Computational Design of Reconfigurables

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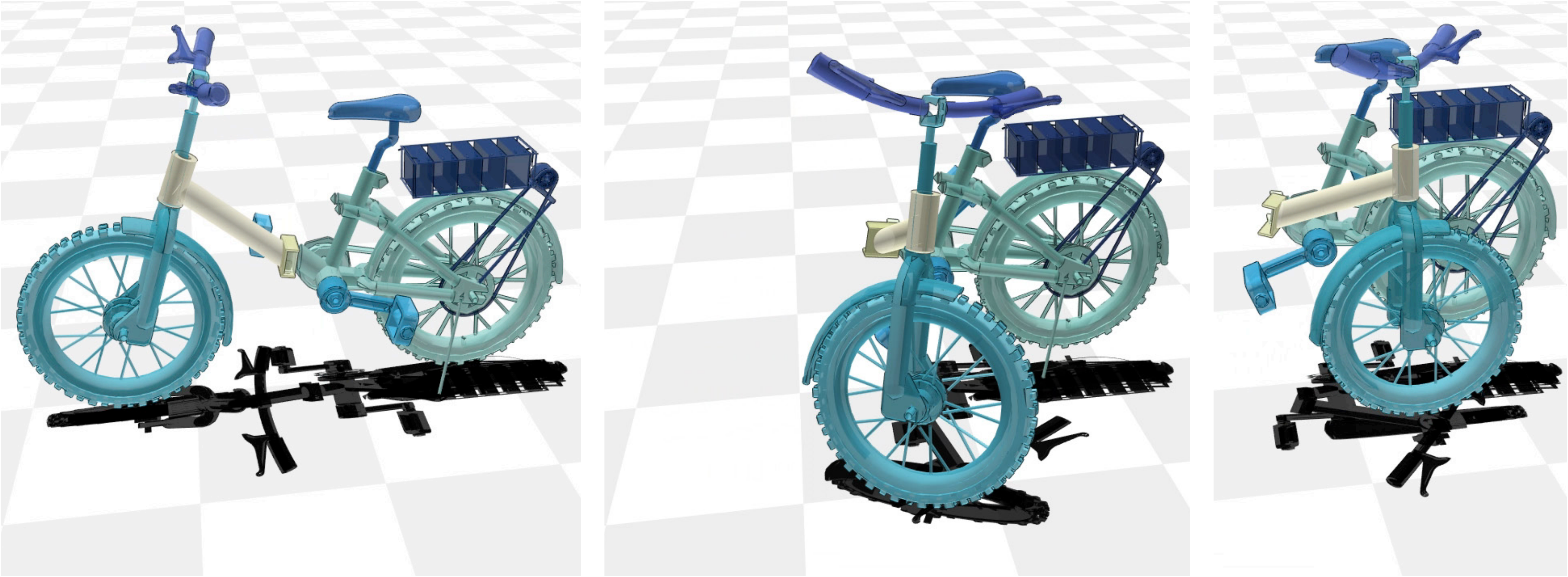
reconfigurable | riːkənˈfɪɡ(ə)rəb(ə)l |

noun

an object or collection of objects whose transformation between various states defines its functionality or aesthetic appeal.

Foldable bicycle is a classic example of a reconfigurable



state #1 *transition* state #2

Transforming furniture is also a reconfigurable

https://youtu.be/A3PDiDLiOEI

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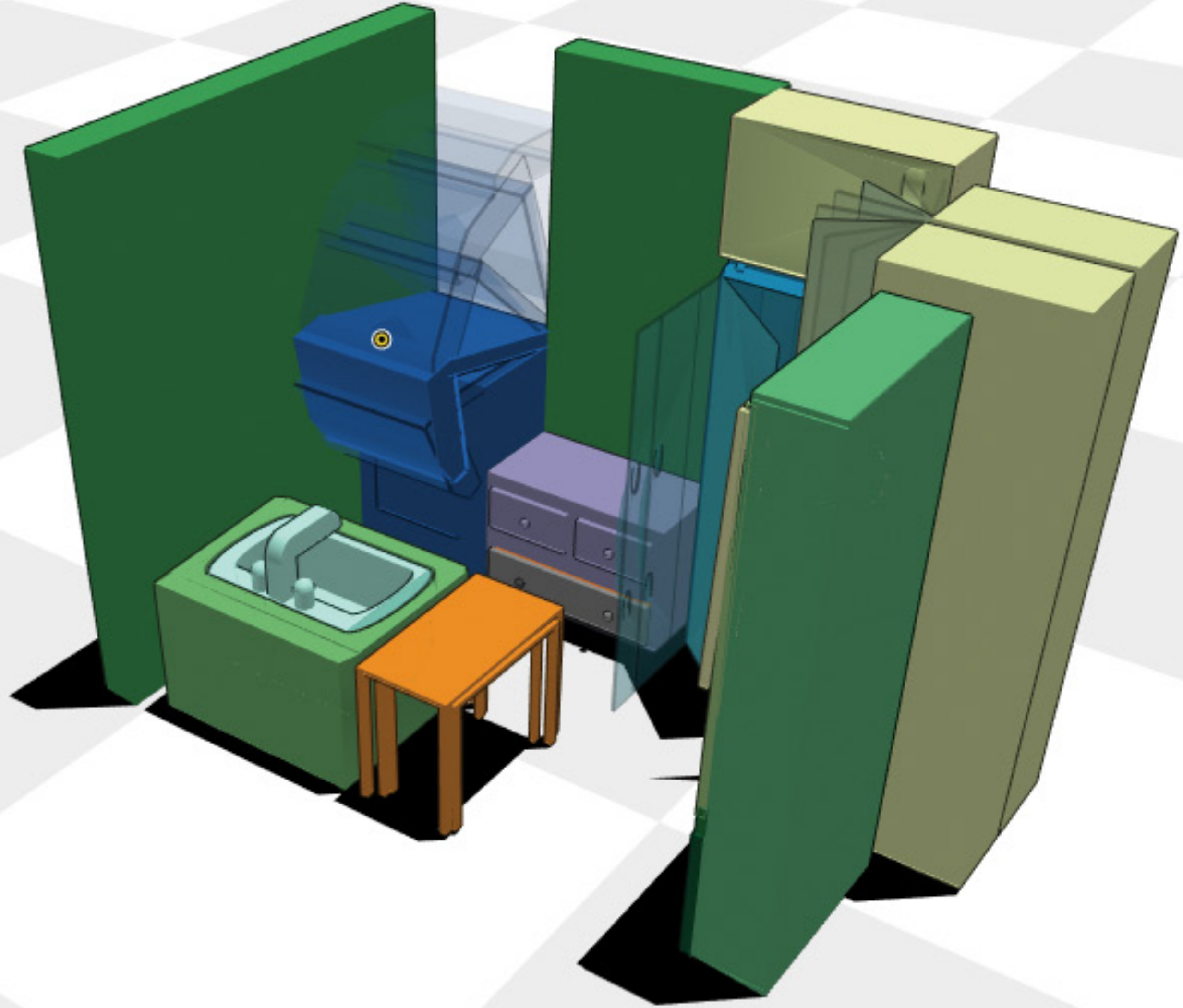
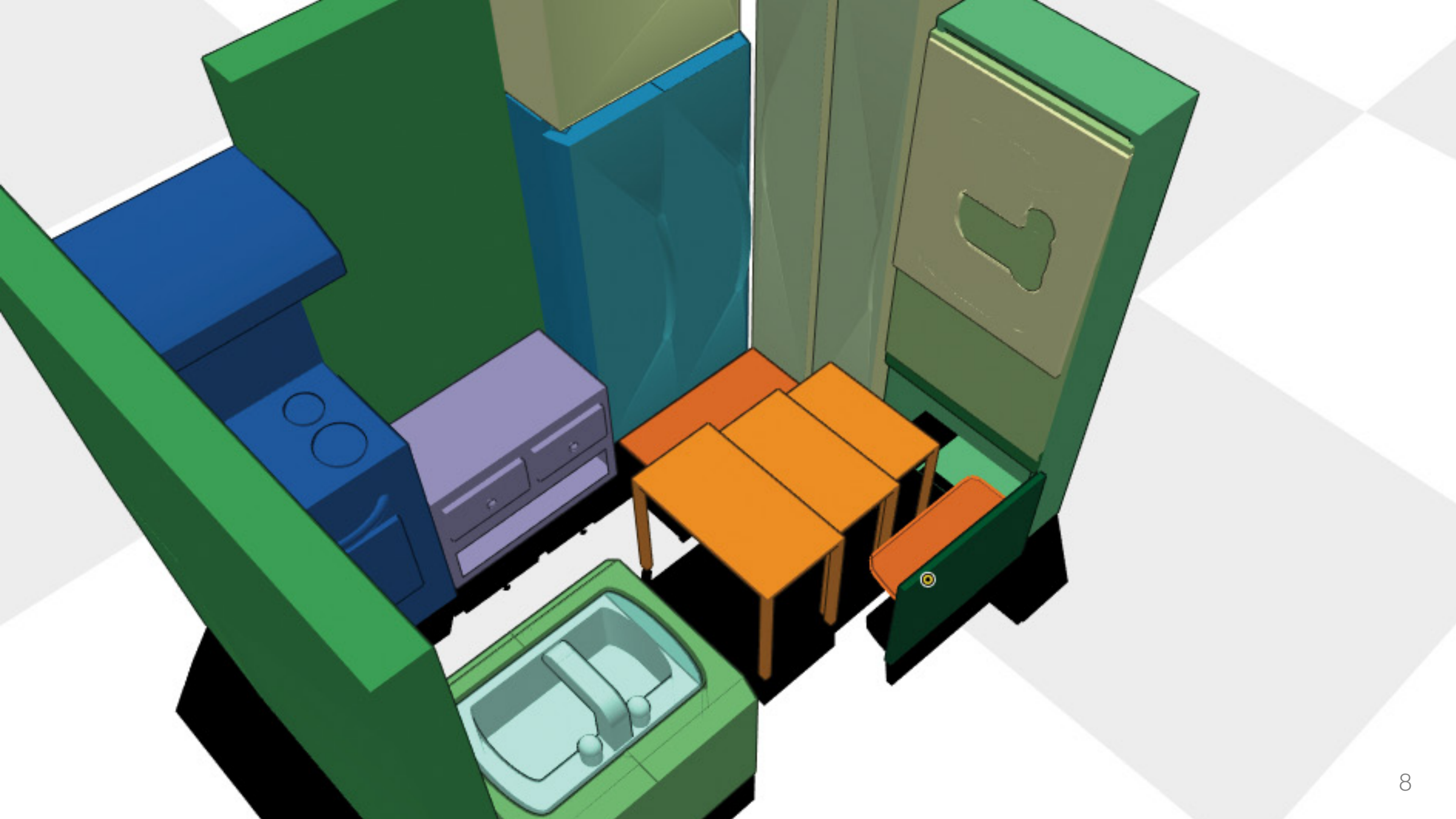
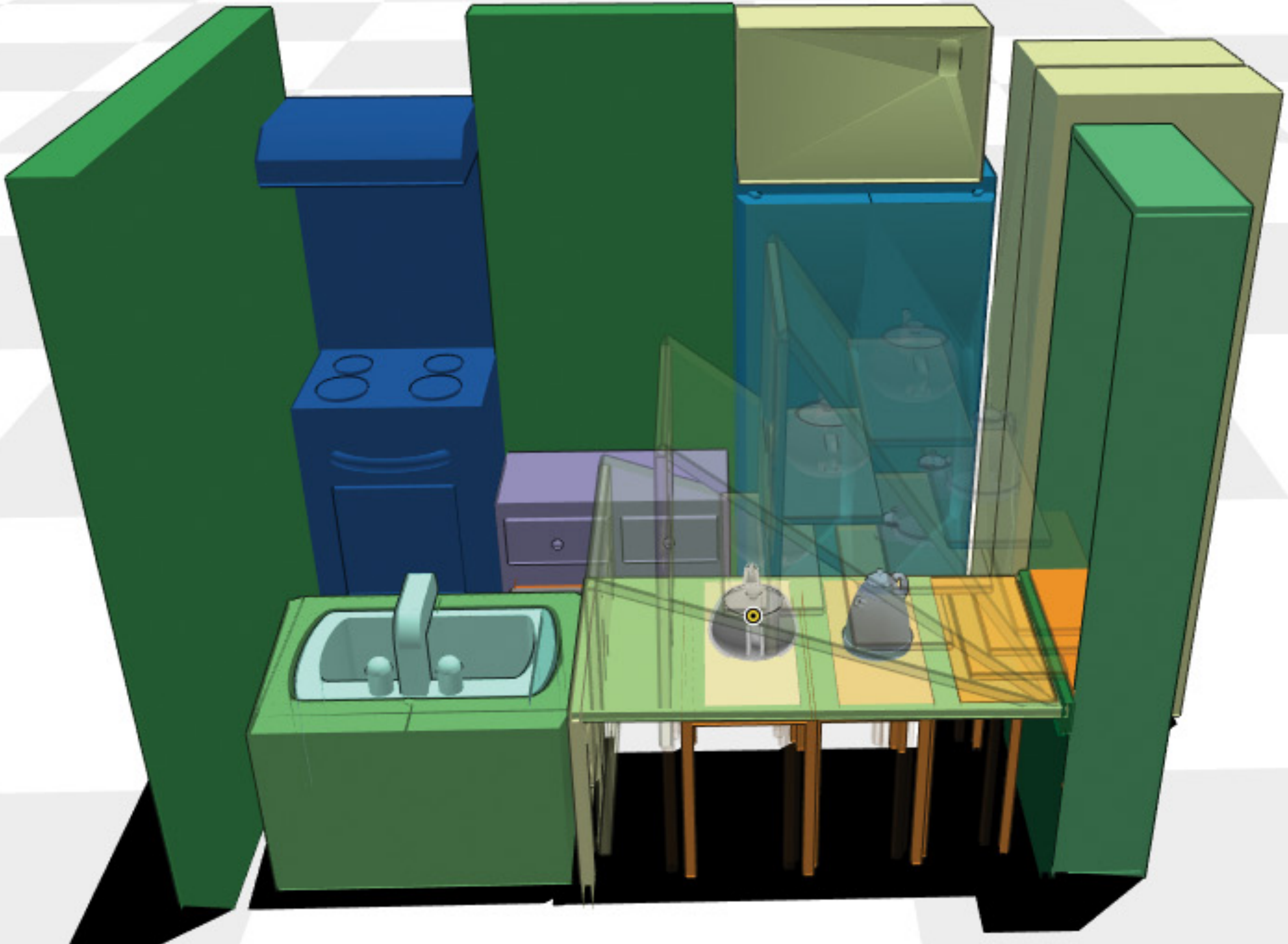
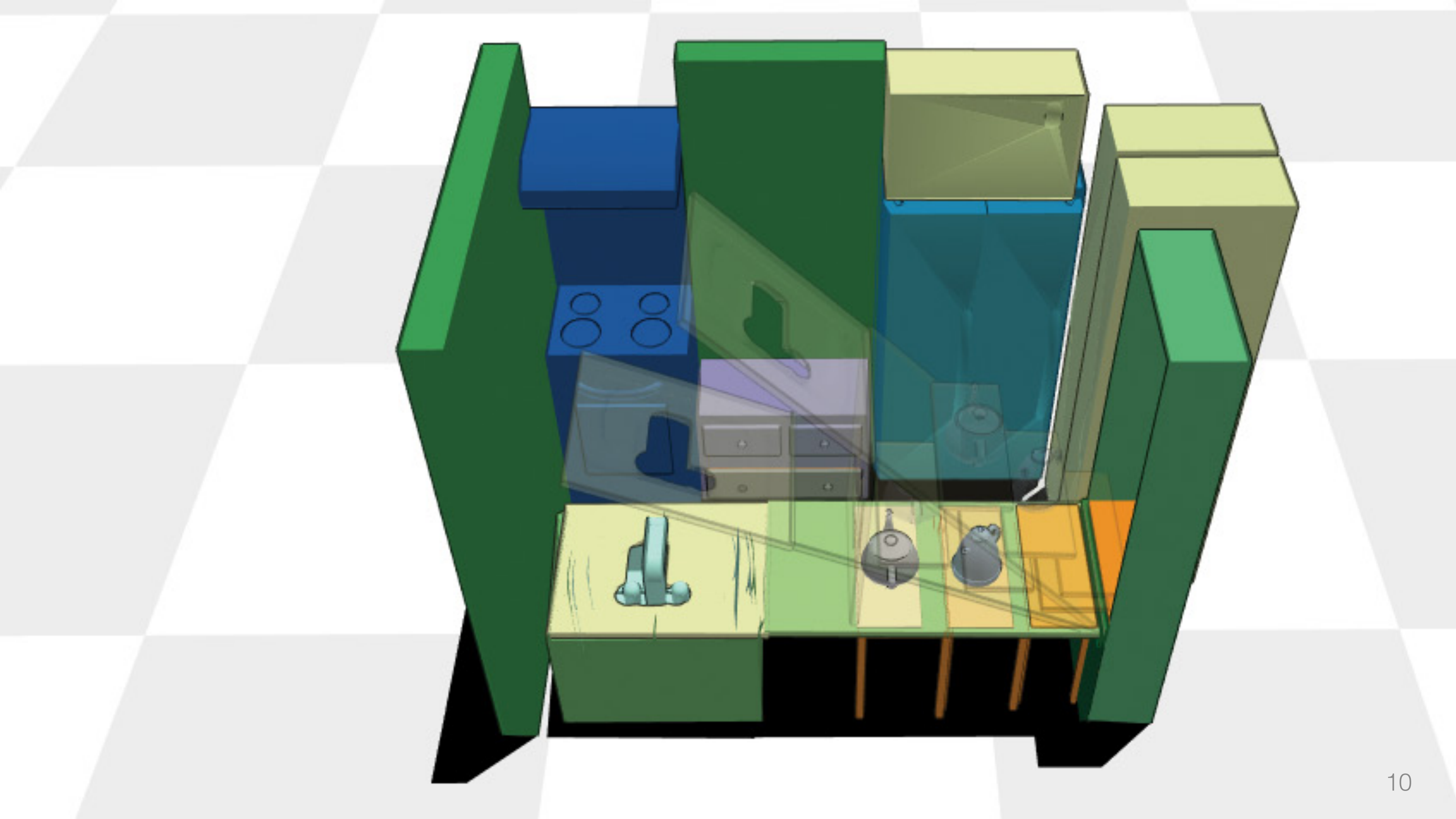
Space-saving kitchen is also a reconfigurable

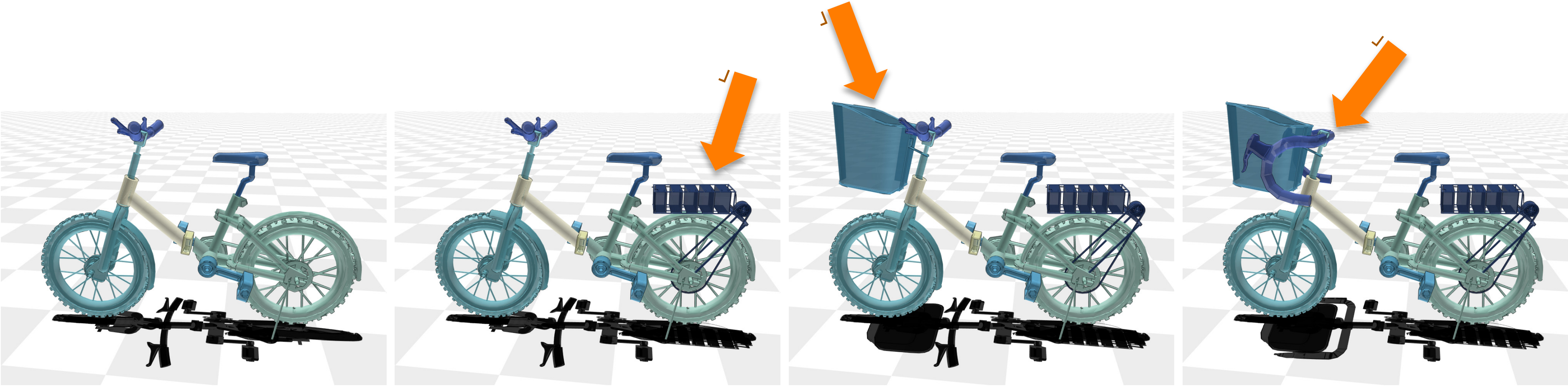






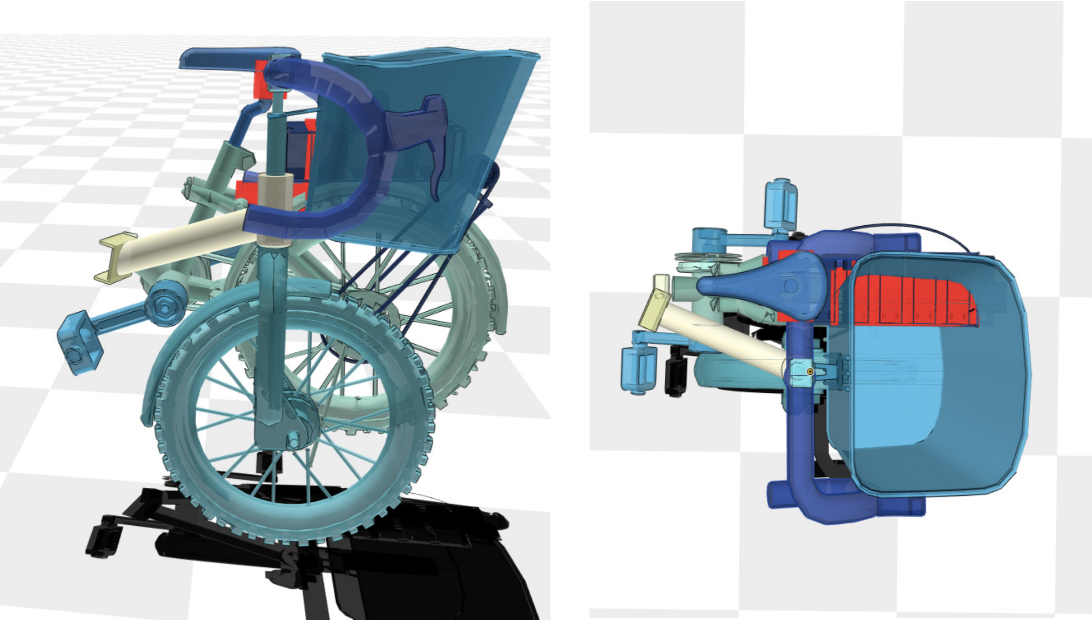


Problems occur if we design each state in isolation…



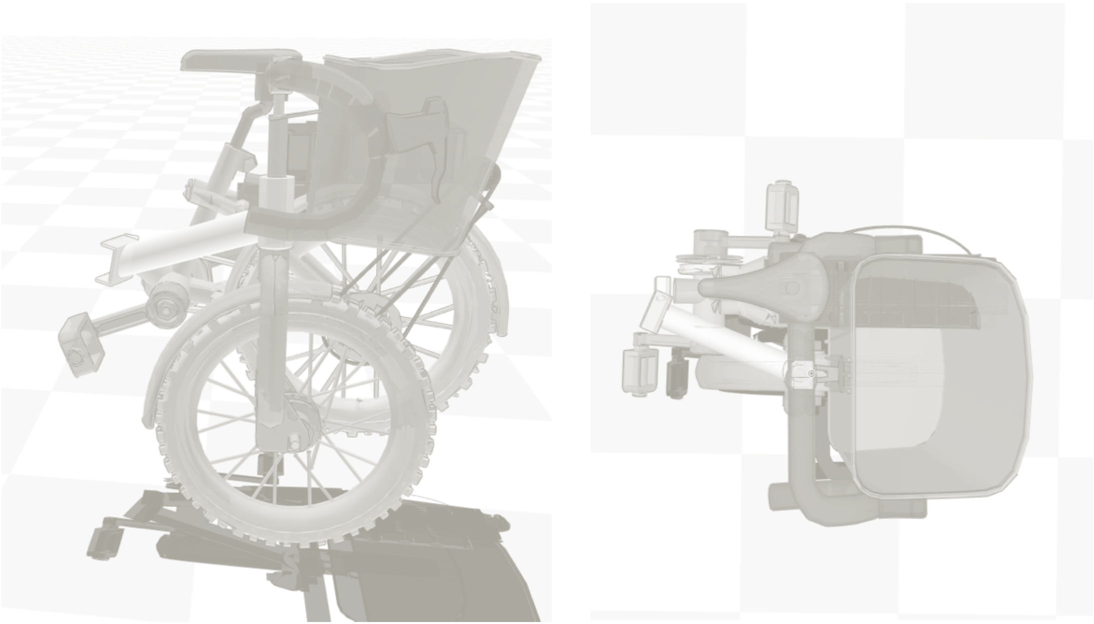
state #1

...collisions prevent transitioning to other states

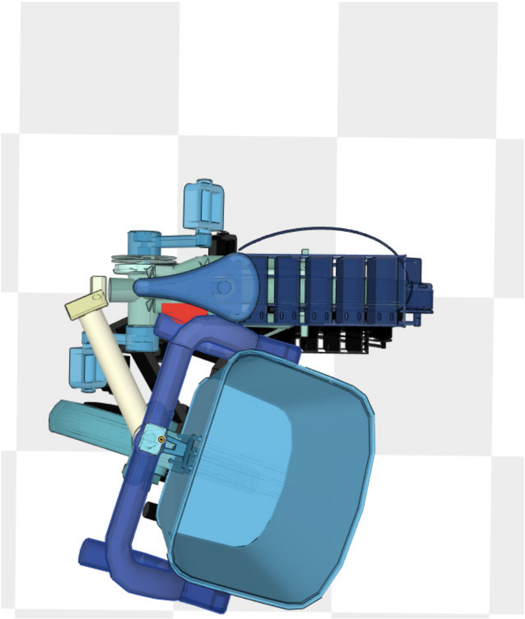


state #2

...collisions prevent transitioning to other states

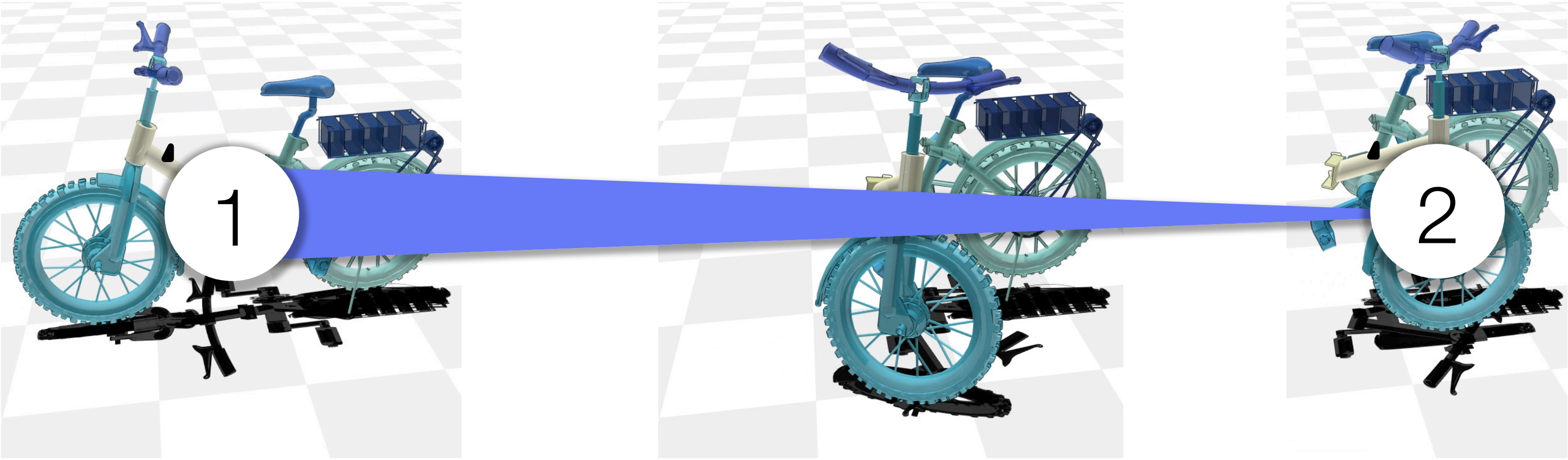


state #2



first contact

We model reconfigurables as a graph of transitions



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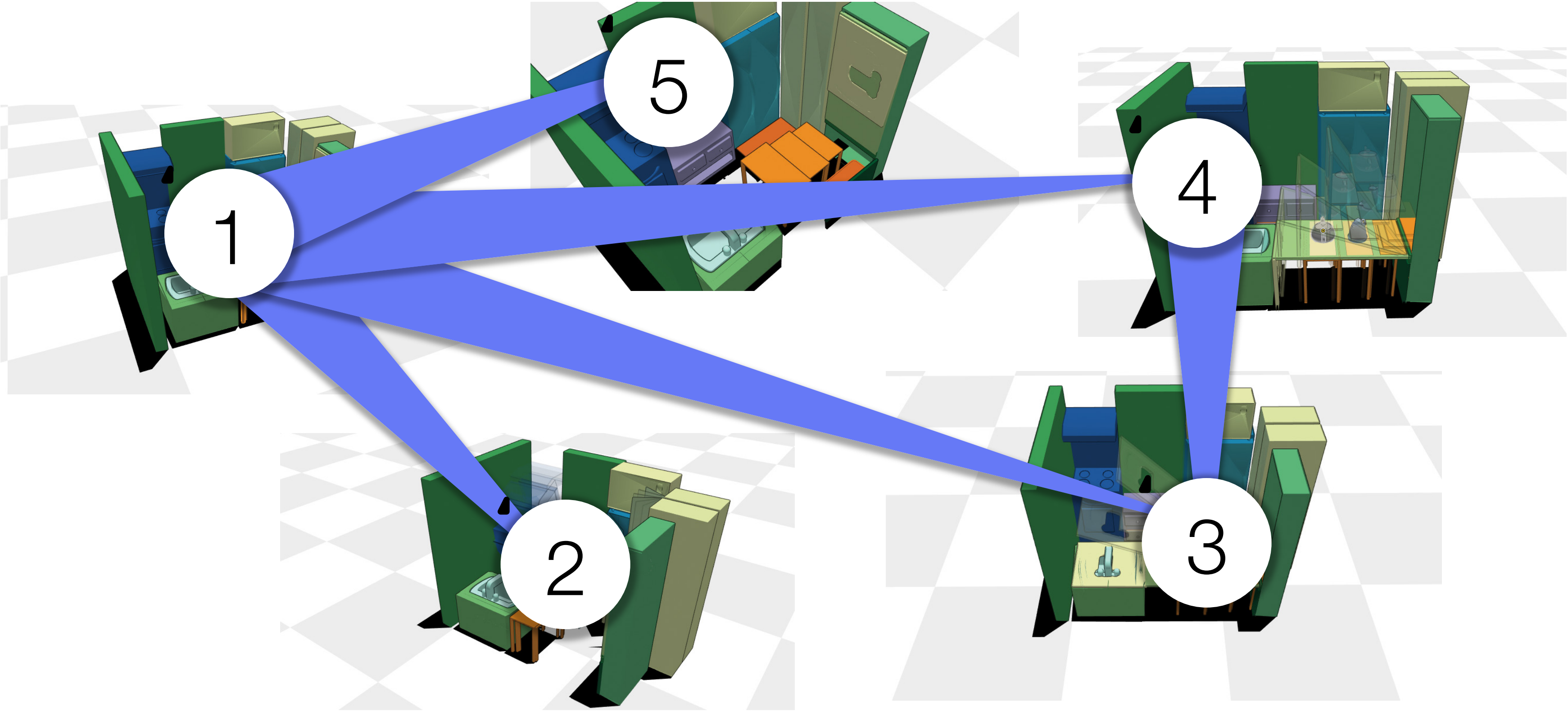
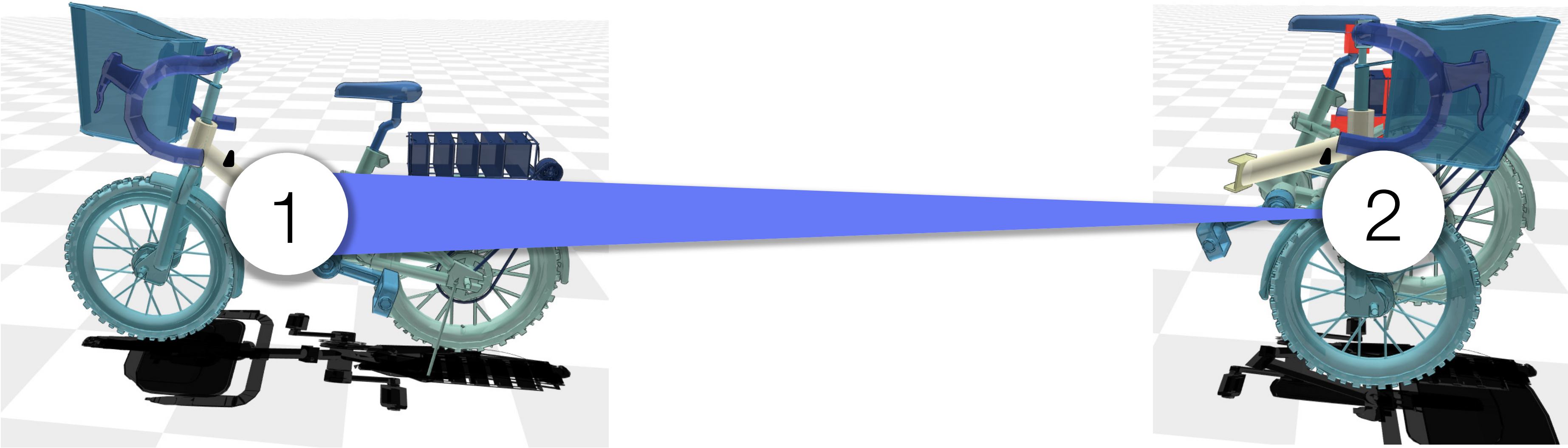


