Towards Shape from Refraction

BMVC 2021

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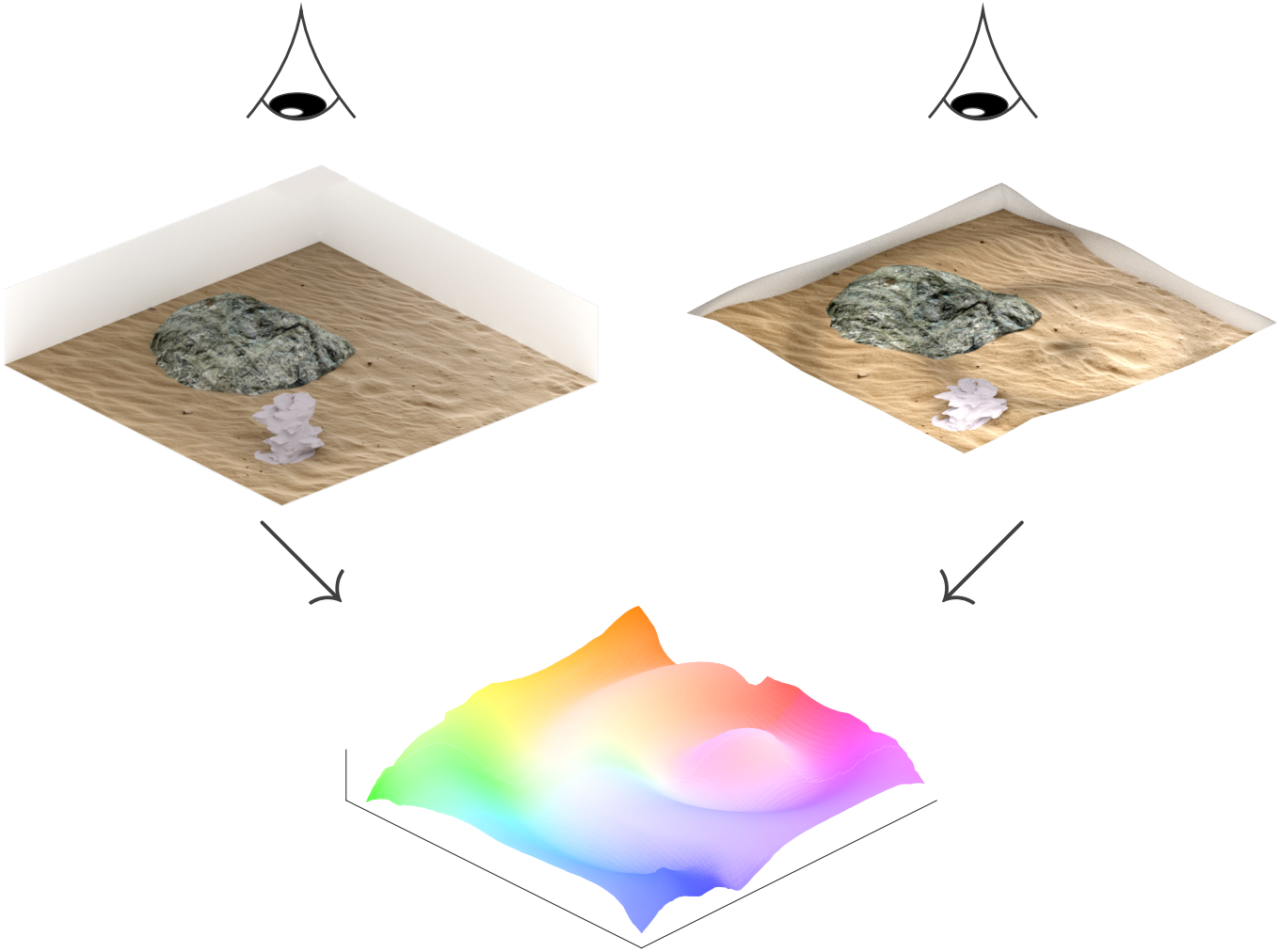
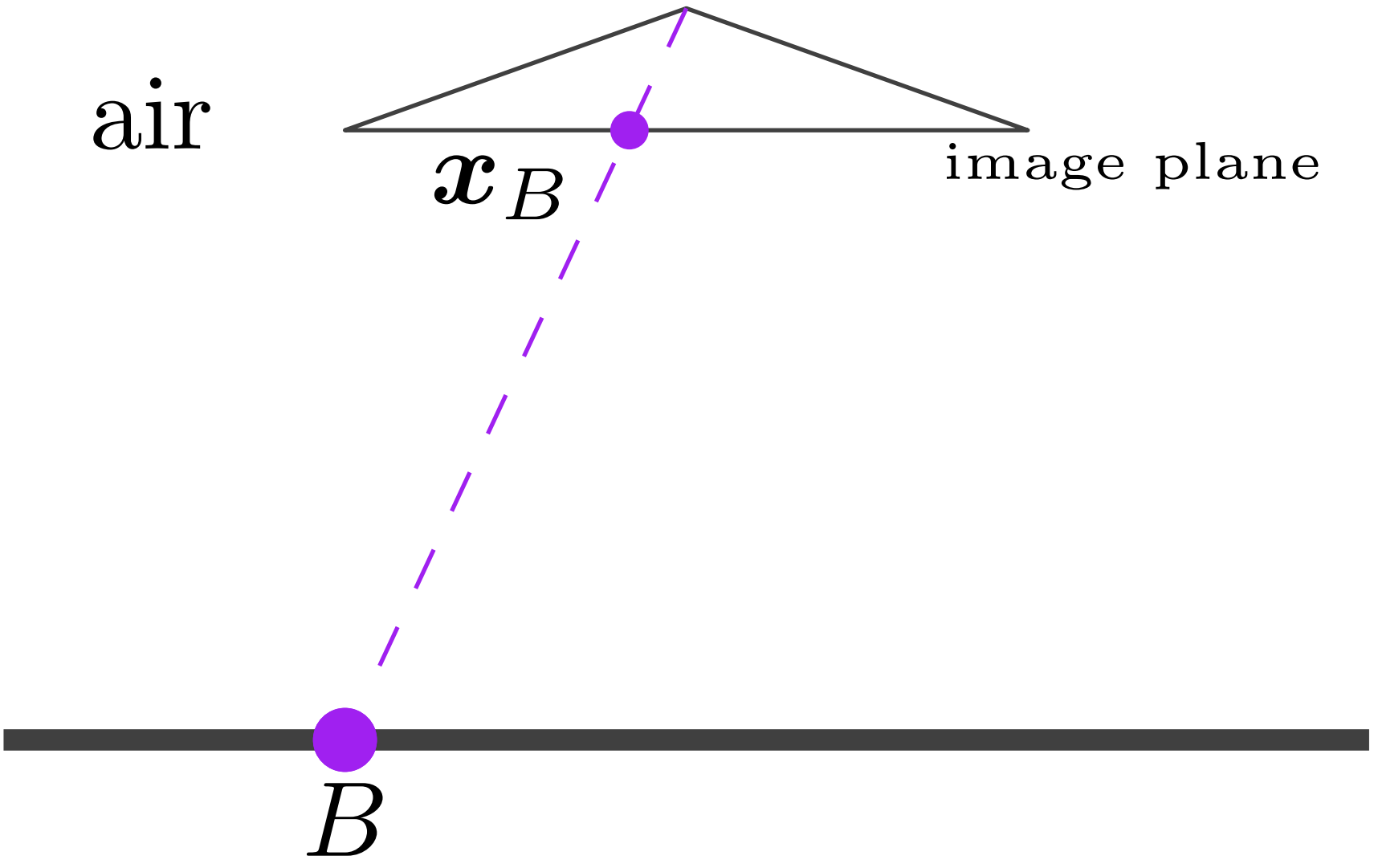
Motivation

