

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

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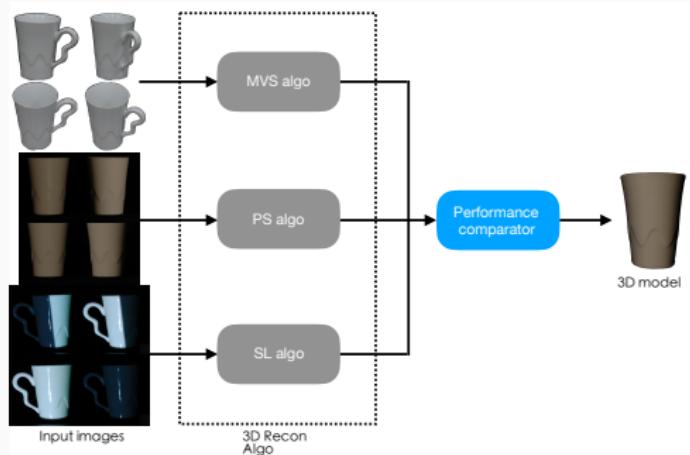
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Motivation

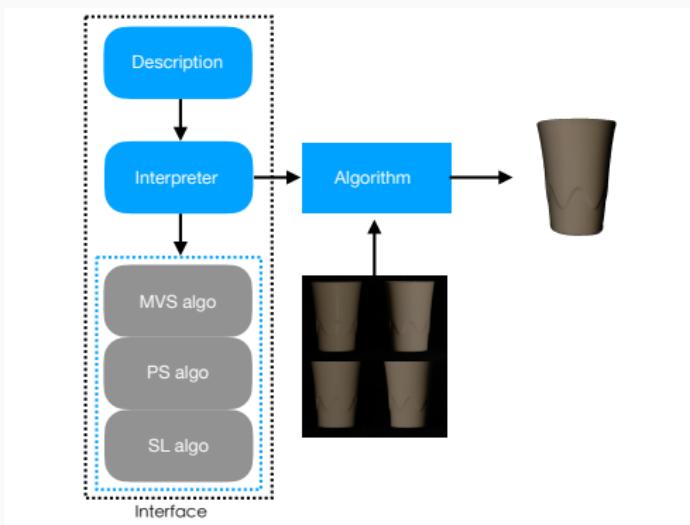
Motivation: traditional 3D reconstruction



Challenges

- Algorithms: vision background, doesn't scale well
- Approach: *try-and-see*

Motivation: interface to 3D reconstruction



Strengths

- Algorithms: no vision background needed, embedding new algorithms is easy
- Approach: a definitive algorithm is chosen

Contribution

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 interpreted so that an appropriate algorithm is chosen to achieve a successful reconstruction result.

Contribution (cont'd)

This contribution is significant because:

- Few algorithms 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.
- A description of object problem condition is provided to hide the algorithmic details, thus understanding of the algorithm, or conditions of applying algorithms are not a prerequisite.

Related Work

Related Work: softwares

Some notable 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

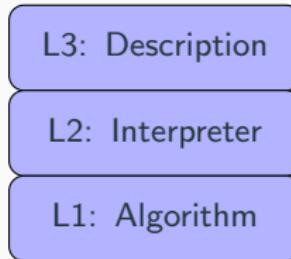


Figure 1: 3-layer interface to 3D reconstruction.

Description

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

Interpreter: translate description to an appropriate algorithm.

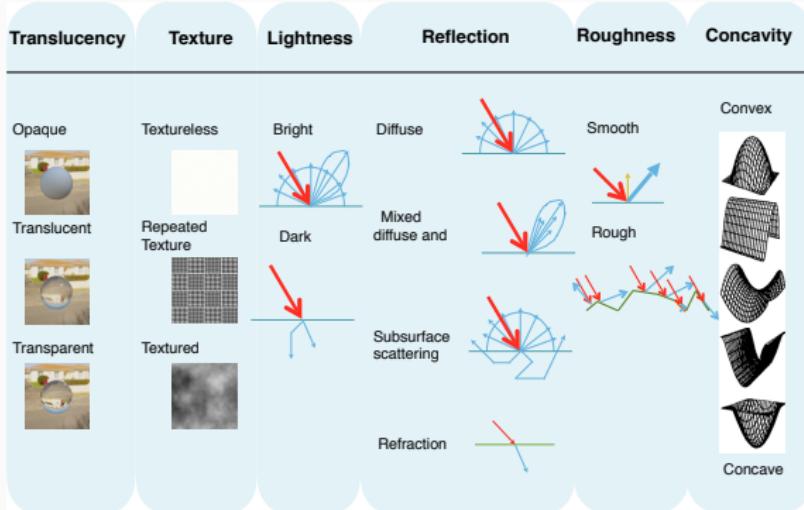
Mapping: discover the relation between problem space and algorithm.

