Development and Application of a Description-based Interface for 3D Object Reconstruction

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Overview

Overview of Thesis

- **Taxonomy**: change the way of viewing algorithms, not from an algorithmic viewpoint, but from a problem-oriented (object-centered) viewpoint. More specifically, each algorithm is mapped to a volume of a $n-$dimensional problem space.
- **Description**: how to describe a sub-space in the $n-$dimensional problem space so that this sub-space(conditions) that an algorithm maps to is well defined;
- **Mapping**: find the mapping between each algorithm and this sub-space in the $n-$dimensional problem space.
- **Interpretation**: test the mapping using synthetic and real-world objects.

Overview

Contribution

Development of an interface for 3D reconstruction problem, which hides algorithmic details and allows users to describe conditions surrounding the problem. This description can be interpreteded so that an appropriate algorithm is chosen to reconstruction a successful result.

Contribution

This contribution is significant because:

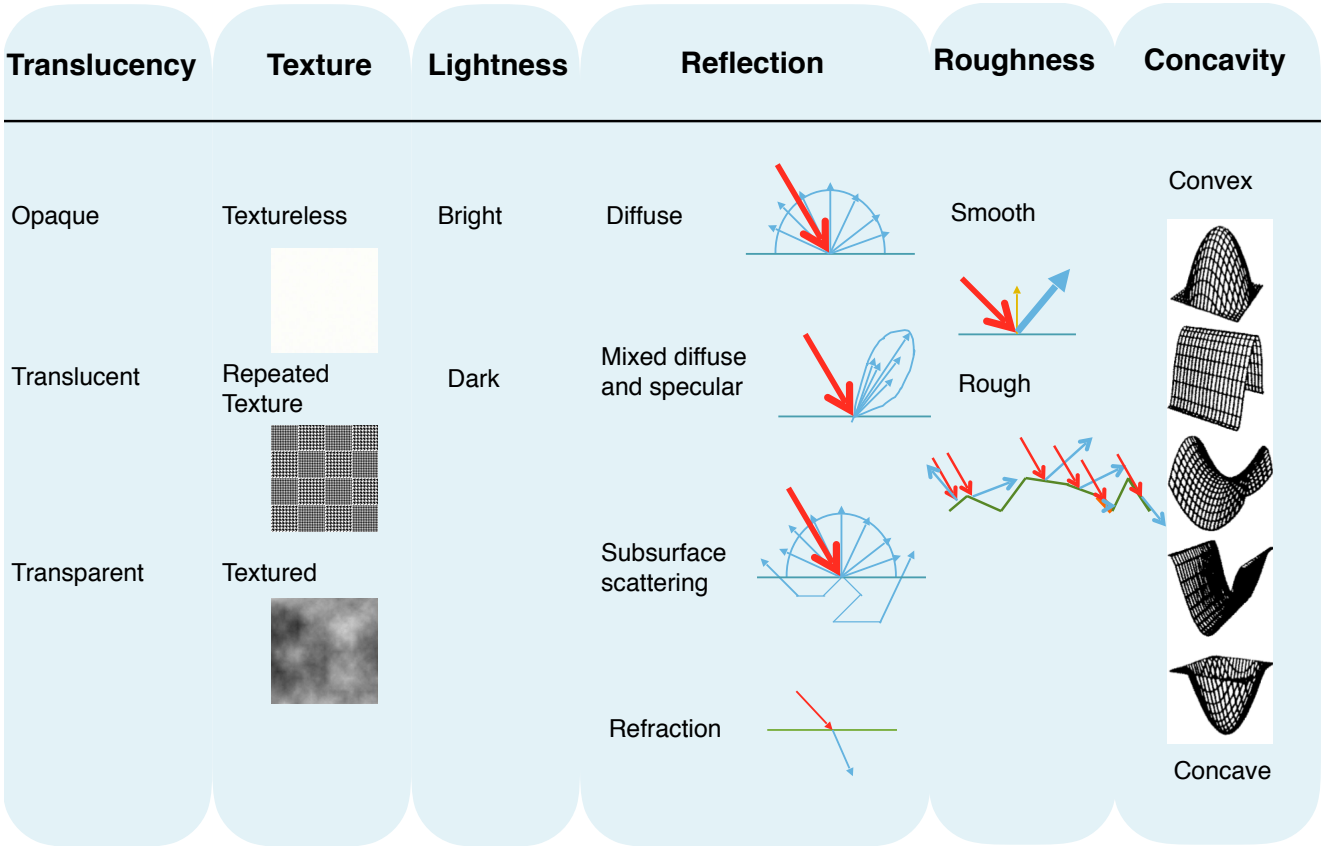
- No single algorithm can work for a diverse categories of objects. The interface, to some extent, can cover a wider range of object categories by incorporating multiple algorithms.
- An description is provides that hides the algorithmic details, thus understanding of the algorithm, or conditions to apply a specific algorithm is not a prerequisite.

