3D RECONSTRUCTION

Real-time 3D reconstruction in-door scene
using moving Kinect

Jiakai Zhang, Hao Liu, YuXu

Reconstruction method

- Reconstruction from images
- Reconstruction from video

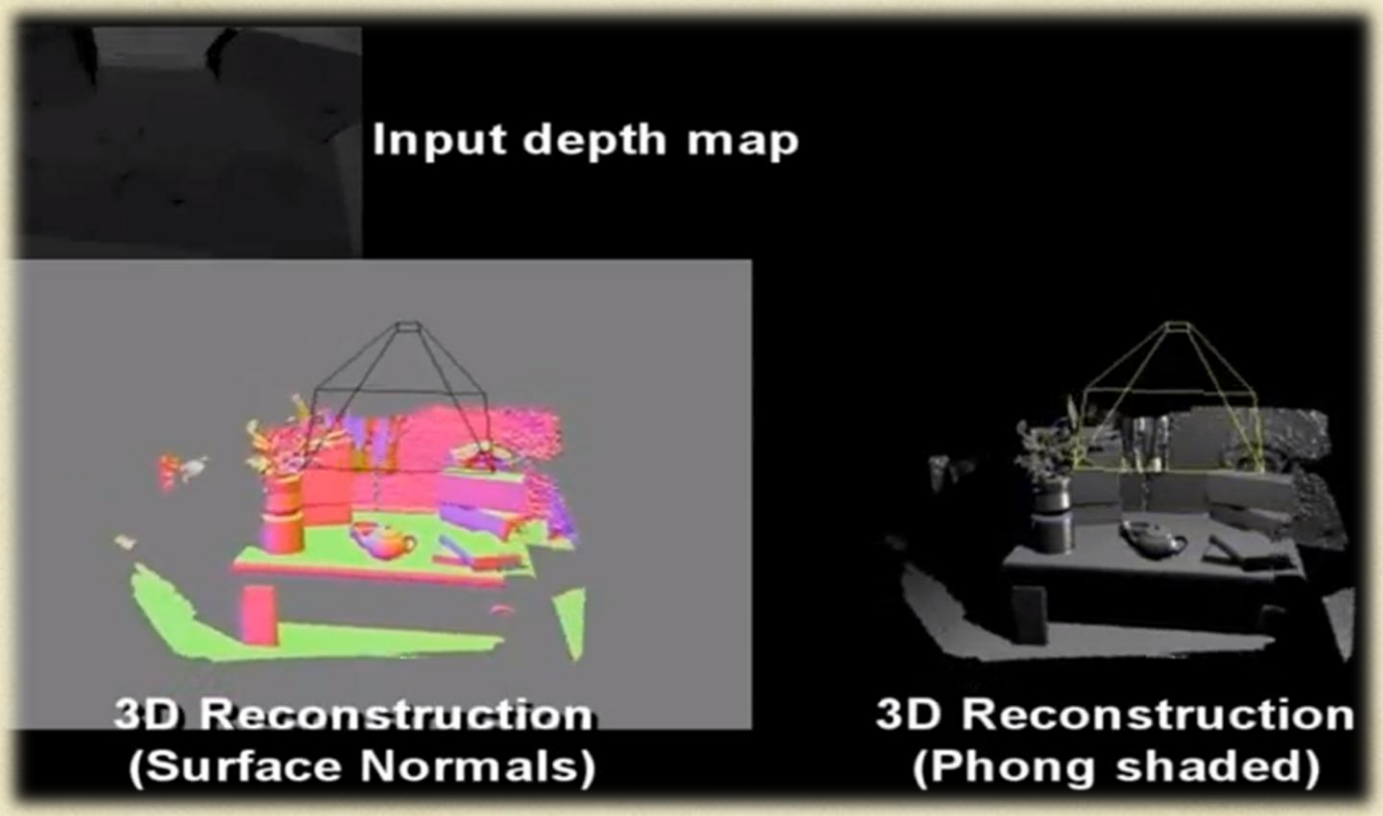
Using Kinect

Raw Depth Image

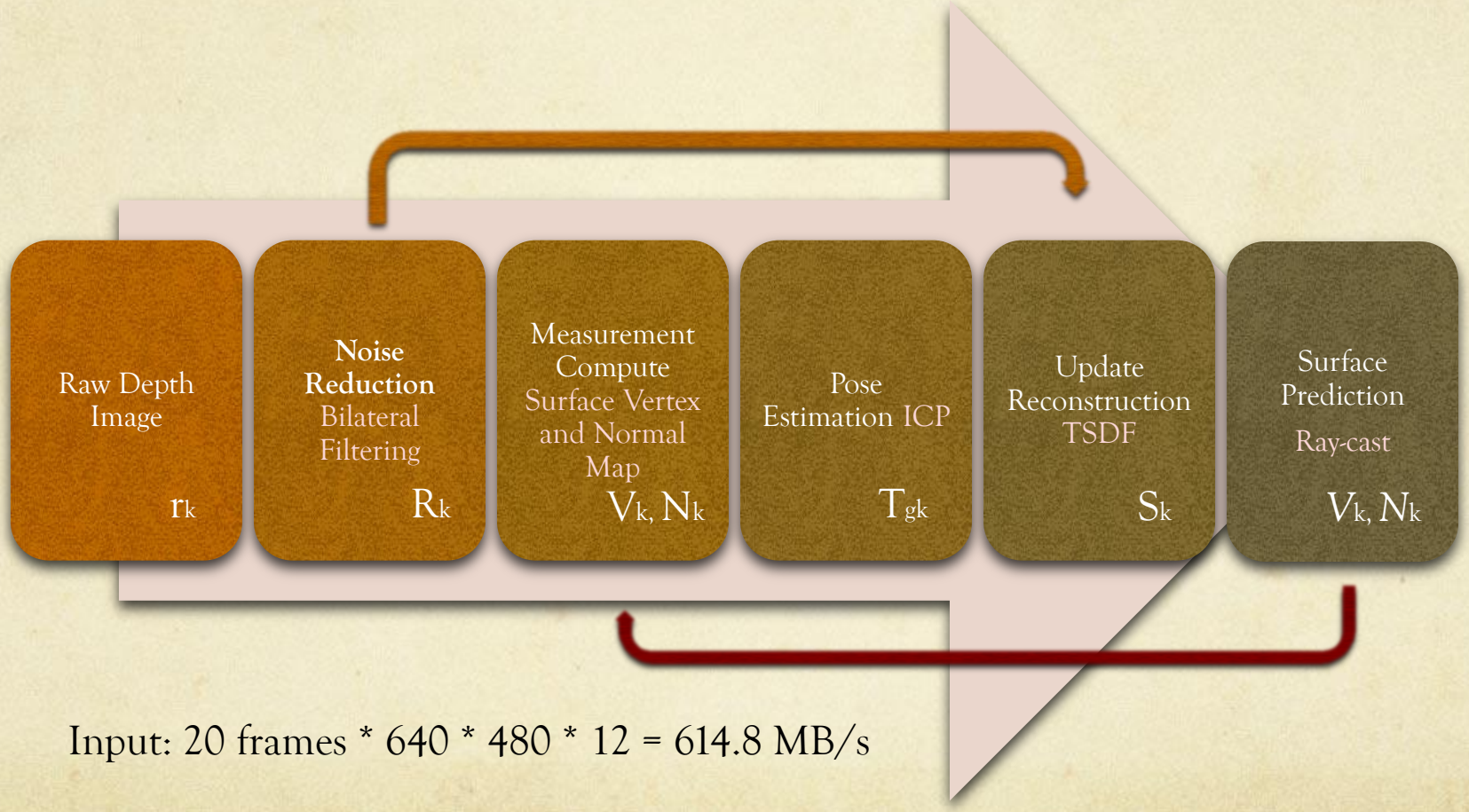
- Infrared laser projector
- Monochrome CMOS sensor

