Selected Topics of the CrossSAVE-CH Project

Stefan Lengauer
Institute of Computer Graphics and Knowledge Visualisation, Graz University of Technology

December 8, 2022

FWF Project: Crossmodal Search and Visual Exploration of 3D Cultural Heritage Objects

- 2019-2022
- Research on pottery analysis (mostly ancient Greek pottery)

Selection of exhibits from the Institute of Classics at the University of Graz
(Source: KFU Graz)

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- 3D digitization **no** project objective

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- Main research objectives

  1)Crossmodal Search

  2)Visual Exploration

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- 2019-2022
- Research on pottery analysis (mostly ancient Greek pottery)
- 3D digitization **no** project objective
- Main research objectives

  1)Crossmodal Search

  2)Visual Exploration
- By-products

  1)Published Datasets

  2)Digital Restoration

Selection of exhibits from the Institute of Classics at the University of Graz *(Source: KFU Graz)*

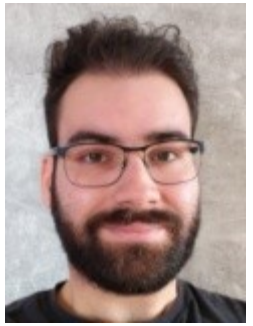
FWF Project: Crossmodal Search and Visual Exploration of 3D Cultural Heritage Objects

- TU Graz Project Members


Stefan Lengauer


Tobias Schreck


Reinhold Preiner


Alexander Komar

- Collaborators

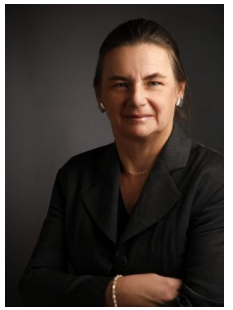
University of Chile


Ivan Sipiran


Benjamin Bustos

University of Graz


Stephan Karl


Elisabeth Trinkl

Challenges related to CH applications

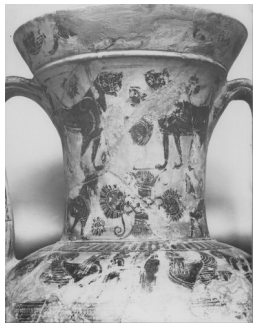
- Challenges: incomplete data, multimodality of data

Challenges related to CH applications

- Challenges: incomplete data, multimodality of data

- Varied modalities of CH data

Sketch/Drawing



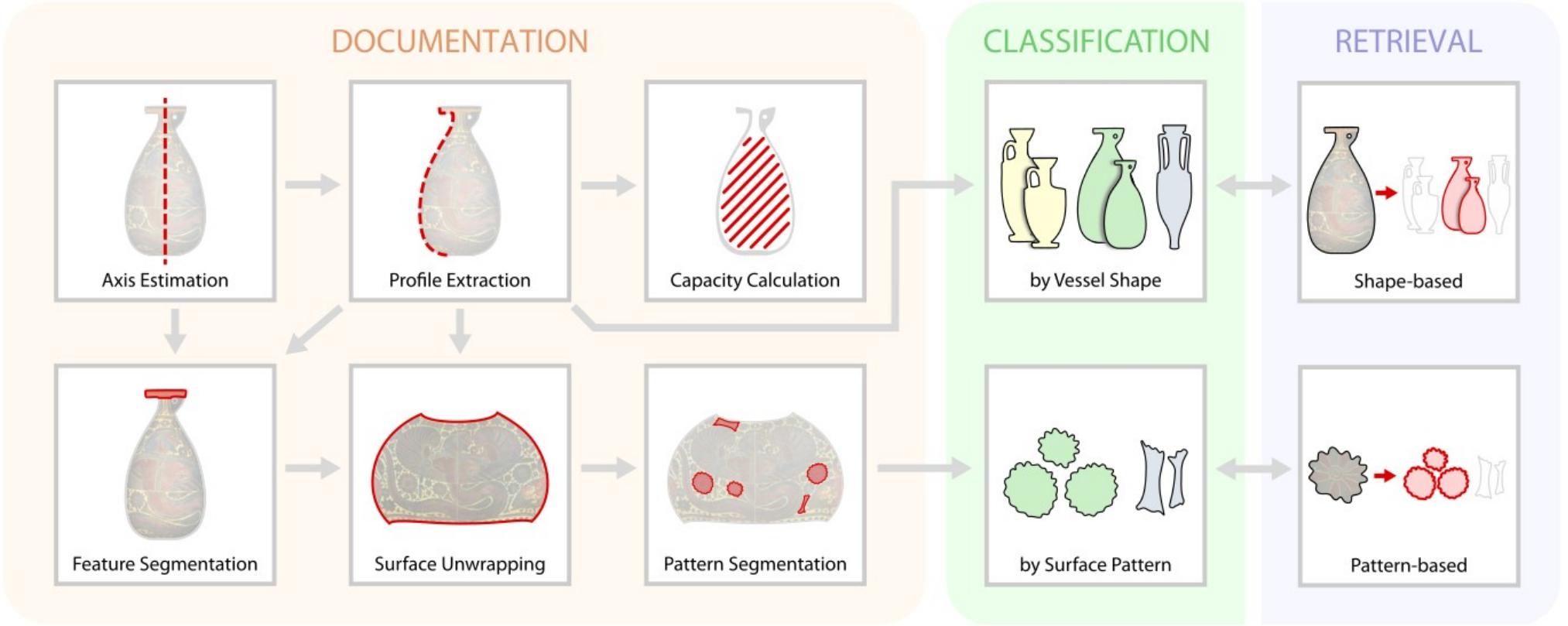
Photographs

3D Model

Metadata

FWF Project: Crossmodal Search and Visual Exploration of 3D Cultural Heritage Objects

- Computerized methods for pottery research



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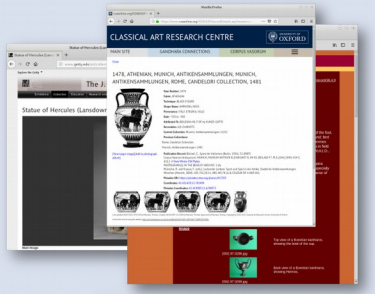
Sources

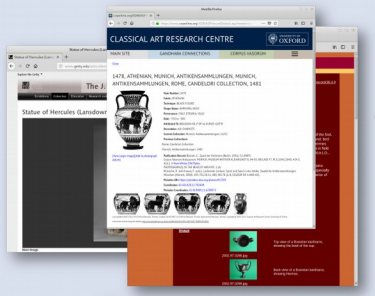


Repositories

Volumes

3D Models

Sources



Repositories

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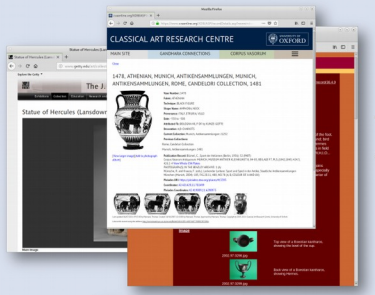
3D Models

Data Preparation

Meta Data

Sources



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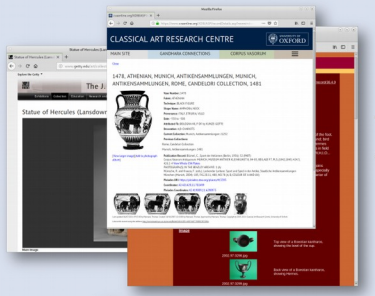

Repositories

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3D Models

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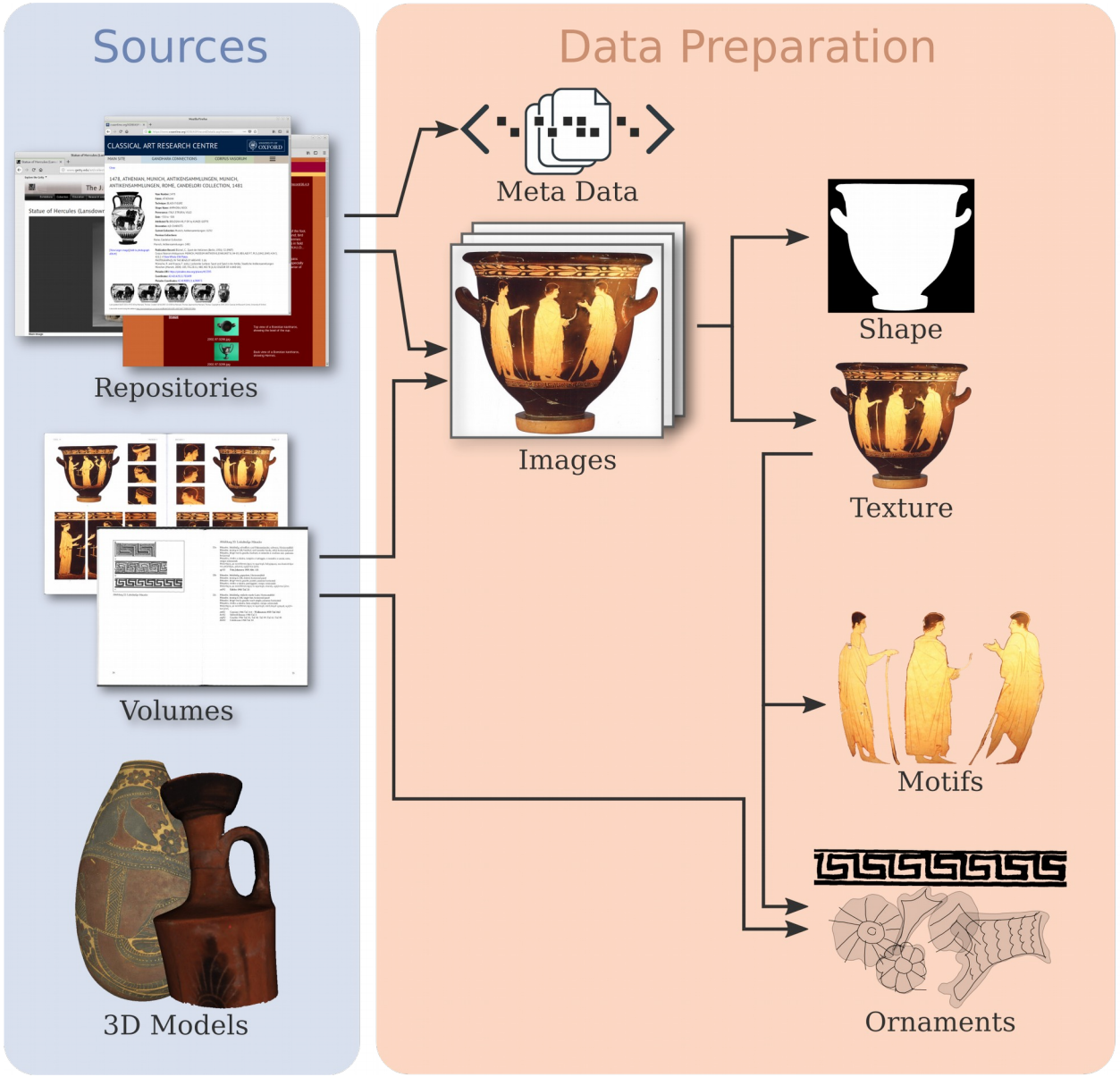
Meta Data

