電腦視覺與應用
Computer Vision and Applications

Lecture02-2-Pinhole camera-Visual Hull case study

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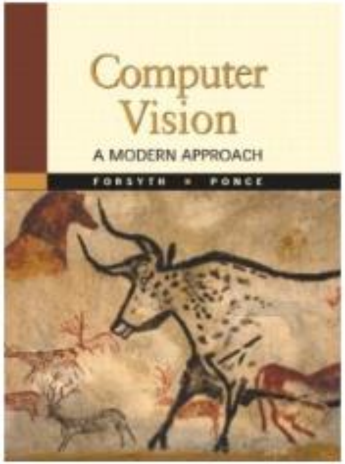
Pinhole Camera

- Case study
  - A simple visual hull algorithm
  - Shape from Silhouette
- To practice the equation of "projection from 3D to 2D"

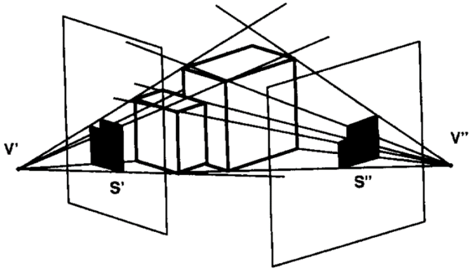
Pinhole Camera

- Lecture reference coverage in following:
  - Computer Vision A Modern Approach, Chapter 26 (partly).
  - And miscellaneous papers from internet resource.



Visual Hull (sentences from Wiki)

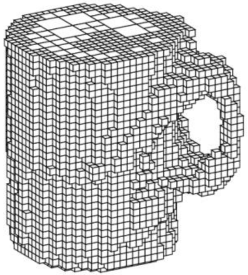
- “A visual hull is a geometric entity created by shape-from-silhouette 3D reconstruction technique introduced by A. Laurentini. This technique assumes the foreground object in an image can be separated from the background. Under this assumption, the original image can be thresholded into a foreground/background binary image, which we call a silhouette image. The foreground mask, known as a silhouette, is the 2D projection of the corresponding 3D foreground object. Along with the camera viewing parameters, the silhouette defines a back-projected generalized cone that contains the actual object. This cone is called a silhouette cone. The upper right thumbnail shows two such cones produced from two silhouette images taken from different viewpoints. The intersection of the two cones is called a visual hull, which is a bounding geometry of the actual 3D object (see the bottom right thumbnail).”



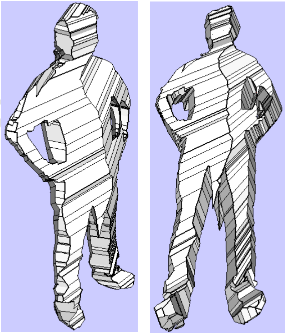
A. Laurentini. "The visual hull concept for silhouette-based image understanding". IEEE Trans. Pattern Analysis and Machine Intelligence.. pp. 150–162.

Visual Hull → Shape from Silhouette

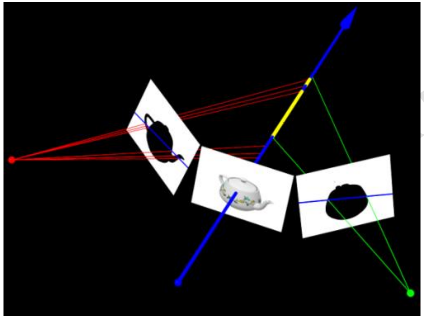
- Three categories from methods
  - Voxel based extraction
  - Exact Polyhedral visual hull
  - Image-based visual hull



1



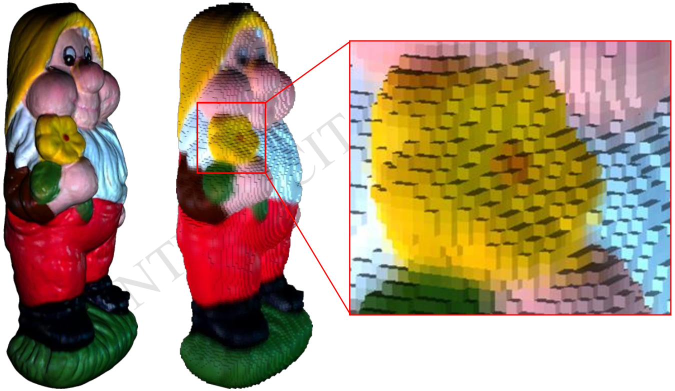
2



3

Voxel (Definition)

“A voxel (volumetric pixel or, more correctly, Volumetric Picture Element) is a volume element, representing a value on a regular grid in three dimensional space.” (sentence from wikipedia)

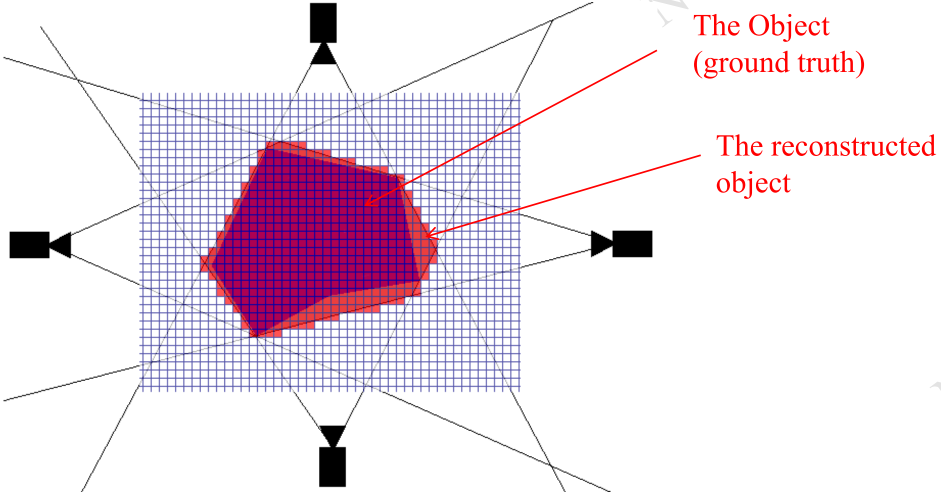


Meshes Voxels

http://www.aardvark3ddesign.co.uk/images/mario/mario007.jpg

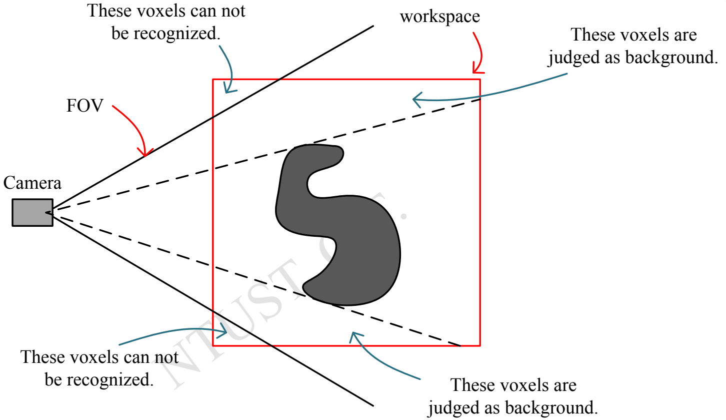
Shape from Silhouette

- Basic idea…

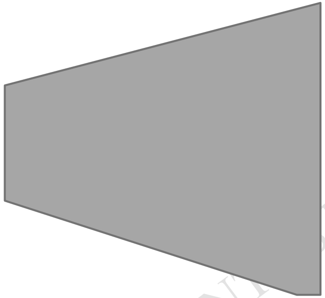


Shape from Silhouette

- Example for 2D Case in One view image



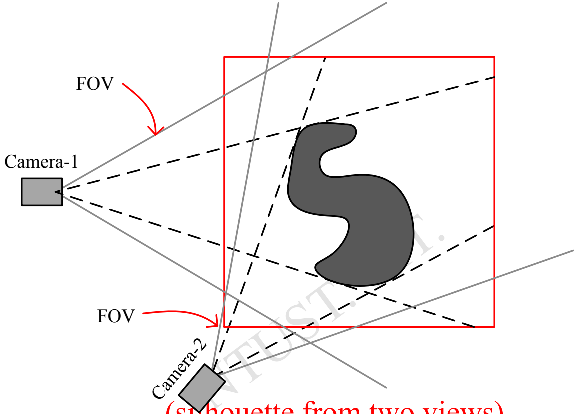
(silhouette from one view)



