Real time Photometric Stereo

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KU Leuven/ESAT/PSI

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Context

VISICS

KULeuven's Computer Vision group

2D image analysis, segmentation, recognition, 3D reconstruction, surface properties, tracking

On 3D specifically:

- Structured light (first one-shot system)
- Uncalibrated Structure-from-Motion (first webservice)
- Photometric stereo (first transportable system)

Real-time Photometric Stereo

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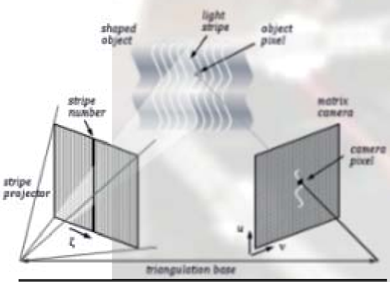
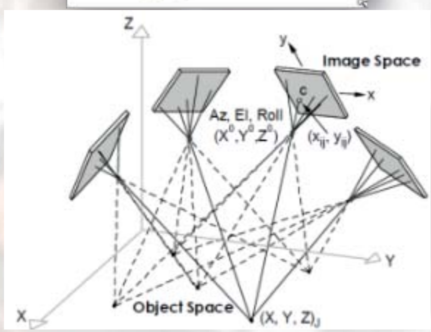
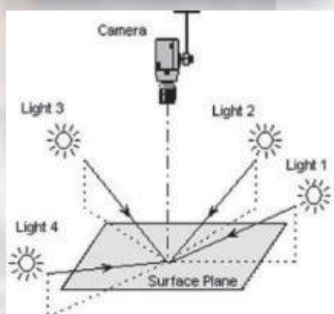
Real-time Photometric Stereo