Our goal is to help the designer keep all transitions collision free

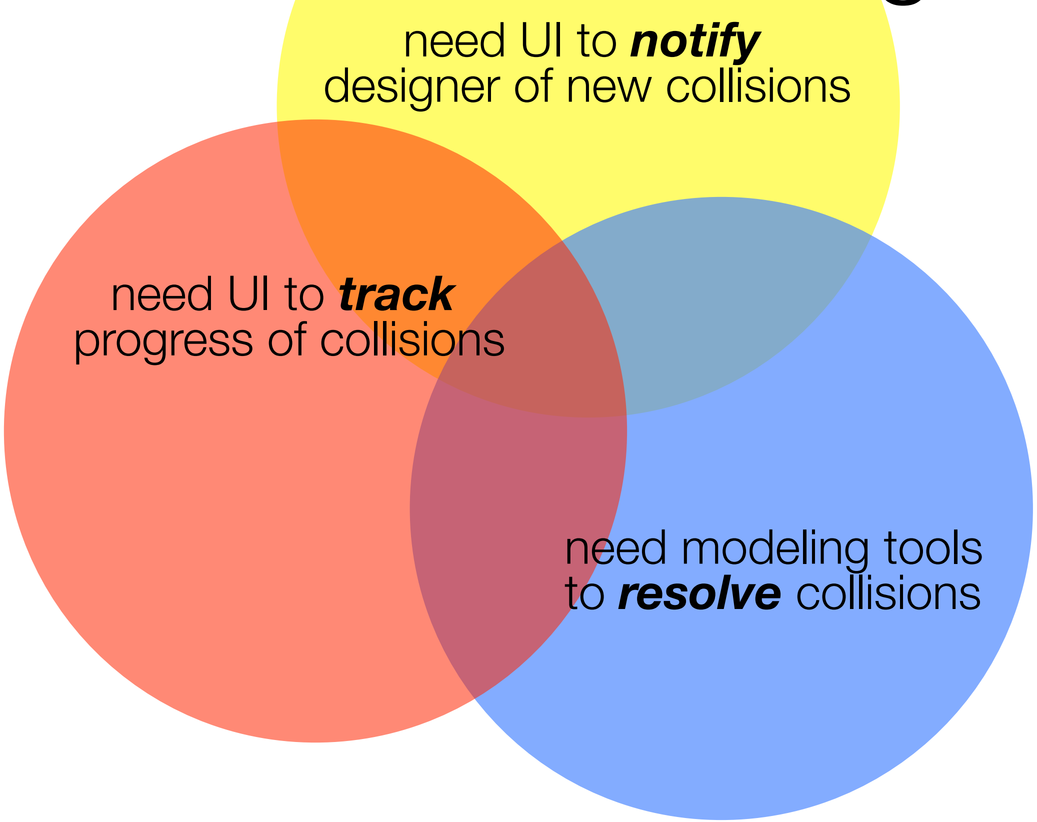


need UI to ***notify***
designer of new collisions

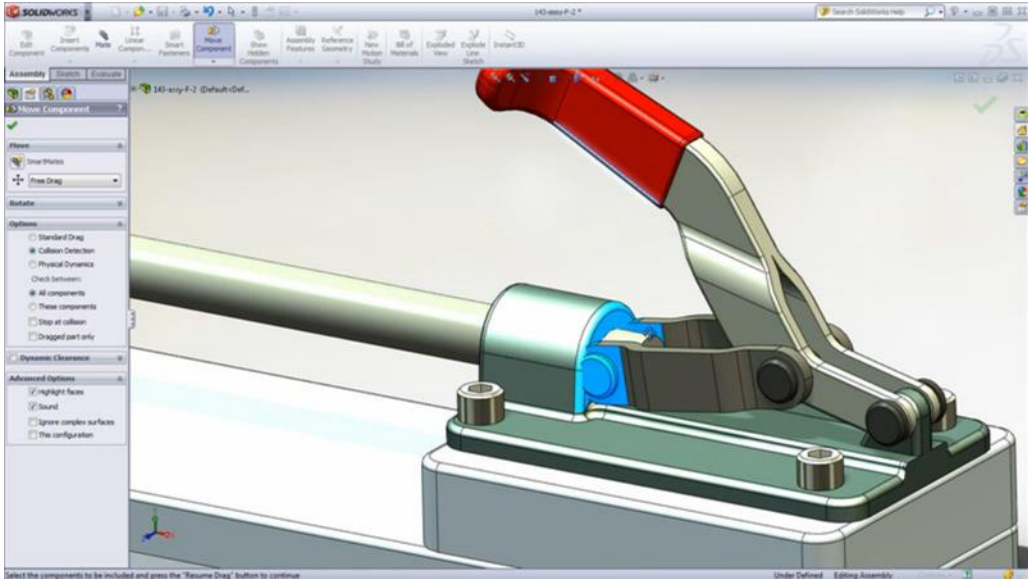
need UI to ***track***
progress of collisions

need modeling tools
to ***resolve*** collisions

Harmonization of all three enables to rapid and creative editing sessions



Traditional CAD tools have limited collision support



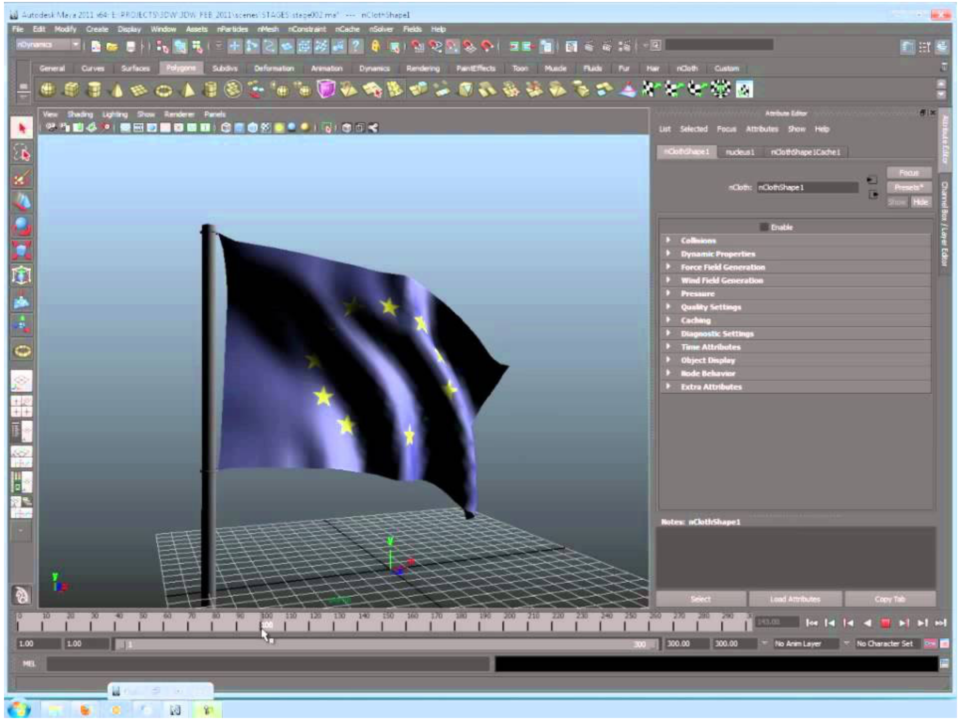
solidworks

offline detection

notification via “audible bell”

no automatic resolution

Animation tools detect and respond to collisions for physically-based effects



maya

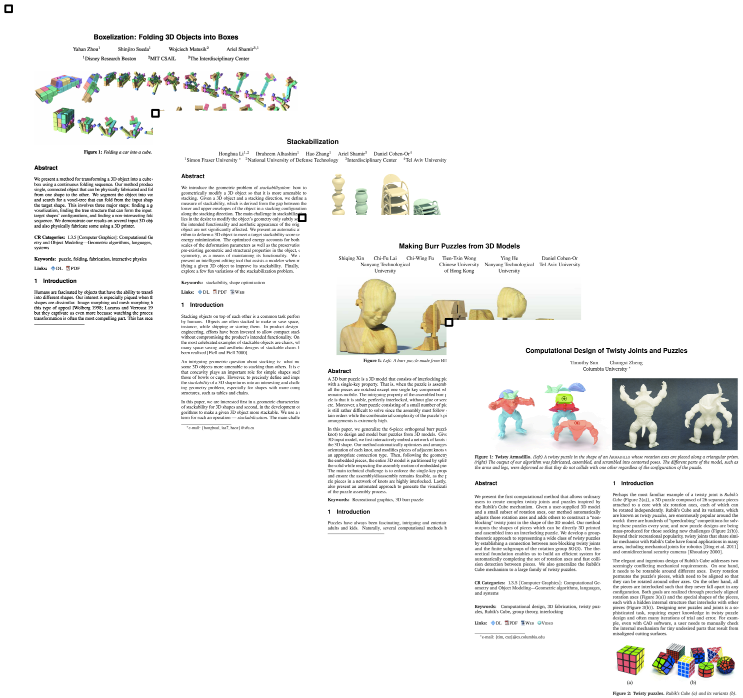
time is linear and “one-way”

no salient *states*

overlaps OK if not noticeable

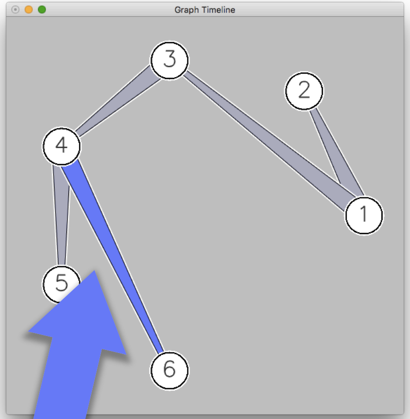
Previous computational design tools either:

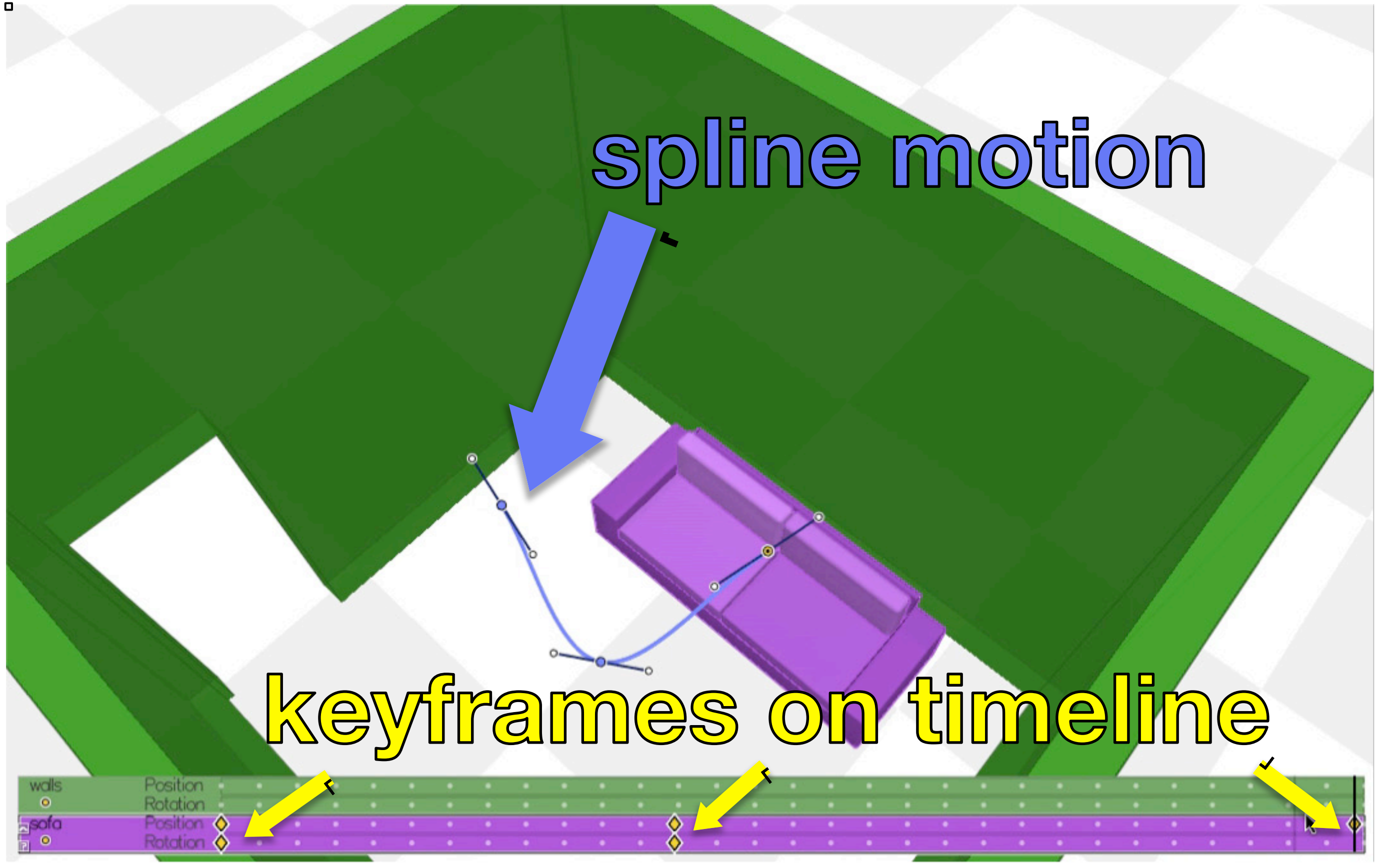
ignore collisions



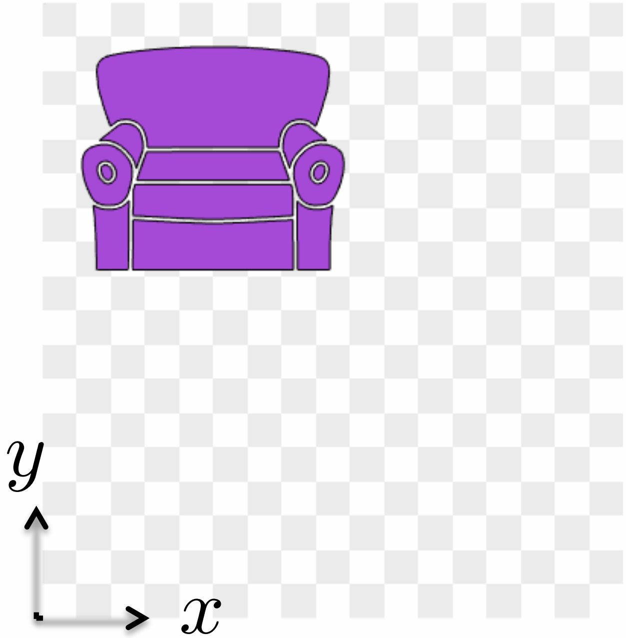
leverage a
specialized subspace

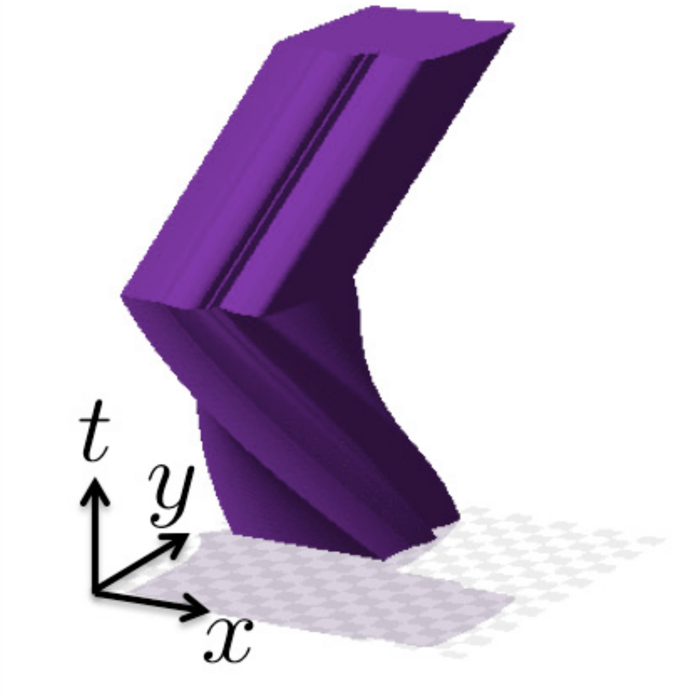
We begin with objects as rigid triangle meshes



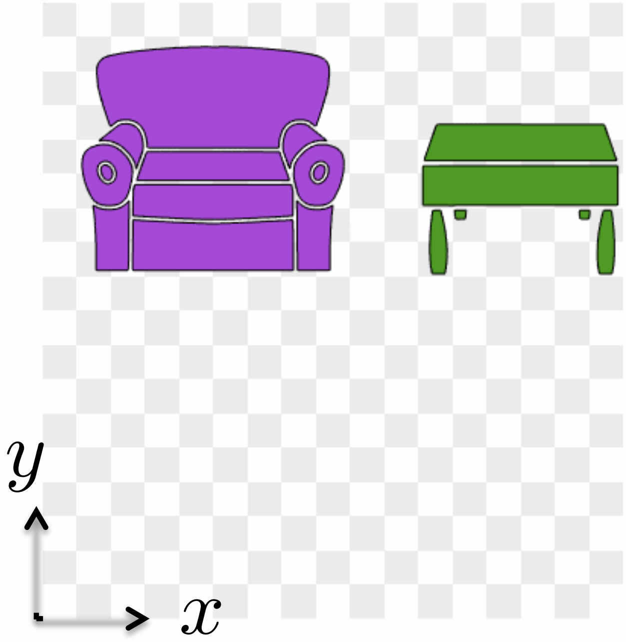


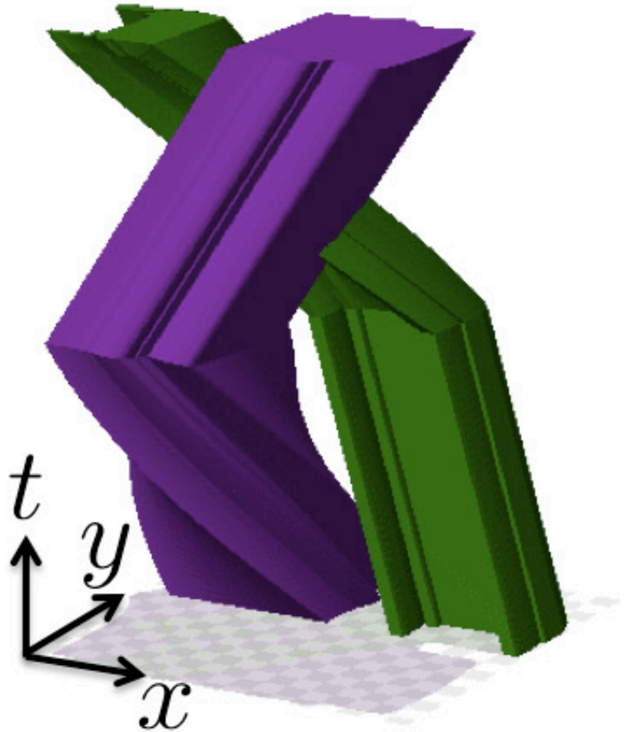
Along each transition an object is a 4D *spacetime* volume



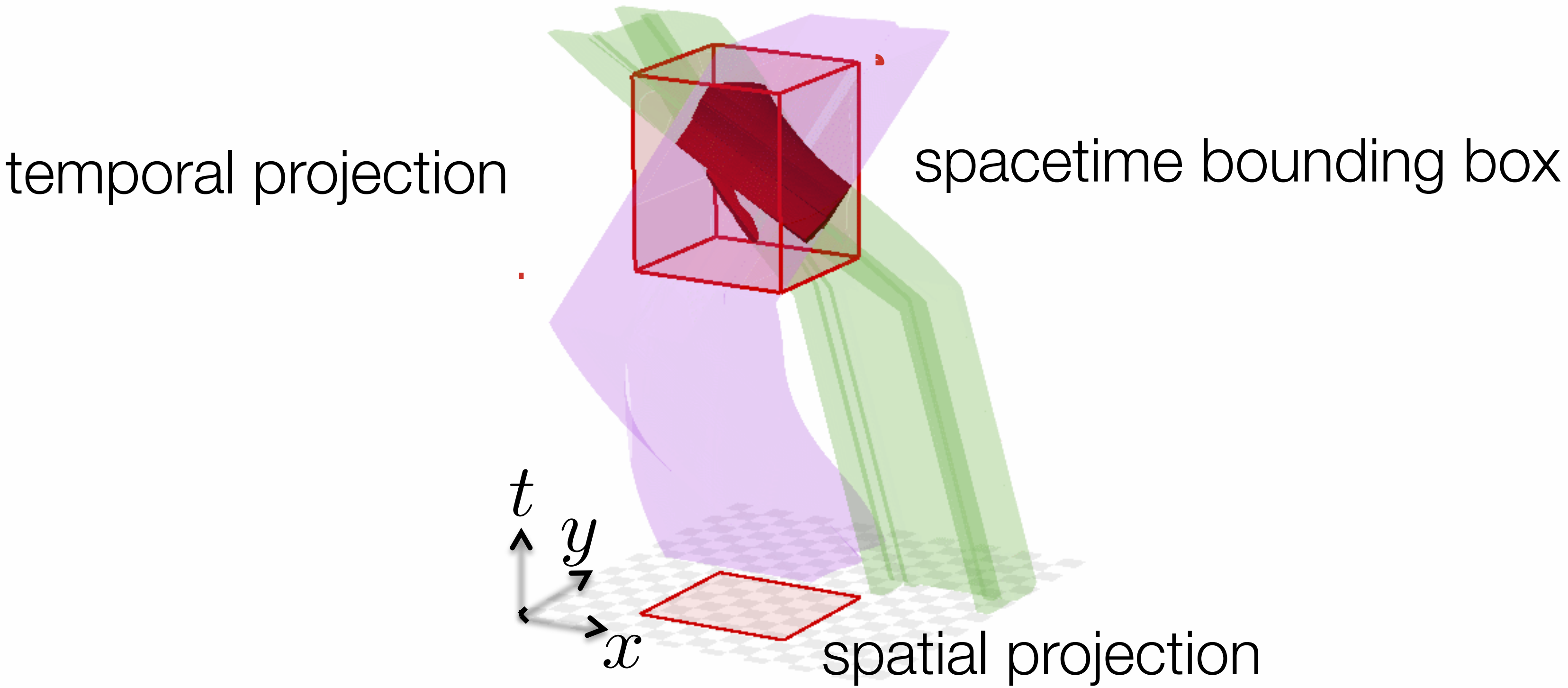


Collisions correspond to intersections in spacetime





Collision Intervals form the foundation of our notification and tracking UIs



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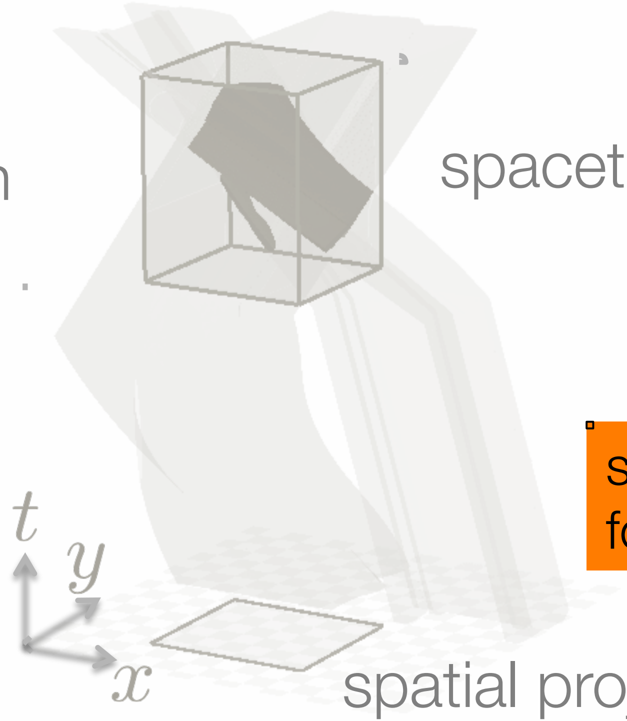
temporal projection