Demo
Kinect Raw data

Real-time Reconstruction

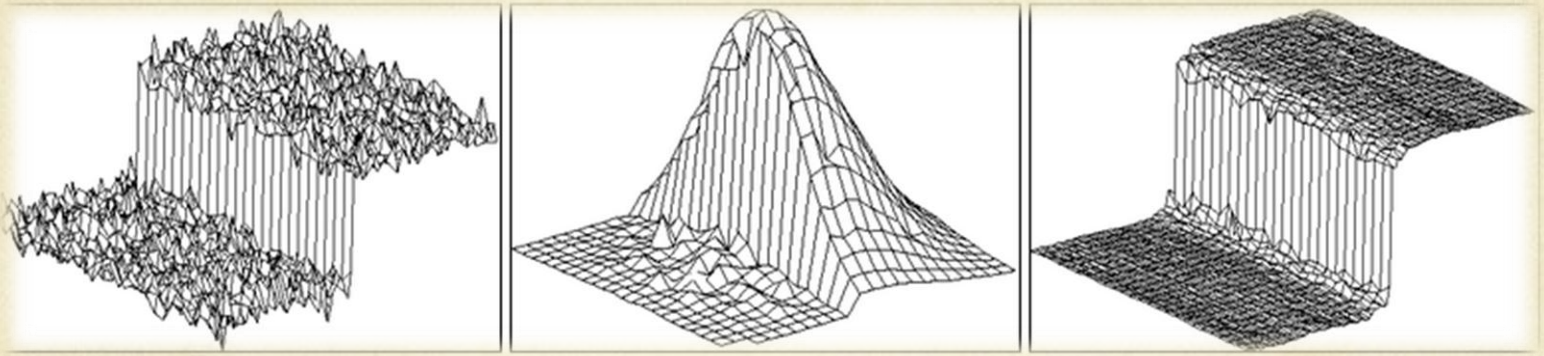


Pipeline



Input: 20 frames * 640 * 480 * 12 = 614.8 MB/s

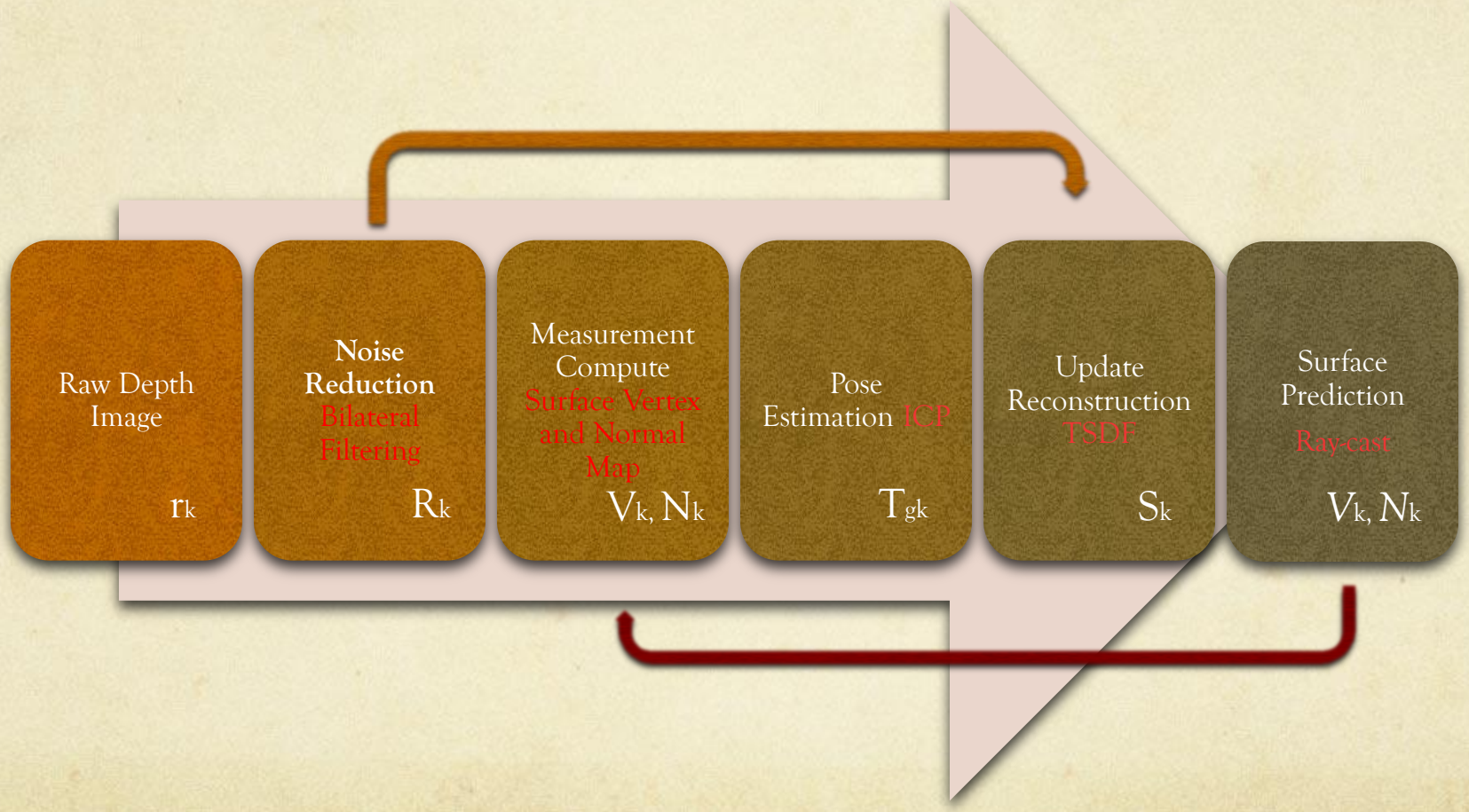
Bilateral Filtering



- $$\mathbf{h}(\mathbf{x}) = k^{-1} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \mathbf{f}(\xi) c(\xi - \mathbf{x}) s(\mathbf{f}(\xi) - \mathbf{f}(\mathbf{x})) d\xi$$

Demo

Pipeline


Raw Depth Image
r_k
Noise Reduction
Bilateral Filtering
R_k
Measurement Compute
Surface Vertex and Normal Map
V_k, N_k
Pose Estimation ICP
T_{gk}
Update Reconstruction
TSDF
S_k
Surface Prediction
Ray-cast
V_k, N_k

ICP 3D shape alignment

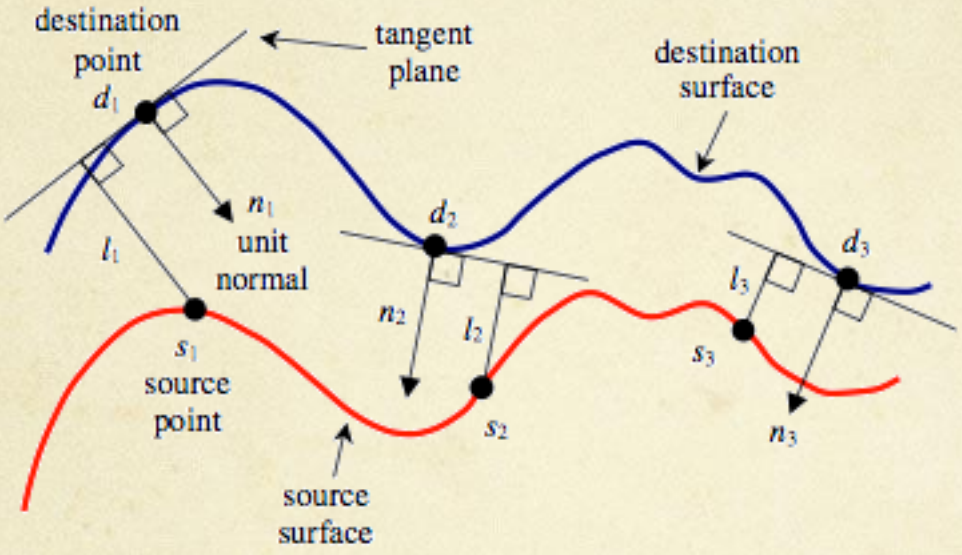


***Figure 1**: Point-to-plane error between two surfaces.*

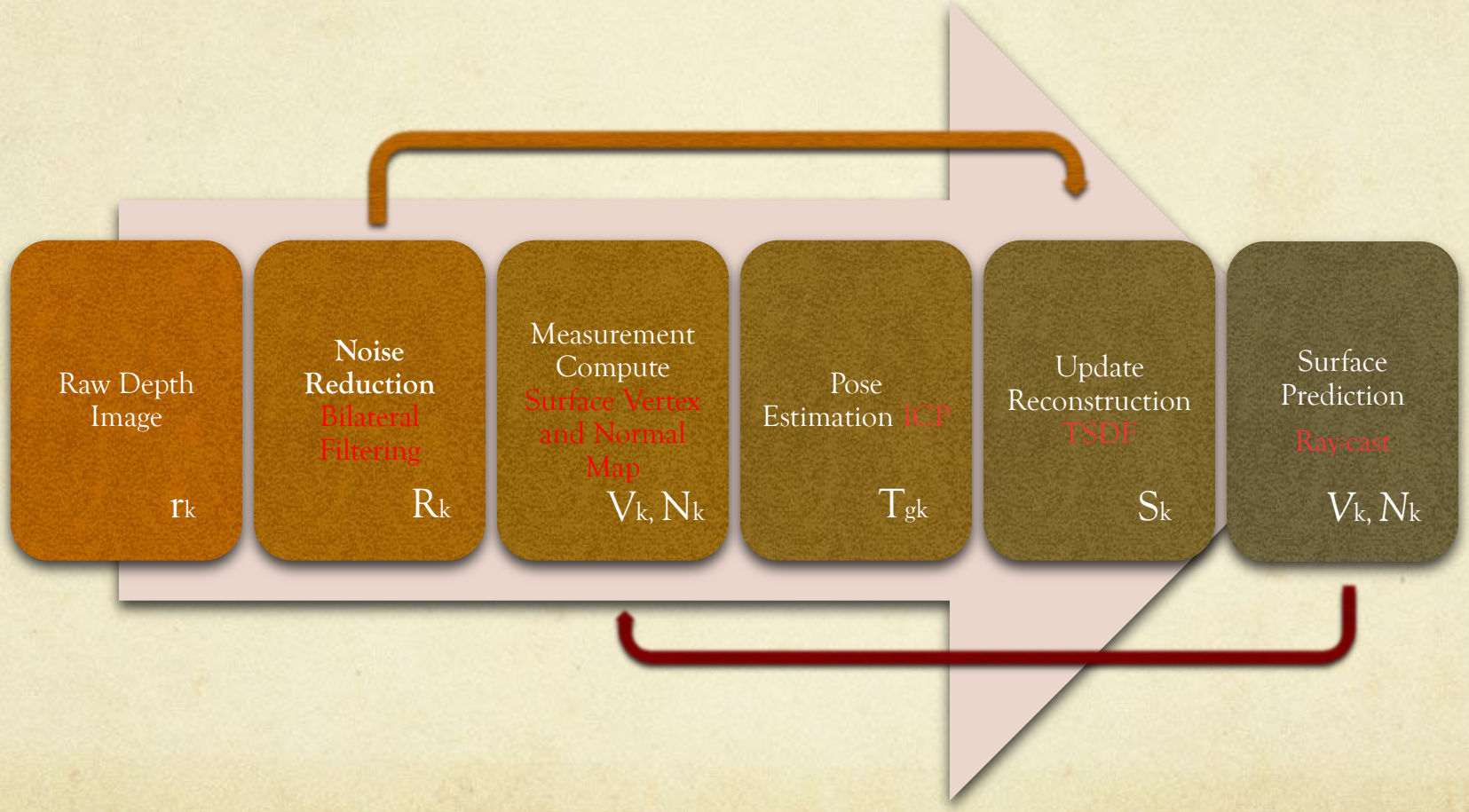
$$\hat{\mathbf{M}} = \mathbf{T}(t_x, t_y, t_z) \cdot \hat{\mathbf{R}}(\alpha, \beta, \gamma) = \begin{pmatrix} 1 & -\gamma & \beta & t_x \\ \gamma & 1 & -\alpha & t_y \\ -\beta & \alpha & 1 & t_z \\ 0 & 0 & 0 & 1 \end{pmatrix}.$$