Structured light	Photogrammetry	Photometric stereo

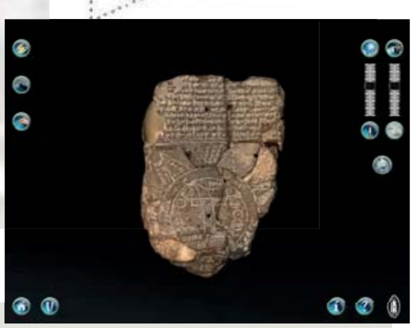






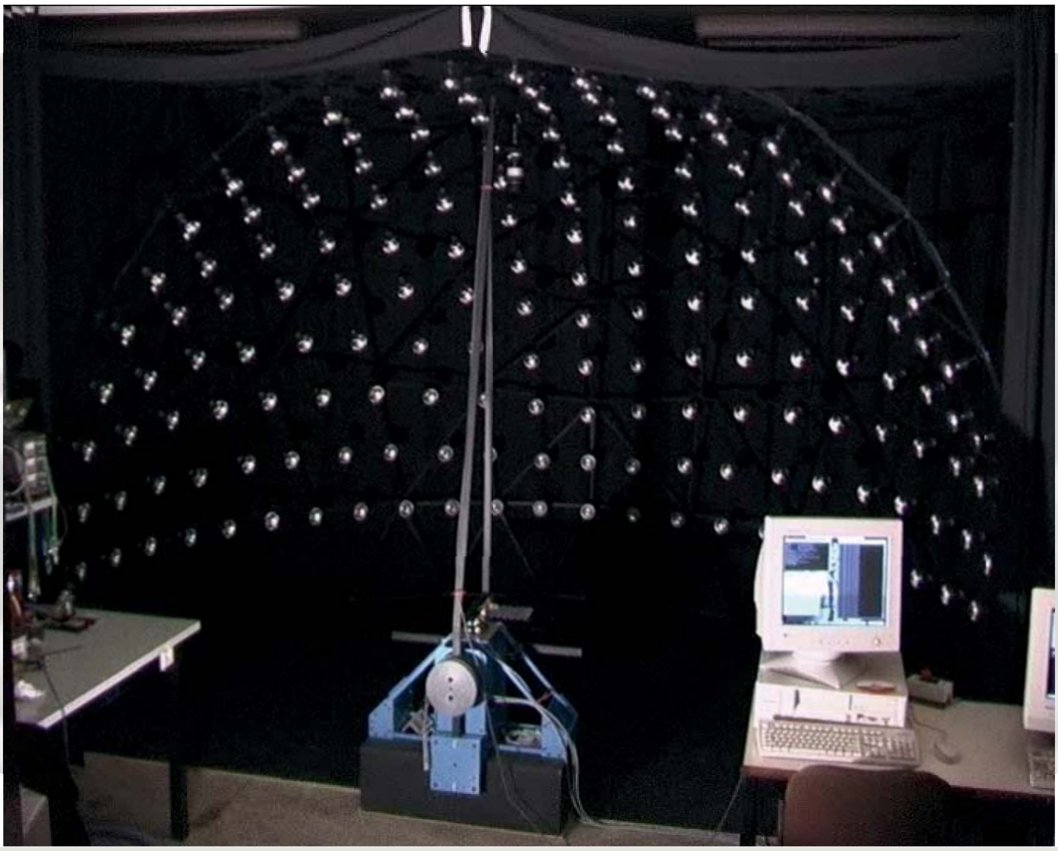






Real-time Photometric Stereo

Photometric stereo using light domes



Real-time Photometric Stereo

Photometric stereo using light domes

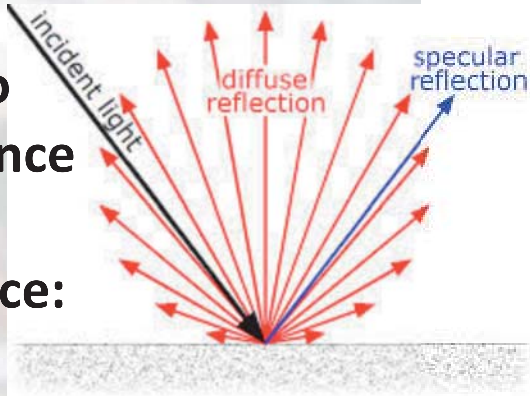
- Photometric strengths :
  - Determine high-frequency 3D details
  - Determine surface reflectance

- Minidome : *single* camera version with 260 LED lights.

Real-time Photometric Stereo

Photometric stereo (PS) – the challenge

The goal of basic PS is to extract the 3D shape (normals) knowing the illumination
and local surface albedo
and the type of reflectance



e.g. assuming a *Lambertian* surface:

$$I = a\,(\mathbf{L}\,.\,\mathbf{n})$$

Real-time Photometric Stereo

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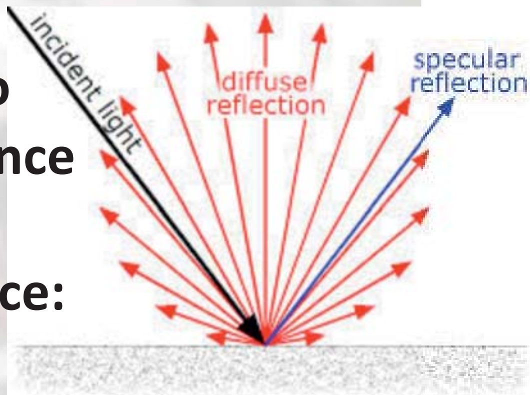

e.g. assuming a *Lambertian* surface:

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***n* can be solved if the surface is illuminated from 3 directions in turn**

Real-time Photometric Stereo

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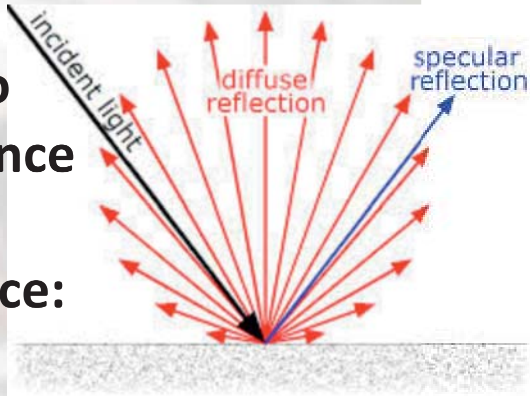

e.g. assuming a *Lambertian* surface:

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More unknowns can be solved (*non-linearly*) if there are more measurements (more light sources)

Real-time Photometric Stereo

Photometric stereo (PS) – the challenge

The previous conditions can be relaxed
A solution for the diffuse (Lambertian) component still possible by removing specular outliers among multiple illuminations; this also allows for a more sophisticated reflectance model: diff + spec comp

e.g.
Verbiest and Van Gool,
Photometric Stereo with Coherent Outlier Handling and Confidence Estimation,
IEEE Conf. on Computer Vision and Pattern Recognition '08

