Automatic Registration and Calibration for Efficient Surface Light Field Acquisition

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Motivations

- Context:
  - National project funded by the french ministry of research.
  - RIAM-project *AMI3D* (no. 04 C 292).
  - *Archiving and Micro-Identification in 3 Dimensions*:
    - Visualization (virtual galleries).
    - Authentication.
- Goals:
  - *Visualization*: capturing the shape and the appearance.
  - Measurements made by non specialist operators:
    - Automated processings.

Motivations

Why surface light fields?

- Surface light field:
  - Representation of the radiance over the surface.
  - Free walkthrough within a fixed lighting environment.
- Our choice:
  - Rendering of art pieces in the conditions of the museum.
- Geometry and radiance must be captured.

Shape measurement
Problematic

- Digitization devices:
  - Not able to capture a whole surface at a time.
  - Require several acquisitions.
  - Each one is defined in its own local frame.
- Using a digitization bench:
  - Register the movement of the scanner wrt. the object.
  - Expensive device.
  - Mobility constraints: cannot be displaced to a measurement site.
- Numerical solutions are prefered.

Shape measurement
Related work

- Iterative methods:
  - [Besl 92], [Turk 94], [Benjemaa 99], [Greenspan 00], [Greenspan 01]
  - Accurate but not automatic (require an initial alignement).
- Feature extraction:
  - [Zhang 04], [Rusinkiewicz 02]
  - Automatic but scene dedicated methods.
- Invariant characteristics:
  - [Johnson 97], [Chen 98], [Zhang 99]
  - No assumption about the scene but computationnally expensive
- Global registration:
  - [Pulli 99], [Huber 01], [Nishino 02], [Zhang 04]
  - Often based on iterative methods: not totally automatic.

Radiance measurement
Problematic

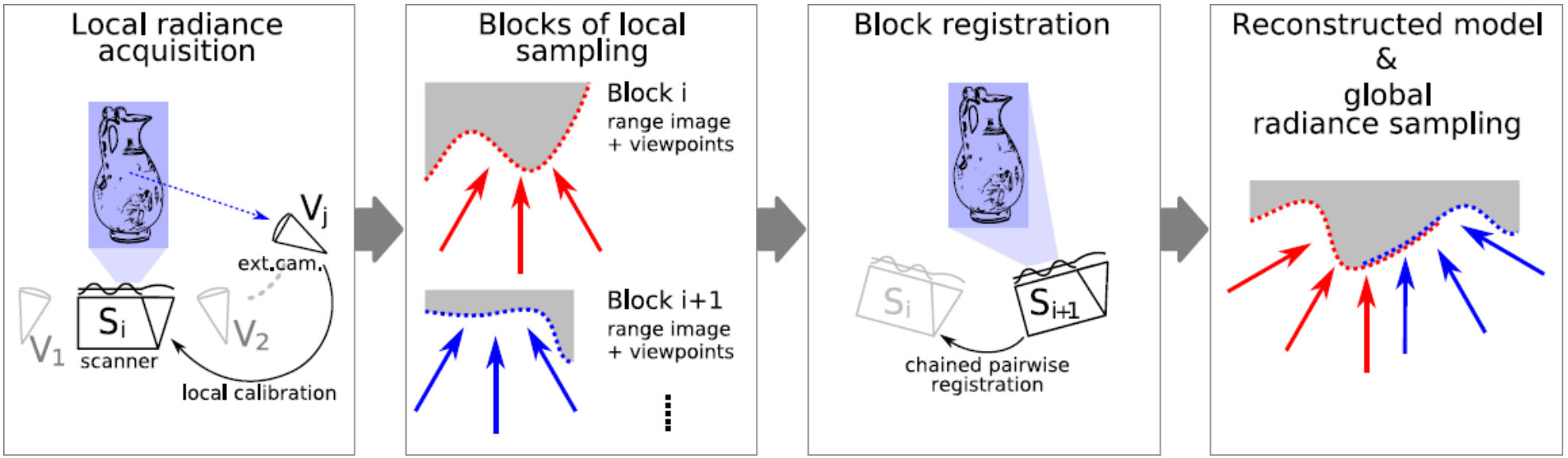
- Capturing effects due to the observer's displacements:
  - Sampling from multiple viewpoints.
- Interpreting the resulting data:
  - Determining viewpoint for each picture.
  - Registering pictures with the acquired geometry.
- Solved by using a camera calibration solution:
  - Point-pixel correspondences must be known.

