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

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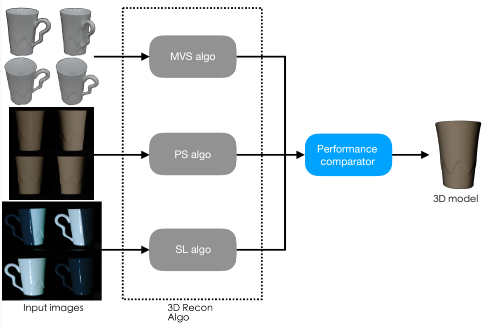
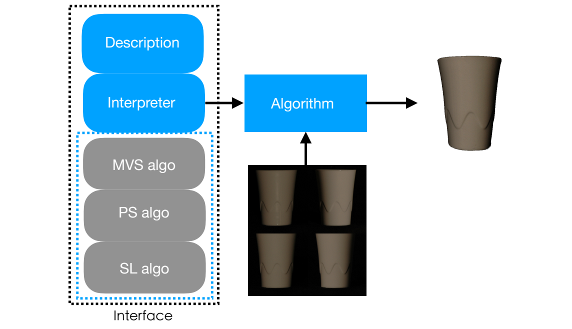
Motivation: traditional 3D reconstruction



Challenges

- Algorithms: vision knowledge required;
- Parameters: not interpretable, meaningful, or conceptually estimatible;
- Approach: *try-and-error*.

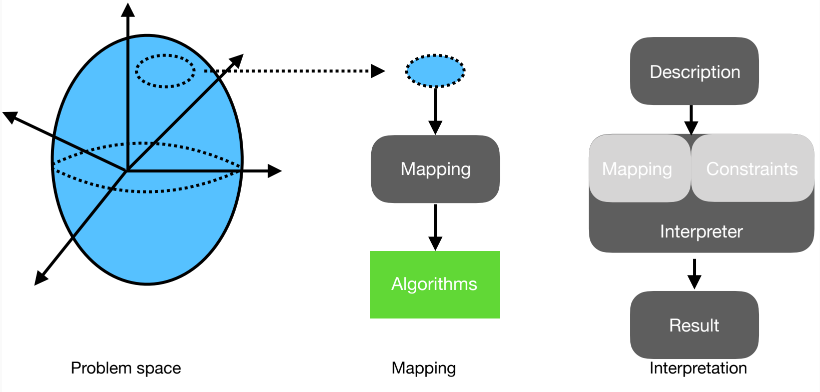
Motivation: interface to 3D reconstruction



Strengths

- Algorithms: description of appearance, no vision background needed, embeding new algorithms is easy;
- Parameters: property parameters are perceptually interpretable& meaningful;
- Approach: choose an algorithm based on mapping.

Overview


Mapping
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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 achieve a successful reconstruction result.

Related Work

Related Work: softwares

Some noteable open source general vision libraries and softwares:

General vision libraries

- Example: OpenCV, VXL, VLFeat, and so on
- Problem: provide APIs for vision routines

3D vision softwares

- Example: PMVS; Bundler, VisualSfM, TheiaSfM; Poisson Recon;
- Problem: cater to specific objects, not applicable for textureless surface

Challenges

1. Not that we don't have enough tools, but the barrier to take advantage of these tools is high.

Related Work: algorithms

Shape from Stereo

- Example: Multi-View Stereo, Structured Light
- Problem: Texture, reflectance

Shape from Intensity

- Example: Shape from Shading, Photometric Stereo
- Problem: Lightness, shape

Shape from Silhouette

- Example: Visual Hull, Space Carving
- Problem: Shape, reflectance

Challenges

1. Few algorithm works for objects with diverse range of properties;
2. The range of problem conditions under which an algorithm works is not known a priori.

Development of Interface

Overview

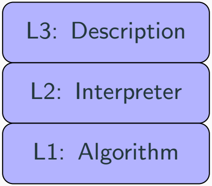


Figure 1: 3-layer interface to 3D reconstruction.

Description

1. define problem space;
2. describe problem condition.

Interpreter: translate description to an appropriate algorithm.