Real-time Photometric Stereo

Photometric stereo (PS) – the challenge

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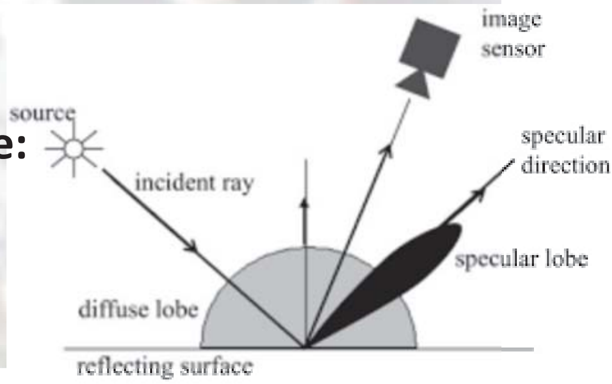
This is what is implemented in our CPU version of minidome software: Lambertian added with a specular lobe of variable width



Real-time Photometric Stereo

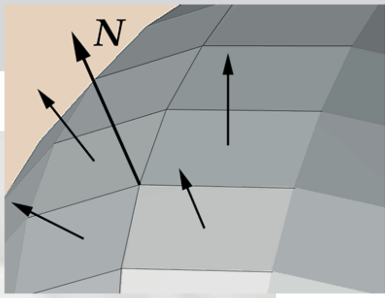
Robust Photometric stereo

Outcome of the software pipeline, for all surface points:

- **Surface normals** (unlike PTM)
- **Albedos (color) : 'diffuse material color'**
- **Specular lobes**

Real-time Photometric Stereo

Robust Photometric stereo



From these

- 3D reconstruction by normal integration, allowing users to make metric measurements

- real-time *shader* filtering for study, research and inspection of objects and artefacts.

Real-time Photometric Stereo

Example:

Cuneiform tablet with stamp

Input data

Real-time Photometric Stereo

Example:

Cuneiform tablet with stamp

Minidome viewer

Real-time Photometric Stereo

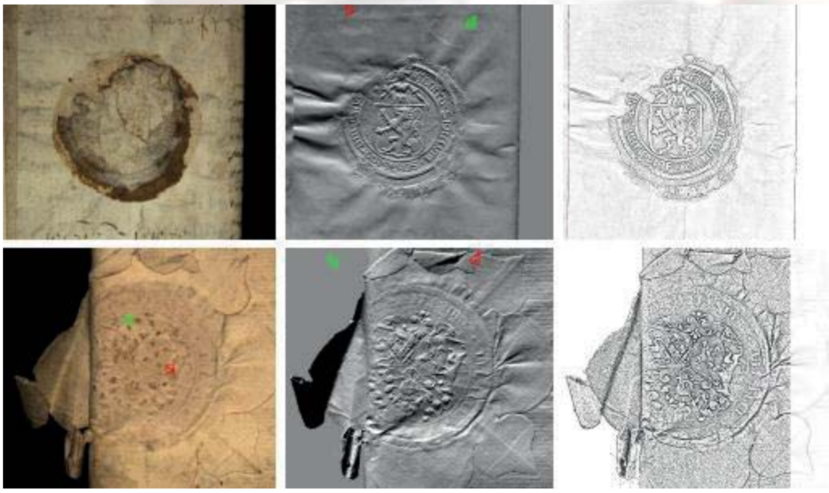
Example:

- British Museum 'Map of the world'
- The oldest cuneiform finding showing a map of Mesopotamia.