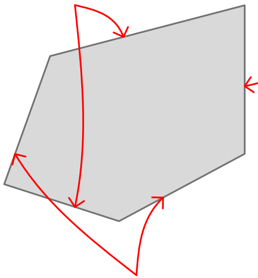
Reconstructed model

Shape from Silhouette

- Example for 2D Case in Two view images



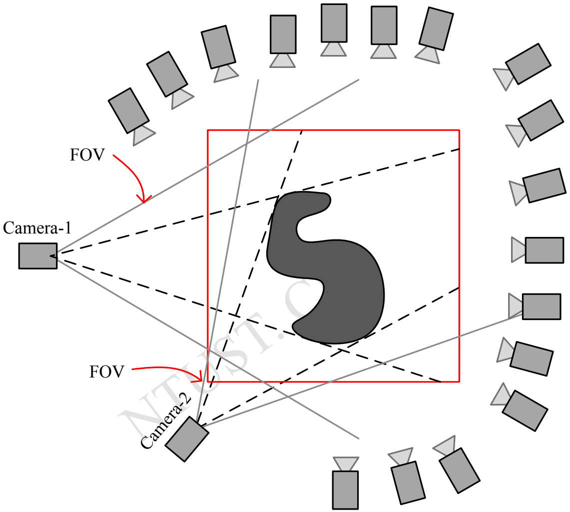
(silhouette from two views)



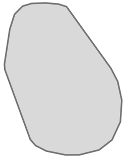
Reconstructed model

Shape from Silhouette

- Example for 2D Case in Many view images



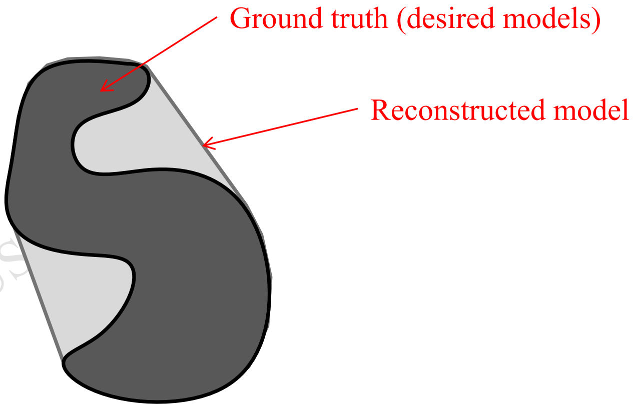
(silhouette from many views)



Reconstructed model
(convex hull)

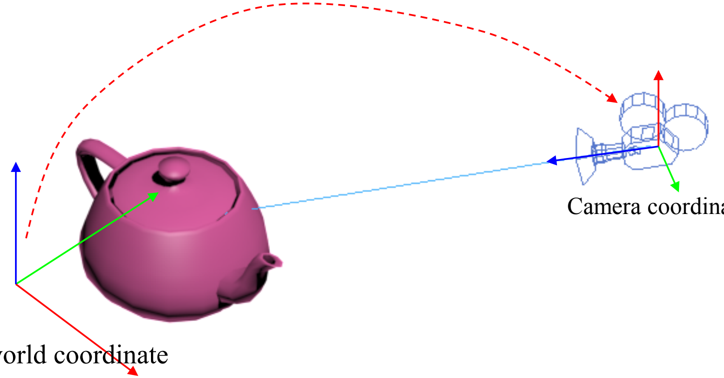
Shape from Silhouette

- Note: the reconstruction model from visual hull is NOT necessary to be always convex (or says convex hull). Why?



Shape from Silhouette

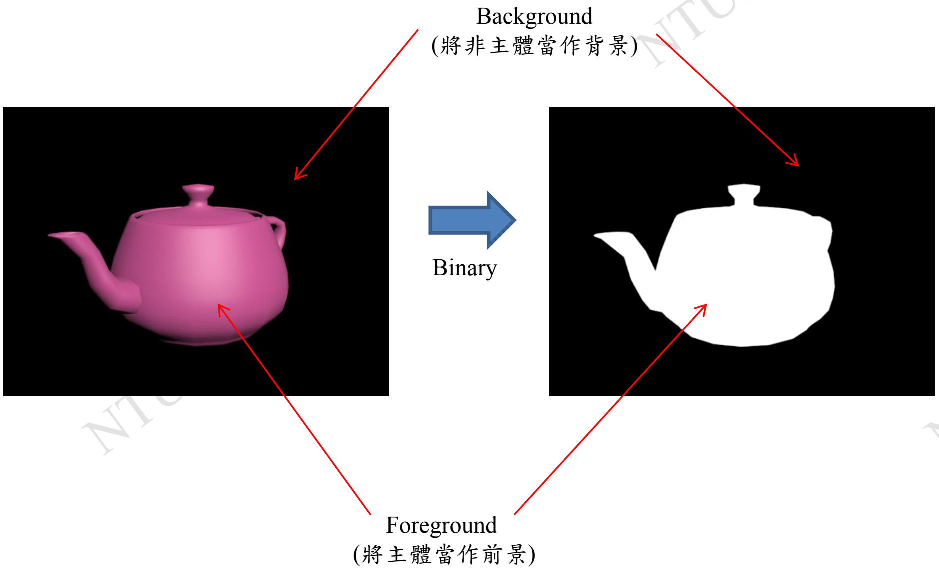
- What do intrinsic and extrinsic parameters mean?



Applying intrinsic parameter

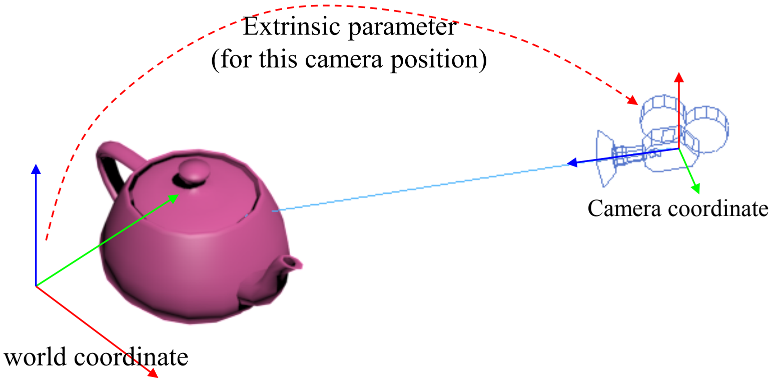
Shape from Silhouette

- What does background subtraction do?