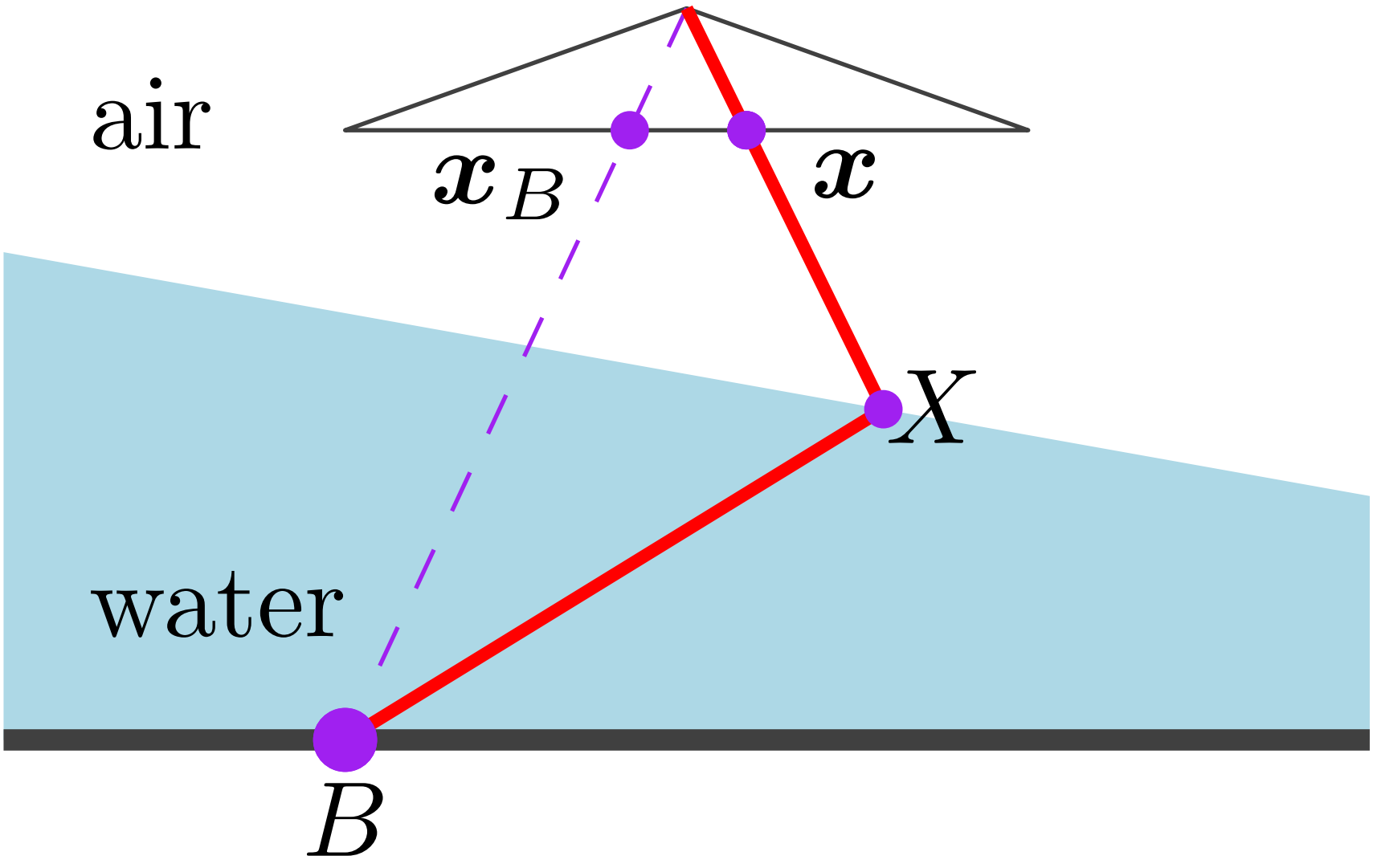
Estimate 3D surface from a **single** refracted image.

