

Learning to Remove Soft Shadows



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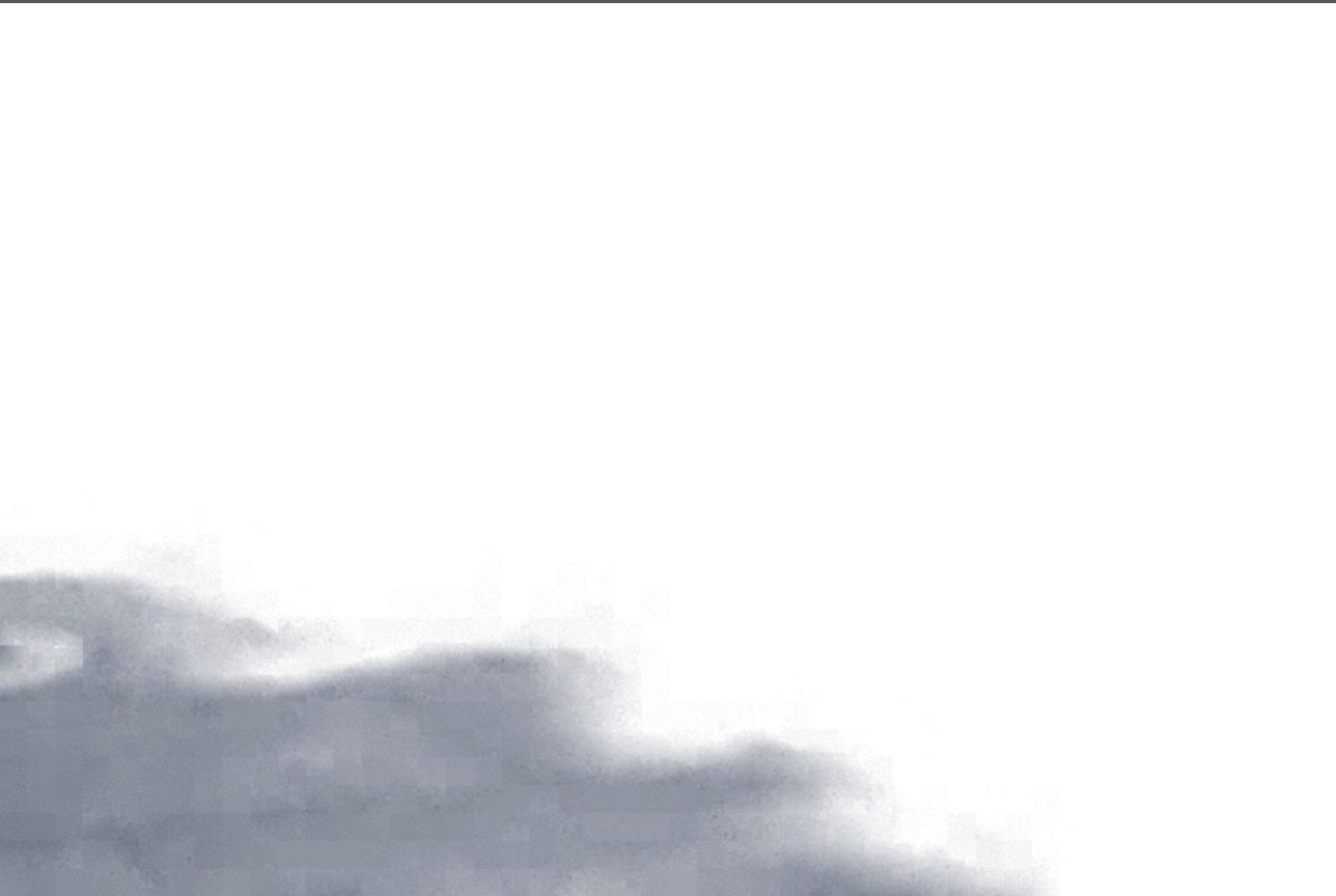




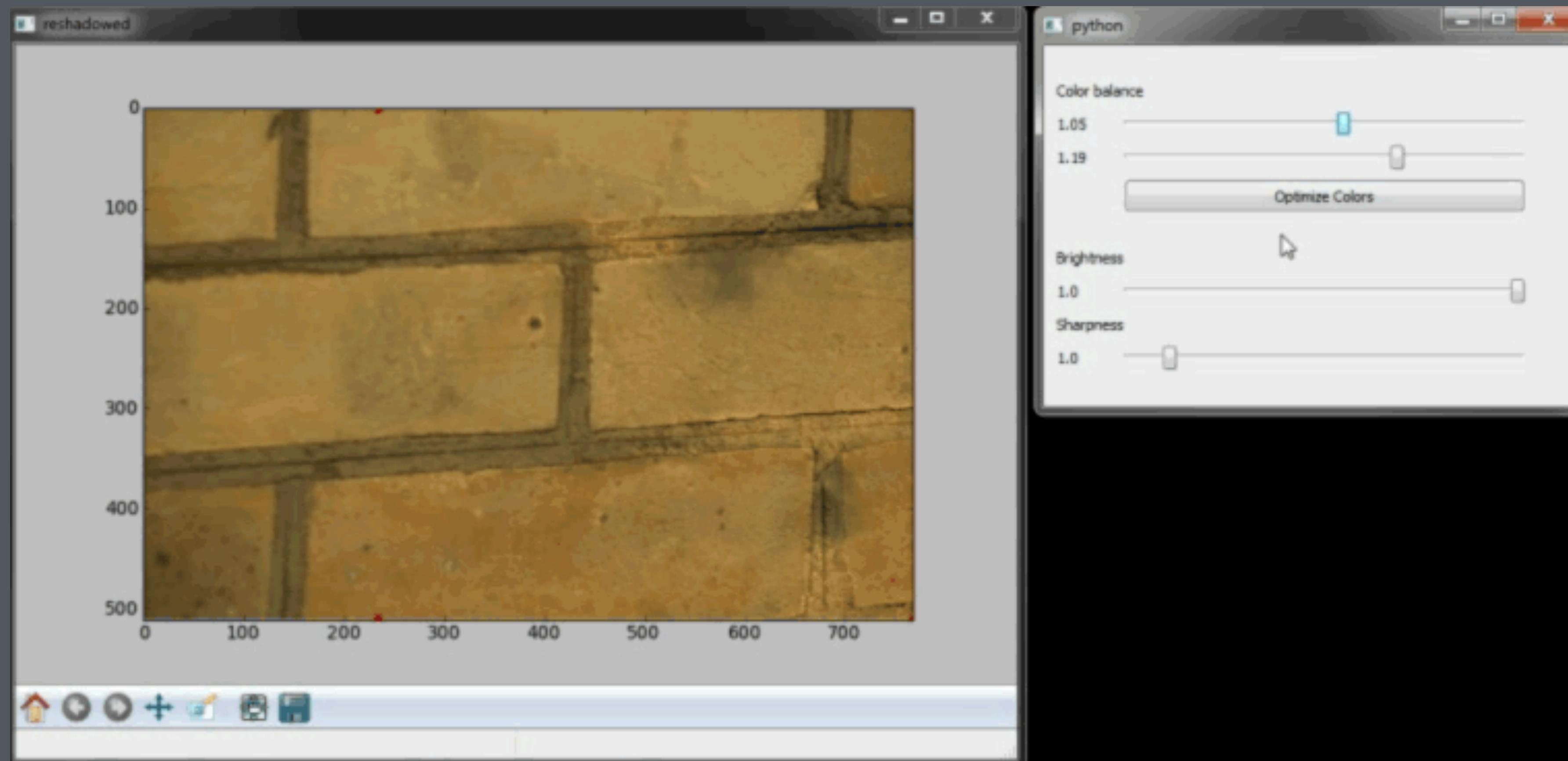








Now we can remove and edit shadows. Exciting!



Previous Work

Intrinsic images

- [Barrow & Tenenbaum 1978]
- [Tappen et al. 2005]
- [Bosseau et al. 2009]

Shadow rendering

- [Parker et al. 1998]
- [Chan and Durand 2003]

Hard shadow removal

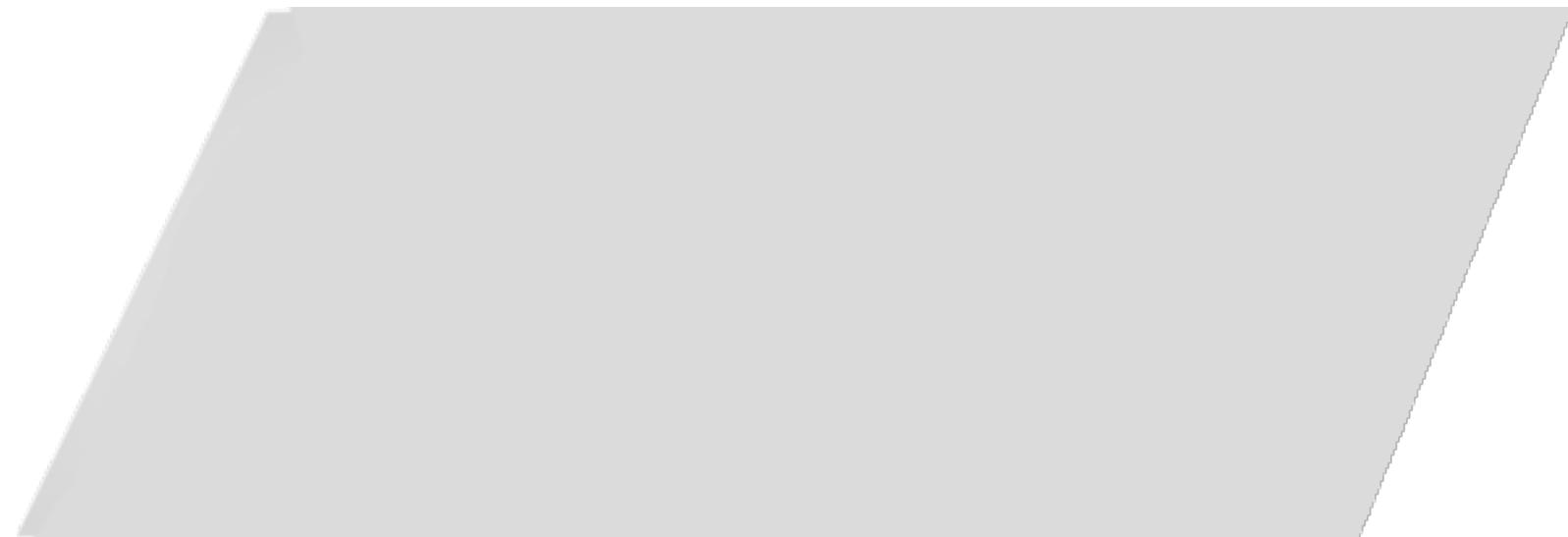
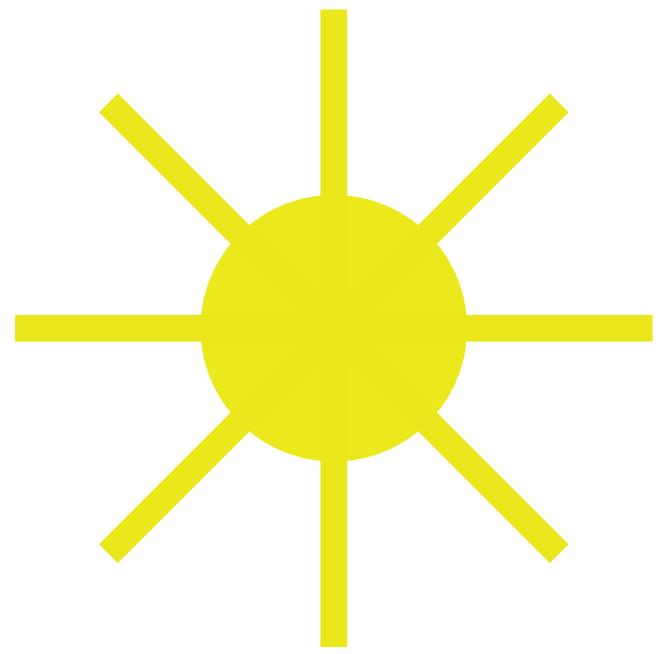
- [Finlayson et al. 2009] illumination-invariant images
- [Shor and Lischinski 2008]

Soft shadow removal

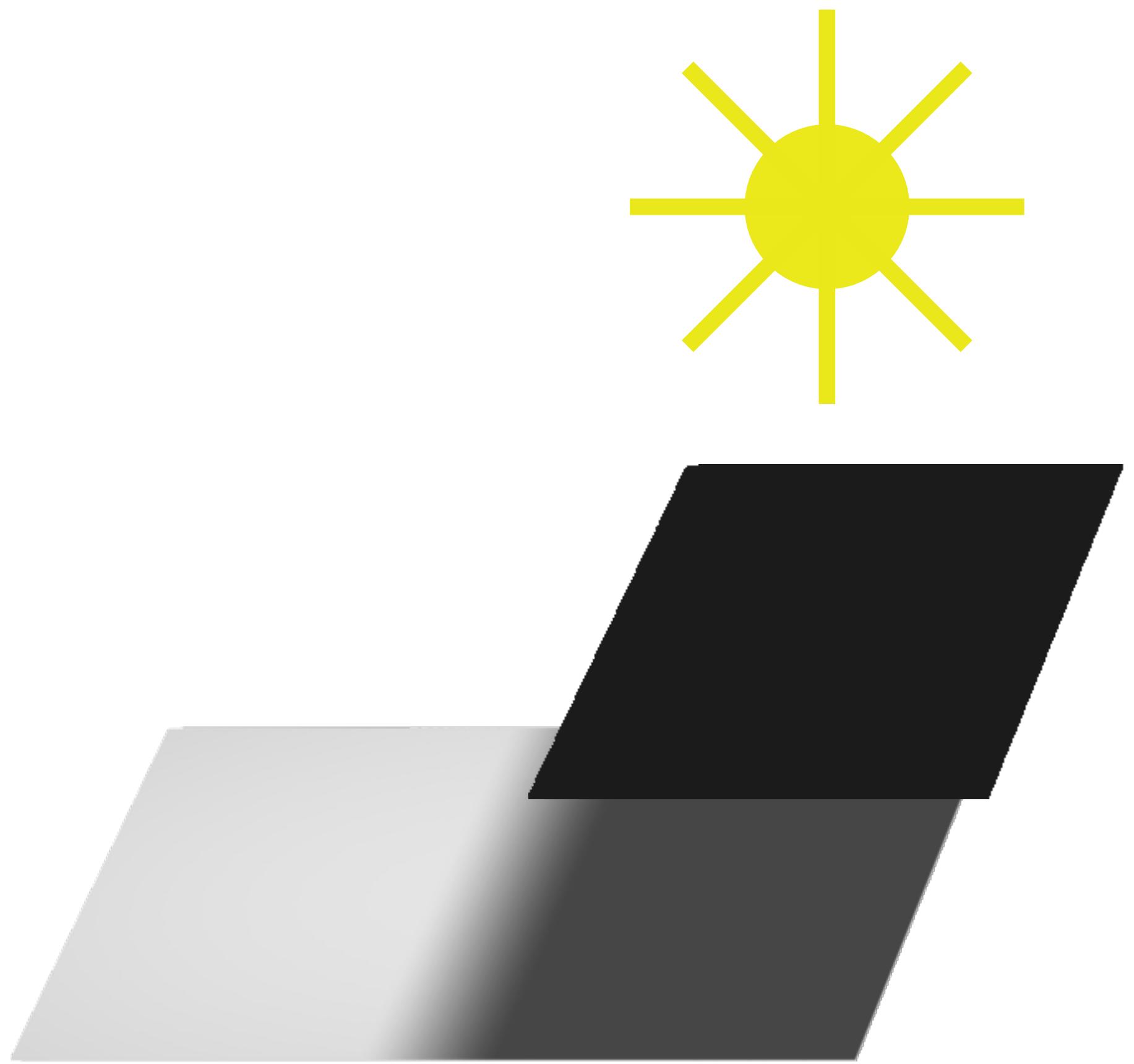
- [Mohan et al. 2007]
- [Arbel and Hel-Or 2011]
- [Wu et al. 2007], [Guo et al. 2012] matting methods

Soft shadows: what do
penumbrae look like?

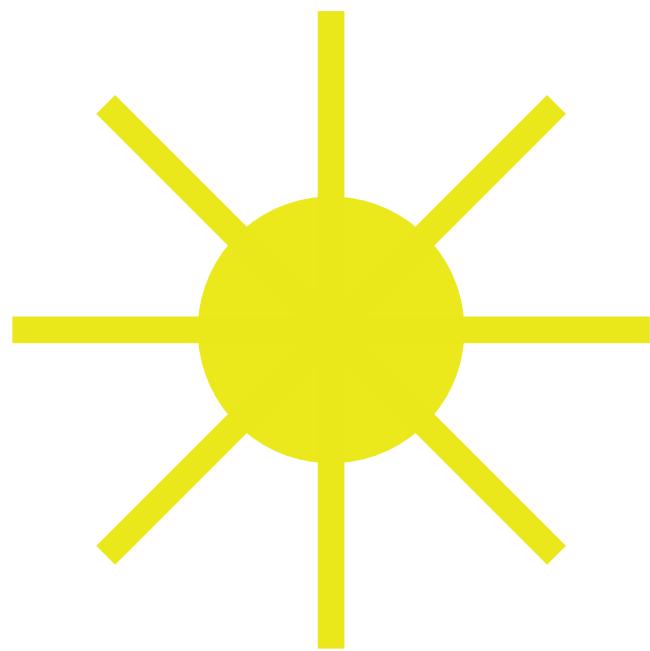
Soft shadows: what do penumbrae look like?