- $\mathbf{M}_{opt} = \arg\min_{\mathbf{M}} \sum_i ((\mathbf{M} \cdot \mathbf{s}_i - \mathbf{d}_i) \bullet \mathbf{n}_i)$ $\quad \mathbf{M} = \mathbf{T}(t_x, t_y, t_z) \cdot \mathbf{R}(\alpha, \beta, \gamma)$
- $\min_{\hat{\mathbf{M}}} \sum_i ((\hat{\mathbf{M}} \cdot \mathbf{s}_i - \mathbf{d}_i) \bullet \mathbf{n}_i)^2 = \min_{\mathbf{x}} |\mathbf{A}\mathbf{x} - \mathbf{b}|^2.$ ➡ SVD

ICP 3D shape alignment

Demo

Pipeline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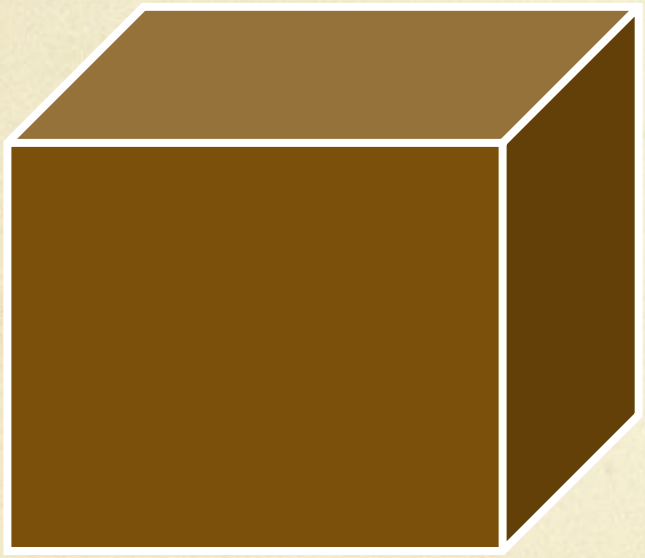
TSDF

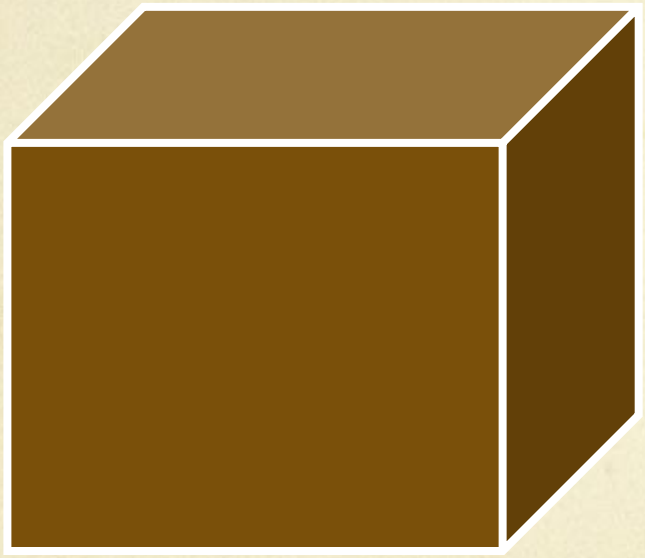


T S D F

- Signed Distance Function

The value in the cube corresponds to the signed distance to the closest zero crossing(surface).

TSDF

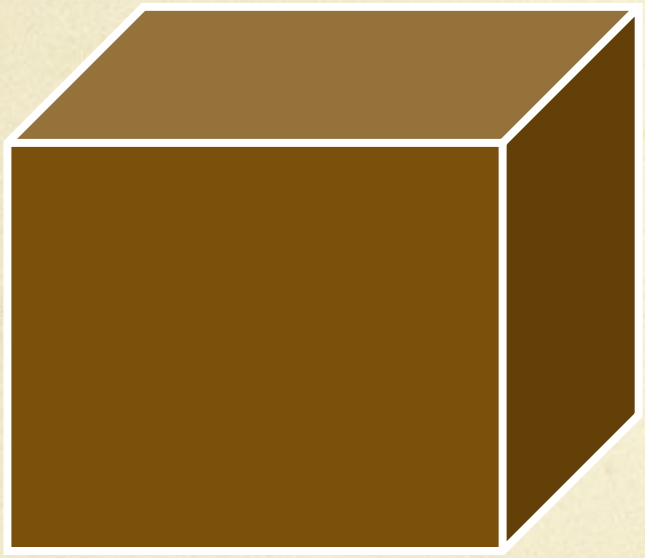


T S D F

- Signed Distance Function
- Truncated Signed Distance Function

$$
\begin{aligned}
F_{R_k}(\mathbf{p}) &= \Psi\left(\lambda^{-1}\|(\mathbf{t}_{g,k} - \mathbf{p}\|_2 - R_k(\mathbf{x})\right), \\
\lambda &= \|K^{-1}\dot{\mathbf{x}}\|_2, \\
\mathbf{x} &= \left\lfloor \pi\left(K T_{g,k}^{-1}\mathbf{p}\right)\right\rfloor, \\
\Psi(\eta) &= \begin{cases} \min\left(1, \frac{\eta}{\mu}\right)\operatorname{sgn}(\eta) & \text{iff } \eta \geq -\mu \\ \textit{null} & \textit{otherwise} \end{cases}
\end{aligned}
$$

TSDF



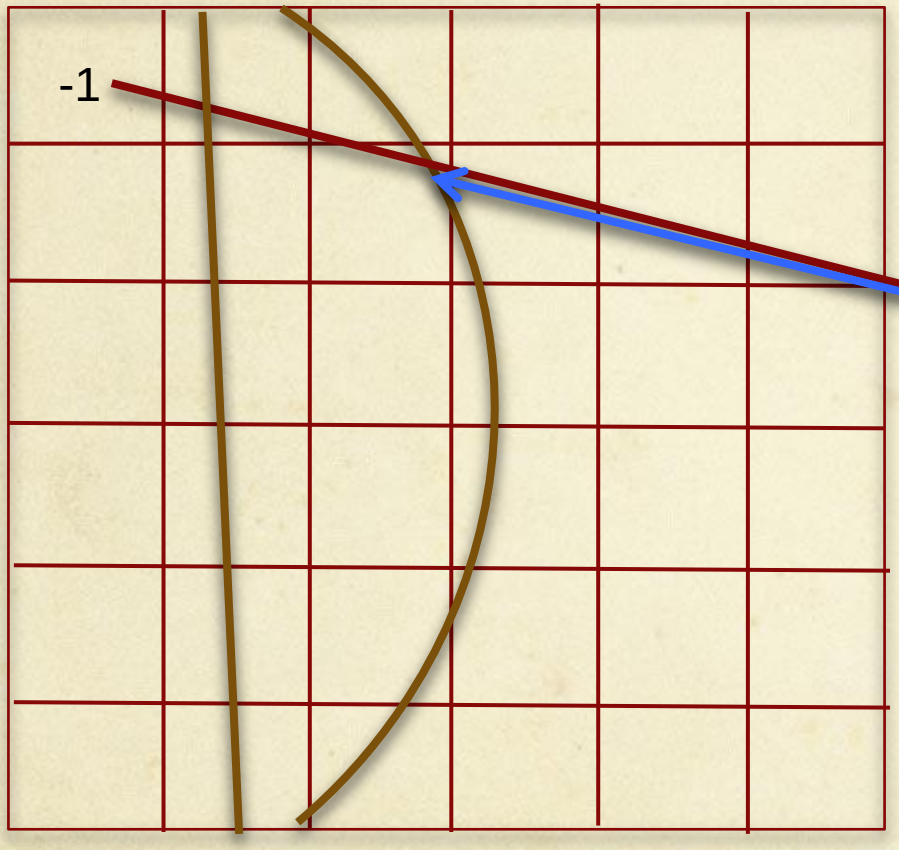
T S D F

- Signed Distance Function
- Truncated Signed Distance Function
- Integrate the cubes from different position.

