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# Methods for 3D Reconstruction

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# Introduction

- Increasing need for geometric 3D models
  - Movie industry, games, virtual environments…
- Existing solutions are not fully satisfying
  - User-driven modeling: long and error-prone
  - 3D scanners: costly and cumbersome
- Alternative: analyzing image sequences
  - Cameras are cheap and lightweight
  - Cameras are precise (several megapixels)

# Outline

- Context and Basic Ideas
- Consistency and Related Techniques
- Regularized Methods
- Conclusions

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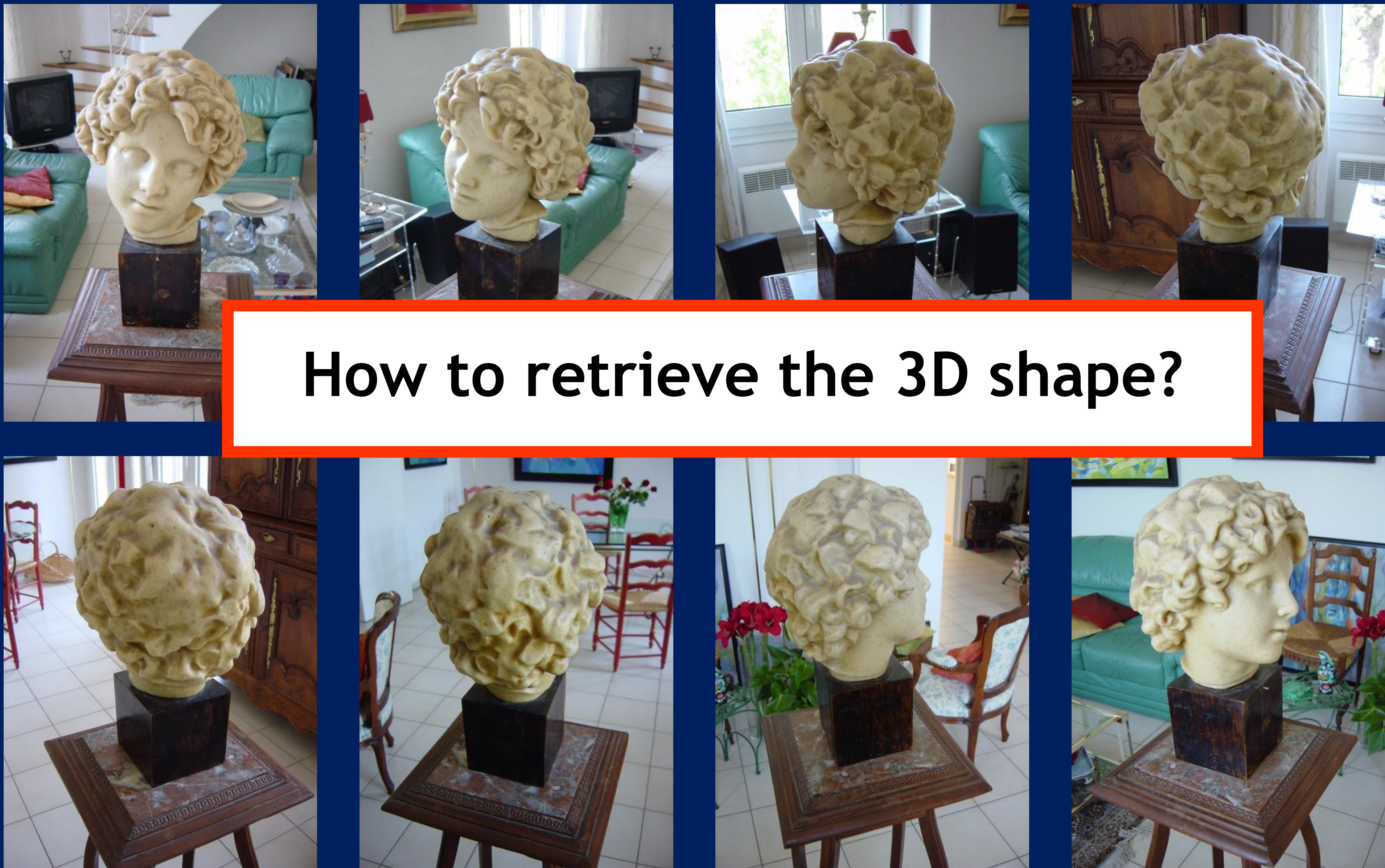
# Scenario

- A scene to reconstruct (unknown a priori)
- Several viewpoints
  - ↳ from 4 views up to several hundreds
  - ↳ 20~50 on average
- "Over water"
  - ↳ non-participating medium