Images

Shape

Texture


Sources
Repositories
Volumes
3D Models
Data Preparation
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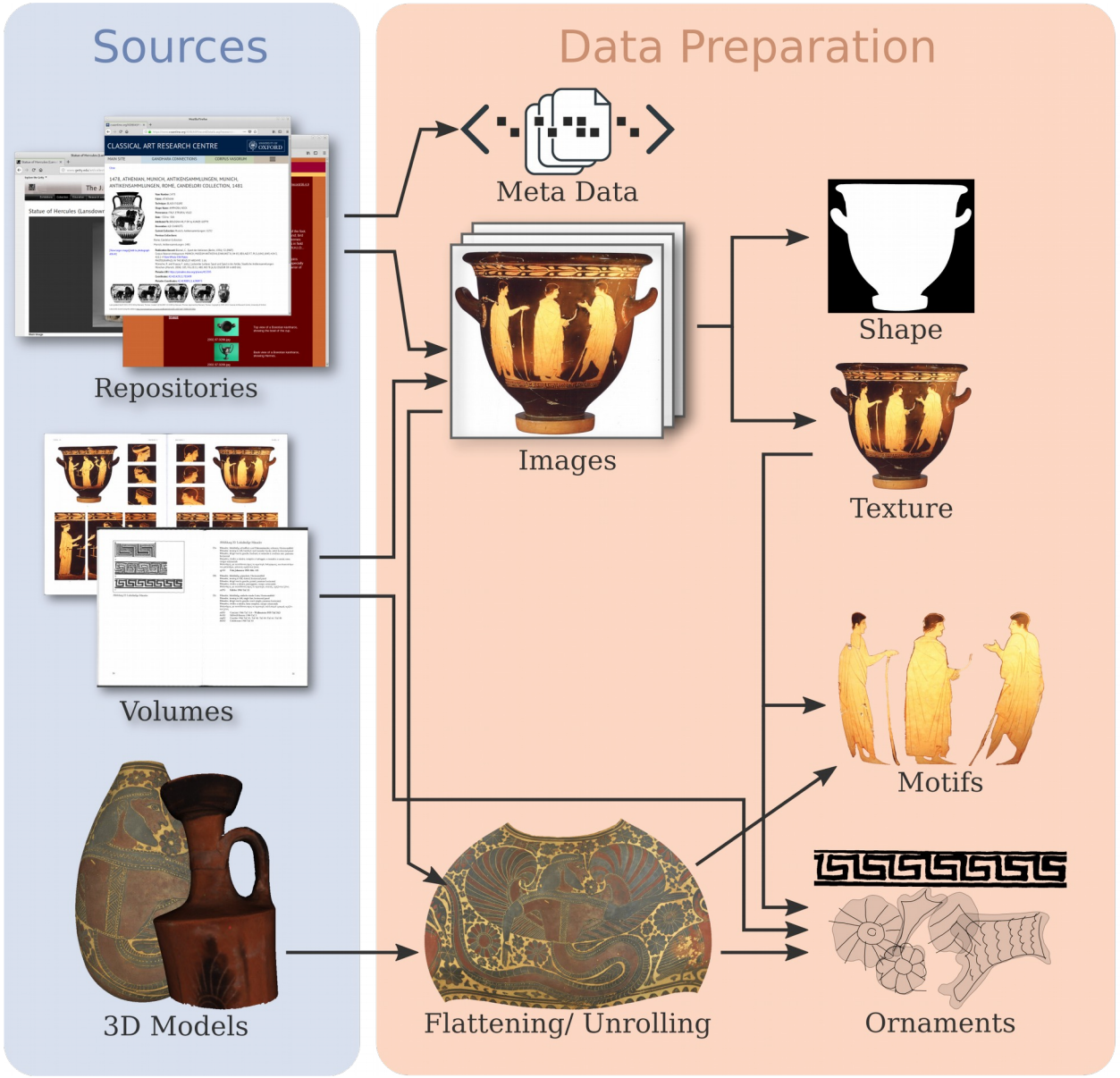
Images
Shape
Texture
Motifs
Ornaments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Flattening/ Unrolling
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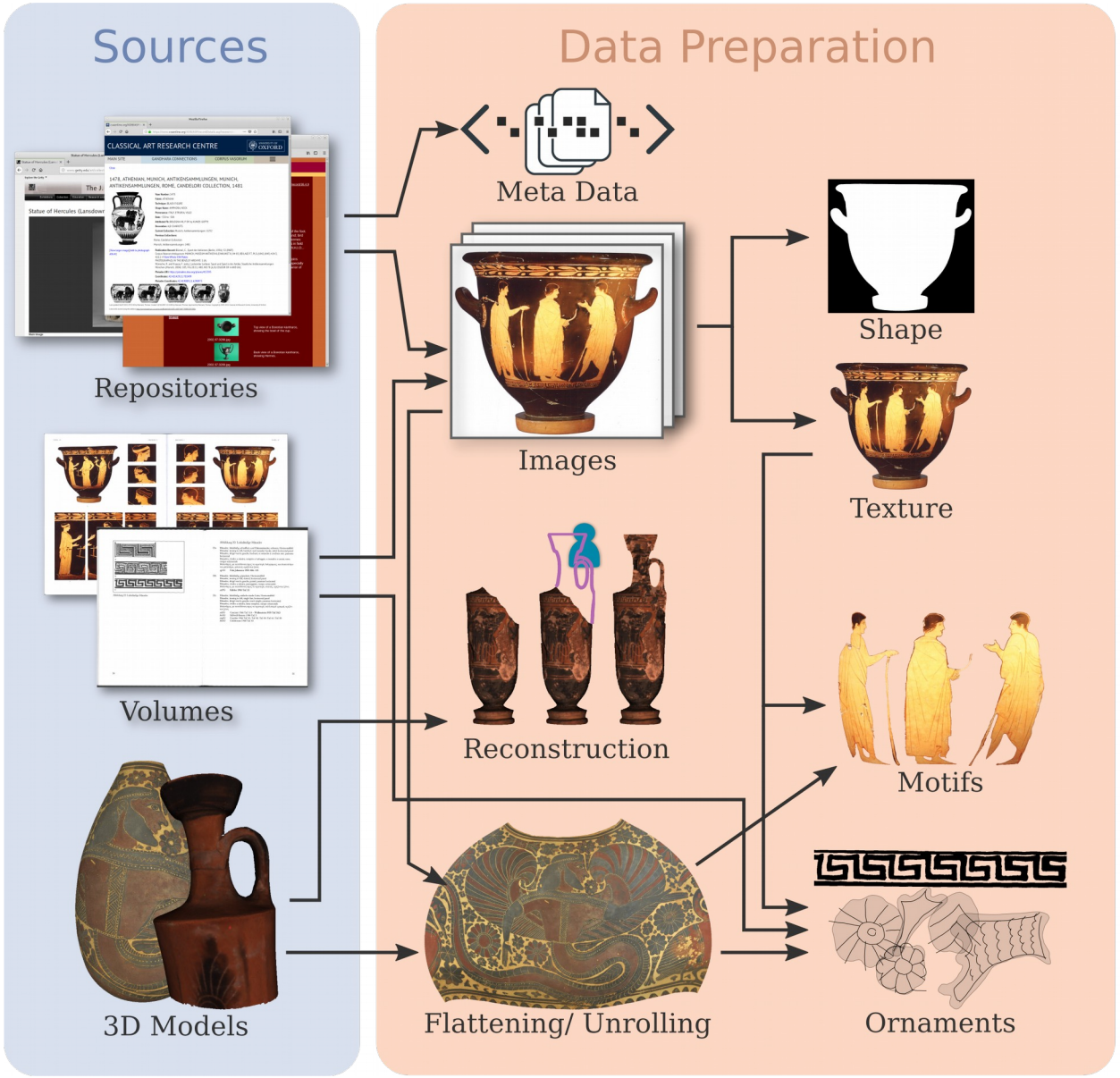
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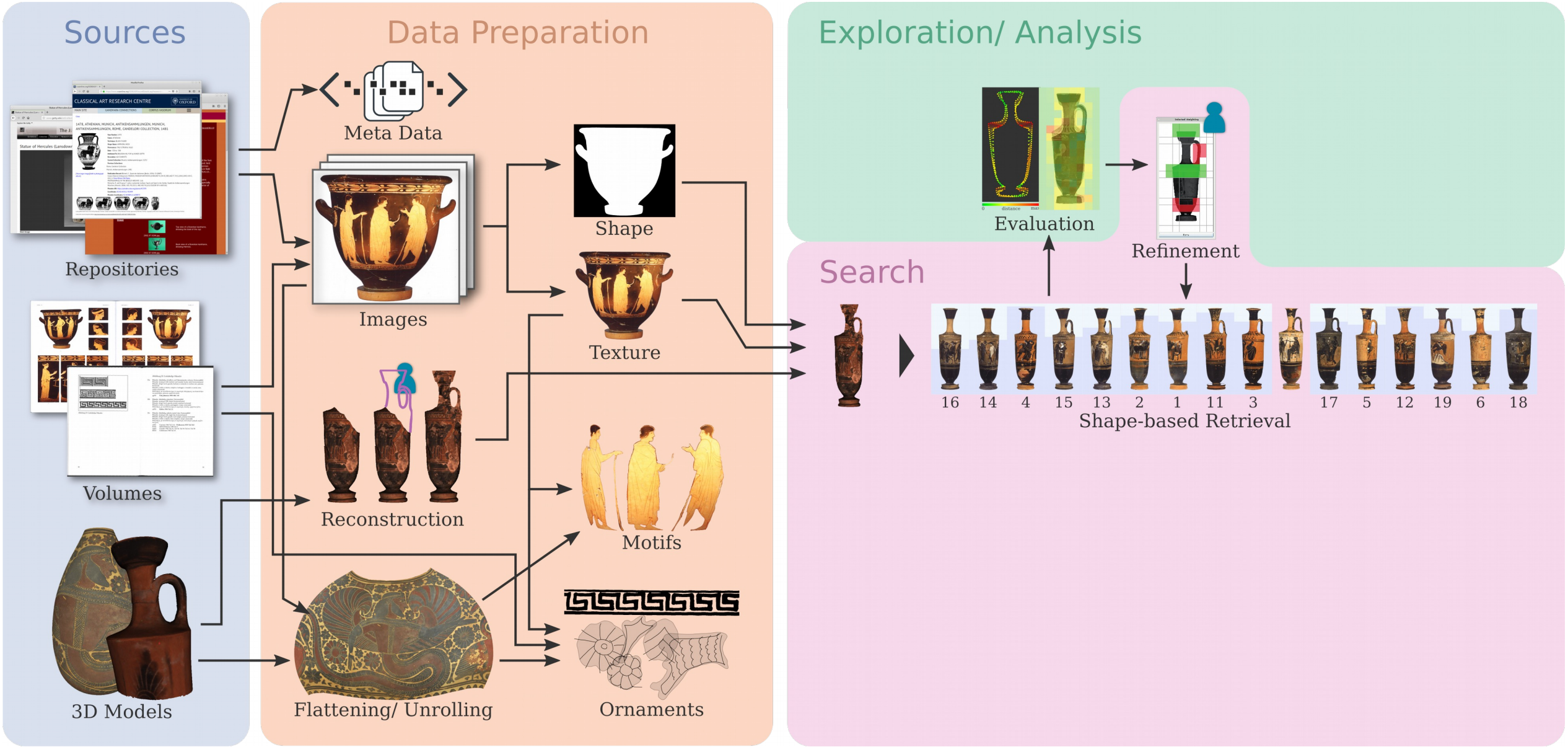
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Data Preparation
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Texture
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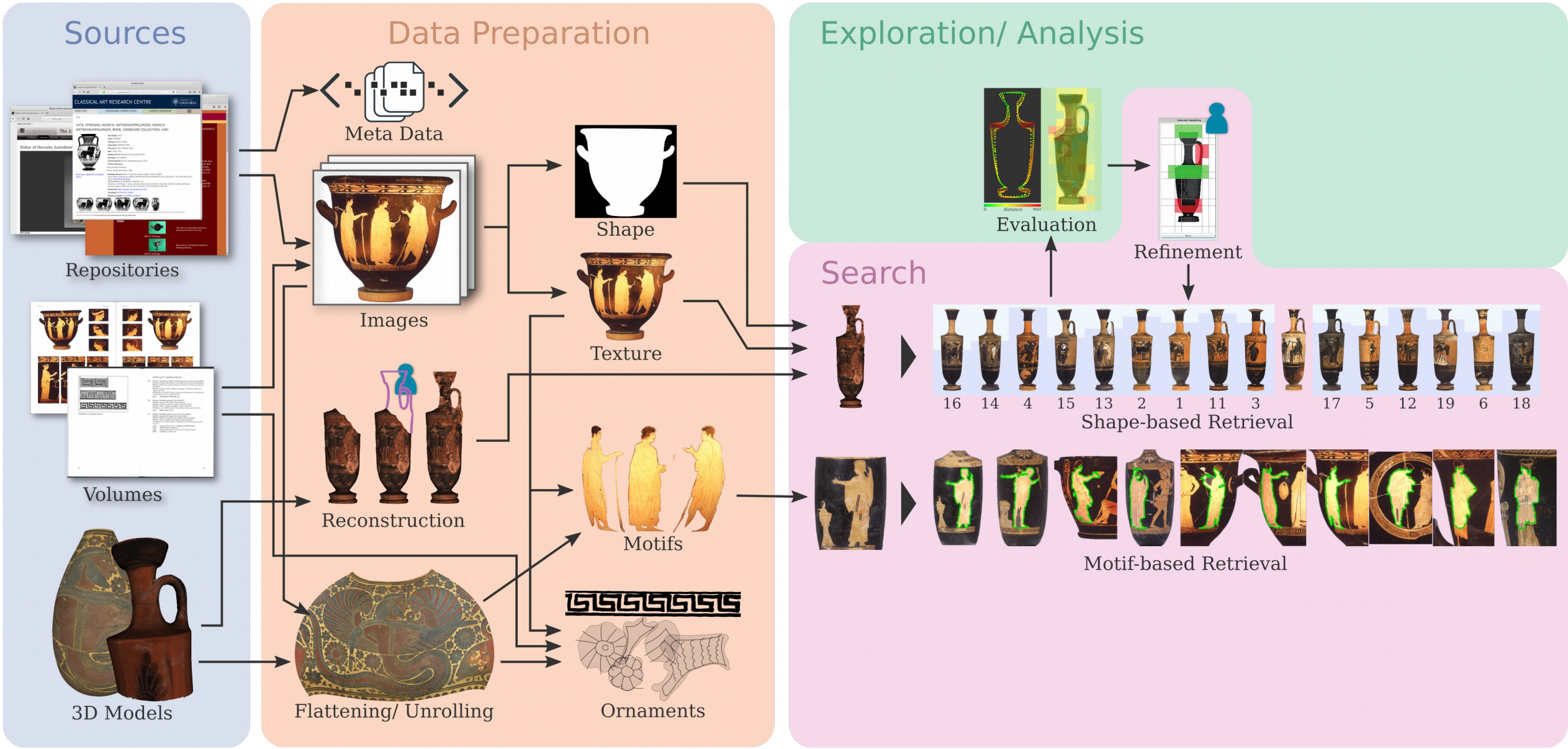
Motifs
Flattening/ Unrolling
Ornaments
Exploration/ Analysis
Evaluation
Refinement
Search
16 14 4 15 13 2 1 11 3 17 5 12 19 6 18
Shape-based Retrieval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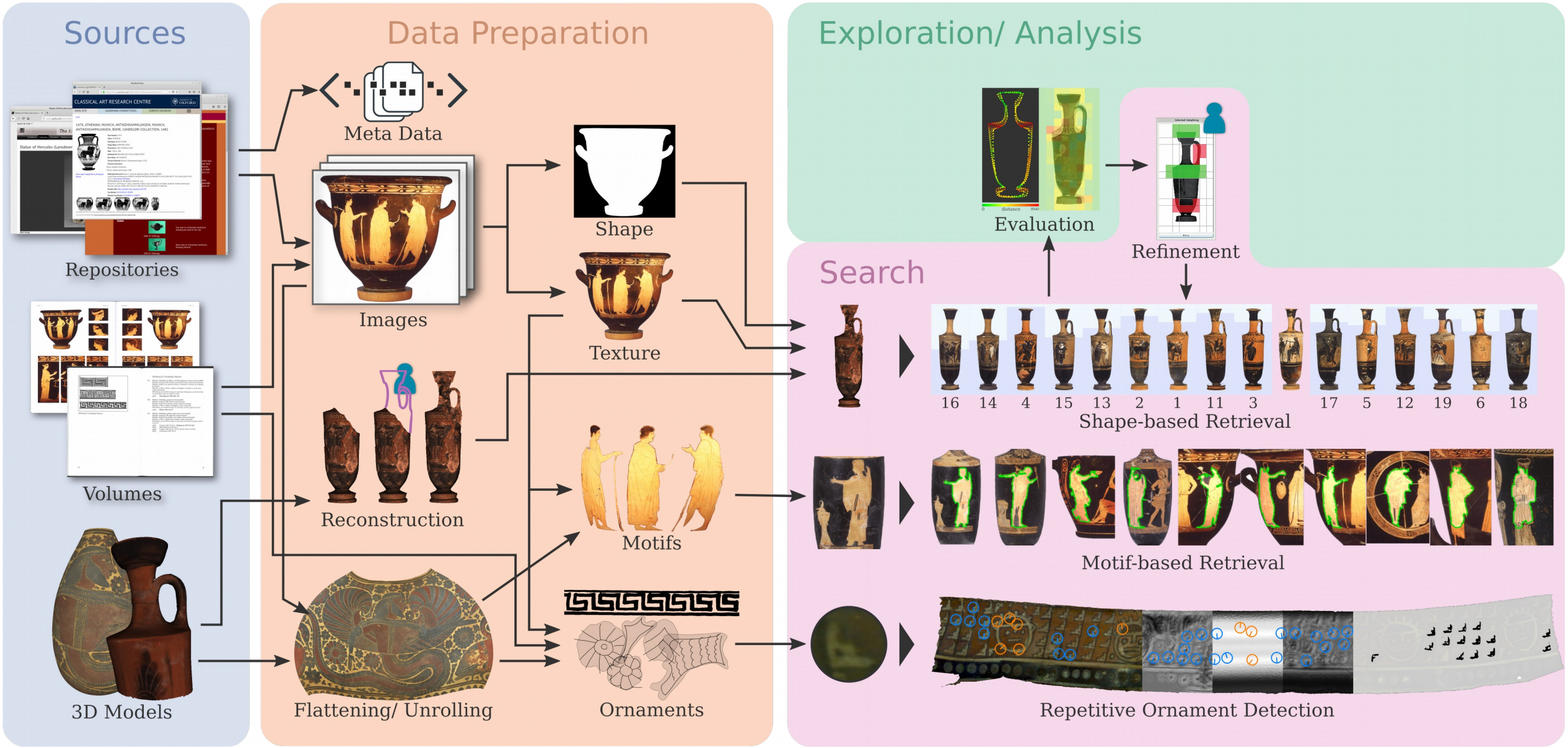
Shape-based Retrieval
Motif-based Retrieval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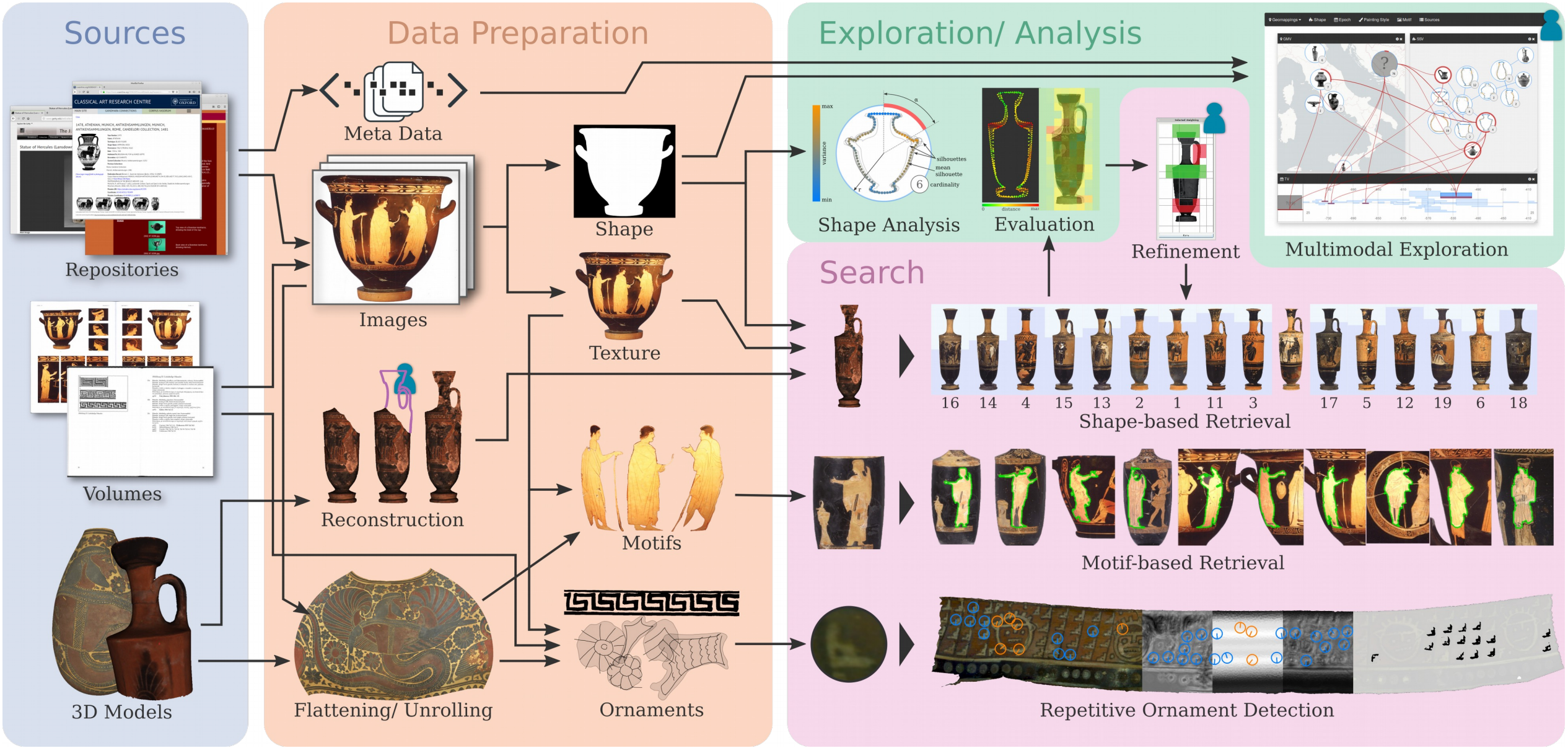
Shape-based Retrieval
Motif-based Retrieval
Repetitive Ornament Detection


Sources
Repositories
Volumes
3D Models
Data Preparation
Meta Data
Images
Reconstruction
Flattening/ Unrolling
Shape
Texture
Motifs
Ornaments
Exploration/ Analysis
max
variance
min
silhouettes
mean
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cardinality
Shape Analysis
distance
Evaluation
Refinement
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Shape-based Retrieval
Motif-based Retrieval
Repetitive Ornament Detection

Concept for shape-based retrieval

Input: Incomplete 3D object + user sketch

- Most excavated objects are fractured → partial (3D) retrieval
- Archaeologists are expected to accurately guess the appearance of a whole vessel based on a single surviving sherd[1]
- Sketching provides an intuitive way to introduce domain knowledge[2]

[1]Roman-Rangel, E., Jimenez-Badillo, D., & Aguayo-Ortiz, E. (2014, November). Categorization of Aztec potsherds using 3D local descriptors. In *Asian Conference on Computer Vision* (pp. 567-582). Springer, Cham.

[2]Li, Bo, Yijuan Lu, Afzal Godil, Tobias Schreck, Benjamin Bustos, Alfredo Ferreira, Takahiko Furuya et al. "A comparison of methods for sketch-based 3D shape retrieval." *Computer Vision and Image Understanding* 119 (2014): 57-80.