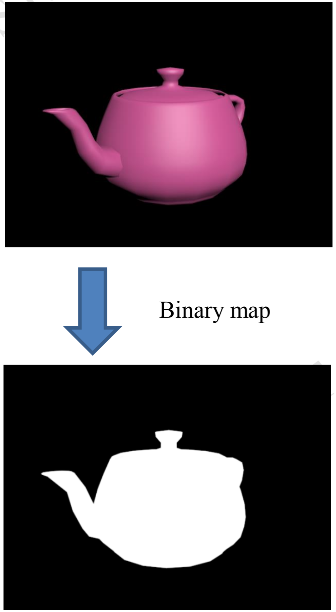


Shape from Silhouette

- Summary

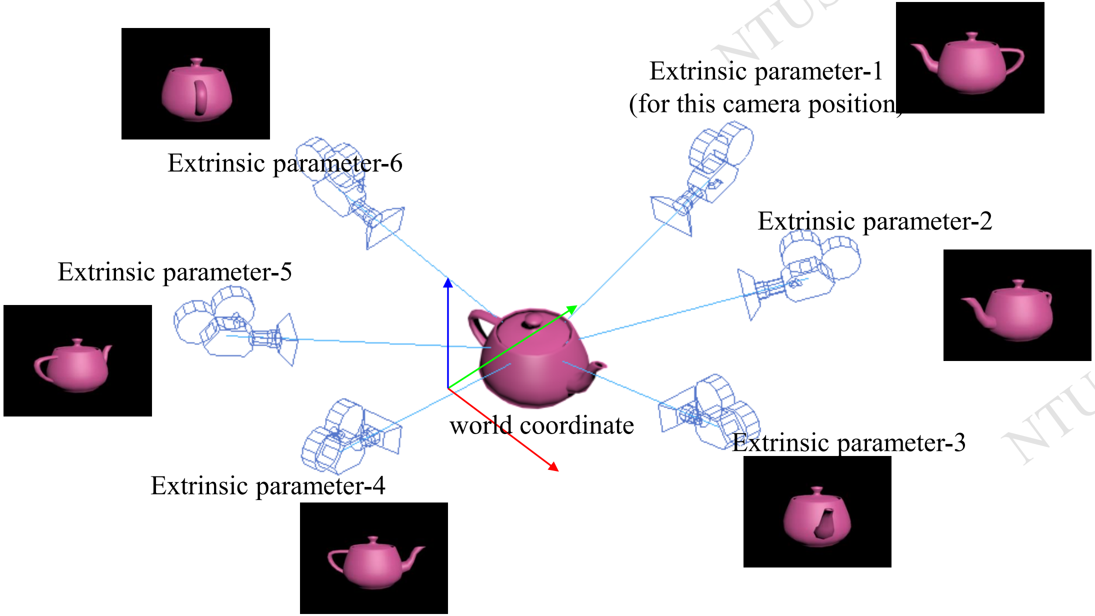


Applying intrinsic parameter



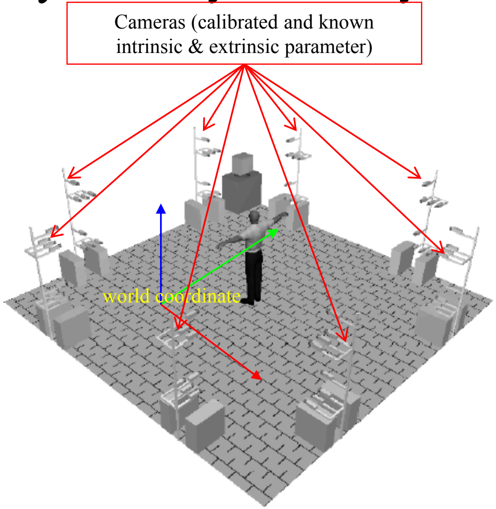
Shape from Silhouette

- Example



Shape from Silhouette (voxel based)

- To be a dynamic system. 8 sync. cameras



Solution:
When cameras' parameters are known (here, for example, eight cameras)
1.Create finite voxels in world coordinate
2.Projection for every voxel to each camera, and judge their existences.

3D reconstruction

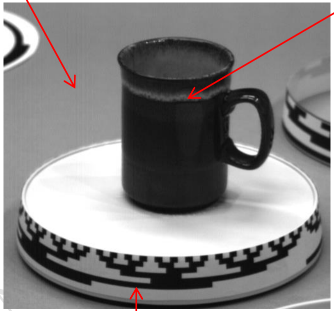
Borovikov, E. and Davis, L. 2000. A distributed system for real-time volume reconstruction. *Computer Architectures for Machine Perception, 2000. Proceedings. Fifth IEEE International Workshop on* (2000), 183–189.

Shape from Silhouette (voxel based)

- One camera + turntable (static object)

Background
(除了想建構的3D model之外的所有pixel都視為背景)

Foreground
(想建構的3D model)



One kind of Checkerboard
(for determining Extrinsic parameter)

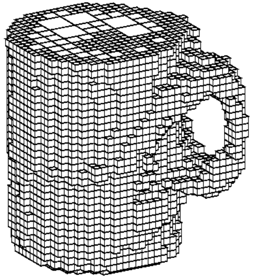
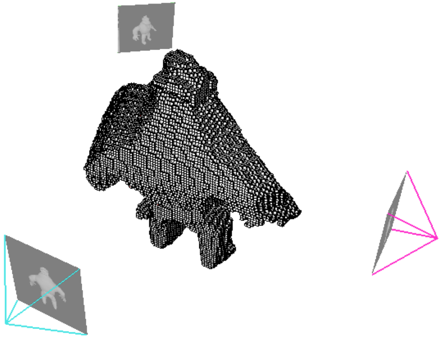


Image by Richard Szeliski

Shape from Silhouette (voxel based)

Summary for the requirement of algorithm

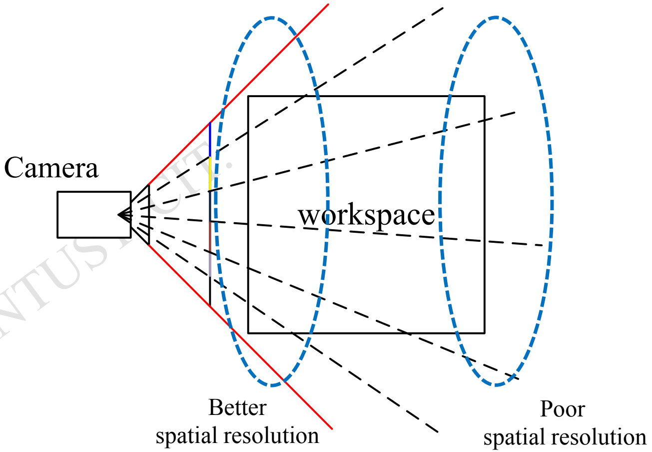
- At least one view (known intrinsic & extrinsic parameters).→ Camera Calibration.
- In each view, background and foreground pixels are needed to be identified. → In practice, "Background subtraction" algorithms may be used.
- The workspace in world coordinate should be defined. → define the volume of one voxel.



Shape from Silhouette (voxel based)

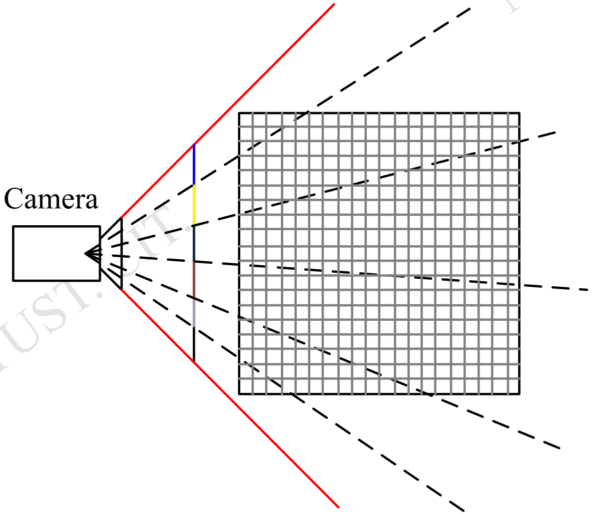
The spatial resolution issue:

- What is the resolution for better quality?
- for example in 2D, → the far, the poor spatial resolution.