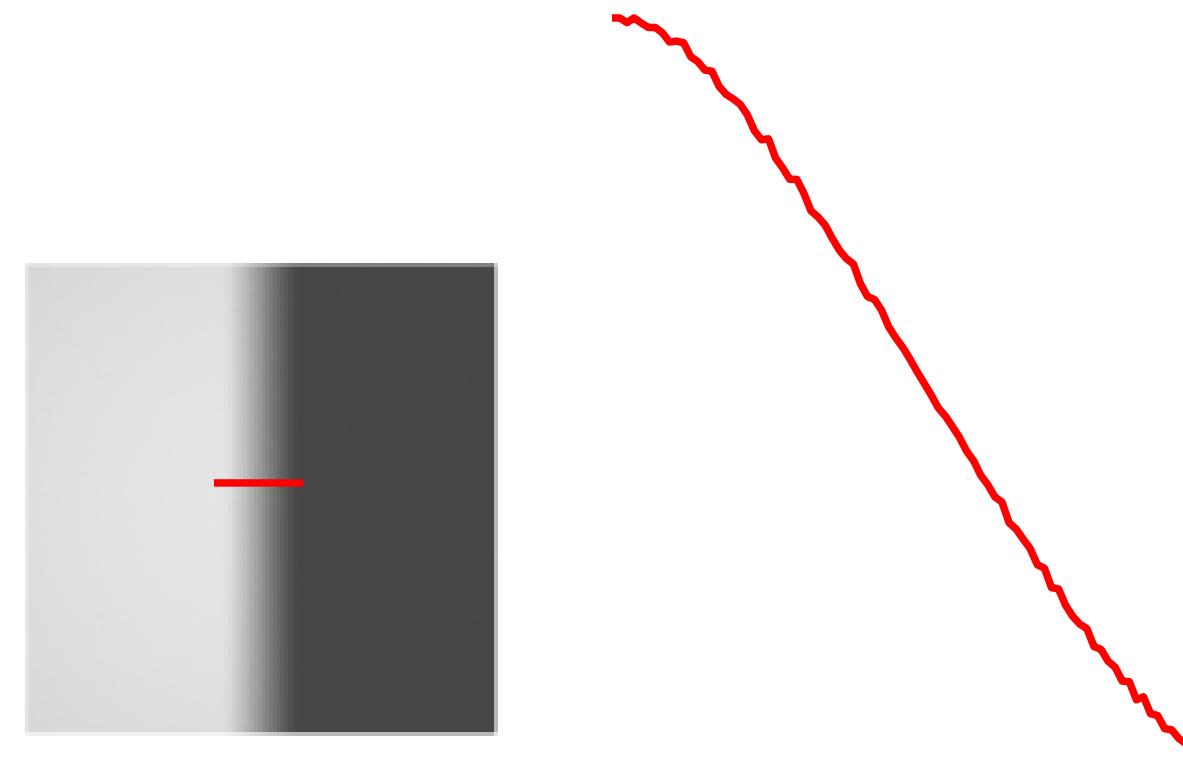
Soft shadows: what do penumbrae look like?



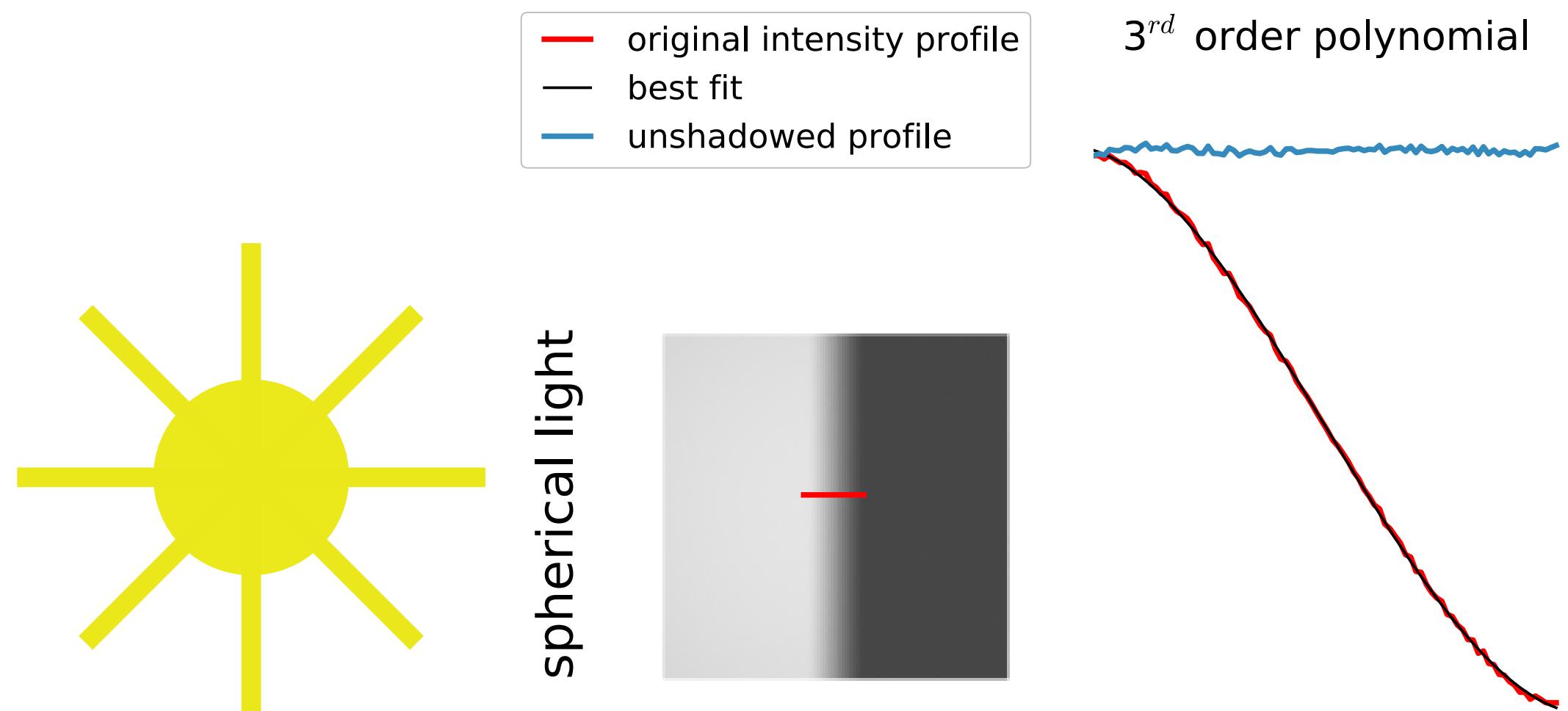
Soft shadows: what do penumbras look like?



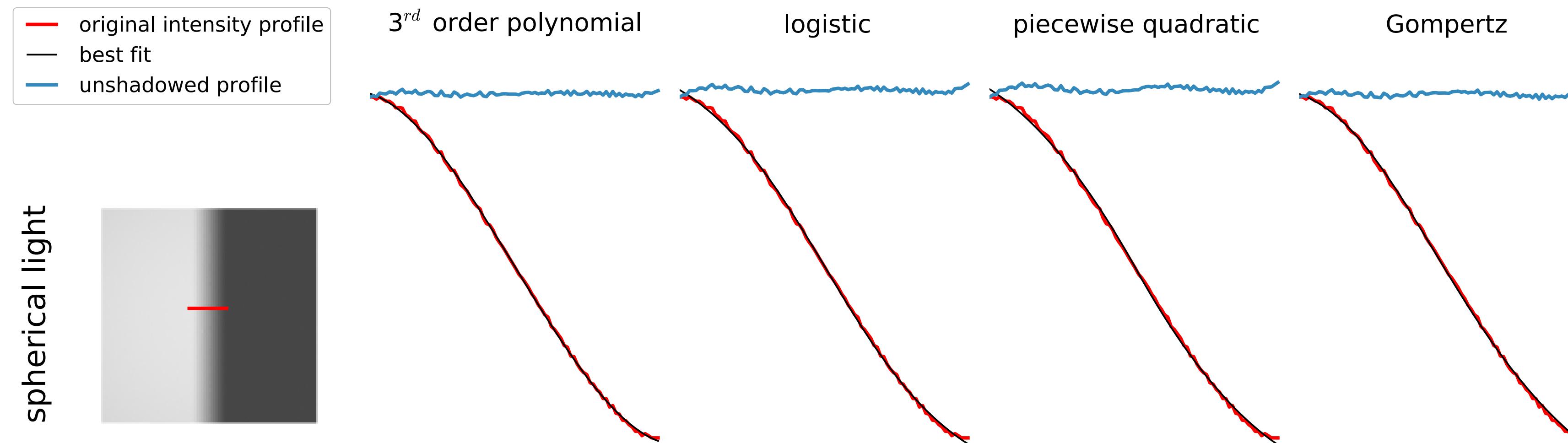
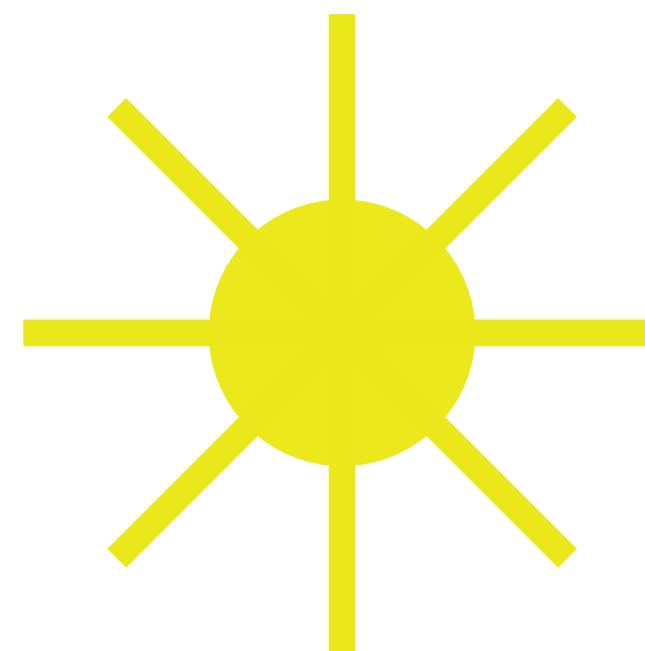
spherical light



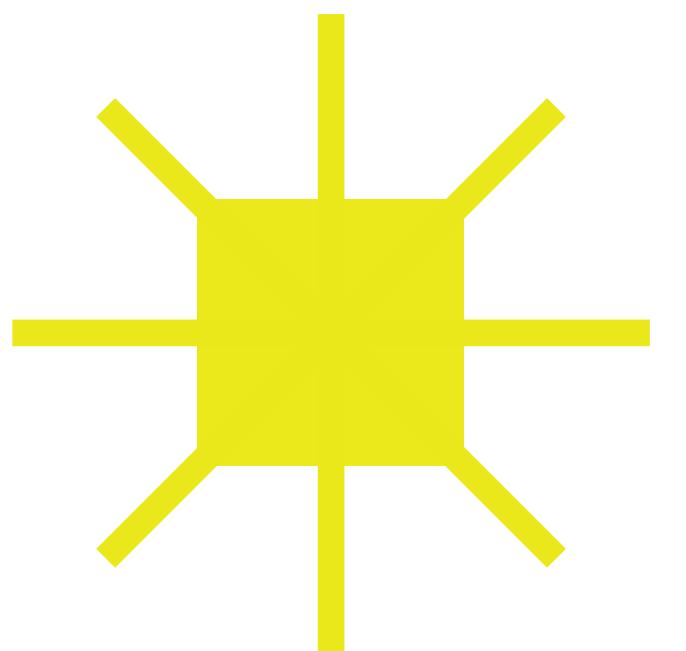
Soft shadows: what do penumbrae look like?



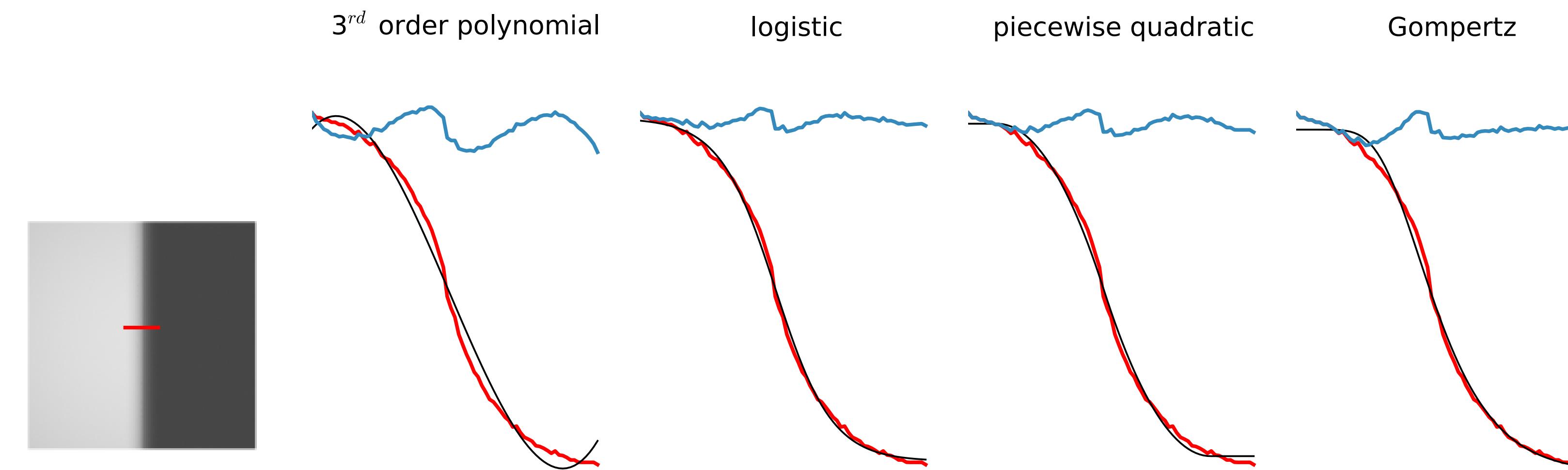
Soft shadows: what do penumbrae look like?



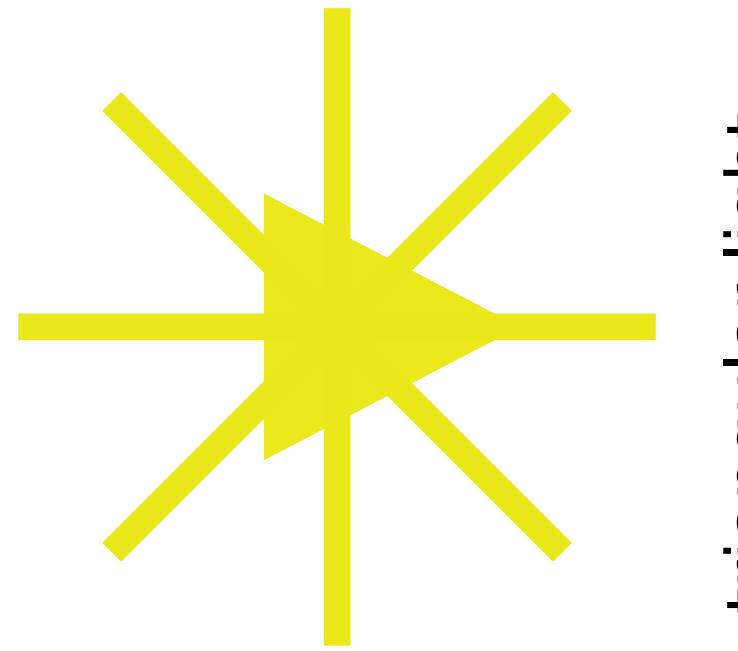
Soft shadows: what do penumbrae look like?



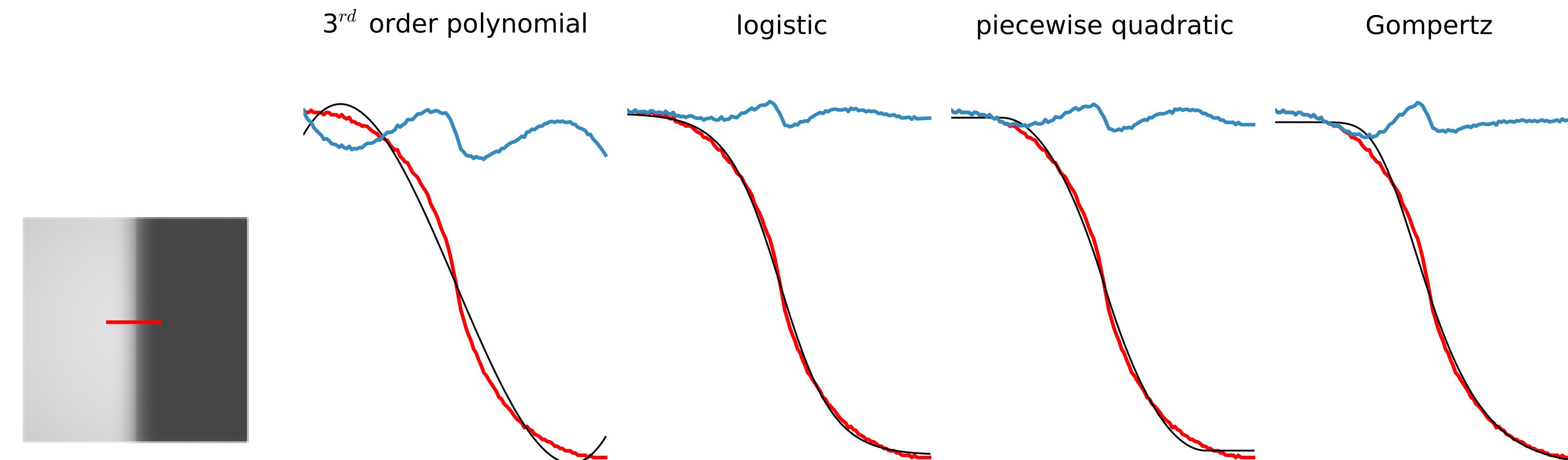
square light



Soft shadows: what do penumbrae look like?