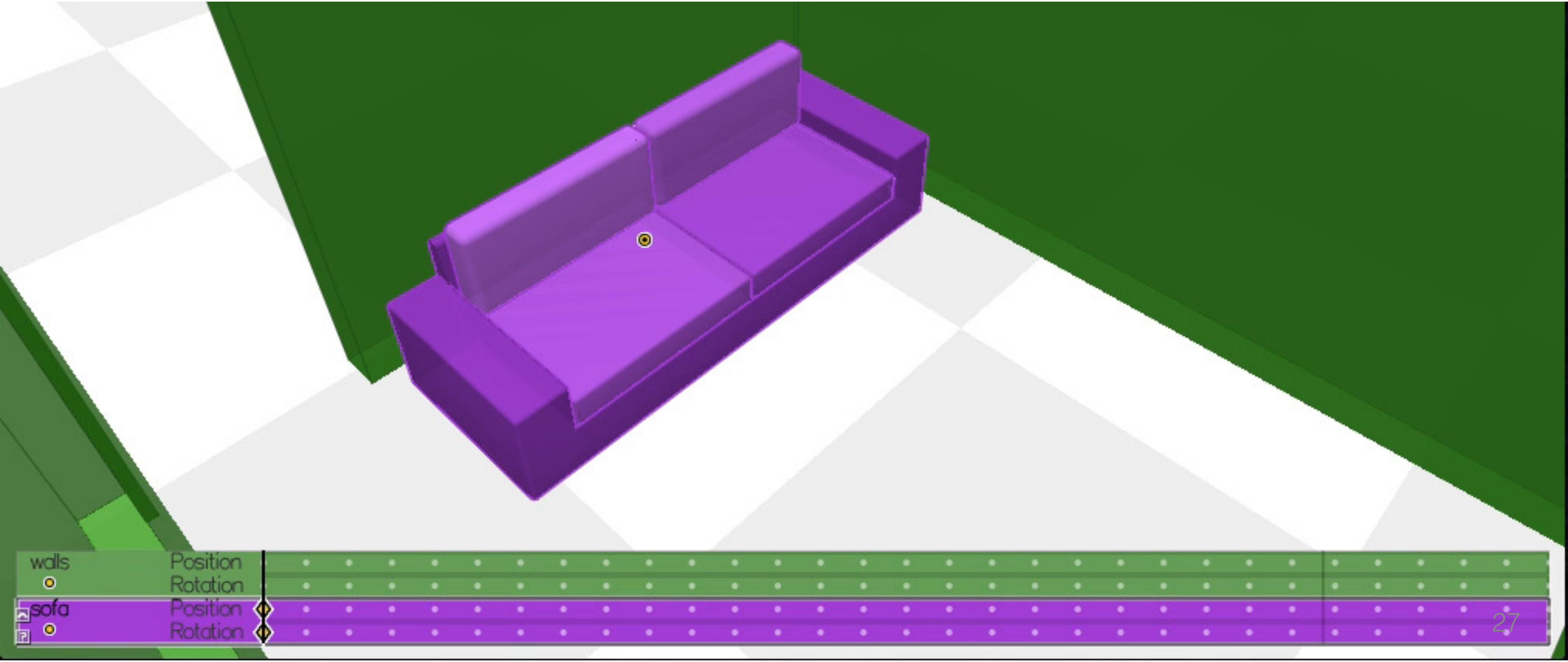


spacetime bounding box

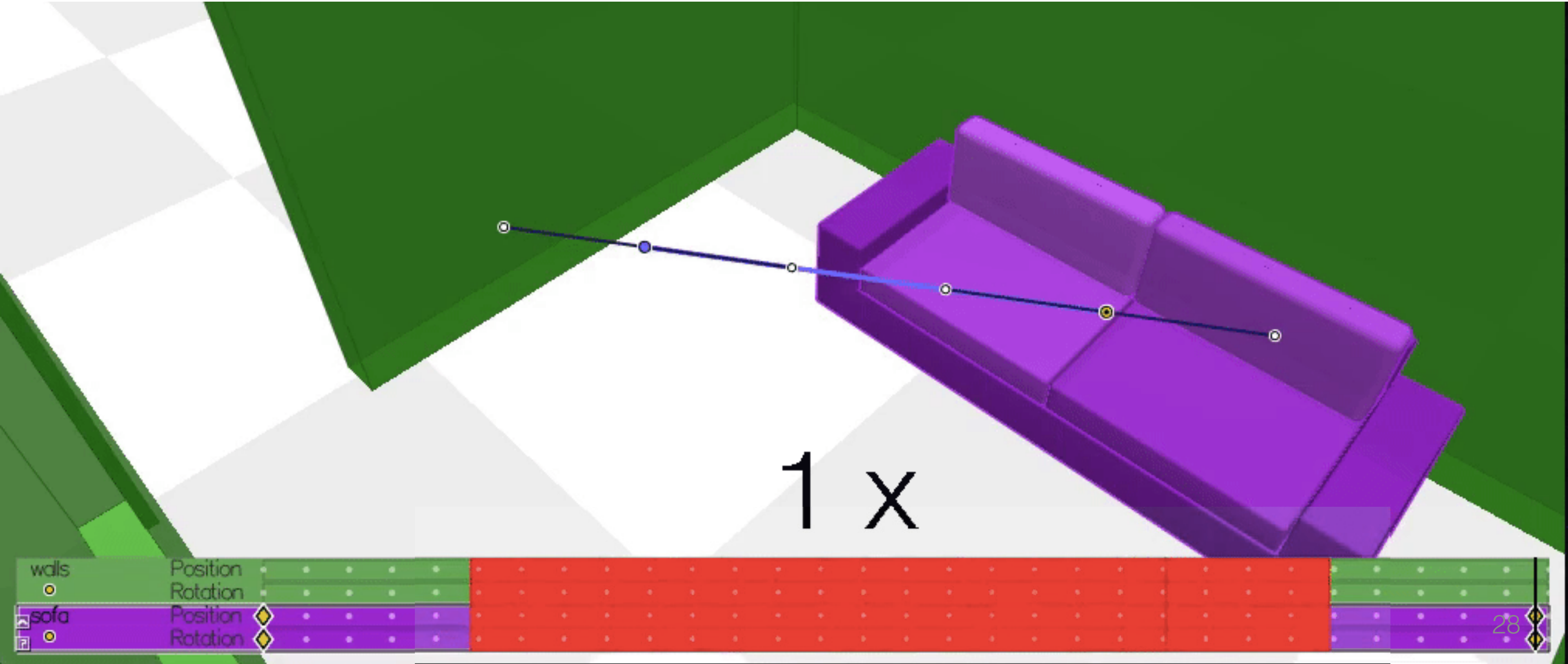
see paper about 4D *k*-DOP for collision interval detection

spatial projection

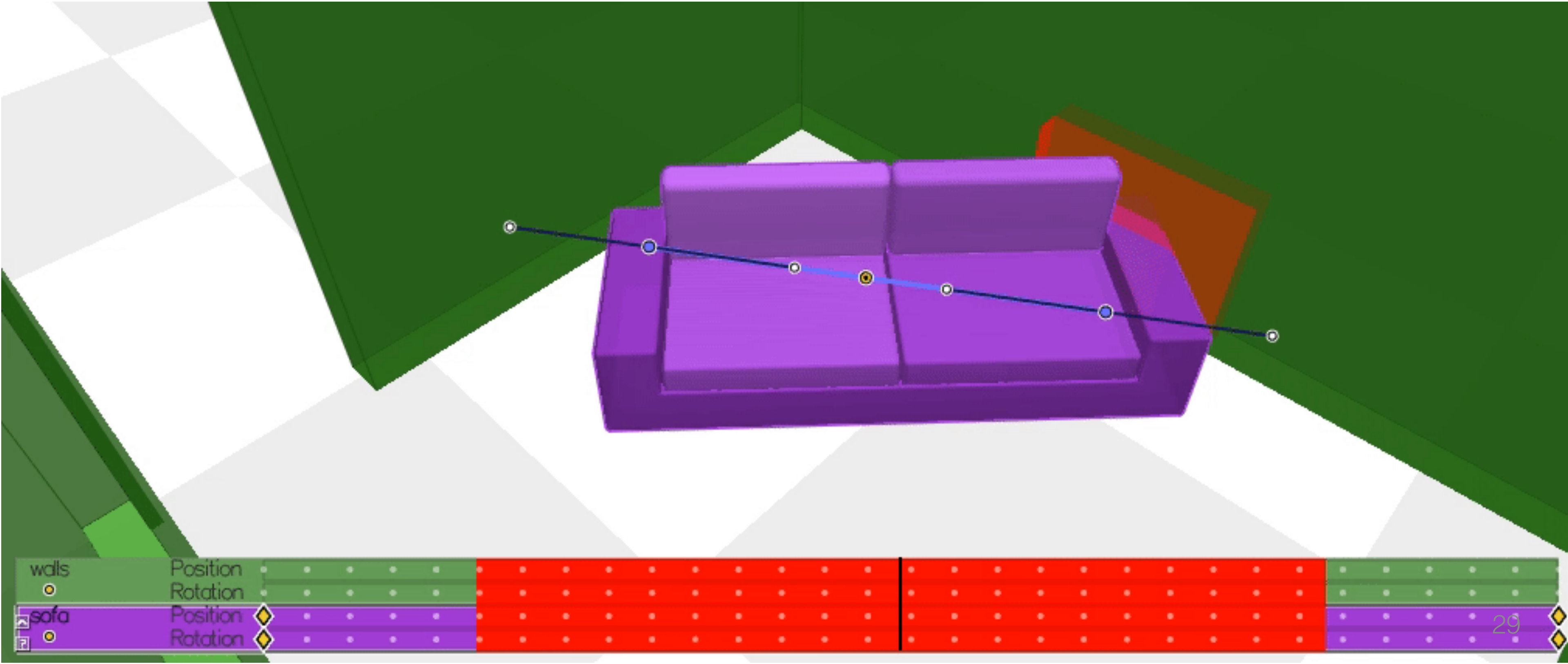
Spatial and temporal projections of collision intervals alert the designer



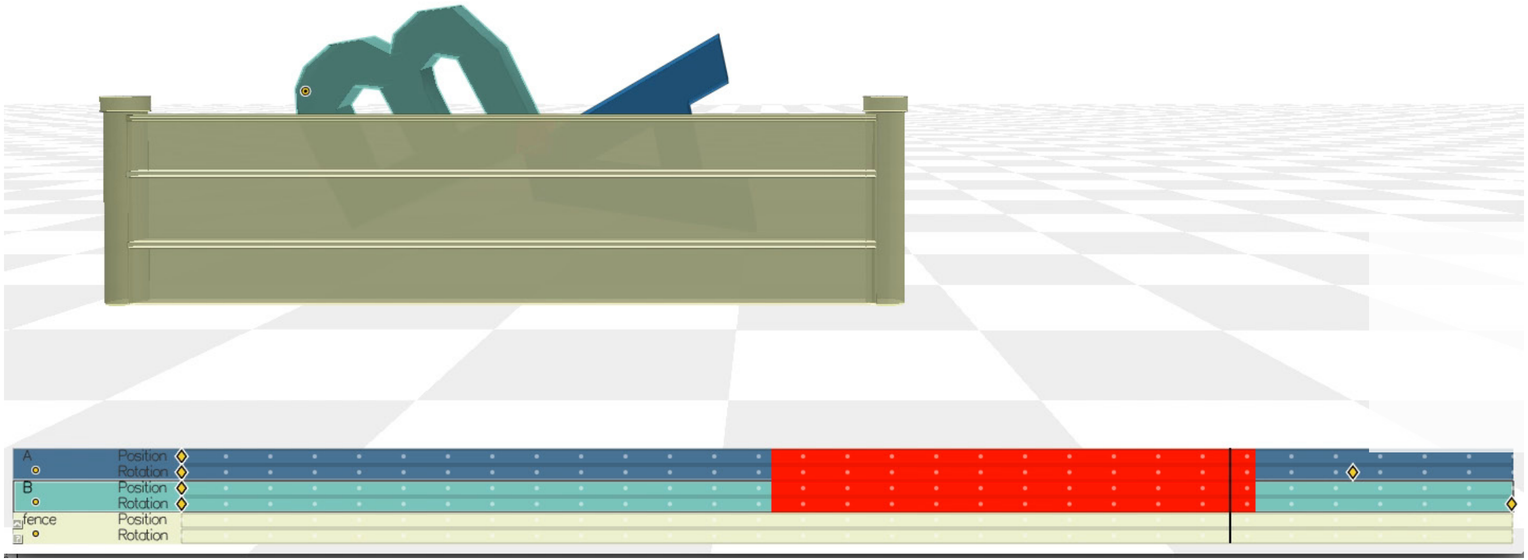
First priority: alert designer *when* collision is occurring



Next: alert designer *where* collision is occurring



Designer’s current view may be poor, *hotkey* tumbles to optimized view



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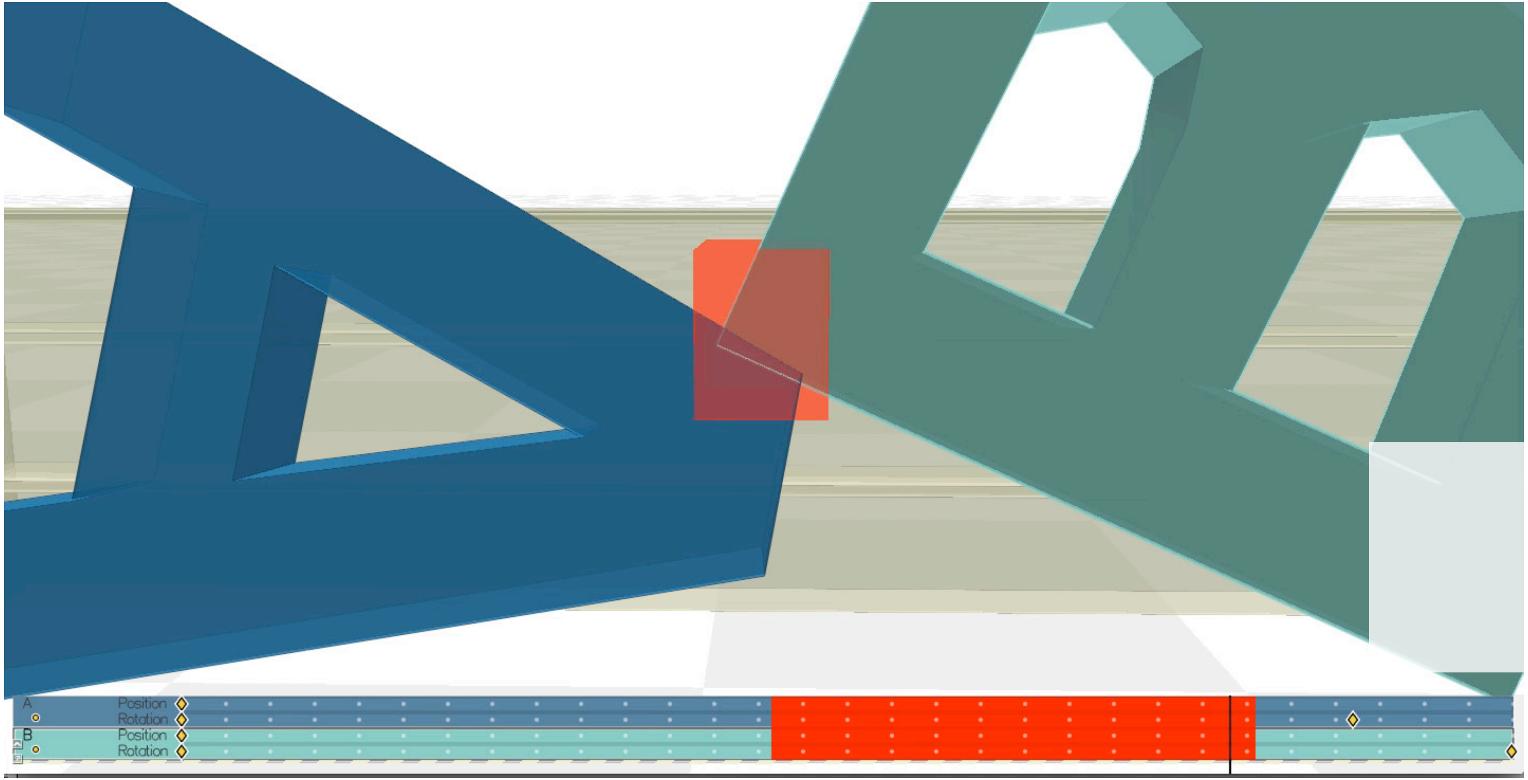
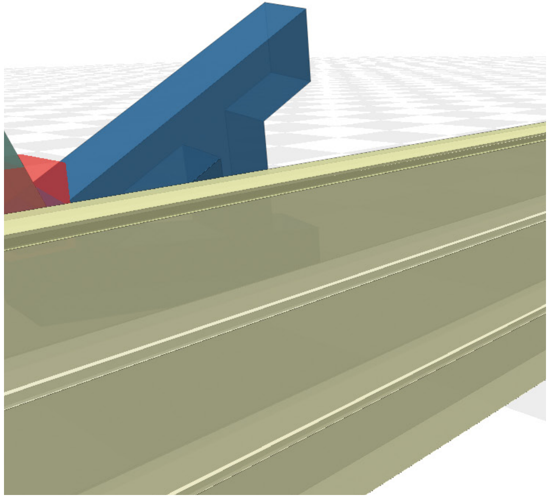


What makes a poor view?



Collision interval
not central

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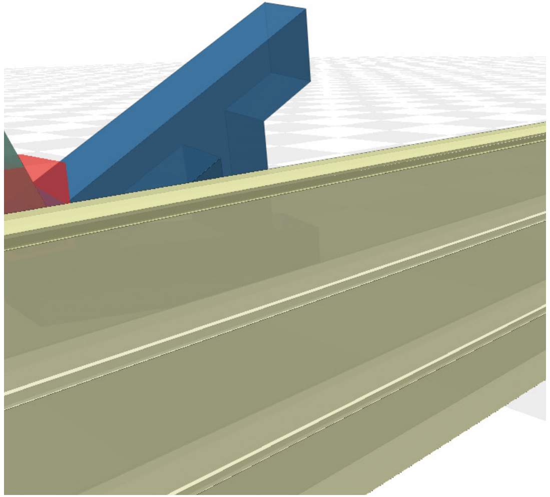

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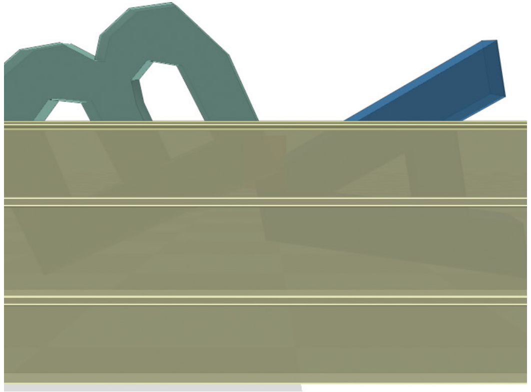
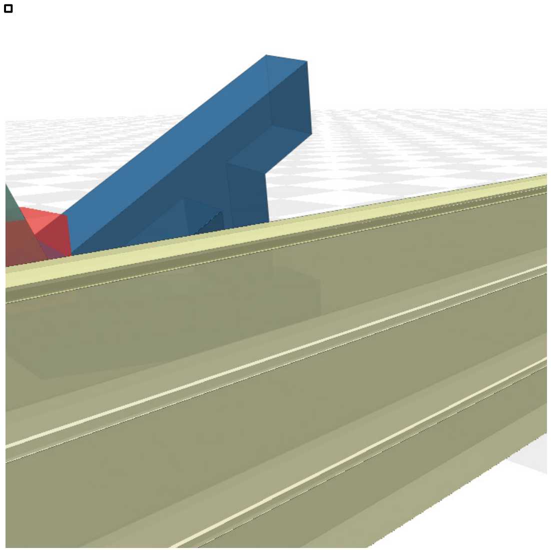


Collision interval
occluded

What makes a poor view?



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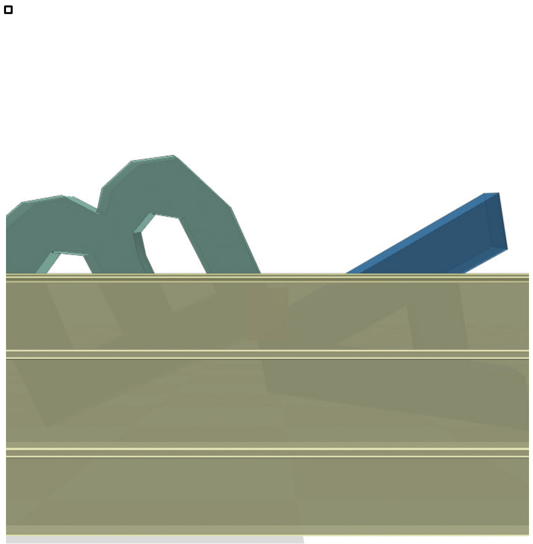

Collision interval
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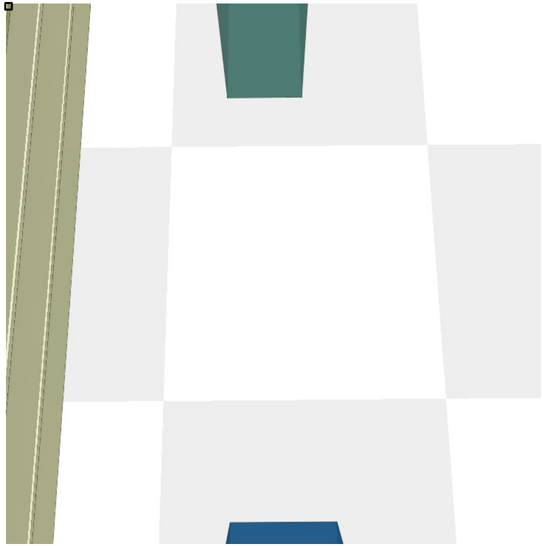
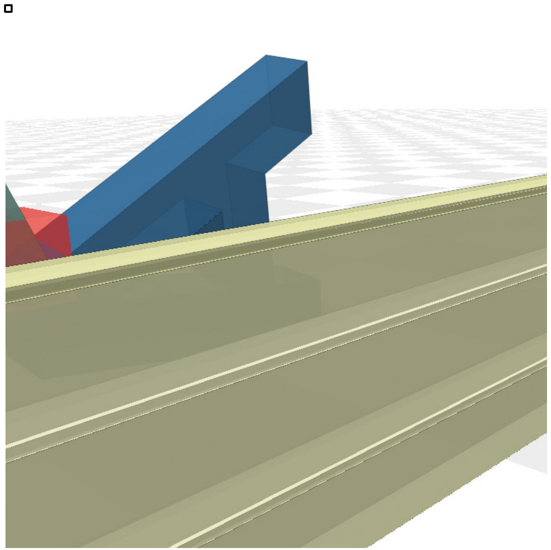
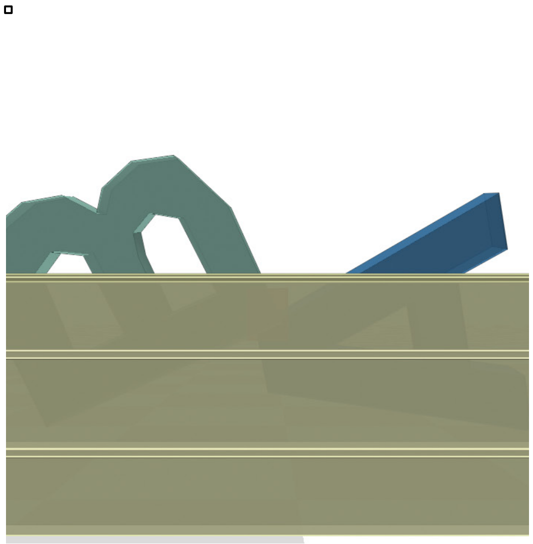


View direction
along trajectory

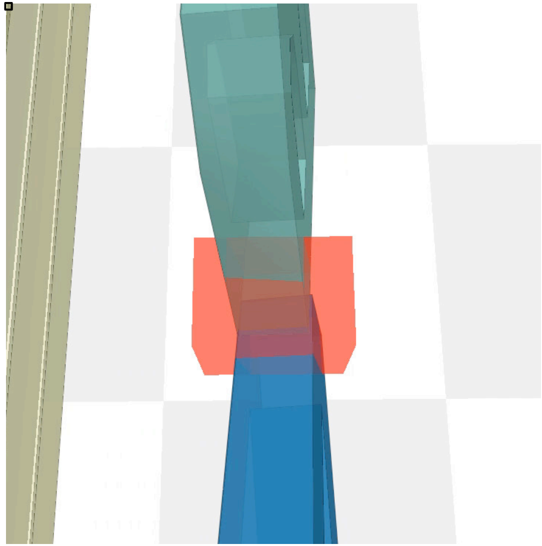
What makes a poor view?



Collision interval not central

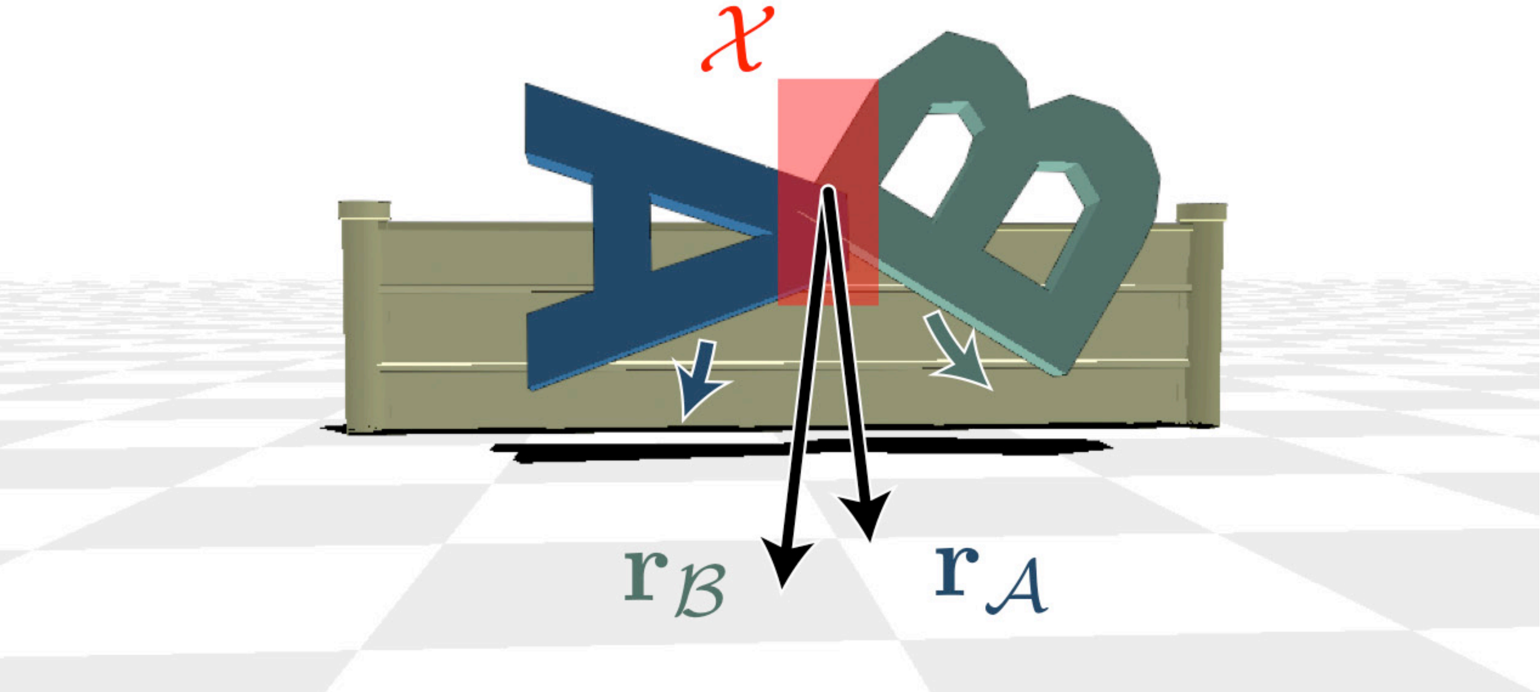


Collision interval occluded



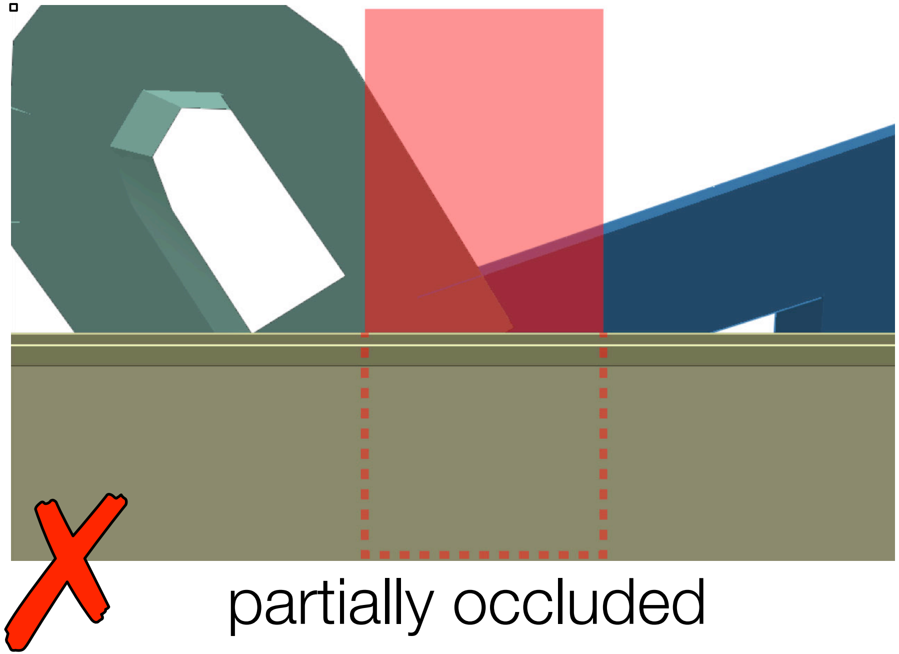
View direction along trajectory

For two objects, center collision interval along view direction orthogonal to motions…



Generally, two choices left: pick direction with least occlusion

$$\mathbf{r}_{\mathcal{A}} \times \mathbf{r}_{\mathcal{B}}$$

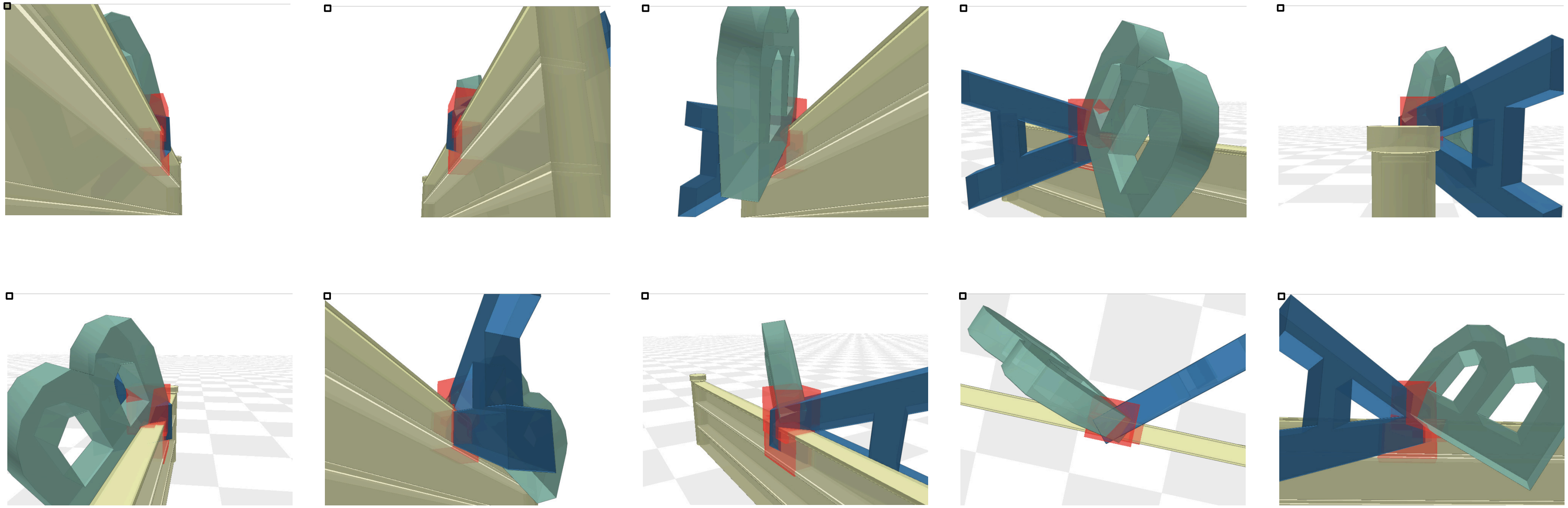


partially occluded

$$-\mathbf{r}_{\mathcal{A}} \times \mathbf{r}_{\mathcal{B}}$$

not occluded

For degenerate views or multiple objects, we search over all views via *Monte Carlo*