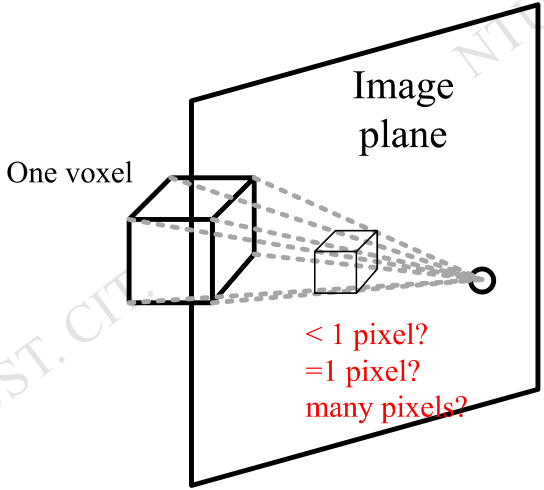
Shape from Silhouette (voxel based)

- The voxel size has a limitation due to spatial resolution.



Shape from Silhouette (voxel based)

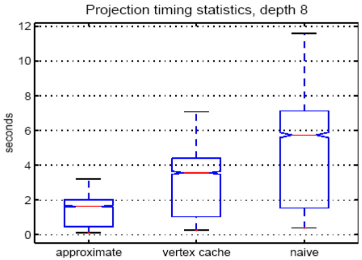
- Voxel size and the projection size issue.



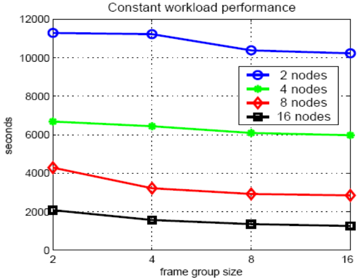
Shape from Silhouette (voxel based)

The speed-up strategy (performance issue)

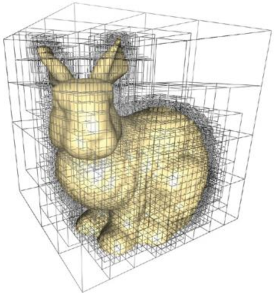
- Use Octree for hierarchically encoding voxels.
- Approximate the “cube” projection
- Parallel processing (clustering)



Voxel projection time



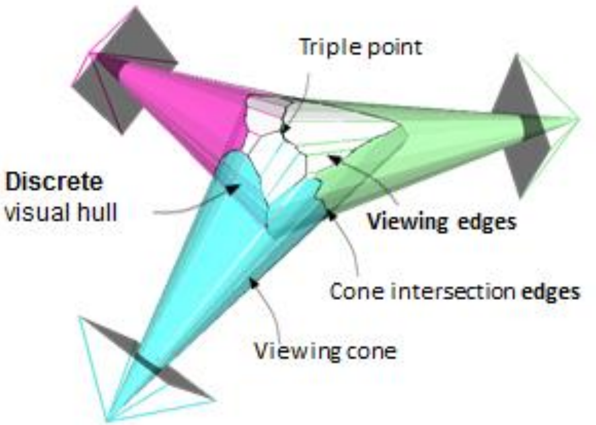
server performance

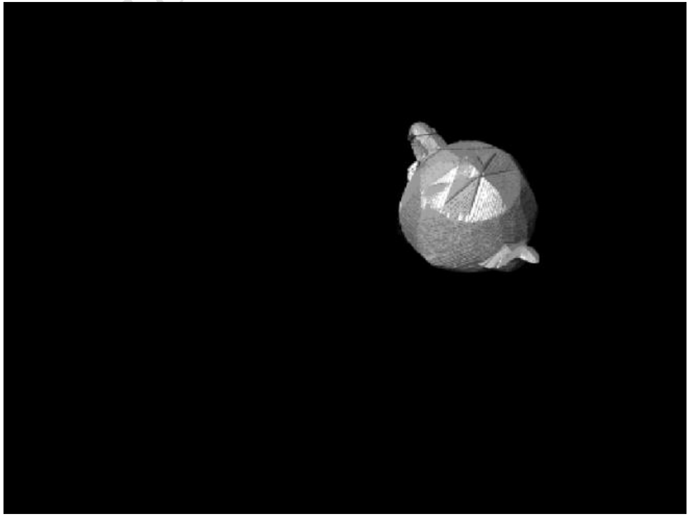


16 PCs (P2-450MHz)
100MBit networks(TCP/IP)

Borovikov, E. and Davis, L. 2000. A distributed system for real-time volume reconstruction. *Computer Architectures for Machine Perception, 2000. Proceedings. Fifth IEEE International Workshop on* (2000), 183–189.

Exact Polyhedral Visual Hulls (EPVH) Algorithm

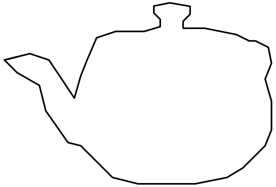




Exact Polyhedral Visual Hulls (EPVH) Algorithm

- Pre-processing: Before processing EPVH algorithm, you may need to "vectorize" your foreground object.

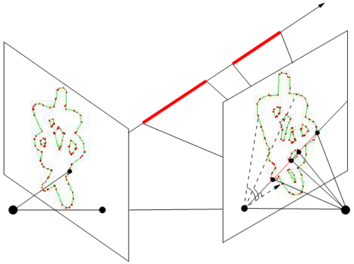
n pixels → foreground

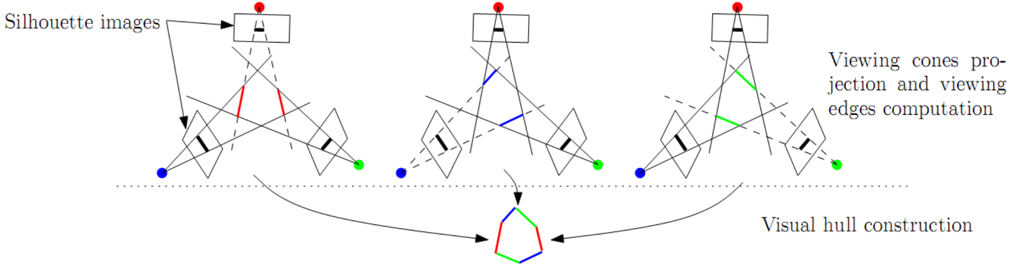


m vertexes for bounding a shape

Exact Polyhedral Visual Hulls (EPVH) Algorithm

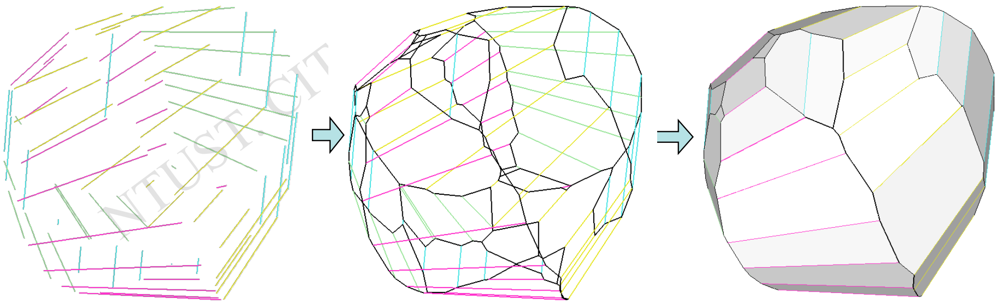
- Determination for viewing edges (epipolar geometry)





Exact Polyhedral Visual Hulls (EPVH) Algorithm

- 3 Steps to EPVH
  - 1. Compute viewing edges
  - 2. Cone intersection edges and triple points
  - 3. Faces.