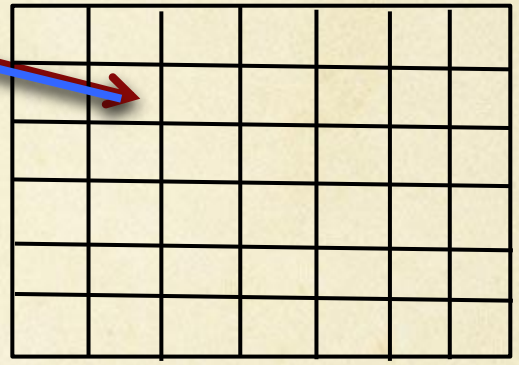
$$F_k(\mathbf{p}) = \frac{W_{k-1}(\mathbf{p})F_{k-1}(\mathbf{p}) + W_{R_k}(\mathbf{p})F_{R_k}(\mathbf{p})}{W_{k-1}(\mathbf{p}) + W_{R_k}(\mathbf{p})}$$

$$W_k(\mathbf{p}) = W_{k-1}(\mathbf{p}) + W_{R_k}(\mathbf{p})$$

TSDF

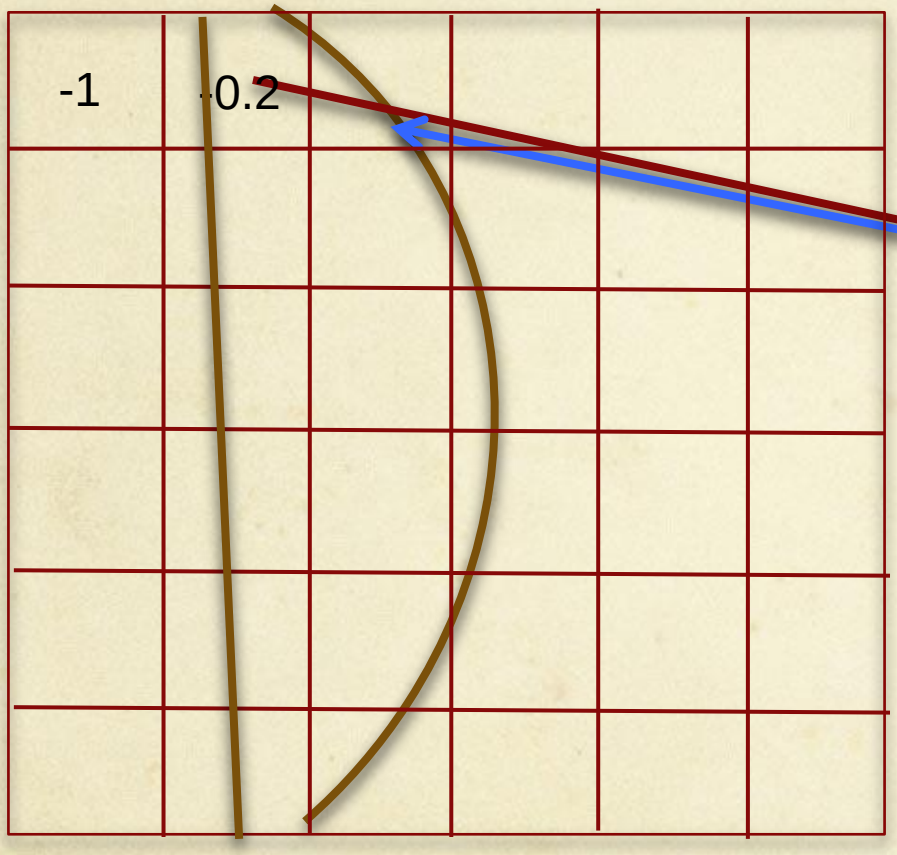


2D Sample

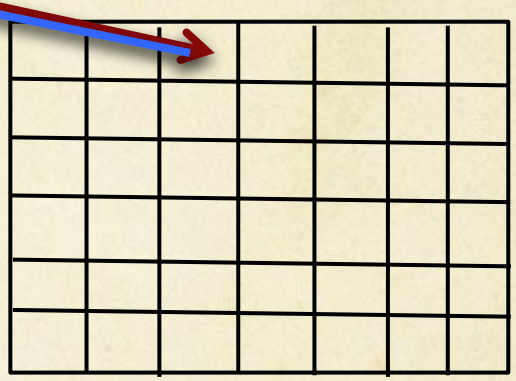


Depth Map from Kinect

TSDF



2D Sample



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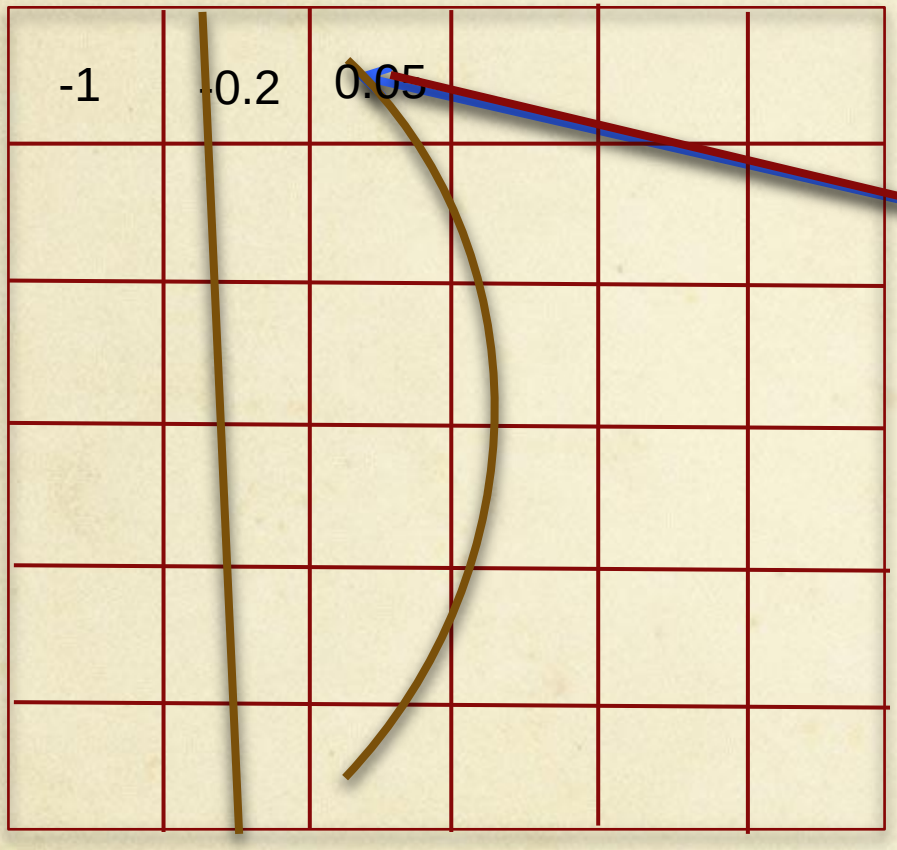
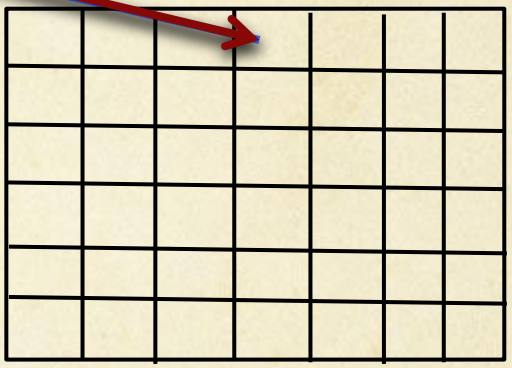
TSDF



2D Sample



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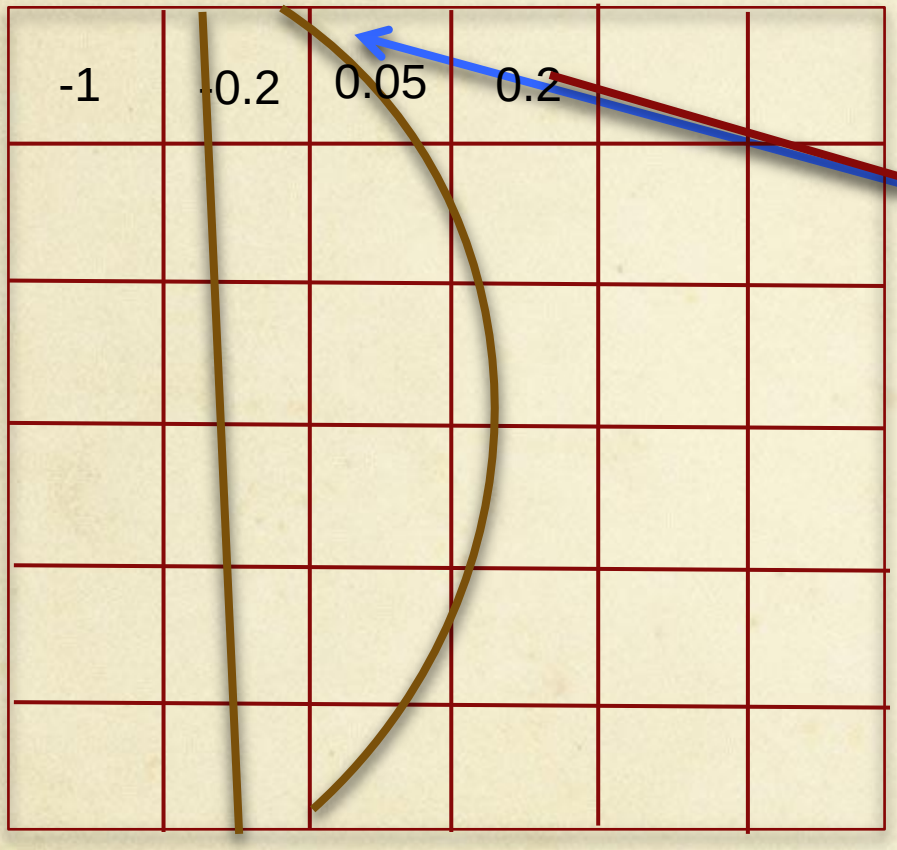
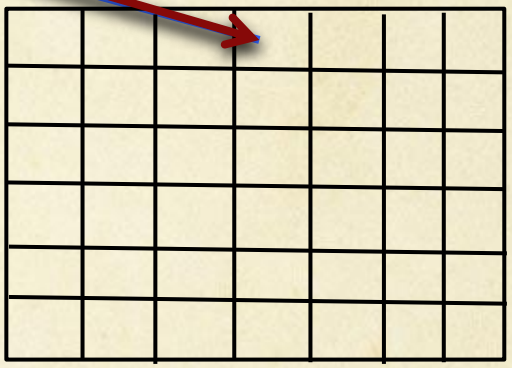
TSDF

