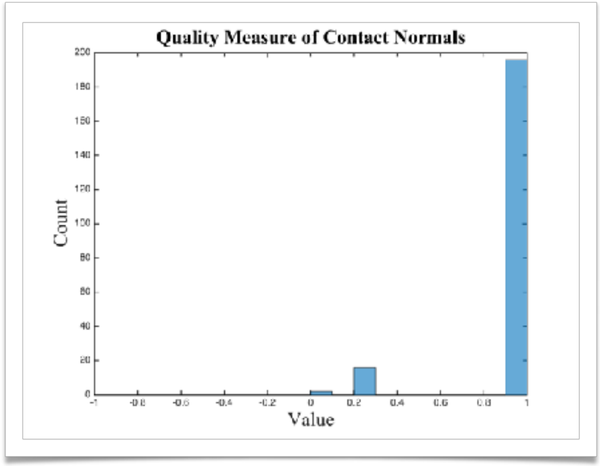


Growth

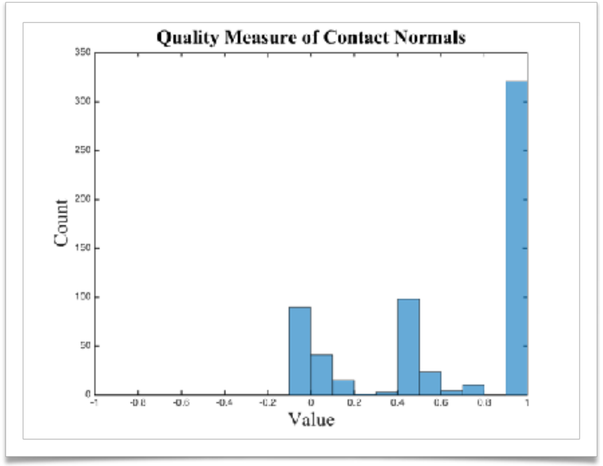


Intersection

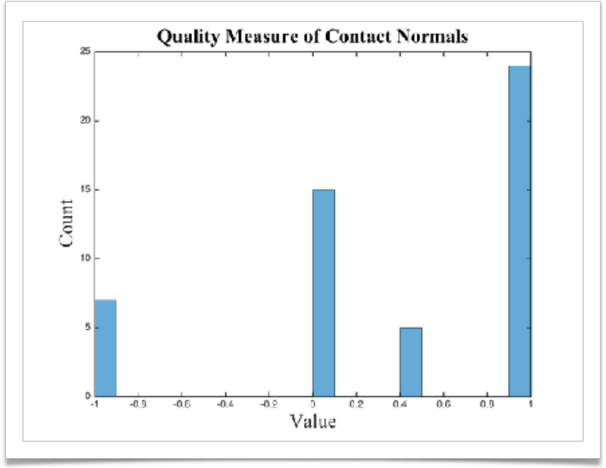




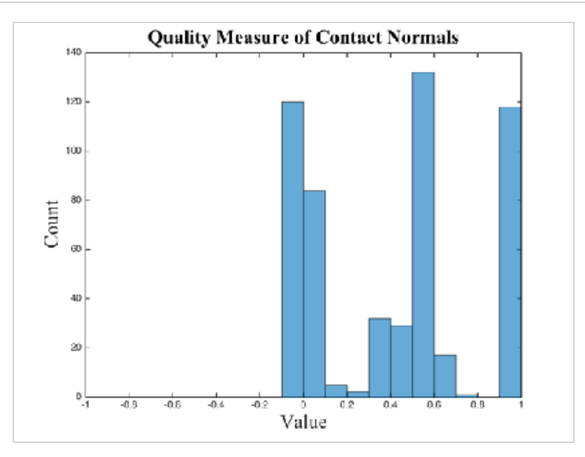
Opposing



Surface SAT

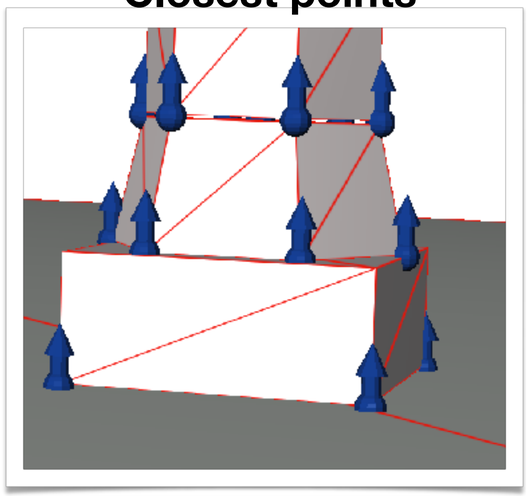


Vertex only

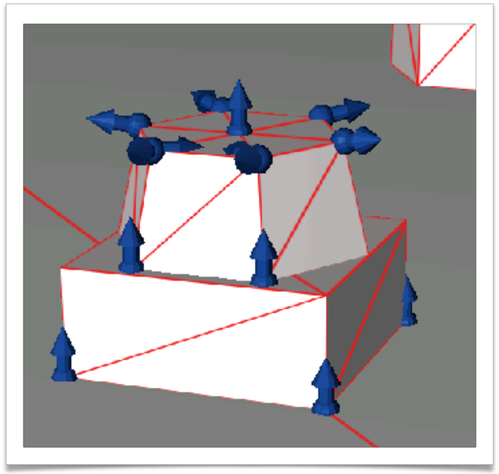


Volume SAT