Exact Polyhedral Visual Hulls (EPVH) Algorithm

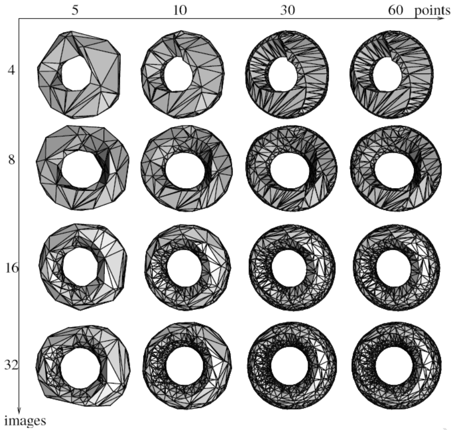
- First, silhouette images are converted to polygons. (convex or non-convex, with holes allowed)
- Each edge is back projected to form a 3D polygon.
- Then each polygon is projected onto each image, and intersected with each silhouette in 2D.
- The resulting polygons are assembled to form the polyhedral visual hull

Exact Polyhedral Visual Hulls (EPVH) Algorithm

- Speed v.s. Completeness

Algorithm 1 Visual hull surface points

for all contours O_j^i in all images: **do**
  for all images k such that $k \neq i$: **do**
    for all points p_j^i in O_j^i : **do**
      compute the epipolar line l of p_j^i in image k,
      for all contours O_l^k in image k: **do**
        compute the intersections of l with O_l^k,
        update depth intervals along the viewing line of p_j^i,
      end for
    end for
    compute the 3D points delimiting intervals along the viewing line of p_j^i.
  end for
end for



Hybrid algorithm

Viewing Edges (Calculation for all epipolar lines) → Retrieve all vertexes → 3D Delaunay Triangulation (may generate interior facets) → Remove all interior facets (The reminder is the answer)

Lower complexity
But efficiency Dominated

Higher complexity
But NOT efficiency Dominated

Exact Polyhedral Visual Hulls (EPVH) Algorithm

- Parallel processing to real-time

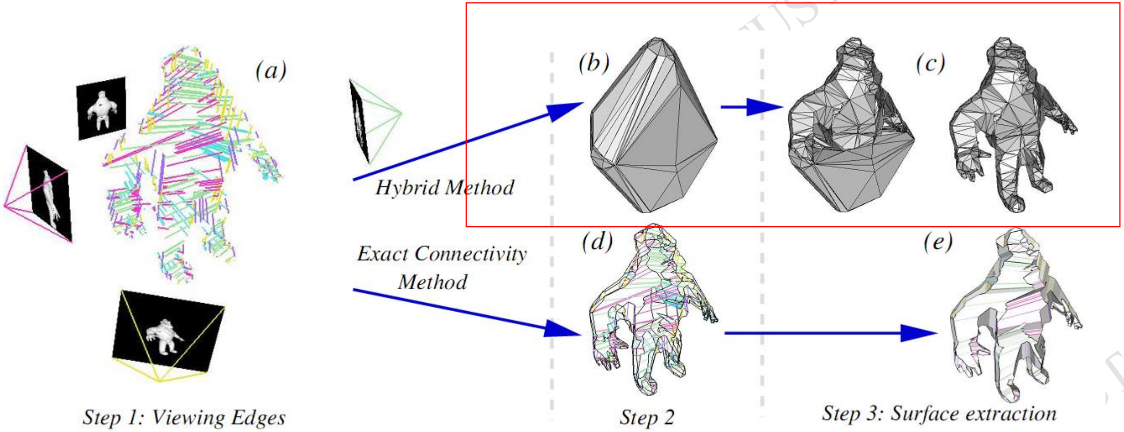


Figure 3: Outline of the visual hull modeling techniques chosen for parallelization. (a) Images of an object are taken, silhouettes are identified, their contours vectorized, and viewing edges are computed for each point of the discretization. (b) The hybrid method computes the Delaunay tetrahedron decomposition of space based on viewing edge vertices. (c) Each tetrahedron is carved according to silhouette consistency, and the final visual hull model is obtained. (d) The exact connectivity method computes the cone intersection components belonging to the visual hull, to complete the entire visual hull polyhedron mesh. (e) Faces are extracted from the mesh representation and the final polyhedron model of the visual hull is obtained.

J.-S. Franco, C. Menier, E. Boyer, and B. Raffin, "A Distributed Approach for Real Time 3D Modeling," *2004 Conf. Comput. Vis. Pattern Recognit. Work.*, 2004.

Exact Polyhedral Visual Hulls (EPVH) Algorithm

- More examples…

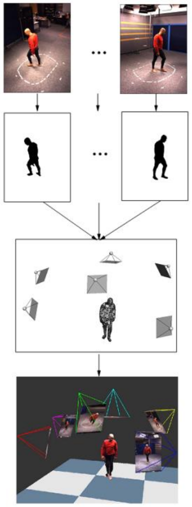
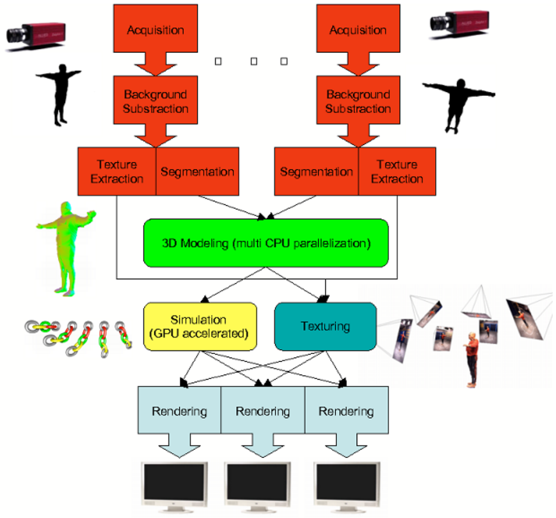
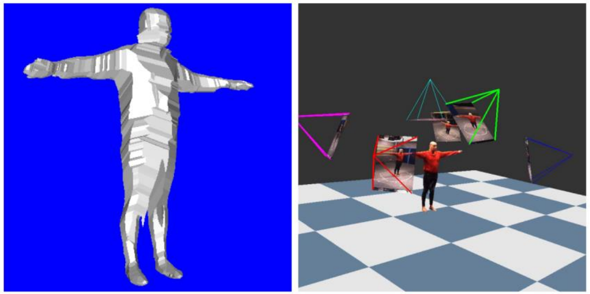


Figure 1. From multi-camera videos to dynamic textured 3D models

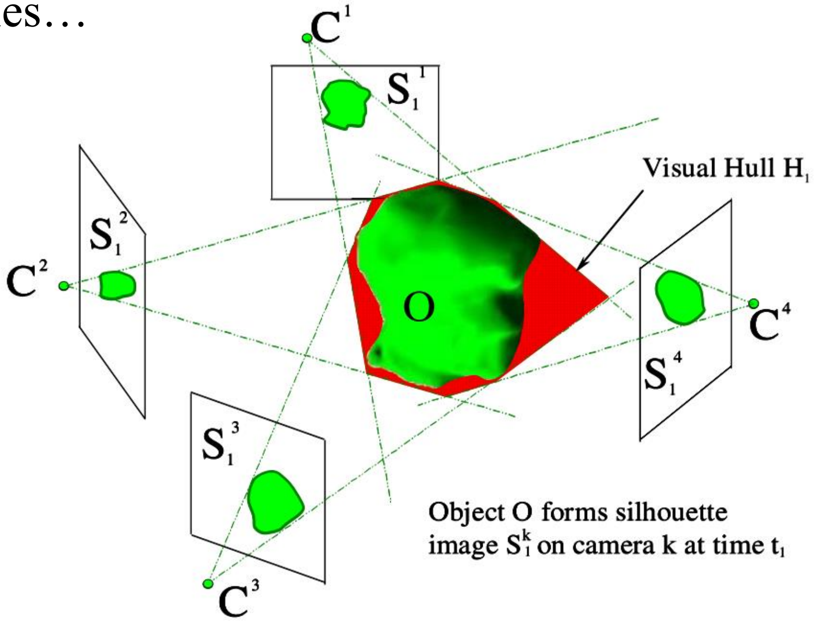




Allard, J., Franco, J.S., Ménier, C., Boyer, E. and Raffin, B. 2006. The grimage platform: A mixed reality environment for interactions. *Computer Vision Systems, 2006 ICVS'06. IEEE International Conference on* (2006), 46–46.