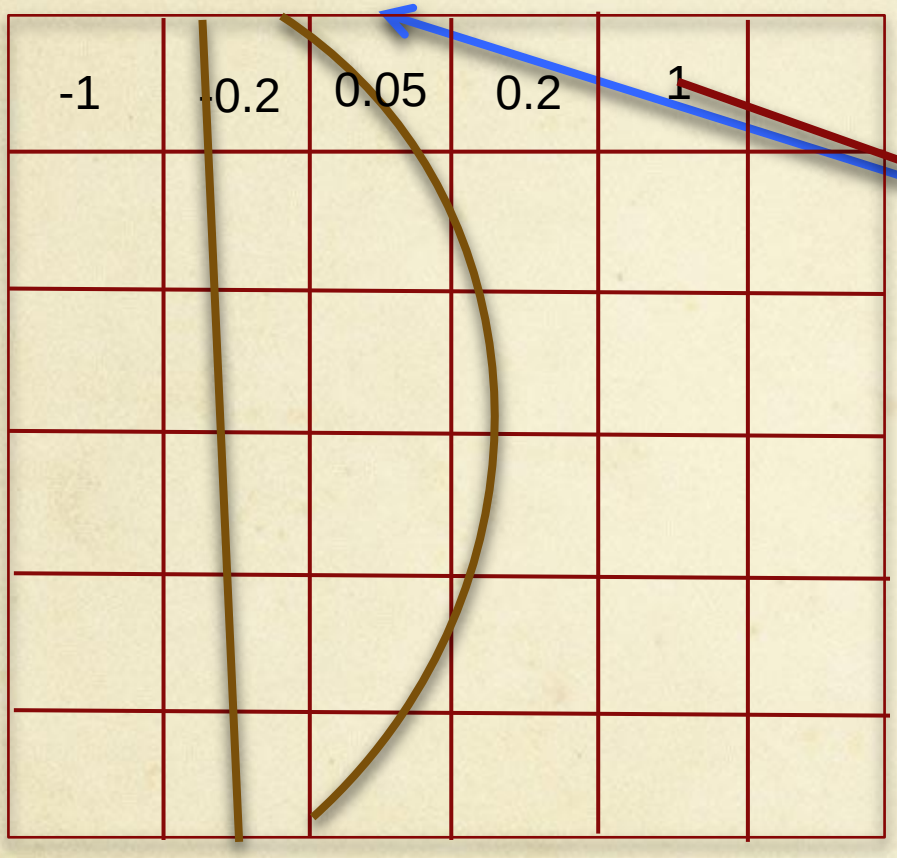


2D Sample

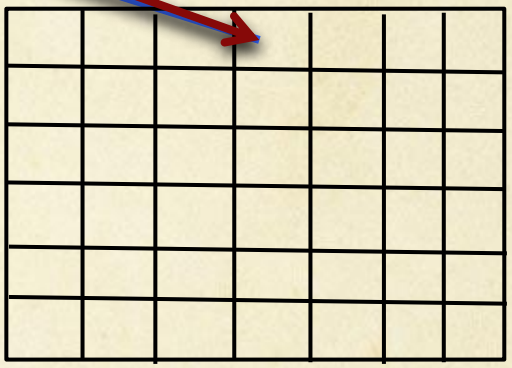


Depth Map from Kinect

TSDF



2D Sample



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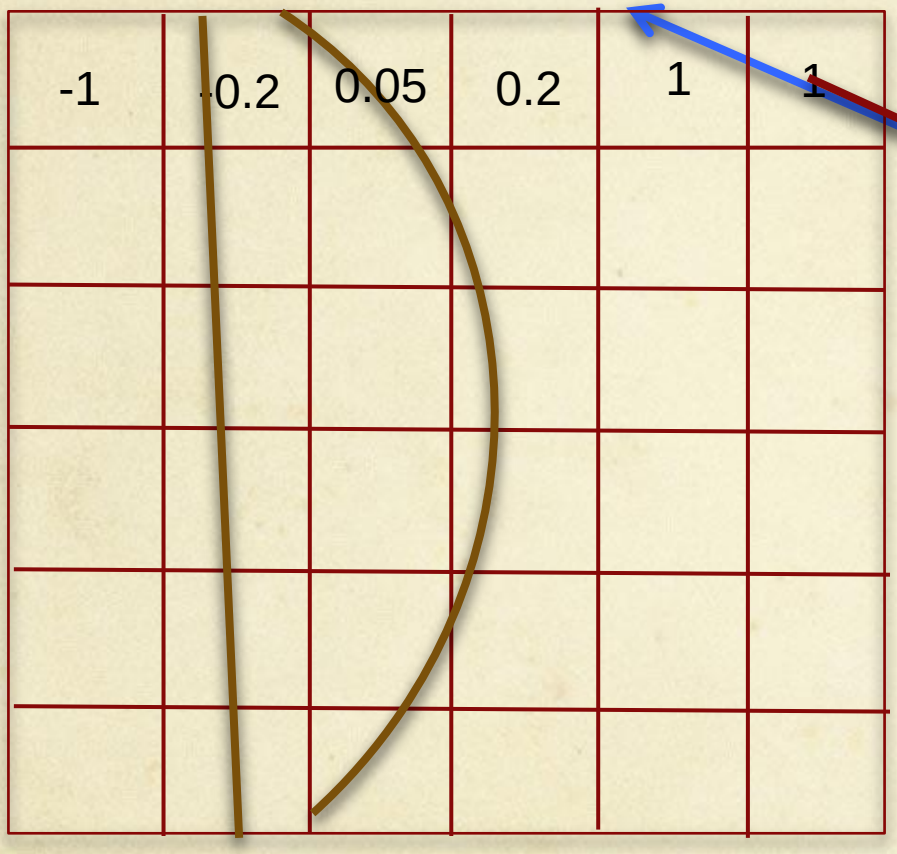

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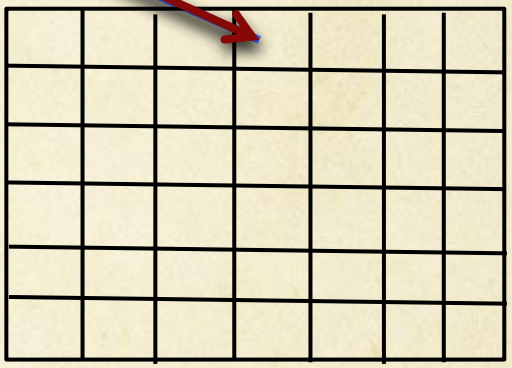