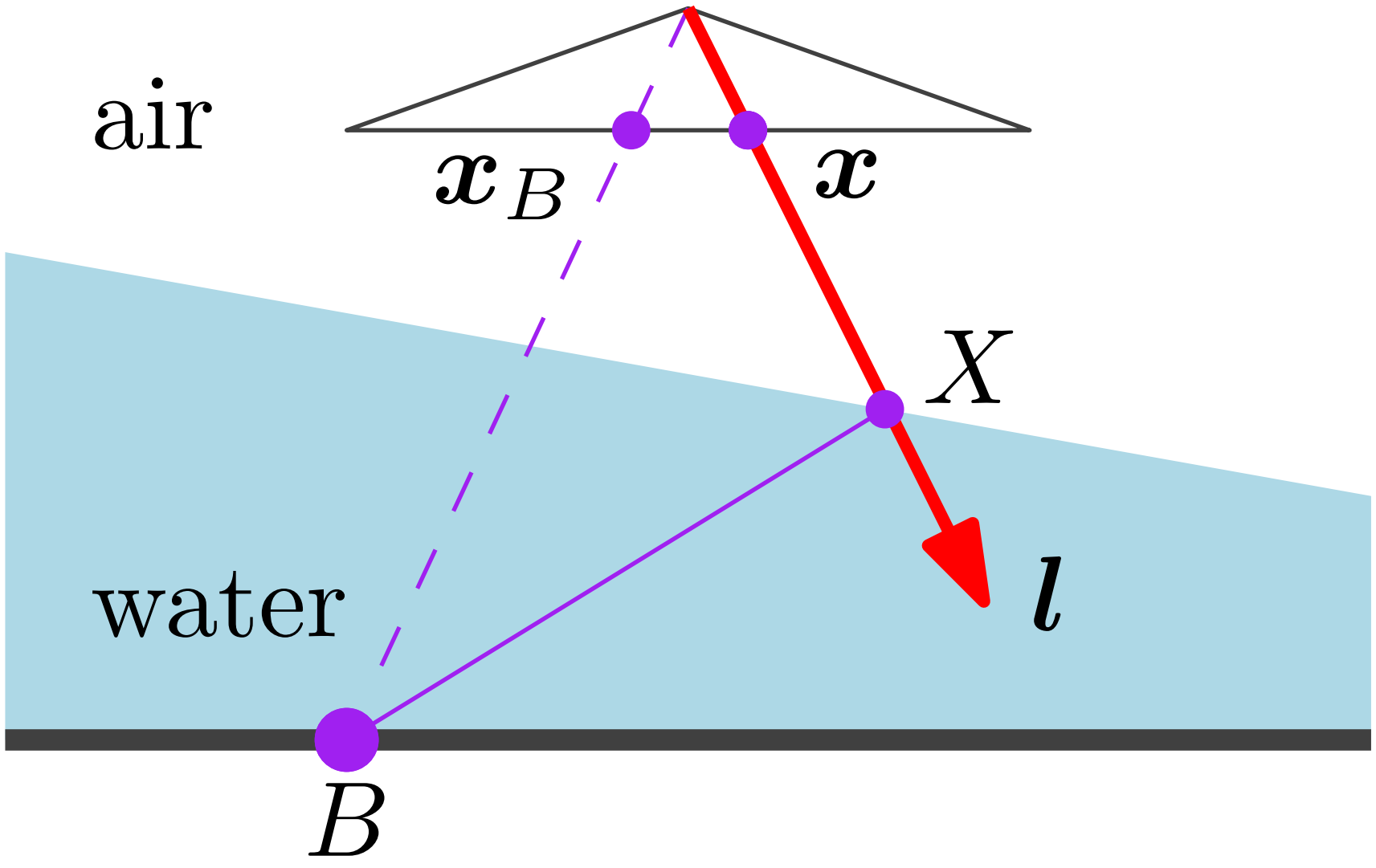


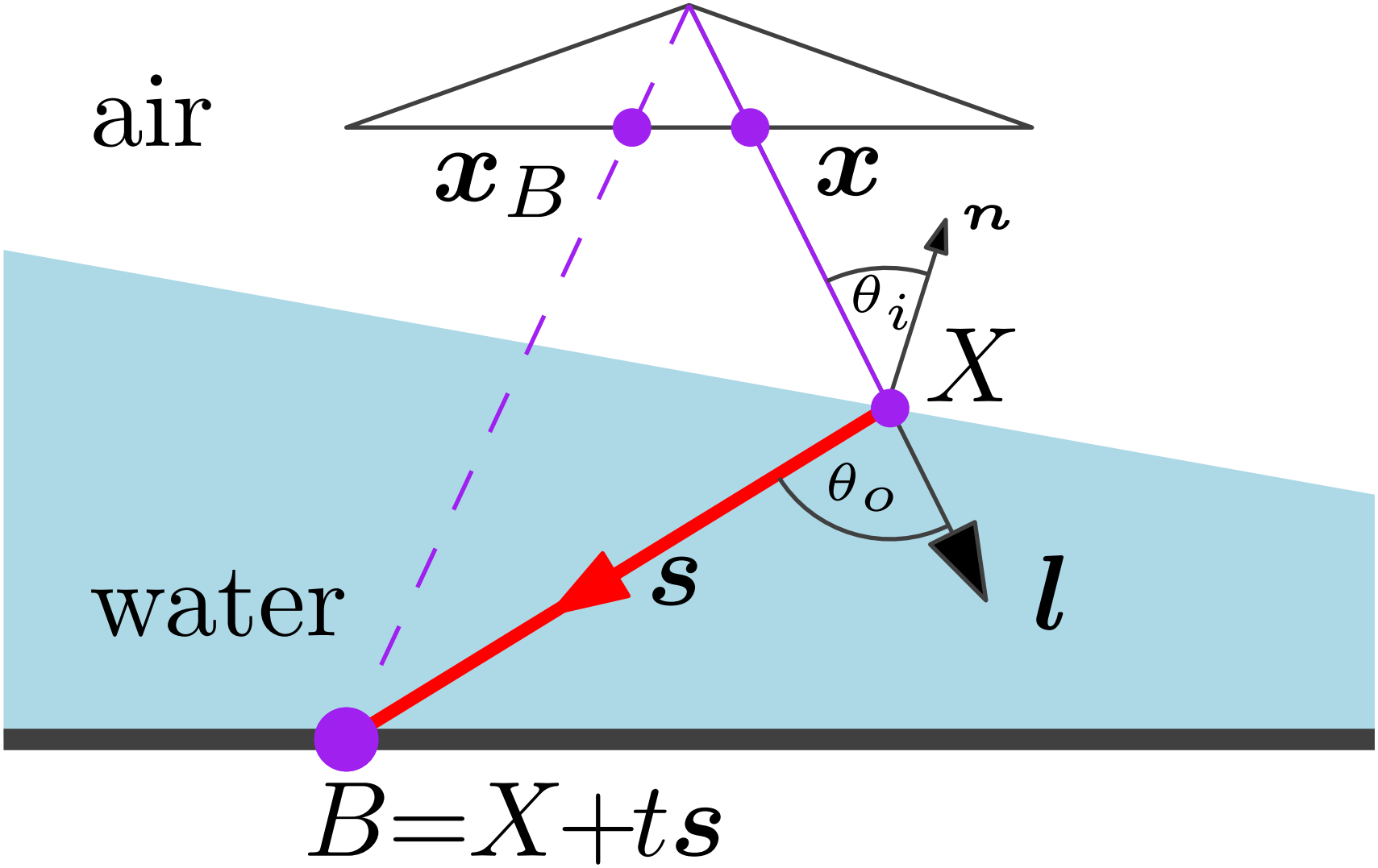
Existing Works

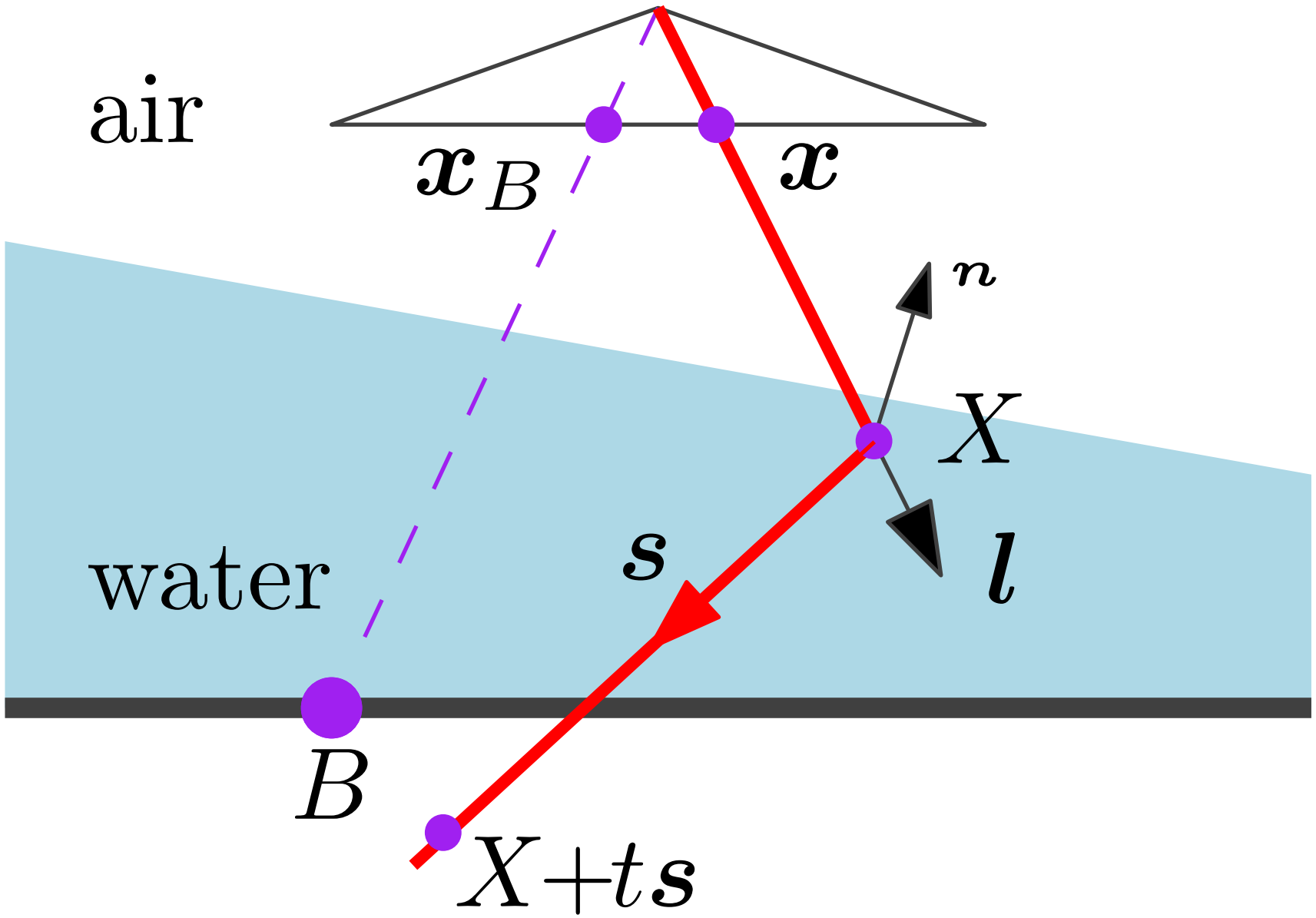
Shan et al. CVPR'12	A single-frame monocular, energy minimization, **flat background** and **orthography**, estimates only a surface **height field**
Qian et al. ECCV'18	Multi-view (4-9 views), energy minimization,
Thapa et al. CVPR'20	{Single, multi}-frame monocular, trained model, **flat background** and **orthography**, estimates only a surface **height field**,
Ours	A single frame, energy minimization, **arbitrary background**, **perspective**