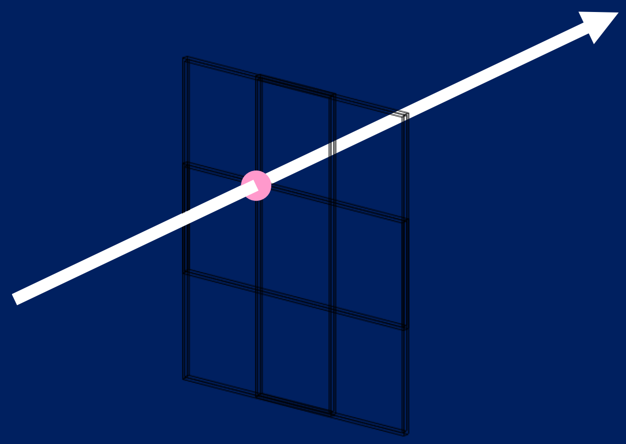
# Sample Image Sequence



**How to retrieve the 3D shape?**

# First Step: Camera Calibration

- Associate a pixel to a ray in space
  - ↳ camera position, orientation, focal length…



2D pixel ⇔ 3D ray

- Complex problem
  - ↳ solutions exist
  - ↳ toolboxes on the web
  - ↳ commercial software available

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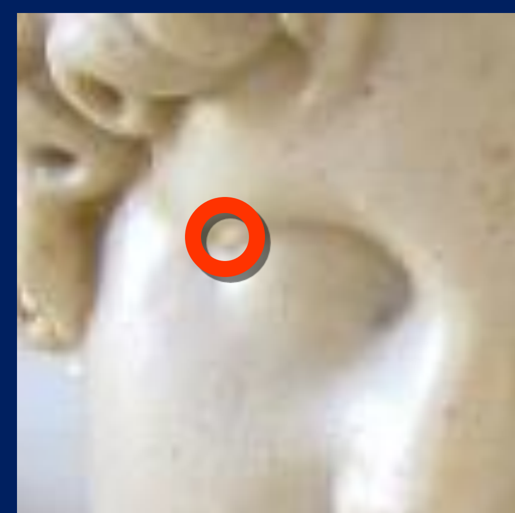
# General Strategy: Triangulation