Depth Map from Kinect

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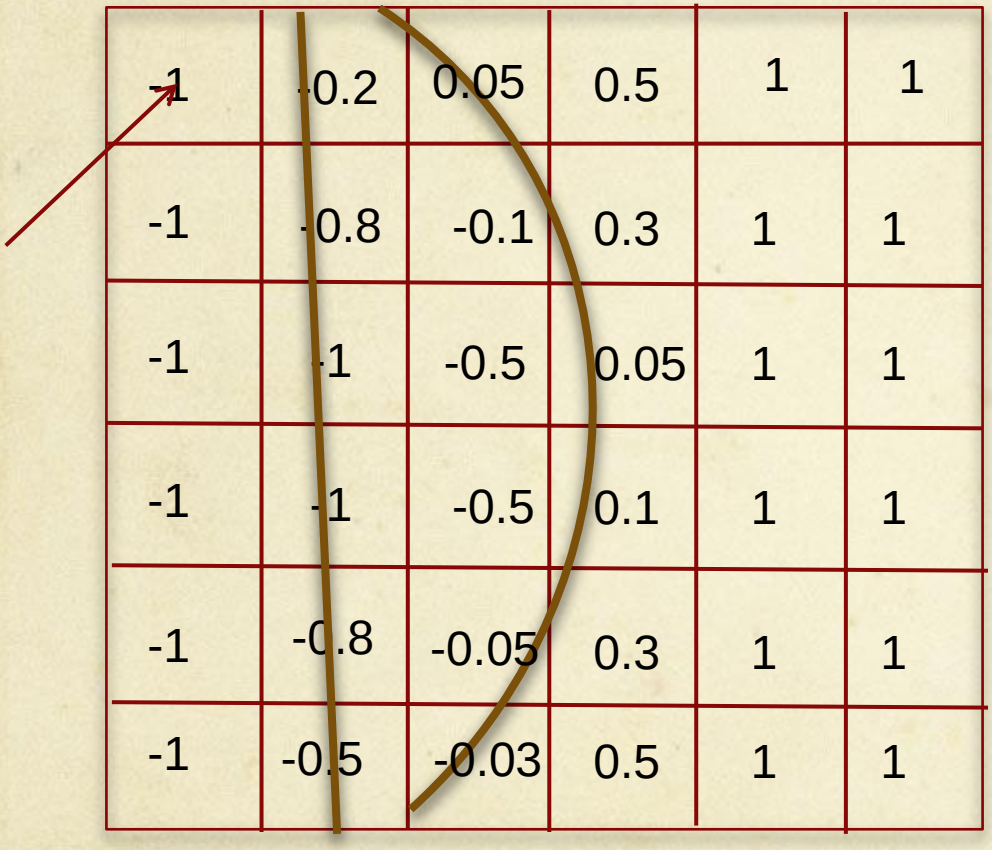
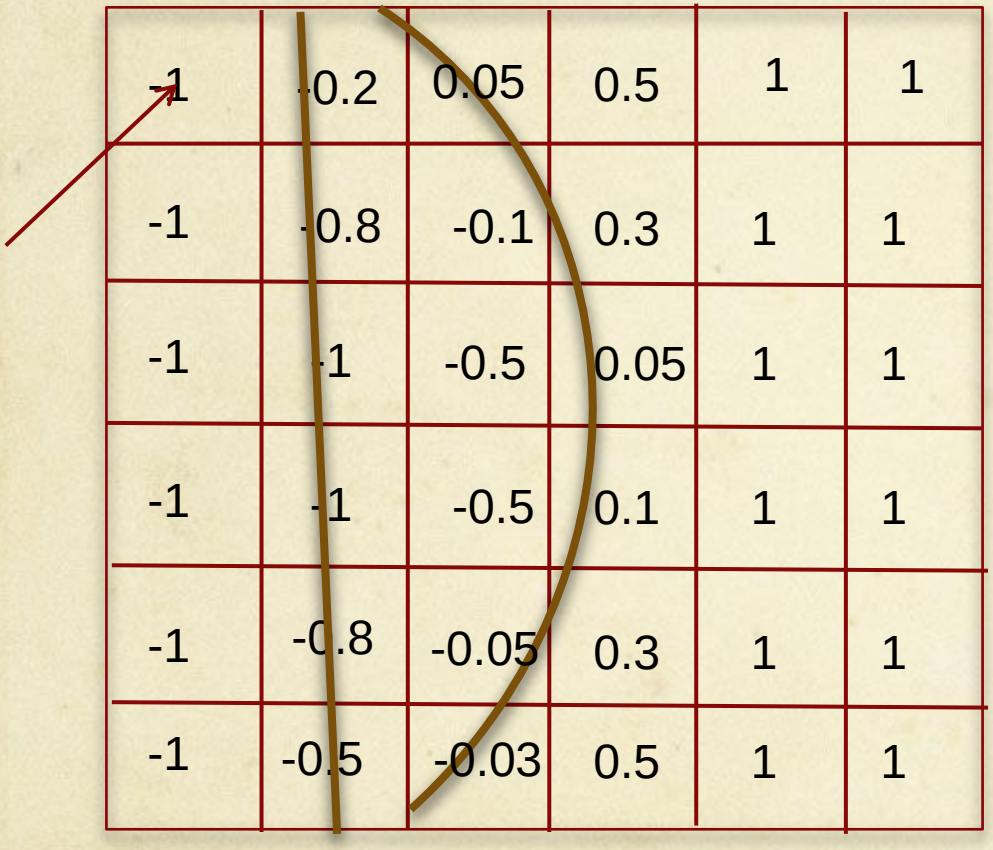


-1	-0.2	0.05	0.5	1	1
-1	-0.8	-0.1	0.3	1	1
-1	-1	-0.5	0.05	1	1
-1	-1	-0.5	0.1	1	1
-1	-0.8	-0.05	0.3	1	1
-1	-0.5	-0.03	0.5	1	1

Integration

- We have depth maps from different camera positions, how can we integrate them together ?
- Integration? or update?
- Weighted? or add up?
- What makes integration possible ?

TSDF



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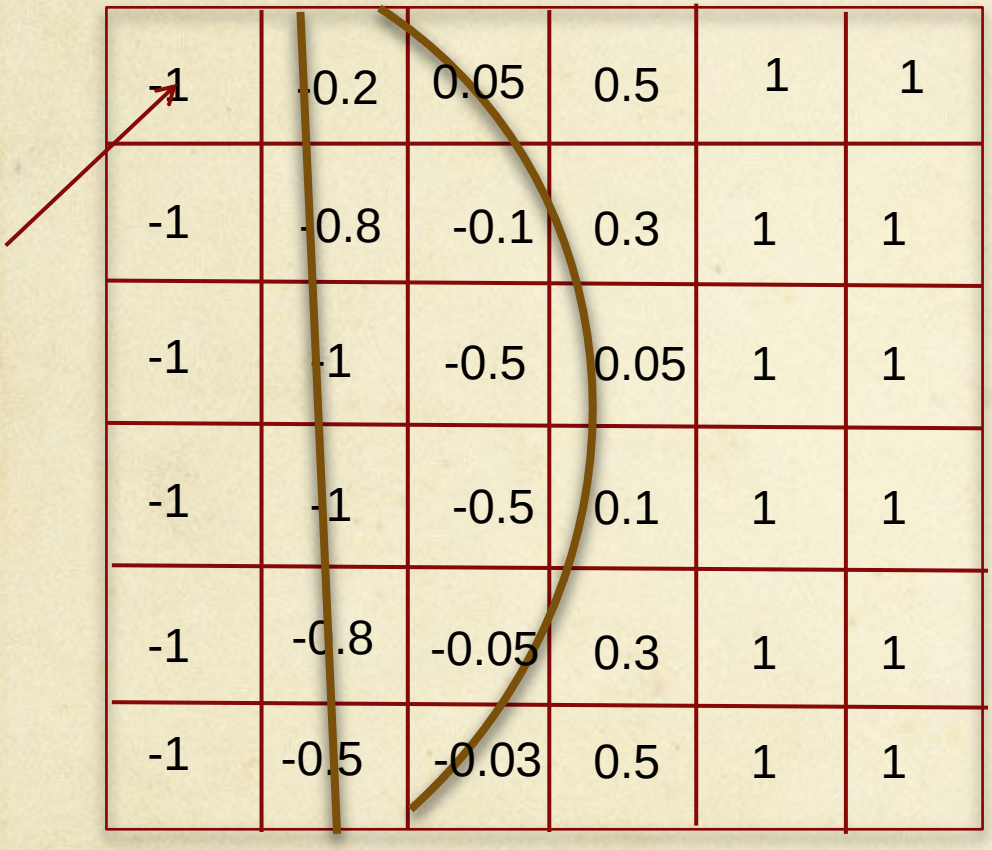

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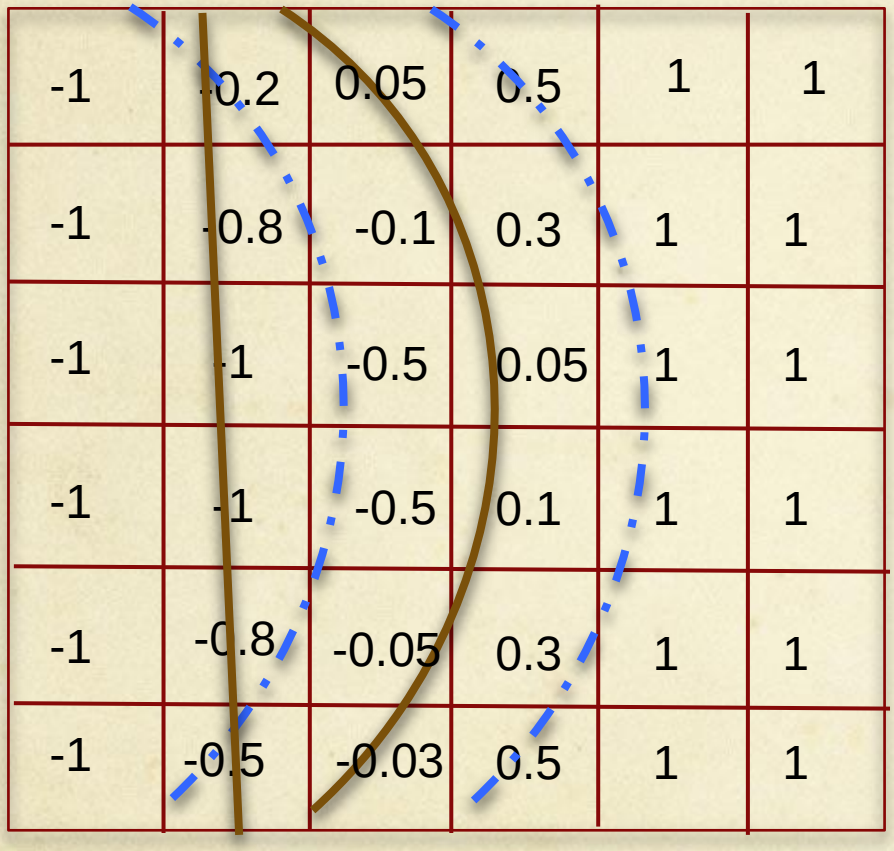
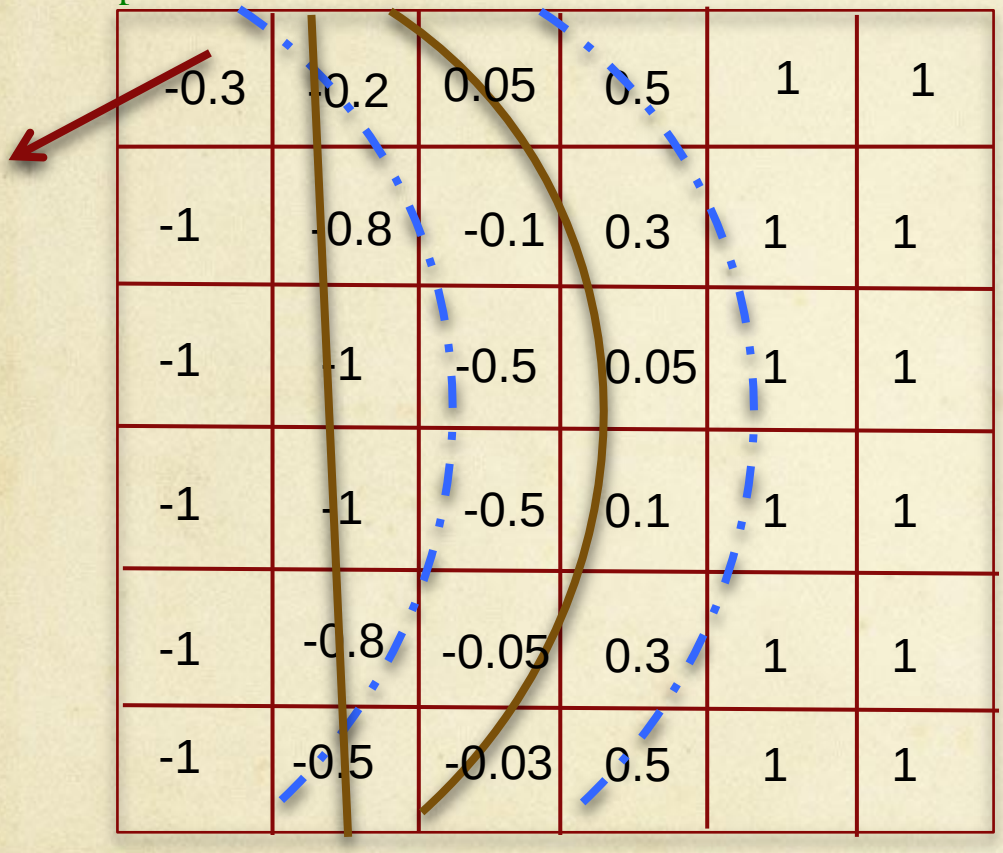