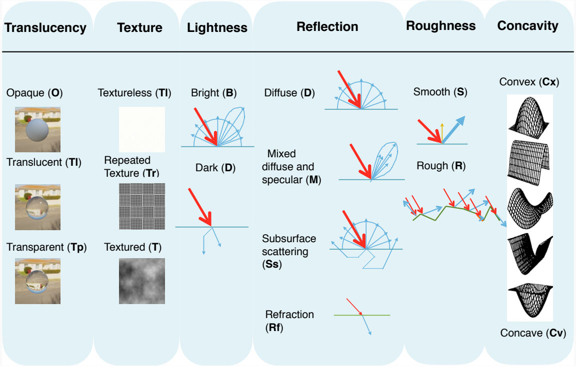
Mapping: discover the relation between problem space and algorithm.

Algorithm

Embed algorithms into the interface

Problem space

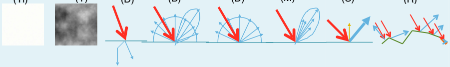
- *algorithm-centered* approach categorizes algorithms based on algorithmic details, as discussed in **Related Work**;
- *object-centered* taxonomy categorizes algorithms based on the problem conditions that the algorithm can reliably works under.



Problem space: four problem conditions

Assumptions:

- Active methods require high surface albedo (bright), in order to demonstrate the effectiveness of these methods, we focus on bright surfaces only.
- Diffuse is caused solely by surface roughness since sub-surface scattering is ignored.



Condition	Texture		Lightness		Reflection		Roughness		Label
	Textureless (TI)	Textured (T)	Dark (D)	Bright (B)	Diffuse (D)	Mixed (M)	Smooth (S)	Rough (R)	
1	Yes			Yes	Yes			Yes	TI-B-D-R
2	Yes			Yes		Yes	Yes		TI-B-M-S
3		Yes		Yes	Yes			Yes	T-B-D-R
4		Yes		Yes		Yes	Yes		T-B-M-S

Description: model and representations

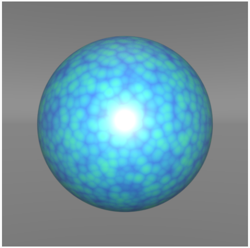
Model	**Representation**
Nature of scene	*Static*
Lighting	*Mixed: ambient, projector, light sources*
Vantage point	*Medium: 10 - 50*
Texture	*Texture randomness*
Lightness	*Diffuse reflectance*
Specularity	*Fresnel reflectance*
Roughness	*Distribution of facet slope*

Description: expression

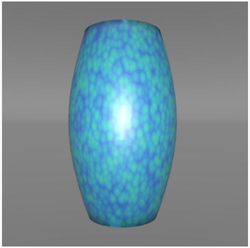
We use three discrete scales to parameterize these properties: *low* (0.2), *medium* (0.5), and *high* (0.8).

Object	Texture	Albedo	Specular	Rough	**Label**
Vase	high	high	high	low	T-B-M-S

Table 1: Description of the object 'vase'.



(a). synthetic sphere

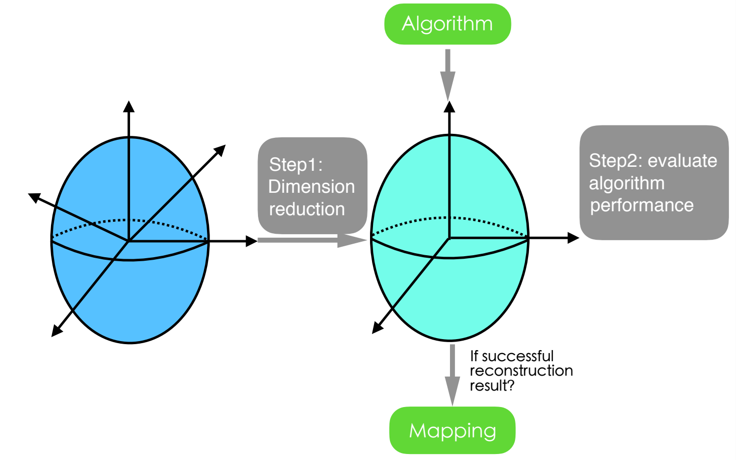


(b). synthetic vase

(c). real-world vase

Mapping

Investigate the problem conditions under which the algorithms can reliably work.