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 work 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 | | | | |
|-----------|------------------|--------------|------------|------------|-------------|-----------|------------|-----------|----------|
| 1 | Textureless (Tl) | Textured (T) | Dark (D) | Bright (B) | Diffuse (D) | Mixed (M) | Smooth (S) | Rough (R) | 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 |
|-------------|-----------------------------|
| Texture | <i>Texture randomness</i> |
| Lightness | <i>Diffuse albedo</i> |
| Specularity | <i>Specular reflectance</i> |
| Roughness | <i>SD of facet slopes</i> |

Table 1: Representations of the 3D reconstruction problem.

Description: expression

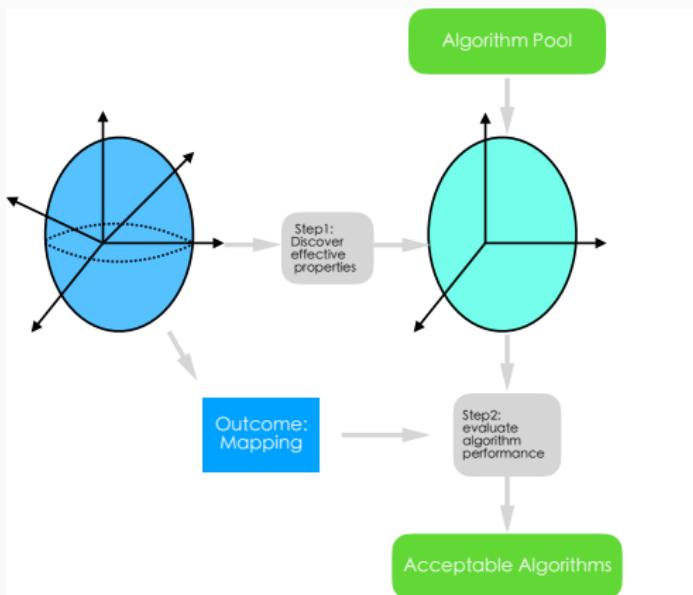
We use three discrete scales to parameterize these properties: *low* (0.2), *medium* (0.5), and *high* (0.8).

| Prob cond | Texture | Albedo | Specular | Rough | Label |
|-----------|---------|--------|----------|---------|----------|
| 1 | low/med | high | low/med | high | TI-B-D-R |
| 2 | low/med | high | high | low/med | TI-B-M-S |
| 3 | high | high | low/med | high | T-B-D-R |
| 4 | high | high | high | low/med | T-B-M-S |

Table 2: Expression of the four problem conditions.

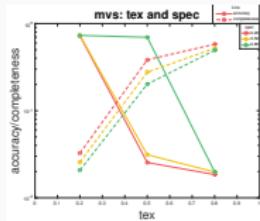
Mapping

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



Mapping: dataset creation

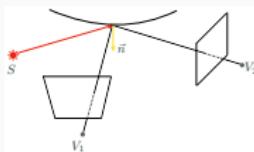
Mapping: notable findings 1



(a). Algo. performance



(c) V_1



(b) Image formation



(d) V_2

Figure 2: (a) shows the algorithm performance w.r.t. texture and specularity. (b) shows the reflection of light off a specular surface. V_1 received the diffuse component while V_2 receives the specular component. (c), (d) shows the images observed from these two views. The specular area (red circle) observed in V_2 is visible in V_1 .

Mapping: notable findings 2

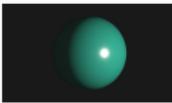
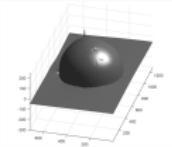
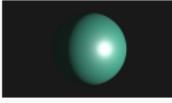
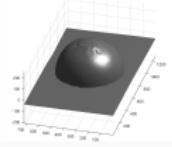
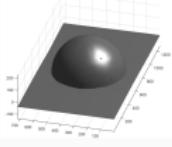
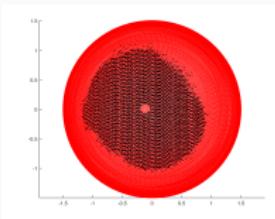
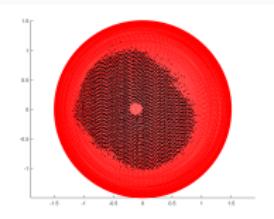
| Image | Normal map | Height map | Angular error |
|---|---|---|---|
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

Figure 3: The effect of roughness on PS. Albedo is set as 0.8, and specular is set as 0.8. (b) demonstrates that a medium level roughness would lead to worse normal estimation since it blurs the specular lobe.