Matching a feature
in at least 2 views
⇩
3D position

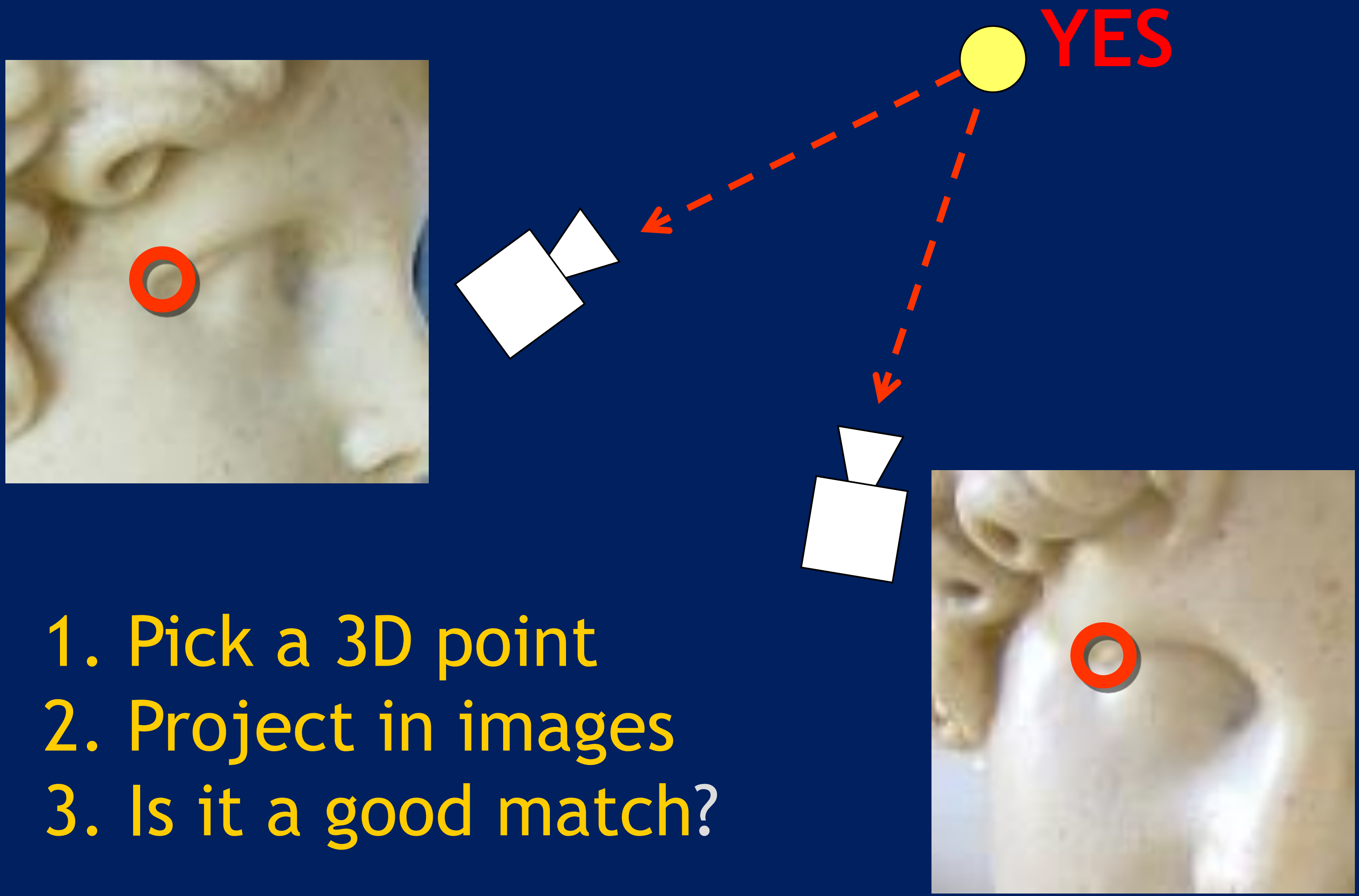
# Matching First

Which points are the same?

Impossible to match all points ⇨ holes.

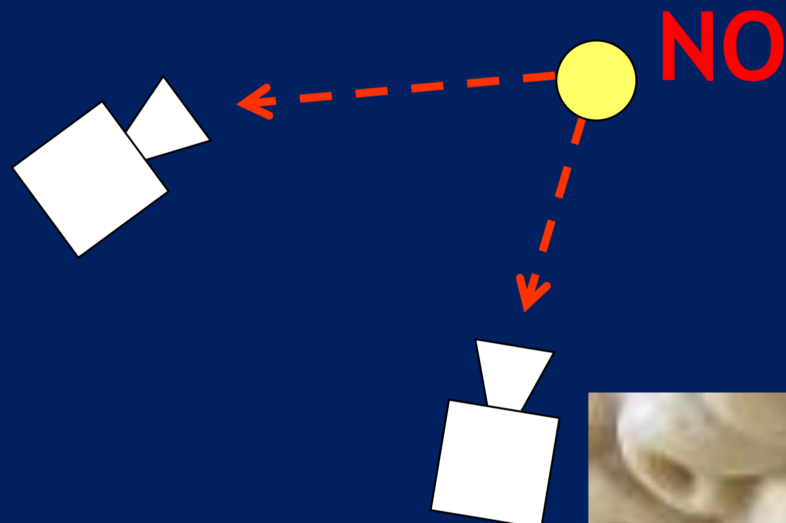
Not suitable for dense reconstruction.

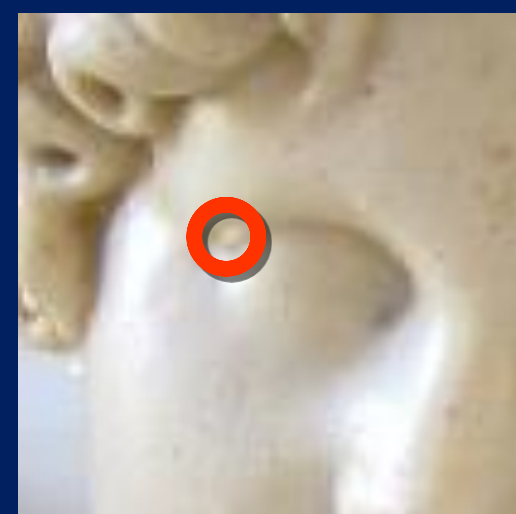
# Sampling 3D Space




1. Pick a 3D point
2. Project in images
3. Is it a good match?

# Sampling 3D Space



1. Pick a 3D point
2. Project in images
3. Is it a good match?

# Consistency Function

*"Is this 3D model consistent with the input images?"*

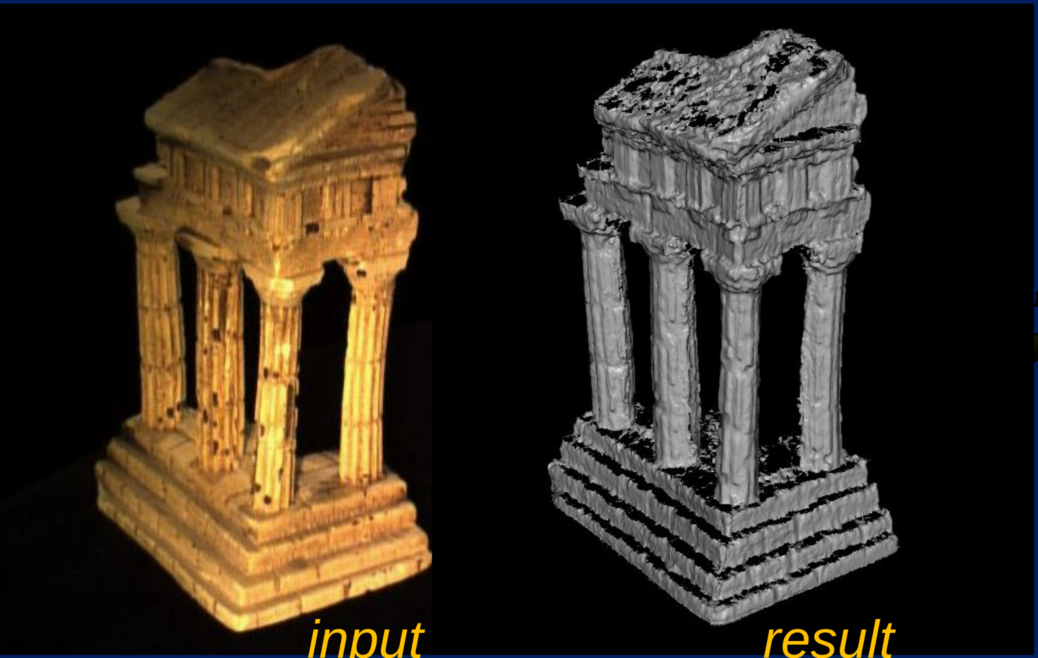
- No binary answer
  - noise, imperfect calibration…
- Scalar function
  - low values: good match
  - high values: poor match