triangular light



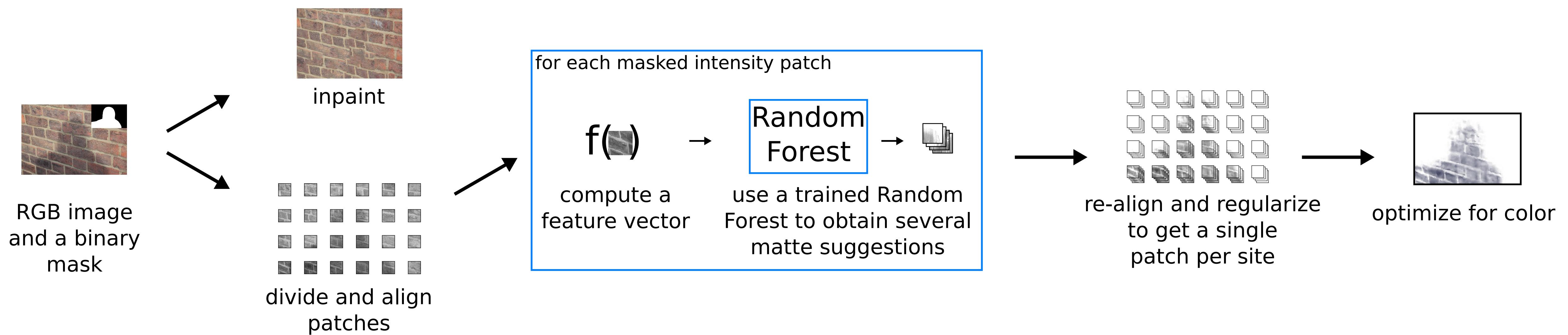
Instead, we looked at
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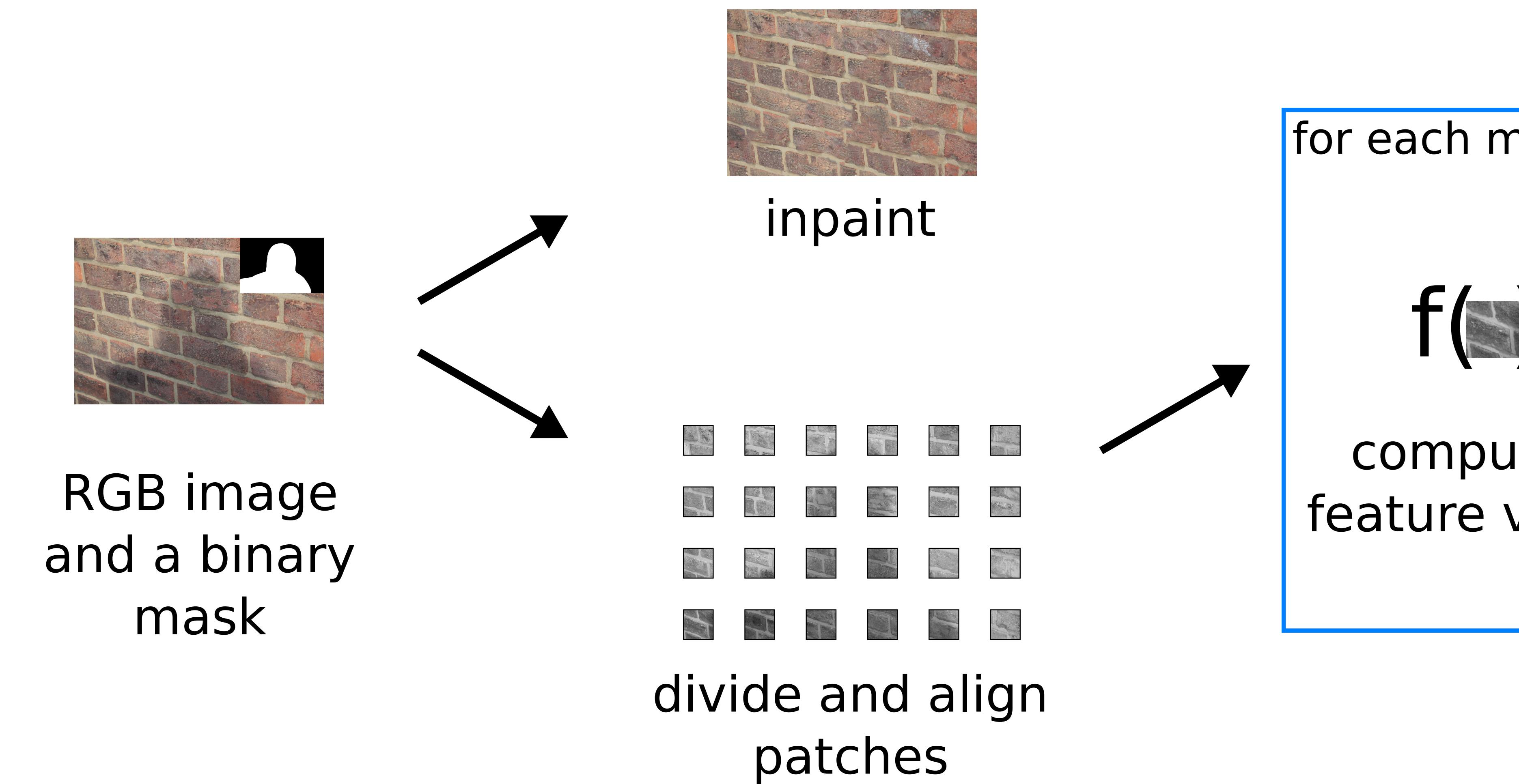


The algorithm taught itself how penumbrae behave, while ignoring texture variation.

System Overview



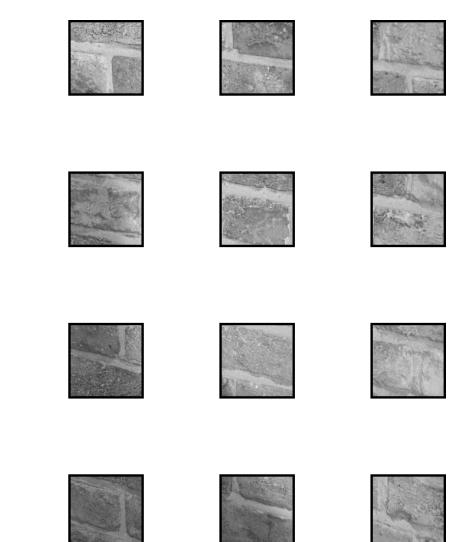
System Overview



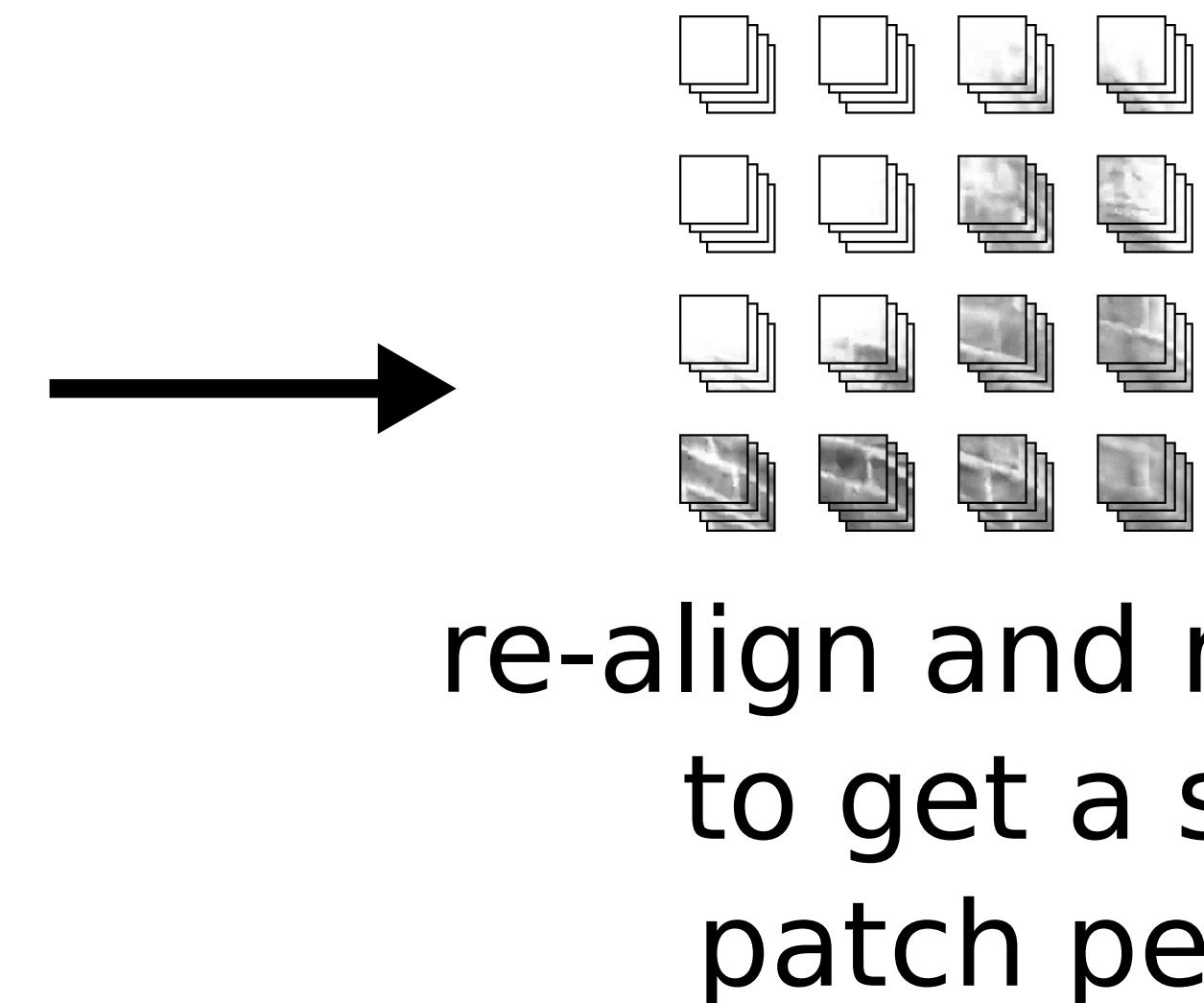
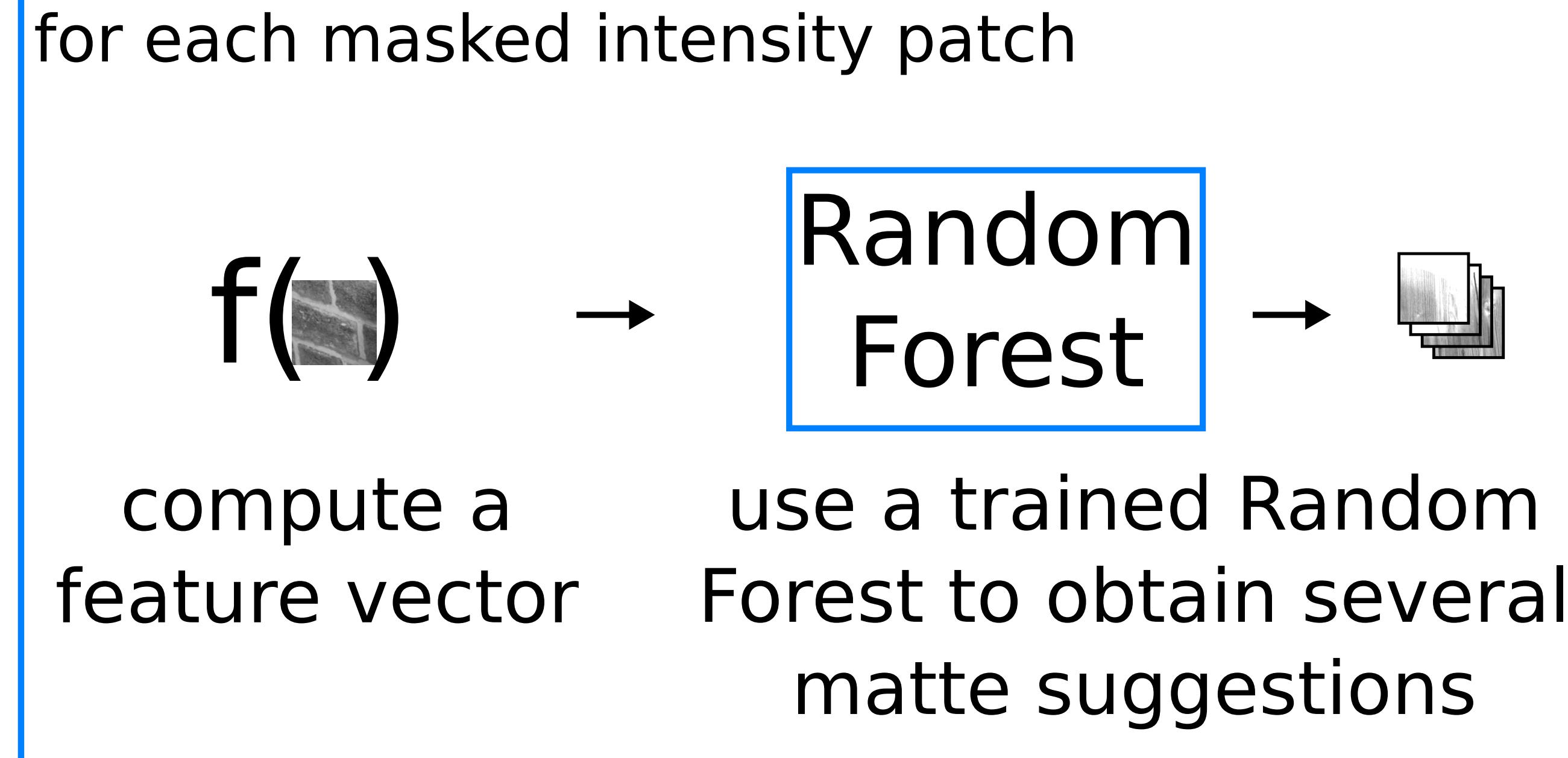
System Overview