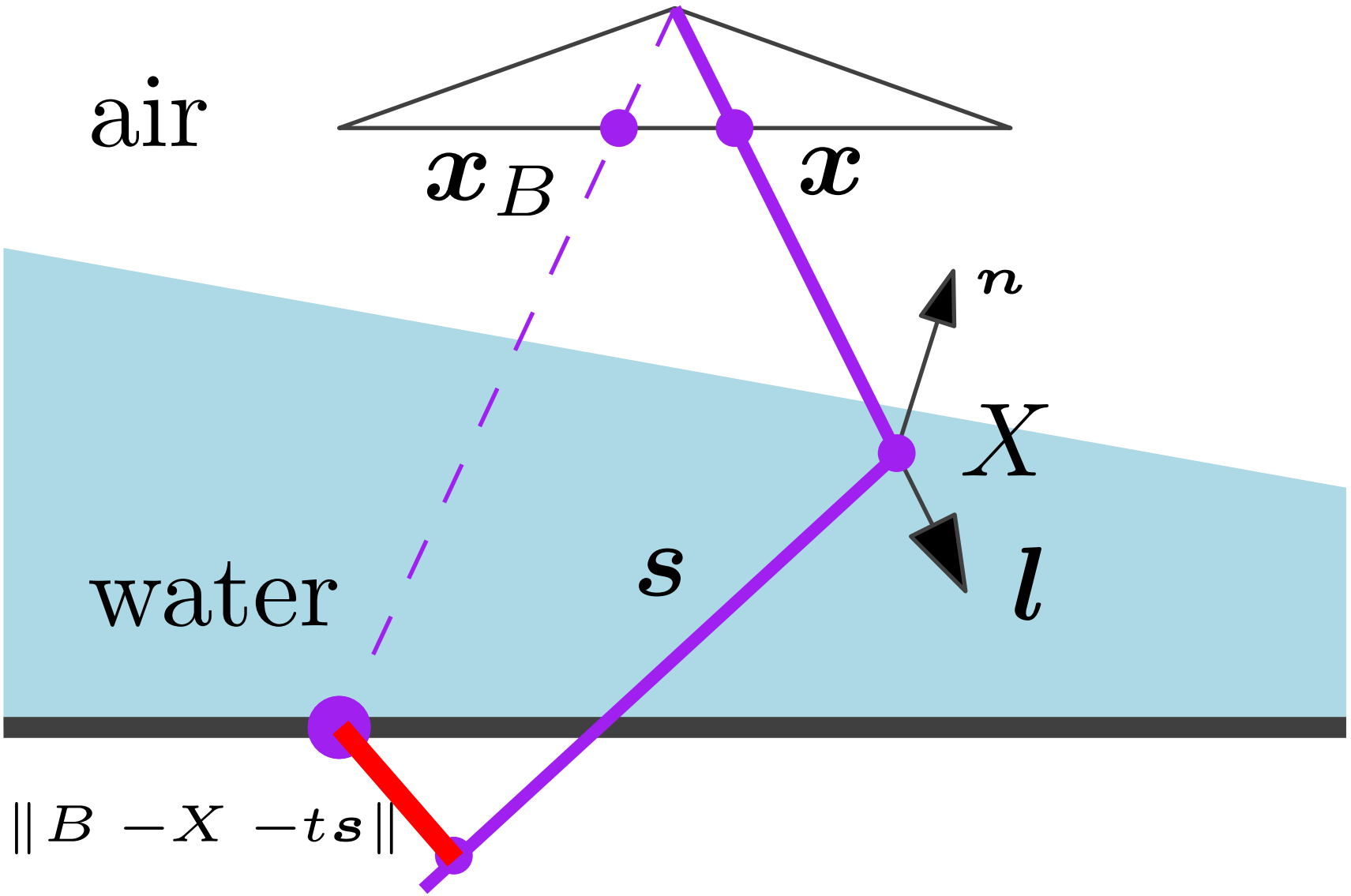

air
$\boldsymbol{x}_B$
image plane
B


air
$\boldsymbol{x}_B$
$\boldsymbol{x}$
X
water
B

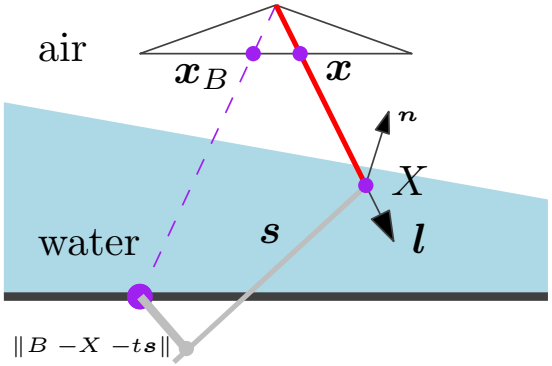

air
$\boldsymbol{x}_B$
$\boldsymbol{x}$
X
water
$\boldsymbol{l}$
B


air
$\boldsymbol{x}_B$
$\boldsymbol{x}$
$\boldsymbol{n}$
θ_i
X
θ_o
$\boldsymbol{s}$
$\boldsymbol{l}$
water
$B = X + t\boldsymbol{s}$


air
$\boldsymbol{x}_B$
$\boldsymbol{x}$
$\boldsymbol{n}$
X
$\boldsymbol{l}$
water
$\boldsymbol{s}$
B
$X+t\boldsymbol{s}$


air
$\boldsymbol{x}_B$
$\boldsymbol{x}$
$\boldsymbol{n}$
X
water
$\boldsymbol{s}$
$\boldsymbol{l}$
$\|B - X - t\boldsymbol{s}\|$

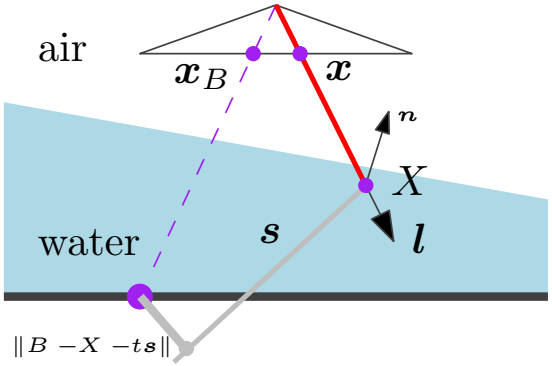
Optimisation



Algorithm

Initialize: set $\boldsymbol{d}$ with our initialization procedure.