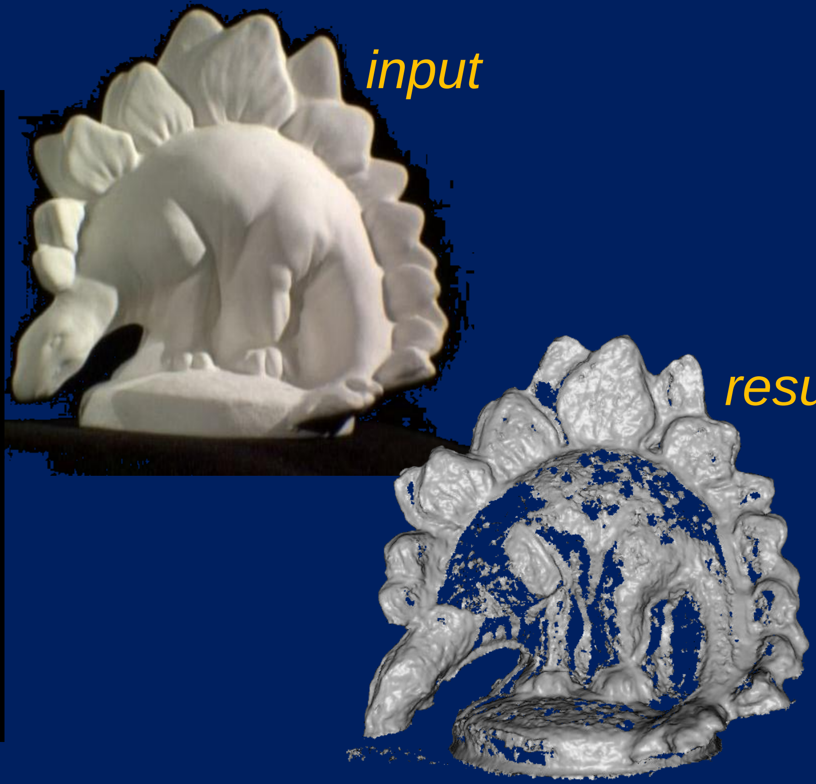
# Examples of Consistency Functions

- Color: variance
  - *Do the cameras see the same color?*
  - Valid for matte (Lambertian) objects only.
- Texture: correlation
  - *Is the texture around the points the same?*
  - Robust to glossy materials.
  - Problems with shiny objects and grazing angles.
- More advanced models
  - Shiny and transparent materials.

# Reconstruction from Consistency Only

- Gather the good points
  - ↳ requires many views
  - ↳ otherwise holes appear

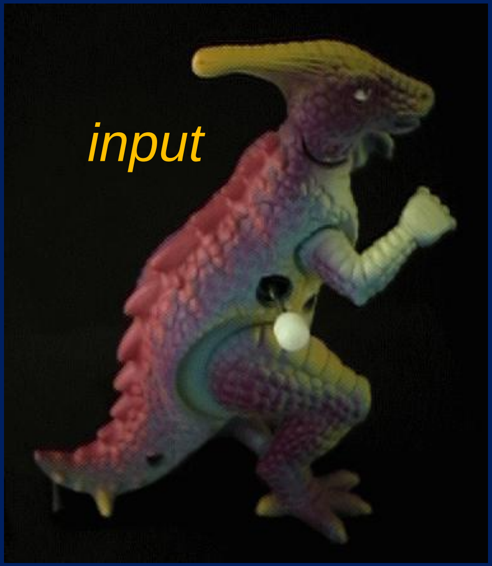


# Reconstruction from Consistency Only

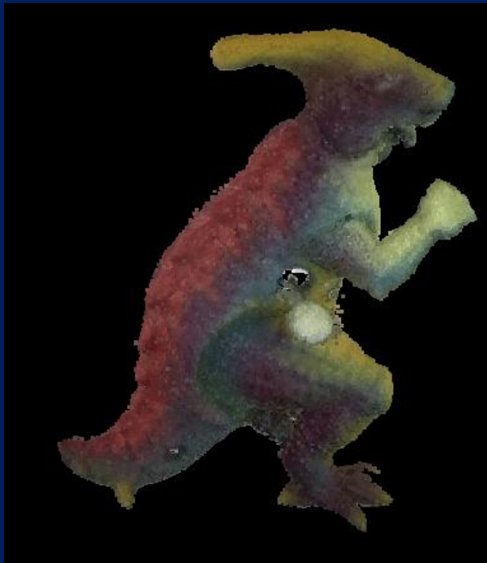
- Remove the bad points
  1. start from bounding volume
  2. carve away inconsistent points