Real-time Photometric Stereo

Literature

- Booklets
- Manuscripts
- Stamps
- Seals



Minidome applications

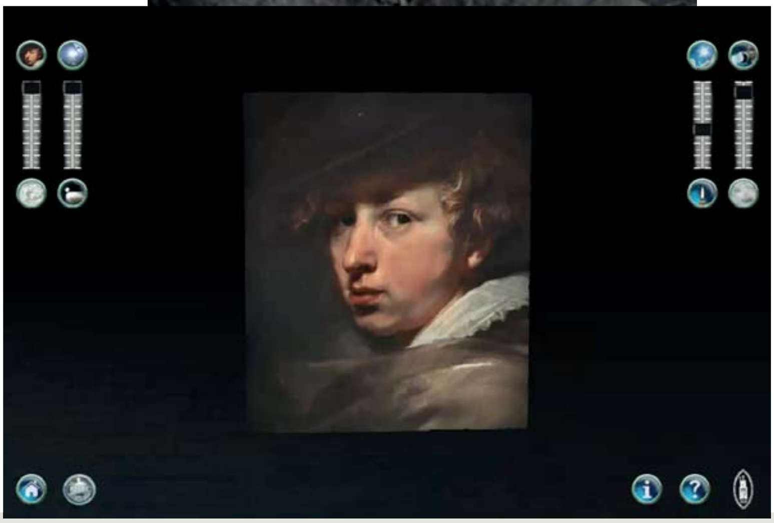
Coins

- Coin collection from museum of Pisa
- specularity / reflections

Minidome applications

Paintings

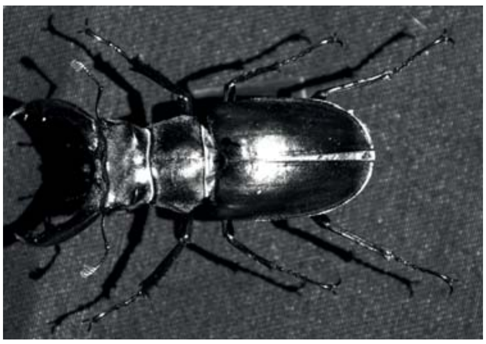
- Van Dyck painting : surface reveals history and possibly identity.
- Brushstrokes of older painting are visible underneath hat and cape.

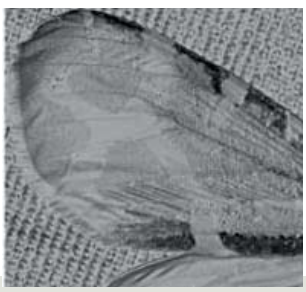


Minidome applications

Entymology

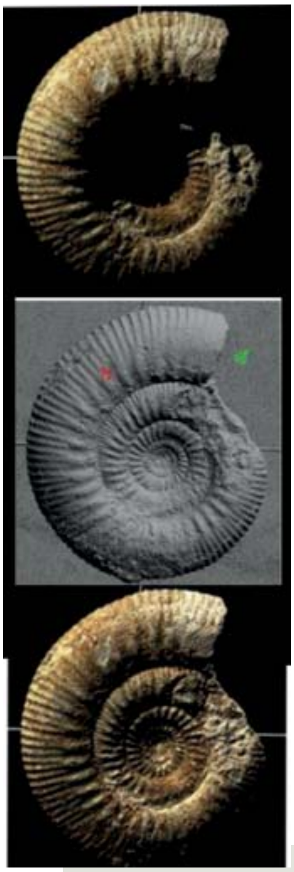
- Insects: traditionally ‘difficult to scan’
- Need for non-destructive measurement techniques.





Minidome applications

Fossils (NHMBerlin)