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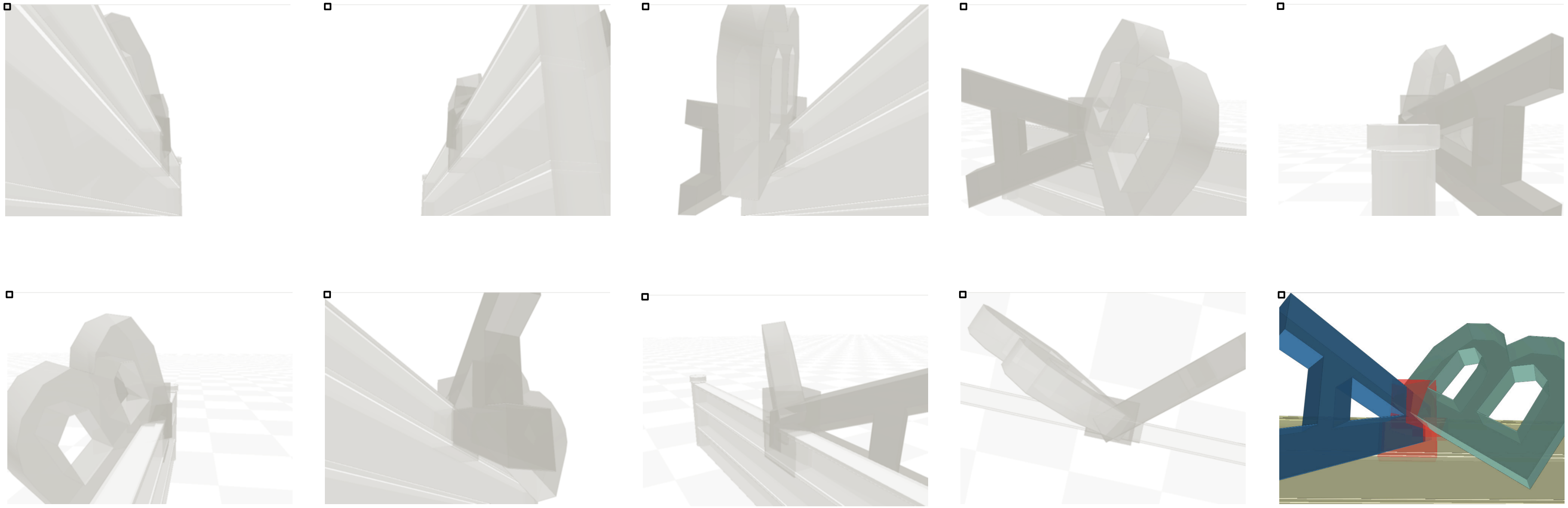

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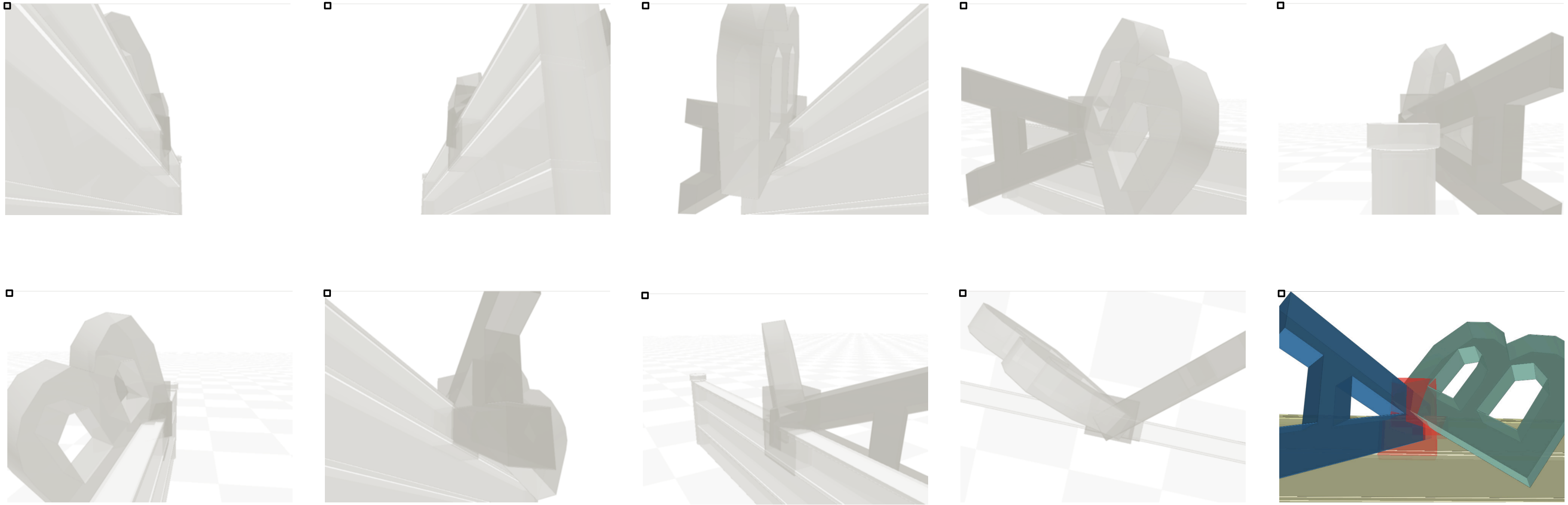
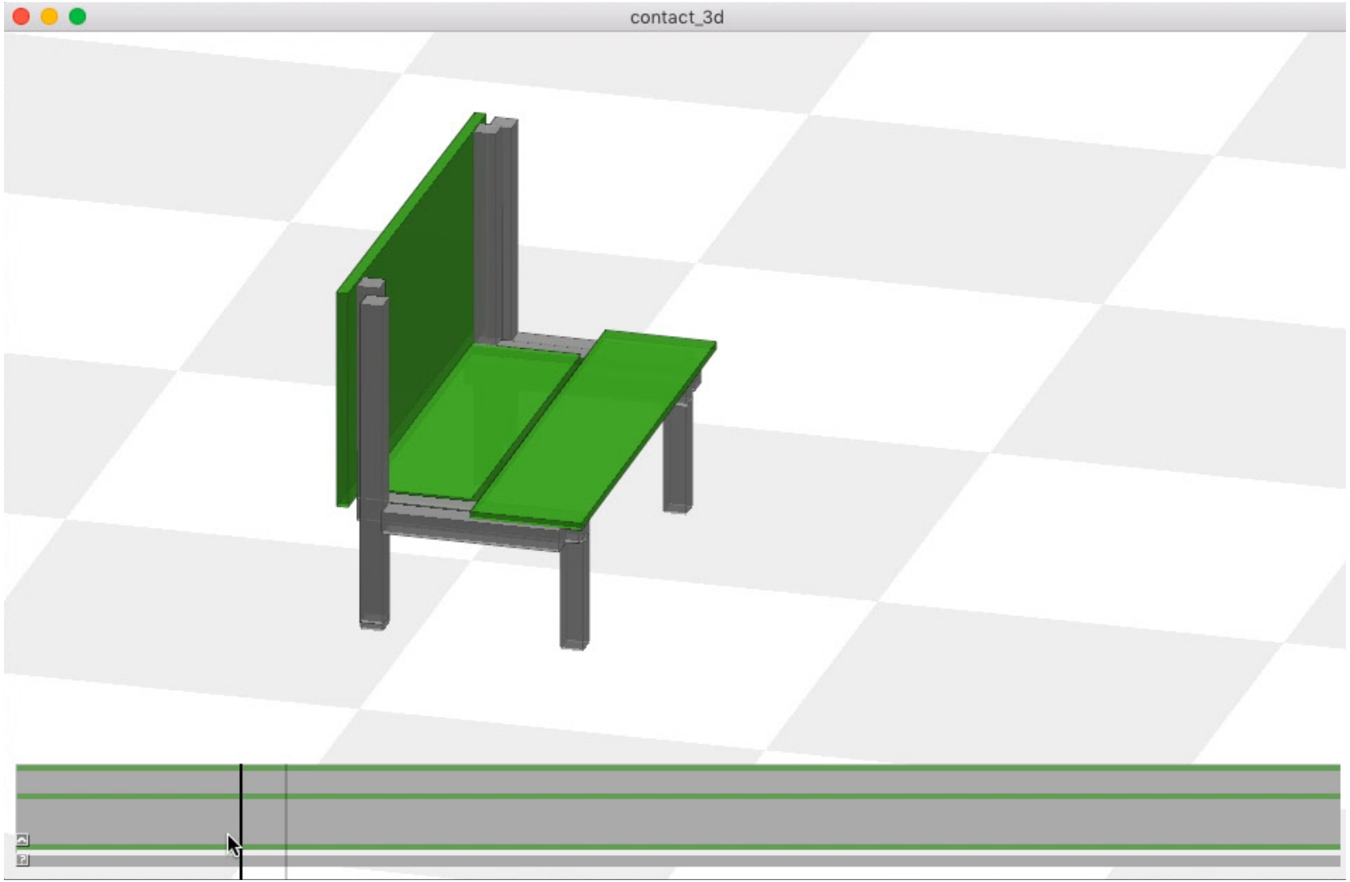
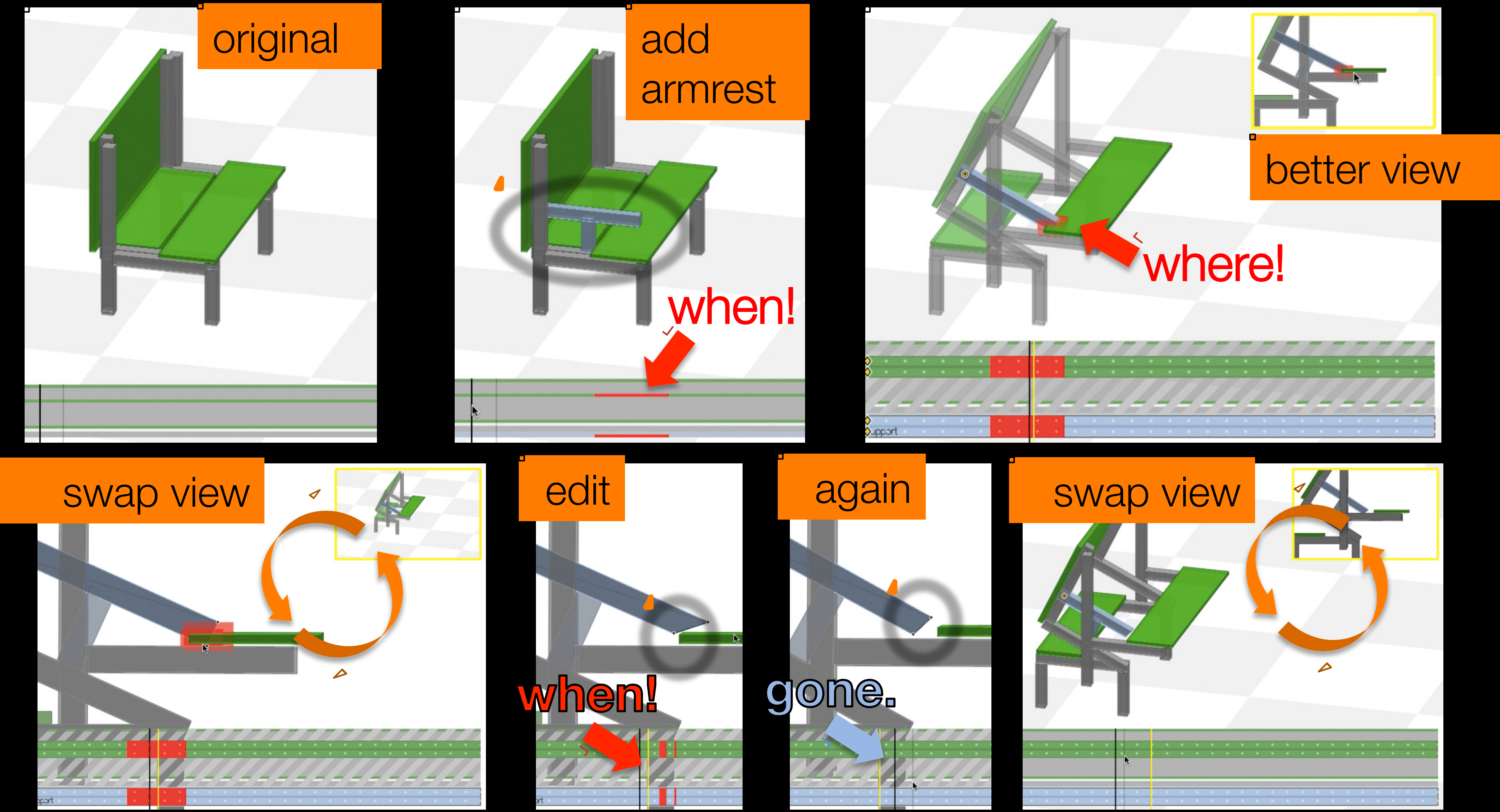
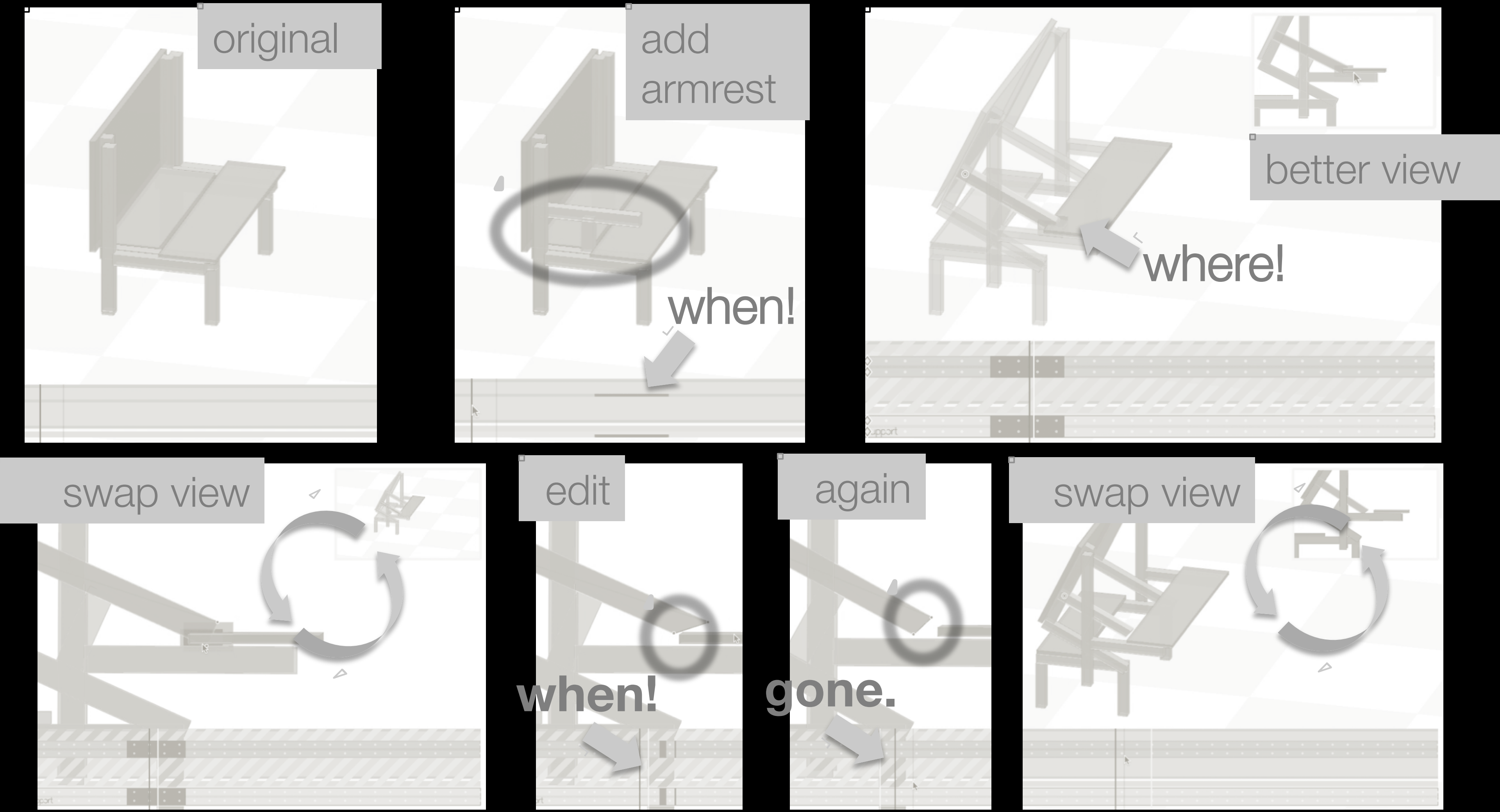


count “red” pixels using hardware “occlusion queries” (GL_SAMPLES_PASSED)

Picture-in-picture allows rapid editing




original
add armrest
when!
better view
where!
swap view
edit
when!
again
gone.
swap view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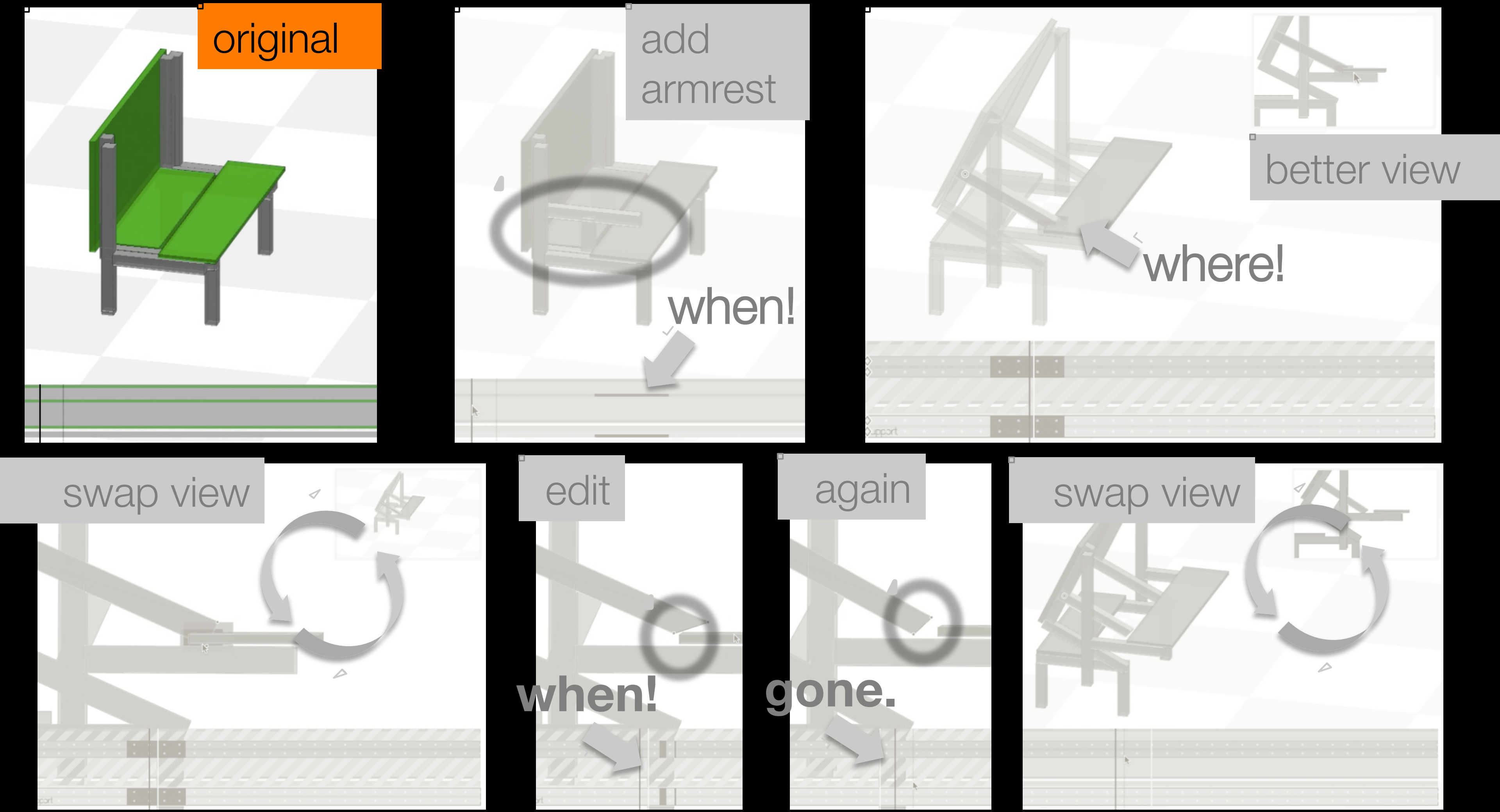
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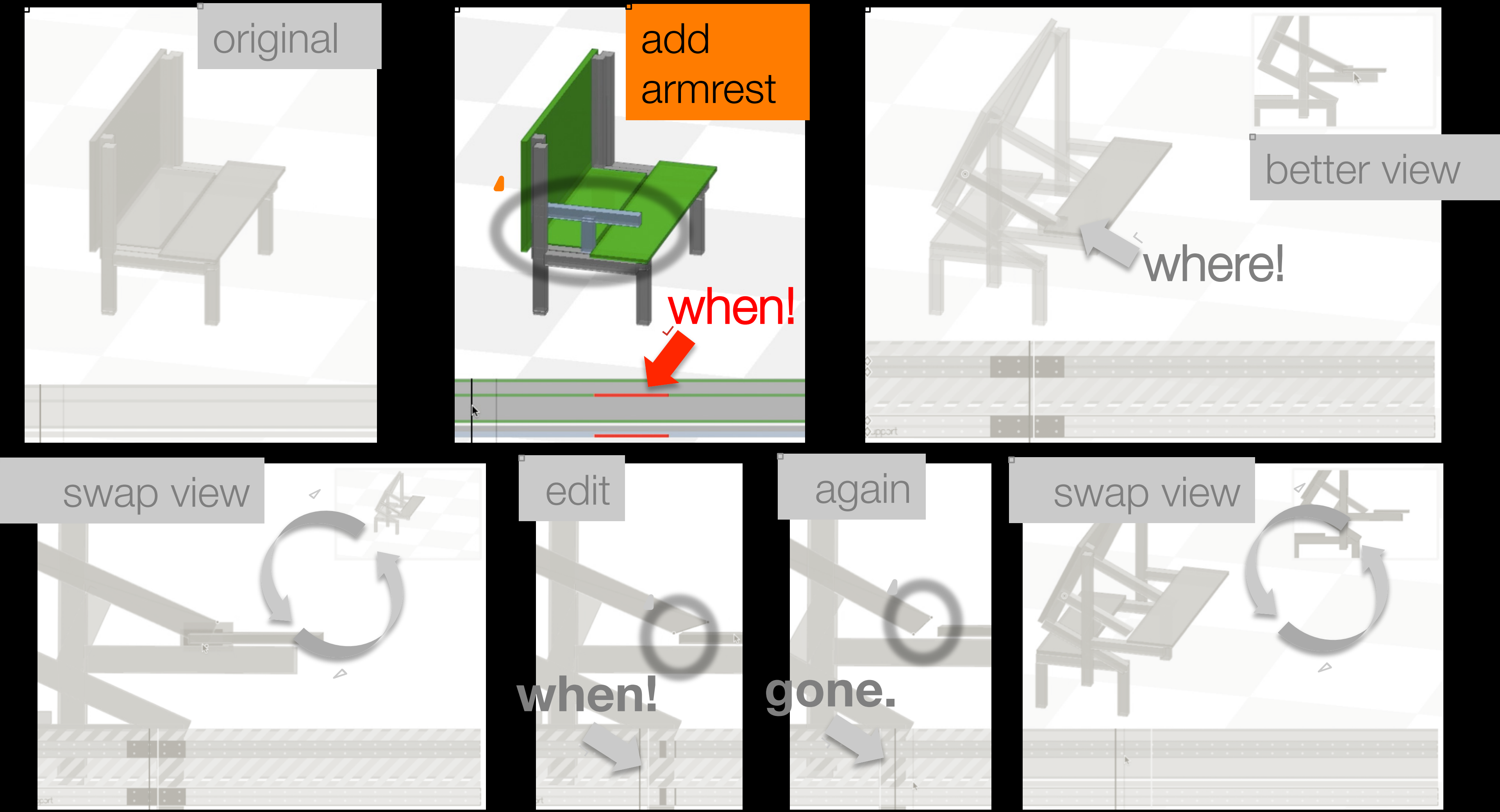
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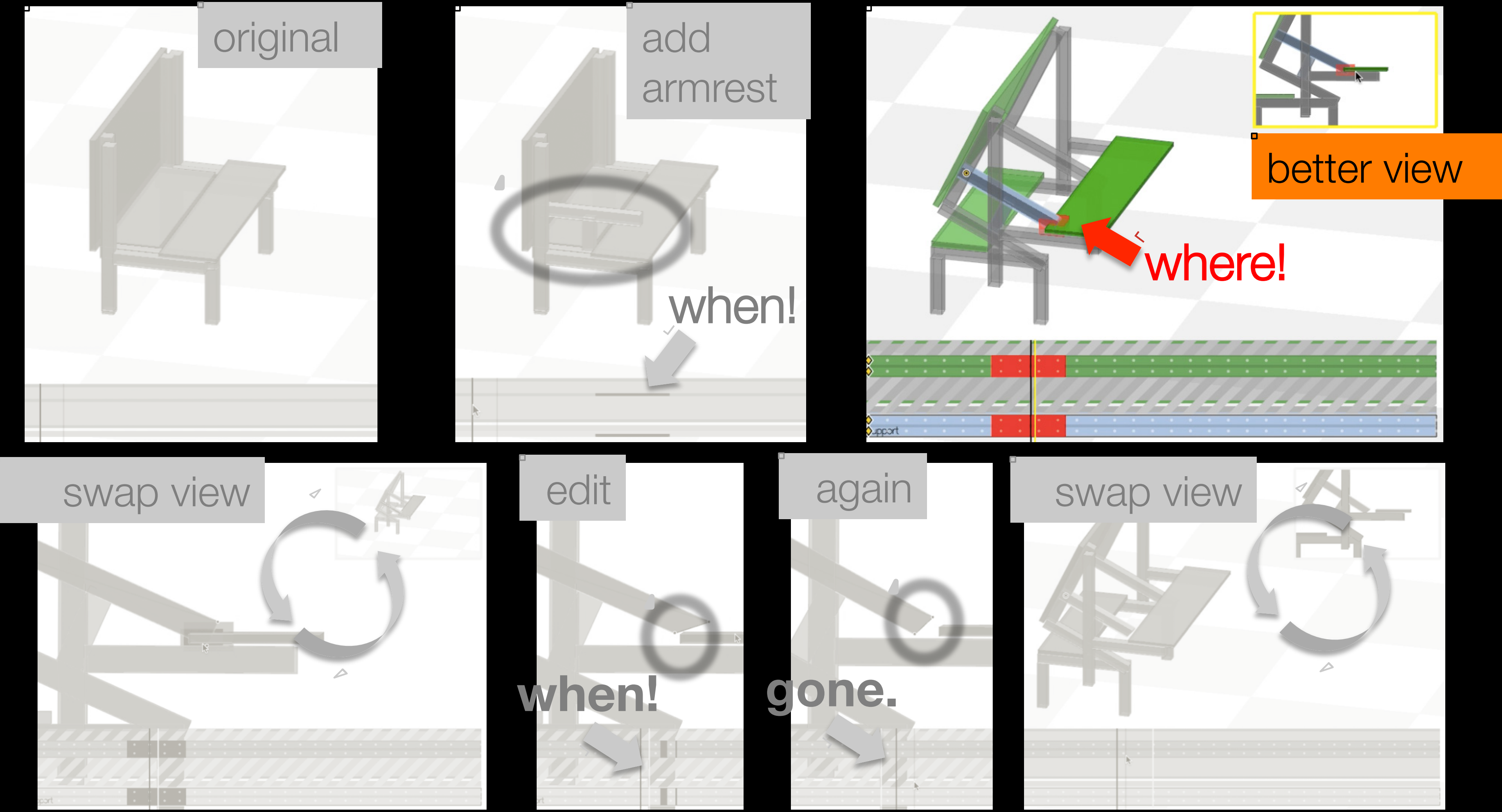
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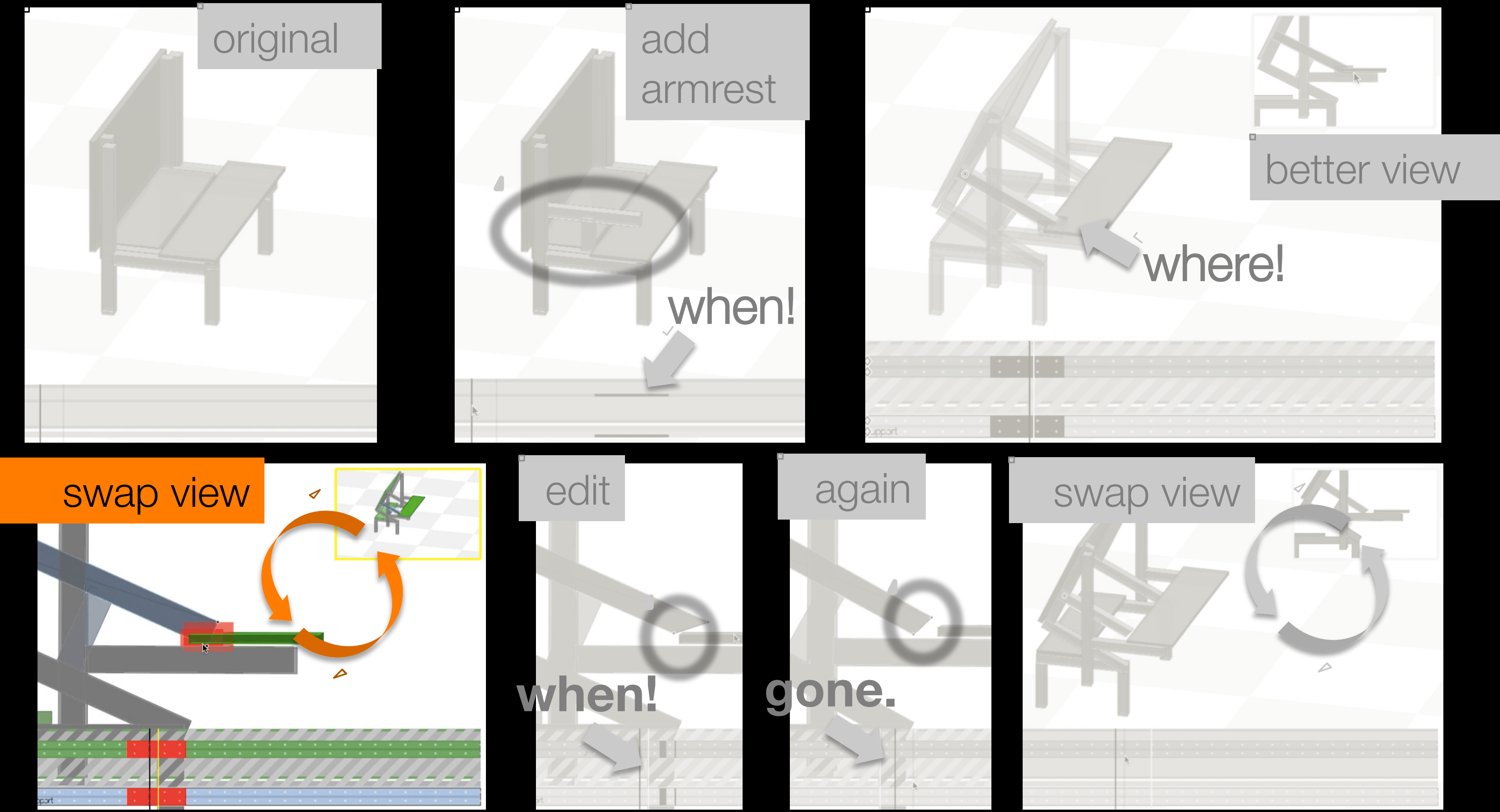
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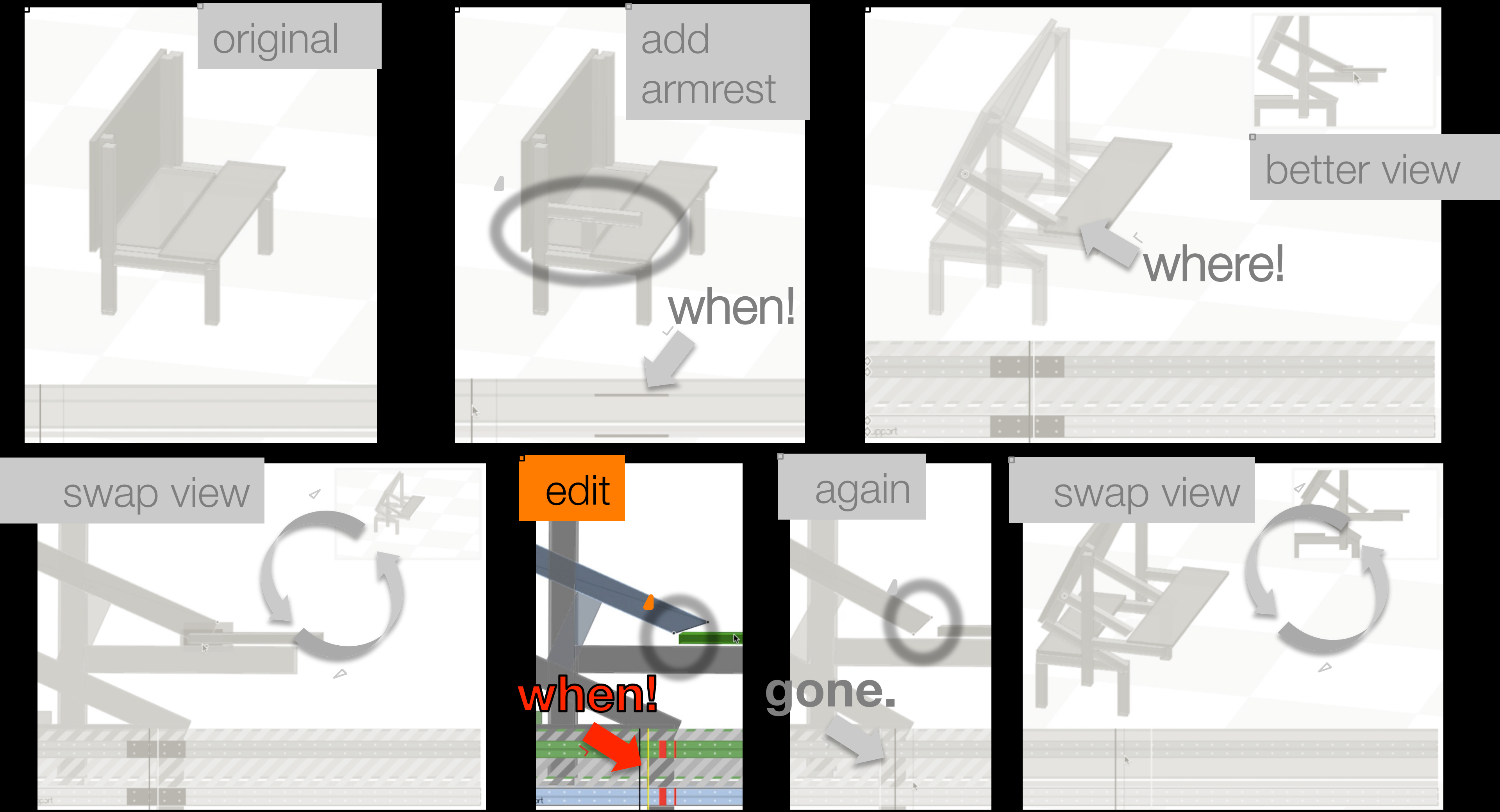