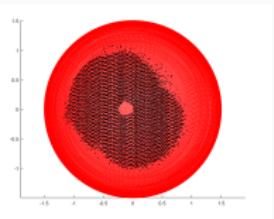
Mapping: notable findings 3



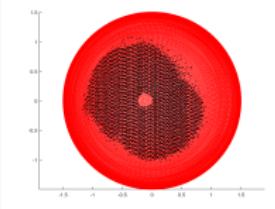
(a) specular: 0.2



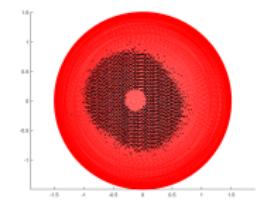
(b) specular: 0.5



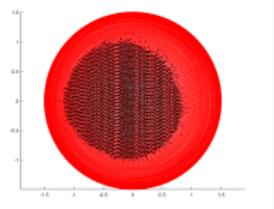
(c) specular: 0.8



(d) roughness: 0.2



(e) roughness: 0.5



(f) roughness: 0.8

Figure 4: (a)-(c): the roughness is set as 0.2, and specular has a negative effect on completeness; (d)-(e): the specular is set as 0.8, roughness has a positive effect on completeness.

Mapping: discussion

- PMVS can work on specular surfaces;
- EPS and GSL fails on highly specular areas, and a blurred specular area causes worse results.

Evaluation of interface

Interpretation: evaluation methodology

Evaluation question

Can the proof of concept interpreter return an appropriate algorithm that achieves a successful reconstruction given the correct description?

Criteria

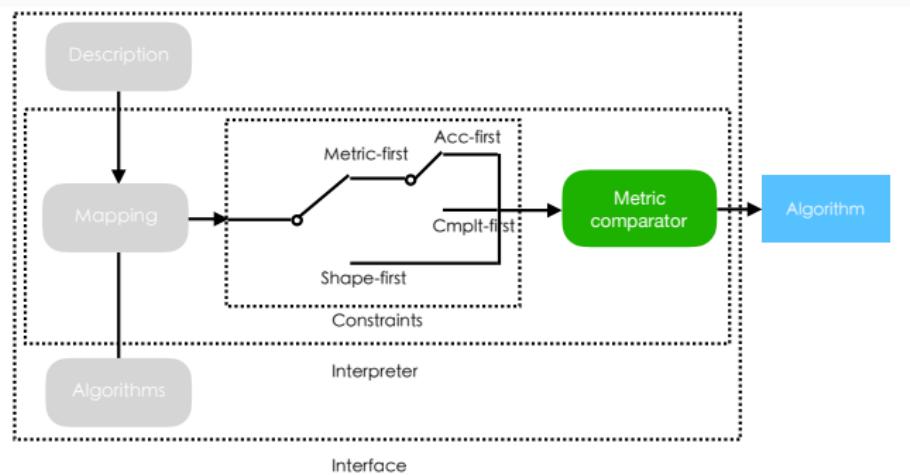
Visual comparison to results of baseline method.

Roadmap

- proof of concept interpreter;
- dataset creation;
- results of interpreter.

Interpretation: proof of concept interpreter

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



Interpretation: dataset creation

Capture

| method | hardware | configuration |
|--------|--------------------------|-------------------------------|
| MVS+VH | camera | 3 heights, 30° baseline angle |
| PS | camera, lamp, 2 ref objs | |
| SL | camera, projector | 10° baseline angle |

Calibration

| method | calibration |
|--------|---|
| MVS+VH | focal length from EXIF, extrinsics using SfM |
| PS | no radiometric calibration performed |
| SL | camera-projector calibration using local homography |

Interpretation: synthetic objects

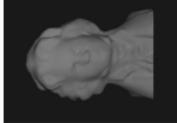
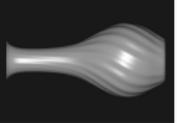
| prob cond# | 1 | 2 | 3 | 4 |
|-------------|---|---|--|---|
| description | textureless diffuse bright | textureless mixed d/s bright | textured diffuse dark/bright | textured mixed d/s dark/bright |
| object |  |  |  |  |

Figure 5: The representative synthetic objects of the four problem conditions for evaluation.

Interpretation: evaluation of interpreter

| Desc # | Bust | Vase1 | Barrel | Vase0 | Interp Algo. |
|--------|---|---|---|---|--------------|
| 1 |  |  |  |  | GSL |
| 2 |  |  |  |  | EPS |
| 3 |  |  |  |  | GSL |
| 4 |  |  |  |  | PMVS |

Interpretation: real-world objects

| prob cond# | 1 | 2 | 3 | 4 |
|-------------|---|---|--|---|
| description | textureless diffuse bright | textureless mixed d/s bright | textured diffuse bright | textured mixed d/s bright |
| object |  |  |  |  |

Figure 6: The representative real-world objects of the four problem conditions for evaluation.

Interpretation: evaluation of interpreter (cont'd)

| Desc # | Statue | Cup | Pot | Vase | Interp Algo. |
|--------|---|---|---|---|--------------|
| 1 |  |  |  |  | GSL |
| 2 |  |  |  |  | EPS |
| 3 |  |  |  |  | GSL |
| 4 |  |  |  |  | PMVS |

Interpretation: discussion

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.