Minidome applications

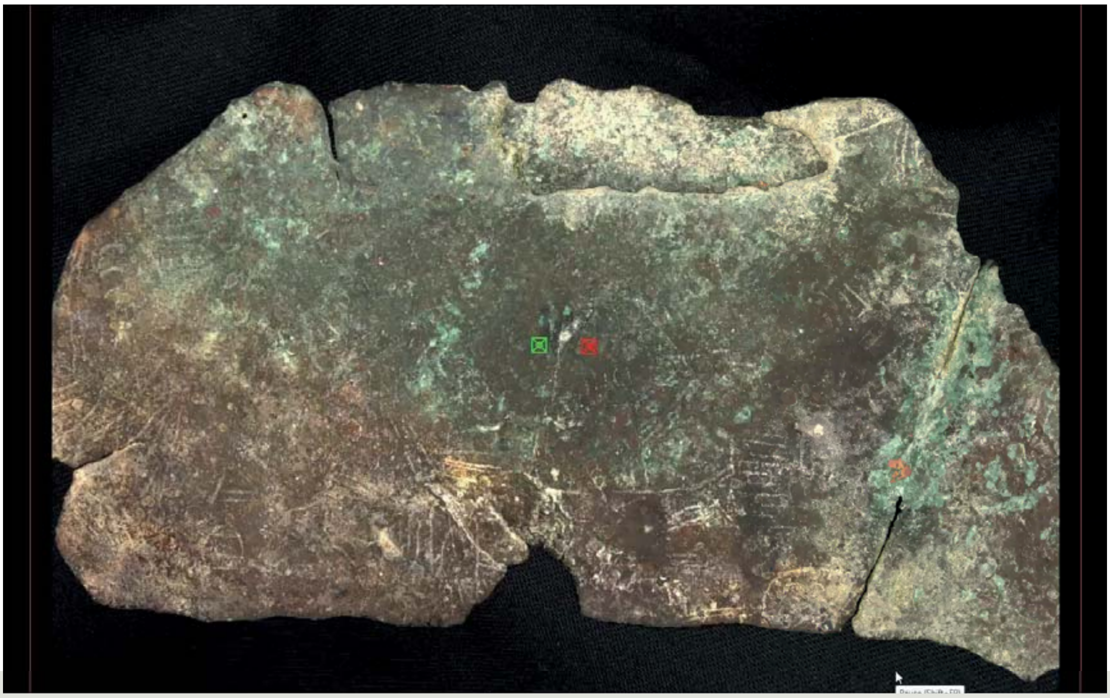
Anthropology

- Ivory piece

Minidome applications

Antropology

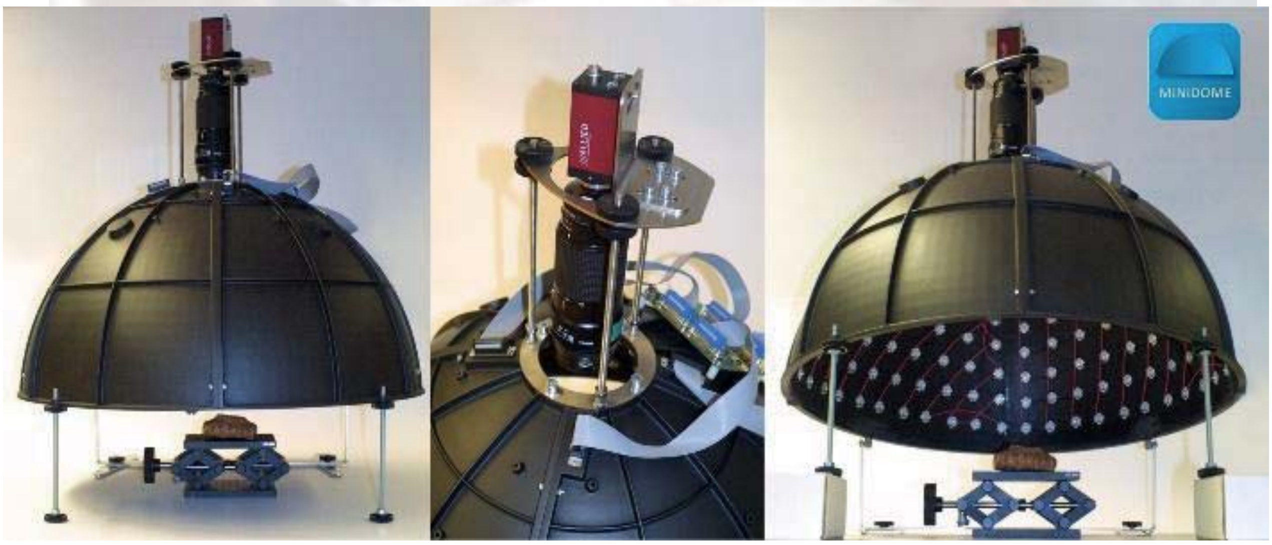
Kent graffiti plate : copper plate found in Kent (UK), origin was never known, until minidome shaders revealed 15th century Ship graffiti (3 master).



Real-time Photometric Stereo

Operational status:

The new minidome setup is more rugged:
3D printing / silicon mall
reproducible and therefore now available @ 11 kEuro



Real-time Photometric Stereo

Operational status:

- Processing speed 2m – 15m, depending on resolution and CPU power.

  E.g. 30 Mpix image sequence (x260), runs > 10 minutes on 8 cores.

- Processing is off-line, as batch job.
- Success of recording (influenced by camera aperture and shutter speed settings) can only be evaluated afterwards.

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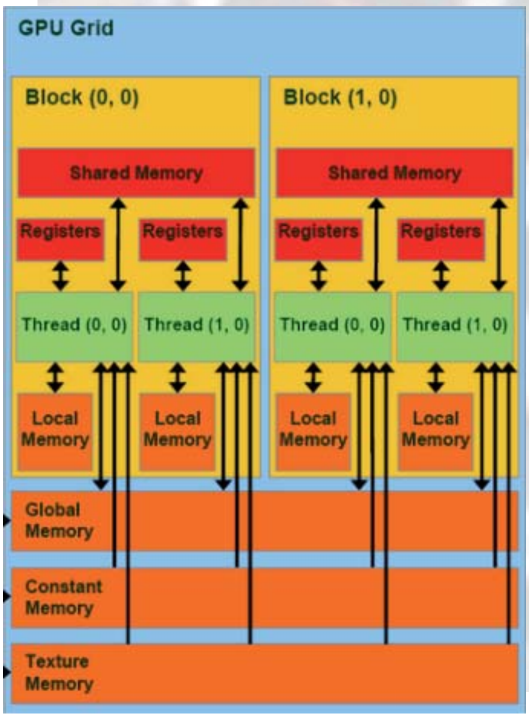
Real-time Photometric Stereo