Radiance measurement
Related work

- Target extraction:
  - [Chen 02]
  - Occlusion problems.
  - Image segmentation may fail.
- Silhouette matching:
  - [Matsushita 99]
  - May fail with symetrical object.
- Infering image-to-geometry correspondences:
  - [Franken 05]
  - Able to automatically generate new correspondences.
  - But an initial set must be provided.

Acquisition of surface light fields
Method overview

- Our acquisition protocol:
  - Automatic range image registration / camera calibration.
  - Mobility constraint – only a lightweight device involved.
  - Suited to the measurement of art pieces.
  - Fast – interactive feedback during the measurement.



Acquisition of surface light fields
Structured light & parameterization

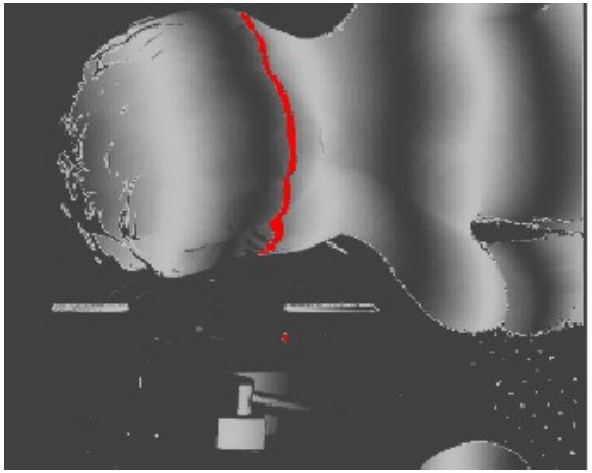
- Phase-shifting structured light:
  - Projection of a gray-scale sinusoid.
  - Capture of the sinusoid phase at each surface point.
- Induce a 1D-parameterization of the surface:
  - Produce a set of strictly different iso-phase lines.

Projection of a gray scale sinusoidal pattern

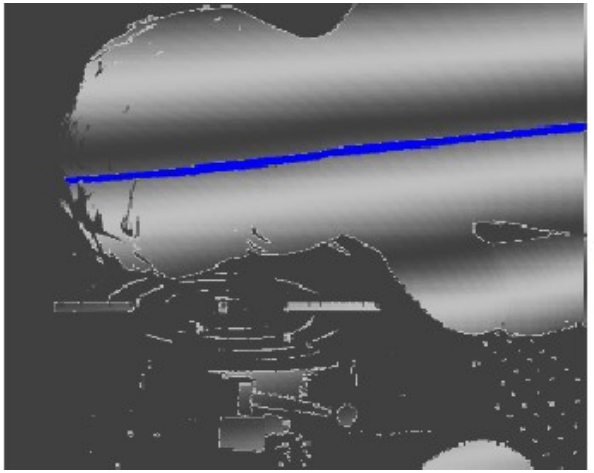
Iso-phase lines observed on the phase map

Acquisition of surface light fields
Structured light & parameterization

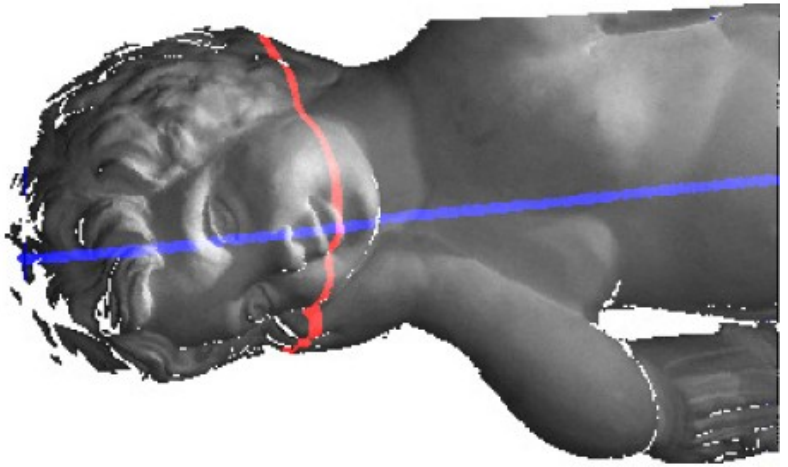
- Extension to a 2D-parameterization:
  - Projection for two stripes orientations.
  - Each surface point is the intersection of two iso-phase lines.
  - Defines a unique couple of coordinates.