TRUNCATION

- To get the surface behind the surface. The camera is moving!
- Only part of distance data is needed, so we can truncate the distance.

TSDF

1 time update !

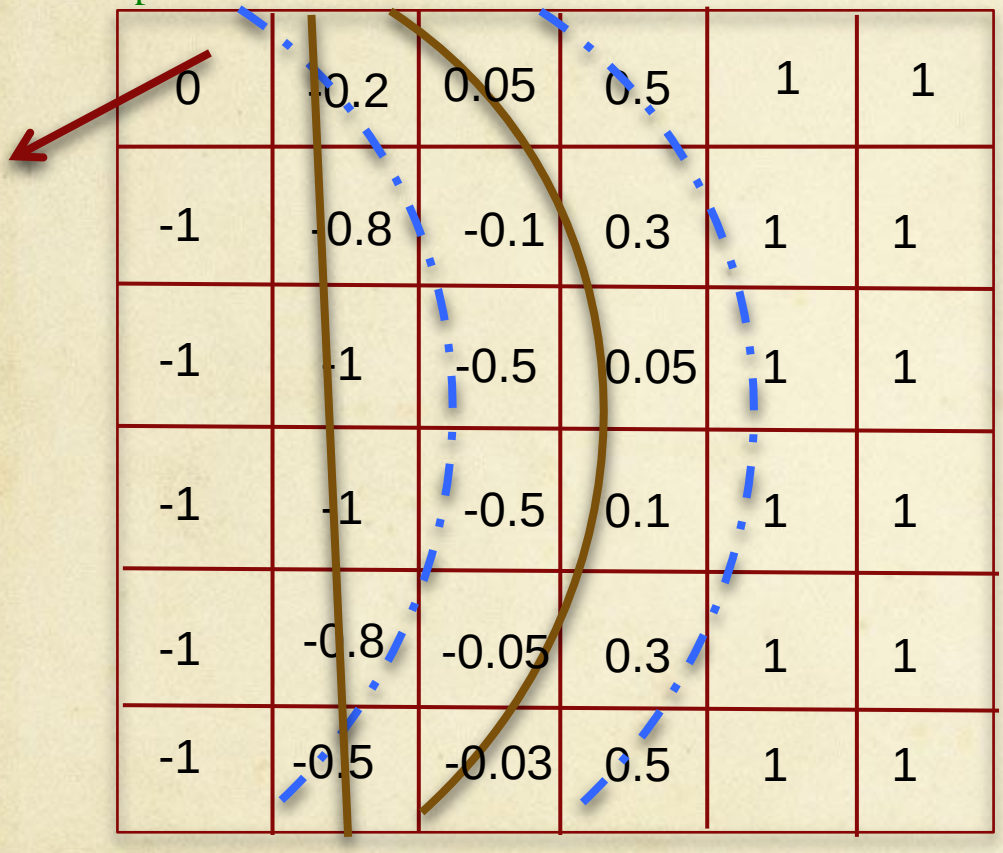


TRUNCATION

- To get the surface behind the surface. The camera is moving!
- Only part of distance data is needed to represent the object, so we can truncate the distance.

TSDF

2 times update !

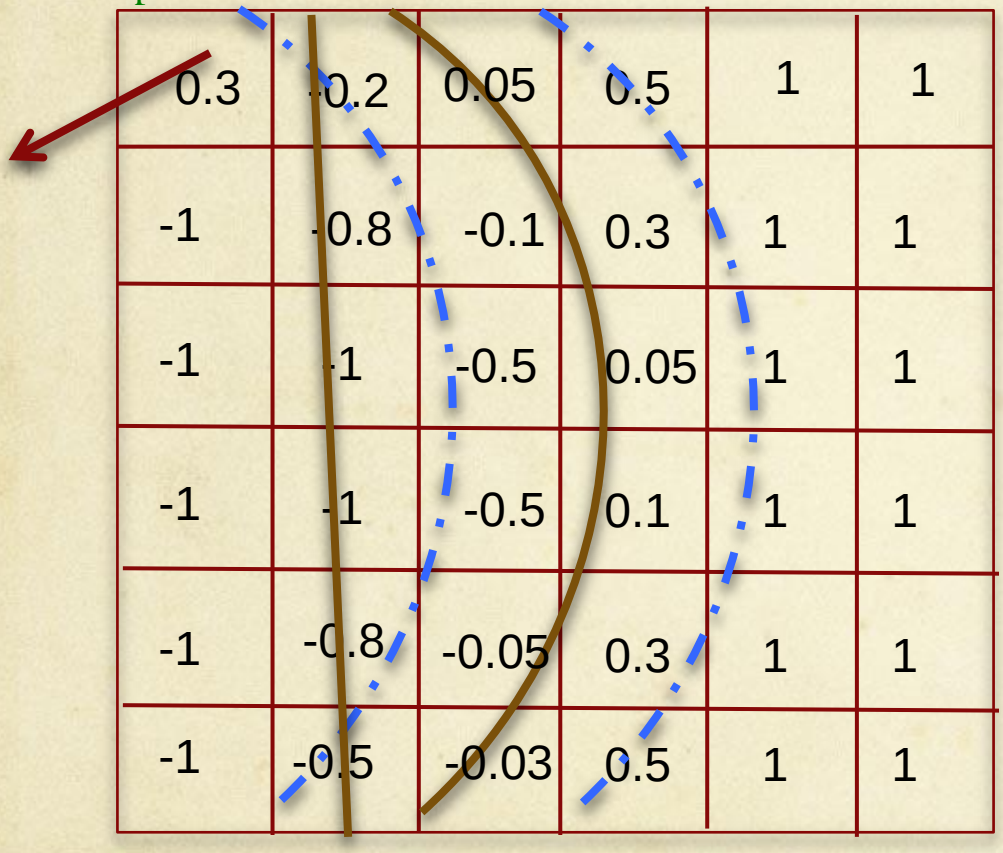


TRUNCATION

- To get the surface behind the surface. The camera is moving!
- Only part of distance data is needed to represent the object, so we can truncate the distance.

TSDF

3 times update !