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Search Space: Archaeological photographs

- Most pottery artifacts only documented by photographs

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Output: Ranked list of results

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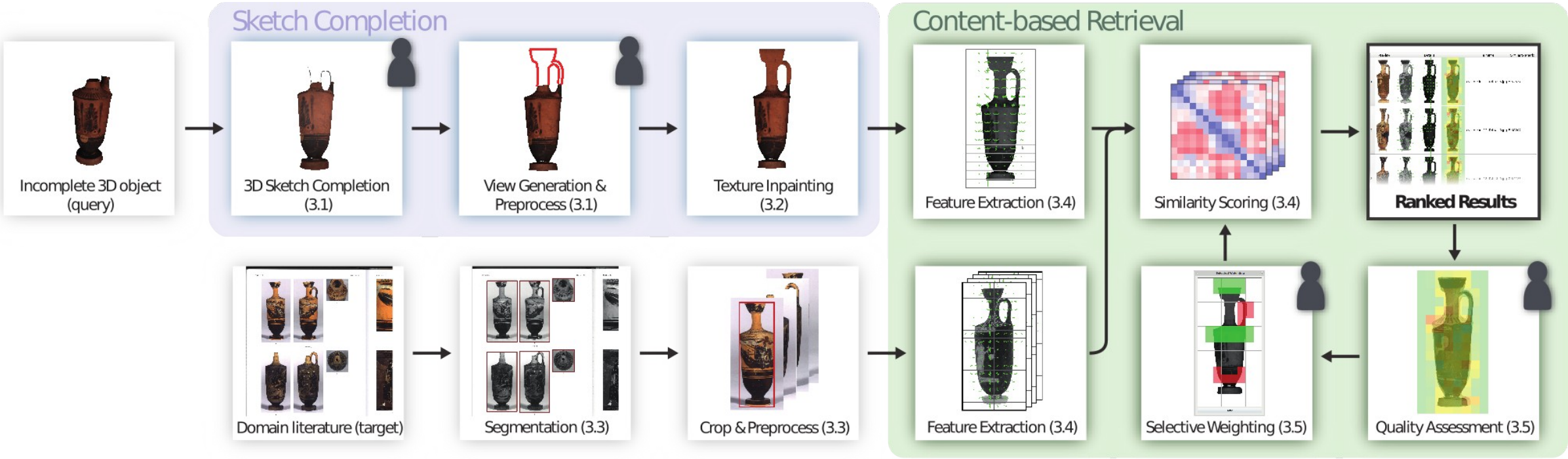

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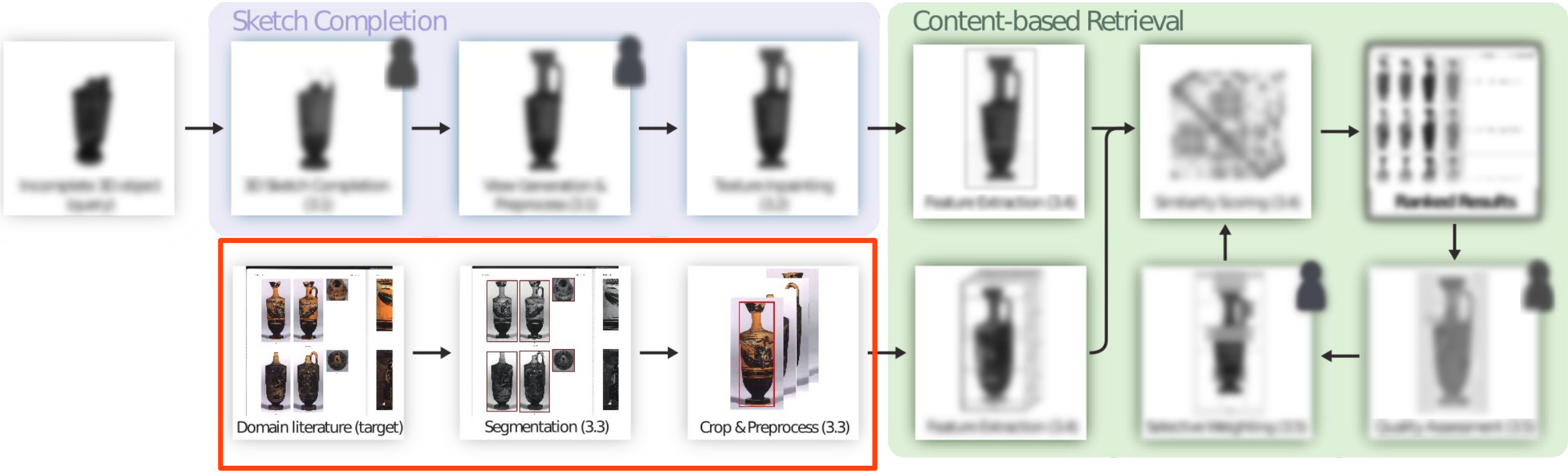
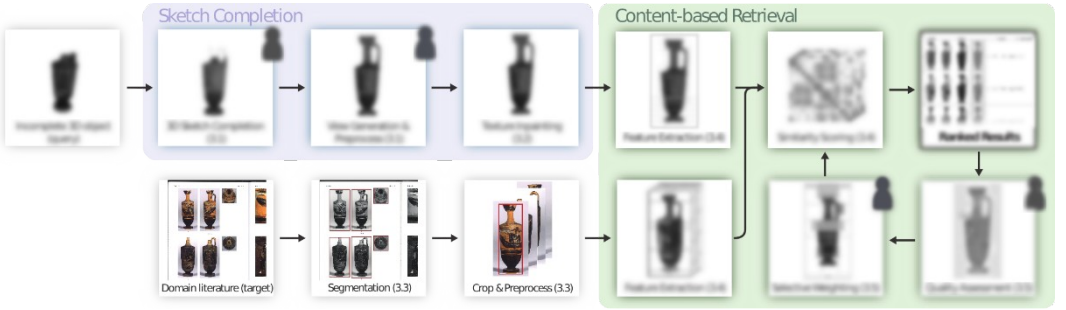
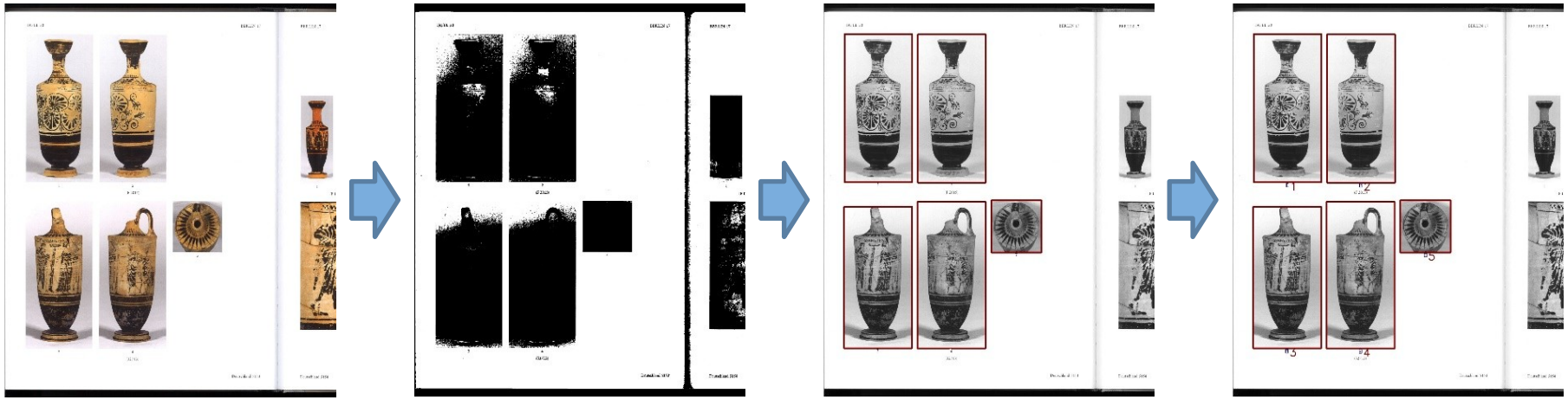


Search Space Generation



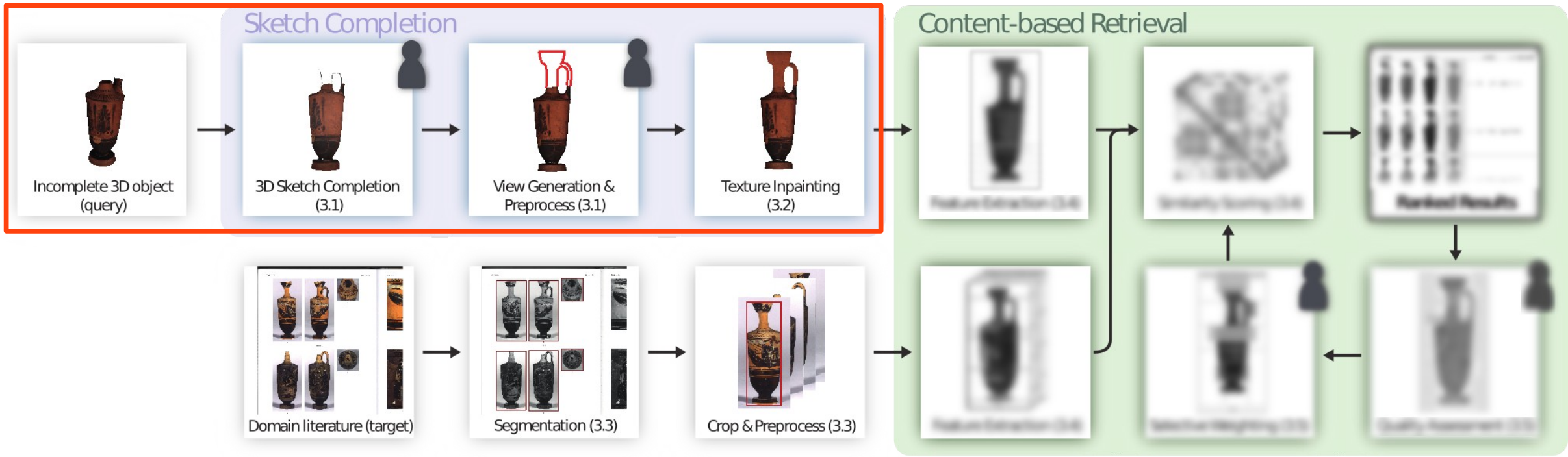
- Search space based on photographs published in the Corpus Vasorum Antiquorum (CVA)[3]
- Scanned print fascicules available as PDF
- Photographs detected with image processing techniques
- In total 3,340 photographs extracted



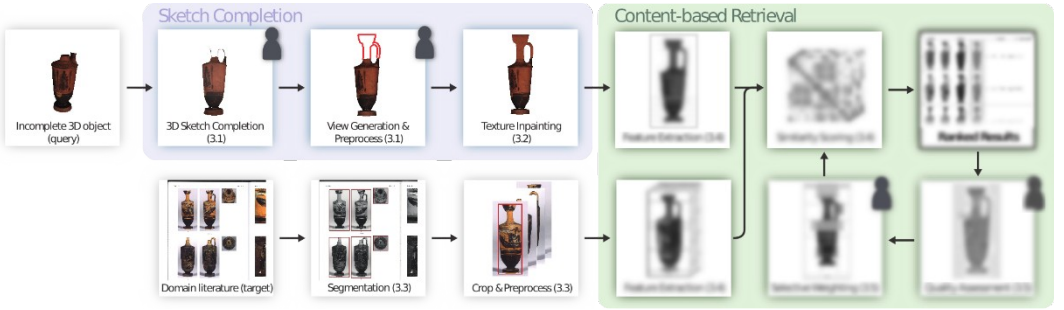
Raw Input | Thresholding | Image Detection | OCR

[3] https://www.cvaonline.org/cva/

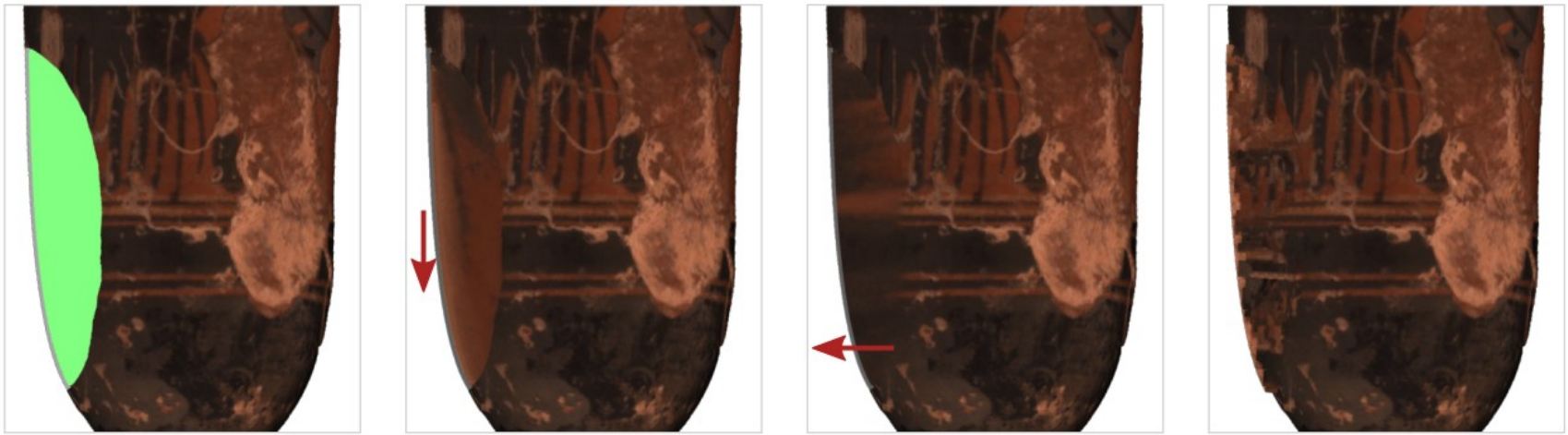
Concept for shape-based retrieval



Query Preparation



- **Goal:** Generate an image similar to the search space photographs
- Sketching of missing parts (and pruning)
- View selection
- Filling newly generated areas with plausible texture[3,4]

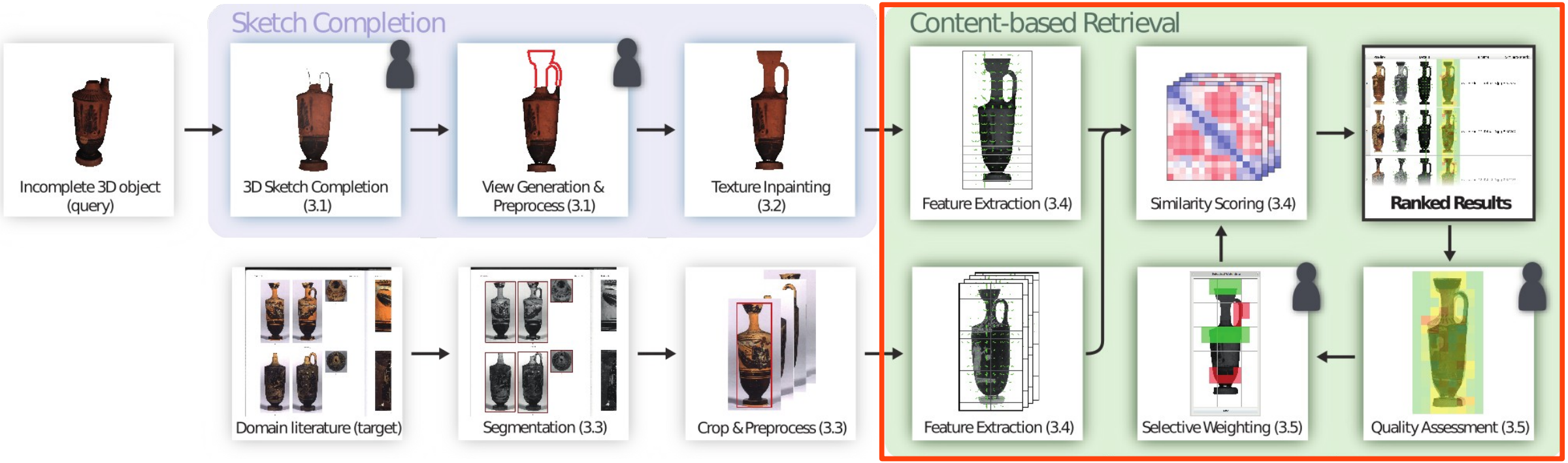


(a) Target Area (b) Texture Synthesis (c) Dir. Texture Synthesis (d) Structure Synthesis

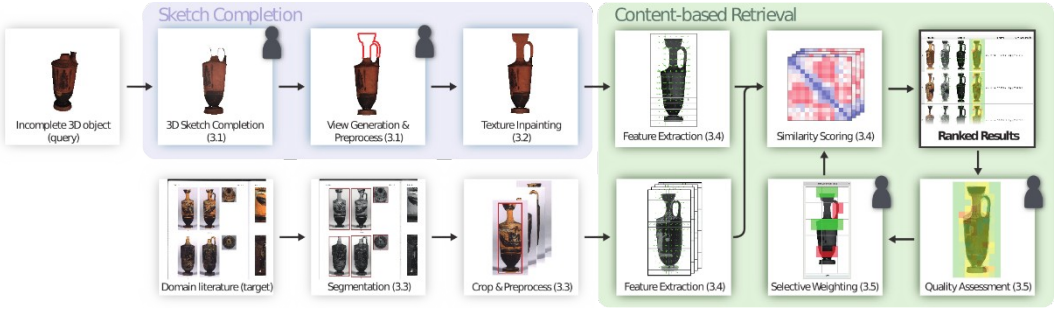
[3]Wei, L.-Y., Levoy, M., “Fast texture synthesis using tree-structured vector quantization”, in *Proceedings of the 27th annual conference on Computer graphics and interactive techniques*, 2000, pp. 479–488.