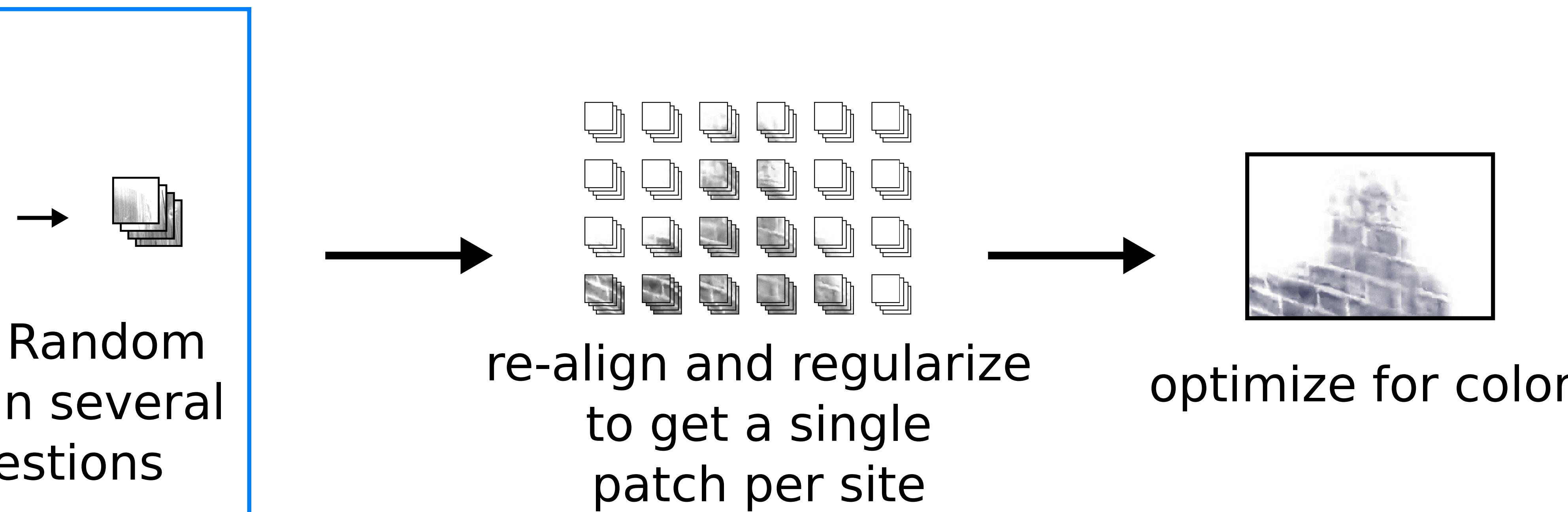
aint



nd align
ches



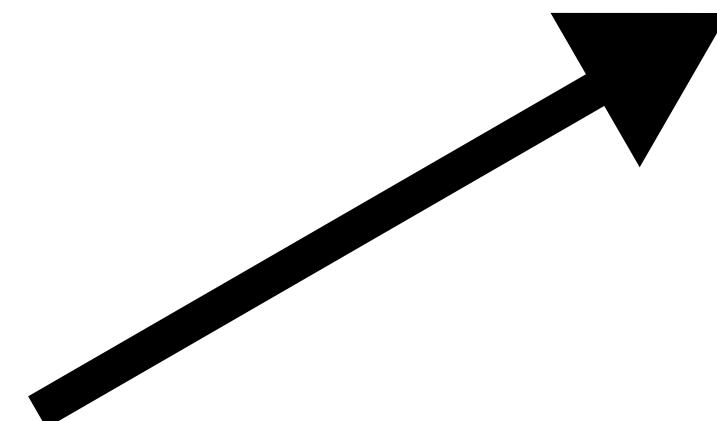
System Overview



System Overview



inpaint



for e

Inpainting



Guided inpainting

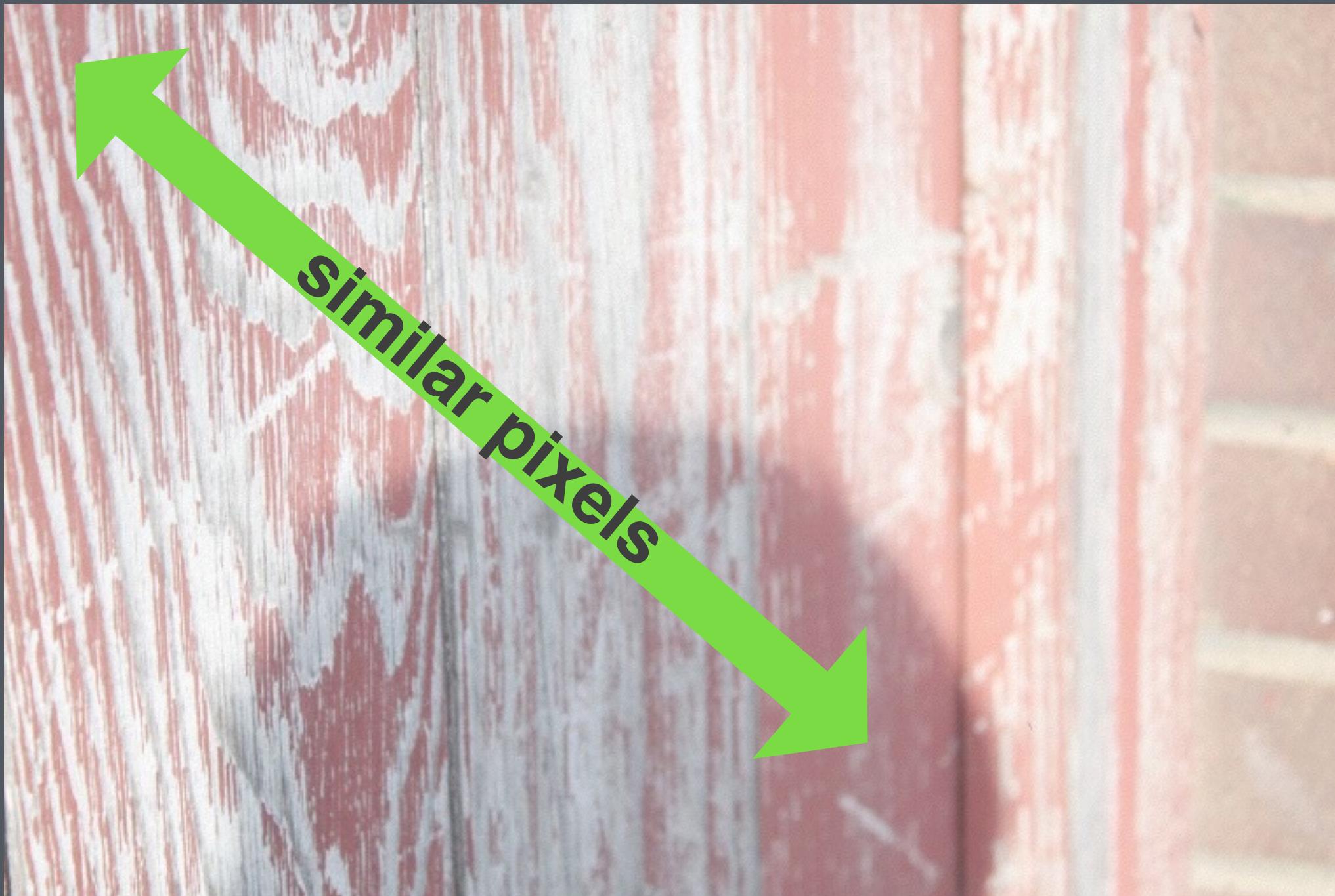


input image



guided inpainting result

Guided inpainting



input image



guided inpainting result

Off-the-shelf inpainting



Preprocessing: patch alignment

Preprocessing: patch alignment



Preprocessing: patch alignment

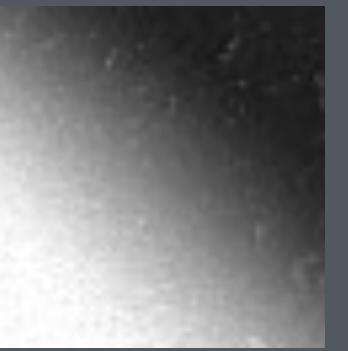
$$f(\quad)$$



aligned

Preprocessing: patch alignment

$f(\quad)$



Preprocessing: patch alignment

- minimize the amount of training data needed
- only learn things, what we cannot parameterize: penumbra fall-off
- we find a Euclidean transform for each patch to bring it as close as possible to the template patch



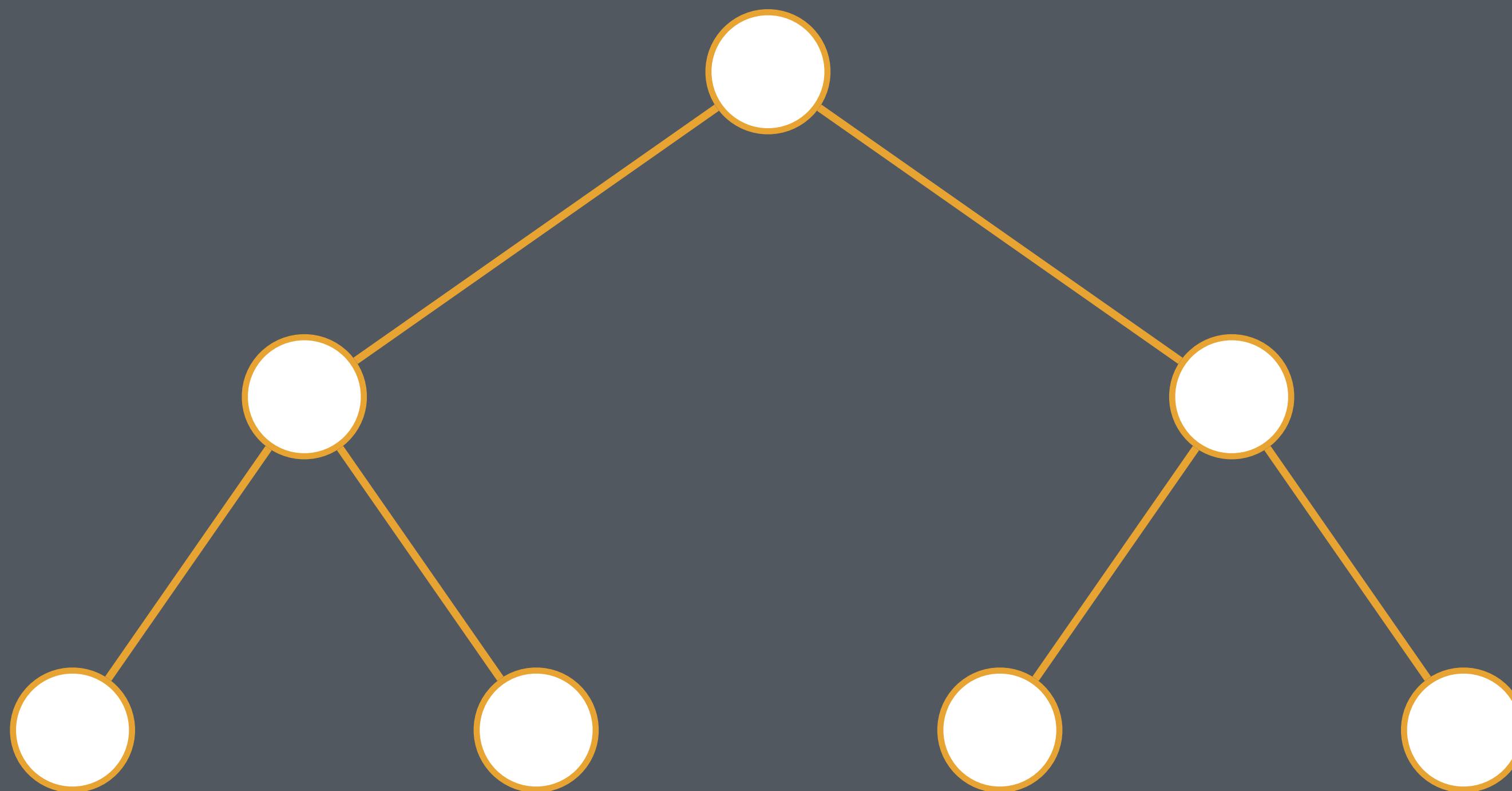
Learning: customized Regression Random Forests