Mapping: algorithms

selected algorithms

- Patch-based Multi-View Stereo (PMVS): propagate-refinement-filtering;
- Example-based Photometric Stereo (EPS): arbitrary BRDF is a linear combination of basis BRDFs;
- Gray-coded Structured Light (GSL): encode spatial informally temporally.

baseline methods

- Volumetric Visual Hull: carve voxels projecting outside of silhouettes;
- Linear-least squares Photometric Stereo: $\mathbf{I} = \rho \mathbf{N} \cdot \mathbf{L}$

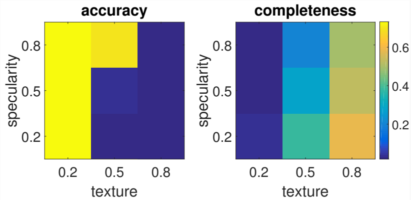
Mapping: dataset

creation of dataset

- We need a dataset contains object with varied visual and geometric properties;
- Generate the dataset using physic-based renderer.

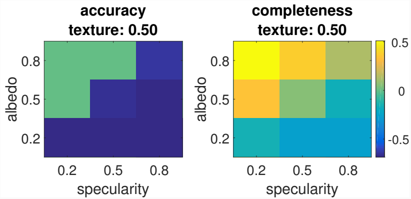
Mapping: reduce dimensionality

Reduce problem space dimensionality by discovering properties that have an effect on algorithm performance.



Mapping: discover mapping

Discover the mapping from problem condition to algorithms

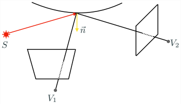


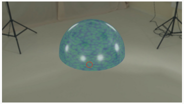
Texture	Albedo	Specular	Roughness
0.5	0.5	0.2	-
0.5	0.8	0.2	-
0.5	0.8	0.5	-

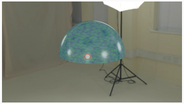
Mapping: theory and observations

We give key observations that can be theoretically justified by theory to demonstrate the insights that could be obtained from the mapping.

1. PMVS can work on specular surfaces provided the surface highly textured

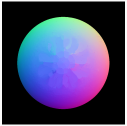






2. EPS and GSL fails on highly specular surfaces, and a blurred specular area leads to worse results.

(a). rough: 0.2



(b). rough: 0.5

(c). rough: 0.8

Evaluation of interface

Interpretation: evaluation methodology

Evaluation questions

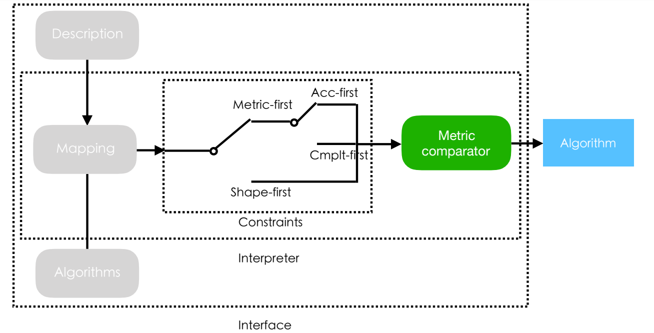
1. Interpreter returns successful reconstruction result given an accurate description of problem condition;
2. Interpreter returns a less successful reconstruction result given a less accurate description of problem condition?
3. Interpreter returns a poor reconstruction result given an inaccurate description of problem condition?

Criteria

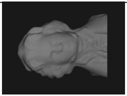
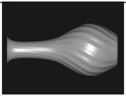
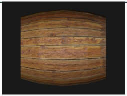
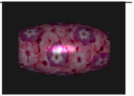
Visual comparison to results of baseline method.

Interpretation: interpreter

An interpreter selects an appropriate algorithm based on description of problem condition and constraints.

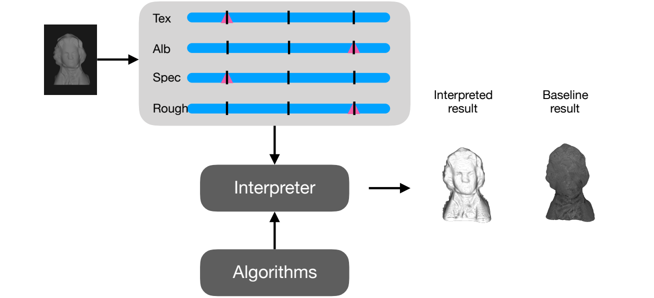


Interpretation: dataset

Cond#	1	2	3	4
description	textureless diffuse bright	textureless mixed d/s bright	textured diffuse dark/bright	textured mixed d/s dark/bright
object				
				