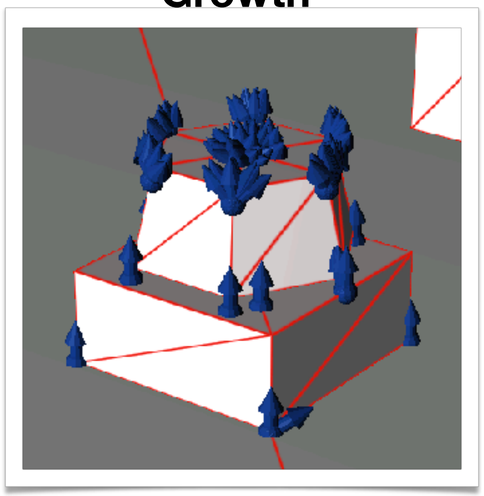
Closest points



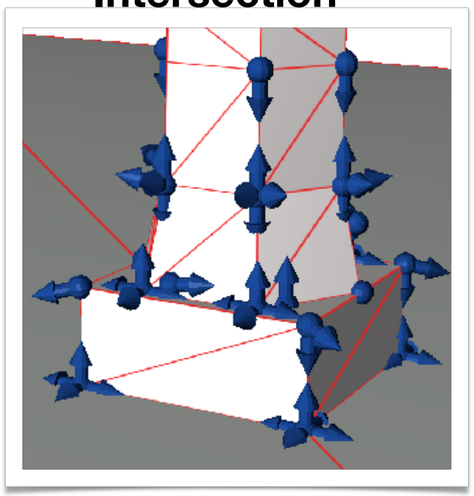
Consistent vertex

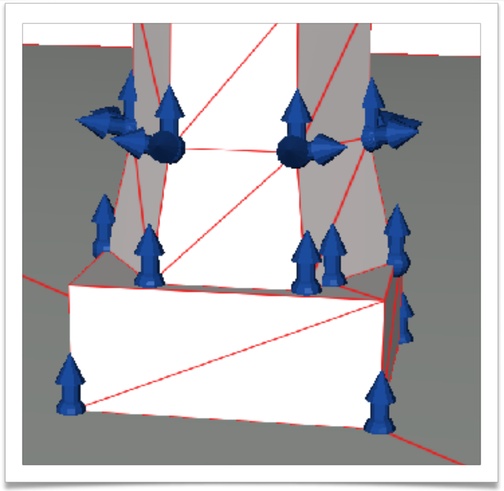


Growth

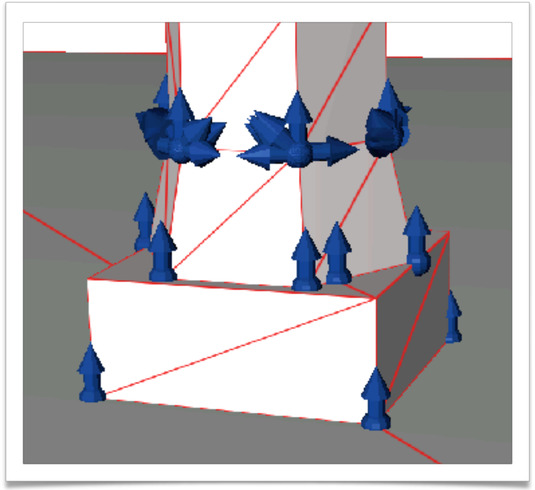


Intersection

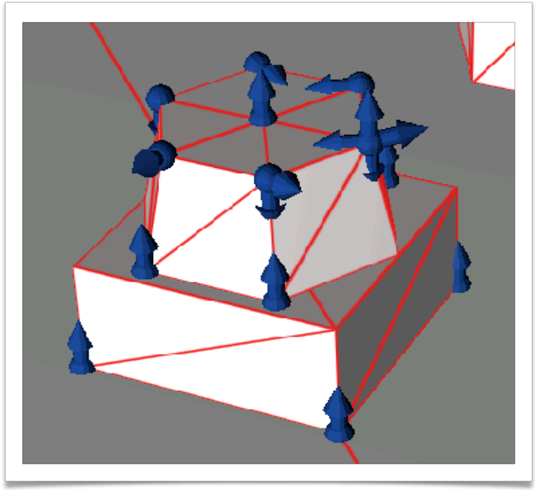




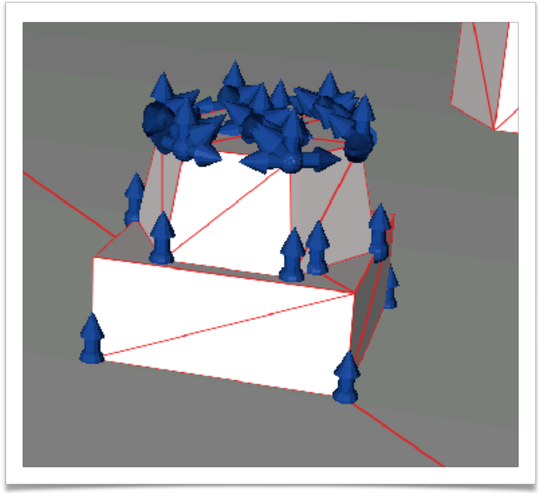
Opposing