1D-parameterization for the first stripes orientation



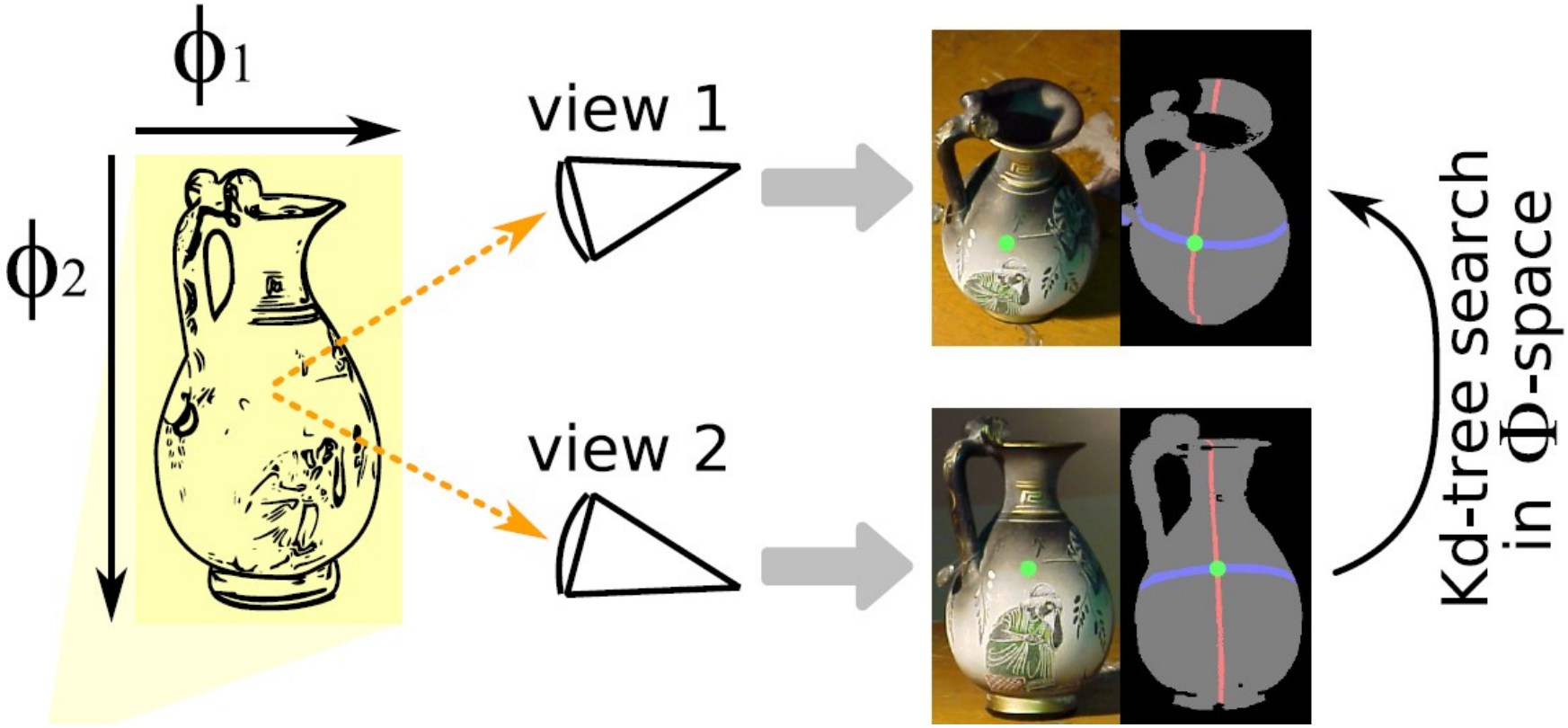
1D-parameterization for the second stripes orientation



A unique couple of coordinates is defined at each surface point

Acquisition of surface light fields
Structured light & parameterization

- Extraction of correspondences:



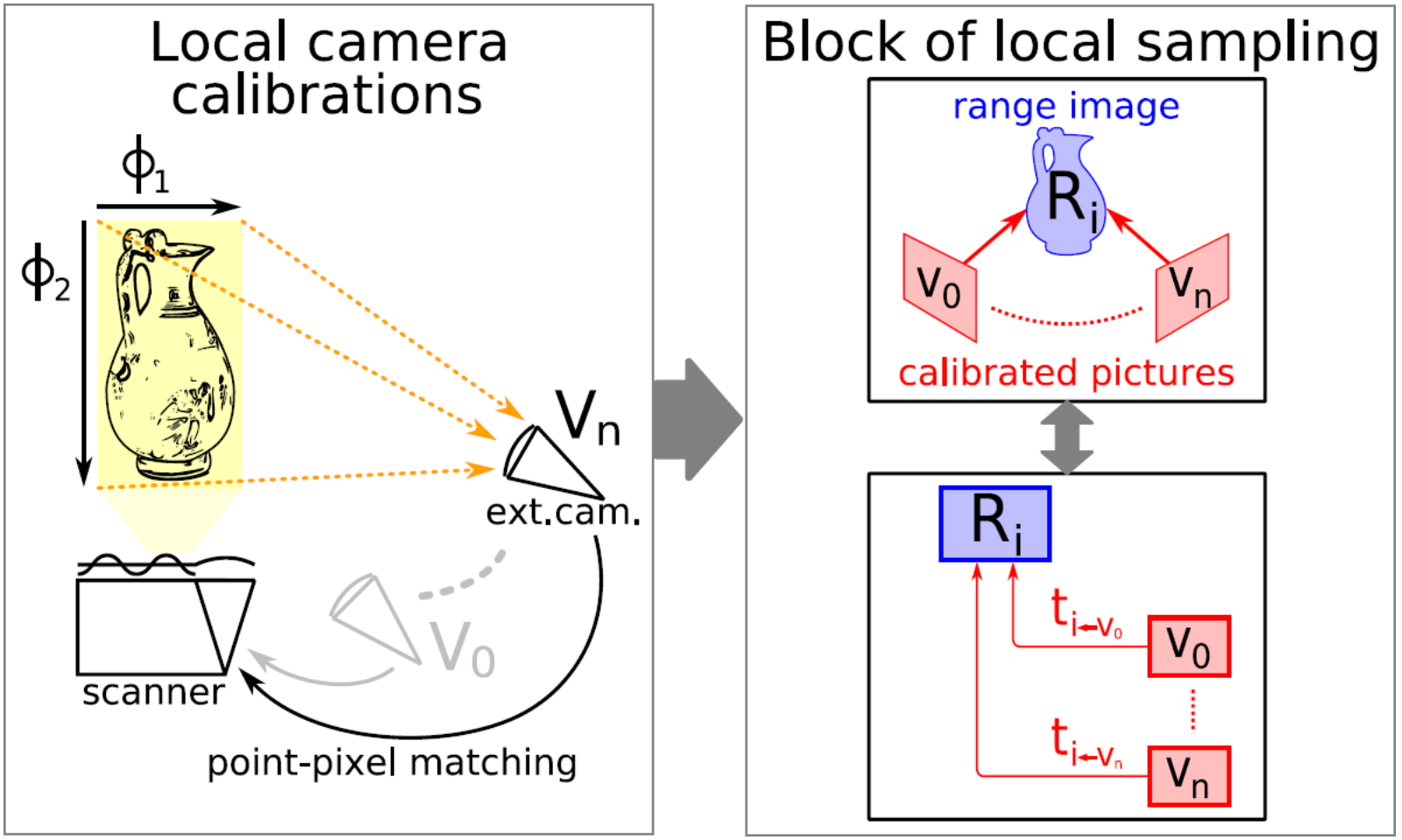
Projection of the 2D-parameterization

Acquisition of the 2D-parameterization from two different viewpoints

Search inside the two viewpoints the elements whose phase coordinates are similar