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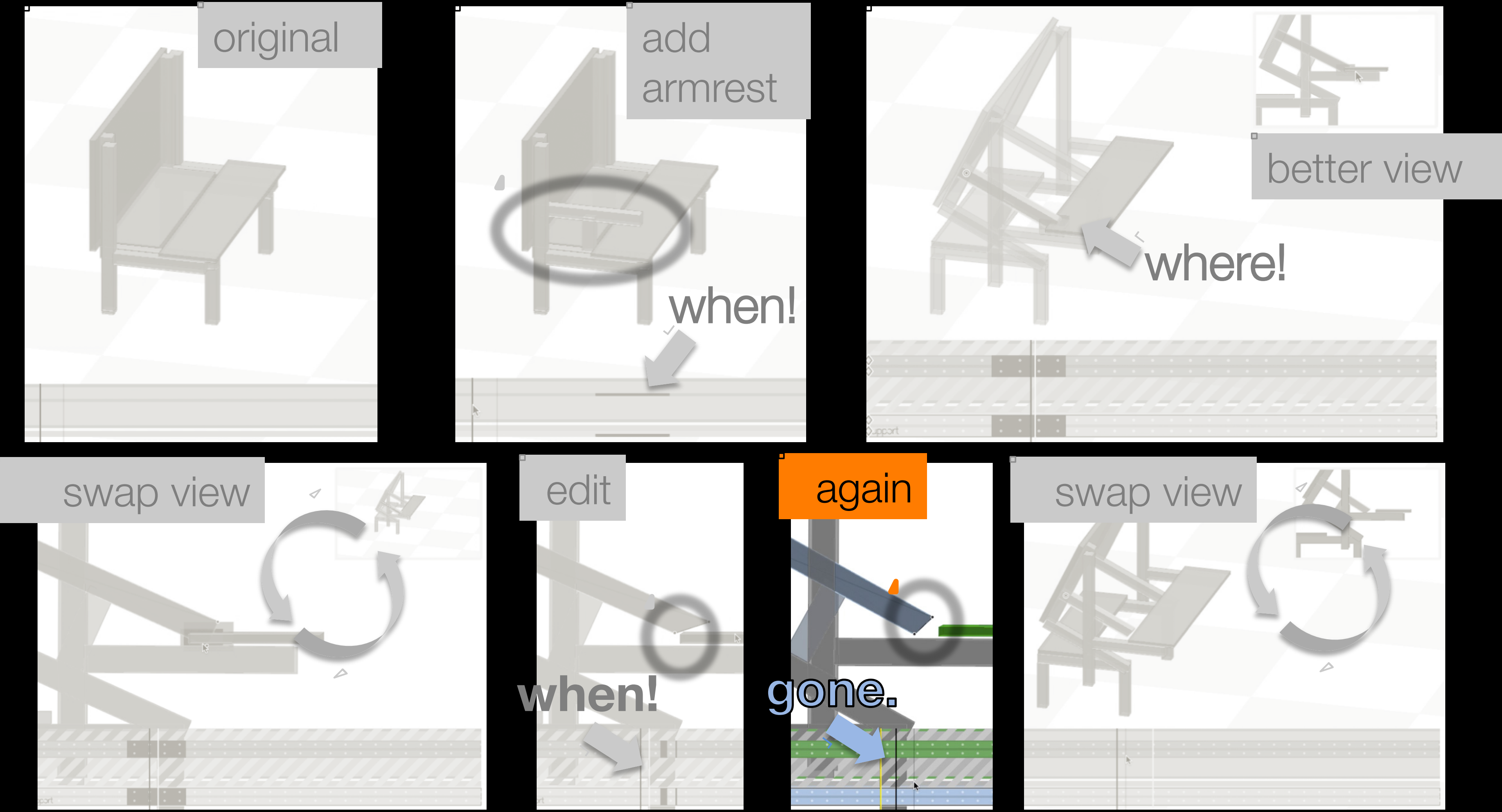
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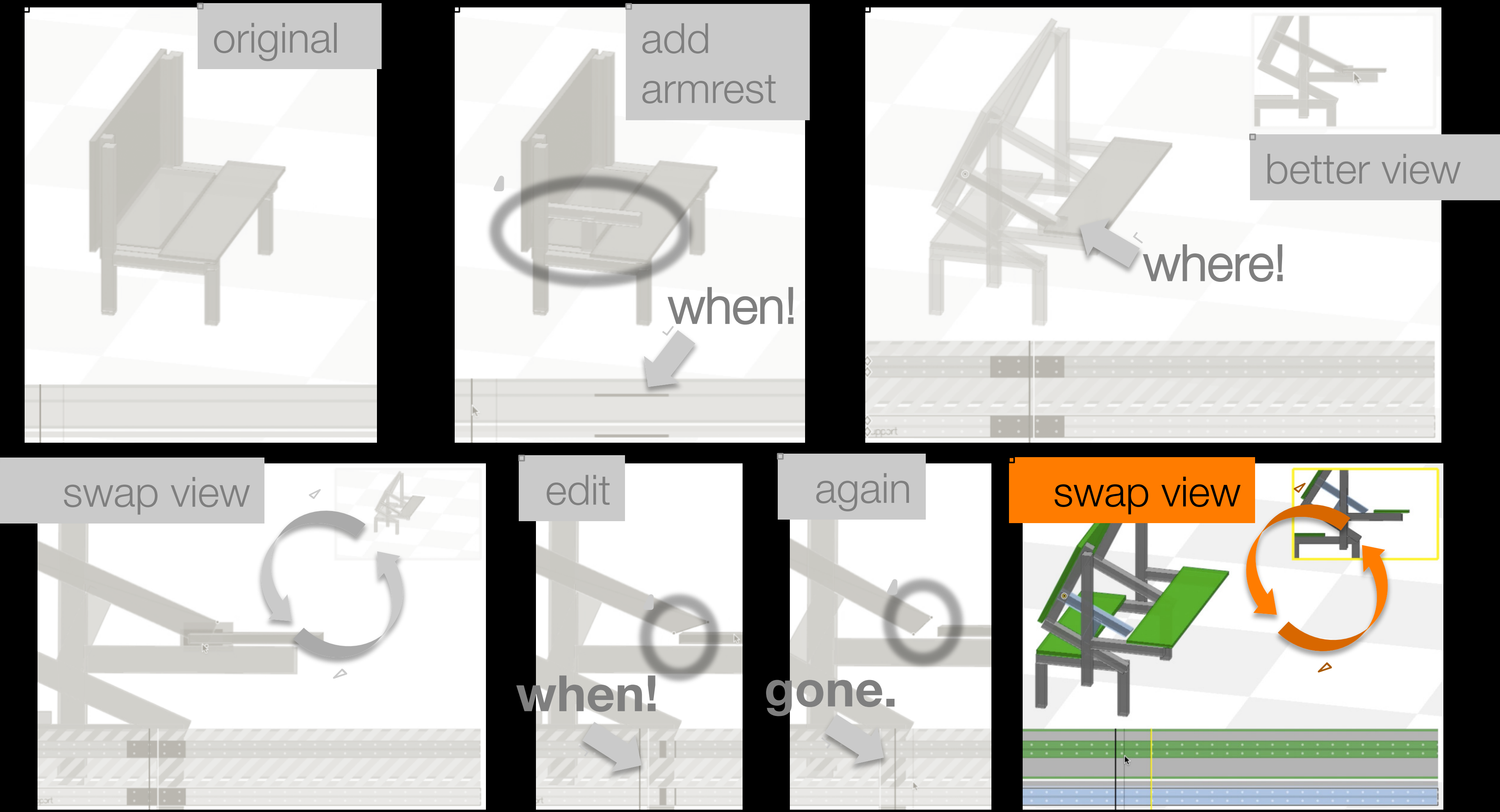
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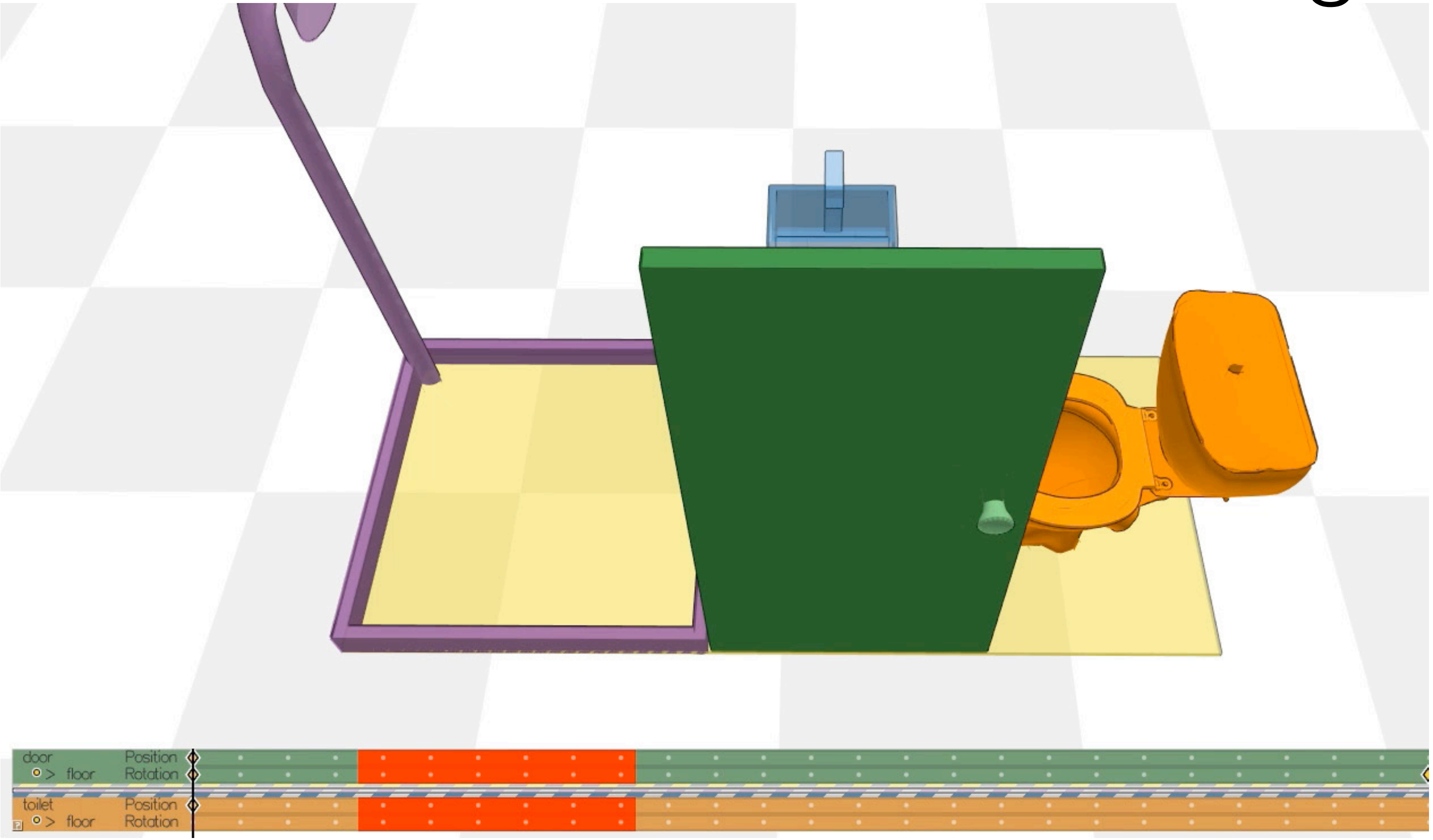
Stroboscopic ghosting complements interactive collision interval tracking



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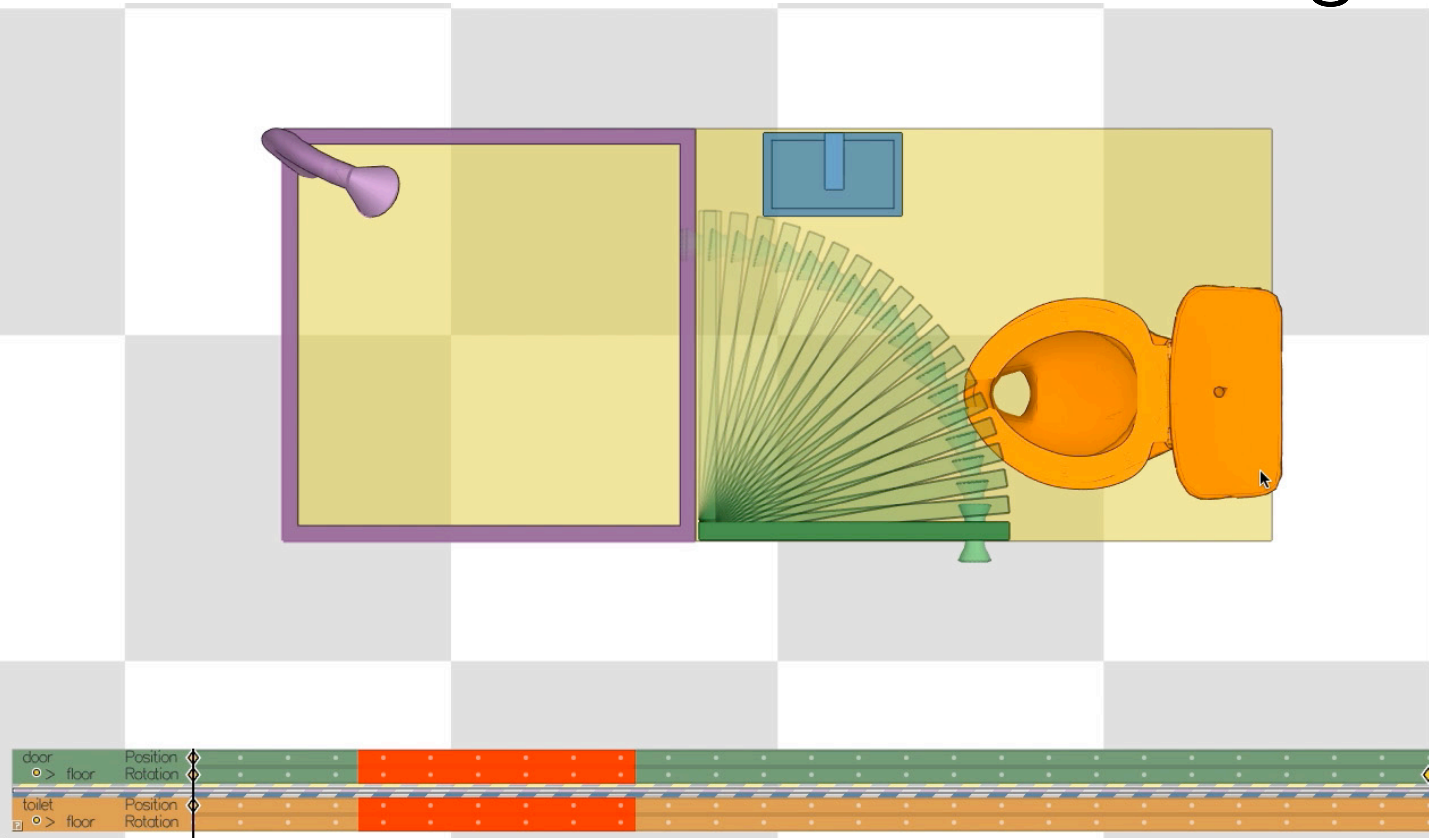

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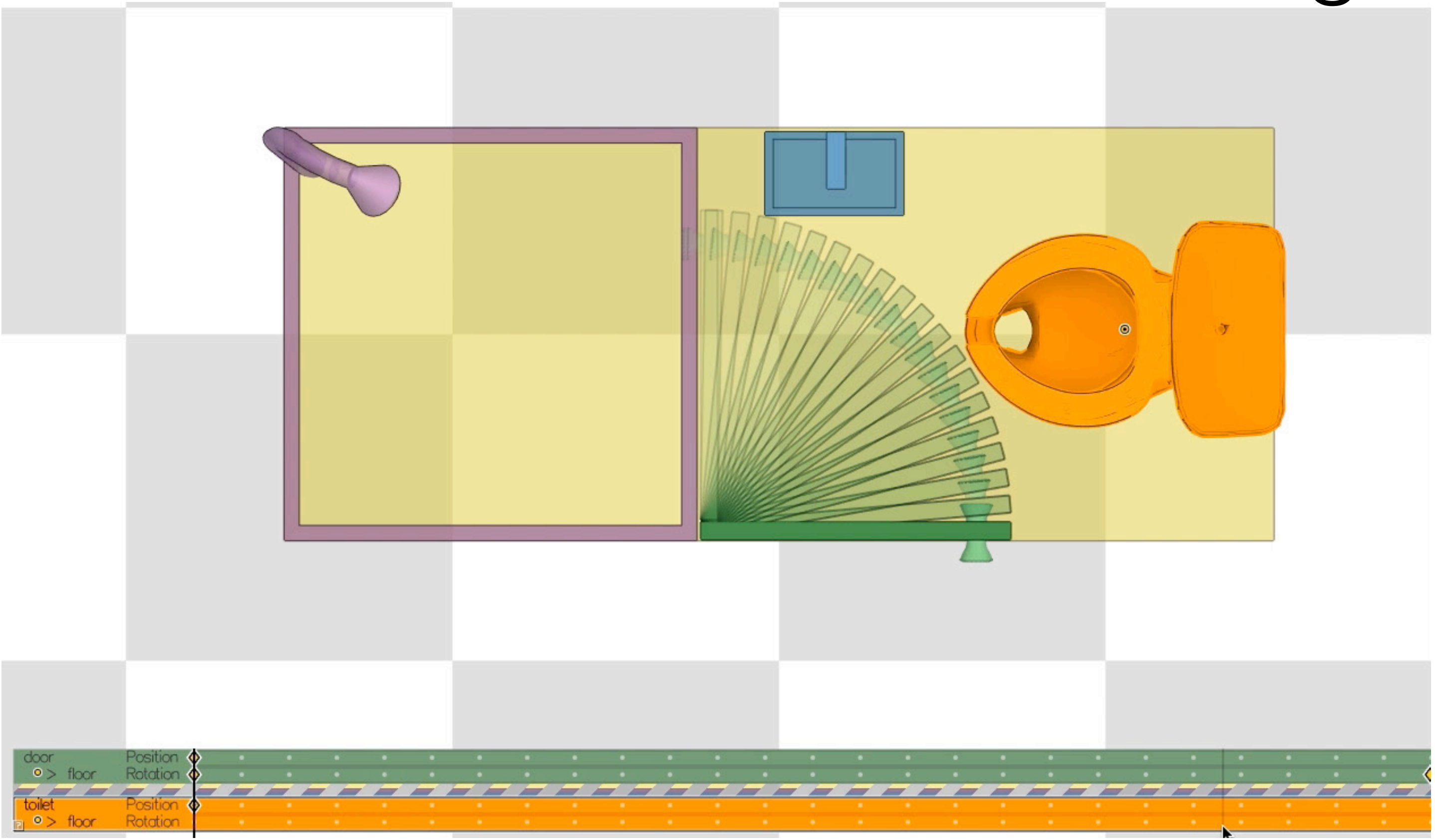
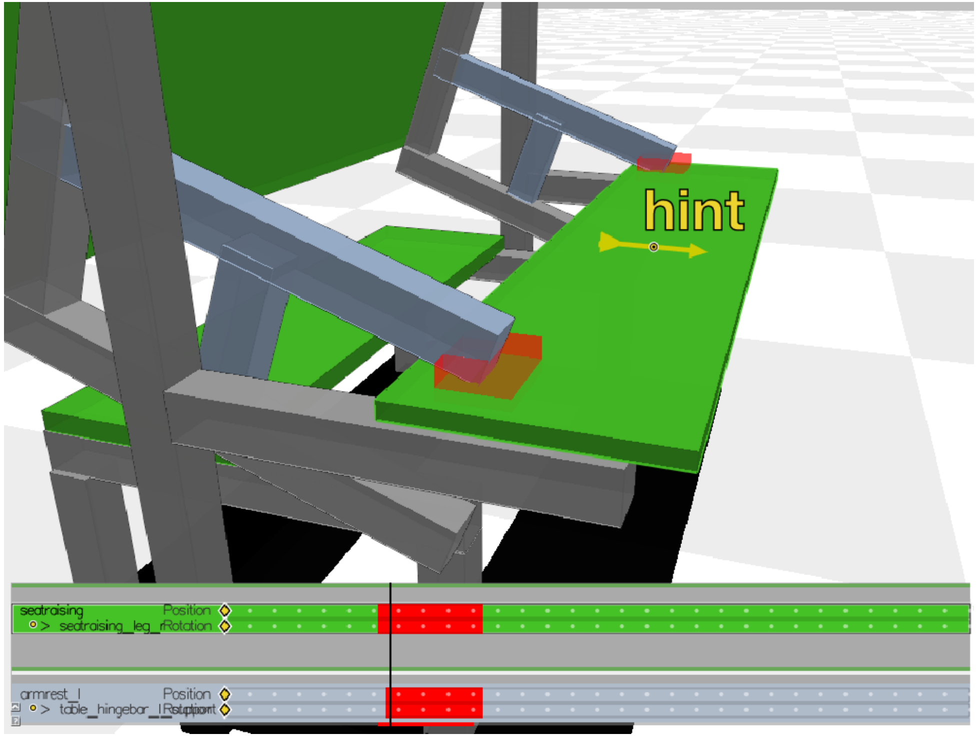


Fixing collisions can be tedious and unintuitive, how about a hint?