Surface SAT



Vertex only



Volume SAT

PARAMETER STUDIES

HIGH RESOLUTION MESHES

We pick subset of local methods that worked well for pillar

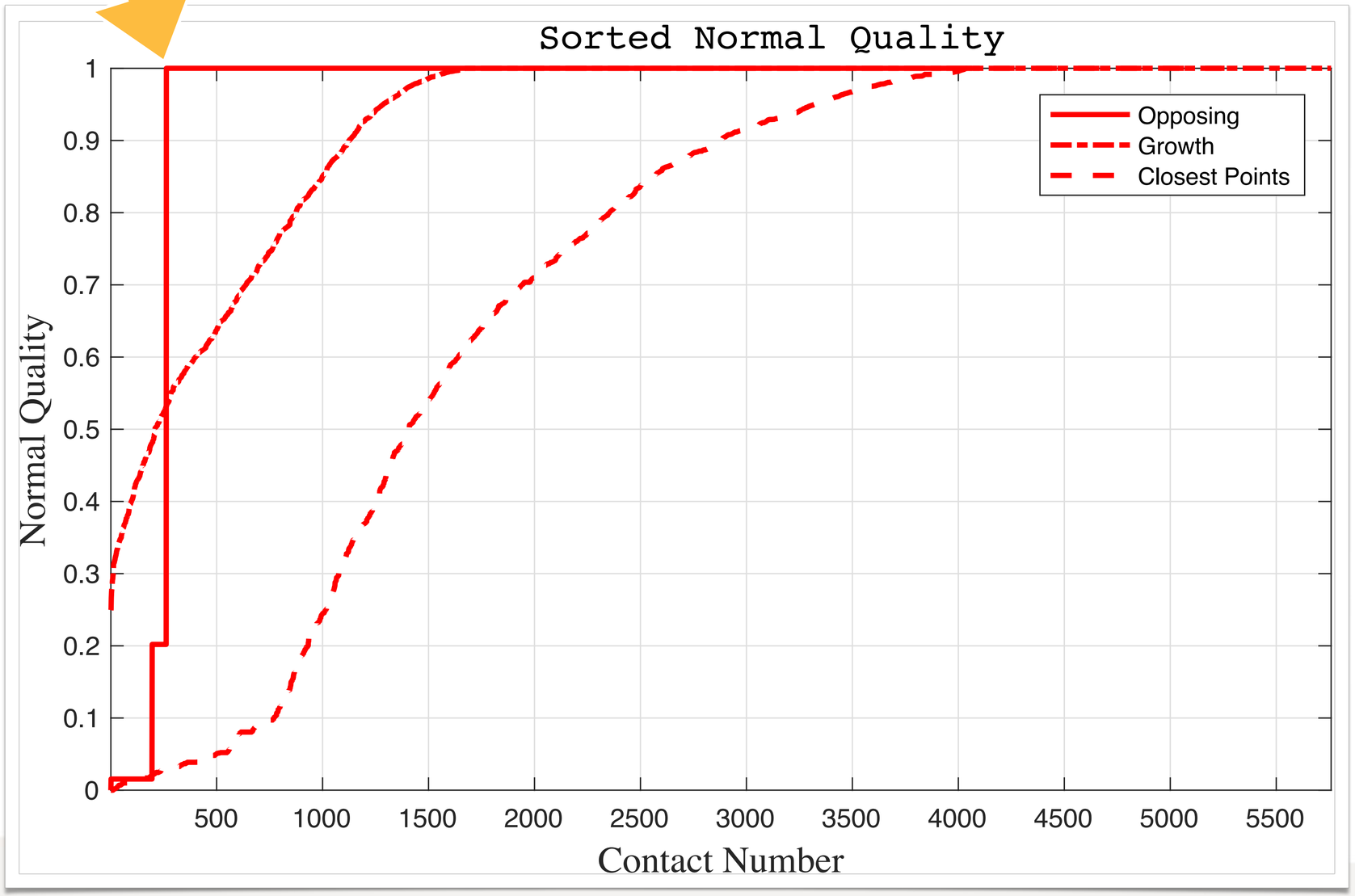
Opposing

Growth

Closest points

EFFECT ON HIGH RESOLUTION MESH

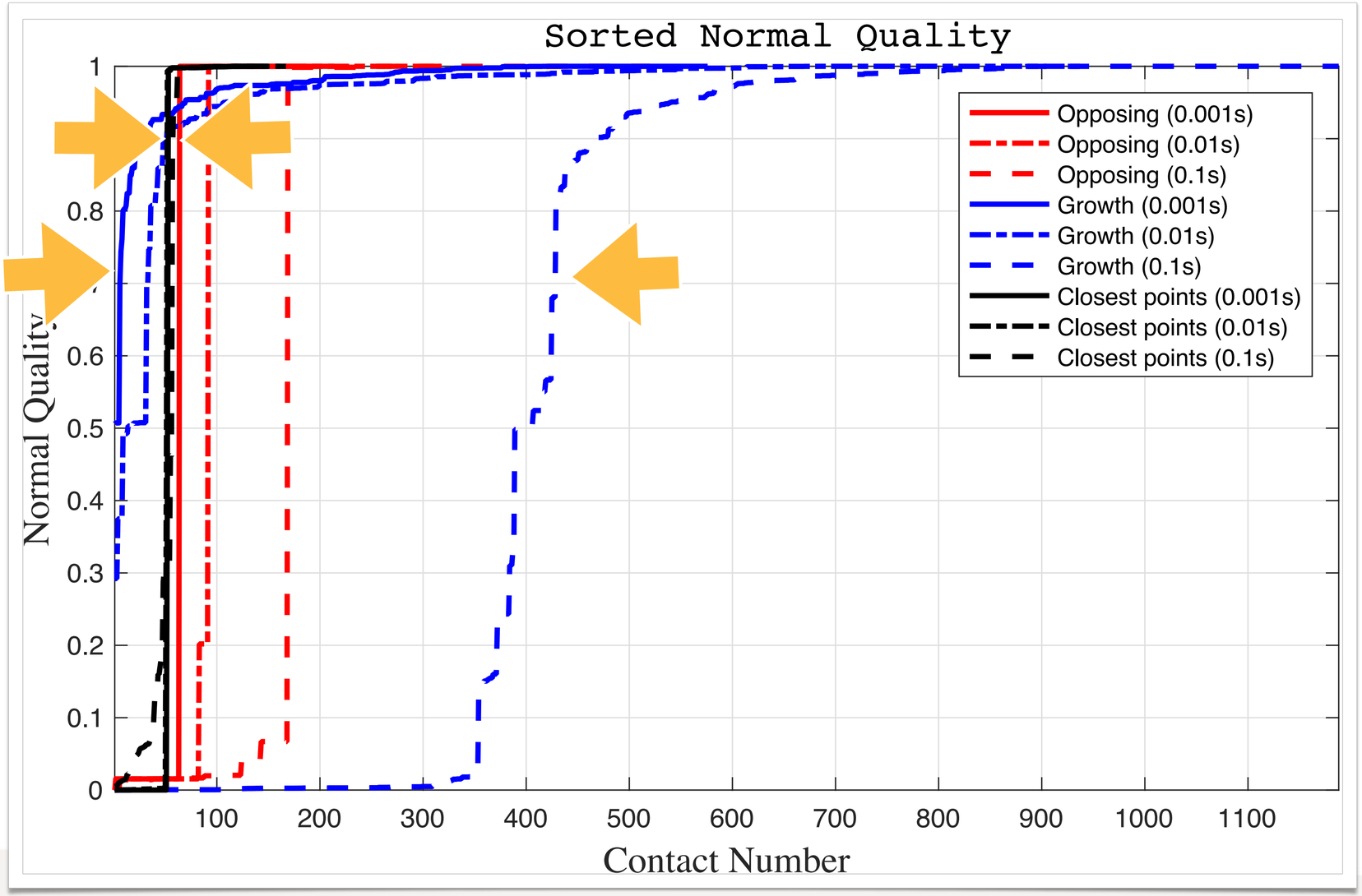
Opposing has higher normal quality