Exact Polyhedral Visual Hulls (EPVH) Algorithm

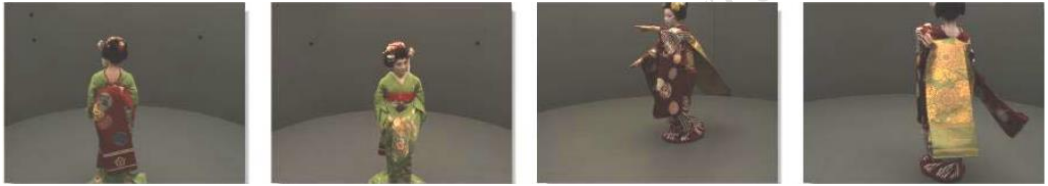
- More examples…

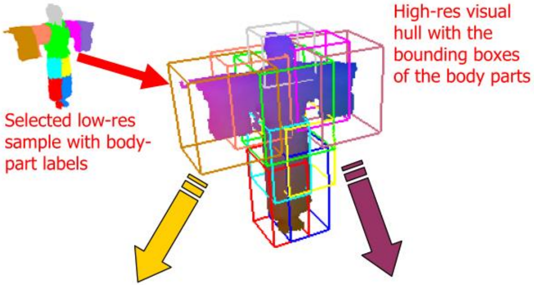


Cheung, G.K.M. 2003. Visual Hull Alignment and Refinement Across Time : A 3D Reconstruction Algorithm Combining Shape-From-Silhouette with Stereo. *Pattern Recognition*. (2003).

Exact Polyhedral Visual Hulls (EPVH) Algorithm

- More examples…

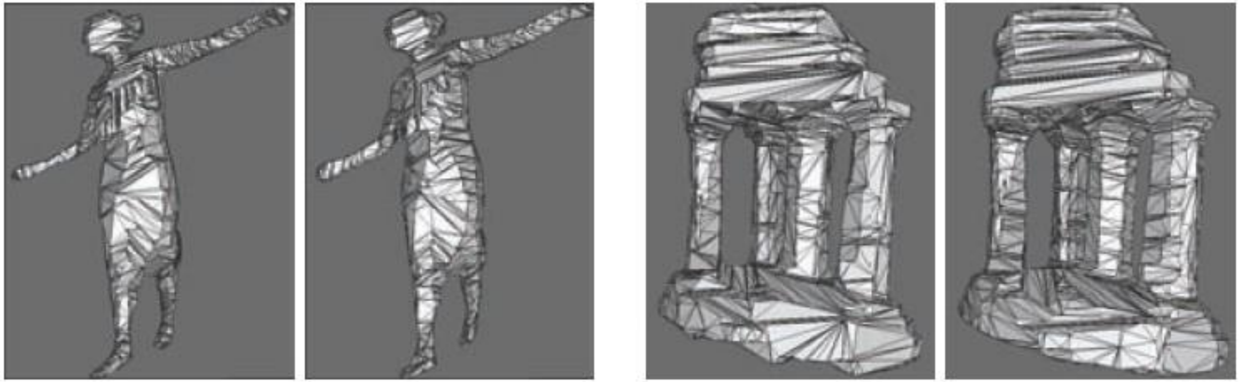




from Prof. Norimichi Ukita

Exact Polyhedral Visual Hulls (EPVH) Algorithm

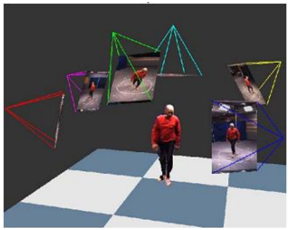
- More examples…

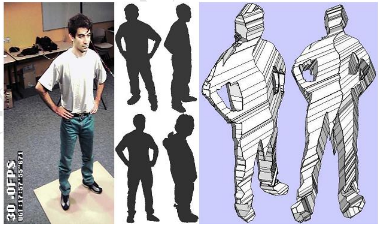


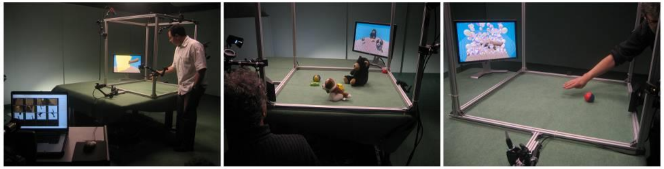
Lee, W., Woo, W. and Boyer, E. 2007. Identifying foreground from multiple images. Proceedings of the 8th Asian conference on Computer vision-Volume Part II (2007), 580–589.

Exact Polyhedral Visual Hulls (EPVH) Algorithm

- Famous team
  - 2003 VVG, Real-Time Capture, Reconstruction and Insertion into Virtual World of Human Actors (INRIA)
  - 2007 SIGGRAPH Grimage Markerless 3D Interactions
  - 2006 ICVS A Mixed Reality Environment for Interactions
  - 2004 IPT Marker-less Real Time 3D Modeling for Virtual Reality

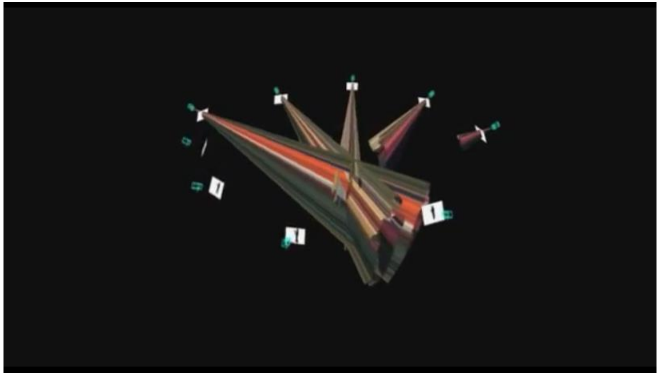


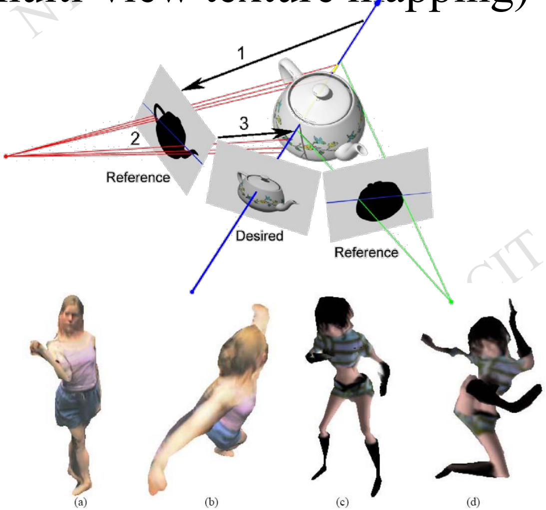




Multi-view in 3D reconstruction (silhouette)

- 4D data (for replay)
- Image based rendering (View-dependent multi-view texture mapping)