Acquisition of surface light fields

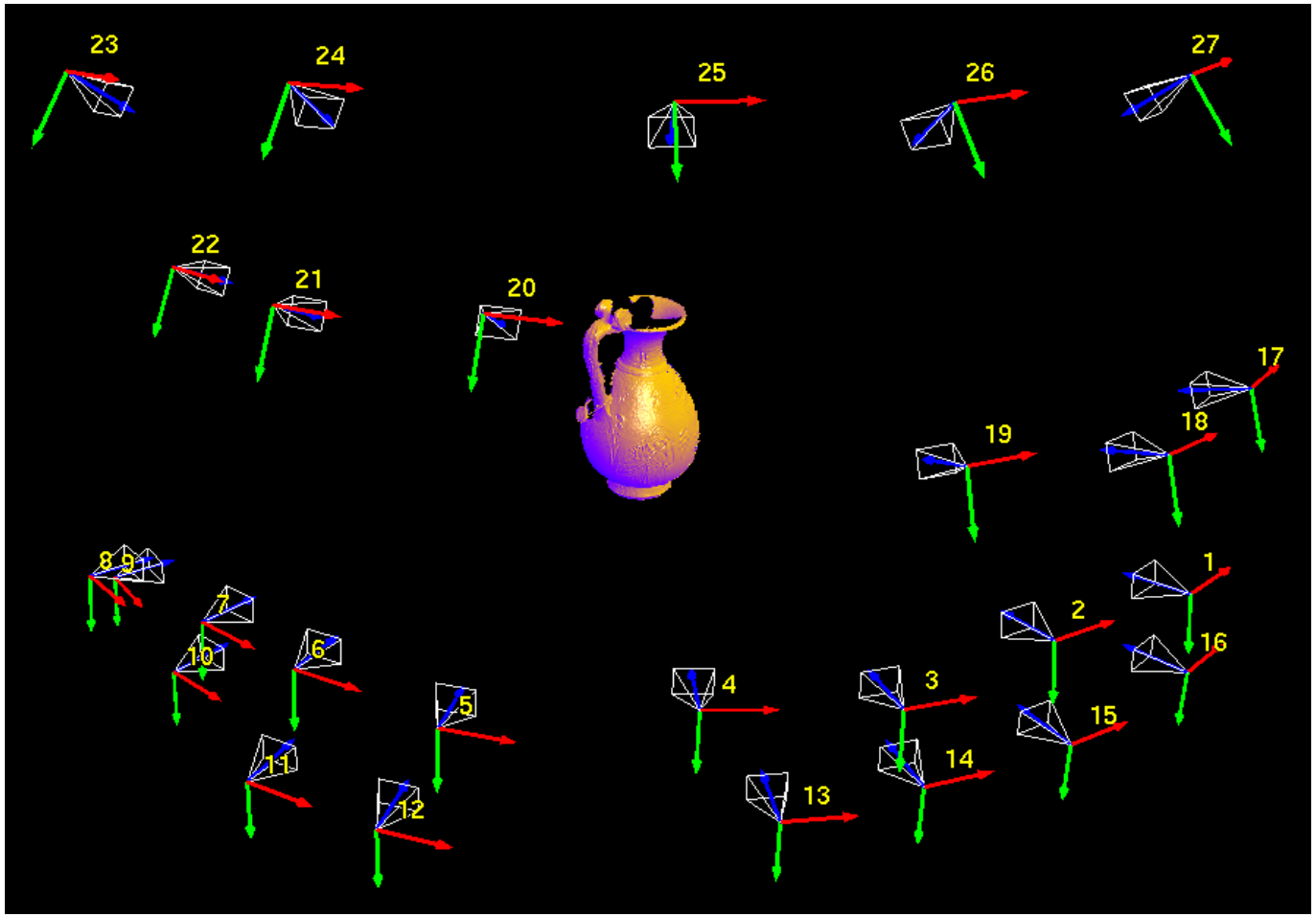
Step 1 – Local sampling block



The radiance is locally sampled by a set of pictures calibrated with respect to the current range image