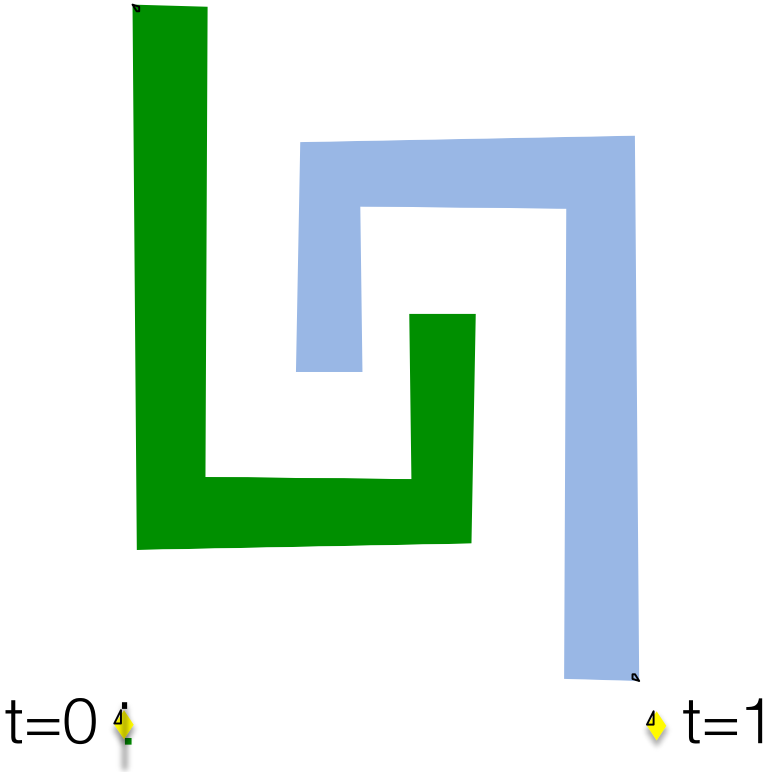


decrease/remove collisions

agnostic to direction of time

in terms of UI DOFs

First contacts between objects produce unreliable, biased directions



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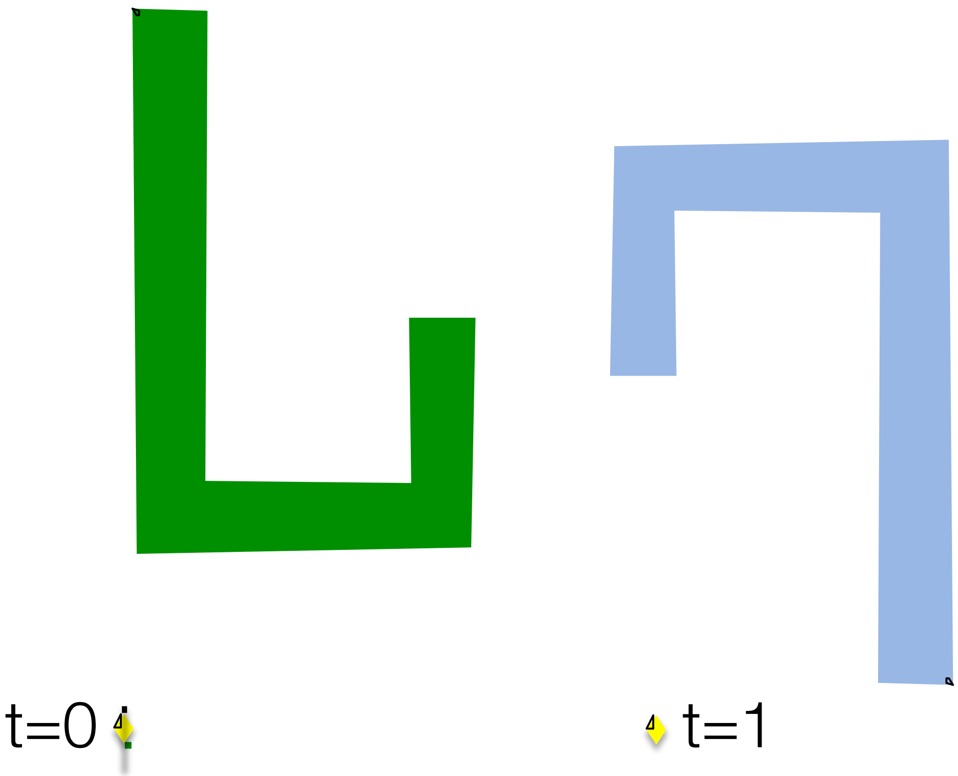

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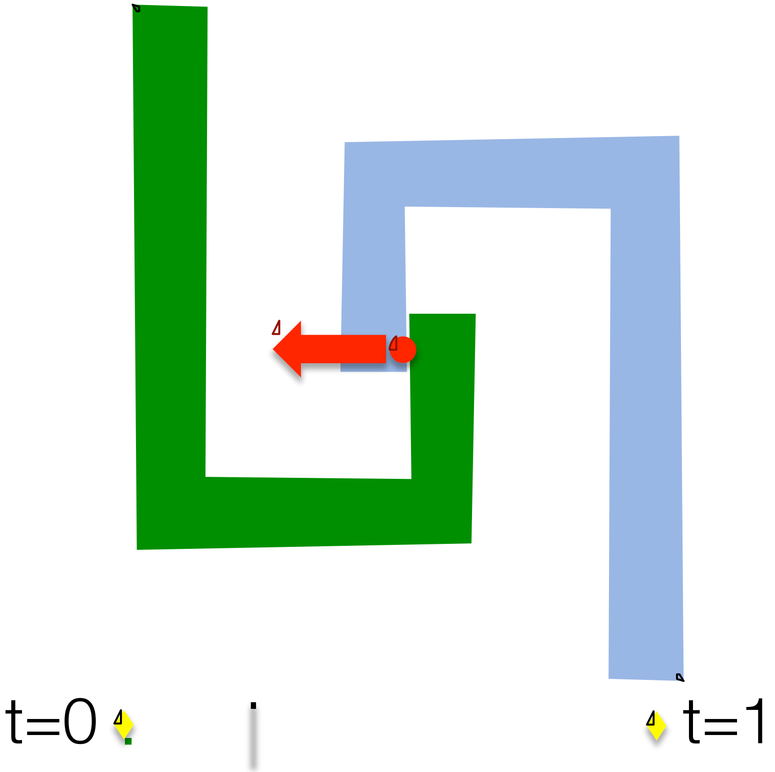
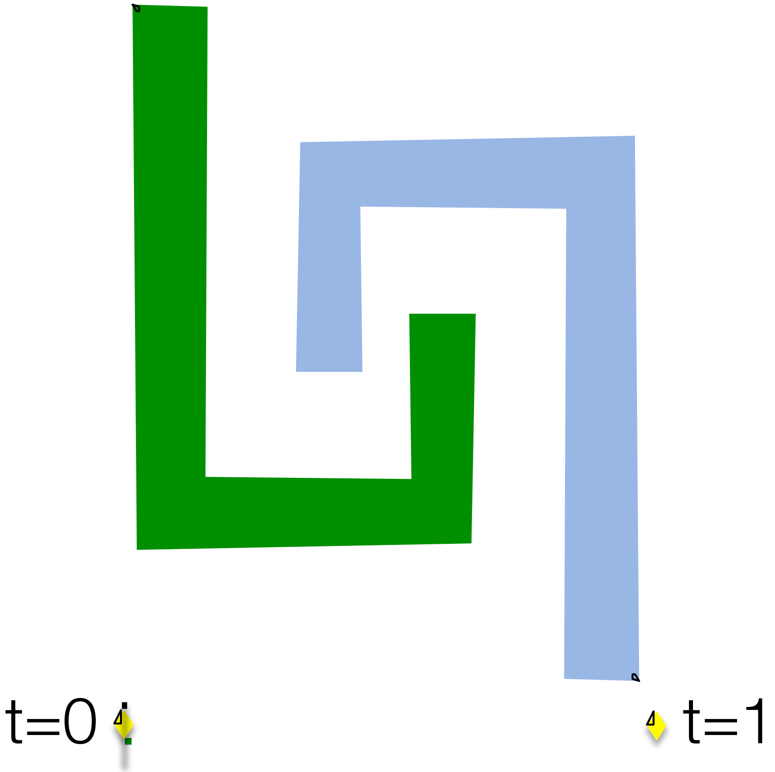


Global solution should *untangle* spacetime intersection



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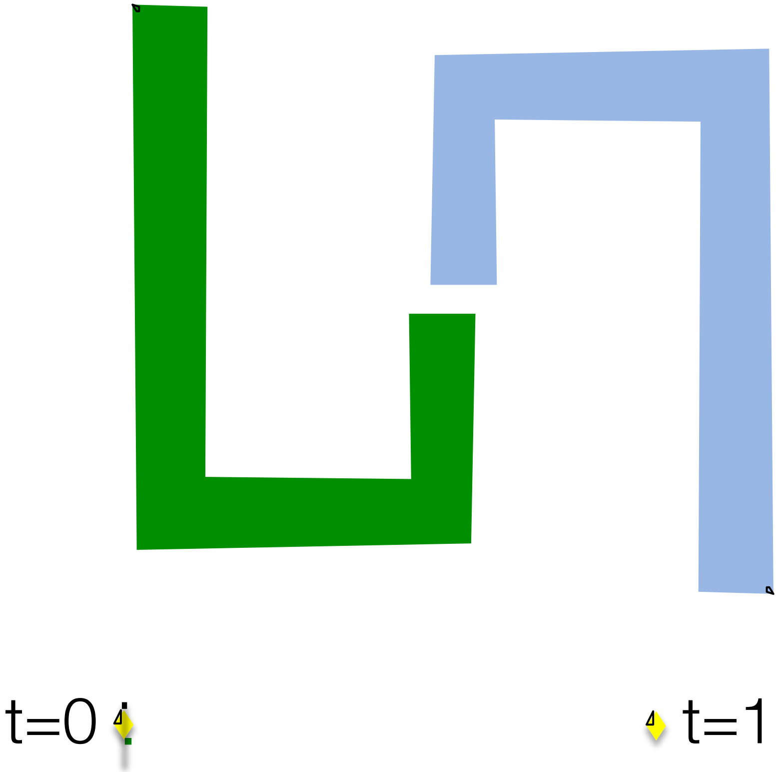

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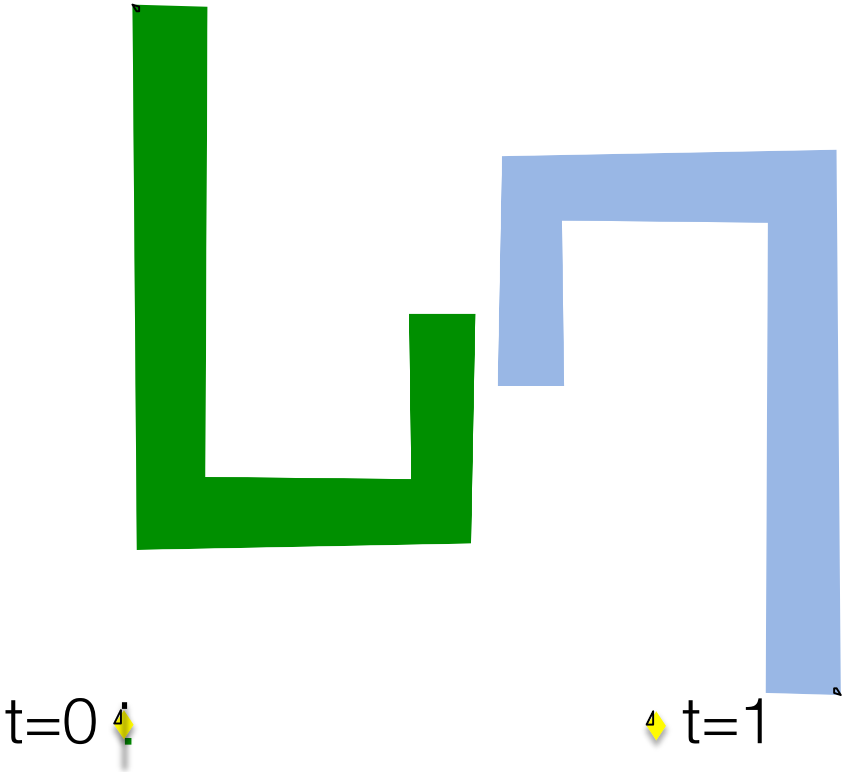
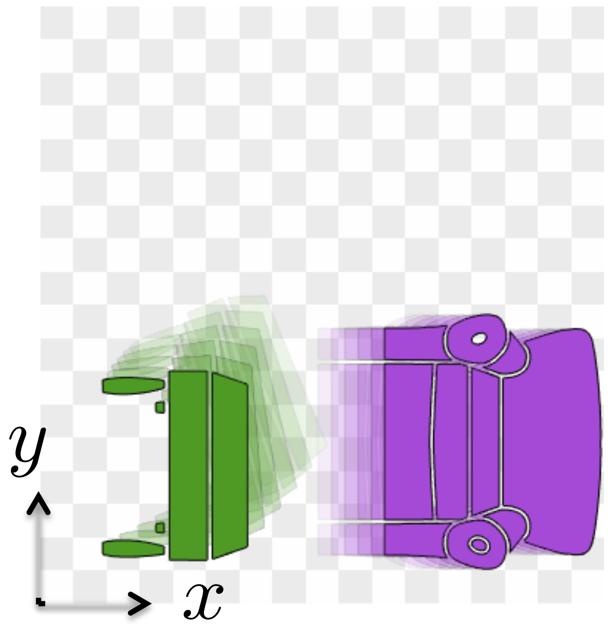
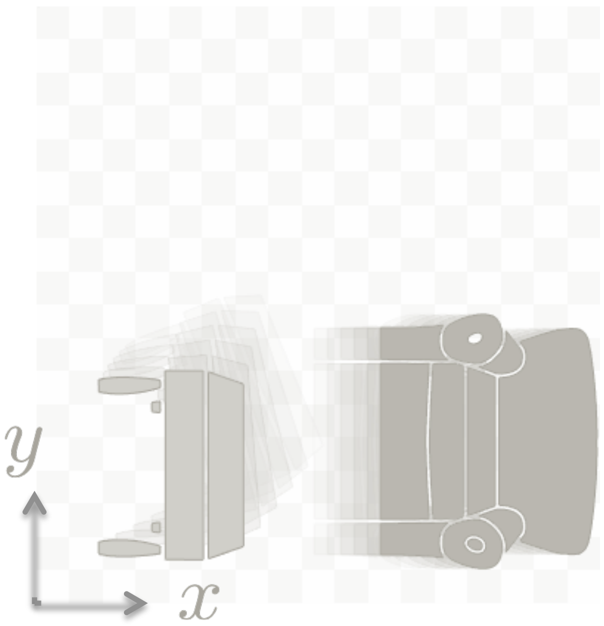


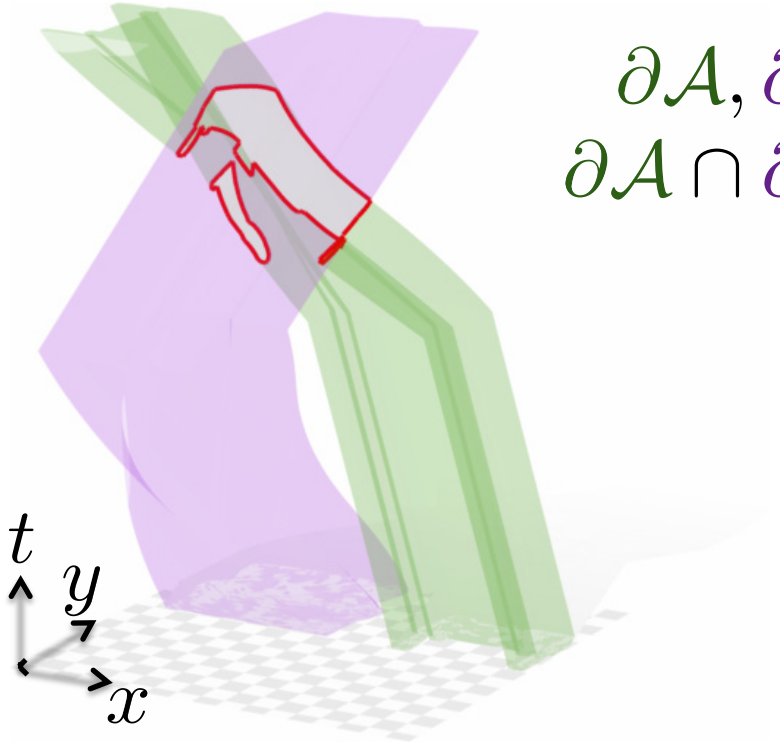
2D reconfigurables *could* be untangled like 3D cloths



$\mathcal{A}, \mathcal{B} \subset \mathbb{R}^3$

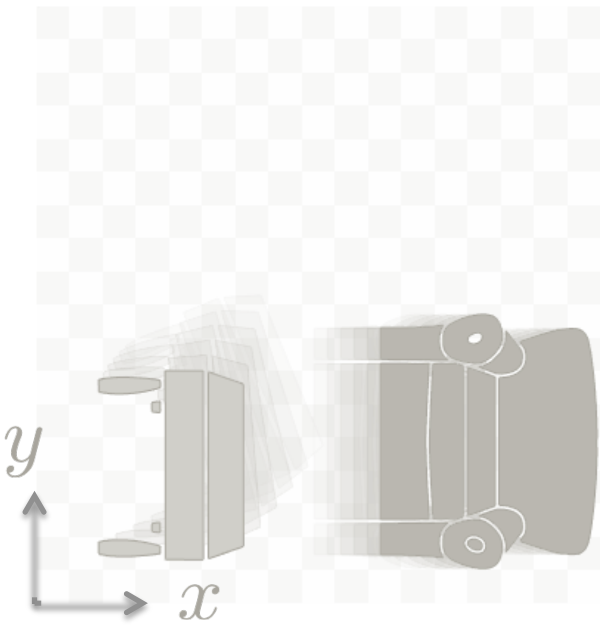
2D reconfigurables *could* be untangled like 3D cloths

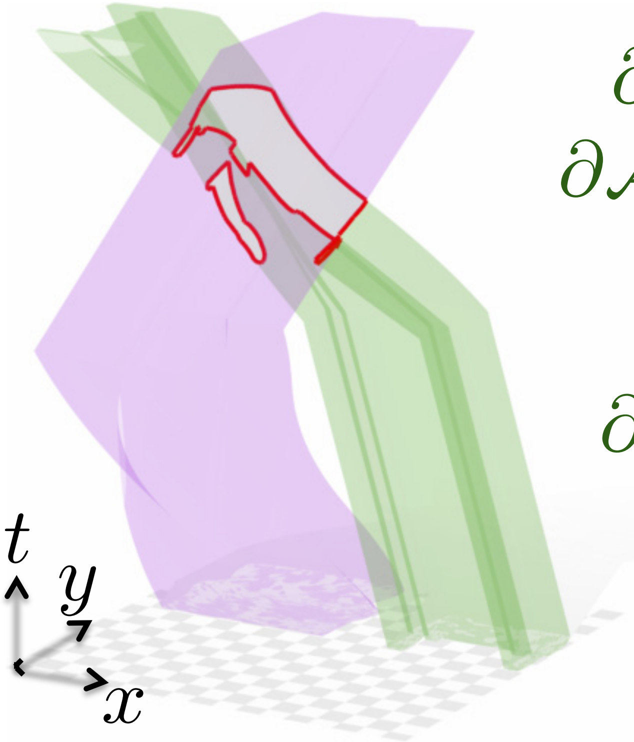




$$\partial\mathcal{A}, \partial\mathcal{B} \in \mathcal{S}_{2\mathrm{D}}$$
$$\partial\mathcal{A} \cap \partial\mathcal{B} \in \mathcal{C}_{1\mathrm{D}}$$

2D reconfigurables *could* be untangled like 3D cloths





$$\partial\mathcal{A}, \partial\mathcal{B} \in \mathcal{S}_{\mathrm{2D}}$$
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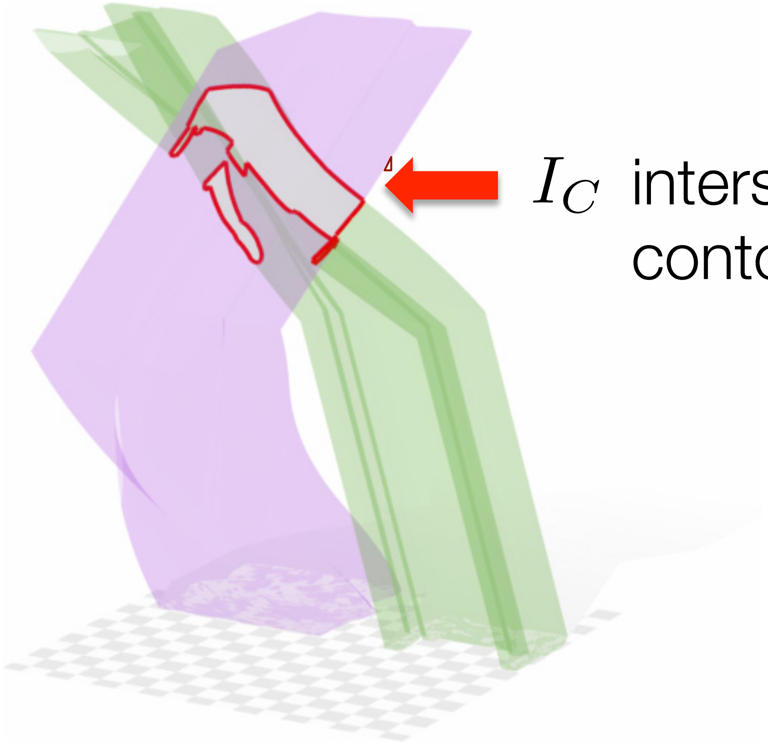
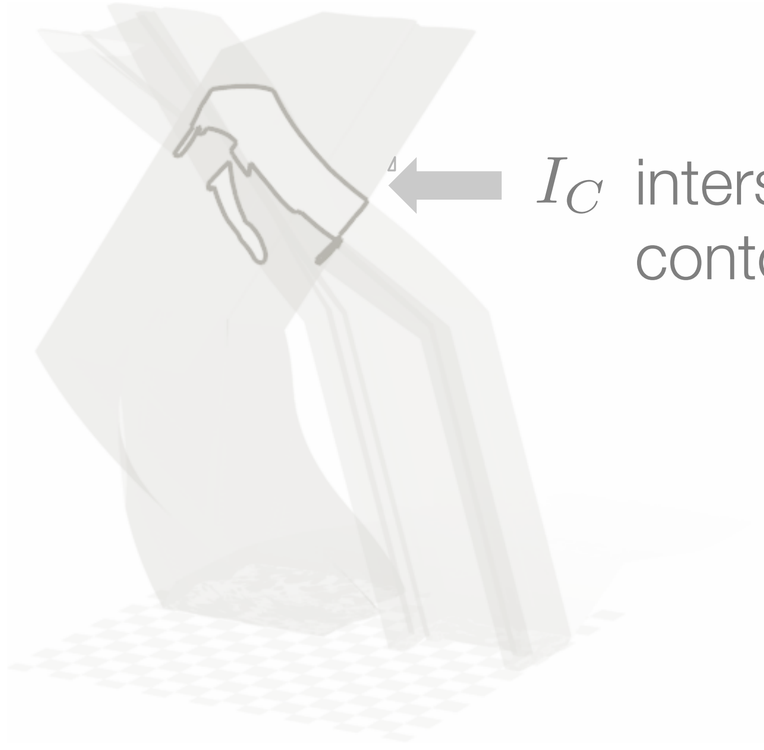
$$\partial\mathcal{A} \cap \partial\mathcal{B} \to \varnothing$$
$$\Downarrow$$
$$\mathcal{A} \cap \mathcal{B} \to \varnothing$$

Minimizing length of intersection curve results in untangling



I_C intersection contour

Minimizing length of intersection curve results in untangling



I_C intersection contour

$$\underset{\mathbf{V}}{\operatorname{argmin}} \; \|I_C\|$$

3D mesh vertices

length

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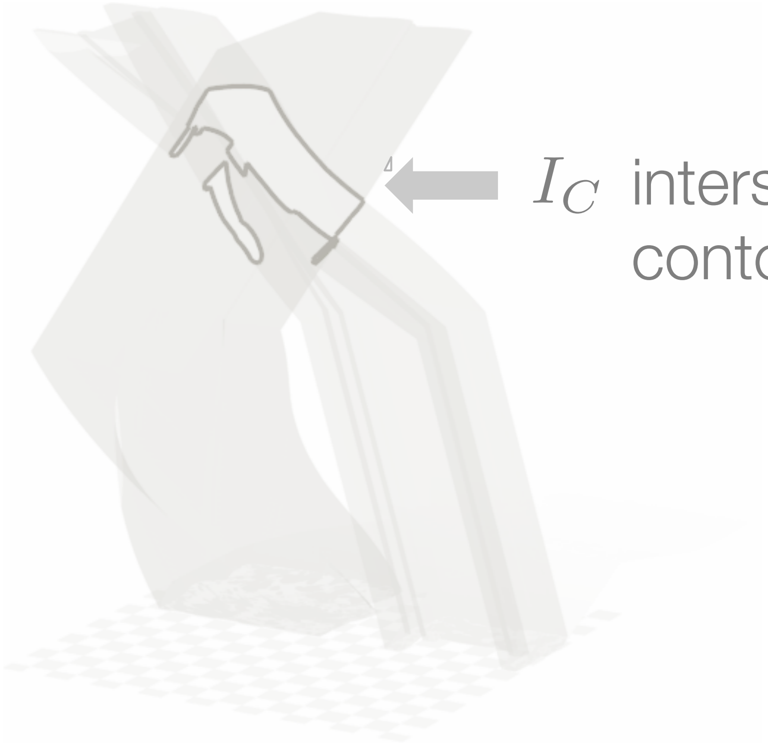

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update via gradient descent

$$\mathbf{V} \leftarrow \mathbf{V} - \nabla_{\mathbf{V}} \|I_C\|$$

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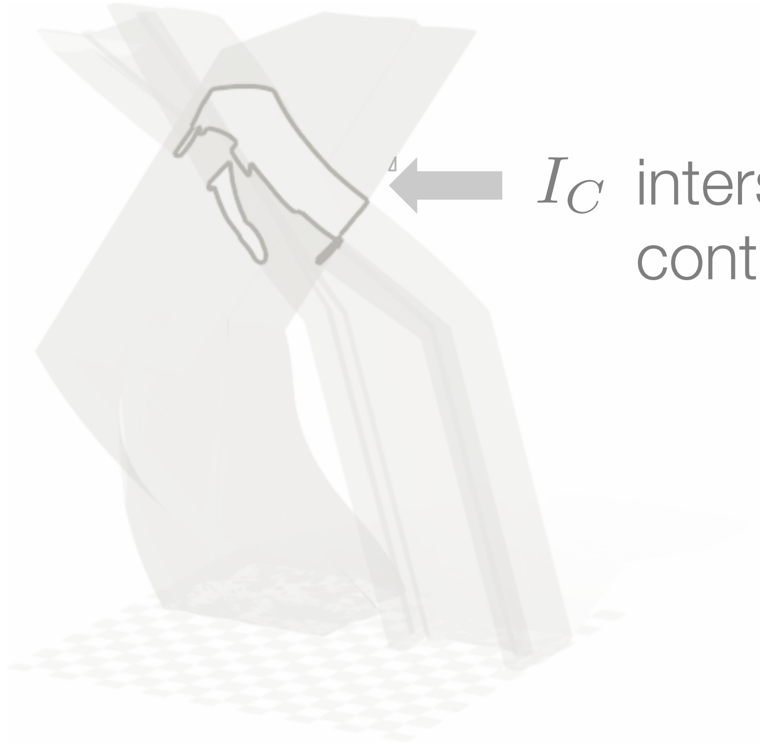

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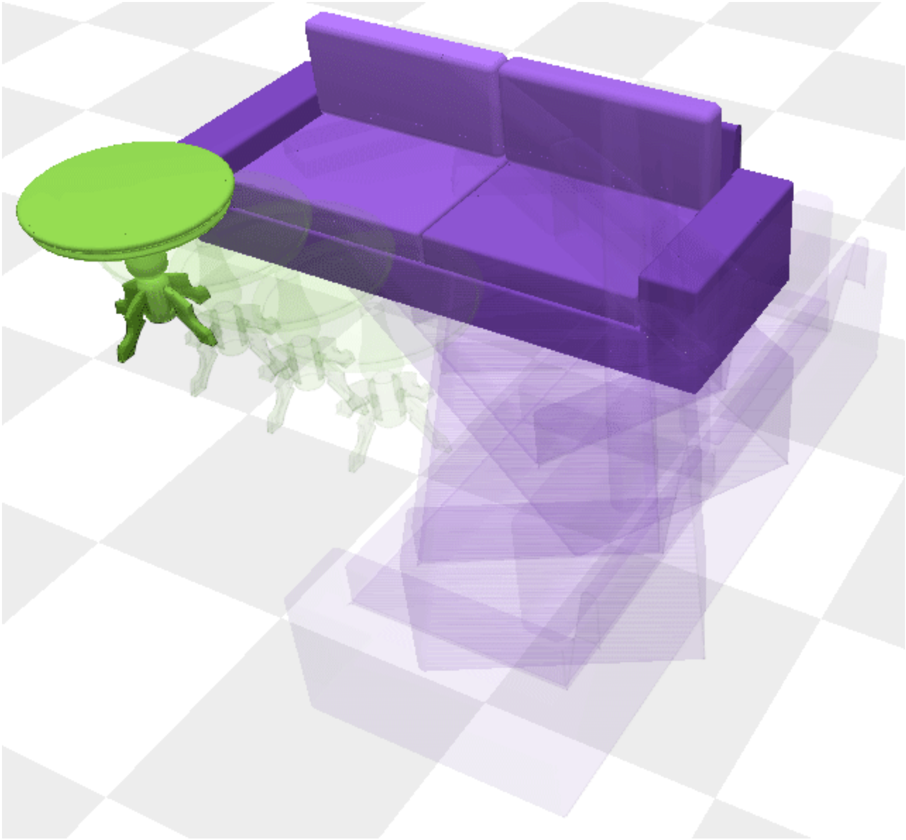
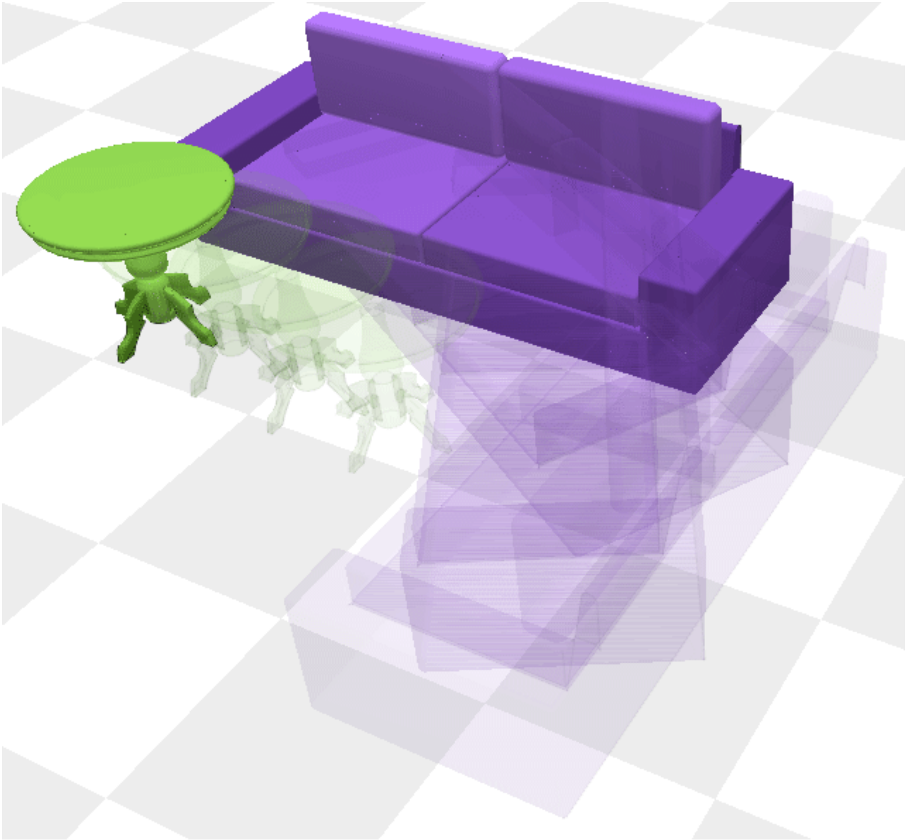
[Volino & M-T 2006]