TIME-STEP DEPENDENCE

Closest points has good normal quality for larger time-steps with smallest sensitivity

Growth is worst for larger time steps

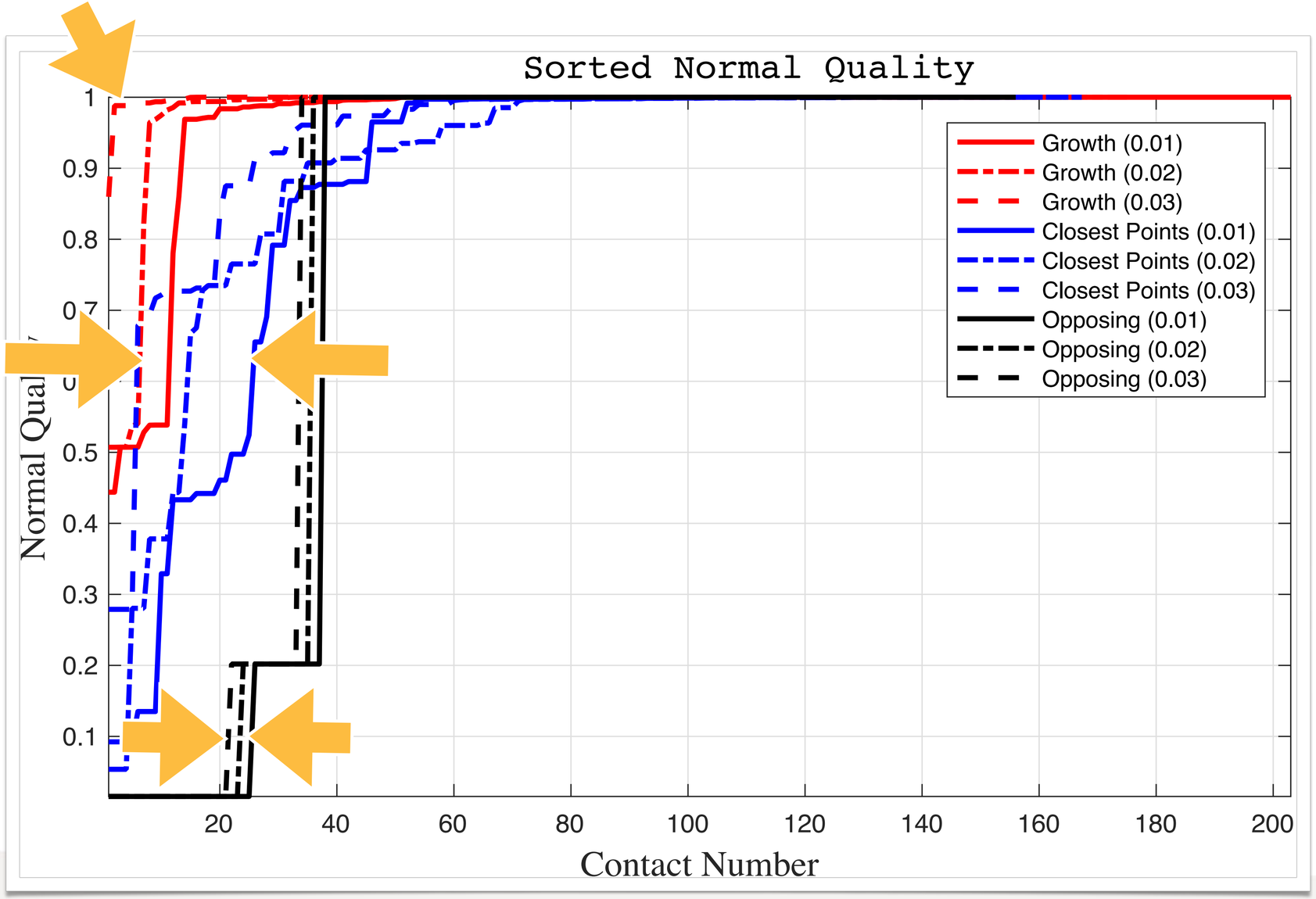


RANDOM NOISE DEPENDENCE

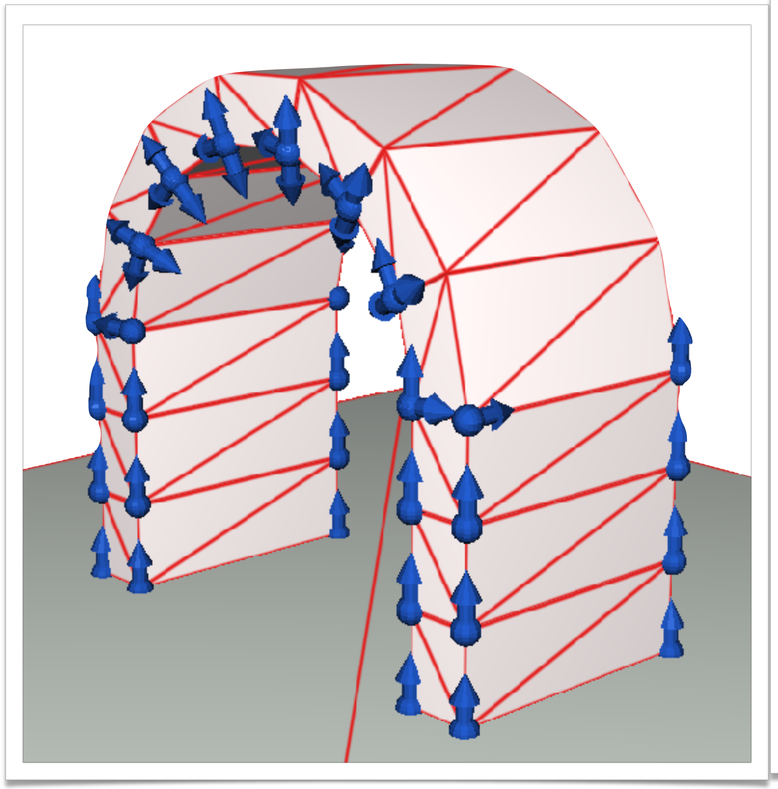
Growth gives better normal quality when adding noise.