Overview

Overview

Taxonomy

- *algorithm-centered* taxonomy categorizes algorithms based on algorithmic details, as discussed in **Related Work**;
- *object-centered* taxonomy categorizes algorithms based on the problem conditions that the algorithm can reliably works under.



Taxonomy (cont'd)

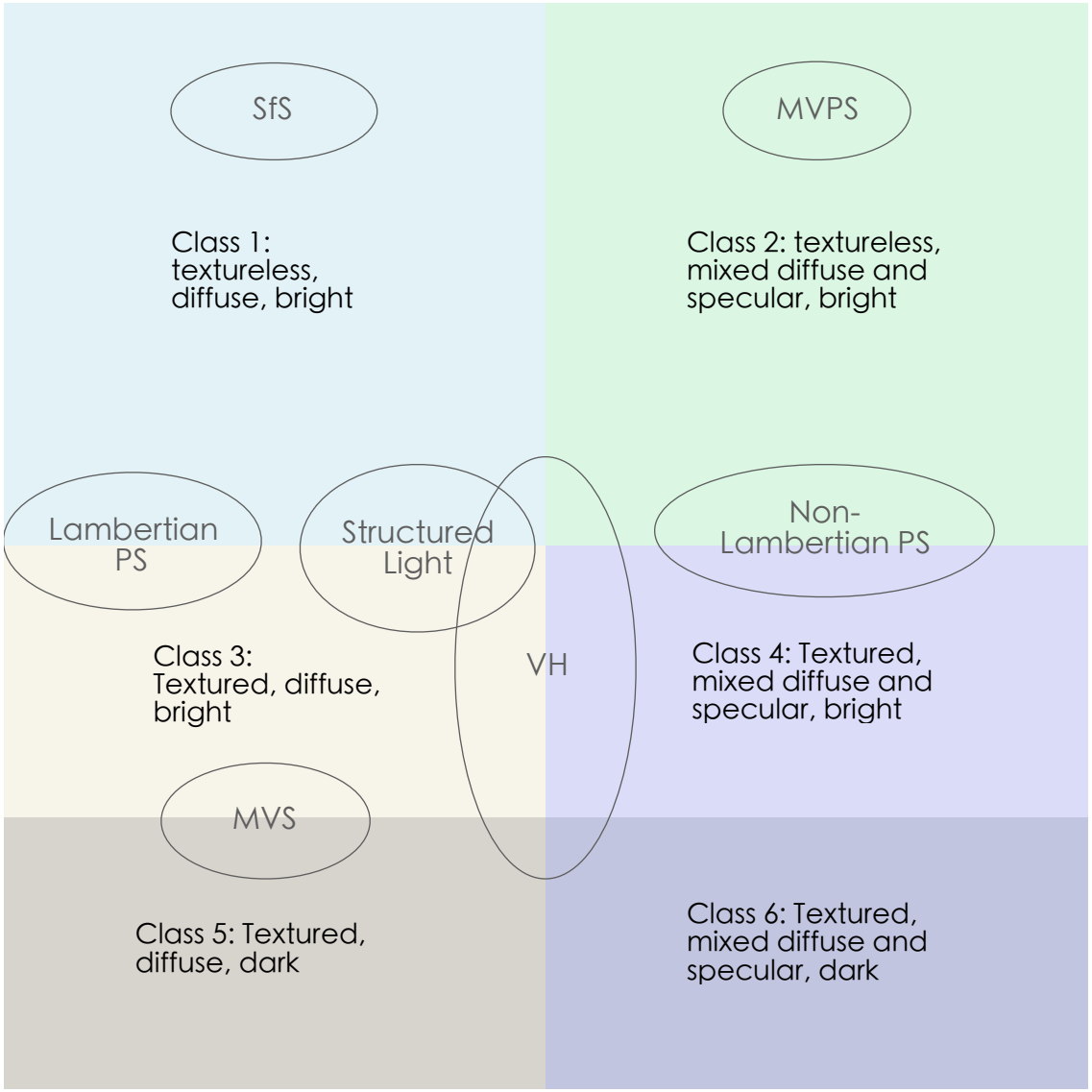
Analyze the conditions of each category of algorithms based on literature reports