Interpretation 1: demonstrative result

We use object ‘bust’ as an example:



Comparison to baseline result

- accuracy: higher quality
- completenss: no unconstructed holes

Interpretation 1: more results

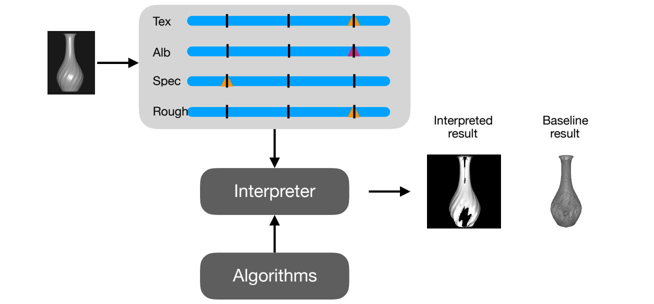
Interpretation 1

Summary

- We have demonstrated that it is feasible to achieve a successful reconstruction result given a description of problem condition, without knowledge of which algorithm to use;
- This could be extended to a wider range of problem conditions given a more complicated object description.

Interpretation 2: demonstrative result

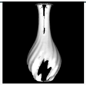
We use object 'vase' as an example:



Comparison to baseline result

- completenss: has unconstructed holes

Interpretation 2: more results

Object	Descriptions and Results				
	Desc$_1$	*Desc*$_2$	*Desc*$_3$	*Desc*$_4$	Correct Desc
Desc	02020208	08080208	08020802	08020202	02080802
Algo	• EPS	• PMVS • EPS • GSL	• BL	• PMVS	• EPS
vase0					
cup					

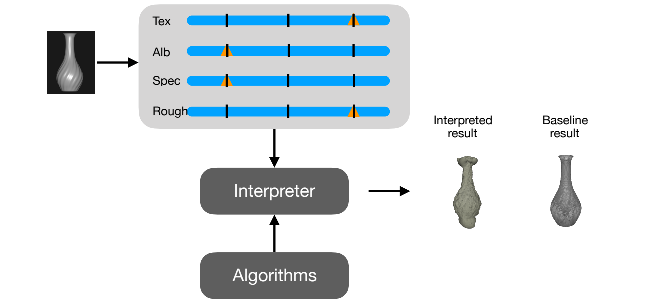
Interpretation 2

Summary

- Algorithm chosen by the interpreter given a less accurate description may or may not achieve a poor result;
- It depends if the return algorithms has at least an overlapping with those returned if given accurate description.

Interpretation 3: demonstrative result

We use object ‘vase’ as an example:

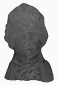
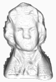
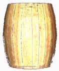


Summary

- accuracy: surface rough, inaccurate
- completeness:

Interpretation 3: more results

More demonstrative results:

Object	Bust	Vase0	Barrel	Vase1
Incorrect Desc	08020802 • BL 	08020208 • PMVS • EPS 	02020802 • BL 	02020208 • EPS 
Correct Desc	02080208 • EPS • GSL 	02080802 • EPS 	08080208 • PMVS • EPS • GSL 	08080802 • PMVS • EPS 

Interpretation 3: more results

Object	Statue	Cup	Pot	Vase
Incorrect Desc	08020802 • BL	08020208 • PMVS • EPS	02020802 • BL	02020208 • EPS
				
Correct Desc	02080208 • EPS • GSL	02080802 • EPS	08080208 • PMVS • EPS • GSL	08080802 • PMVS • EPS
				

Interpretation 3

Summary

- Algorithm chosen by the interpreter given inaccurate description have a higher probability of achieving a poorer result;

Conclusions

Conclusions

- the proposed description is able to give correct reconstruction for non-concave objects
- To deal with more complicated objects, we need more complicated properties, or ways to describe the objects, but the challenge is the easy mathematical representation might not be available.
- Using the simple descriptive language and proof-of-concept interpreter, we demonstrate the possibility of using descriptive properties to hide algorithmic details.

Take-away message

Computer vision should focus on more than just algorithms, but easier accessibility.