[4]Criminisi, A., Pérez, P., Toyama, K., “Region filling and object removal by exemplar-based image inpainting”, *IEEE Transactions on image processing*, vol. 13, no. 9, pp. 1200–1212, 2004

Concept for shape-based retrieval

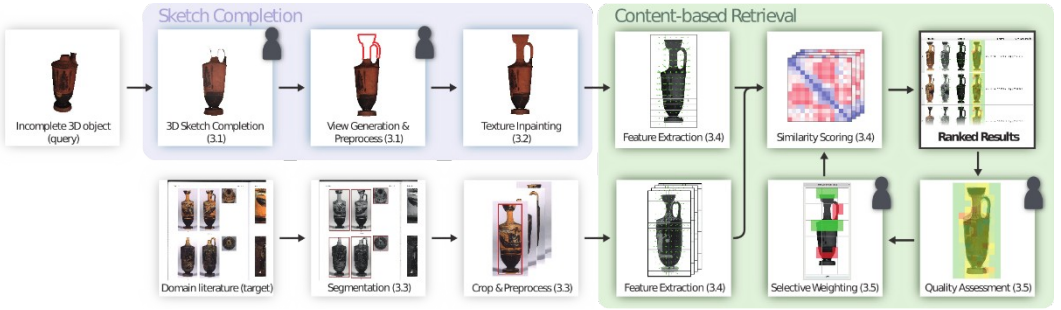


Content-based Retrieval



- The prepared query is compared to each entry in the search space
- All images have to be brought into a numerical representation (Feature Vector)

Content-based Retrieval



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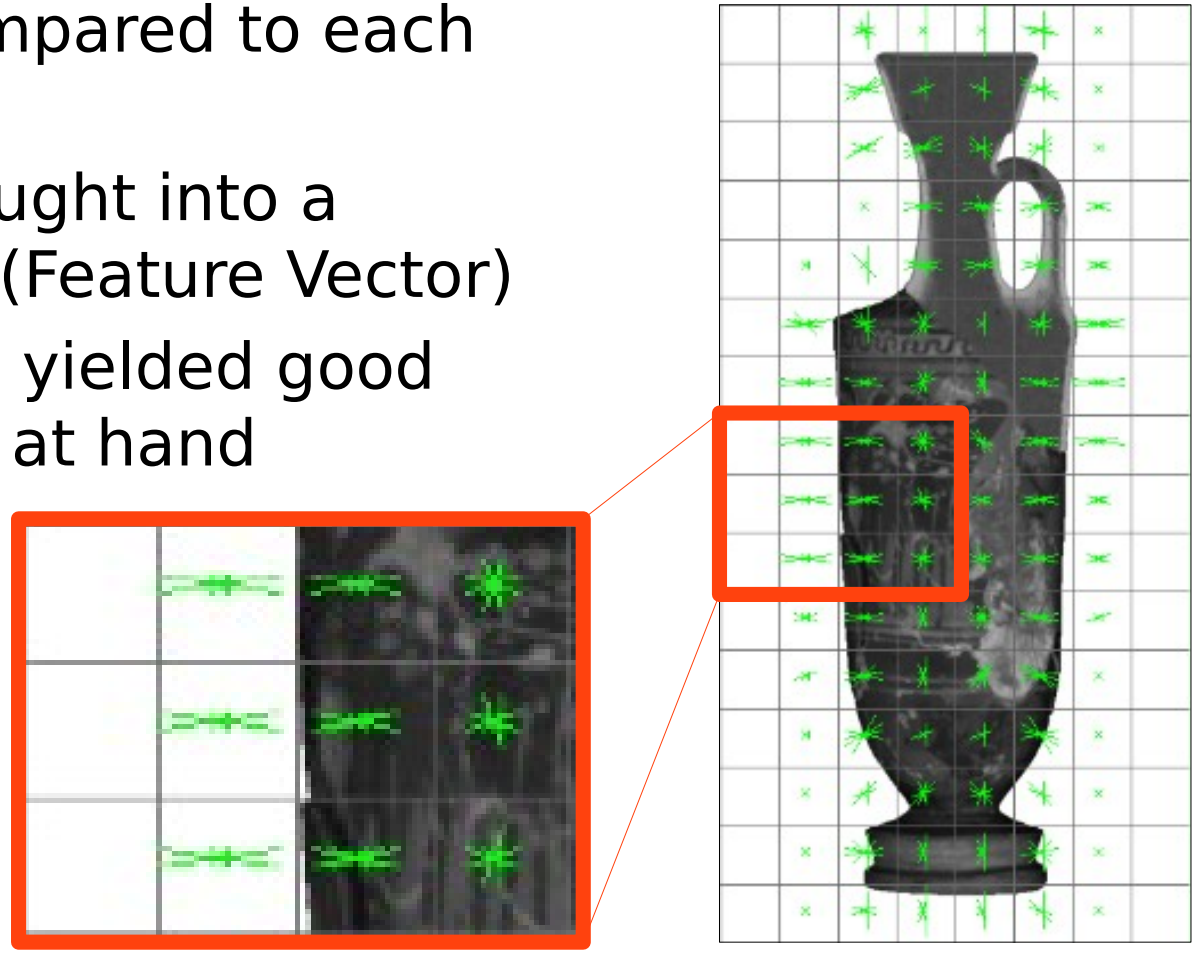
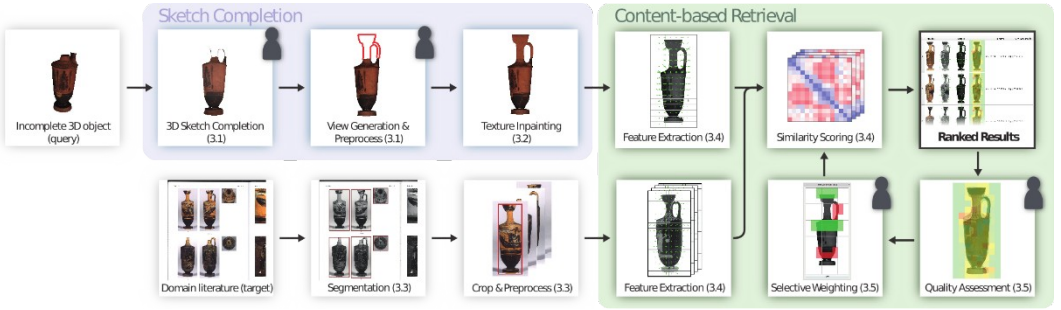
- All images have to be brought into a numerical representation (Feature Vector)
- Gradient-based features[5] yielded good results for the application at hand



Content-based Retrieval



- The prepared query is compared to each entry in the search space
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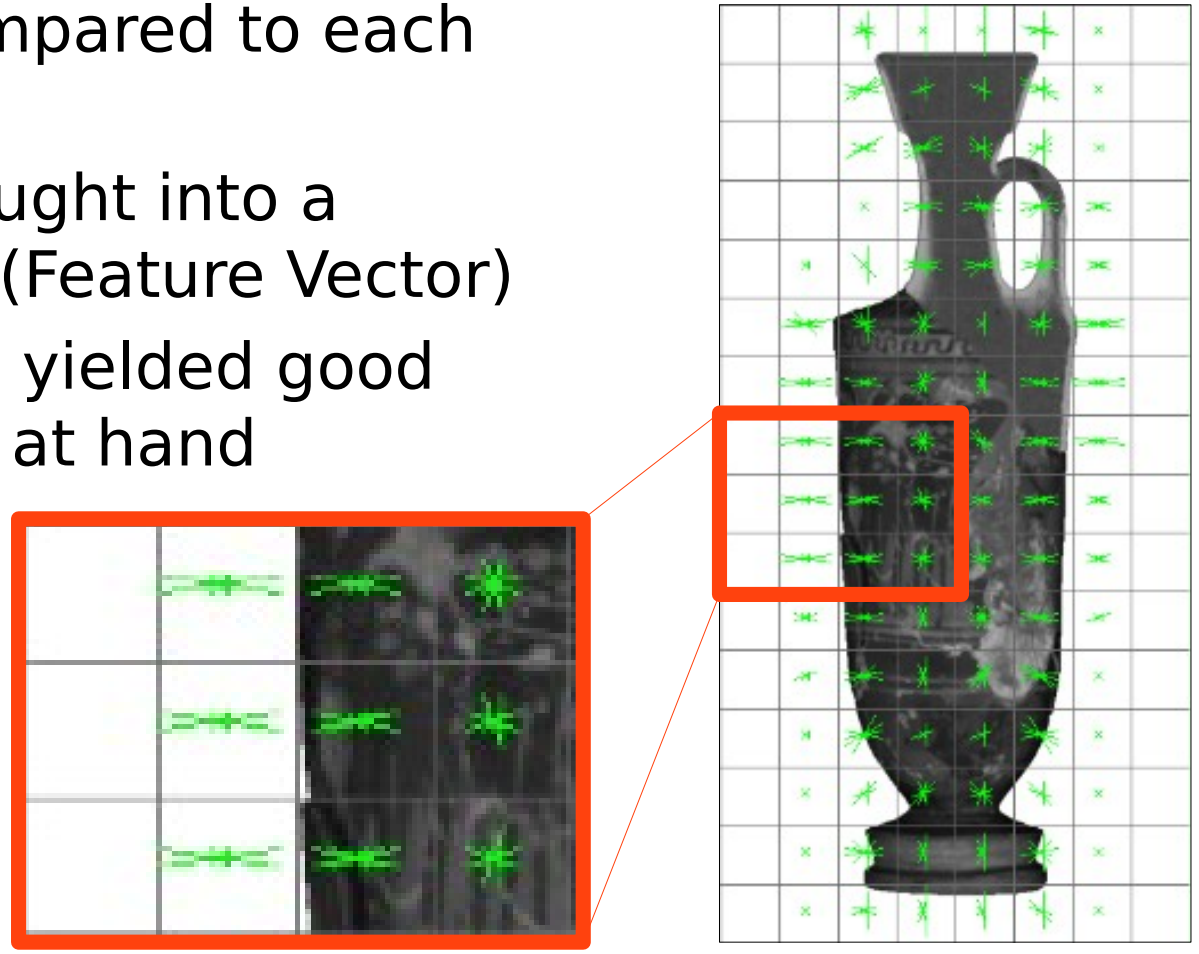
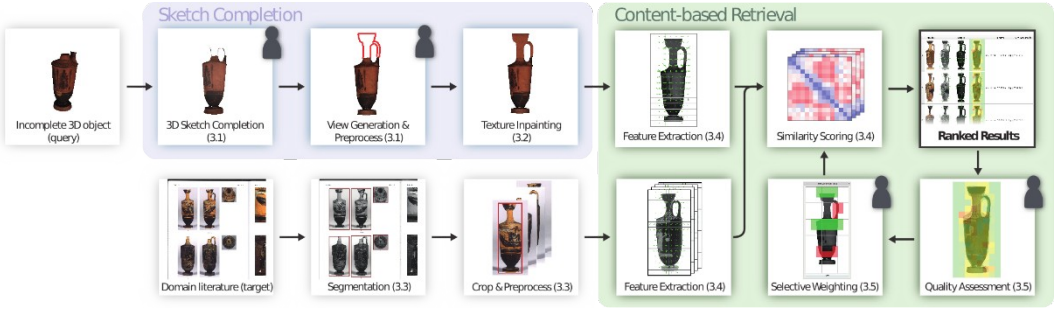
- Gradient-based features[5] yielded good results for the application at hand
- Pairwise comparison of values for similarity measure

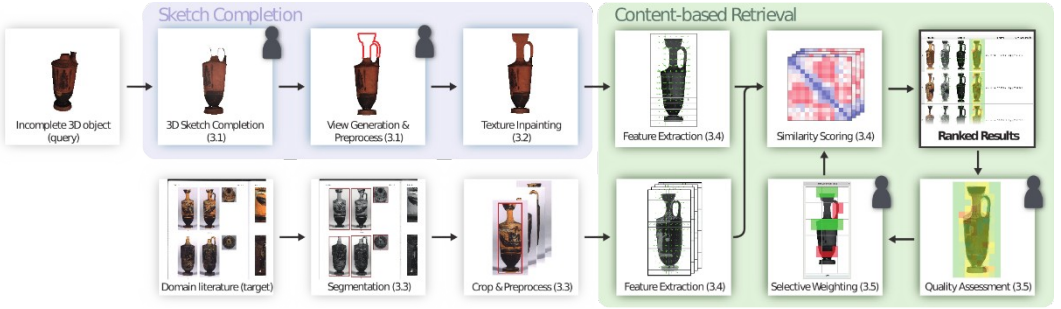


Results


Sketch Completion
Content-based Retrieval
Incomplete 3D object (query)
3D Sketch Completion (3.1)
View Generation & Preprocess (3.1)
Texture Inpainting (3.2)
Feature Extraction (3.4)
Similarity Scoring (3.4)
Ranked Results
Domain literature (target)
Segmentation (3.3)
Crop & Preprocess (3.3)
Feature Extraction (3.4)
Selective Weighting (3.5)
Quality Assessment (3.5)


Reference
HOG
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Hits (D)
0 (1.0)

Results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Reference
HOG
HOG
Hits (D)
0 (1.0)
15 (0.71)
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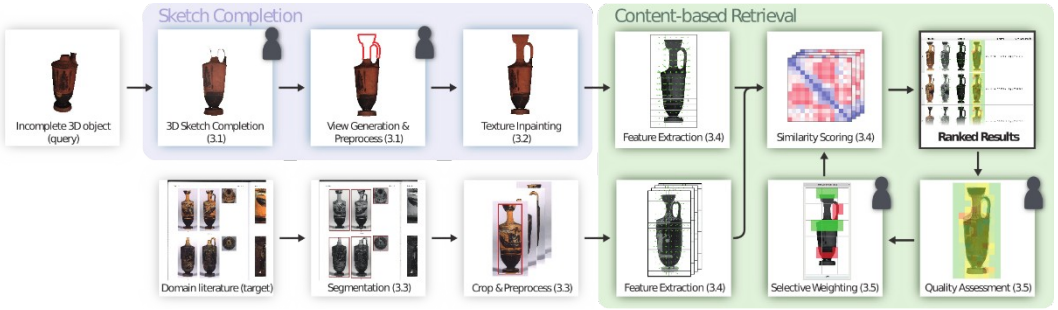
15 16 17 13 4 23 3 19 14 10 7 28 11 9 5

Results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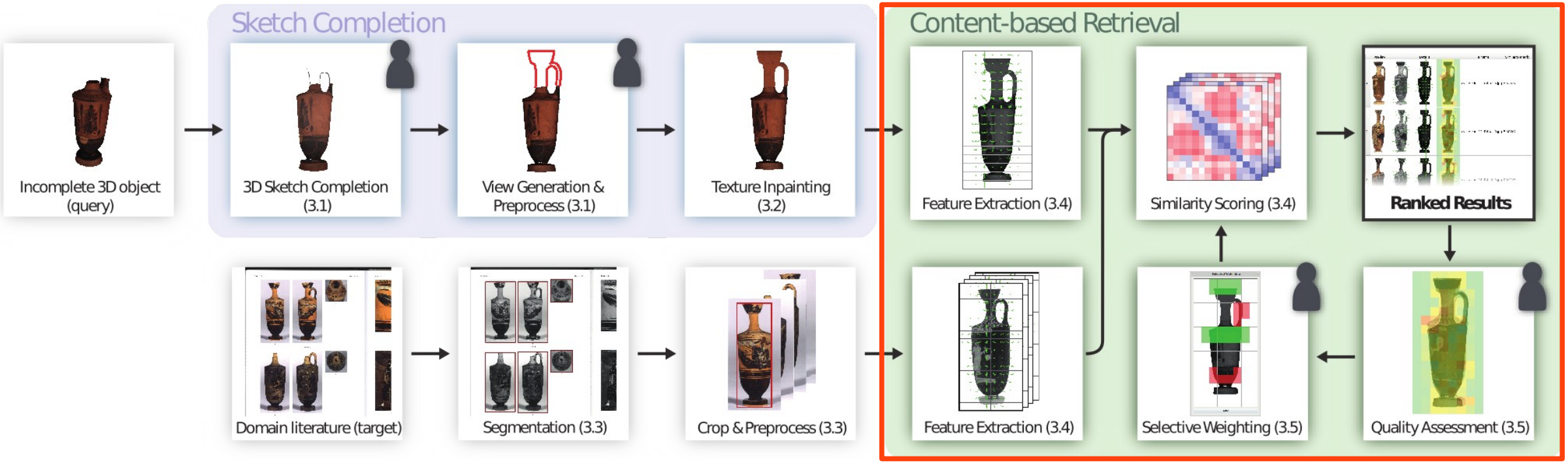
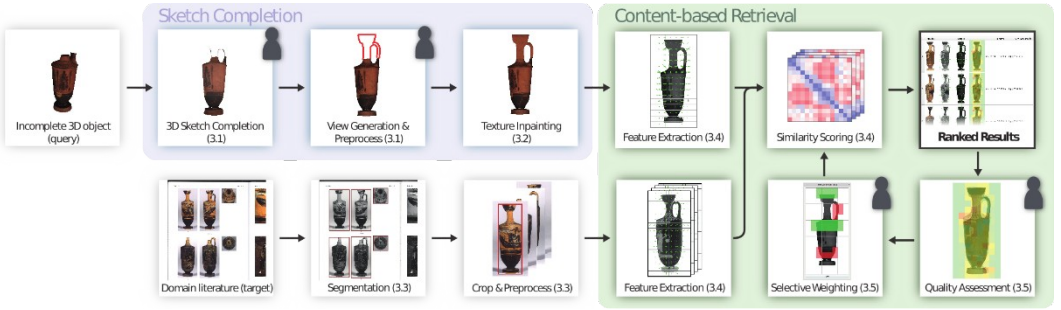
Reference
HOG
HOG
HOG
Hits (D)
0 (1.0)
15 (0.71)
22 (0.51)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
15 16 17 13 4 23 3 19 14 10 7 28 11 9 5
15 13 16 11 3 14 4 17 5 19 1 2 23 7 29 12 6 10 18 9 28 20