  ↳ requires texture
    - otherwise incorrect geometry




# Summary of "Consistency Only Strategy"

- With high resolution data
  - mostly ok (except textureless areas)
  - sufficient in many cases
- Advice: try a simple technique first



- More sophisticated approach
  - fill holes
  - more robust (noise, few images…)

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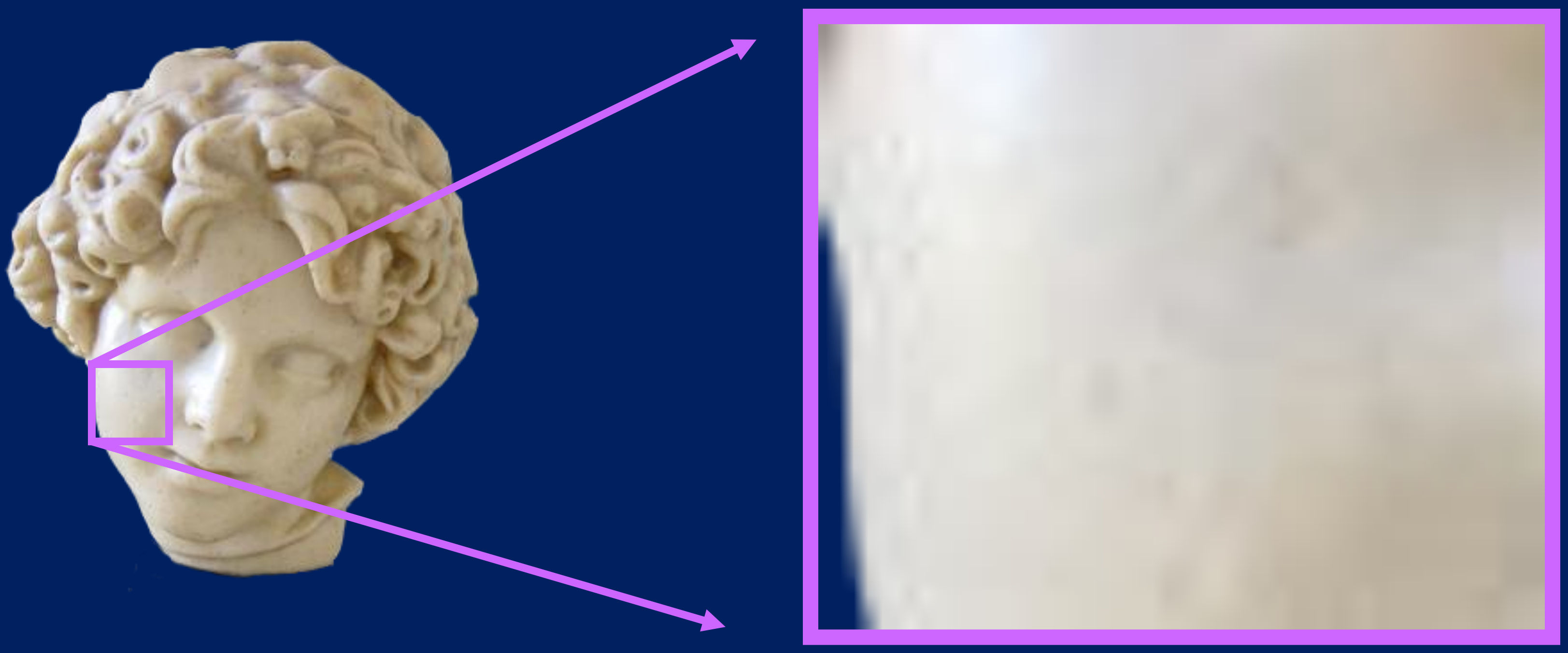
# Consistency is not Enough



- Textureless regions
  - Everything matches.
  - No salient points.