Optimisation

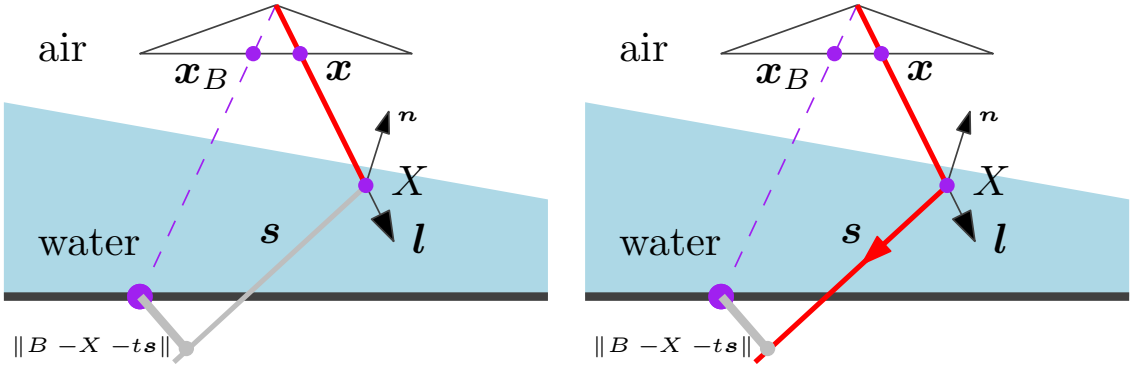


Algorithm

Initialize: set $\boldsymbol{d}$ with our initialization procedure.

Calculate point cloud X and normals $\boldsymbol{n}$ from $\boldsymbol{d}$

Optimisation



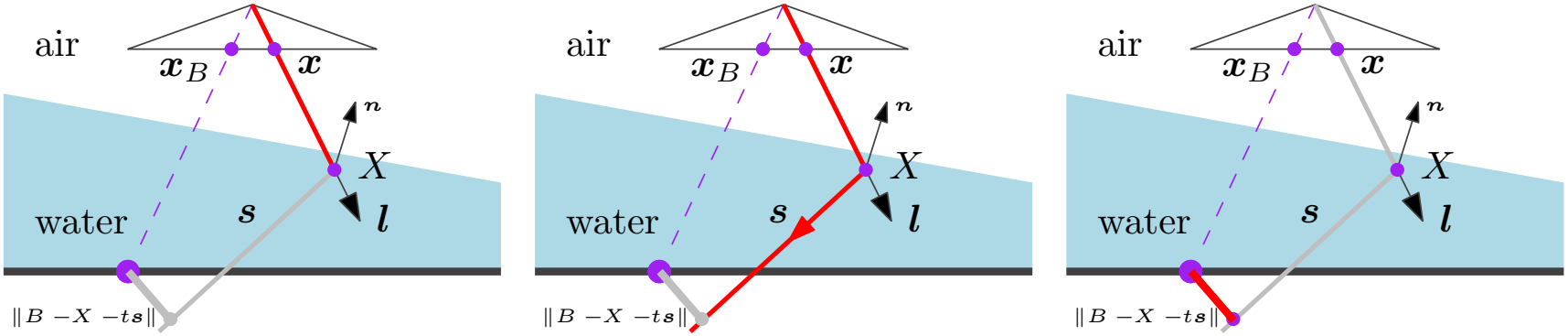
Algorithm

Initialize: set $\boldsymbol{d}$ with our initialization procedure.

Calculate point cloud X and normals $\boldsymbol{n}$ from $\boldsymbol{d}$

Reconstruct light path by calculating $\boldsymbol{s}$ from Snell's law.

Optimisation



Algorithm

Initialize: set $\boldsymbol{d}$ with our initialization procedure.

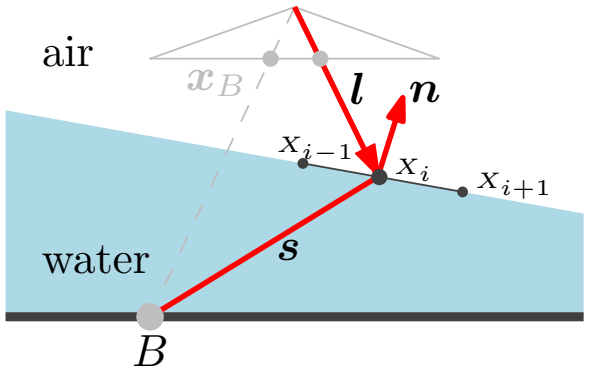
Calculate point cloud X and normals $\boldsymbol{n}$ from $\boldsymbol{d}$

Reconstruct light path by calculating $\boldsymbol{s}$ from Snell's law.

Optimize $\boldsymbol{d}$ s.t. it minimizes the $\|B - X - t\boldsymbol{s}\|_2$

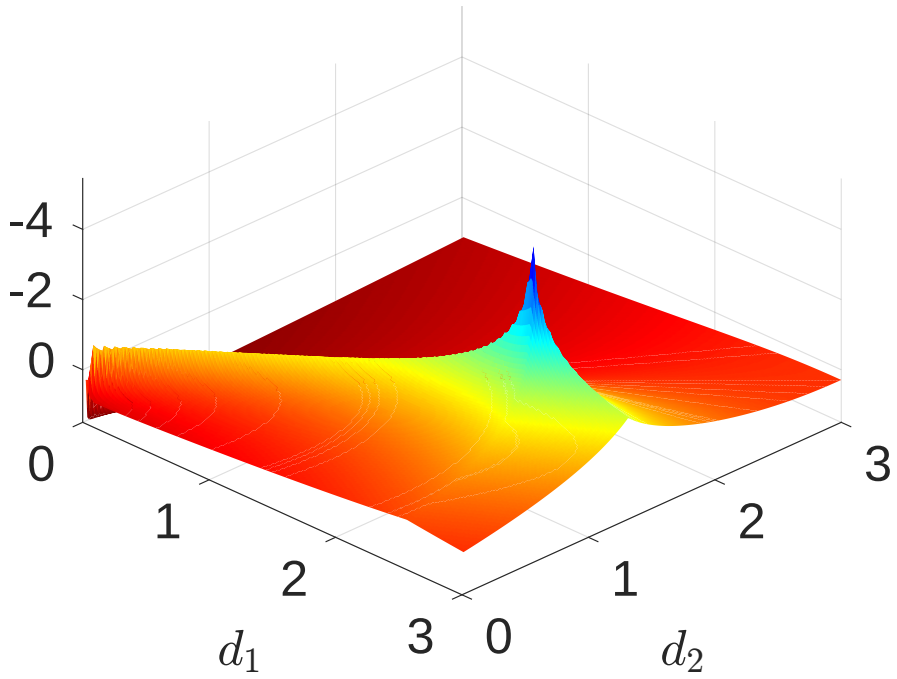
Surface Normals

- $\boldsymbol{n}$ has 3 DOF.
- We do not directly optimize normals.
- We optimize $\boldsymbol{d}$, normals are implicit.