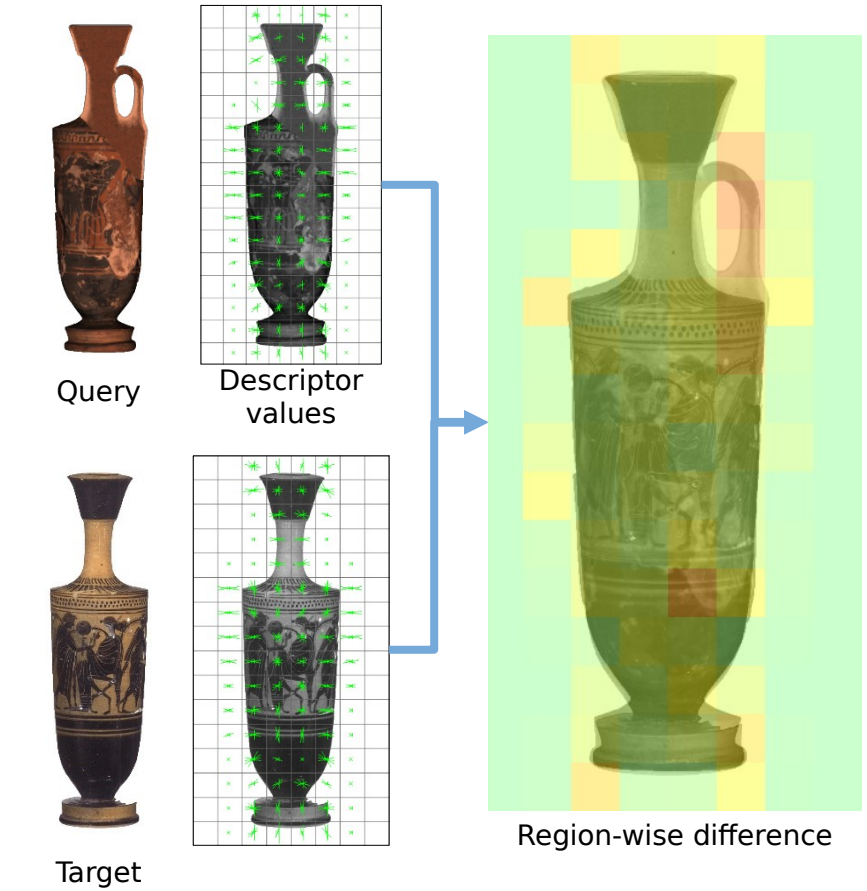
Concept for shape-based retrieval

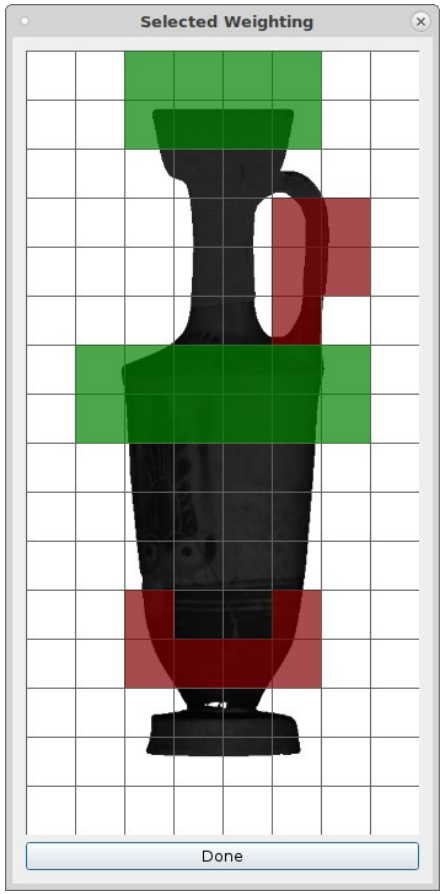


Relevance Feedback

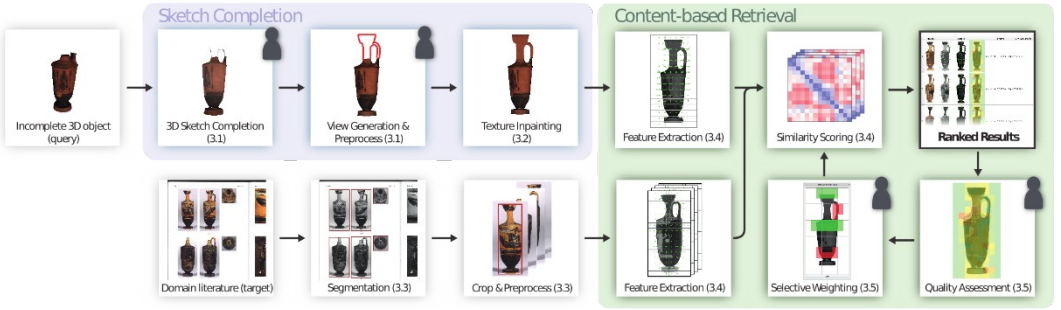


- Iterative result analysis and selective weighting





Results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Hits (D)
HOG
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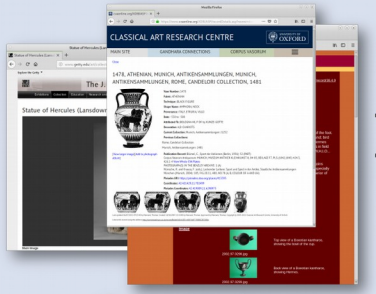
HOG
15 16 17 13 4 23 3 19 14 10 7 28 11 9 5
15 (0.71)
HOG
15 13 16 11 3 14 4 17 5 19 1 2 23 7 29 12 6 10 18 9 28 20
22 (0.51)
16 14 4 15 13 2 1 11 3 17 5 12 19 6 18 10 7 23 9 28 20 30 29
23 (0.41)

Sources

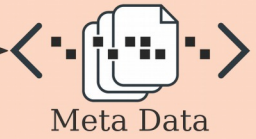


Repositories

Volumes

3D Models

Data Preparation



Meta Data

Images

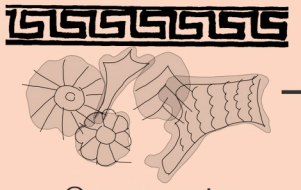
Reconstruction

Flattening/ Unrolling

Shape

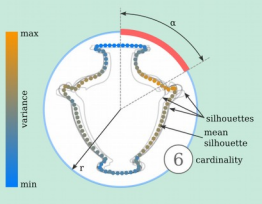
Texture

Motifs

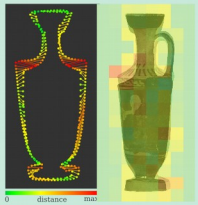


Ornaments

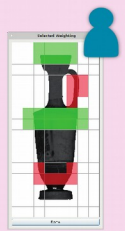
Exploration/ Analysis



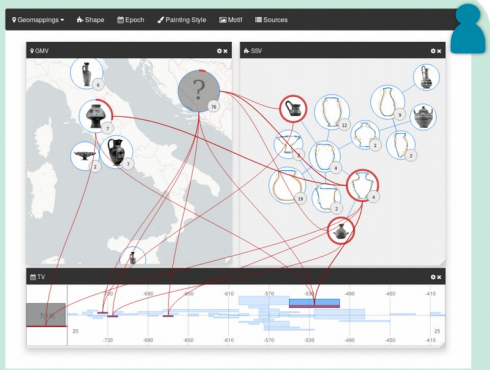
Shape Analysis



Evaluation



Refinement

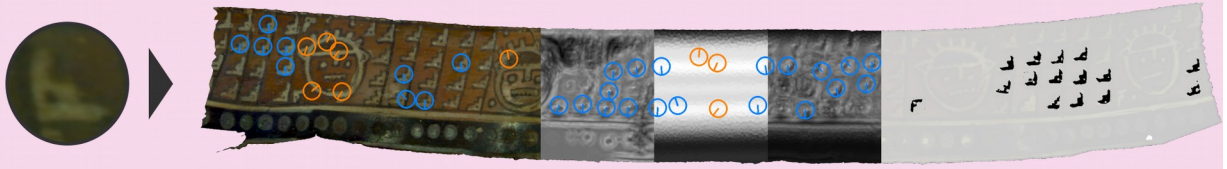


Multimodal Exploration

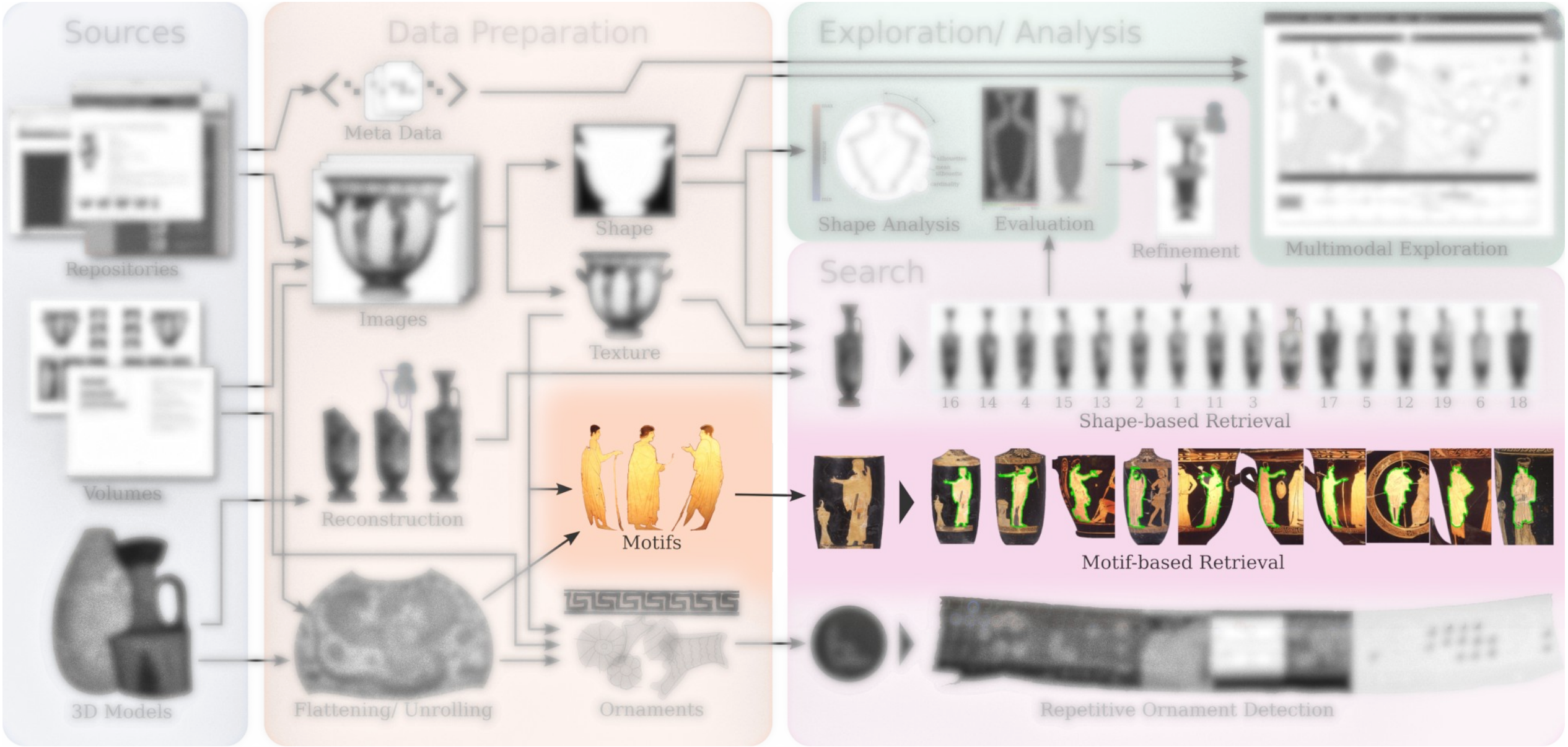
Search

Shape-based Retrieval

Motif-based Retrieval



Repetitive Ornament Detection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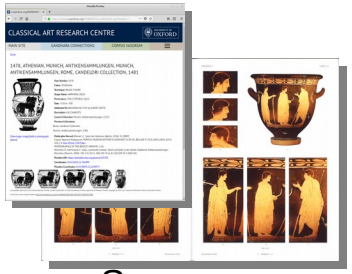
Shape Analysis
Evaluation
Refinement
Multimodal Exploration
Search
16 14 4 15 13 2 1 11 3 17 5 12 19 6 18
Shape-based Retrieval
Motif-based Retrieval
Repetitive Ornament Detection

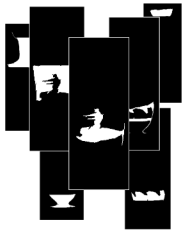
Concept

Preparation: Database creation

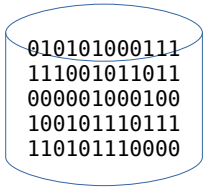
1) Segmentation
2) Feature Extraction
3) Insertion into database



Sources



Preprocessing
Feature Extraction



Search space

Concept

Preparation: Database creation

1)Segmentation

2)Feature Extraction

3)Insertion into database

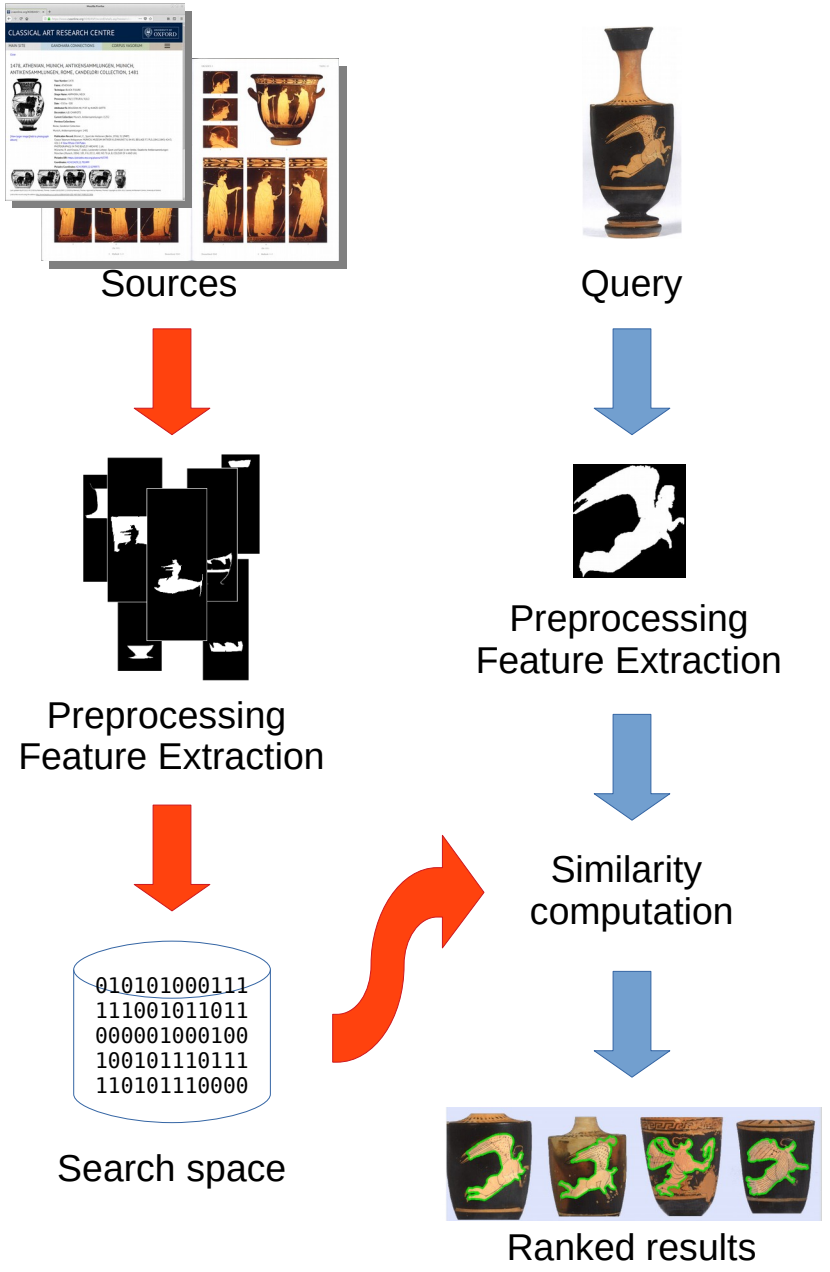
Input: Selected reference image

1)Preprocessing

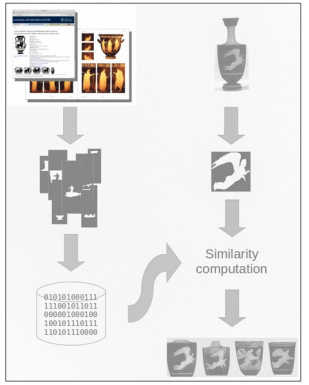
2)Feature Extraction

3)Similarity computation

Output: Ranked list of results



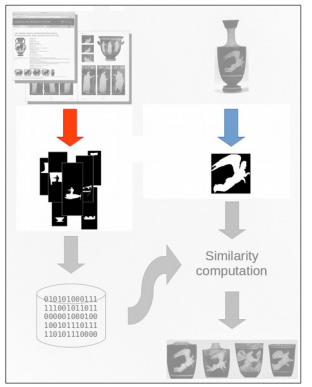
Sources



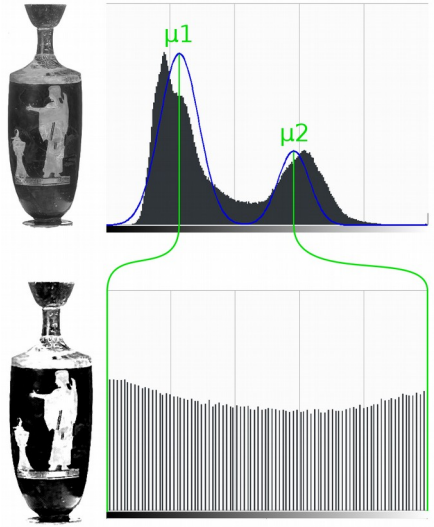
- Sources
  - Corpus Vasorum Antiquorum Berlin 13[6]
  - Corpus Vasorum Antiquorum Dresden 3[7]
- Search space
  - Different vessel shapes (lekythoi, crates, cups, plates, etc.)
  - Numerous motifs of various types
  - 99 images → **937** (152 + 785) silhouettes

[6]Zimmermann-Elseify, N., CVA Berlin 13: Attisch rotfigurige Lekythen. *C.H. Beck*, 2013.
[7]Eschbach, N., *CVA Dresden 3: Attisch rotfigurige Keramik*, C.H. Beck, 2018.

Motif Preserving Segmentation



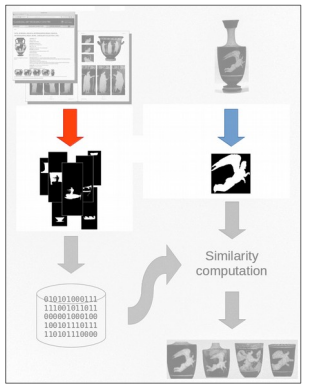
- Contrast enhancement and binarization
  1) Find *fg* and *bg* peaks in the grayscale histogram
  2) Map the colors in-between to the whole range
  3) Binary image from tresholding



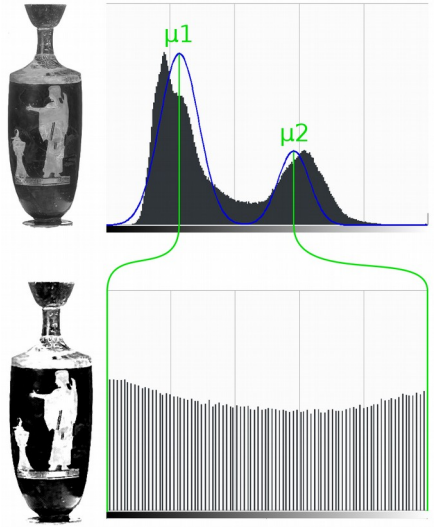
Original Contrast enhancement Thresholding

[8]Felzenszwalb, Pedro F., and Daniel P. Huttenlocher. "Efficient graph-based image segmentation." *International journal of computer vision* 59.2 (2004): 167-181.