Algo.	Texture	Brightness	Reflectance	Roughness	Concavity
MVS	Textured	-	Mixed	-	-
SfS	-	Bright	Lambertian	-	Convex
L PS	-	Bright	Lambertian	-	Convex
NL PS	-	Bright	Mixed	-	Convex
SL	-	Bright	Diffuse	-	Convex
VH	-	-	-	-	-

Table: Problem conditions of six categories of algorithms based on literature reports. "L" stands for Lambertian, and "NL" for Non-Lambertian.

Taxonomy (cont'd)

The *object-centered* taxonomy of the six categories of algorithms.



Overview

Description: model and representations

Model	**Representation**
Texture	*Texture randomness*
Lightness	*Albedo*
Specularity	*Specular/diffuse ratio*
Roughness	*SD of facet slopes*
Concavity	*Surface curvature*

Table: A Model and corresponding representations of the 3D reconstruction problem.

Description: expression

We use three discrete scales to parameterize these properties: *low* (0.2), *medium* (0.5), and *high* (0.8).

Object	Texture	Albedo	Specular	Rough	**Label**
Class 1	low/med	high	low/med	high	TI-B-D-R
Class 2	low/med	high	high	low/med	TI-B-M-S
Class 3	high	high	low/med	high	T-B-D-R
Class 4	high	high	high	low/med	T-B-M-S
Class 5	high	low/med	low/med	high	T-D-D-R
Class 6	high	low/med	high	low/med	T-D-M-S

Table: Expression of the reconstruction problem for the object classss.

Overview

Mapping

Investigate the problem conditions under which the algorithms can reliably work. This strucure of this chapter is as follows

- Establsh the *effective problem domain* (EPD): cope with large variation in material and shape.
- Evaluate within EPD: evaluate algorithmic performance within EPD
- Derive mapping

Mapping: setup

Use Blender's physical-based render engine, Cycles to generate synthetic datasets.

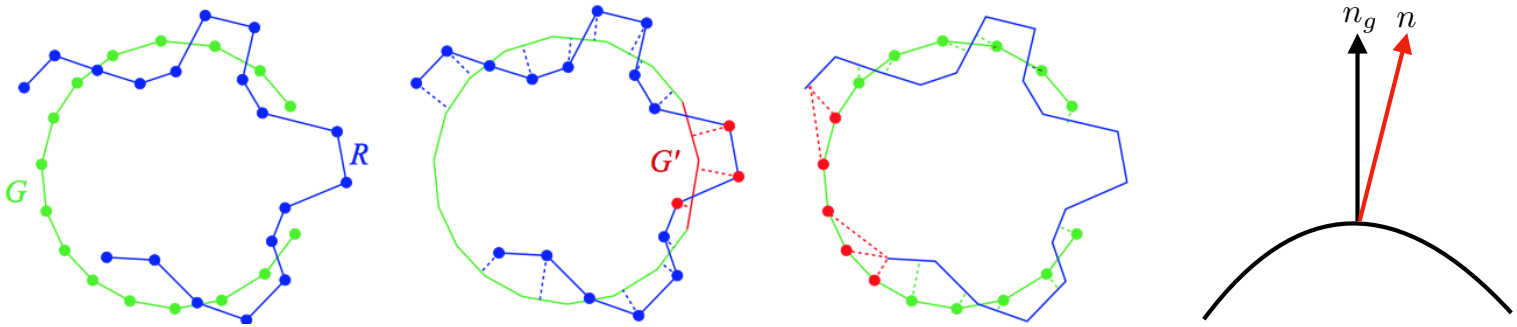
Mapping: algorithms and baseline

Technique	Texture	Albedeo	Specular	Roughness
PMVS: patch-based, seed points propagation MVS.	High	-	Low	-
EPS: example-based Photometric Stereo	-	High	Low	High
GSL: Gray-code Structured Light technique	-	High	Low	High
VH: volumetric Visual Hull.	-	-	-	-
LLS-PS: linear least squares Photometric Stereo.	-	High	Low	High

Table: Summary of the selected and baseline algorithms.