nearest-neighbor search

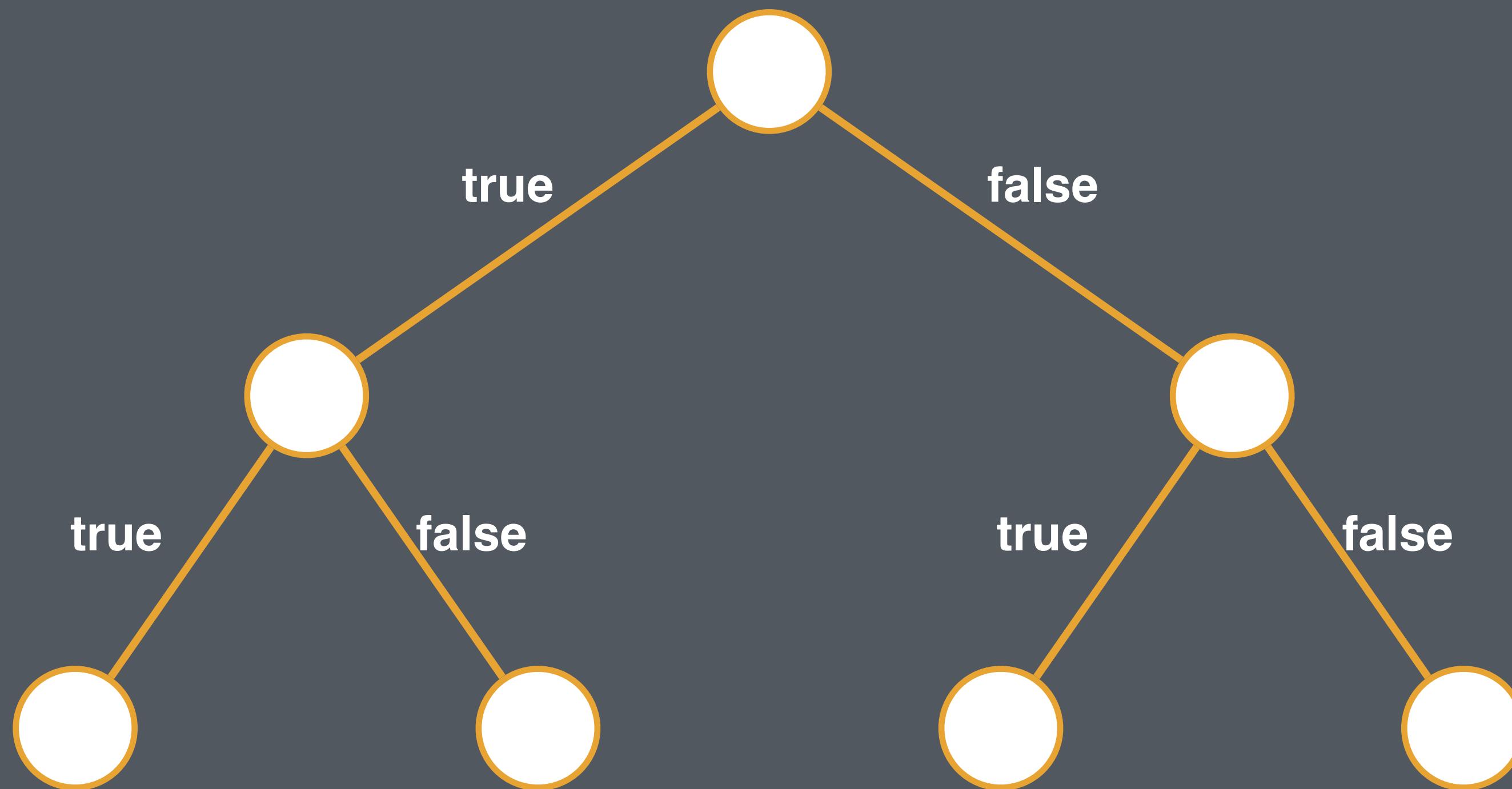
in **non-Euclidean space**

guided by training data

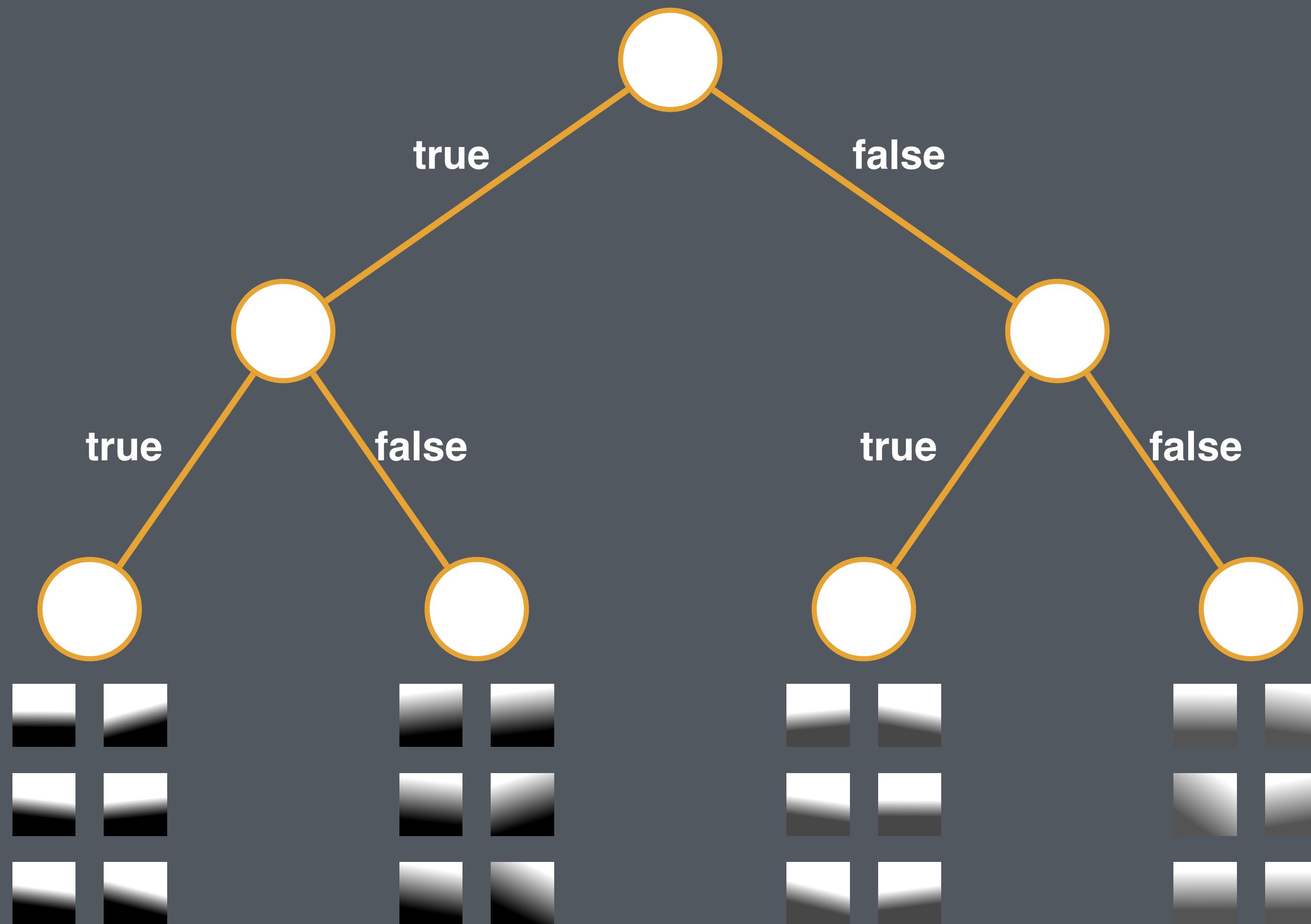
Learning

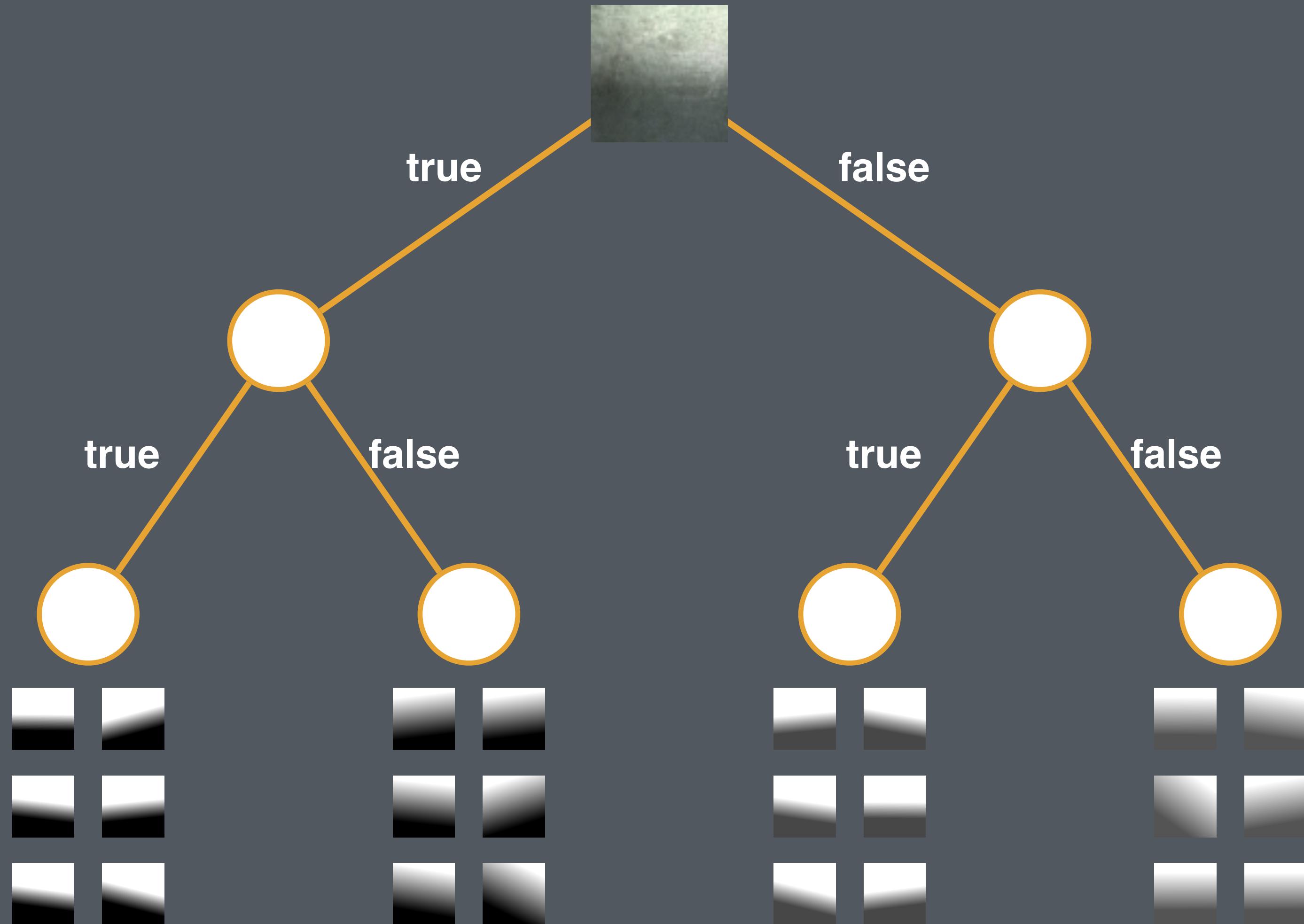


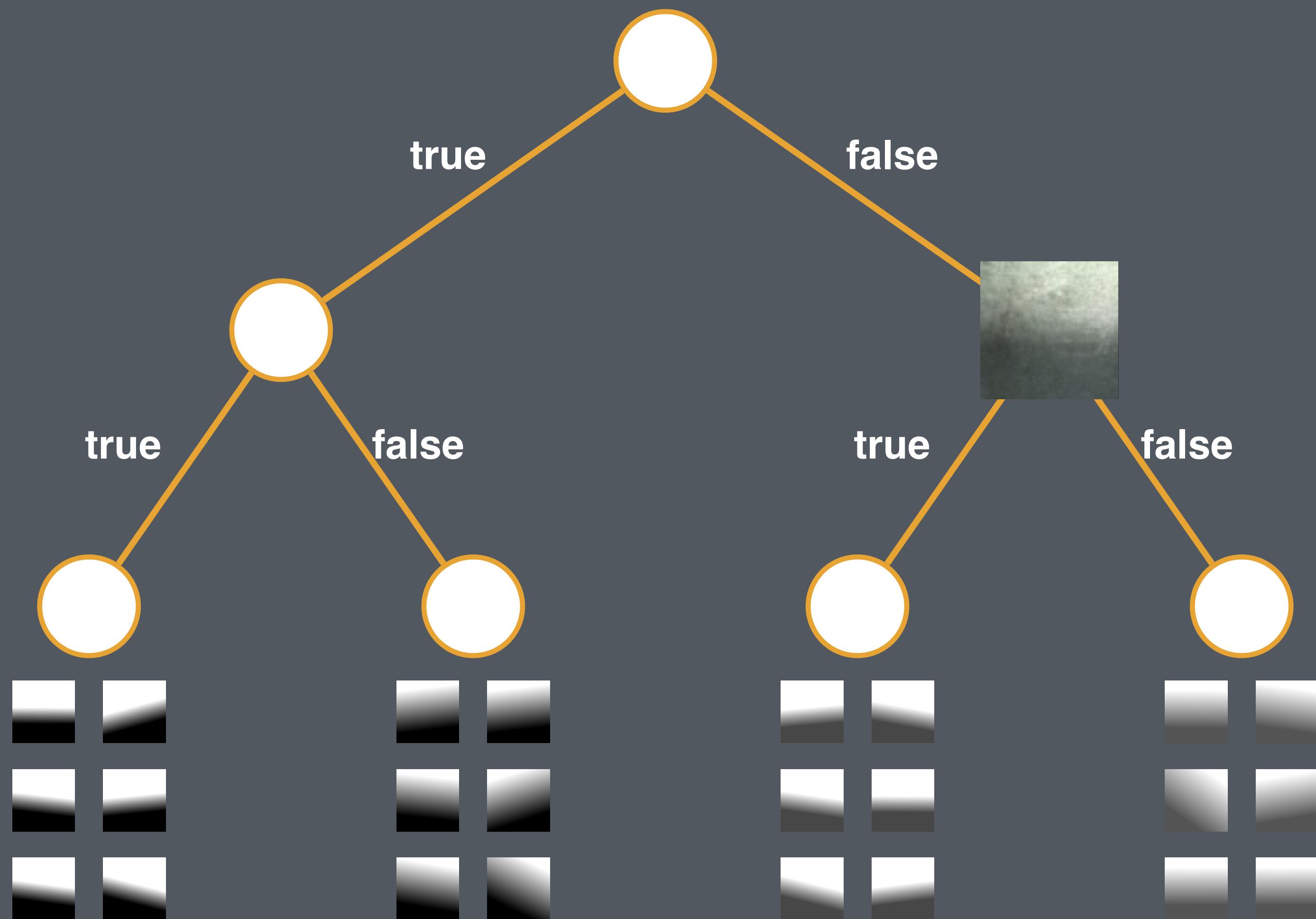
Learning

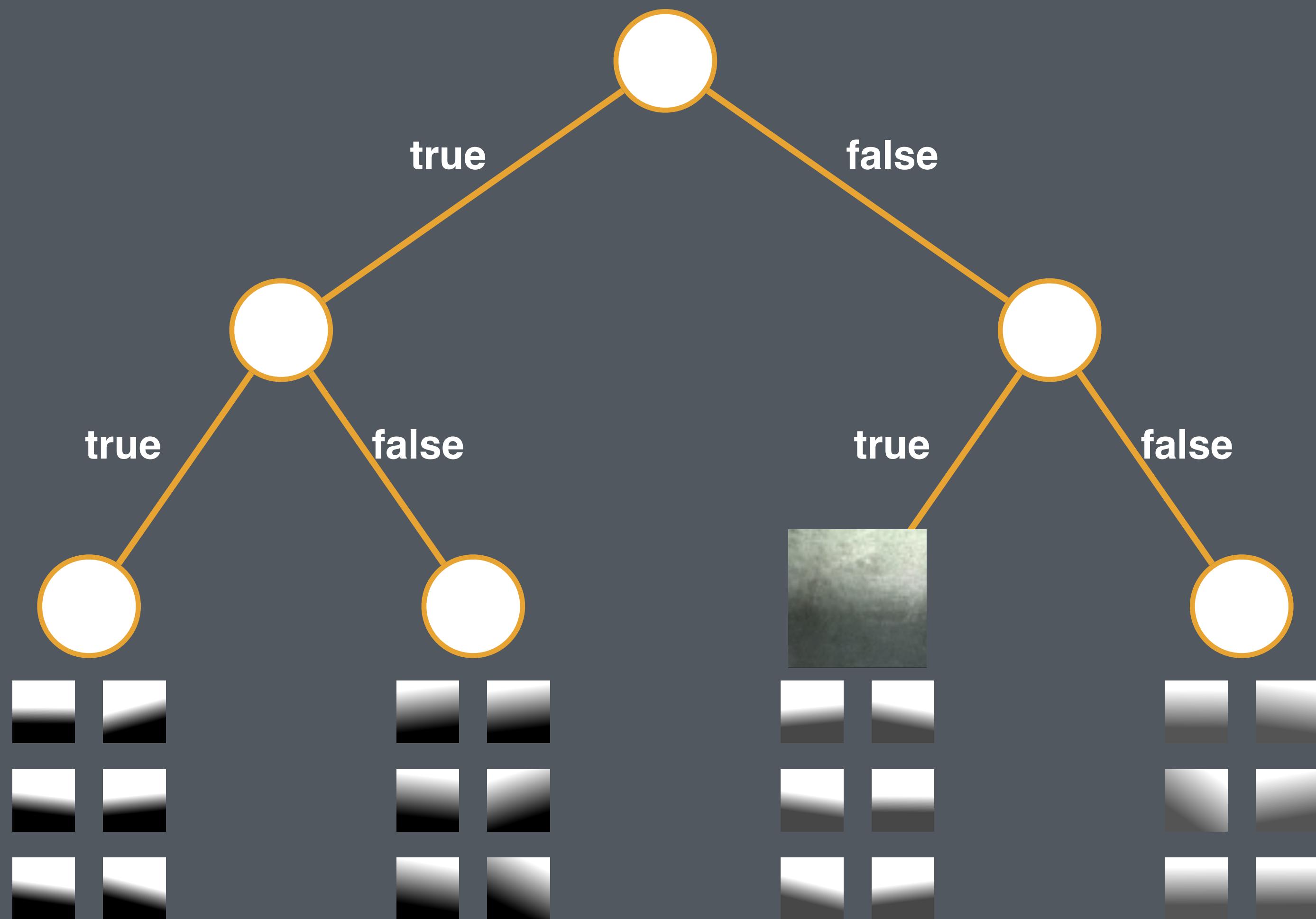


Learning

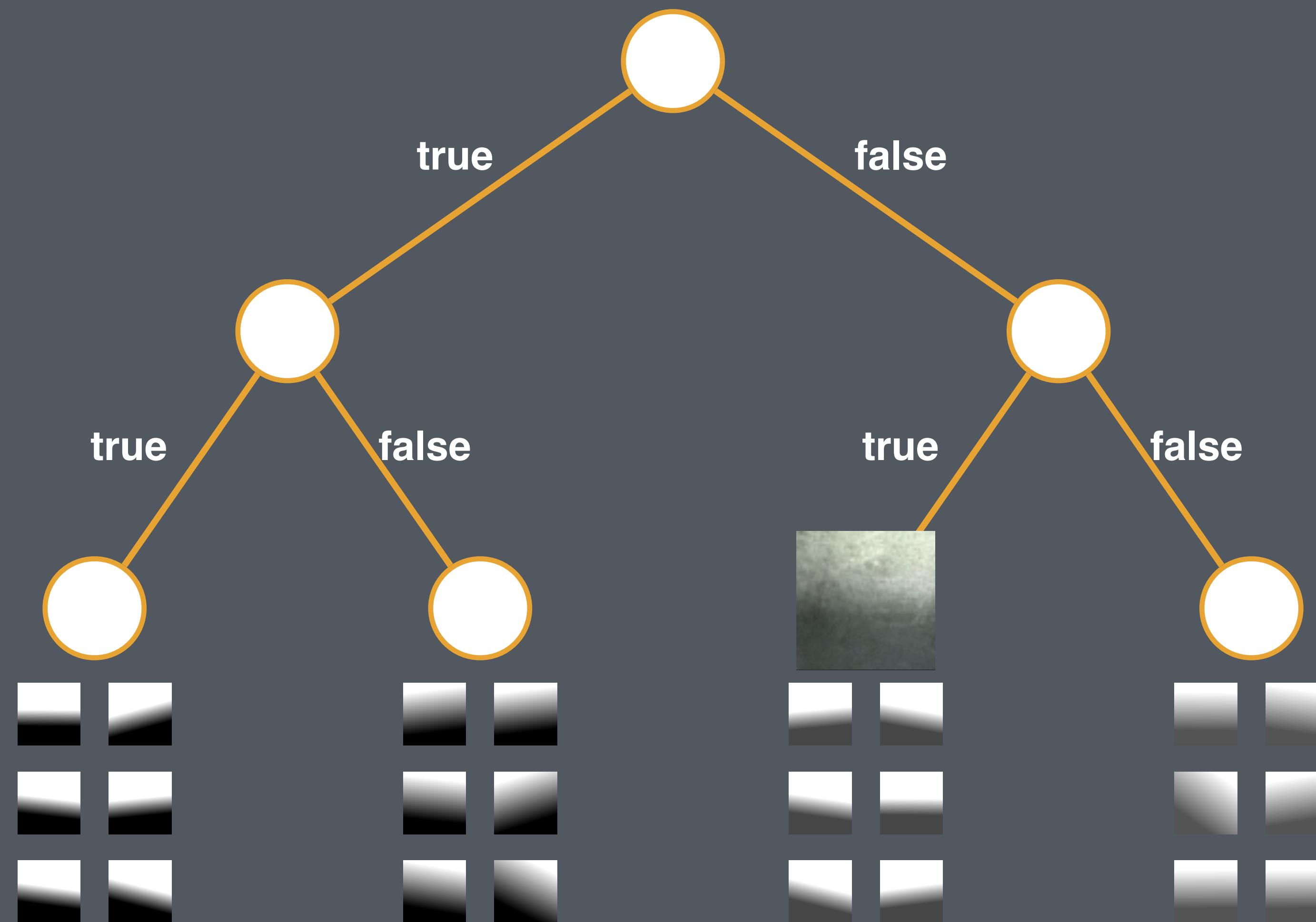








$$H_n = \log(\det \Sigma_{\mathcal{S}_n})$$



Feature vector

Our feature vector contains:

- normalized pixel intensity values (shifted in the intensity domain so that their mean falls at 0.5),

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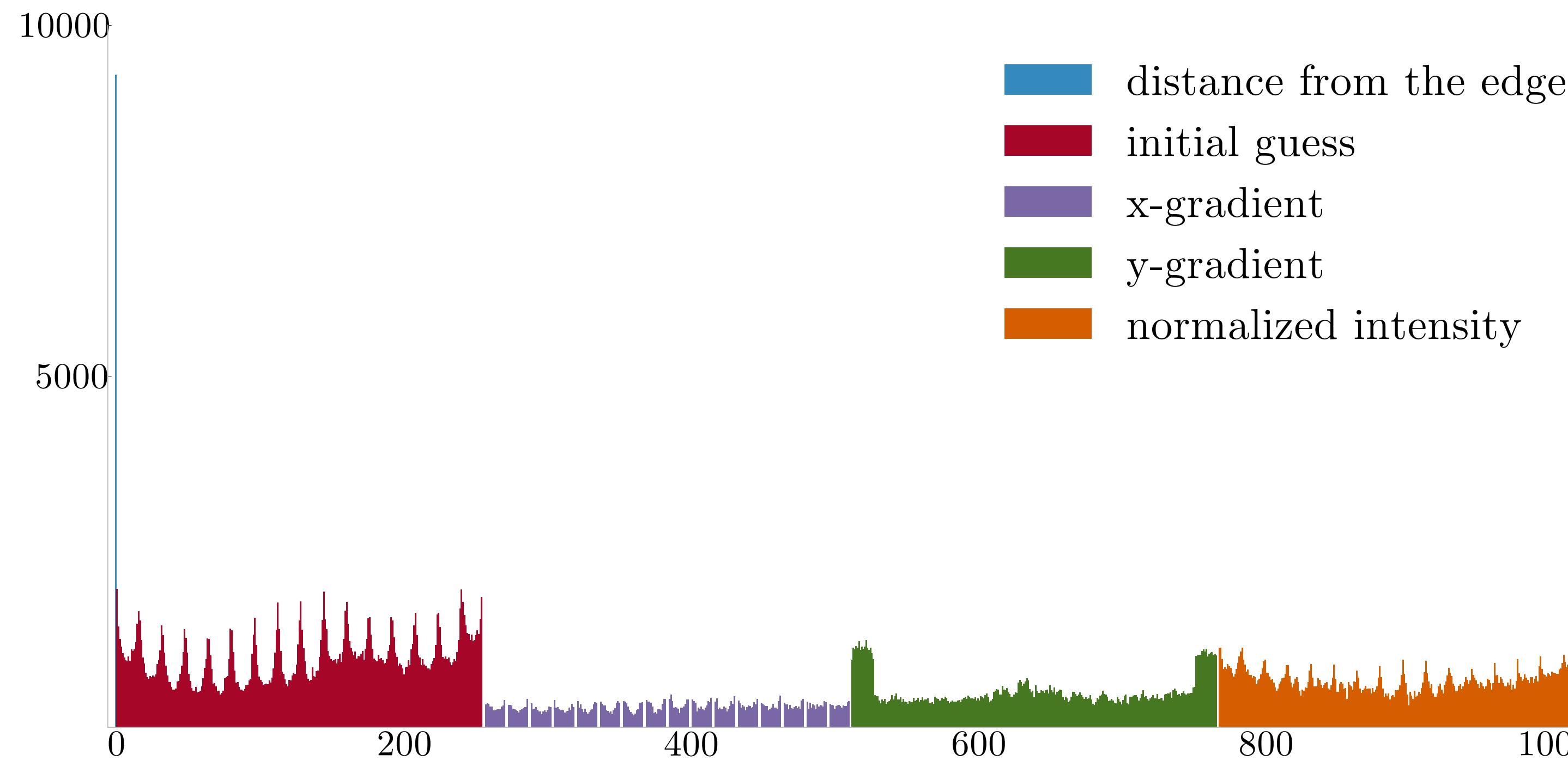
- normalized pixel intensity values (shifted in the intensity domain so that their mean falls at 0.5),
- x- and y-gradients (finite differences),
- normalized distance from the edge of the user-masked region,