Motif Preserving Segmentation

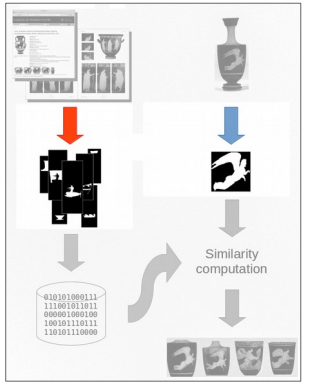


- Contrast enhancement and binarization
  1) Find *fg* and *bg* peaks in the grayscale histogram
  2) Map the colors in-between to the whole range
  3) Binary image from tresholding
- Segmentation[8]
  - Labels are assigned to coherent image areas



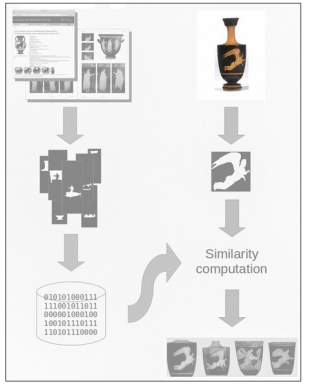
Original Contrast enhancement Thresholding Segmentation Export

Motif Preserving Segmentation



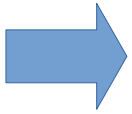
Segmentations obtained from two different approaches

Query Specification

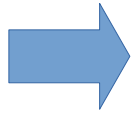


- Loading reference image
- Rough selection of motif with brush tool
- Real-time silhouette extraction in the background
- Same feature extraction as with the search space objects

Brush Selection

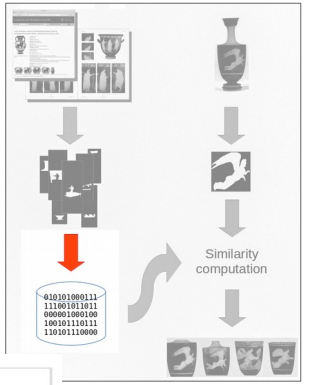


Query Segmentation



Extracted Silhouette

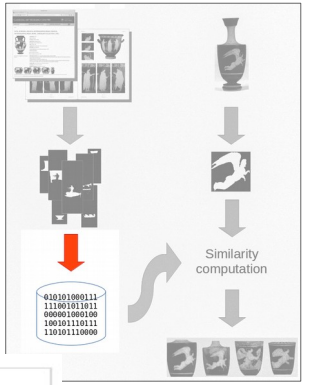
Silhouette Descriptor



Shape Contexts Descriptor[9]

1. Silhouette sampling
   - Silhouette approximation with a fixed number of points N
2. Histogram computation
   - For each point:
     1. Determine direction and distance to all other points
     2. Sort into radial and angular bins
     3. Normalize

Silhouette Descriptor



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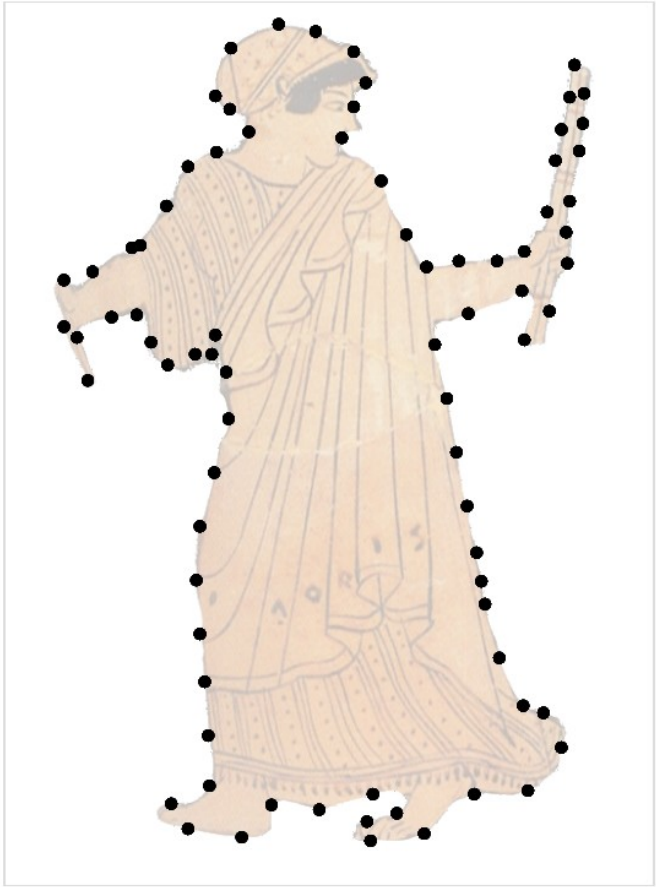
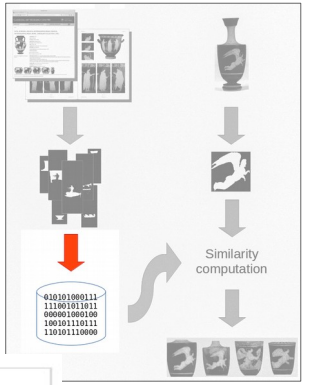


Silhouette Descriptor



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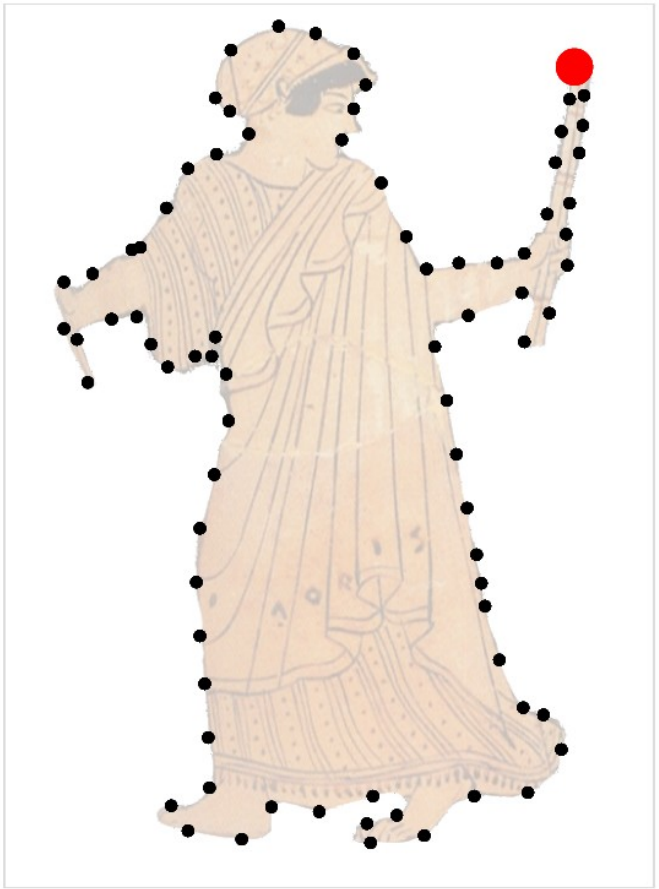
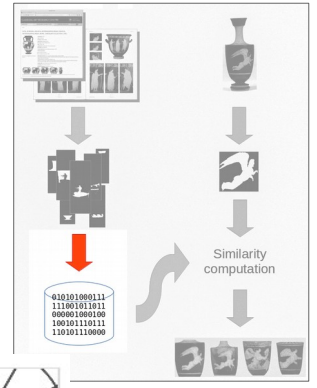


Silhouette Descriptor



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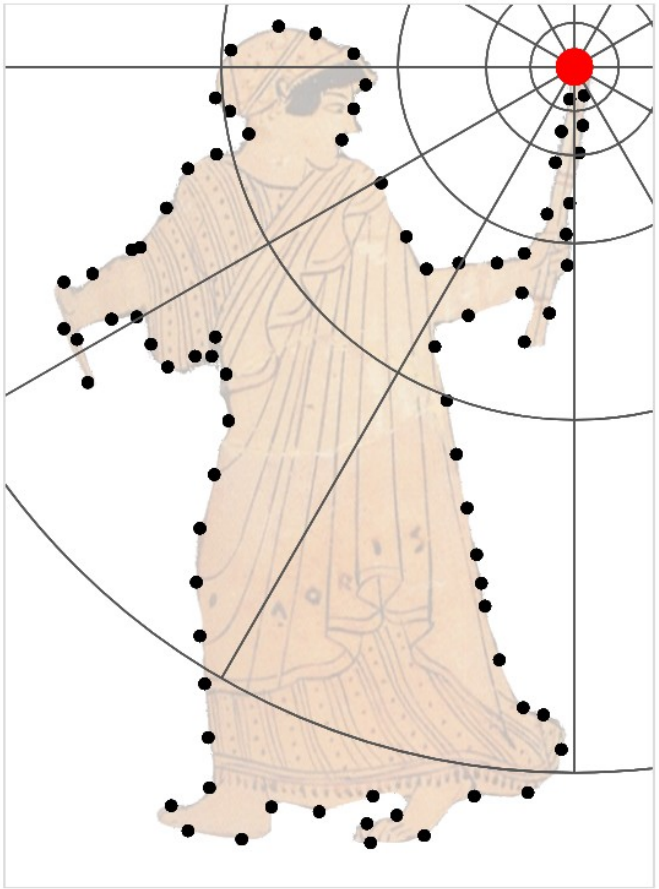
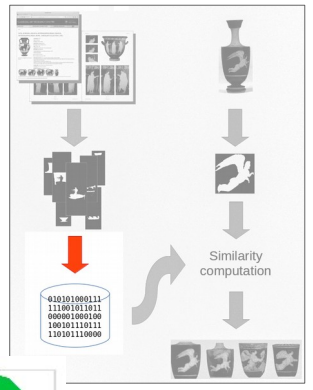


Silhouette Descriptor



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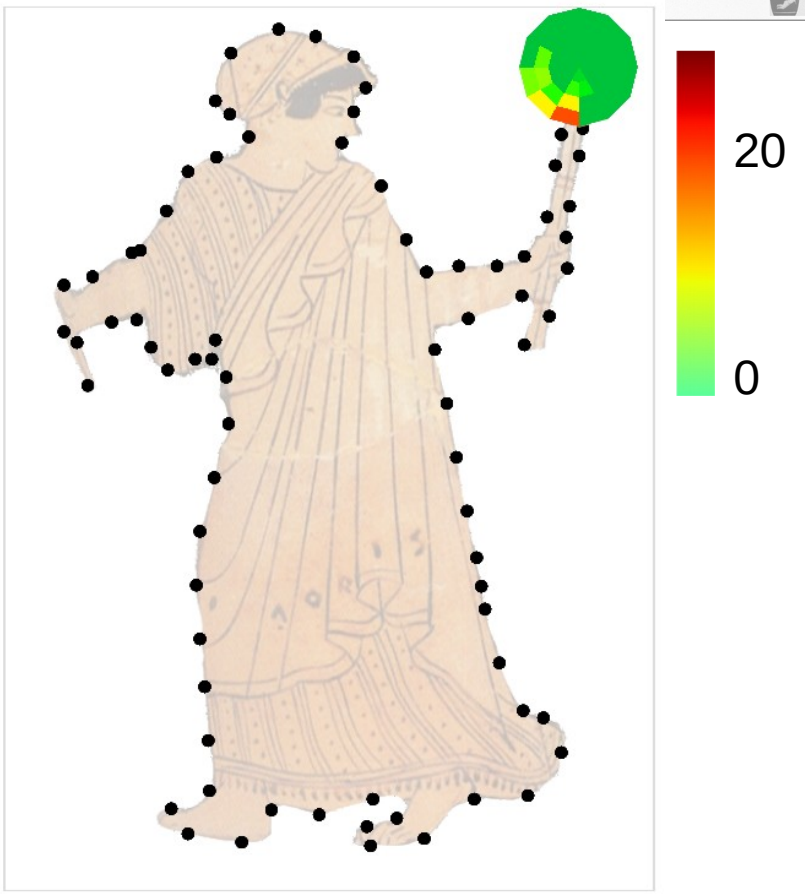
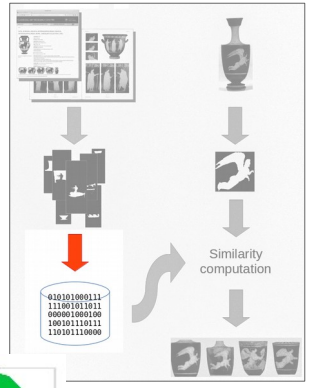


Silhouette Descriptor



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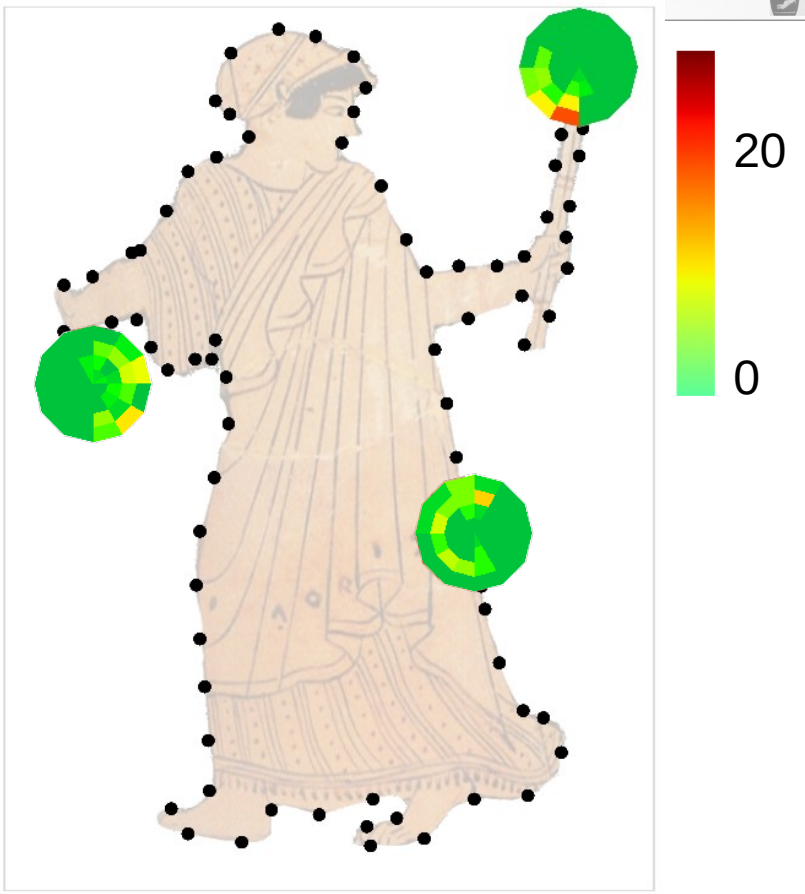
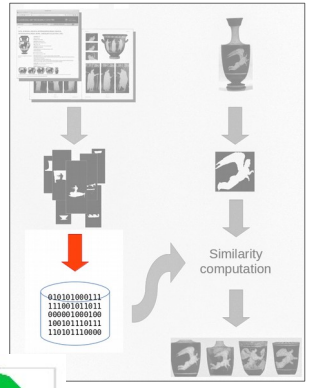
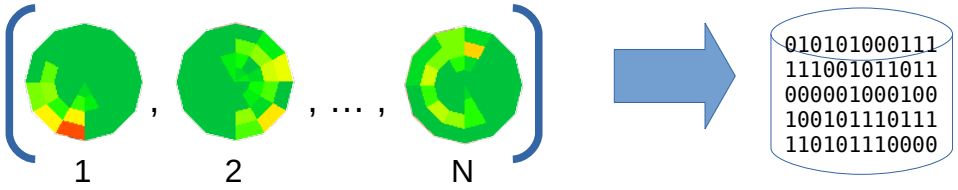


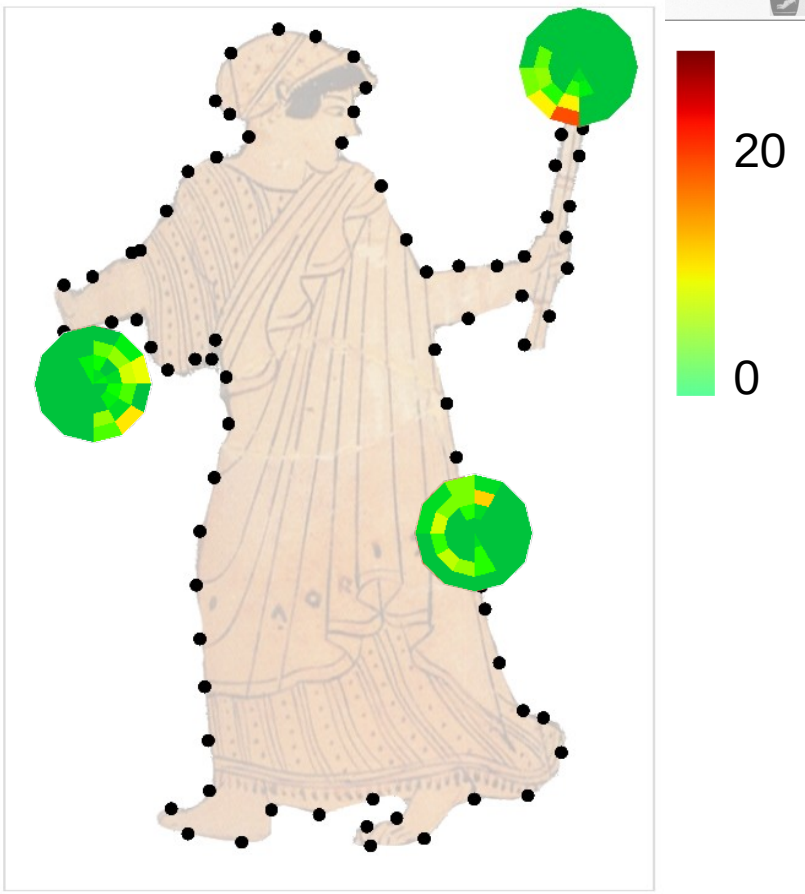
Silhouette Descriptor



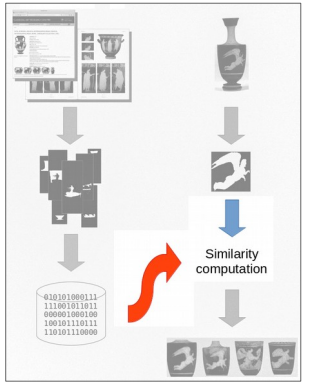
Shape Contexts Descriptor[9]

1. Silhouette sampling
   - Silhouette approximation with a fixed number of points N
2. Histogram computation
   - For each point:
     1. Determine direction and distance to all other points
     2. Sort into radial and angular bins
     3. Normalize
3. Insert histograms vector into database



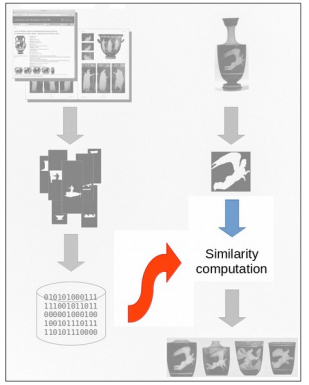


Similarity Computation



- Compare of every silhouette of the search space to the query silhouette given by the histograms $\{q_i\}$
- For each target silhouette, given by the histograms $\{t_j\}$:
  1) Find optimal assignment[10] π of all q_i to t_j

Similarity Computation



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- For each target silhouette, given by the histograms $\{t_j\}$:
  1) Find optimal assignment[10] π of all q_i to t_j
  2) Compute overall assignment costs

$$H(\pi) = \sum_i C(q_i, t_{\pi(i)})$$

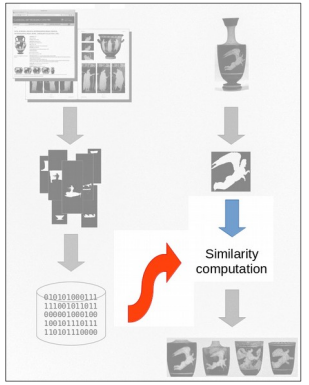
$H($  $) \approx 0$

$H($  $) > 0$

$H($  $) \gg 0$

[10] Jonker, Roy, and Anton Volgenant. "A shortest augmenting path algorithm for dense and sparse linear assignment problems." *Computing* 38.4 (1987): 325-340.