Closet points is most sensitive

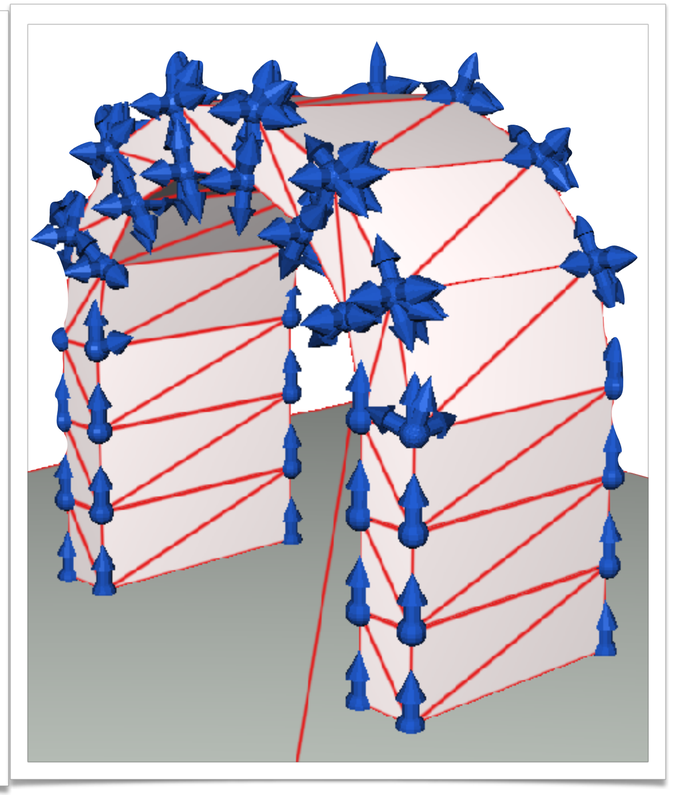
Opposing is less sensitive



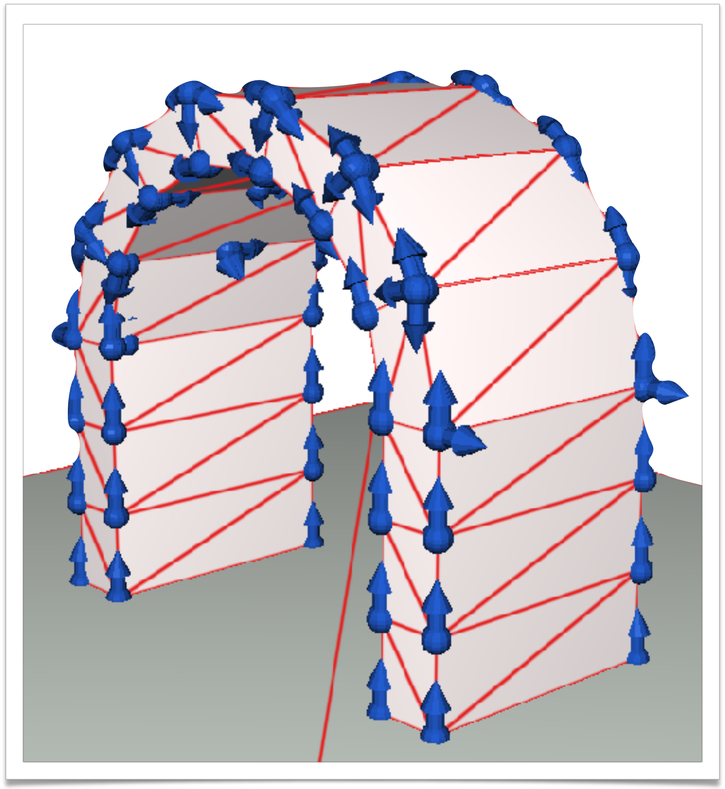
ARCH EXAMPLE



Closest points
with
empty space