- $\boldsymbol{n}_i$ of a point X_i is determined by adjacent points (X_{i-1}, X_{i+1}).
- When we optimise the entire surface, we can get $\boldsymbol{n}$.

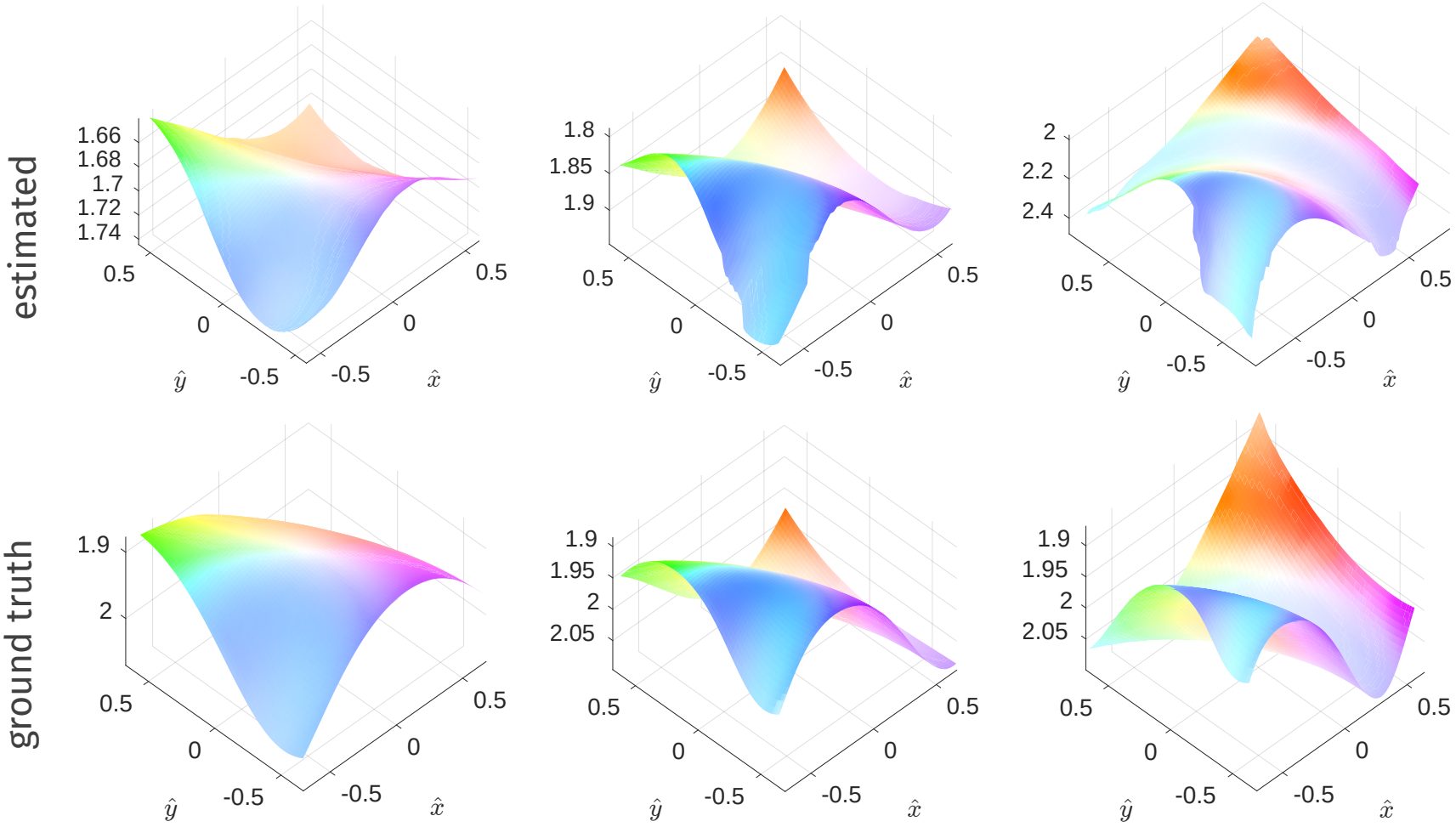
Joint Optimisation of the Entire Surface