Naive extension to 3D objects is problematic



$$\mathcal{A}, \mathcal{B} \subset \mathbb{R}^4$$

Naive extension to 3D objects is problematic

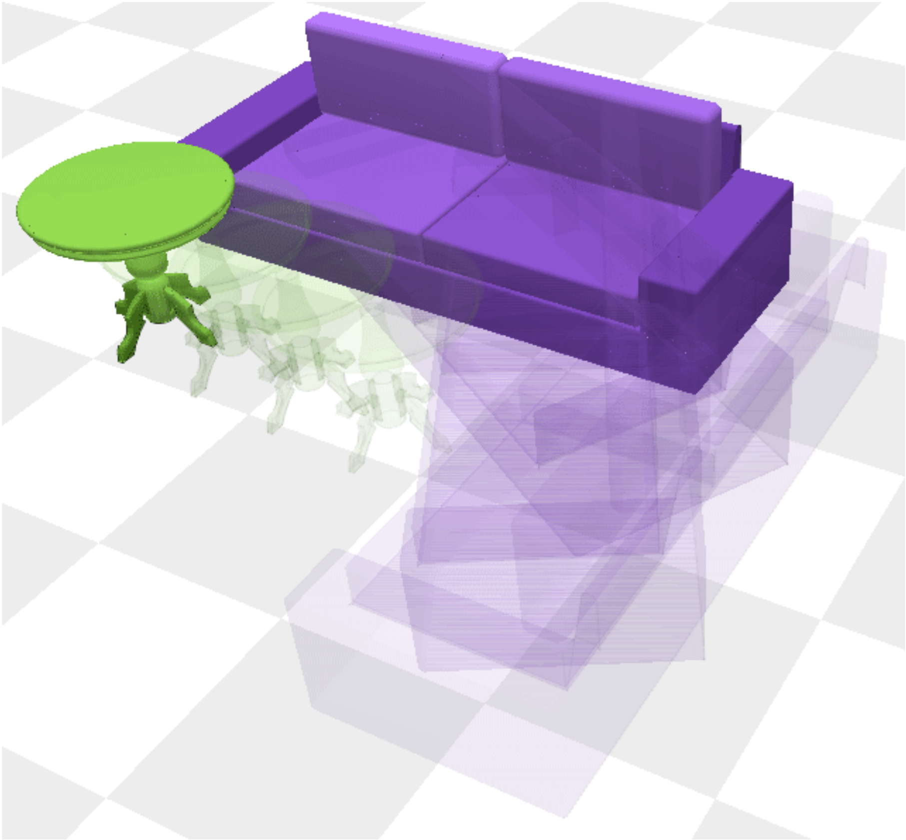


$$\partial\mathcal{A}, \partial\mathcal{B} \in \mathcal{S}_{3D}$$

$$\partial\mathcal{A} \cap \partial\mathcal{B} \in \mathcal{S}_{2D}$$

Difficult to compute or optimize over

Naive extension to 3D objects is problematic



$$\partial\mathcal{A}, \partial\mathcal{B} \in \mathcal{S}_{3\text{D}}$$

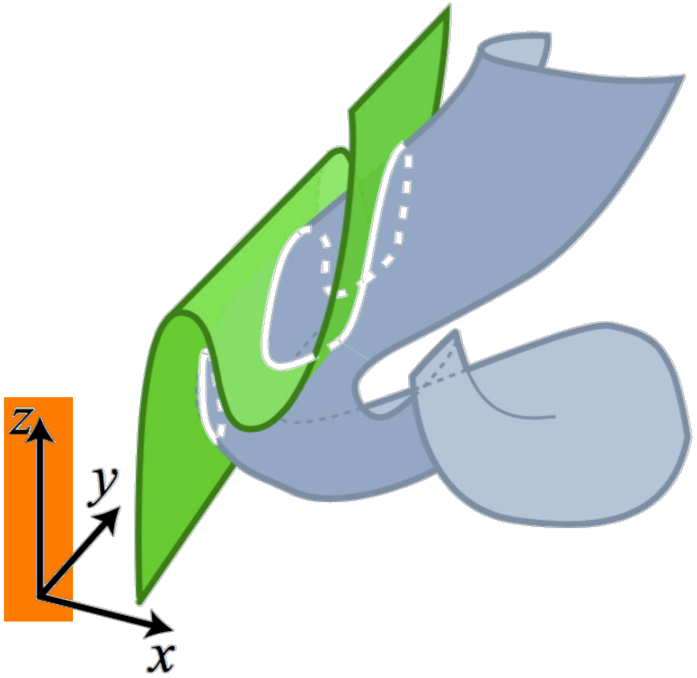
$$\partial\mathcal{A} \cap \partial\mathcal{B} \in \mathcal{S}_{2\text{D}},$$

Difficult to compute or optimize over

How to minimize surface area of intersection?

$$\underset{\text{UI}}{\operatorname{argmin}} \; |I_S|$$

Intersections of generic surfaces are non-trivial to parameterize…



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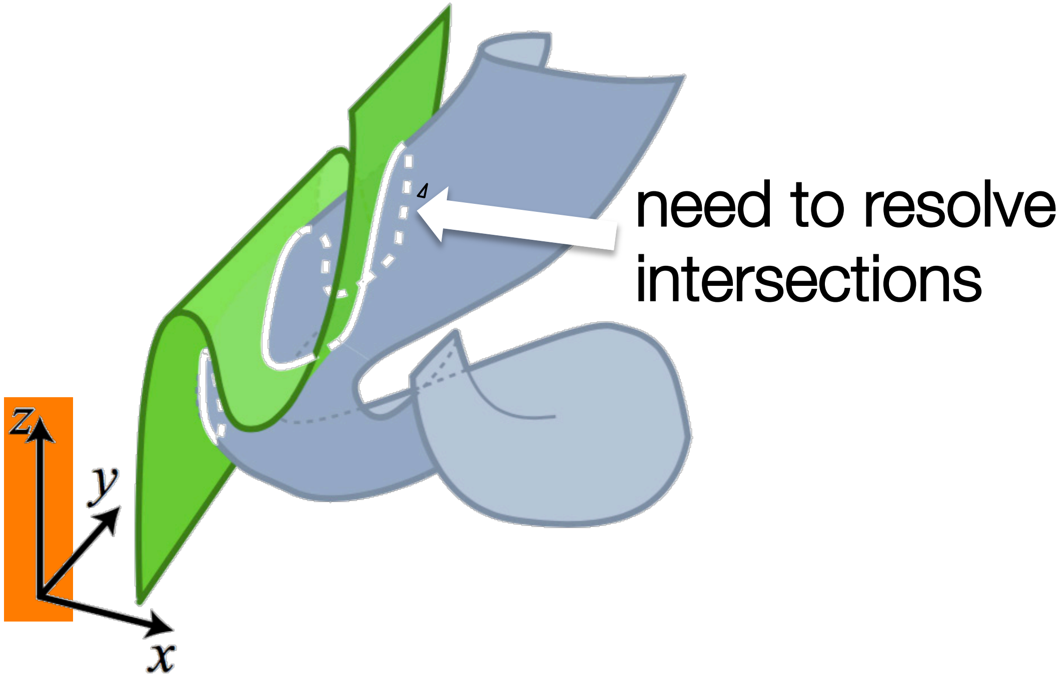
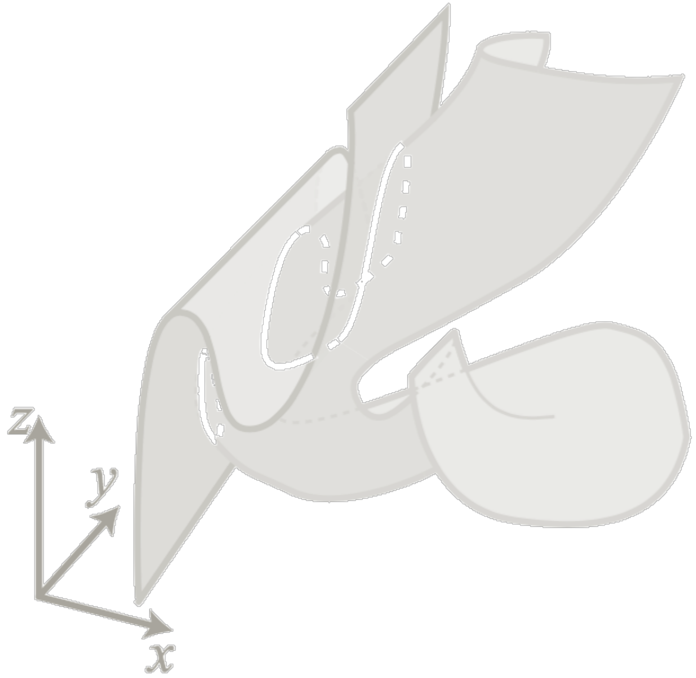
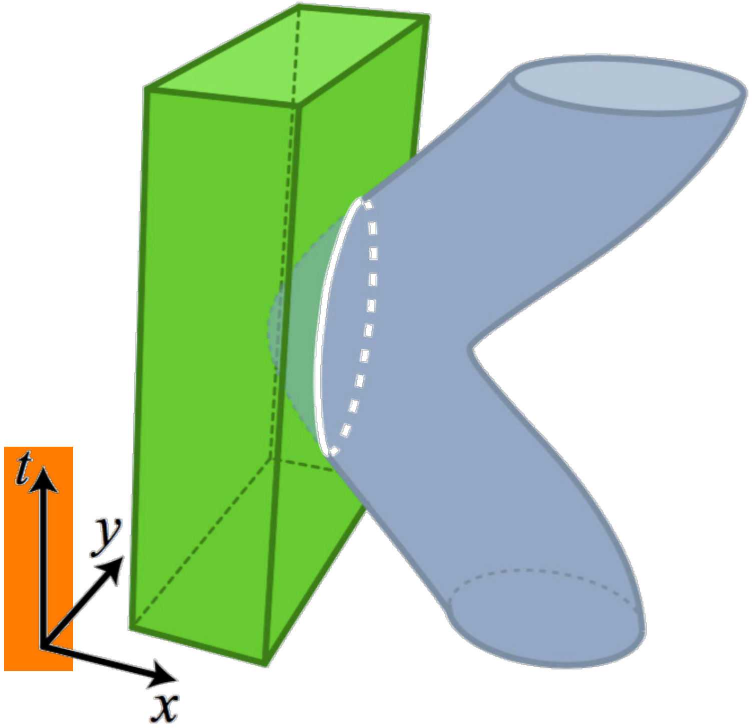


… but spacetime surfaces are explicit functions of monotonic time





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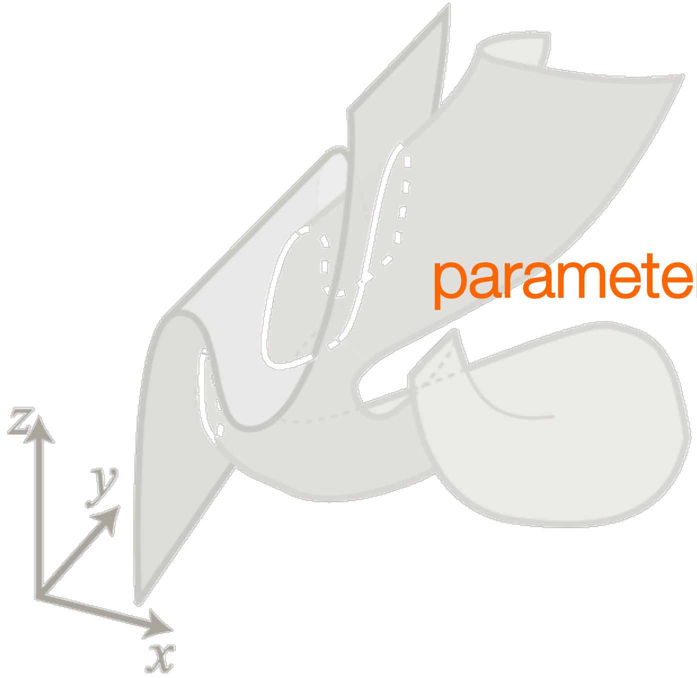

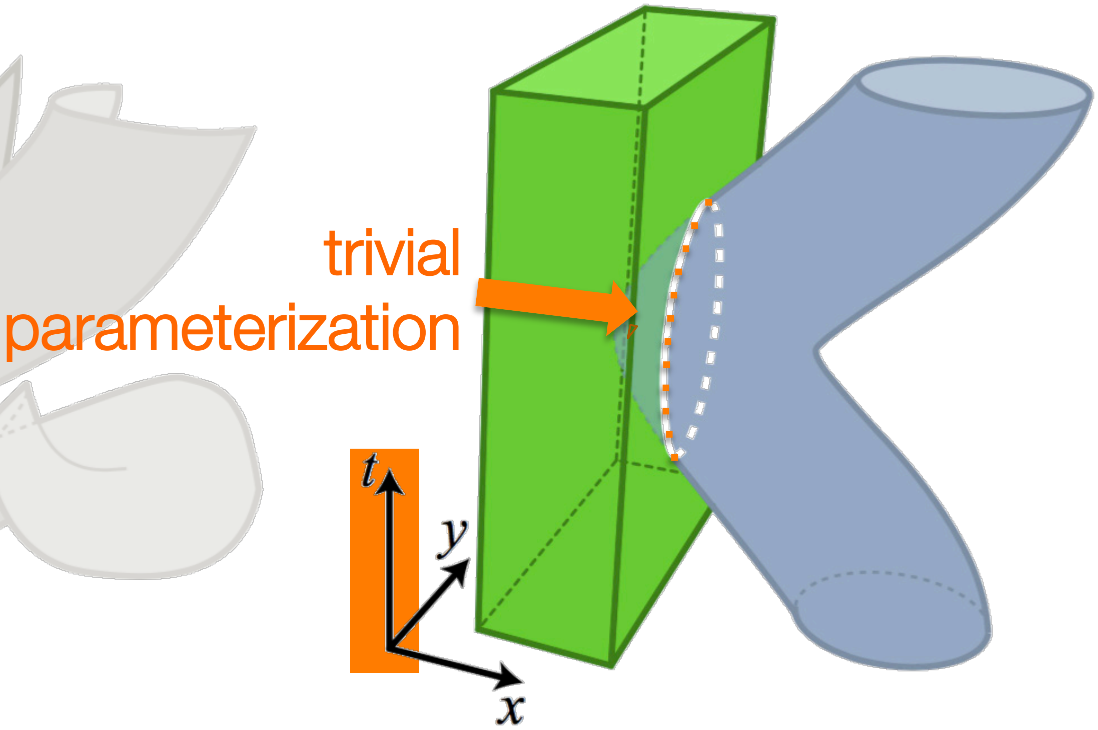

Spacetime intersection surface area reduces to integral of 1D intersection contours

$$\underset{\mathrm{UI}}{\operatorname{argmin}} \; |I_S|$$

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Spacetime intersection surface area reduces to integral of 1D intersection contours

$$\underset{\mathrm{UI}}{\operatorname{argmin}} \int_0^1 \|I_C(t)\| \, dt$$

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Applying the chain rule reveals UI couples surface positions across time

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apply chain rule

Applying the chain rule reveals UI couples surface positions across time

$$\underset{\mathrm{UI}}{\operatorname{argmin}} \int_0^1 \|I_C(t)\| \, dt$$

$$\mathrm{UI} \leftarrow \mathrm{UI} - \int_0^1 \left(\nabla_{\mathrm{UI}} \mathbf{V}_t\right) \left(\nabla_{\mathbf{V}_t} \|I_C(t)\|\right) \, dt$$

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[Volino & M-T 2006]

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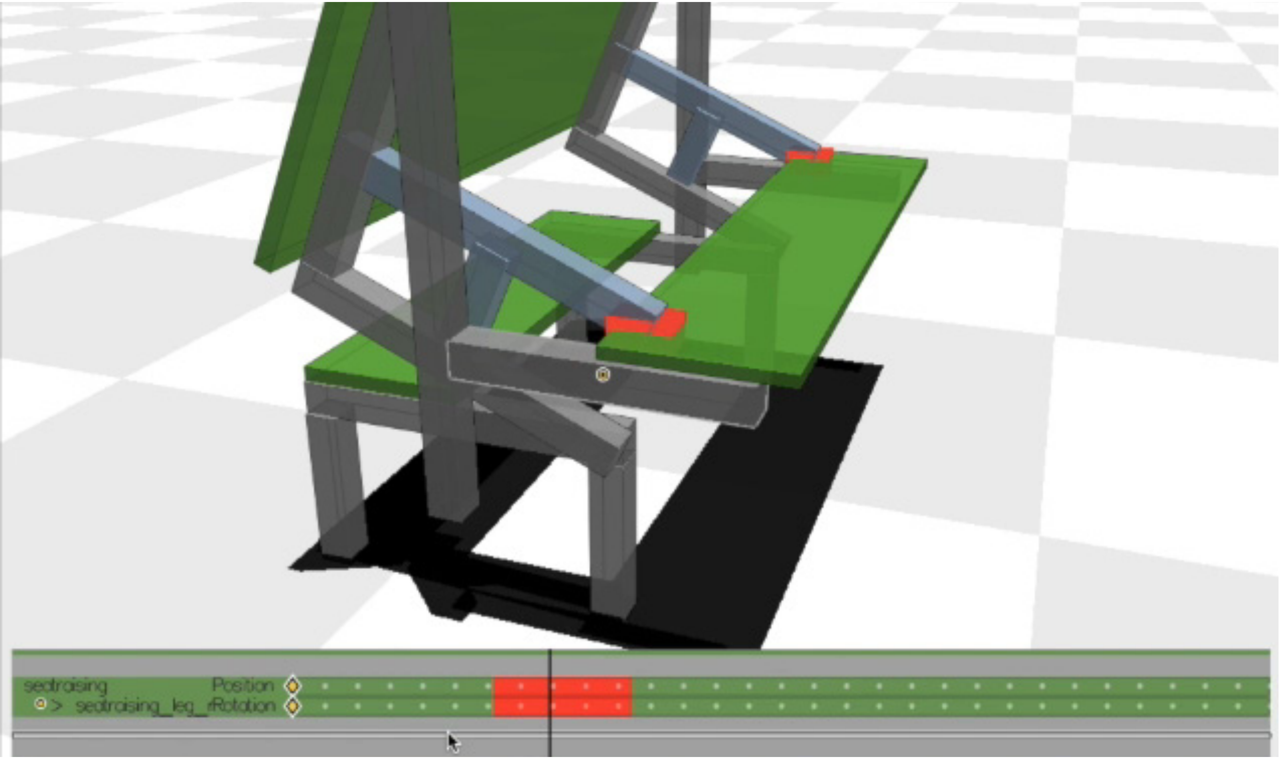
See paper for details…
[Harmon et al. 2011]
[Umetani et al. 2011]

Gradient direction with respect to UI immediately helps as hint



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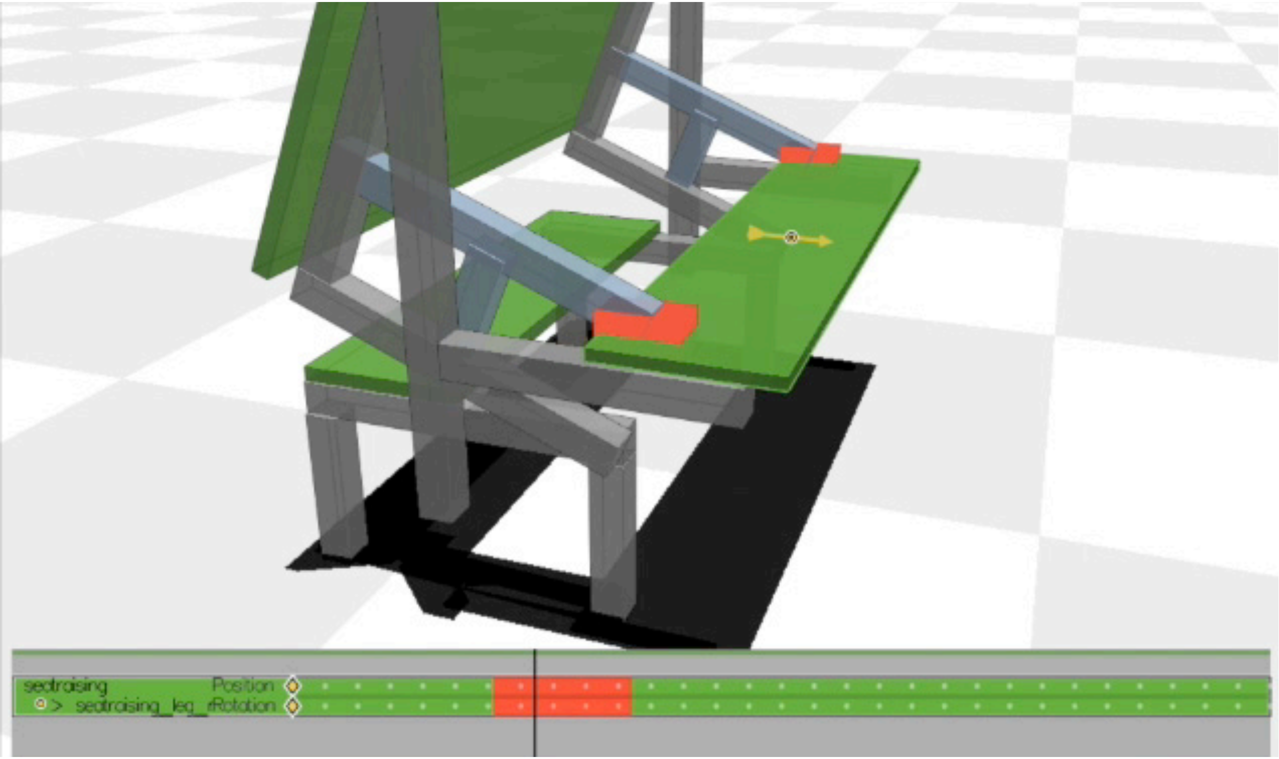

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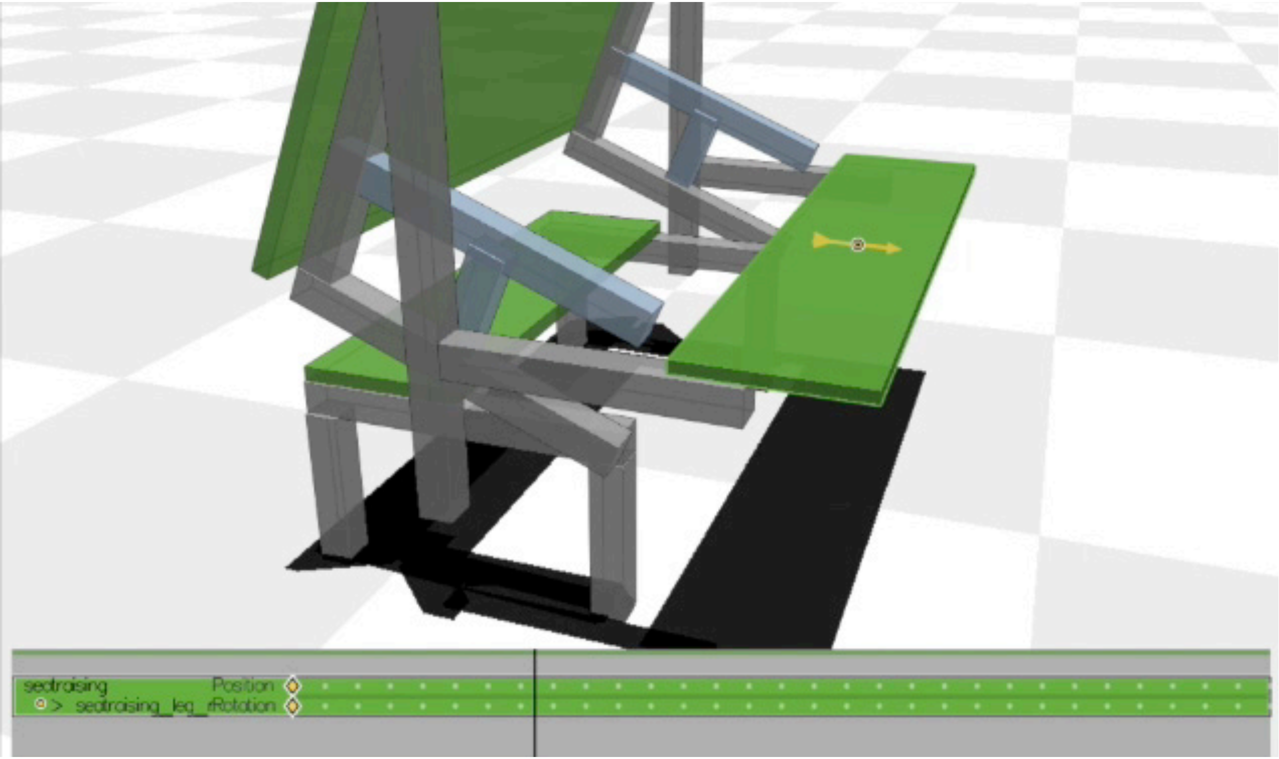
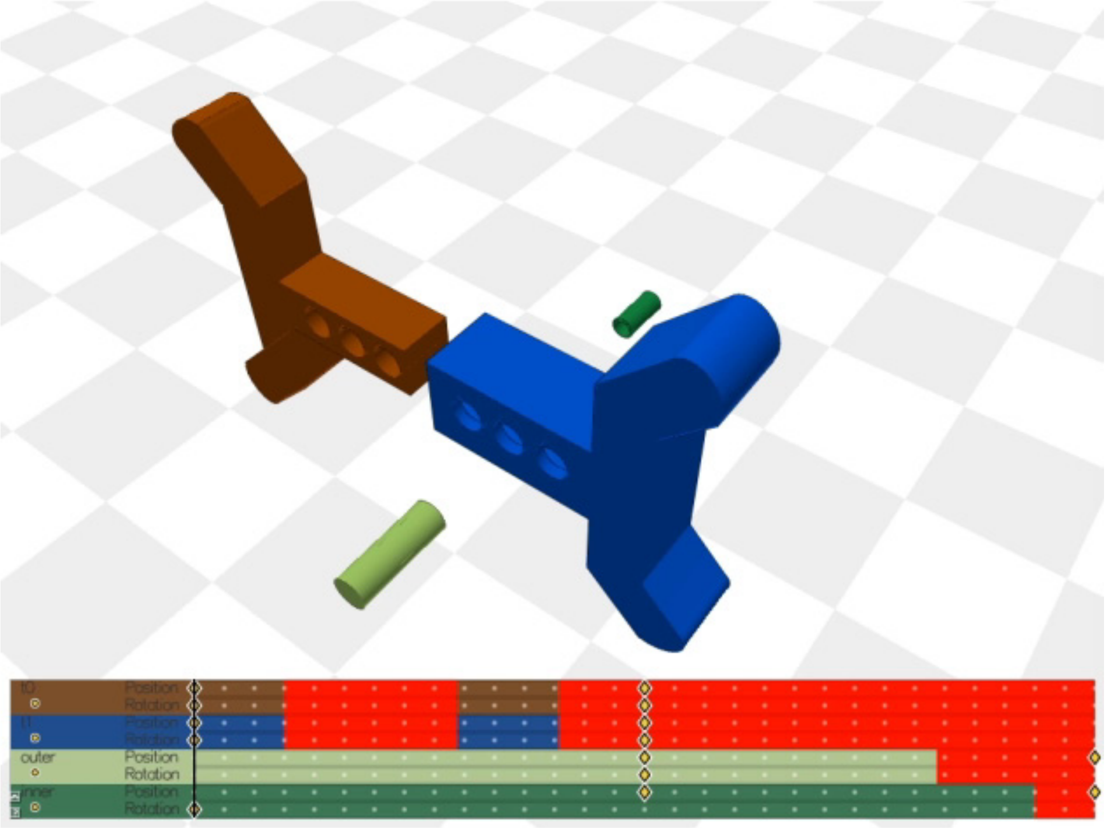