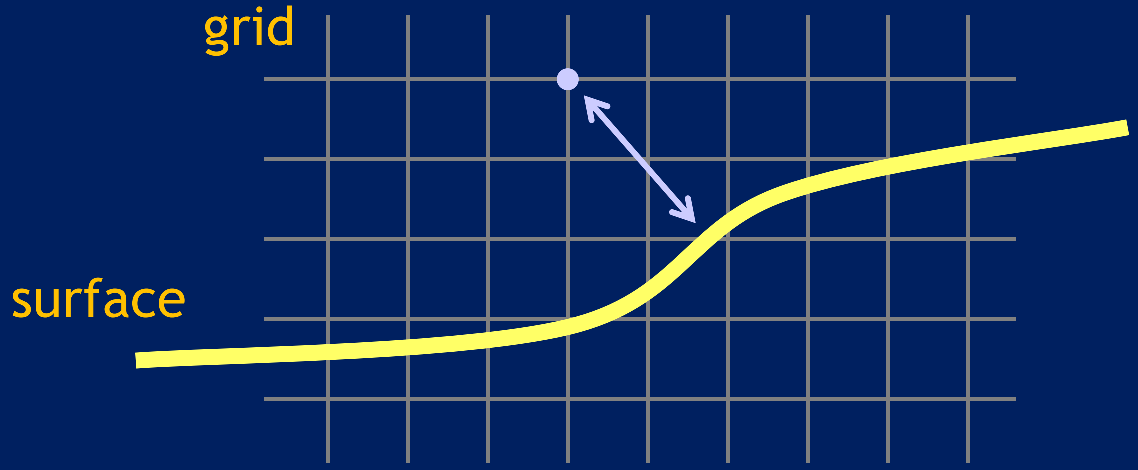
# An Ill-posed Problem

*There are several different 3D models consistent with an image sequence.*

- More information is needed.
  - User provides a priori knowledge.
  - Classical assumption: Objects are “smooth.”
  - Also know as *regularizing the problem*.
- Optimization problem:
  - Find the “best” smooth consistent object.

# Minimal Surfaces with Level Sets

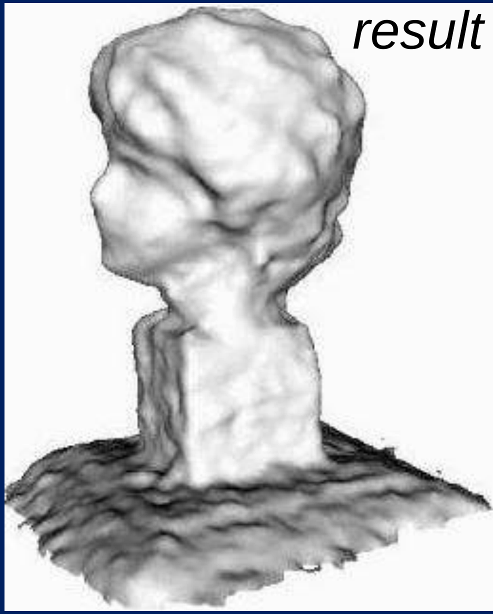
- Smooth surfaces have small areas.
  - ↳ "smoothest" translates into "minimal area."
- Level Sets to search for minimal area solution.
  - ↳ surface represented by its "distance" function




Each grid node stores its distance to the surface.

# Minimal Surfaces with Level Sets

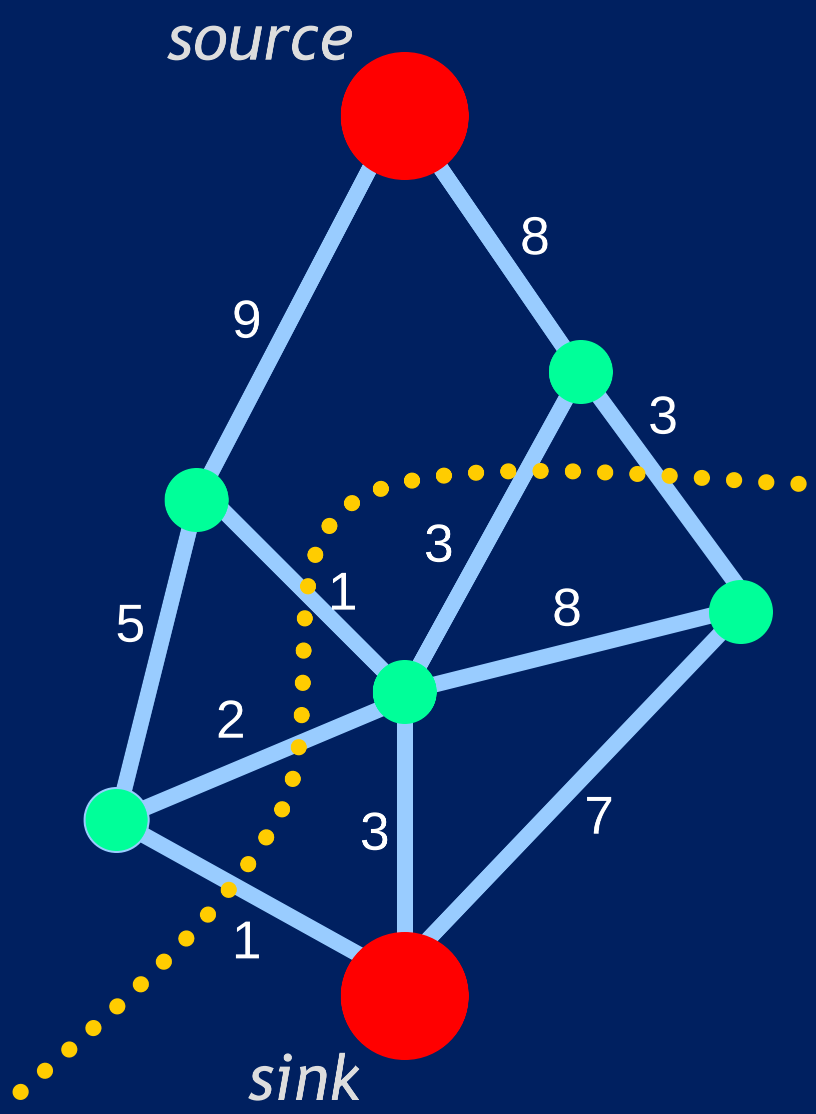
- Distance function evolves towards best tradeoff consistency vs area.
- Advantages
  - match arbitrary topology
  - exact visibility
- Limitations
  - no edges, no corners
  - convergence unclear (ok in practice)