GPU implementation :

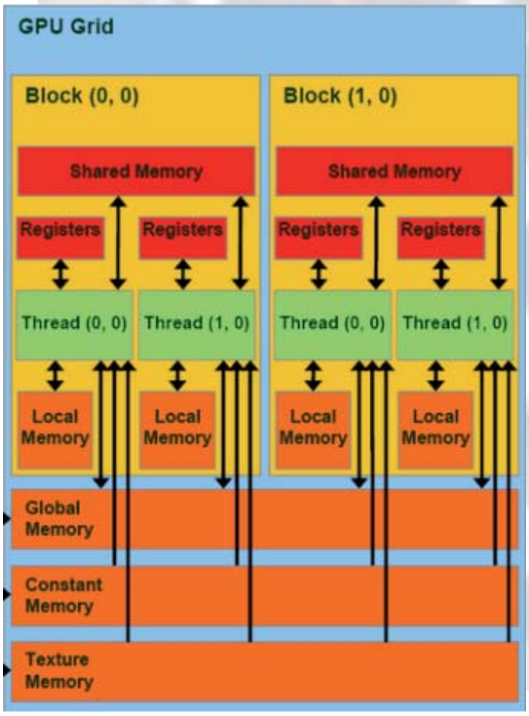


GPU implementation:

- Processing of PS is parallel per pixel, based on (at most) 260 observations (LEDs)
- Each pixel is executed by one available thread on the GPU, but each thread deals with multiple pixels
- Careful optimization between thread processing power / memory type: shared, register, cache, global (red is faster but limited) / memory coalescing

Real-time Photometric Stereo

GPU implementation :



More information on the GPU implementation found in the Photometric Week 2015 paper

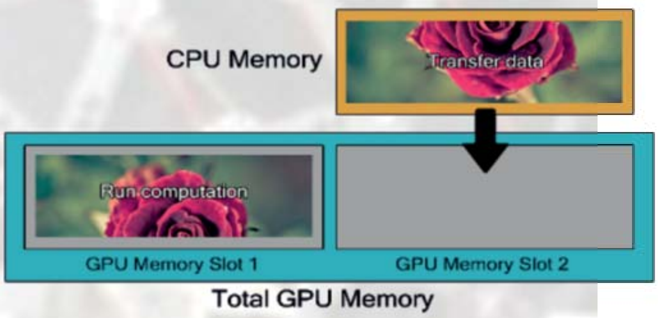
A. Pevar et al.
Real-time photometric stereo

Real-time Photometric Stereo

GPU implementation :

GPU implementation:

- **Further optimizations: 260 images call for quite a lot of memory and may not fit on a typical GPU.**
- **1) images are sliced into sections and processed one by one.**
- **2) processing takes advantage of the possibility of *transfer concurrency* while a previous stored slice is processed**



Real-time Photometric Stereo

GPU implementation :

Results:

- Speedup close to factor 1000. Depends on graphics card specs.
- Tabel shows performance increase on GTX 780ti.
  On GX980 speedup increases with another factor > 1.5.
  On TitanX another > 1.5..
  Unit: milliseconds

	CPU	GPU
1.2MP	158*10^3	265
1.7MP	252*10^3	267
2.7MP	401*10^3	431
3MP	445*10^3	480
6MP	891*10^3	966
28MP	4185*10^3	5009

Real-time Photometric Stereo

Additional examples (30Mpix)

Real-time Photometric Stereo

Future and ongoing work

- **CPU:**
  - Extracting BRDFs
  - Classifying materials
- **GPU:**
  - Adding specularities
- **hardware:**
  - Microdome
  - Multi-spectral

Real-time Photometric Stereo

Conclusions

- **Robust Photometric stereo algorithm on GPU**
- **Allows for live processing and visual feedback during recording**
- **Future work on more complex material representation such as BRDFs** (also see S. Georgoulis, M. Proesmans, and L. Van Gool, *A Gaussian Process Latent Variable Model for BRDF Inference*, ICCV, 2015)


Thank you !