$d_1 = 2.5, d_2 = 1.5$

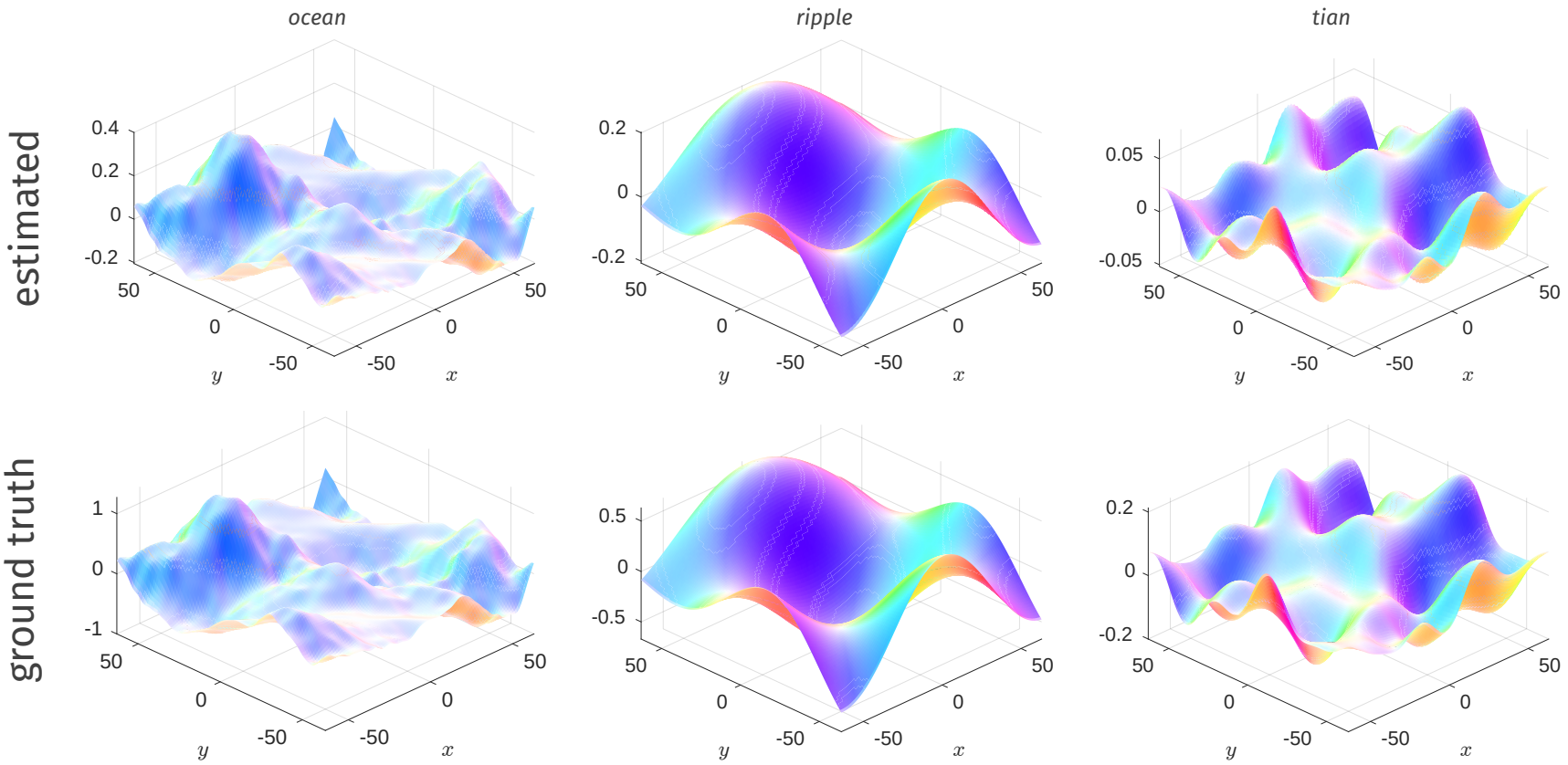
- We optimize ***d***, but normals are used to estimate direction ***s***.
- ***n*** is connected to other points (via surface derivatives).
- ***d*** is optimized via normals, it is **insensitive** to scaling.

Synthetic Results - *wave1* - complex background



Ours		4 views - Qian et. al.	
RMSE	MAE	RMSE	MAE
0.14	6.06°	**0.014**	**4°**

Synthetic Results - Ortographic Projection



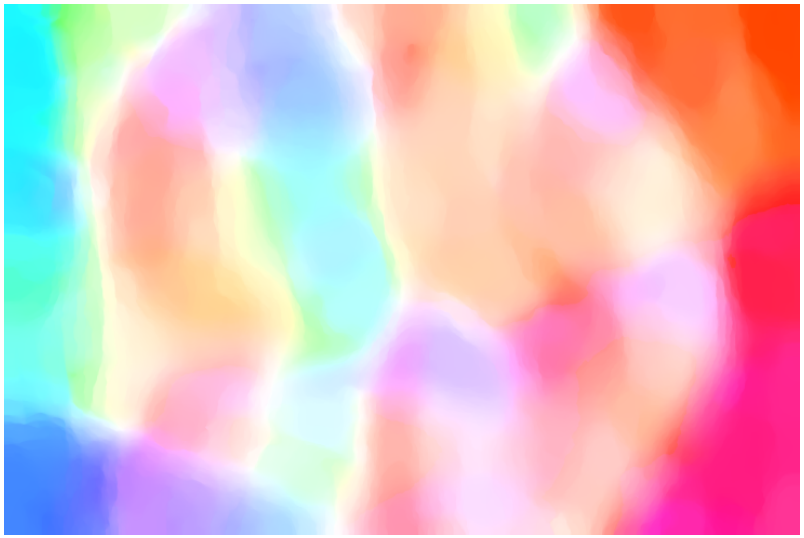
	Ours		Single frame - Thapa et. al.	
	RMSE	MAE	RMSE	MAE
ocean	**0.230**	1.301°	0.262	NA
ripple	**0.217**	0.649°		
tian	**0.248**	1.364°		

Real World Experiment - Background Image

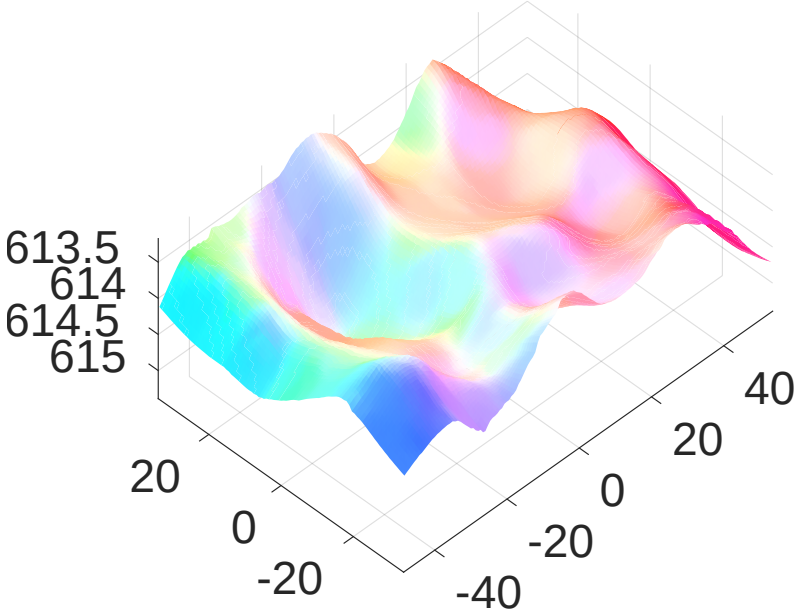
Real World Experiment - Refracted Image

Real World Experiment - Results

Optical Flow



Estimated Surface



Code and data are available at:
https://github.com/sulcantonin/SfR-BMVC21.git