Similarity Computation



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- For each target silhouette, given by the histograms $\{t_j\}$:
  1) Find optimal assignment[10] π of all q_i to t_j
  2) Compute overall assignment costs

$$H(\pi) = \sum_i C(q_i, t_{\pi(i)})$$

- Similarity of query and target $\propto H^{-1}$
- Ranking of search space silhouettes according to similarity

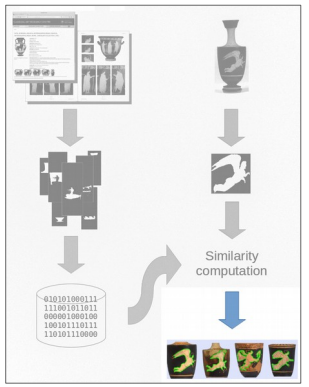
$H($  $) \approx 0$

$H($  $) > 0$

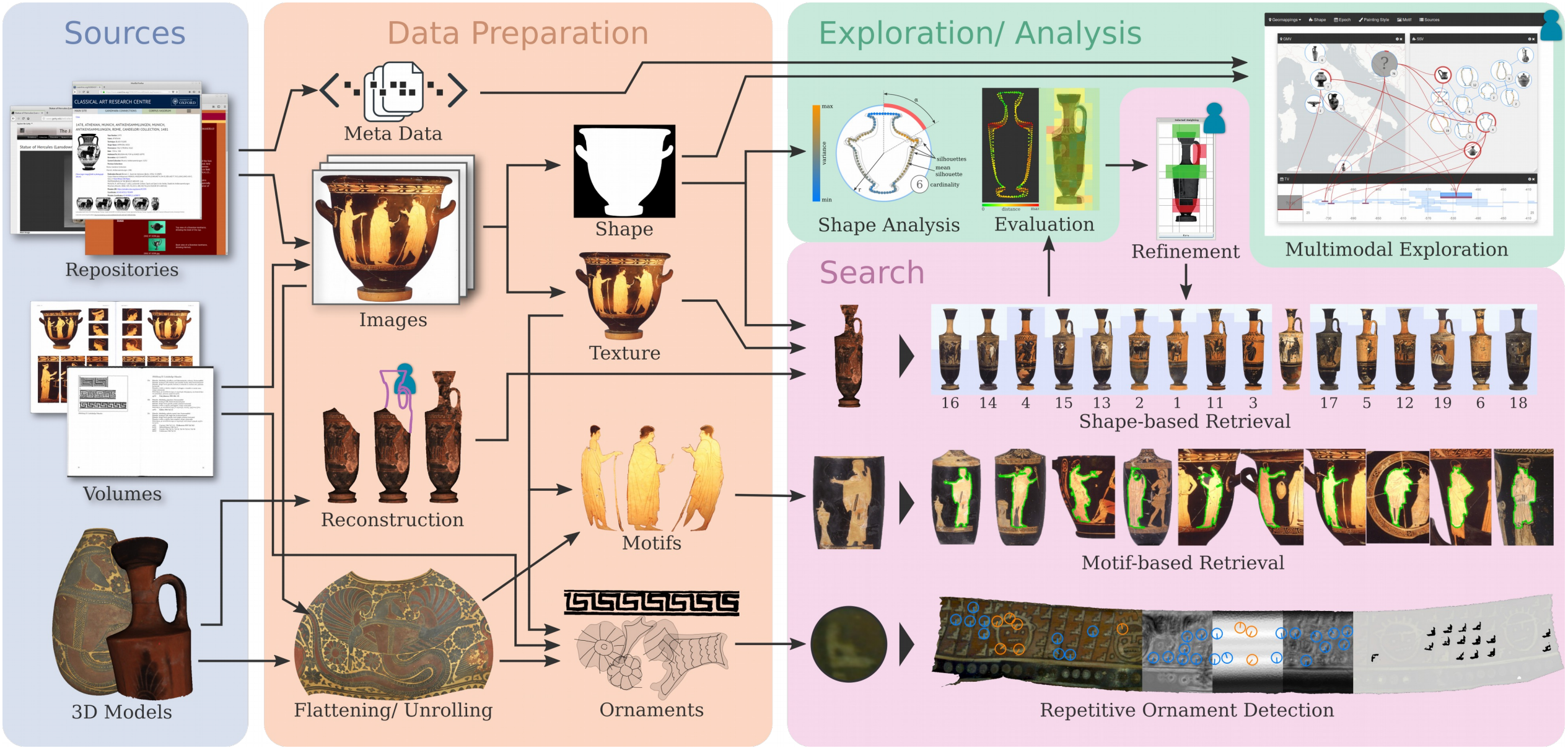
$H($  $) \gg 0$

[10]Jonker, Roy, and Anton Volgenant. "A shortest augmenting path algorithm for dense and sparse linear assignment problems." *Computing* 38.4 (1987): 325-340.

Experimental Evaluation



Proof of concept with queries taken from the search space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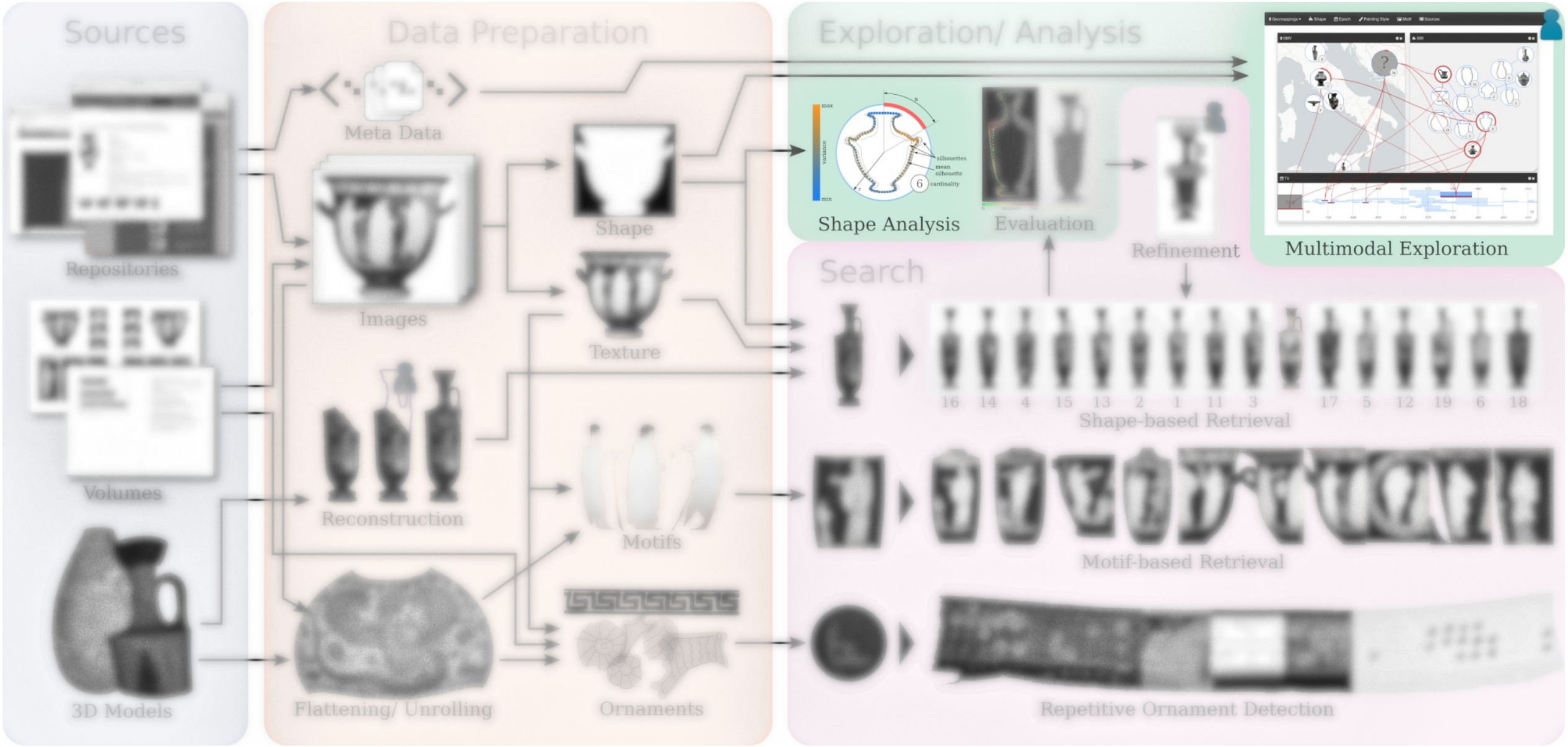
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16 14 4 15 13 2 1 11 3 17 5 12 19 6 18
Shape-based Retrieval
Motif-based Retrieval
Repetitive Ornament Detection

Motivation

- Relations of objects along different traits essential for gaining new insights
- Different modalities have to be considered simultaneously
  - Shape
  - Provenance
  - Date
  - Fabric
  - Decoration
- Established techniques for single attributes

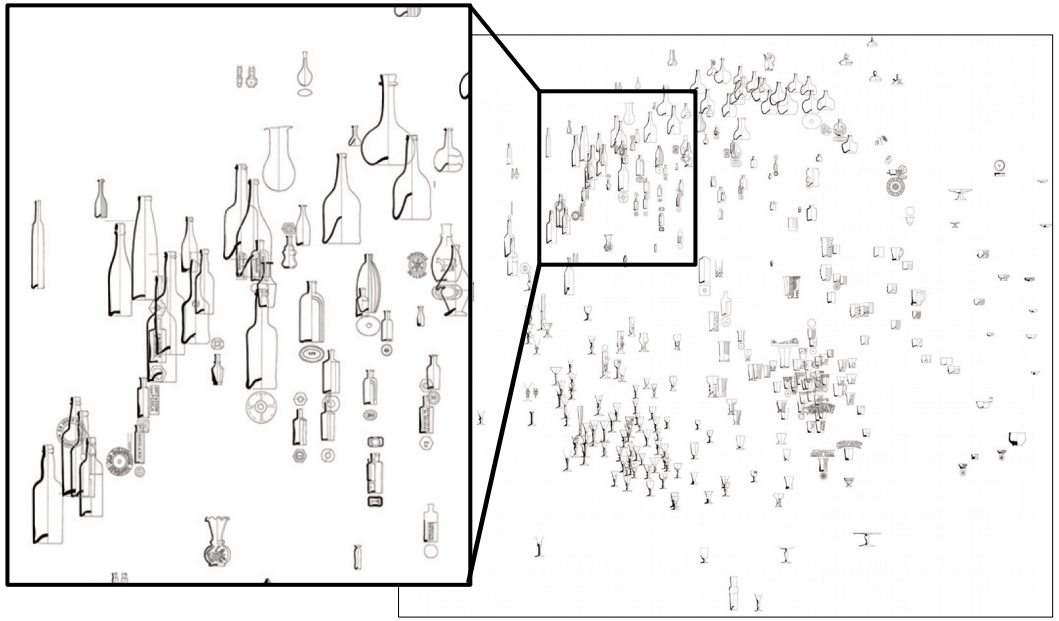
9032359, ATHENIAN, Berlin, Antikensammlung, F2238

- **Vase Number:** 9032359
- **Fabric:** ATHENIAN
- **Technique:** BLACK GLAZE
- **Shape Name:** LEKYTHOS
- **Provenance:** ITALY, NOLA
- **Decoration:** Body: UNDECORATED
- **Current Collection:** Berlin, Antikensammlung: F2238
- **Publication Record:** Corpus Vasorum Antiquorum: BERLIN, PL.(4548) 55.1-3 View Whole CVA Plates
- **Pleiades URI:** https://pleiades.stoa.org/places/432981
- **Coordinates:** 40.930481,14.52847
- **Pleiades Coordinates:** 40.926823,14.524545

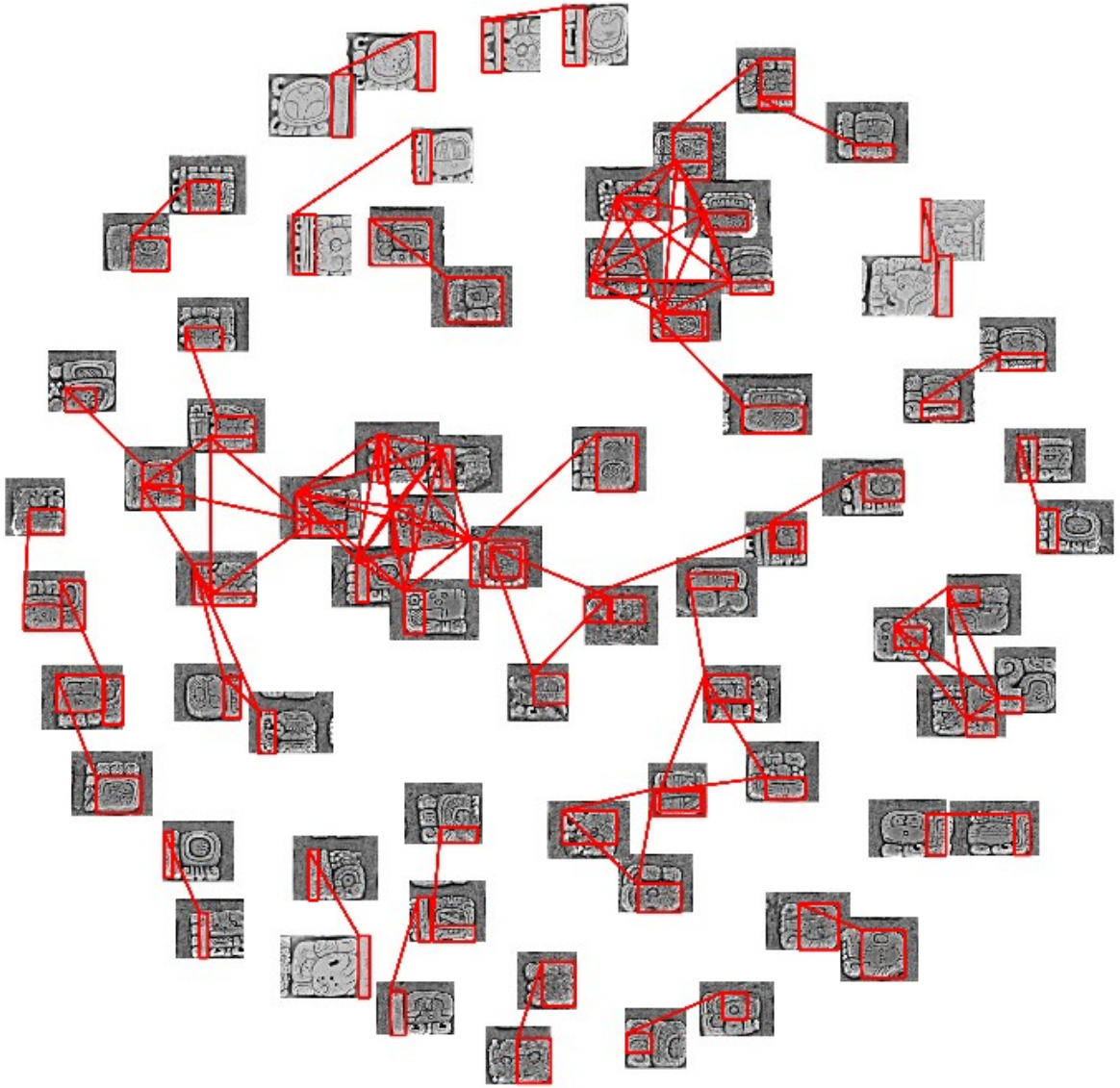
208452, ATHENIAN, Berlin, Antikensammlung, F2225

- **Vase Number:** 208452
- **Fabric:** ATHENIAN
- **Technique:** RED-FIGURE
- **Shape Name:** LEKYTHOS
- **Provenance:** ITALY, NOLA
- **Date:** -475 to -425
- **Attributed To:** SEIRENISKE P by BEAZLEY
- **Decoration:** Body: NIKE RUNNING TO ALTAR
- **Current Collection:** Berlin, Antikensammlung: F2225
- **Publication Record:** Beazley, J.D., Attic Red-Figure Vase-P… Corpus Vasorum Antiquorum: BERLIN, ANTIKENSAMMLUNG CVA Plates
- **Pleiades URI:** https://pleiades.stoa.org/places/432981
- **Coordinates:** 40.930481,14.52847
- **Pleiades Coordinates:** 40.926823,14.524545

Related Work

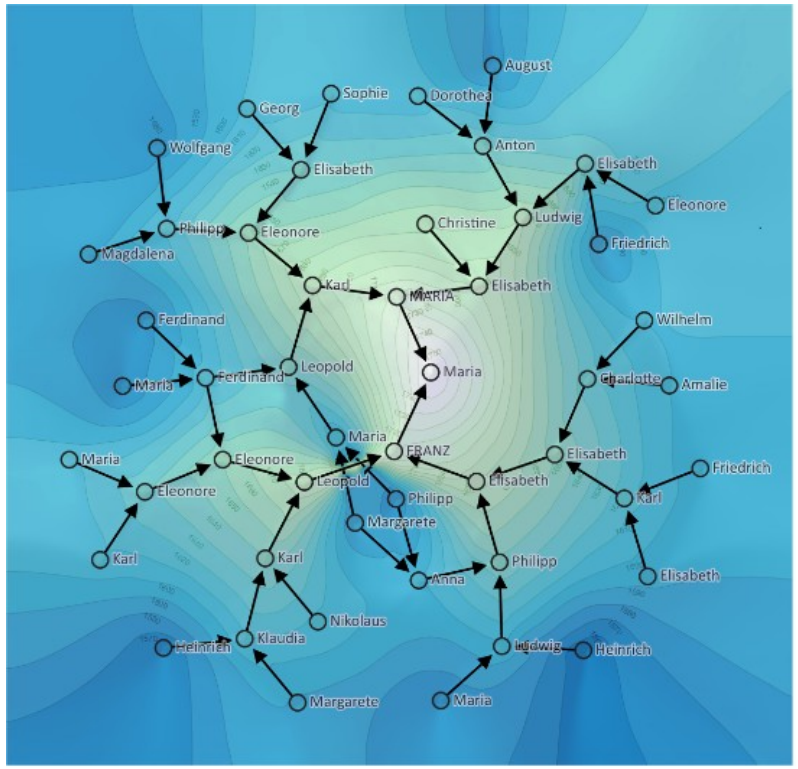


van der Maaten, L., Boon, P., Lange, G., Paijmans, H. and Postma, E., 2006. Computer vision and machine learning for archaeology. *Proceedings of Computer Applications and Quantitative Methods in Archaeology*, pp.112-130.