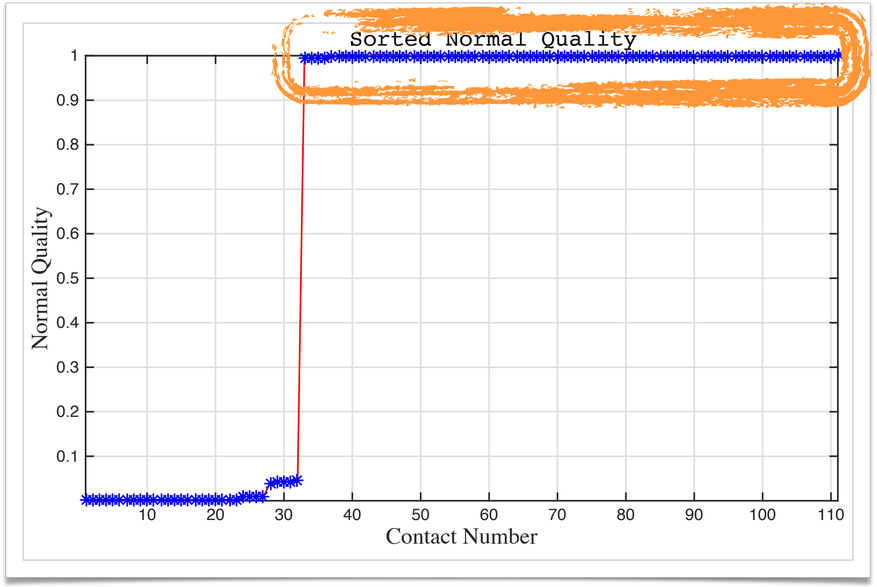


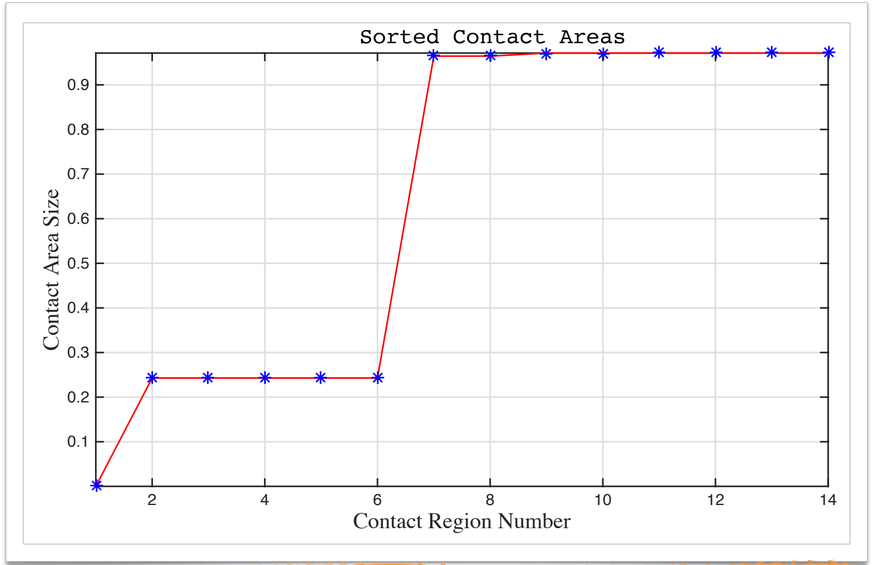
Closest points
no
empty space



Opposing

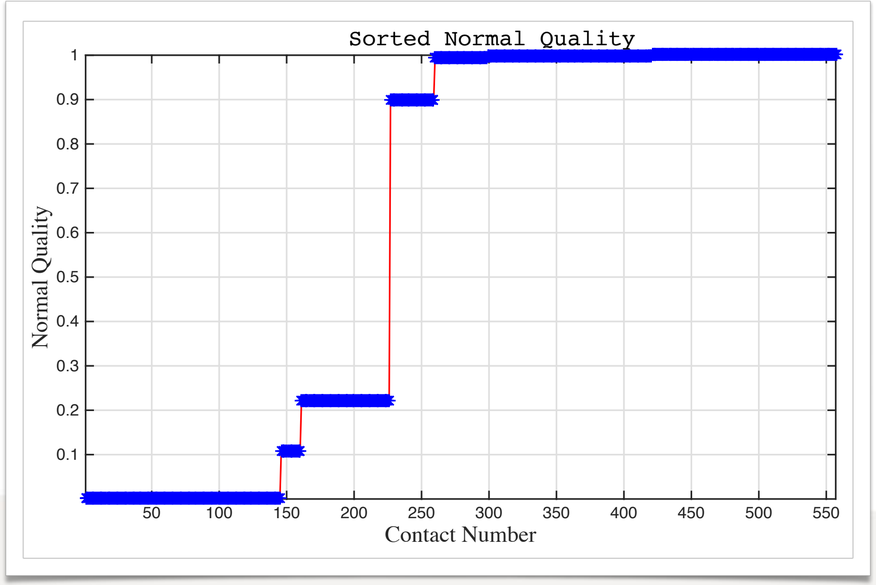
Closest points has better normal quality