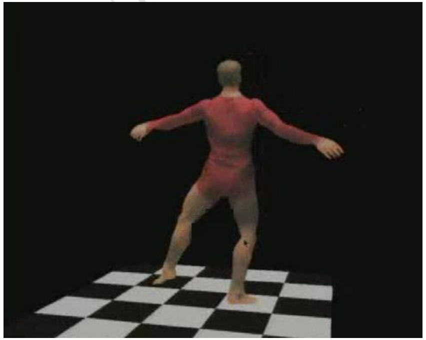
https://youtu.be/21YUA-SalO0

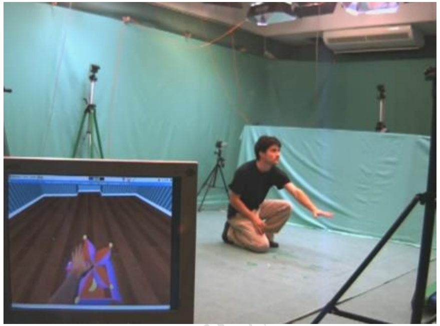
W. Matusik, C. Buehler, R. Raskar, S. J. Gortler, and L. McMillan, "Image-based visual hulls," *Proc. 27th Annu. Conf. Comput. Graph. Interact. Tech. - SIGGRAPH '00*, pp. 369–374, 2000.

http://people.csail.mit.edu/wojciech/IBVH/index.html

Exact Polyhedral Visual Hulls (EPVH) Algorithm

- Video demo example





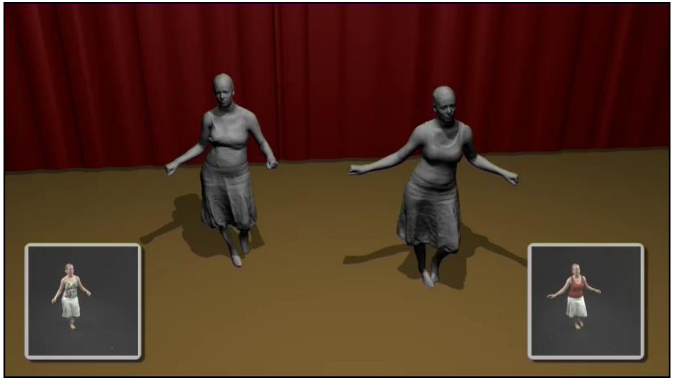
http://www.youtube.com/watch?v=ZG53YDVW1Ik
http://www.youtube.com/watch?v=YsbIxB_KU8E

Application and video demo

- Motion analysis—cont.

Fundamentals and Current Technique

- Multi-view video – dynamic 3D reconstruction



SIGGRAPH 2008

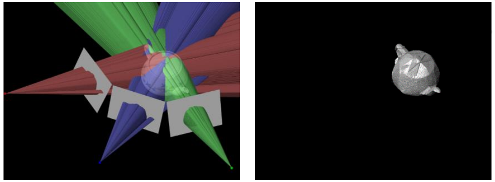
Background: limitation of modern 3D scanner

- Modern 3D scanners have difficult on obtaining intricate objects, particularly for translucent material, , thin and tiny structures.
- The surface properties, such as reflectance, color and roughness, usually affect the scanning accuracy.
- For conventional 3D scanners, the post-production, including noise removal, hole-filling, merging and integration, are time-consuming and unpredictable.

Why “shape from silhouette(SFS)” works

- A famous algorithm called “visual hull” is widely used for carving the 3D shapes from their silhouettes.
- To avoid inconsistent 3D estimation due to surface properties.
- No systematic error from merging procedures

Voxel based visual hull



Exact polyhedral visual hull (EPVH)

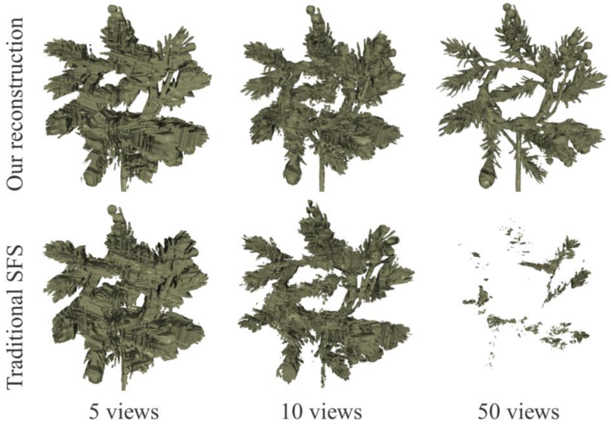
Richard Szeliski 2003

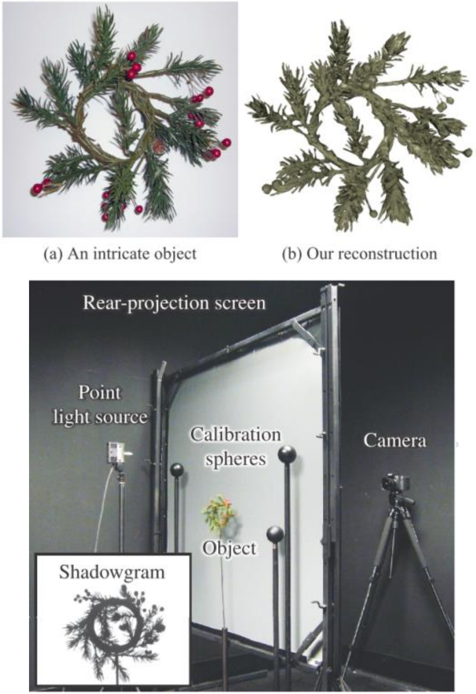
Why we use shadows for SFS?

- To extend to the limitation of DOF in cameras.
- To obtain distinct silhouettes rather than those from image post processing.
- Much easy to identify the silhouette boundary, particularly for translucent or intricate objects.
- Based on off the shelf components, affordable, and no optical design is required.

Visual hull for 3D reconstruction

- The number of views issue:
  - The more views, the better reconstruction ?
  - NOT exactly, for example:





Yamazaki, S., Narasimhan, S., Baker, S. and Kanade, T. 2007. Coplanar shadowgrams for acquiring visual hulls of intricate objects. *Computer Vision, 2007. ICCV 2007. IEEE 11th International Conference on* (2007), 1–8.

Visual hull for 3D reconstruction

- Shadow art

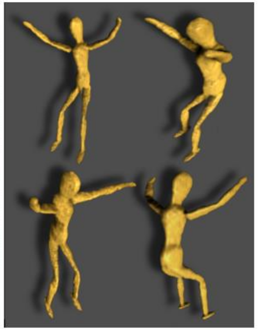
https://www.youtube.com/watch?v=GV8umUgohcg

Visual hull for 3D reconstruction

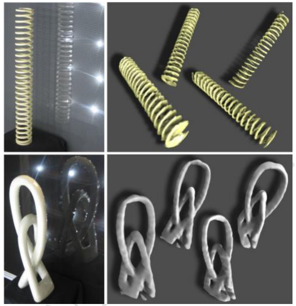
- Multiview Visual-Hull based algorithm: Shape from silhouette (Shadow silhouette-2)

Hardware setup

Shadows



Reconstructed 3D



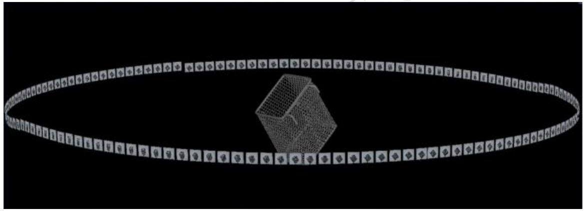
Reconstructed 3D (another example)

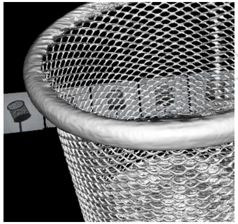
D. Lanman, R. Raskar, A. Agrawal, and G. Taubin, “Shield fields modeling and capturing 3D occluders,” *ACM Trans. Graph.*, vol. 27, no. 5, p. 131, Dec. 2008.

Visual hull for 3D reconstruction

- Translucent object and intricate object

(a) (b) (c) (d)





T. H. Lin, H. T. Chang, S. J. Hu, "3D Reconstruction of Intricate Objects using Planar Cast Shadows," *ACM SIGGRAPH 2013*, Poster, July 2013, Anaheim, CA, USA.