Feature vector

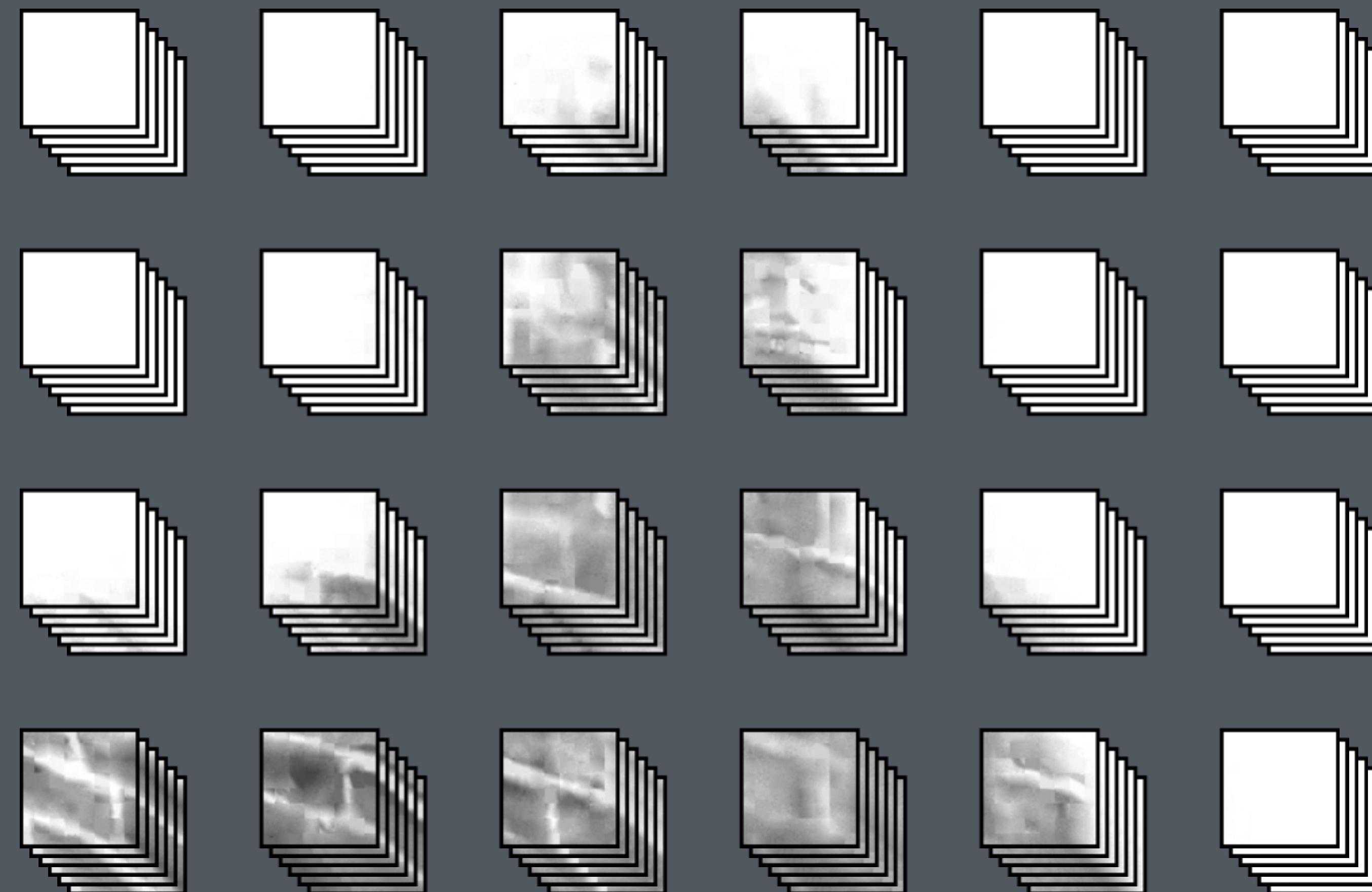
Our feature vector contains:

- normalized pixel intensity values (shifted in the intensity domain so that their mean falls at 0.5),
- x- and y-gradients (finite differences),
- normalized distance from the edge of the user-masked region,
- predicted matte for this patch (initial guess).

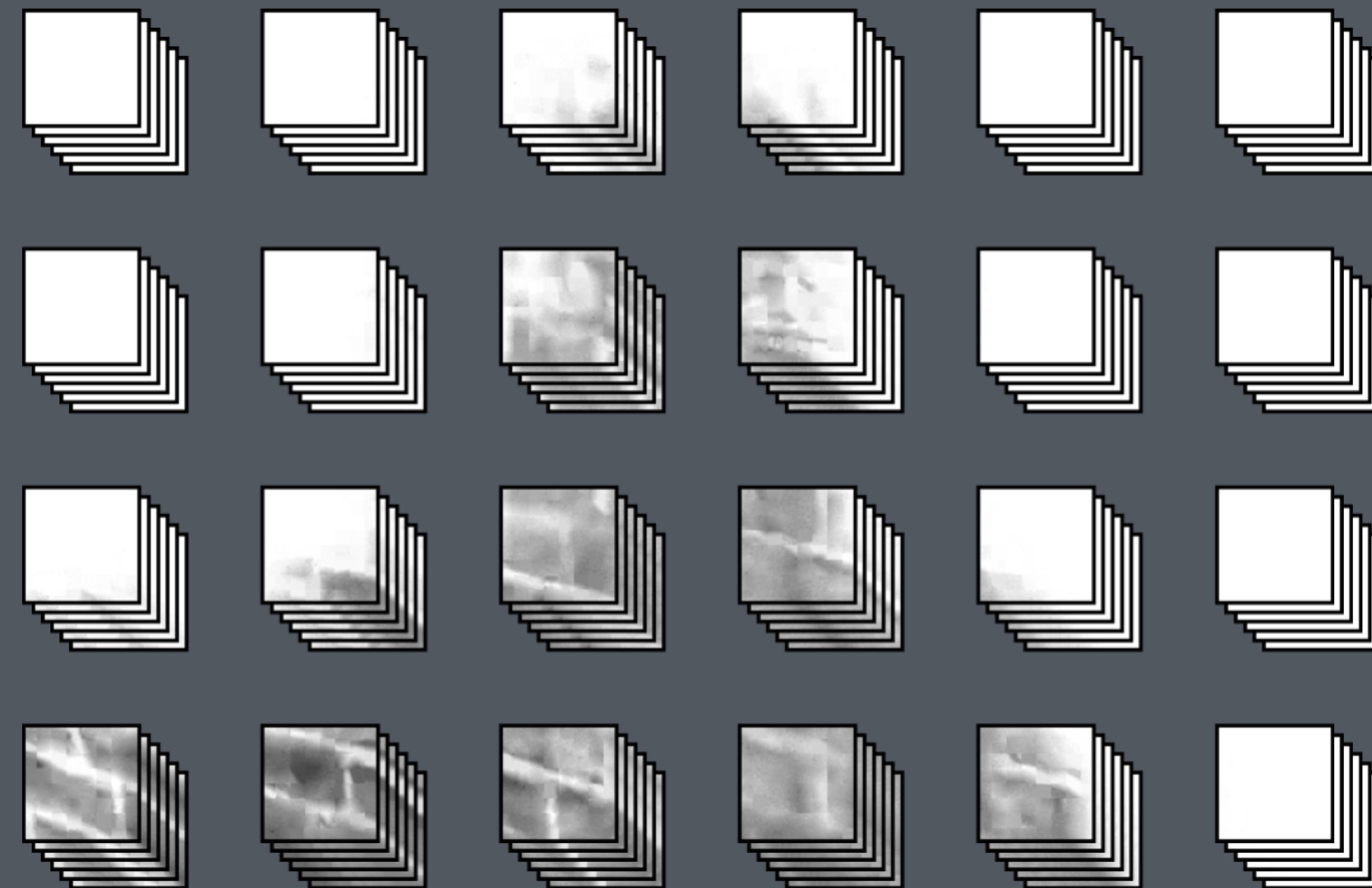
Feature frequency



Regularization



Regularization



Post-processing

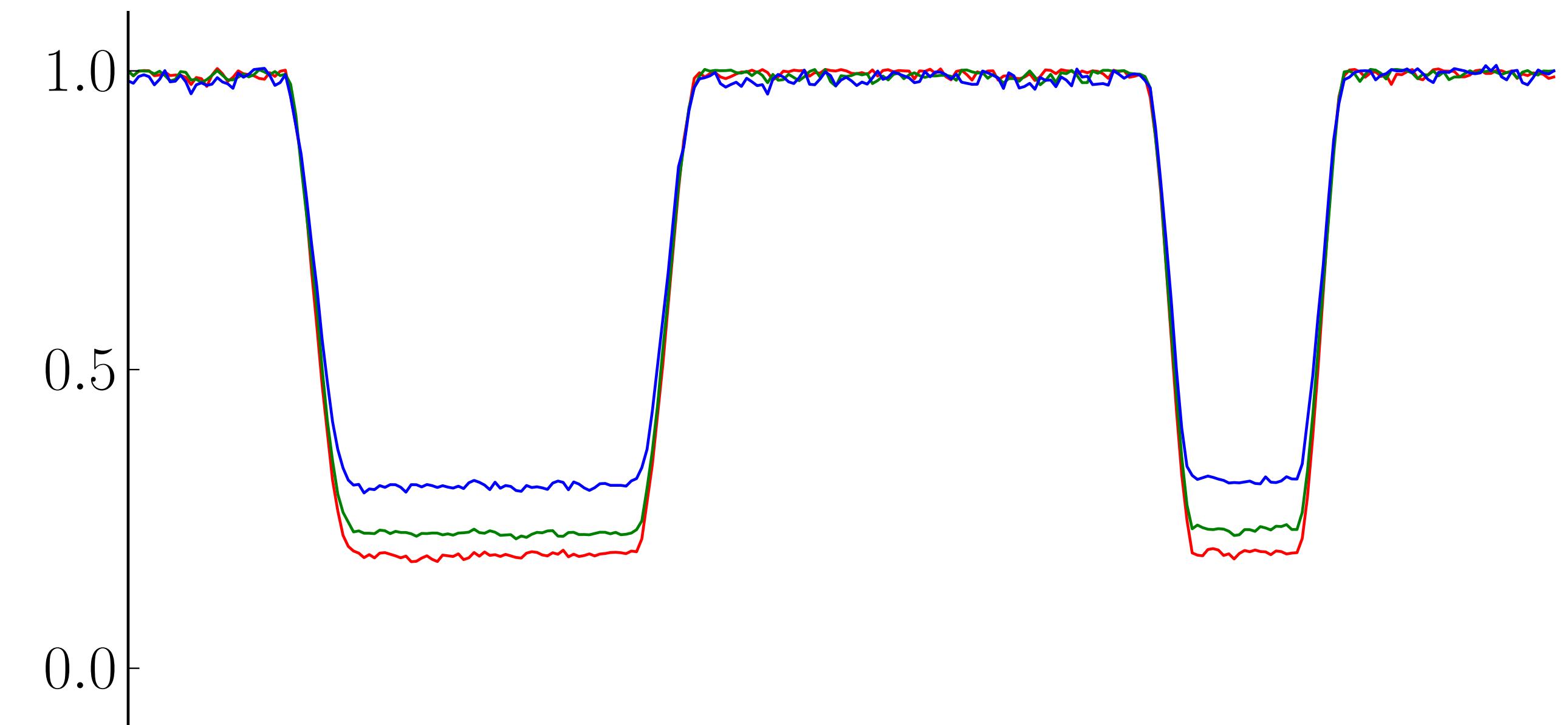
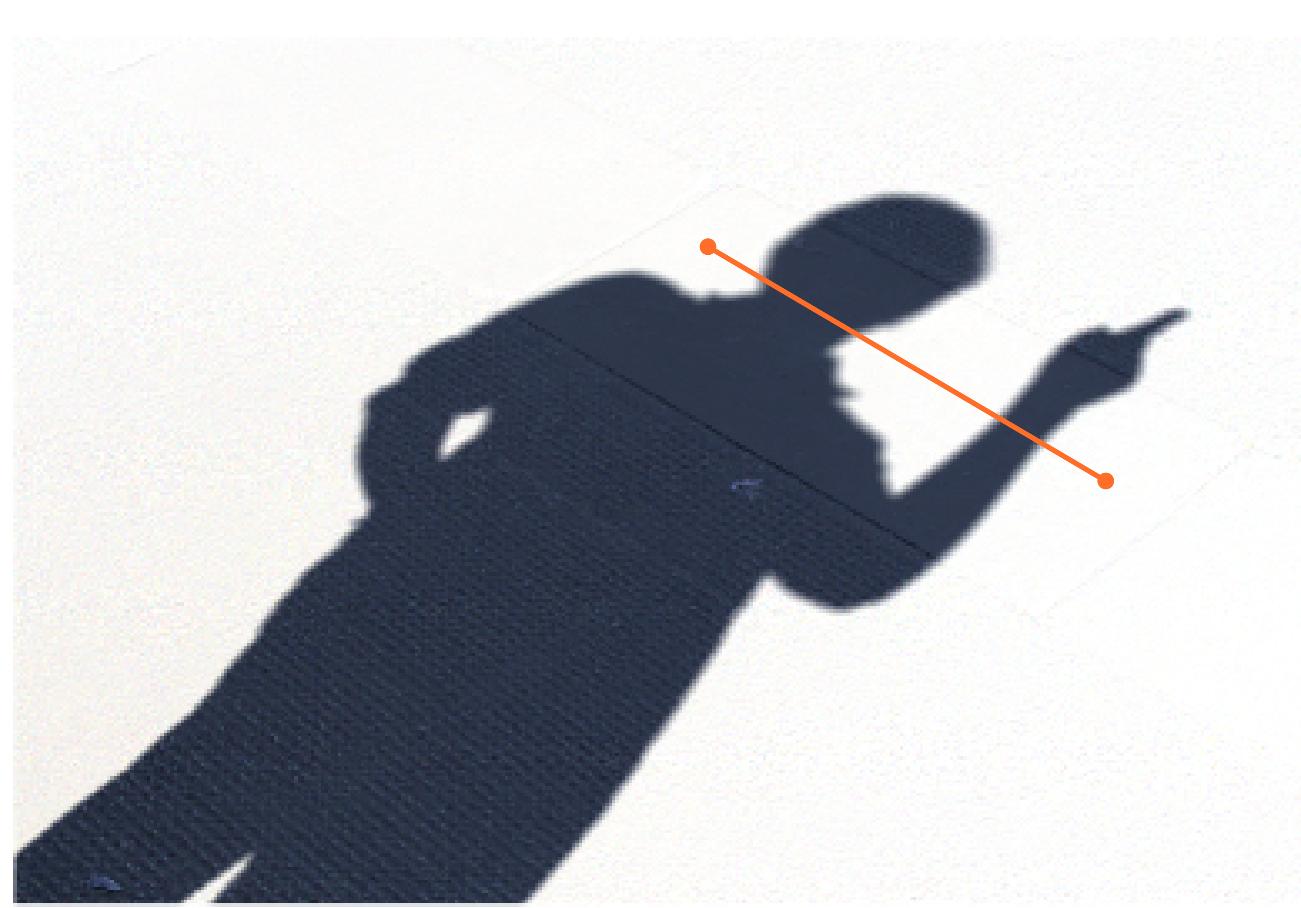
- Before “putting the patches down” on the graph, we re-align them to their original orientation.
- After regularization we have a single-channel shadow matte.
- Final optimization recovers color.

Post-processing



naive solution

Post-processing: color optimization



Post-processing



naive solution



our solution

Results!