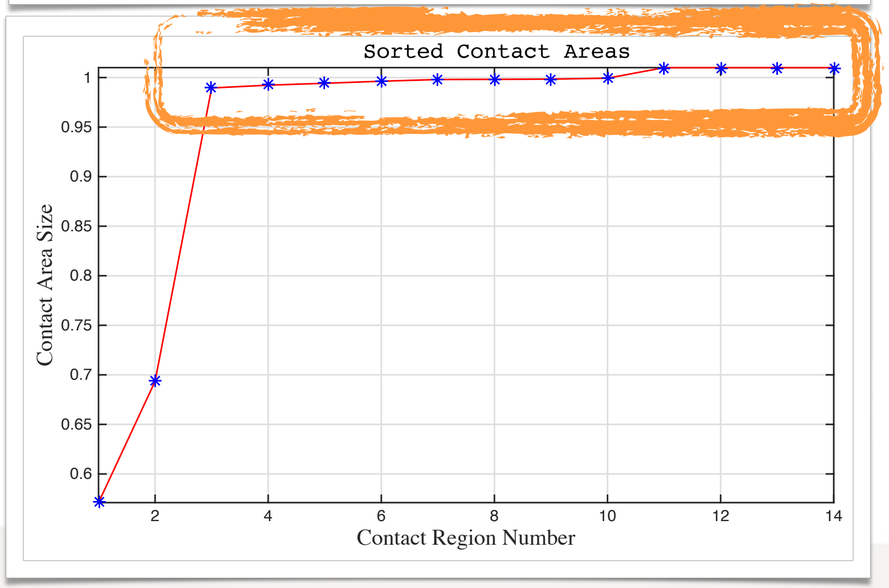




Closest Points

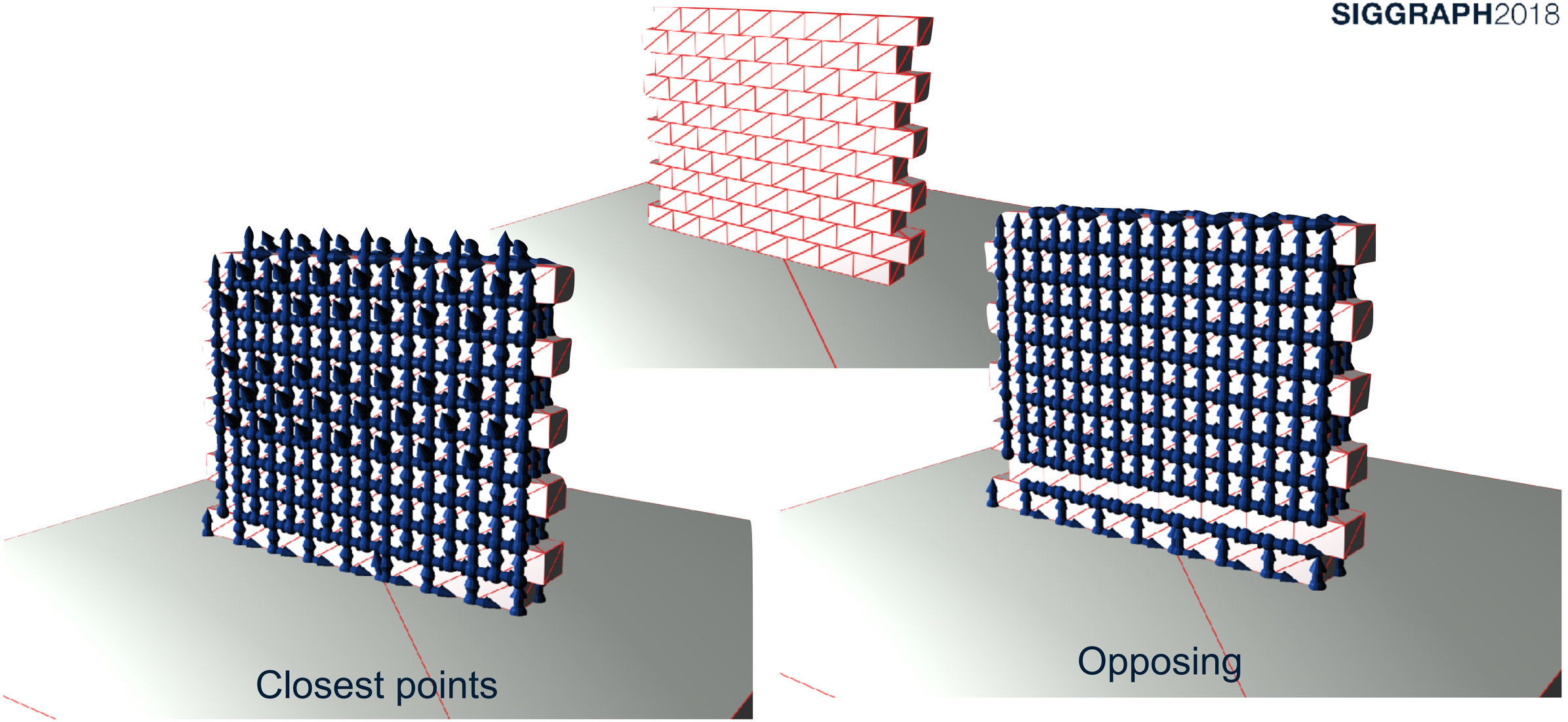
Opposing has better areas



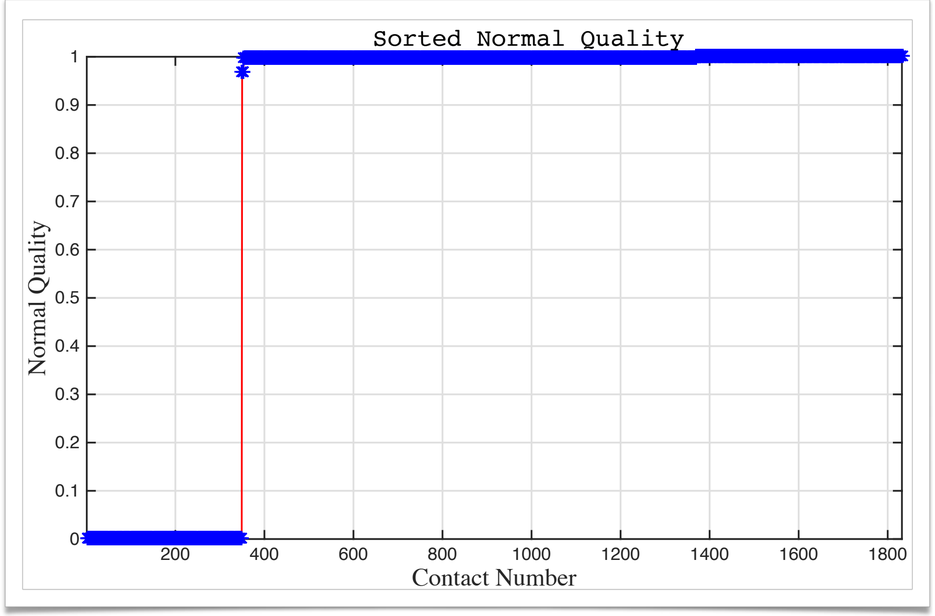


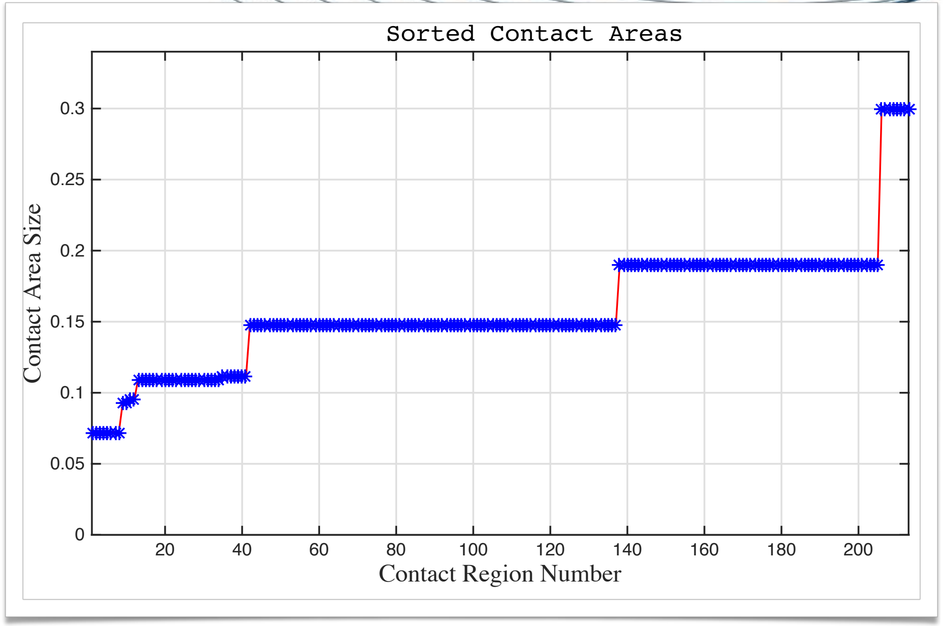
Opposing

WALL EXAMPLE


Closest points
Opposing

Closest Points





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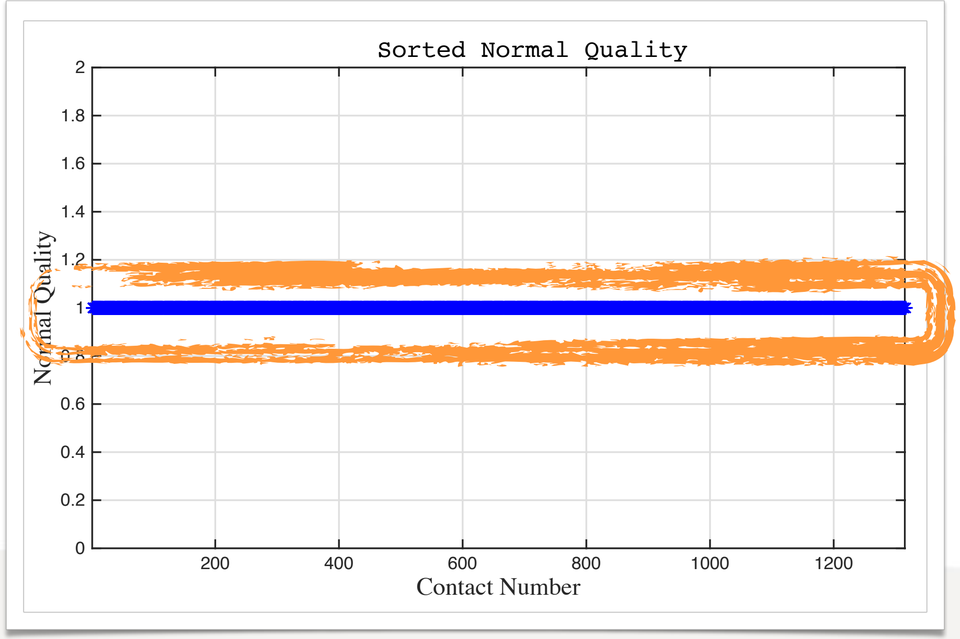
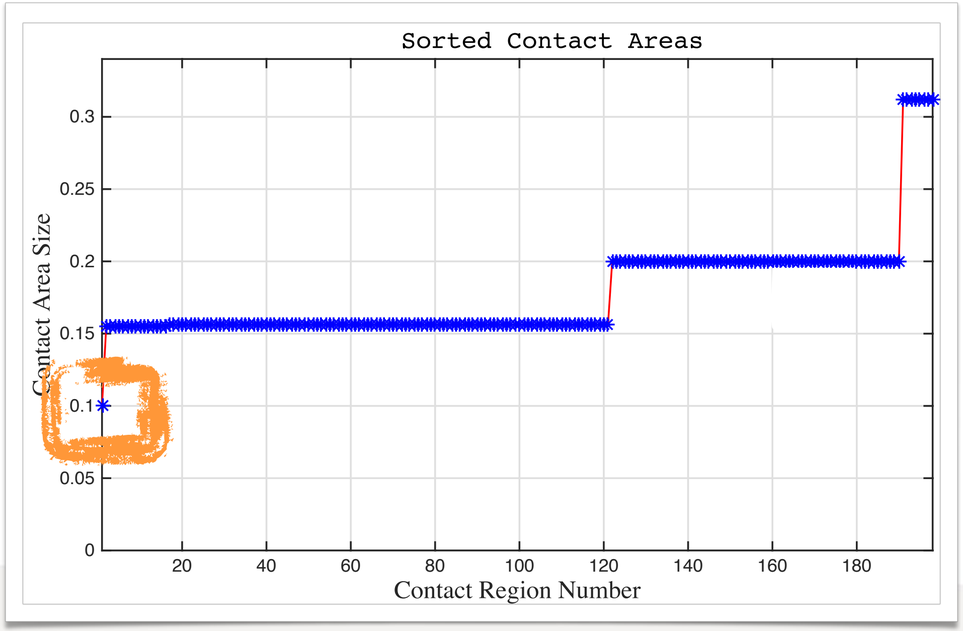
Closest points has poor quality and smaller coverage

Opposing





Opposing performans best

CONCLUSION

- We carefully designed five fundamental cases that we named **Sliding point**, **Two points**, **Point in crack**, **Internal edge** and **Cliff edge** that widely spans the challenges in computing normal information. Our cases are limited in the sense that they only partially cover cases with mixed curvature.
- We presented simple **Pillar**, **Arch** and **Wall** examples with explicit defined quality measures to provide the community with a specific tool for comparison.
- We presented the **Opposing** and **Growth** methods.
- We have demonstrated that **simulations are very sensitive** towards contact point generation and particular correct normal information is challenging to provide given the limitations of using a local method.

No Local Silver Bullet

THANKS

Questions?

rainbow.ku.dk

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