Visual hull for 3D reconstruction (shadow reconstruction)

(72 shadow images and 72 color images)

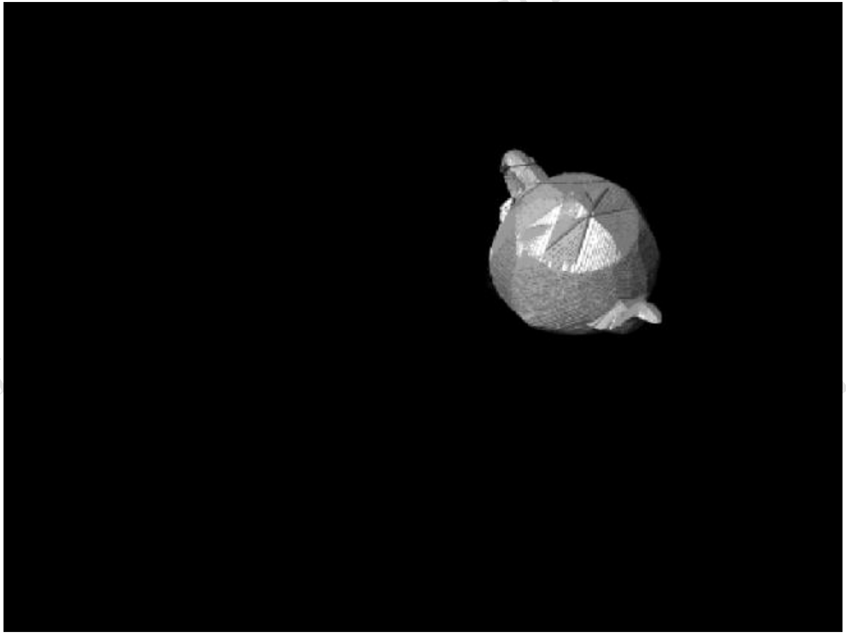
(72 shadow images and 72 color images)

(72 shadow images and 72 color images)

(72 shadow images and 72 color images)

Image-based rendering

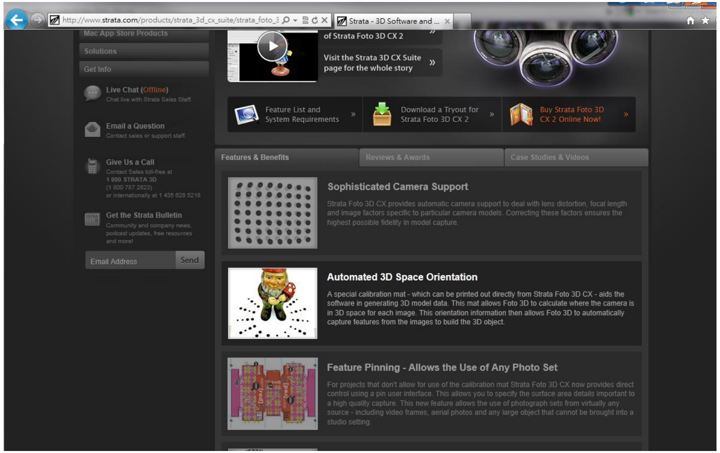
- Example

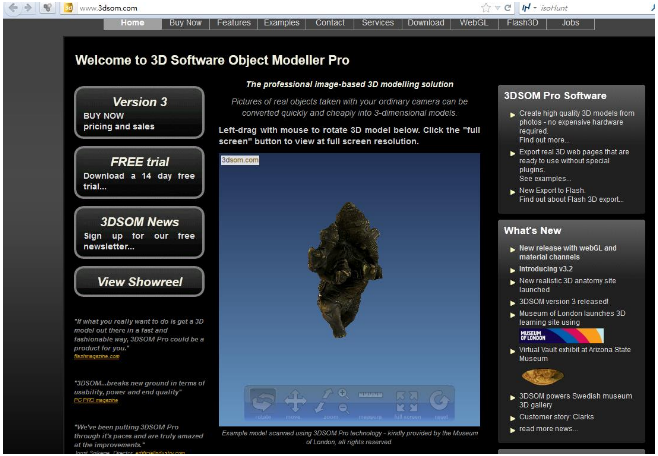


W. Matusik, C. Buehler, R. Raskar, S. J. Gortler, and L. McMillan, “Image-based visual hulls,” *Proc. 27th Annu. Conf. Comput. Graph. Interact. Tech. - SIGGRAPH ’00*, pp. 369–374, 2000.
http://people.csail.mit.edu/wojciech/IBVH/index.html

Commercial product (based on Visual Hull)

- Strata 3D
- 3D SOM

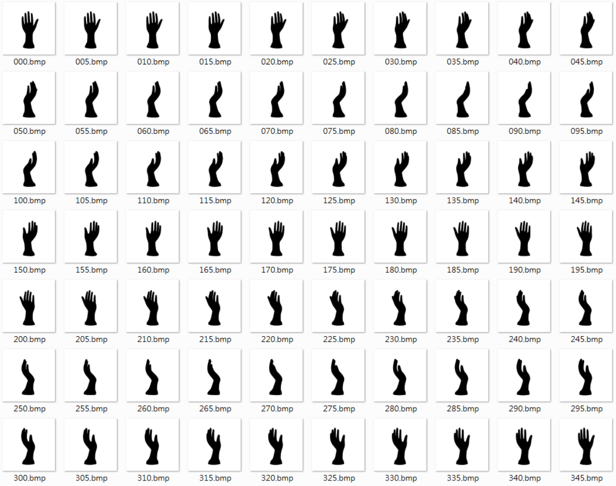




http://www.strata.com/products/strata_3d_cx_suite/strata_foto_3d_cx/
http://www.3dsom.com/

Multi-view in 3D reconstruction (silhouette)

- Shape from silhouette (voxel)



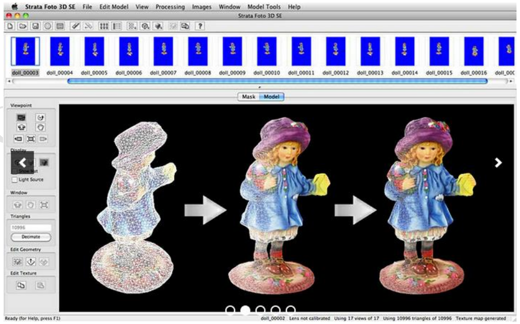
T. H. Lin, H. T. Chang, S. J. Hu, "3D Reconstruction of Intricate Objects using Planar Cast Shadows," *ACM SIGGRAPH 2013*, Poster, July 2013, Anaheim, CA, USA.

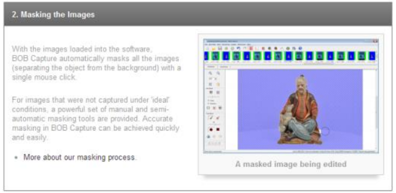
Multi-view in 3D reconstruction (silhouette)

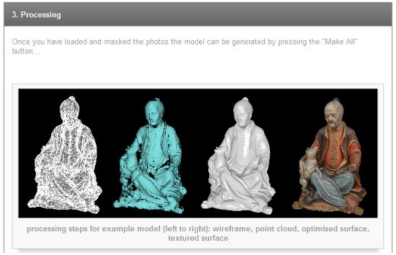
- Multiview Visual-Hull based algorithm
- Commercial production: Strata, 3DSOM.
- Put objects on a pattern then take multiple-view pictures

Object (to be reconstructed)

Specific pattern (for calibration)







Strata Foto 3D, https://www.strata.com/foto-3d-cx-create-textured-3d-models-from-your-digital-camera/
3DSOM Pro, Modeler, http://www.bigobjectbase.com/capture-process/

Multi-view in 3D reconstruction (silhouette)

- Reconstruction Example (by Strata 3D)

Figure from homework of "Applications of 3D Modeling and Design"

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