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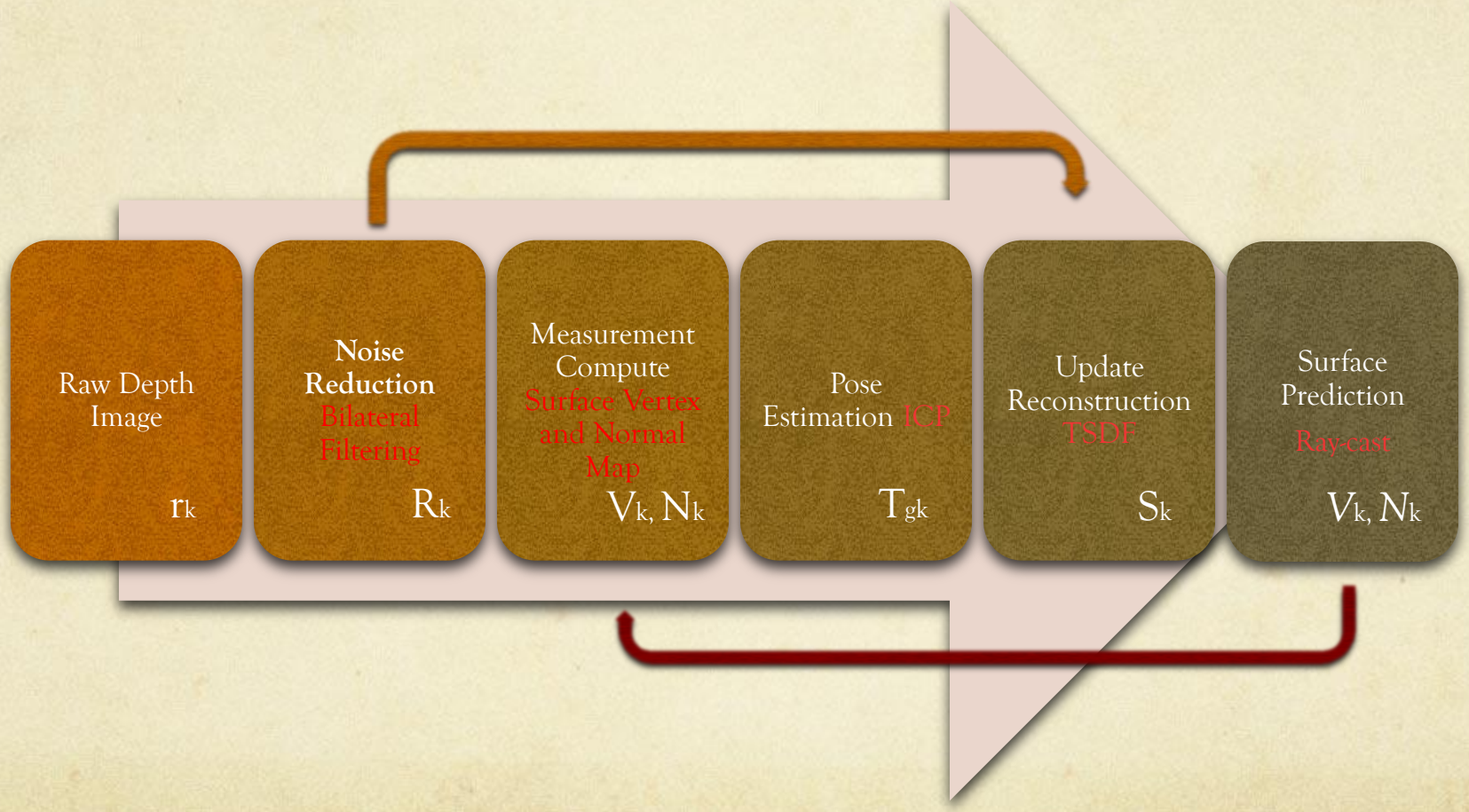
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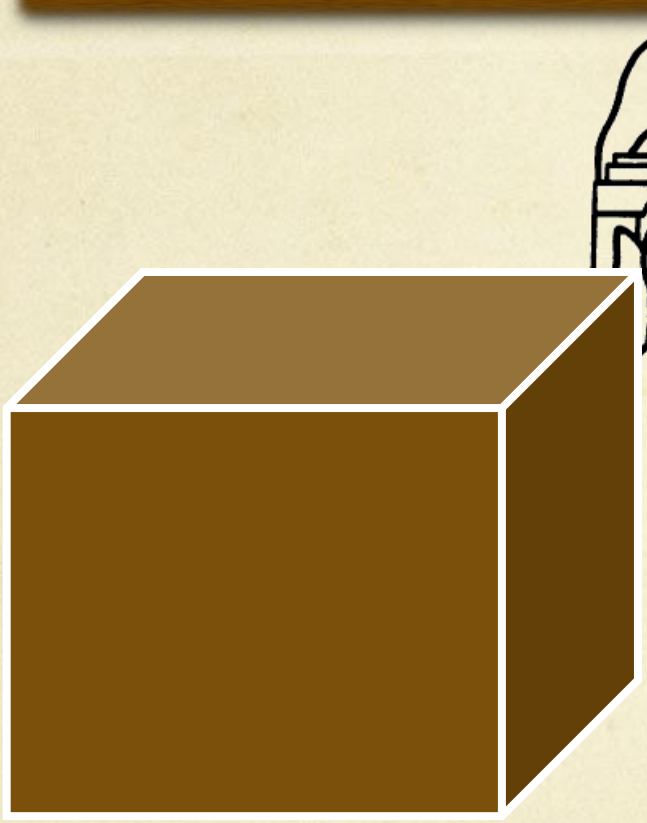
RAY CASTING



RAY CASTING

- Cast only, no chasing.
- Transfer the TSDF cube in to some thing the computer can understand, Vertex fusion.
- Take a photo using X-ray.

RAY CASTING

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-1	-0.8	-0.1	0.3	1	1
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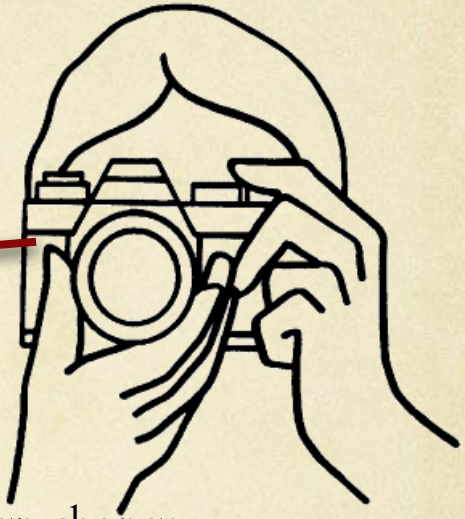
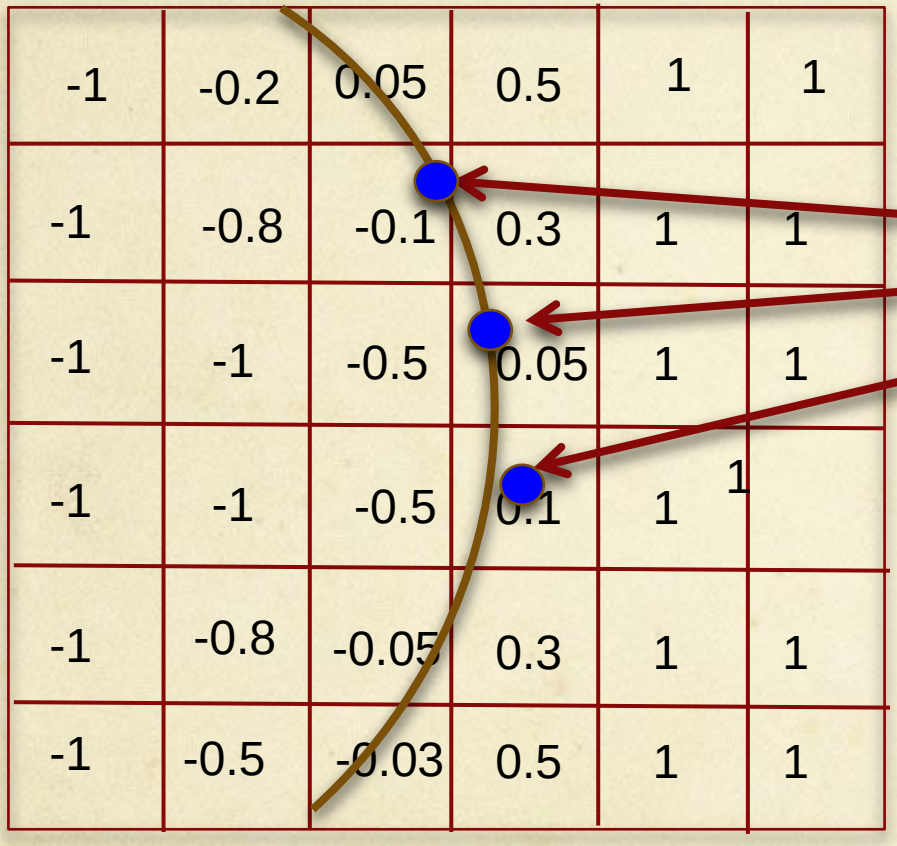
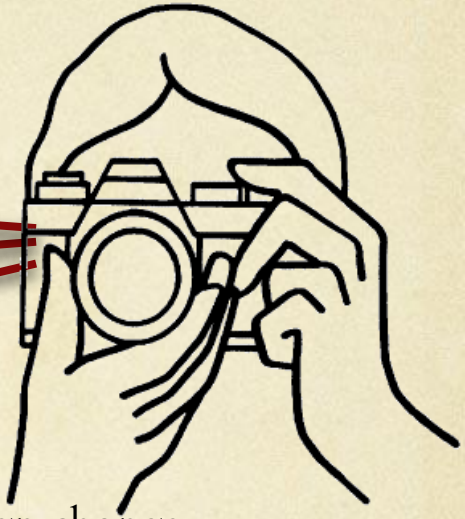


- Detect the sign change.
- Two scales search
- Linear regression

RAY CASTING





- Detect the sign change.
- Two scales search
- Linear regression
- Normal Vectors

Real-time Reconstruction

Demo

Reference

[1] KinectFusion: Real-Time Dense Surface Mapping and Tracking. *Microsoft Research*

[2] B. Curless and M. Levoy. A volumetric method for building complex models from range images.

[3] M. Harris, S. Sengupta, and J. D. Owens. Parallel prefix sum (scan) with CUDA. In H. Nguyen, editor, GPU Gems 3, chapter 39, pages 851–876. Addison Wesley, August 2007. 3.5

[4] C. Tomasi and R. Manduchi. Bilateral filtering for gray and color images. In Proceedings of the ICCV, 1998.

[5] C. Rasch and T. Satzger. Remarks on the O(N) implementation of the fast marching method.

[6] Y. Chen and G. Medioni. Object modeling by registration of multiple range images. Image and Vision Computing (IVC), 10(3):145–155,1992

[7] Kok-Lim Low Linear Least-Squares Optimization for Point-to-Plane ICP Surface Registration

Thanks !!!