Mapping: quantitative measures and criteria

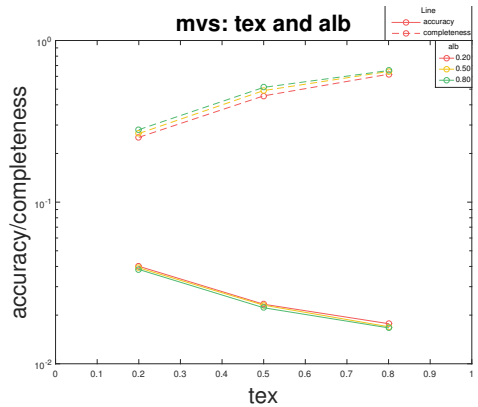
- accuracy: the distance d such that $X\%$ of the points on R are within distance d of G is considered as accuracy;
- completeness: the percentage of G that is reconstructed by R;
- angular error: angle between the estimated and ground truth normal, *i.e.*, $arccos(n_g^T n)$.



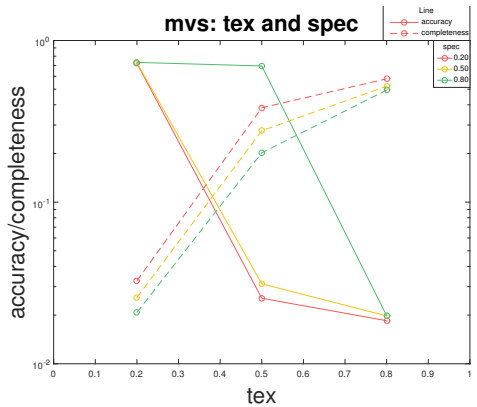
Mapping: EPD of PMVS

Table: Problem conditions for establishing the *effective problem domain* of PMVS.

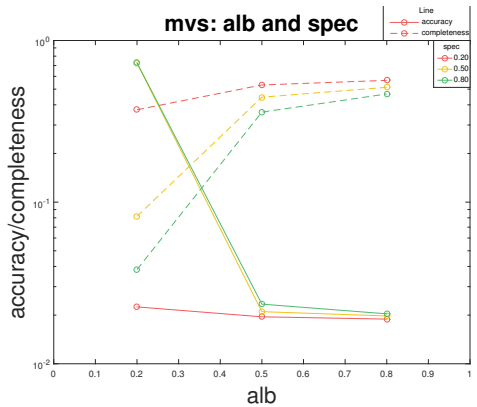
Group	Texture	Albedo	Specular	Roughness
(a)	[0.2, 0.8]	[0.2, 0.8]	0.0	0.0
(b)	[0.2, 0.8]	0.8	[0.2, 0.8]	0.0
(c)	[0.2, 0.8]	0.8	0.0	[0.2, 0.8]
(d)	0.8	[0.2, 0.8]	[0.2, 0.8]	0.0
(e)	0.8	[0.2, 0.8]	0.0	[0.2, 0.8]
(f)	0.8	0.8	[0.2, 0.8]	[0.2, 0.8]



(a)



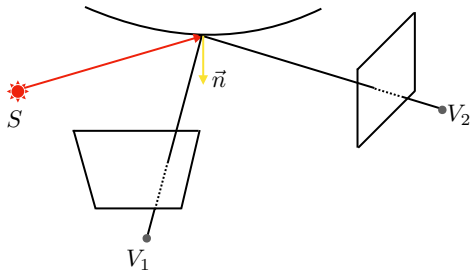
(b)



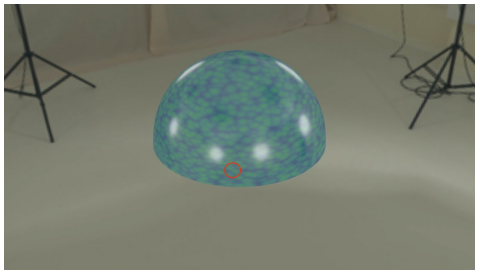
(d)