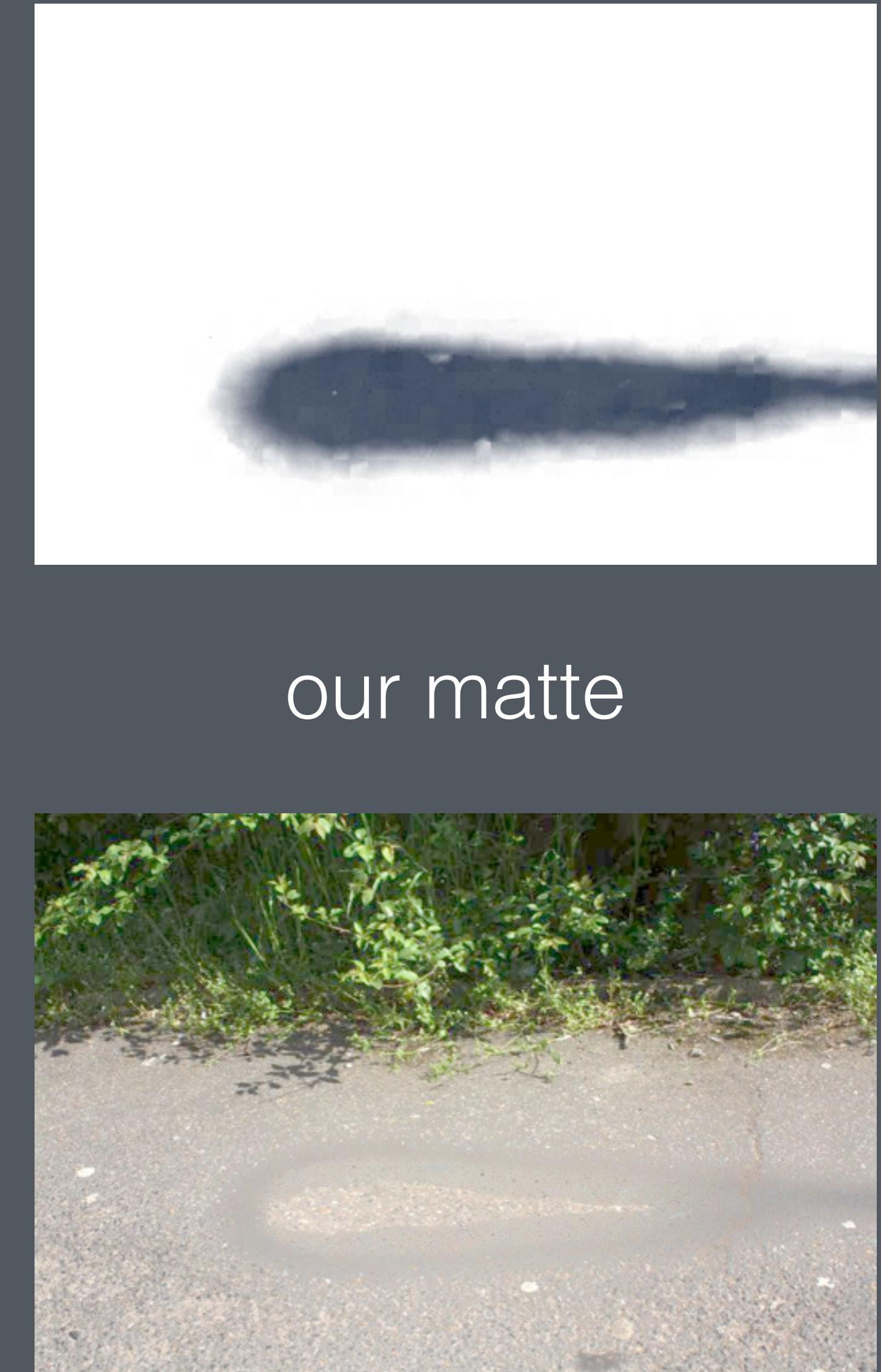
input



ours



our matte



Guo et al. 2012

Arbel & Hel-Or 2011



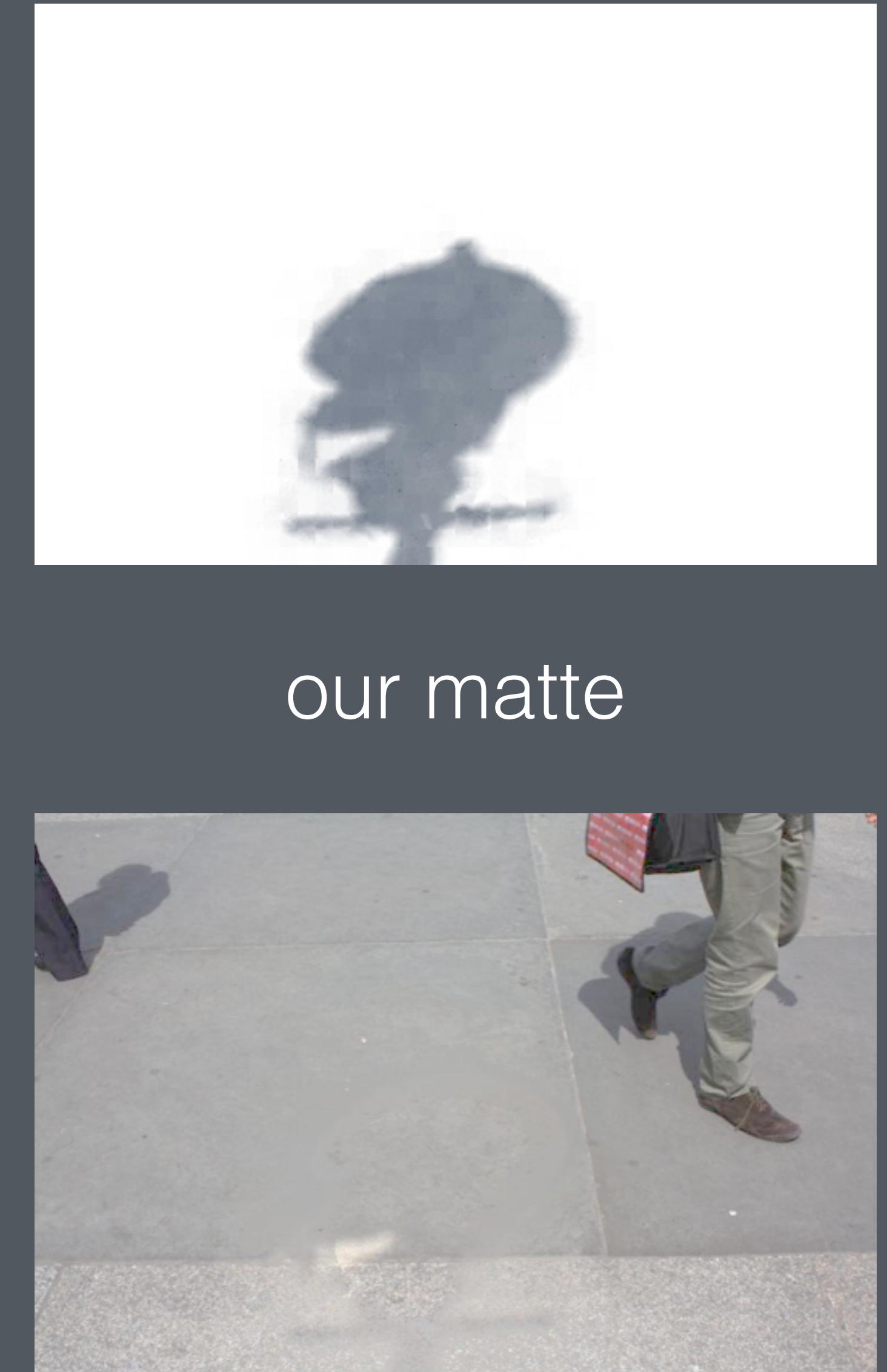
input



ours

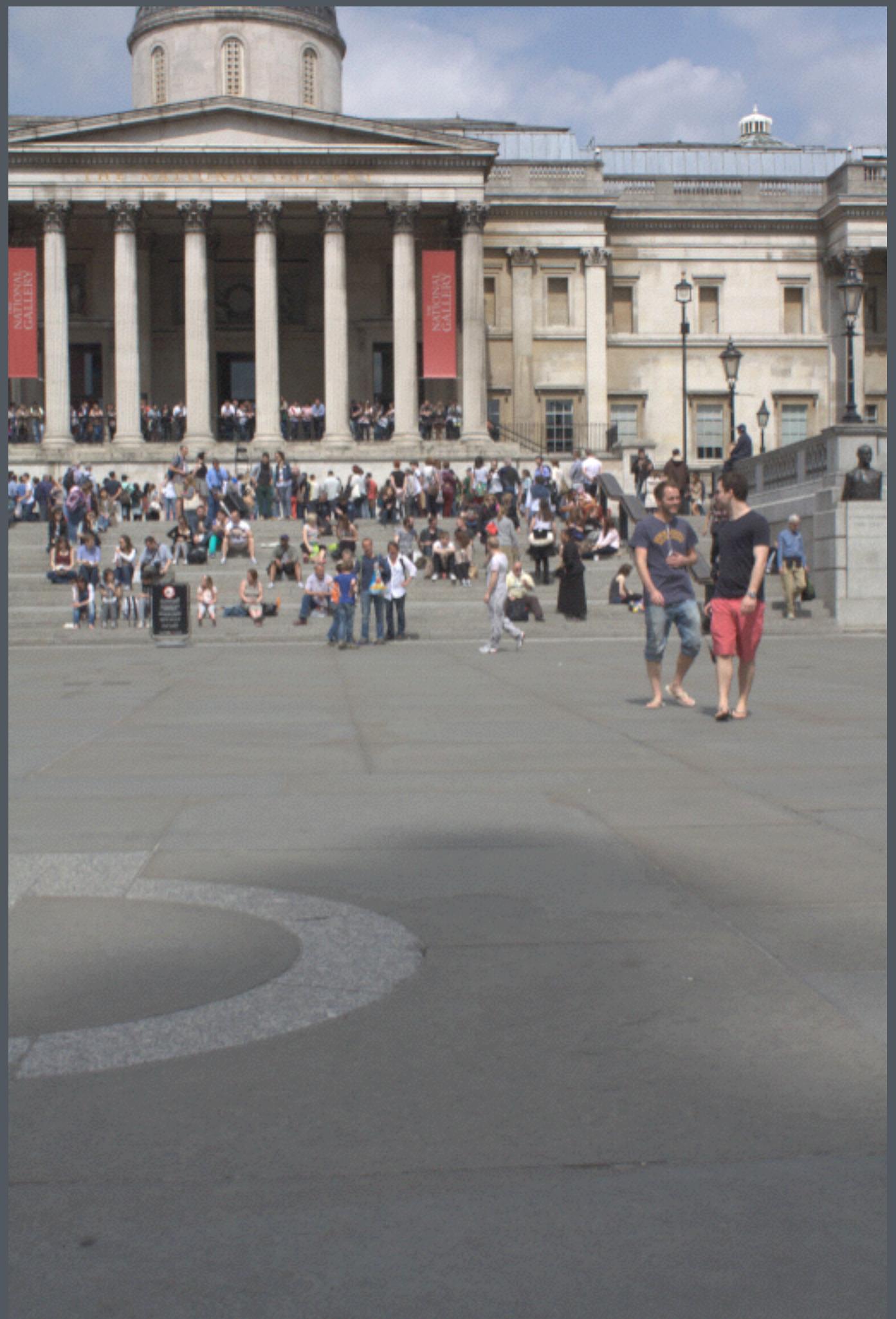


our matte



Guo et al. 2012

Arbel & Hel-Or 2011



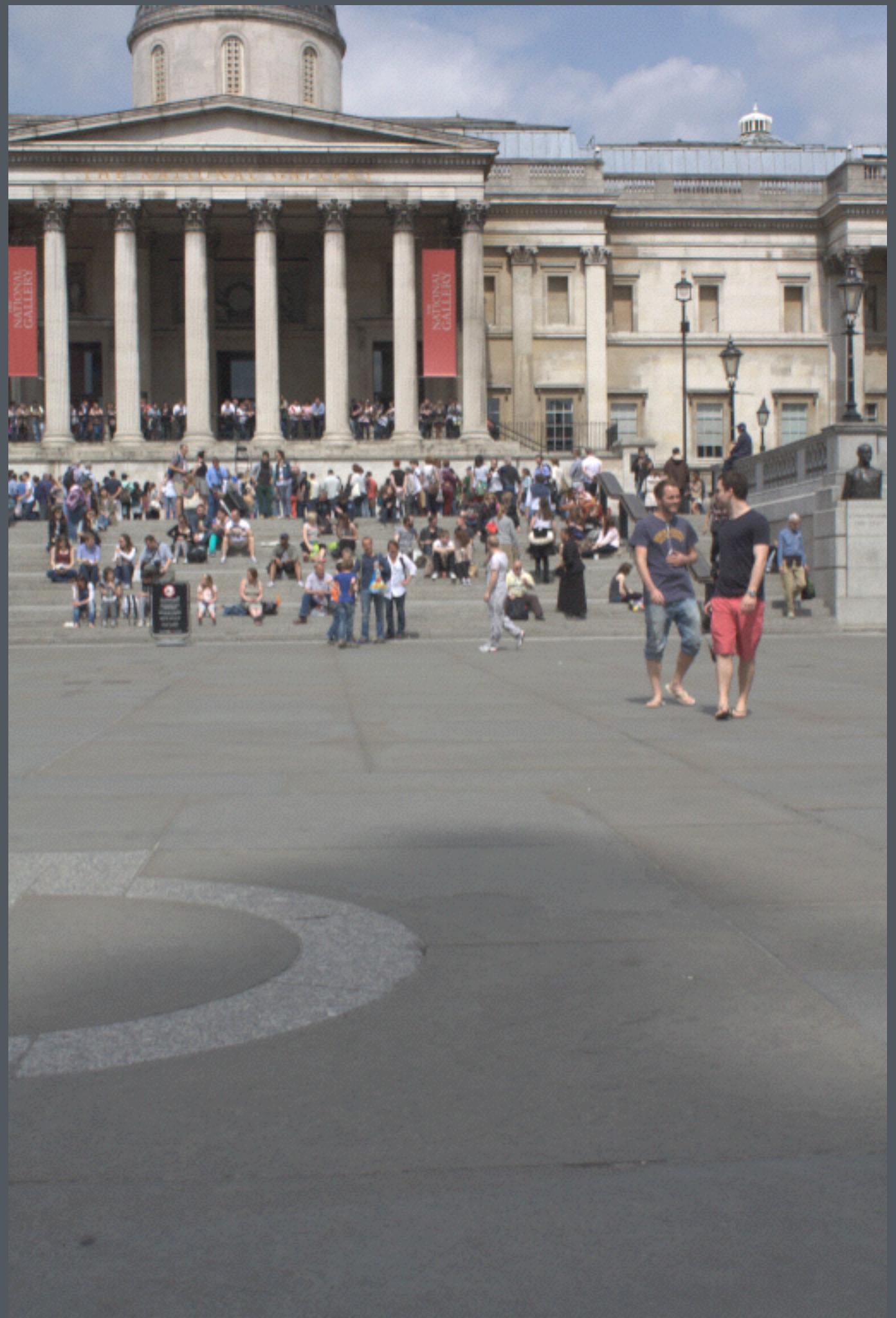
input



input



initial guess



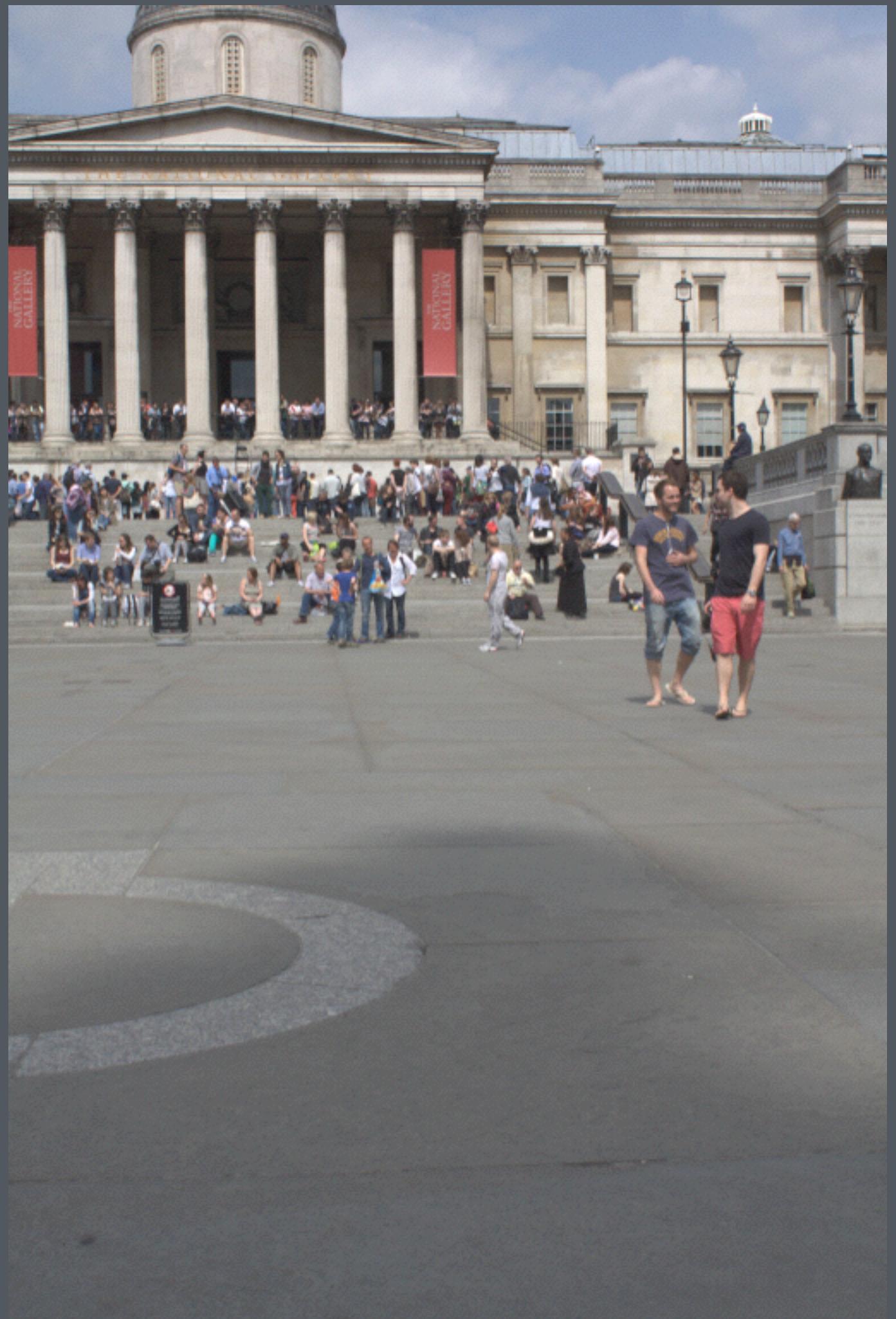
input



initial guess



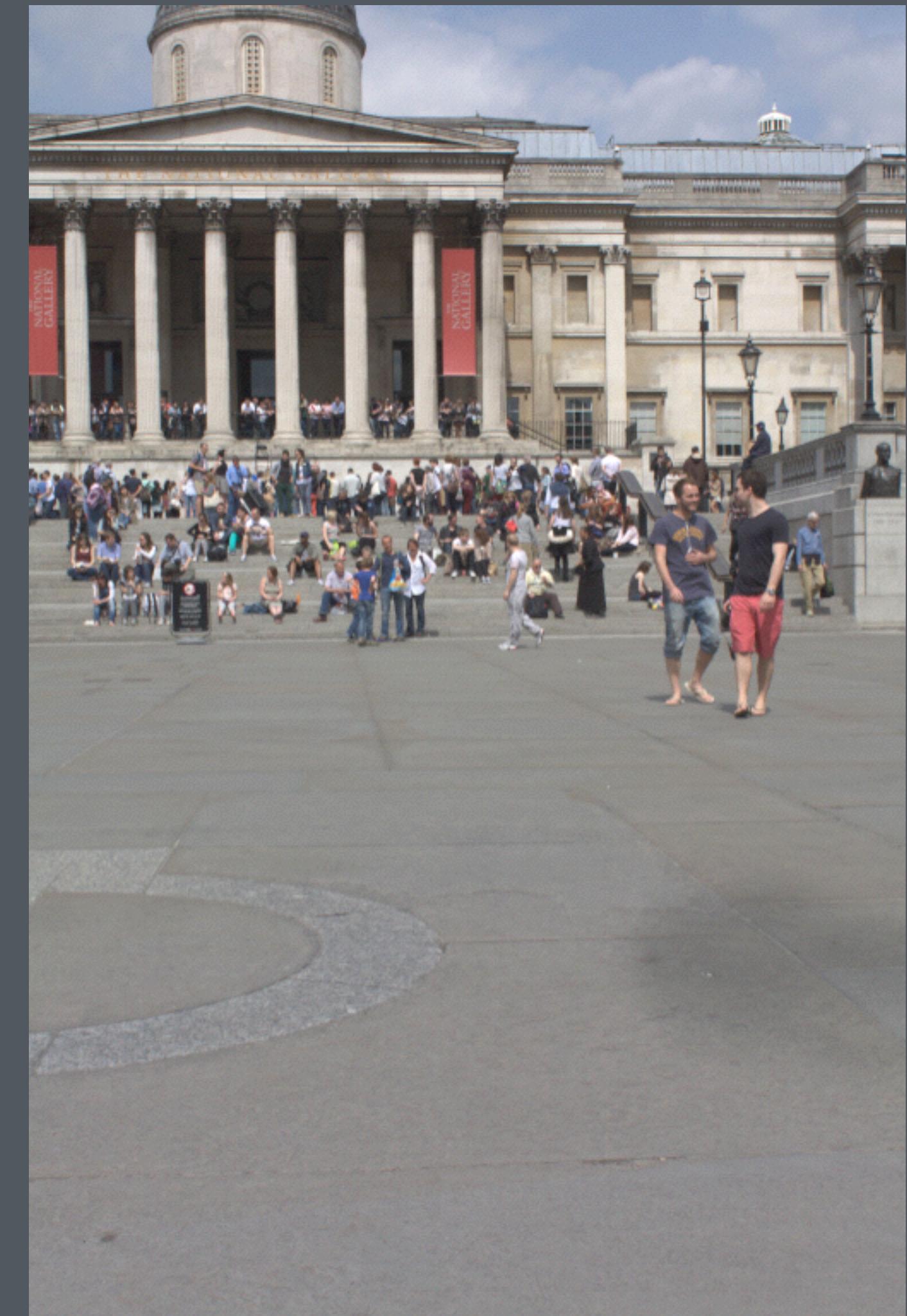
output



input



input mask



output

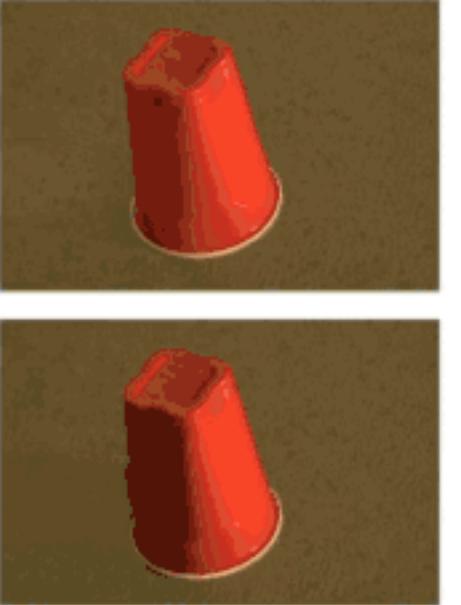
Summary of results

- The first perceptual user study of soft shadow removal methods.
- 2x more soft shadow images than previously available.
- Our results were chosen as the most convincing overall.
- Our method also wins in synthetic measures (distance to ground truth), but this is not a good success criterion.