# Snakes

- Explicit surface representation
  - triangle mesh
- Controlled setup
- Robust matching scheme
  - precise
  - handles very glossy material
  - computationally expensive

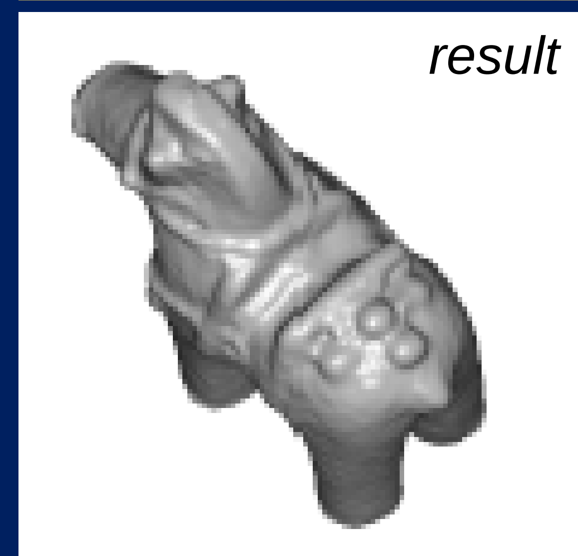

# A Quick Intro to Min Cut (Graph Cut)




- Given a graph with valued edges
  - find min cut between *source* and *sink* nodes.
- Change connectivity and edge values to minimize energy.
- Global minimum or very good solution.

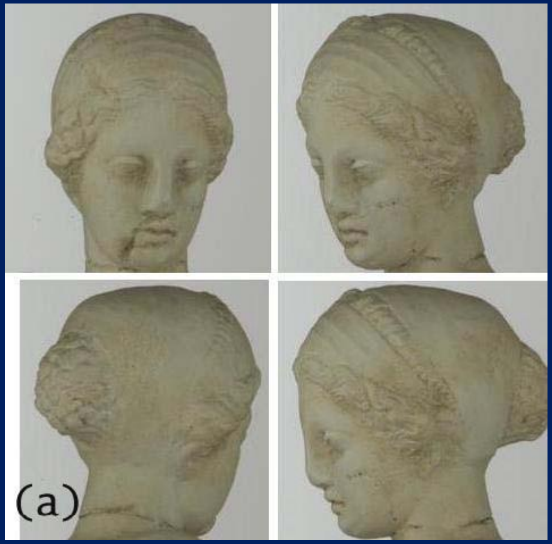
# Minimal Surfaces with Graph Cut

- Graphs can be used to compute min surfaces
- Visibility must be known
  - requires silhouettes
- Advantages
  - high accuracy
  - capture edges, corners
  - convergence guaranteed