Mapping: EPD of PMVS (cont'd)

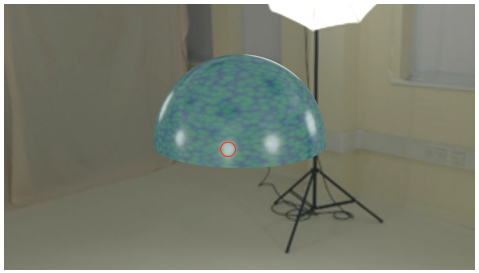
(a). Texture and Albedo
(b). Texture and Specularity



(a) Image formation



(b) V_1

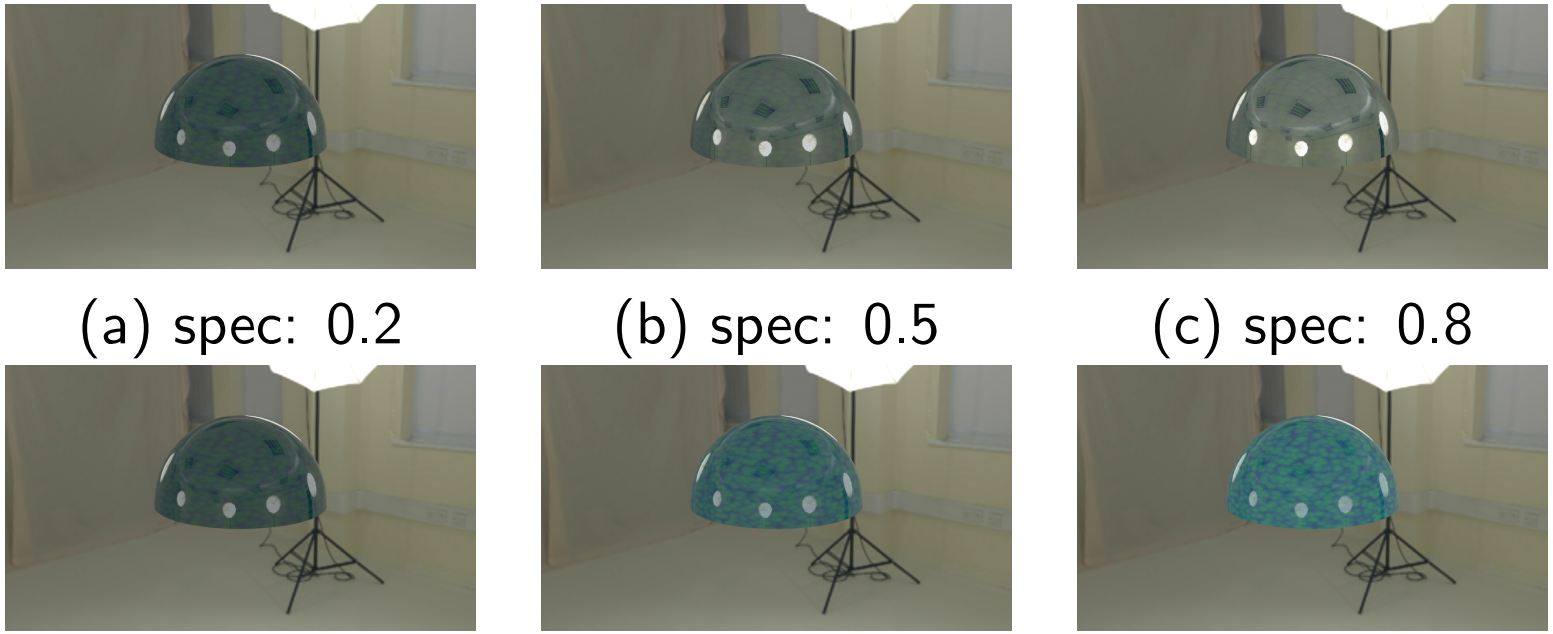


(c) V_2

Figure: (a) shows the reflection of light off a specular surface. V_1 received the diffuse component while V_2 receives the specular component. (b), (c) shows the images observed from these two views. The specular area (red circle) observed in V_2 is visible in V_1.