Two-phase perceptual study

Ranking

Ranking Tutorial



most natural

Please drag these 2 images to arrange them in order from most to least natural in appearance. Put the most natural looking image at the top.

After deciding, please select how confident you are about your choice.

There will be a few rounds and each time you will be shown 2 or more images to rank. Make sure you're comfortable with how to arrange them and click the button below to start.

least natural

How confident are you of your answer?

(not really confident) 1 2 3 (very confident)

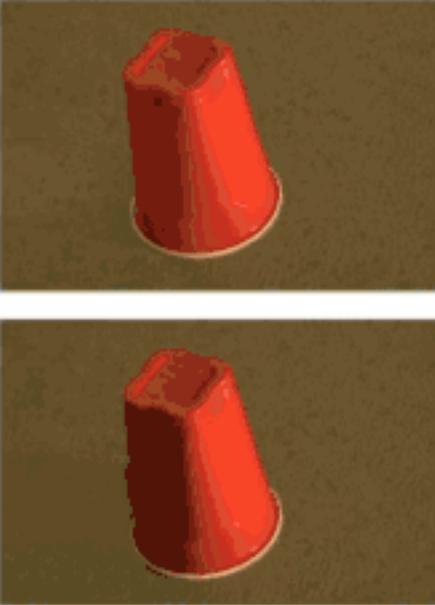
(please indicate confidence to continue)

Got it, let's go!

Two-phase perceptual study

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Ranking Tutorial



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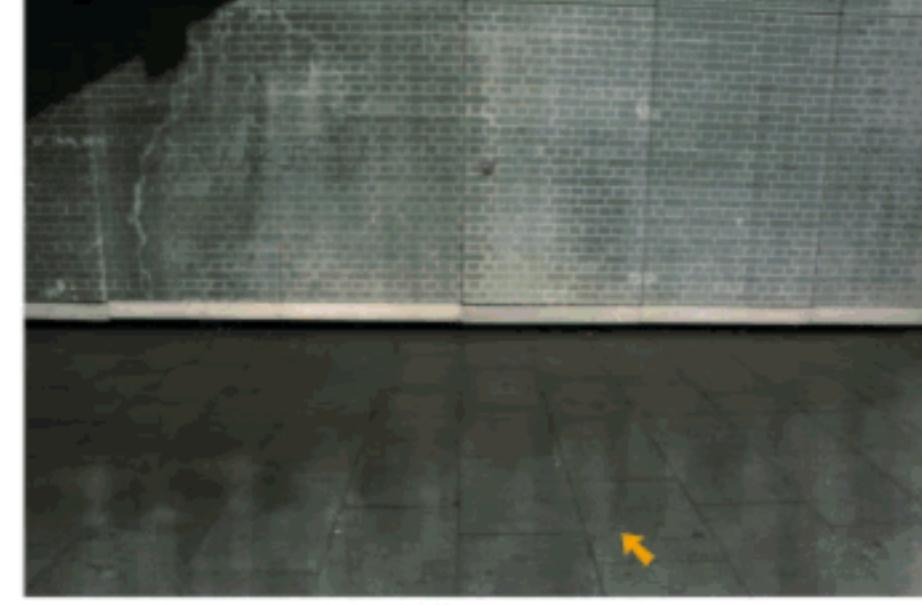
least natural

How confident are you of your answer?

(not really confident) 1 2 3 (very confident)

(please indicate confidence to continue) Got it, let's go!

Detection Tutorial



In this task we will show you several images. Some of them have been processed to have their shadows removed in the region pointed to by the orange arrow. Please rate how successful the shadow removal was. If you cannot see any shadows and everything looks natural, please select a higher score. If some shadow is still visible and/or there are obvious defects in the image, please answer 1.

After deciding, please select how confident you are about your choice.

How successfully was the marked shadow removed?

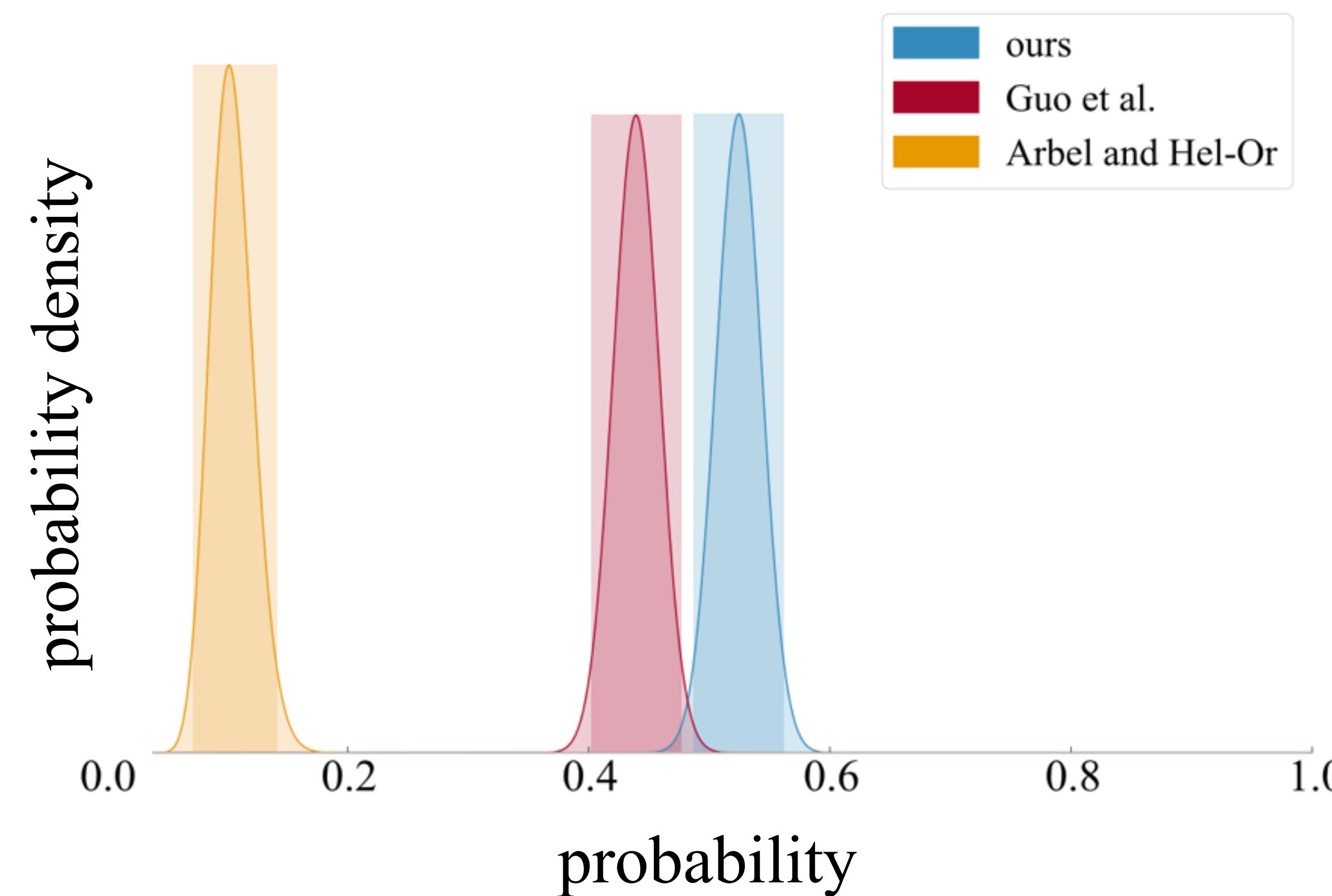
(not successfully at all) 1 2 3 4 (very successfully)

How confident are you of your answer?

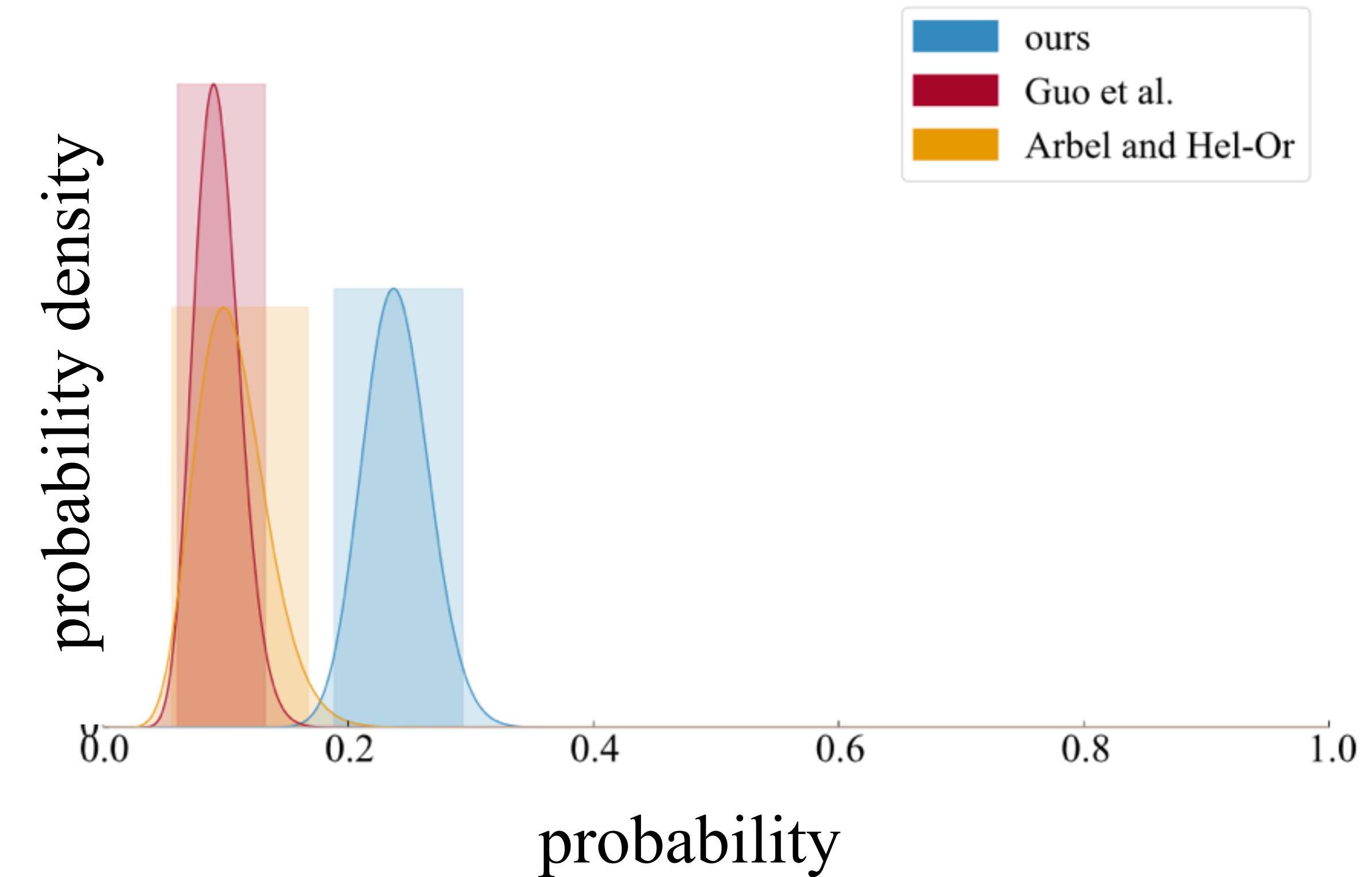
(not really confident) 1 2 3 (very confident)

(please answer both questions to continue) Got it, let's go!

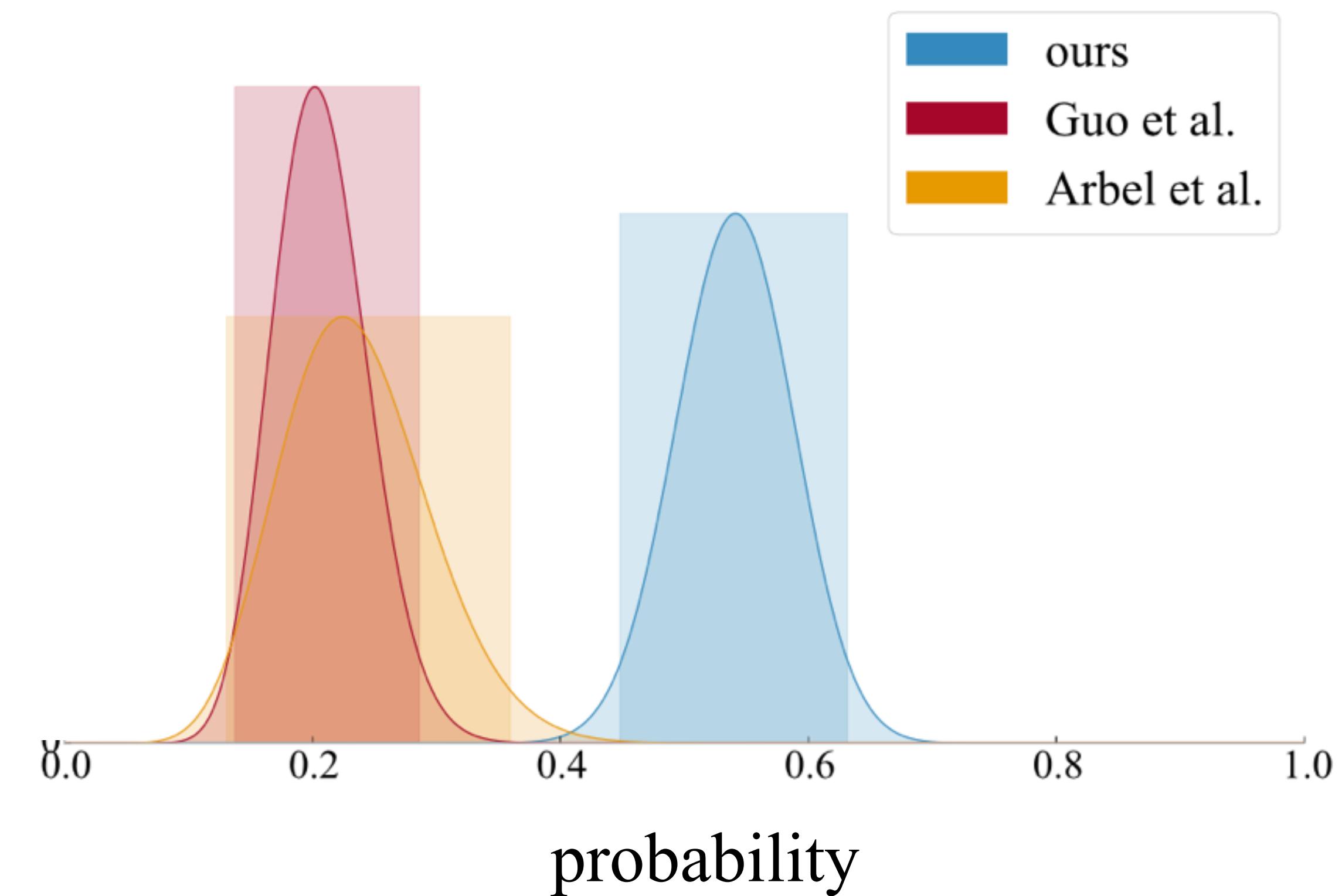
Probability of winning ranking



probability of 'perfect' shadow removal



probability of winning both ranking and detection



Limitations

Limitations



input image



unshadowed result

Limitations



initial guess (inpainting)



unshadowed result

Conclusions

Our method learns about physical phenomena from synthetic data. It uses the fruits of graphics research together with machine learning to create perceptually superior results.

See our website for:

- paper + video + results
- data generation / rendering scripts
- user study code
- algorithm code

<http://visual.cs.ucl.ac.uk/pubs/softshadows/>

Thanks!