Collisions involving many objects can be very tedious to fix…



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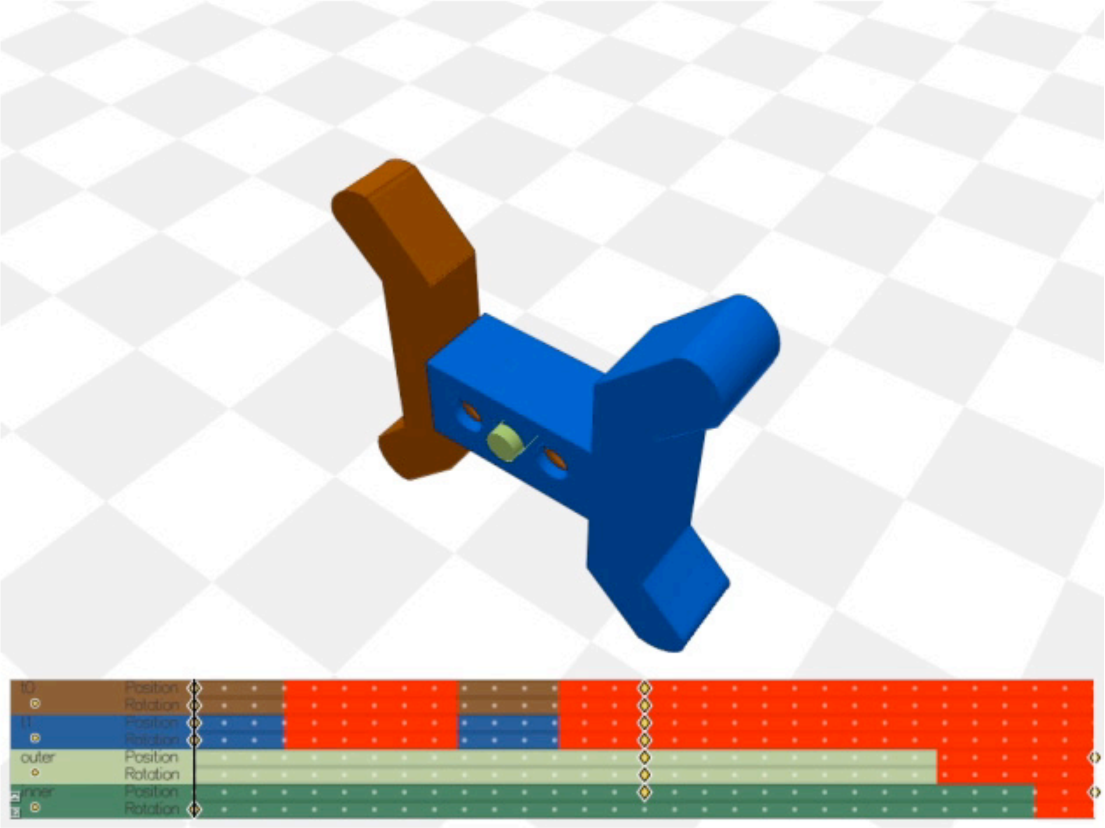
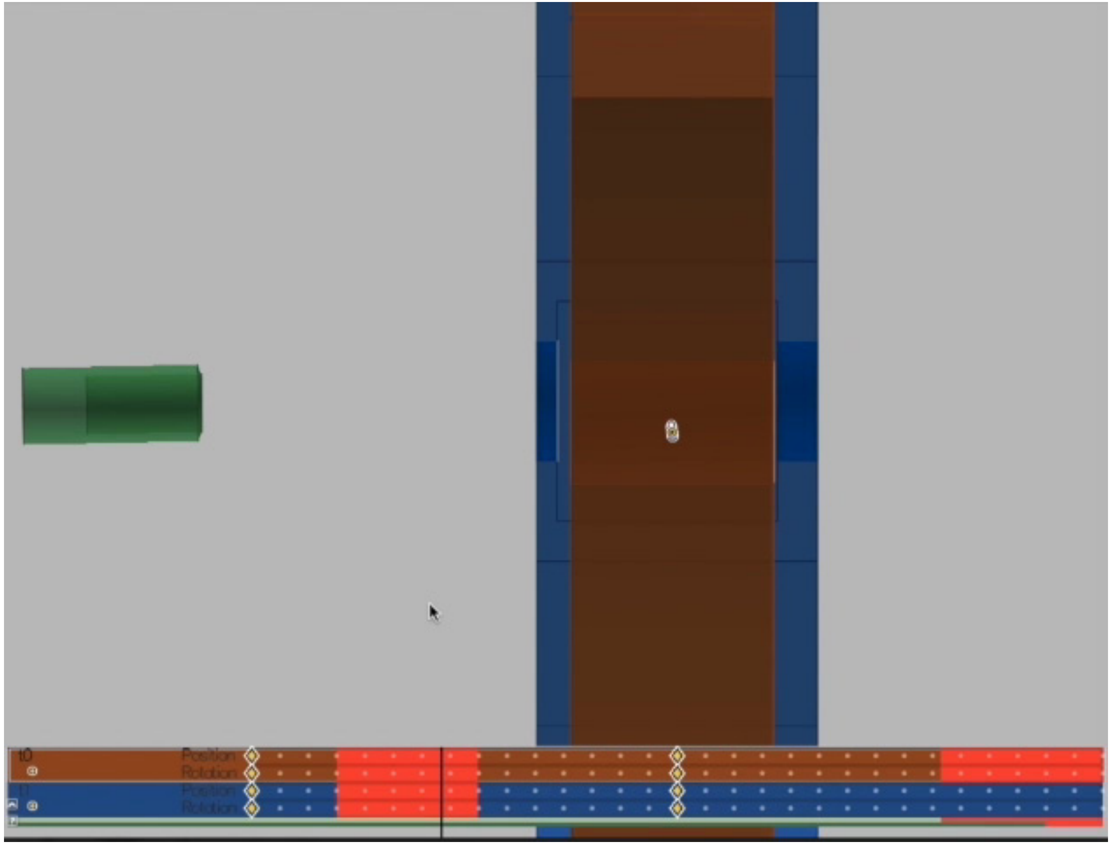


… manually fixing one collision may cause more at another place or time



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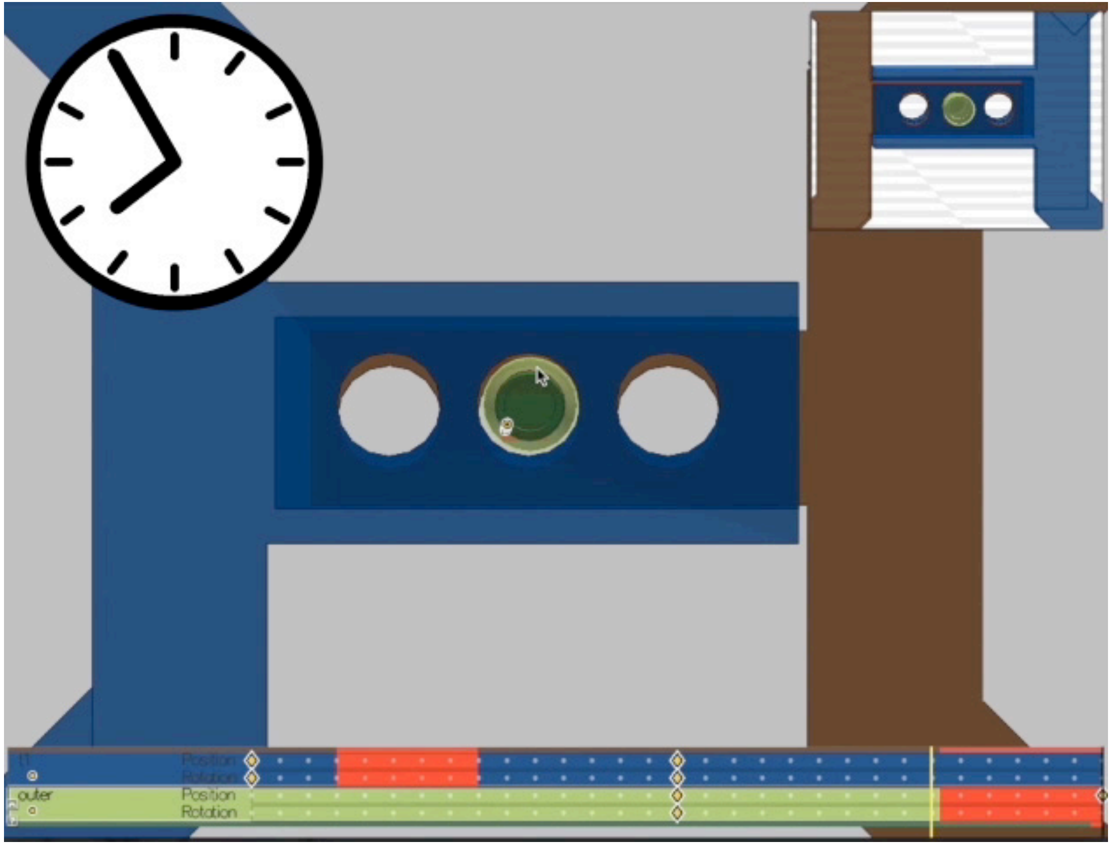

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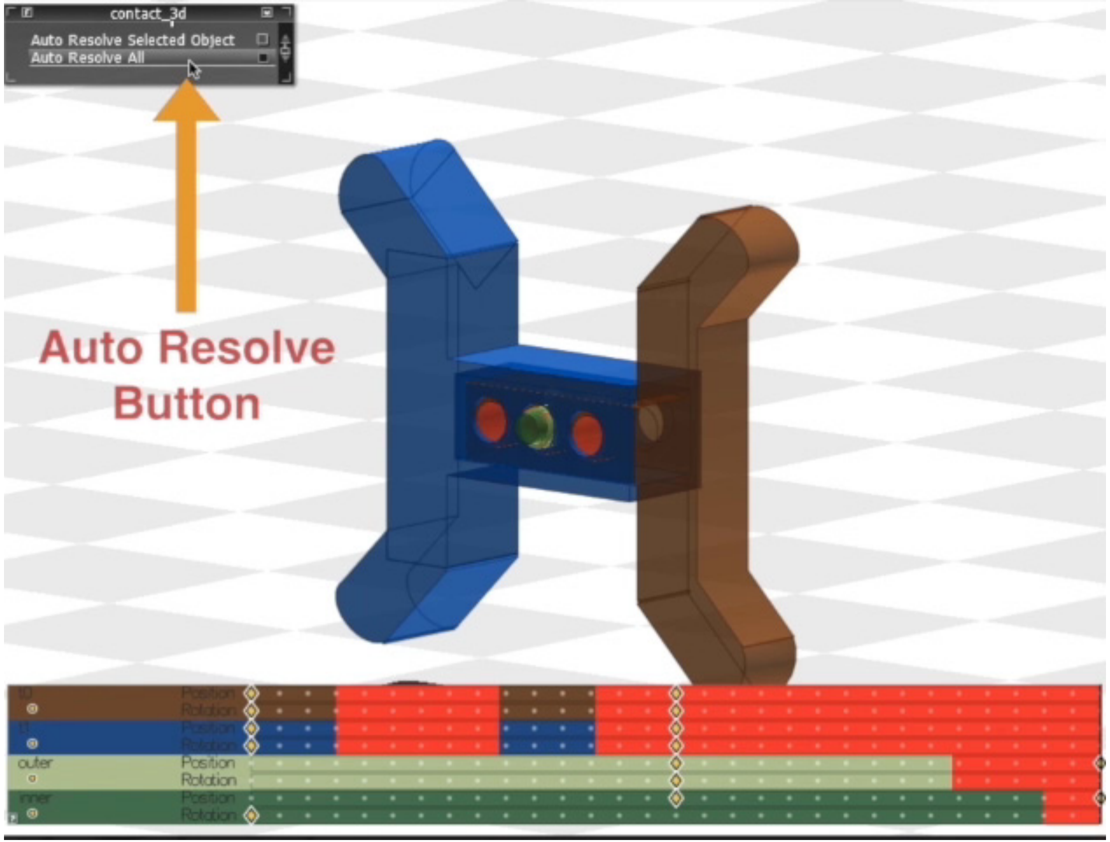

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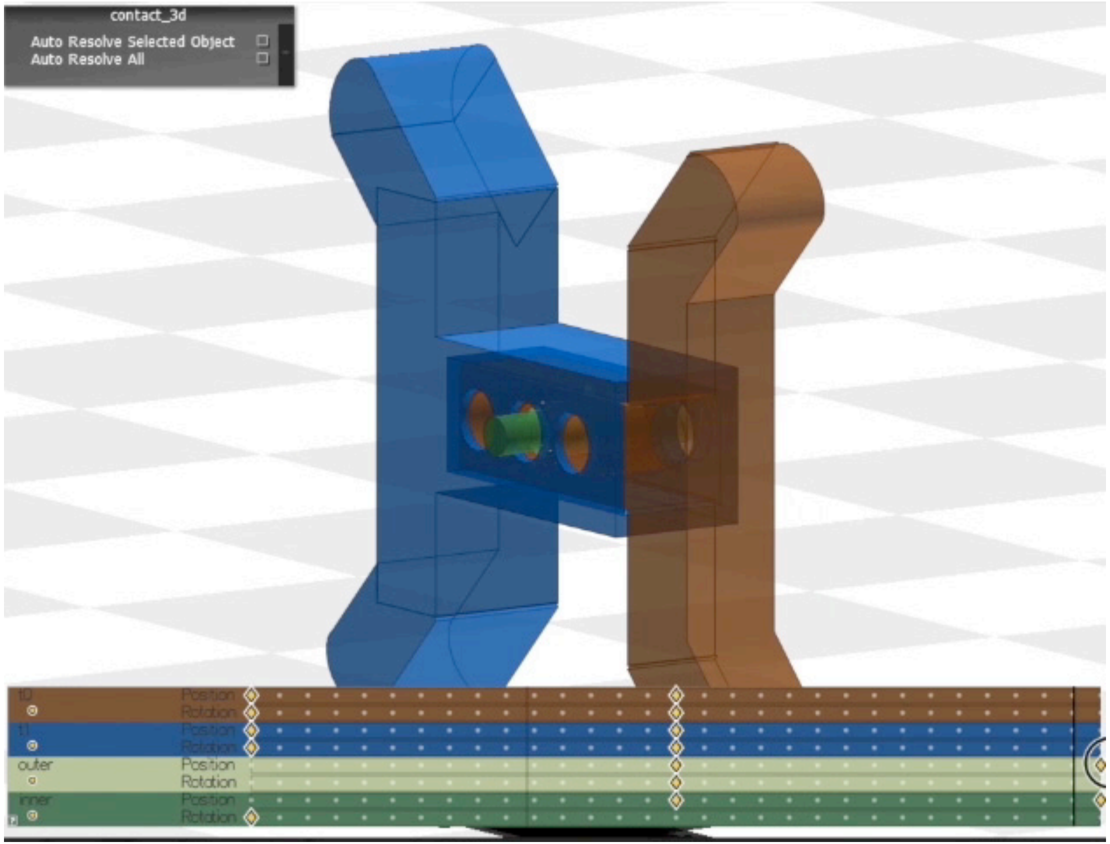
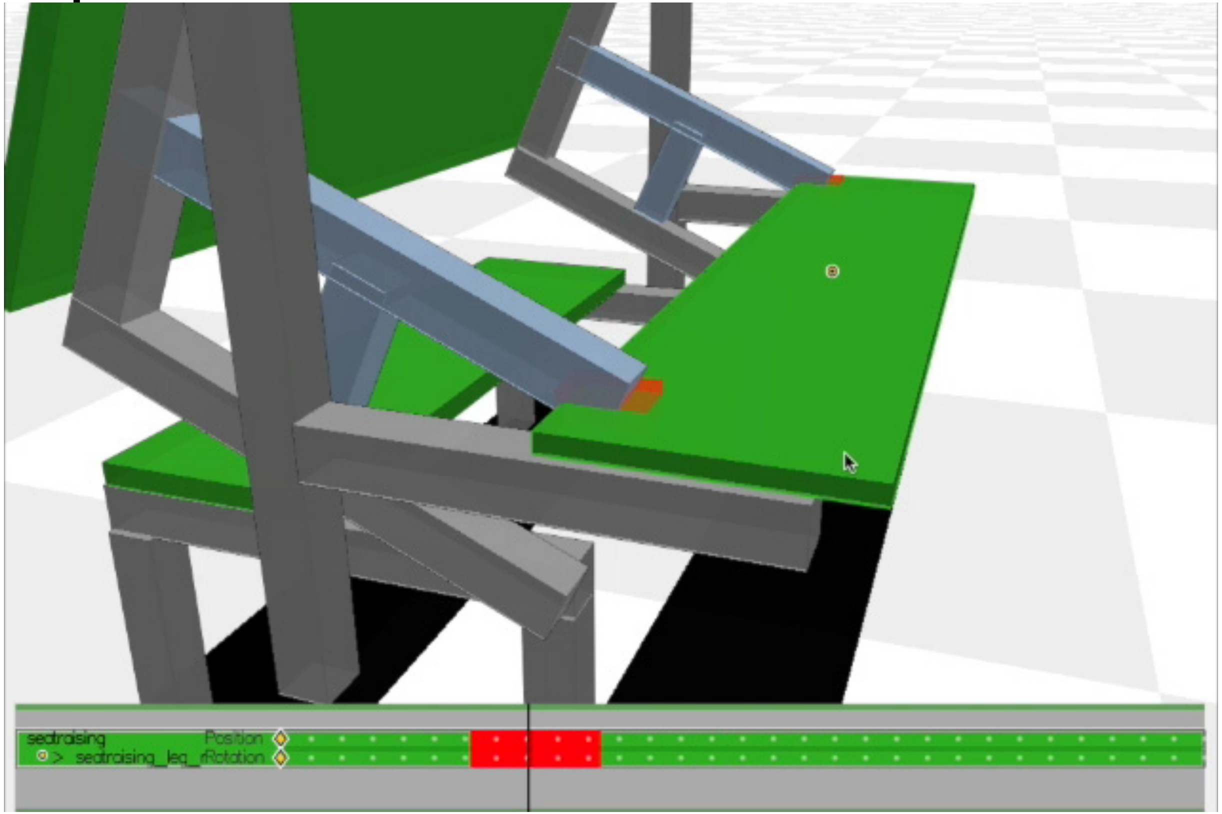


Sometimes, one part's geometry is less important than another's…



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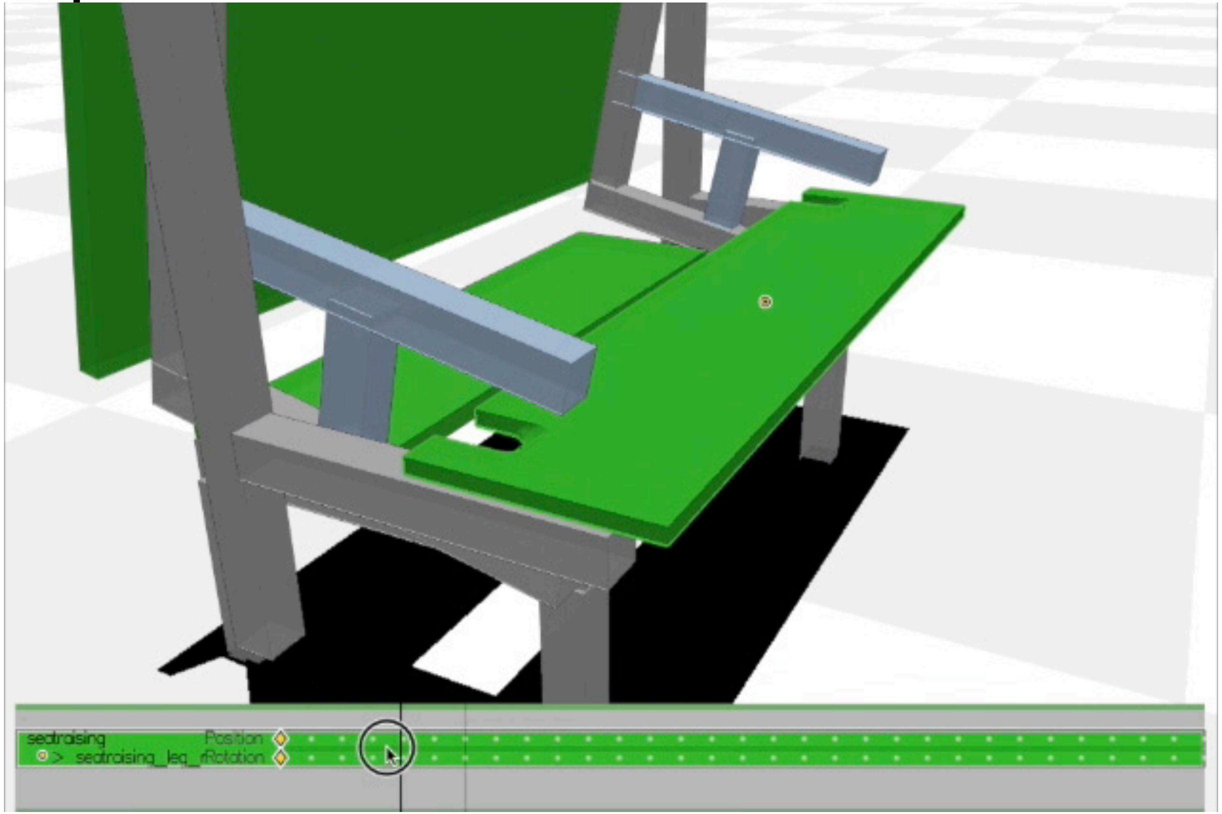

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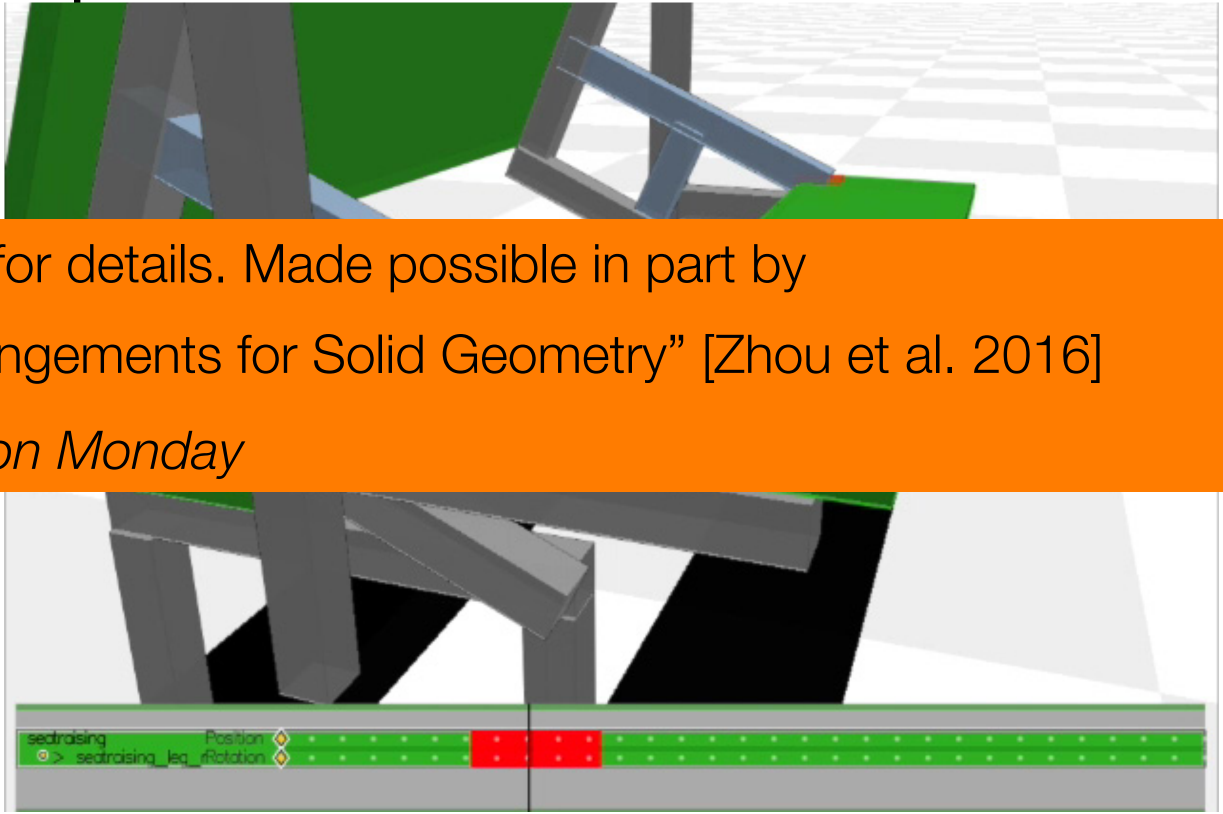
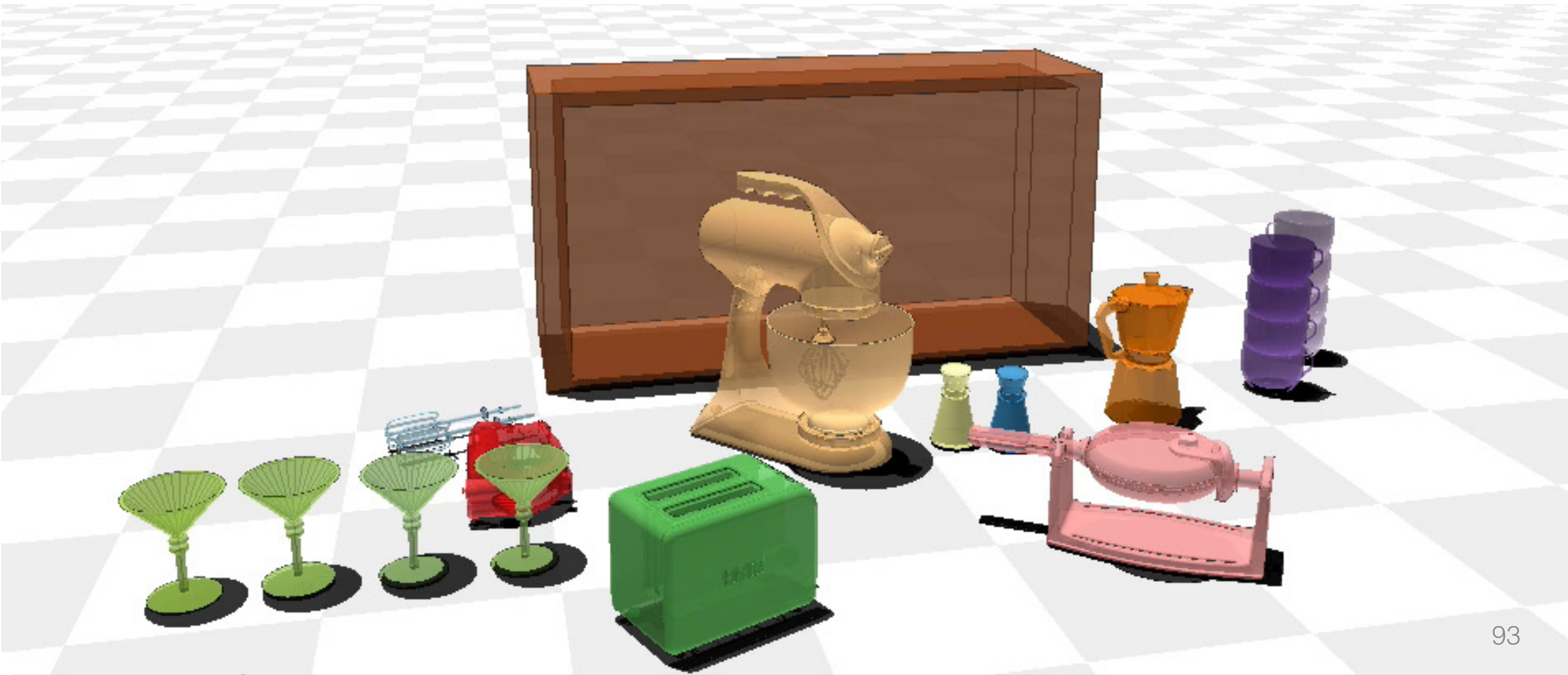


See paper for details. Made possible in part by

"Mesh Arrangements for Solid Geometry" [Zhou et al. 2016]

presented on Monday

Swept volume carving invites creative space-saving solutions



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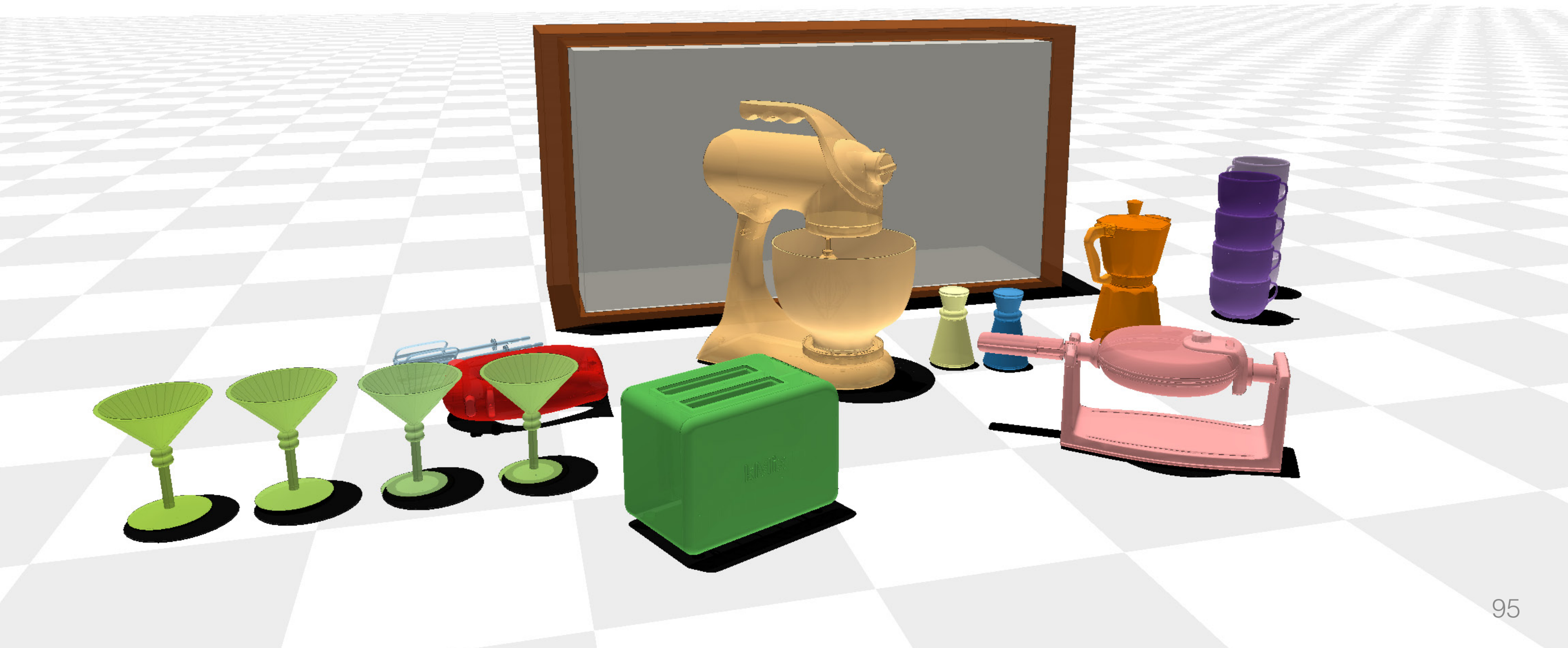

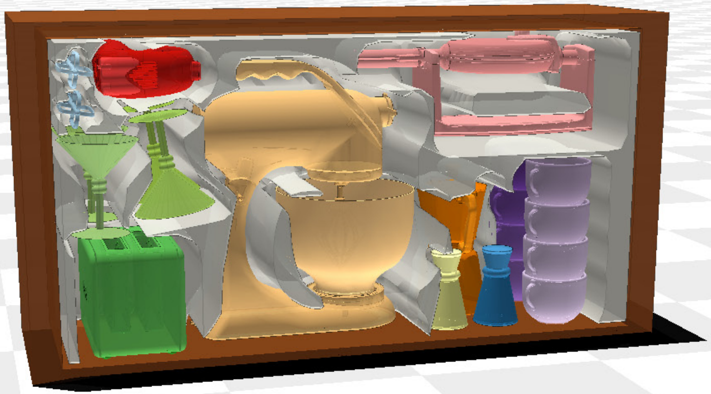

Limitations & Future Work

modeling space extend to full modeling / deformation tools

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physics	feasibility extends beyond collisions

Acknowledgements

We thank Keenan Crane and Henrique Maia for illuminating discussions.

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Computational Design of Reconfigurables

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