Mapping: EPD of PMVS (cont'd)

(d). Albedo and Specularity



(a) spec: 0.2 (b) spec: 0.5 (c) spec: 0.8

(d) alb: 0.2 (e) alb: 0.5 (f) alb: 0.8

Figure: (a)-(c). The albedo is set as 0.2, (d)-(f). The specularity is set as 0.2. According to energy conservation, as the specular component increases, the diffuse component decreases.

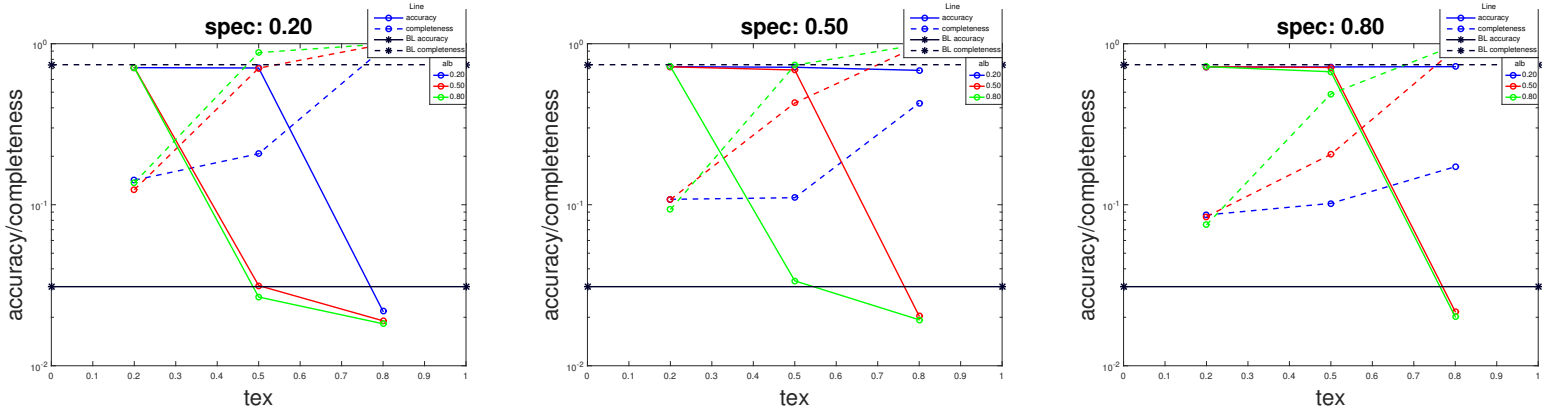
Mapping: *effective properties* of PMVS

Metric	Texture	Albedo	Specular	Roughness
Accuracy	✓	✓	✓	✗
Completeness	✓	✓	✓	✗

Table: The *effective problem domain* of PMVS in terms of accuracy and completeness.

Mapping: mapping construction

- accuracy and completeness improves consistently as the *texture* level increases.
- Accuracy and completeness results deteriorate consistently as *specularity* increases, and this negative impact is most significant when texture level is medium or albedo value is low.
- The effect of *albedo* on a surface with low texture is negligible. However, albedo has a noticeably more significant positive impact on completeness as the texture of a specular surface increases.



(a) (b) (c)

Figure: Performance of PMVS under varied conditions of changing property values. The baseline method serves as the guidelines to determine the

Mapping: mapping construction (cont'd)

Metric	Texture	Albedo	Specular	Roughness
Accuracy	0.5	0.5	0.2	-
&Completeness	0.5	0.8	0.2	-
	0.5	0.8	0.5	-
	0.8	0.2	0.2	-
	0.8	0.5	0.2	-
	0.8	0.8	0.2	-
	0.8	0.5	0.5	-
	0.8	0.8	0.5	-
	0.8	0.5	0.8	-
	0.8	0.8	0.8	-

Table: The working problem conditions of PMVS in terms of the two metrics *accuracy* and *completeness*.