Acquisition of surface light fields

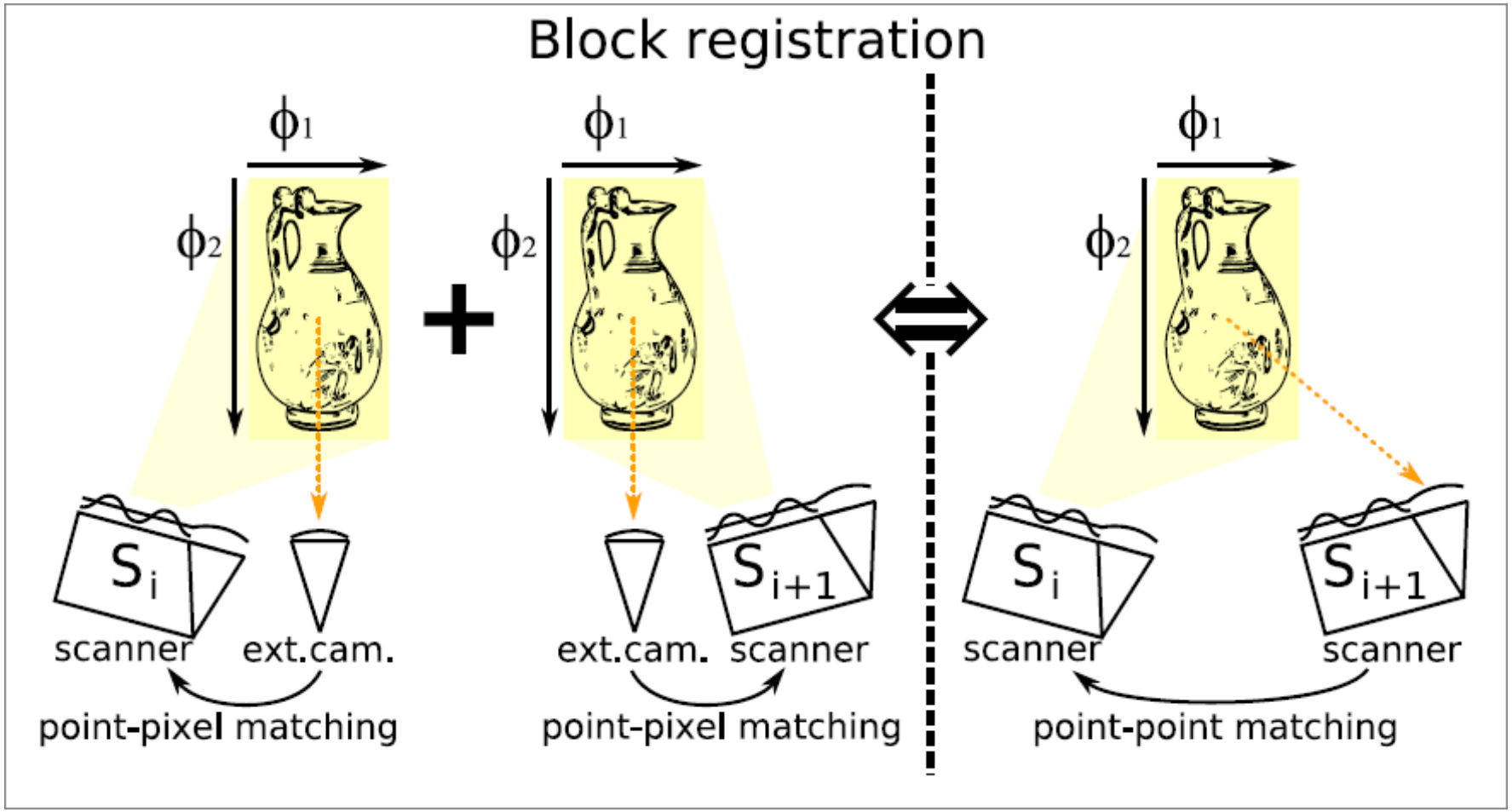
Step 1 – Local sampling block



The example of an acquired local sampling block, made of a range image and a set of locally calibrated viewpoints

Acquisition of surface light fields

Step 2 – Block registration



The use of the external camera as a fixed reference between two successive scanner poses

Acquisition of surface light fields
Step 3 – Merge data

- Mesh reconstruction:
  - Merging the overlapping registered range images.
  - VRIP algorithm [Curless 96].

- Set radiance on geometry:
  - Associate the appropriate sampling to each geometric primitive.
  - Image space reprojection of the reconstructed mesh.
  - Use the optical parameters fitted during viewpoints calibration.