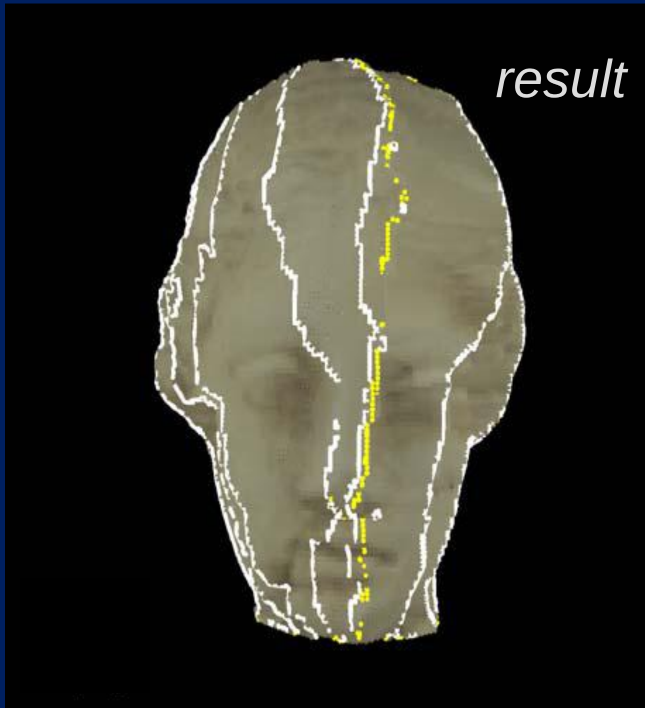



# Exploiting Silhouettes

*input*

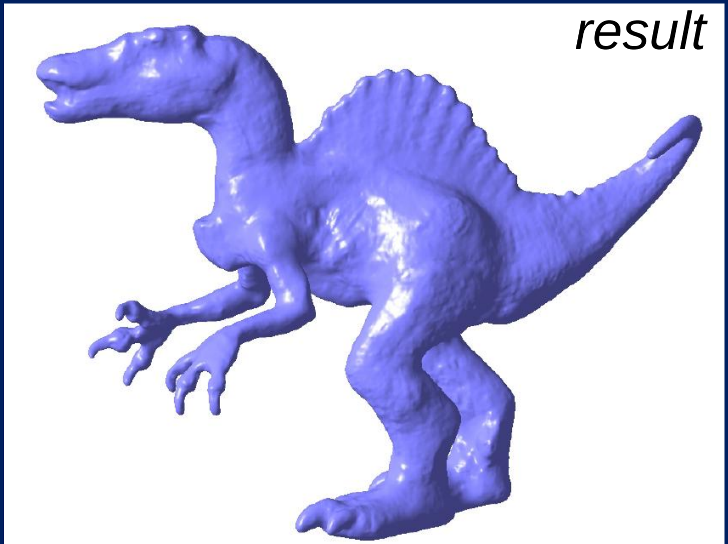



- Traditional techniques
  - 3D model only inside silhouettes
- Exact silhouettes
  - coherent framework
  - high accuracy at silhouettes
  - robust
  - but computationally expensive
    - (4D graph)
  - lacks detail (can be improved)



# Exploiting Silhouettes

- Exact silhouettes
  - more detail
  - slightly less robust
    - silhouettes handled separately
  - better tradeoff
  - but computationally expensive (2 hours +)

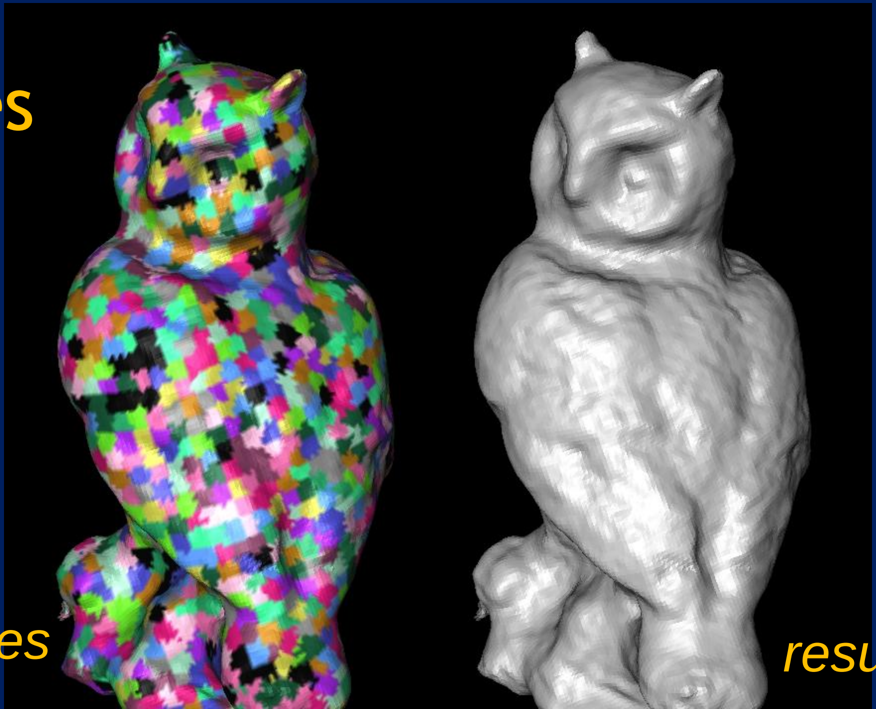



# Multi-scale Approach

- Optimizing only a narrow band
- Progressive refinement
  - About 10 to 30 minutes (and no exact silhouettes)

# Patchwork Approach

- Build model piece by piece
  - save memory and time
  - helps with visibility
  - scale up easily
  - about 15 to 40 minutes
    - can be improved
  - no exact silhouette
  - more complex implementation


patches

# Challenges for the Future

- Shinny materials: metal, porcelain…
- Choice of the parameters
  - Controlled setup is ok.
  - Difficulties: handheld camera, outdoor,…
- Visibility and graph cut
  - Restricted setup
  - Only at “large scale”
  - Promising direction: iterative graph cuts

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# Going Underwater

- Main point to adapt: consistency function
  - More robust matching
  - “Inverting” perturbations
- Thin features (plants, seaweed…)
- Objects in motion

# Conclusions

- 3D reconstruction is a hard problem.
- Solutions exist.
  - Need to be adapted to specific environment.
- Consistency carries information and adds detail.
  - Regularization removes noise and fills holes.
- Start with a simple solution.
  - A complete failure is not a good sign.

# Thank you

Presentation based on Sylvain Paris work