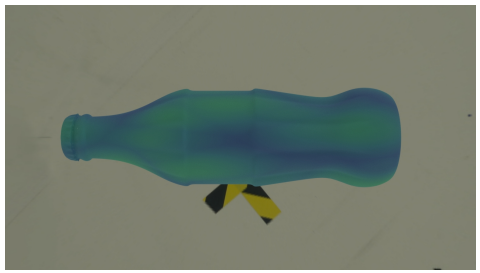
Overview

Interpretation

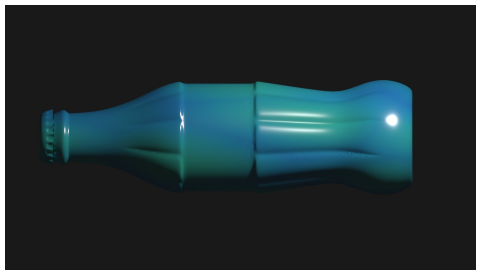
Key Evaluation Questions:

- Is the mapping robust to changes of the shape of objects?
- Can the proof-of-concept interpreter return a satisfactory reconstruction given the correct description?

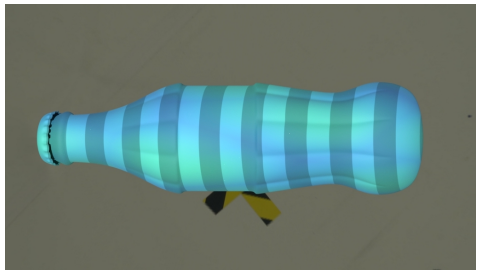
Interpretation: evaluation of mapping



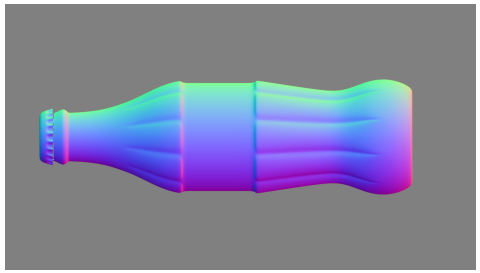
MVS



PS

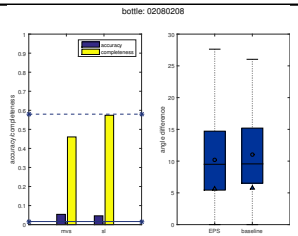
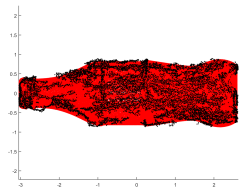
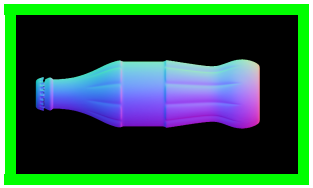
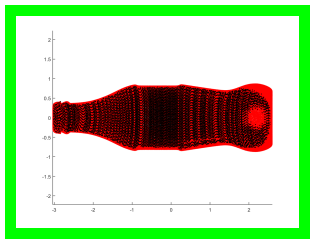
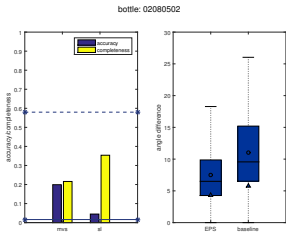
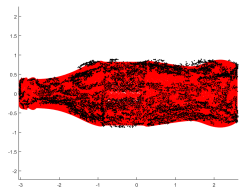
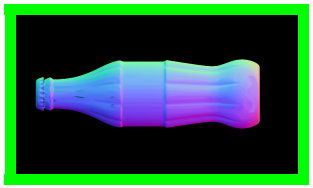
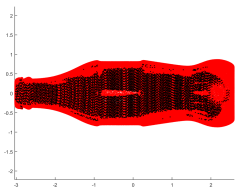