Results
Renderings

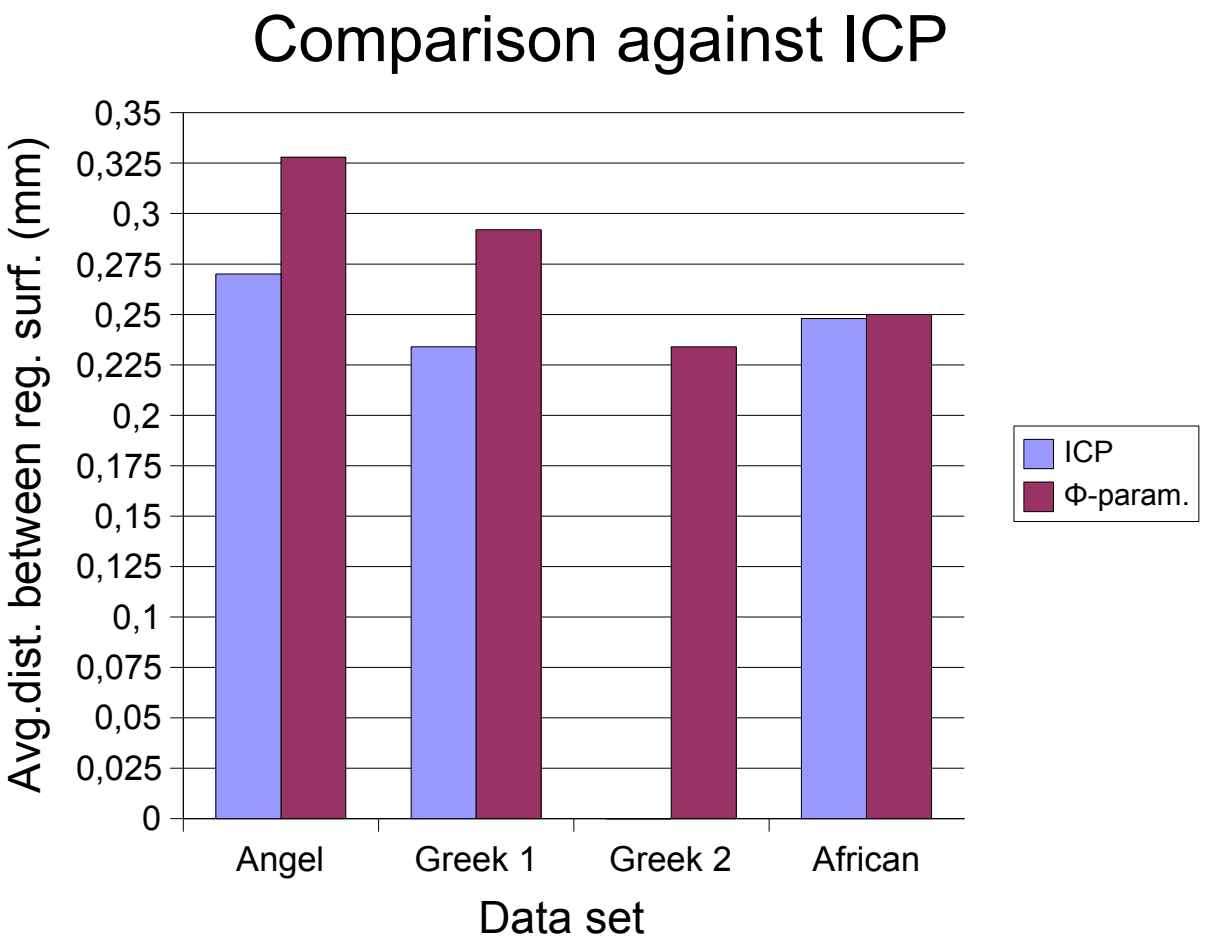
- Renderings of two acquired surface light fields:

The African wood statue:
***6** range images, **42** viewpoints*

The Greek vase:
***5** range images, **23** viewpoints*

Results

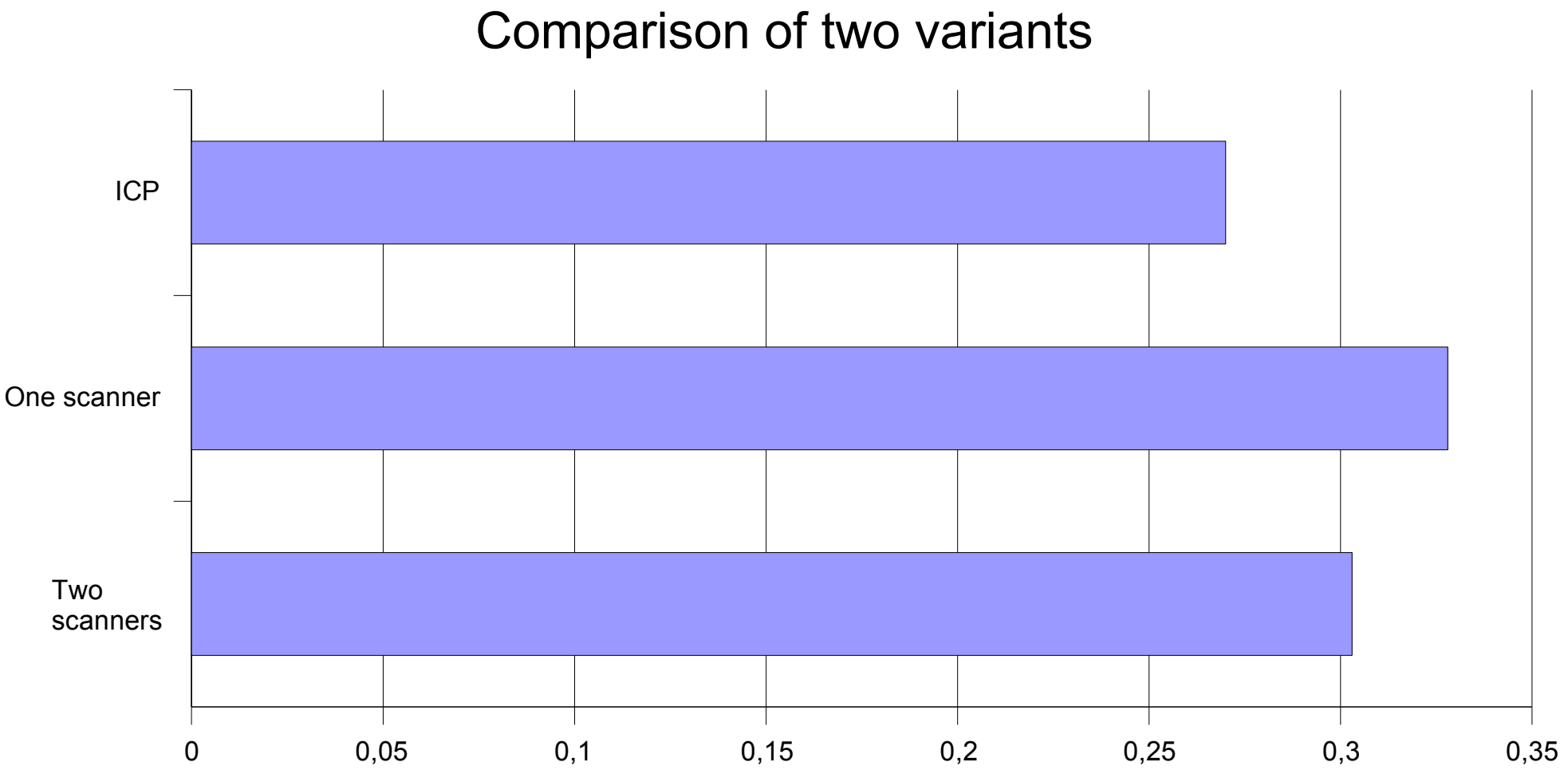
Registration accuracy



- Our method is less accurate...
- But ICP is not totally automatic.
  - May fall into a local minimum.

Results

Registration accuracy



- The intermediate camera introduces additionnal uncertainties.
- Two scanners: more accurate, but less than ICP.

Results
Registration accuracy

- Evaluation of the error accumulation:

Average distance of all registered pairs	*Distance between the first and the last range images*
0.243mm	0.477mm

*Measurement of the error accumulation for the registration chain of the Venus at Bath, made of **23** range images*

- *Venus at bath*: chained registration of 23 range images:
  - The accumulation has a low incidence.
- Induces no significant reconstruction artifact.

Results
Registration speed

- Timings for pairwise registration:

Nb. points in the 1st scan	*Nb. points in the 2nd scan*	*Nb. corres. found*	*Registration time (ms)*
325K	331K	15K	629
331K	329K	2K	455
75K	76K	3K	419
215K	182K	10K	579
23K	20K	11K	250

Number of correspondences found and the registration time for several pairs of scans

- Many registration points available.
- Fast compared to iterative methods.
  - Provide an interactive feedback.

Results
Camera calibration

- Timings for viewpoint calibration:

Set	*Nb. corres. found*	*Calibration time (ms)*
Greek, view 2	15K	1073
Greek, view 16	2.9K	514
Greek, view 27	19K	1327
African, view 9	0.7K	286
African, view 36	31K	1419
African, view 39	16K	881

  - Many calibration points available.
  - Fast enough to be used interactively.

Conclusion

Contribution

- Acquisition of surface light fields from real objects:
  - Automatic camera calibration
  - Automatic range image registration.
- Suited to digitize art pieces:
  - No contact.
  - No displacement.
- Interactive speeds:
  - Provide an interactive feedback during the measurement.

Conclusion
Drawbacks

- Chained pairwise registration:
  - Cumulative error.
  - *But*: good starting point for a global registration solution.
- Radiance acquisition:
  - For each viewpoint: 1 picture + 2D-parameterization.
  - Forbids the use of a hand-held camera.
  - Acquisition time may be increased.

Conclusion

Future works

- Full bi-directional acquisition:
  - Take account of the lighting variations.
  - Must to localize a light source.
  - Evaluation of the incidence of the sampling density.

Questions?

- Thank you for your attention.