SL

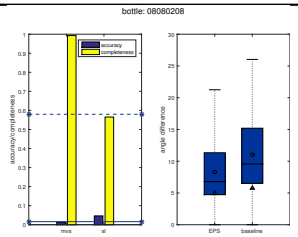
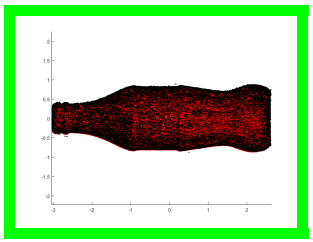
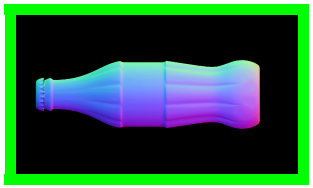
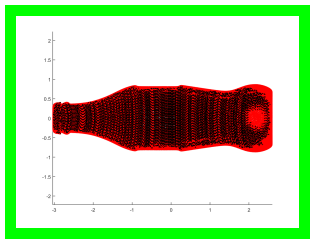
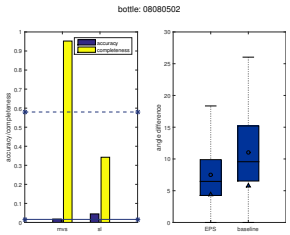
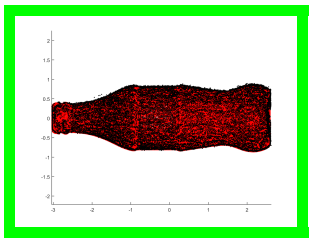
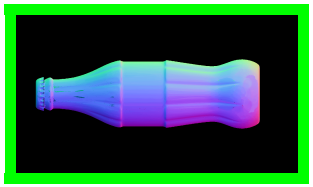
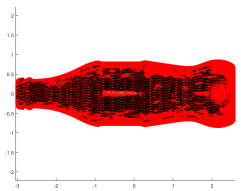


Normal groundtruth

Interpretation: evaluation of mapping

Mapping	Quantitative results	Qualitative results
EPS, GSL	   	(a). tex(0.2), alb(0.8), spec(0.2), rough(0.8)
EPS	   	(b). tex(0.2), alb(0.8), spec(0.5), rough(0.2)
	MVS	PS SL

Interpretation: evaluation of mapping (cont'd)

Mapping	Quantitative results	Qualitative results
PMVS, EPS, GSL	 	 
	(c). tex(0.8), alb(0.8), spec(0.2), rough(0.8)	
PMVS, EPS	 	 
	(d). tex(0.8), alb(0.8), spec(0.5), rough(0.2)	
	MVS	PS SL

Interpretation: evaluation of interpreter

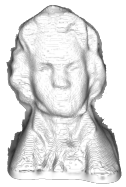
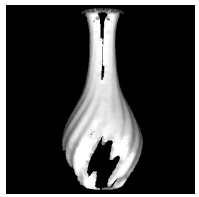
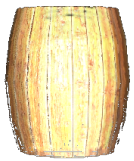
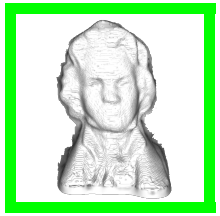
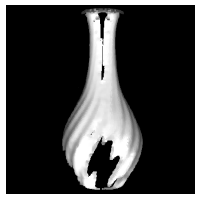
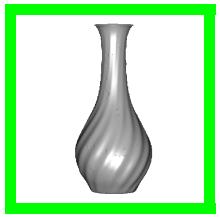
Desc #	Barrel	Vase0	Bust	Vase1	Selected Algo.
1					GSL
2					PMVS
3					GSL
4					EPS

Figure: The evaluation of interpreter using synthetic objects. The first column presents the description provided to the interpreter. Description *i* matches with condition *i* in Table **??**. The last column is the algorithm selected by the interpreter. The object of which condition matches the description is labeled in

Interpretation: real-world objects

class #	1	2	3&4	5&6
description	textureless diffuse bright	textureless mixed d/s bright	textured diffuse dark/bright	textured mixed d/s dark/bright
object				
label	(a)	(b)	(c)	(d)

Figure: The rerepsentatives of the six classes of objects used for evaluation.

Interpretation: evaluation of interpreter (cont'd)

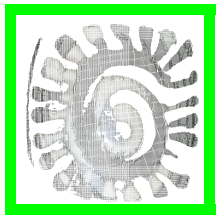
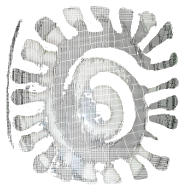
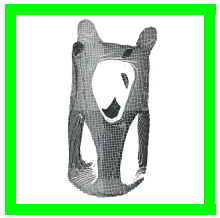
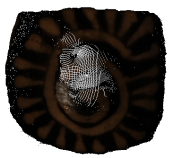
Desc #	Pot	Vase	Statue	Cup	Selected Algo.
1					GSL
2					PMVS
3					GSL
4					EPS

Figure: The evaluation of interpreter using real-world objects. The first column presents the description provided to the interpreter. Description *i* matches with condition *i* in Table **??**. The last column is the algorithm selected by the interpreter. The object of which the condition matches the description is labeled

Overview

Questions?