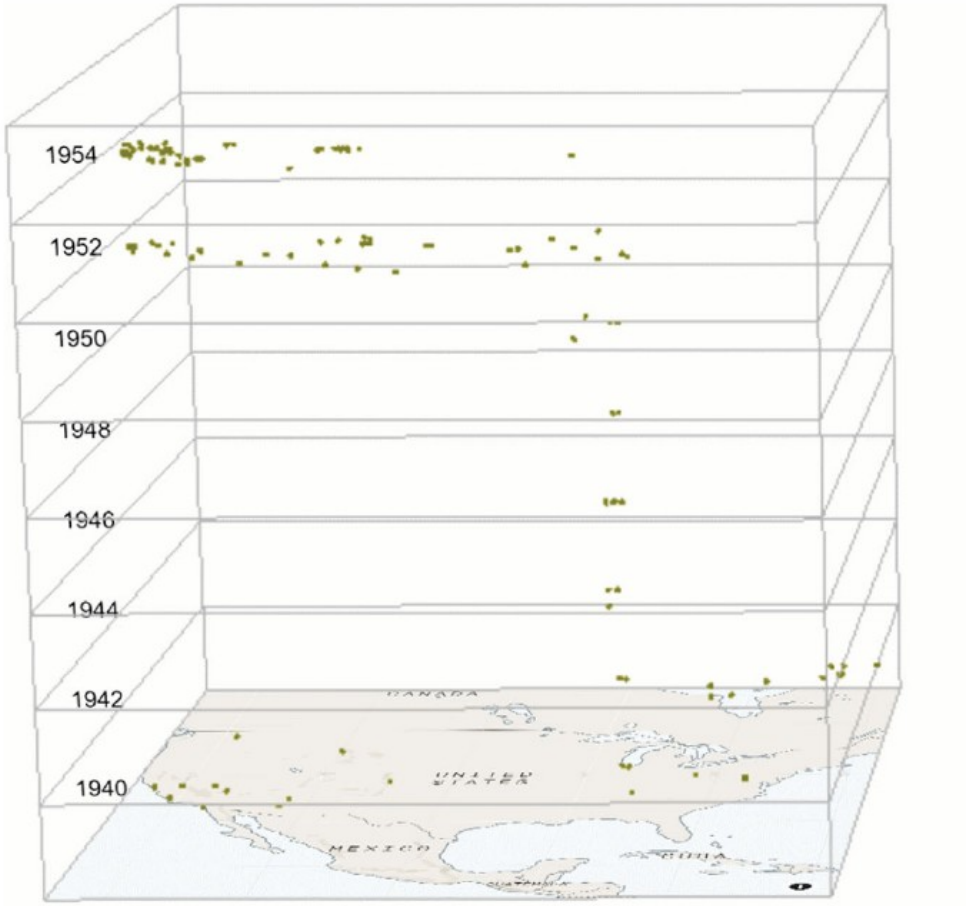


Bogacz, B., Feldmann, F., Prager, C. and Mara, H., 2018. Visualizing Networks of Maya Glyphs by Clustering Subglyphs. In *Proceedings of the Eurographics Workshop on Graphics and Cultural Heritage.*

Related Work



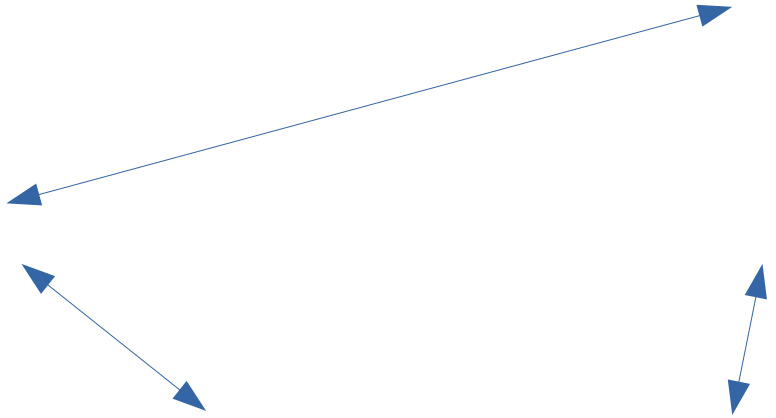
Preiner, R., Schmidt, J., Krösl, K., Schreck, T. and Mistelbauer, G., 2020, June. Augmenting Node-Link Diagrams with Topographic Attribute Maps. In *Computer Graphics Forum* (Vol. 39, No. 3, pp. 369-381).



Windhager, F., Salisu, S., Leite, R.A., Filipov, V., Miksch, S., Schreder, G. and Mayr, E., 2020. Many Views Are Not Enough: Designing for Synoptic Insights in Cultural Collections. *IEEE Computer Graphics and Applications, 40(3*), pp.58-71.

Our Approach

- Established views for individual attributes
- Linking of interactive views
- Currently supported modalities:



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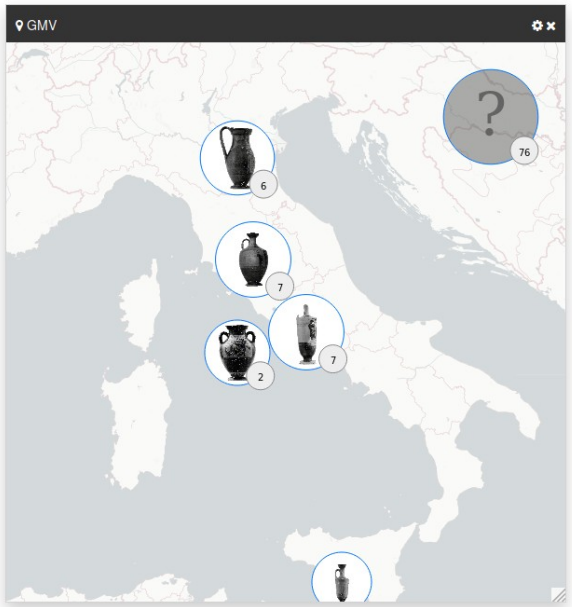
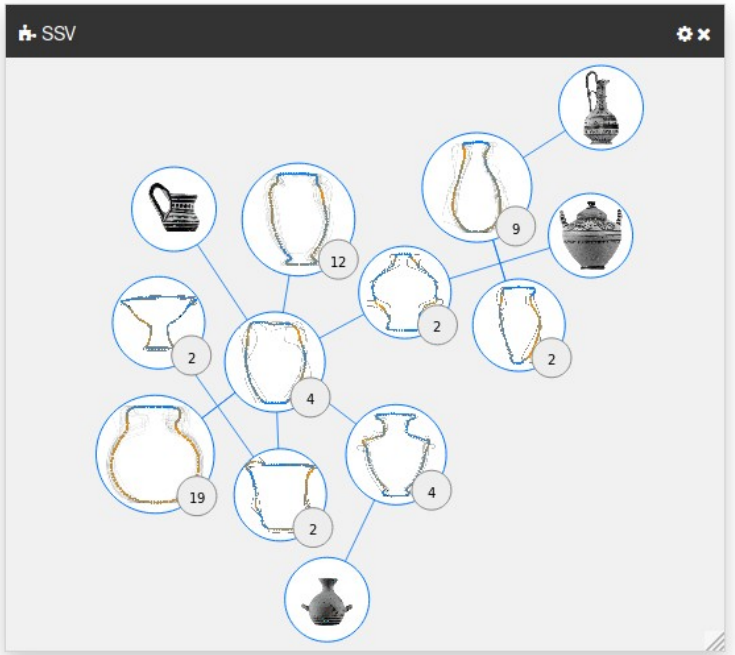
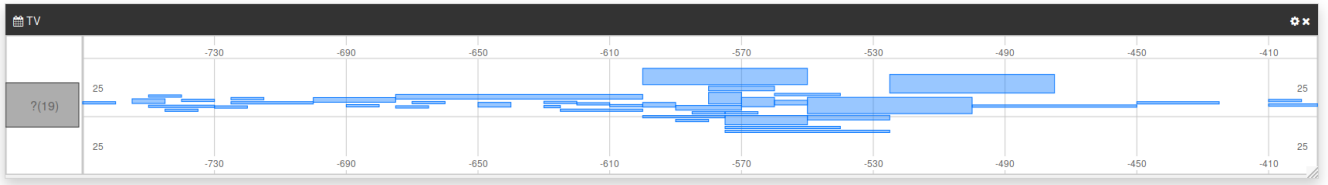


Findplace



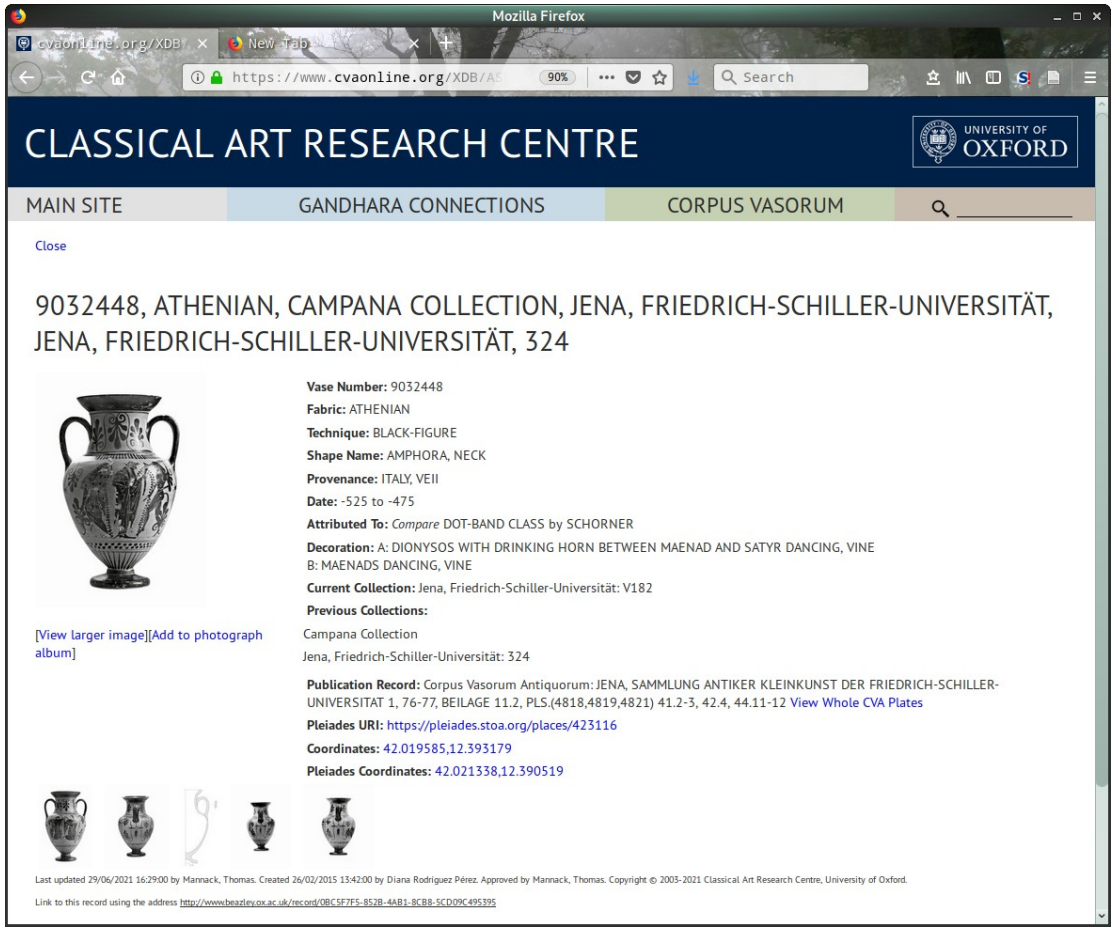
Shape



Date

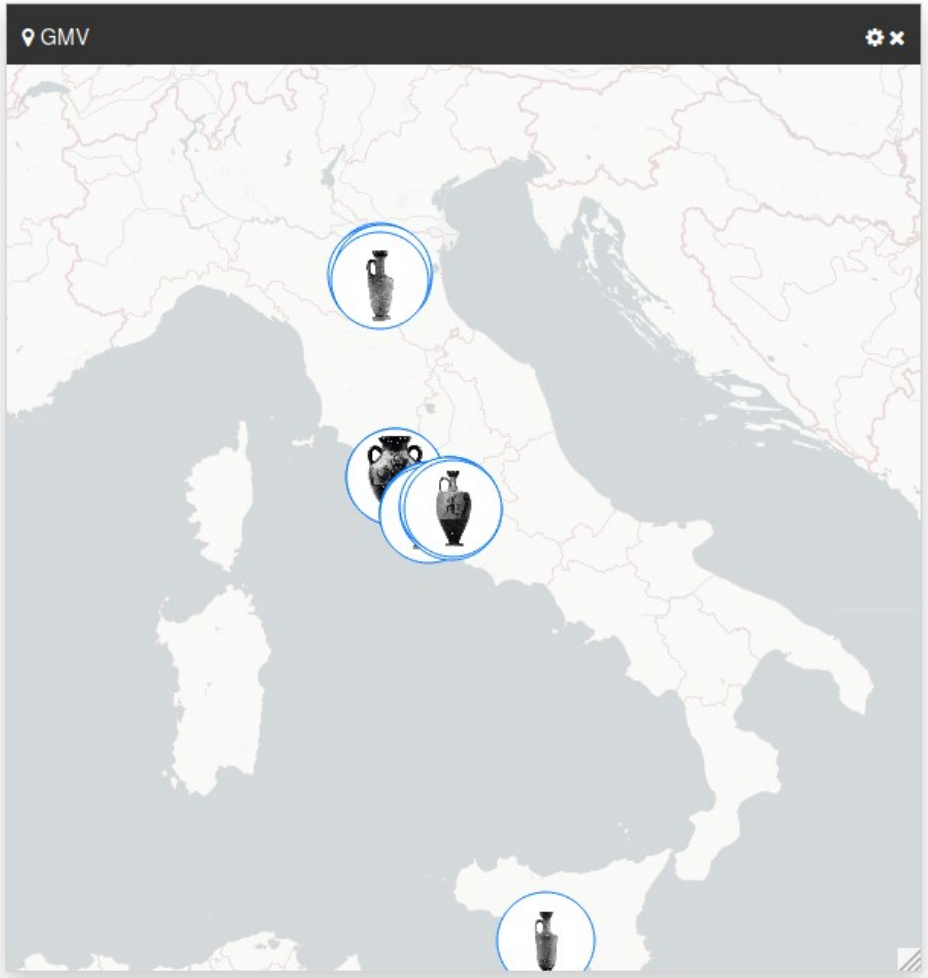
Sources

- Sources: CVA Volumes
  - Dresden 2
  - Erlangen 2
  - Göttingen 3
  - Jena 1
  - Munich 16
- Related Metadata extracted from the *Beazley Archive Pottery Database*[11]
- 614 Vases with 2,799 images
  - 61% have dating information
  - 32% have provenance information



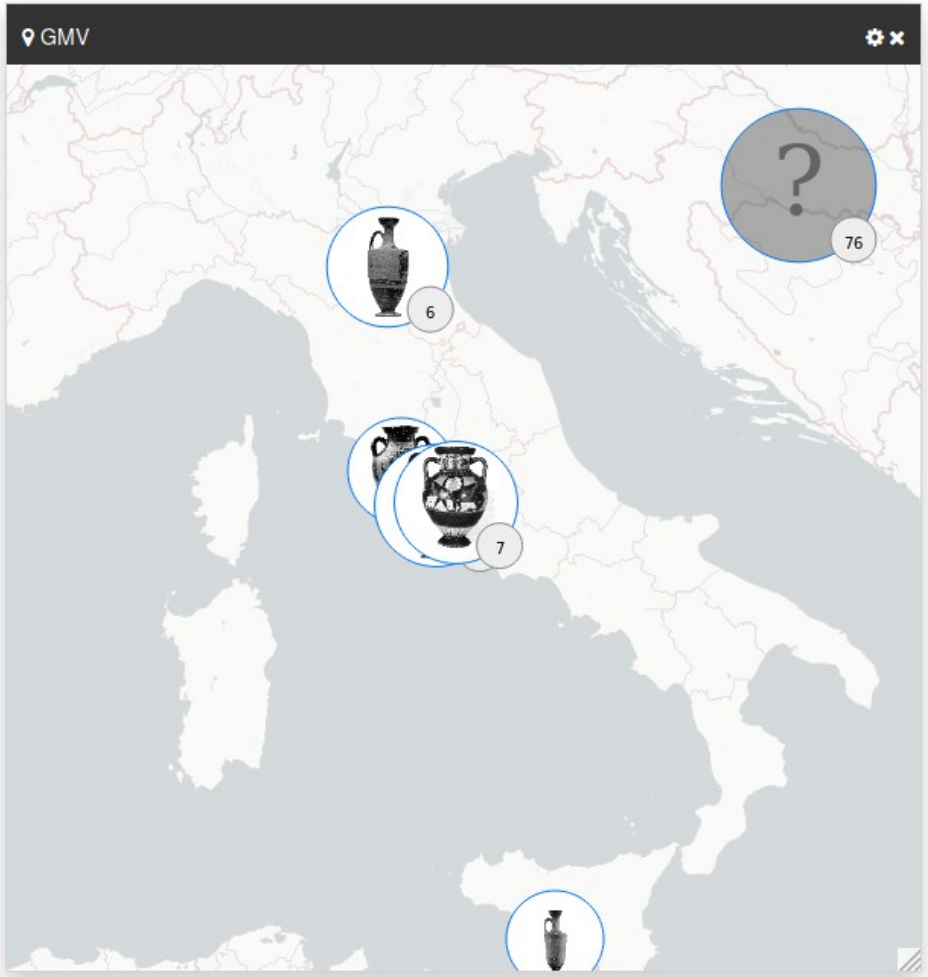
[11] https://www.beazley.ox.ac.uk/index.htm

Findspot View



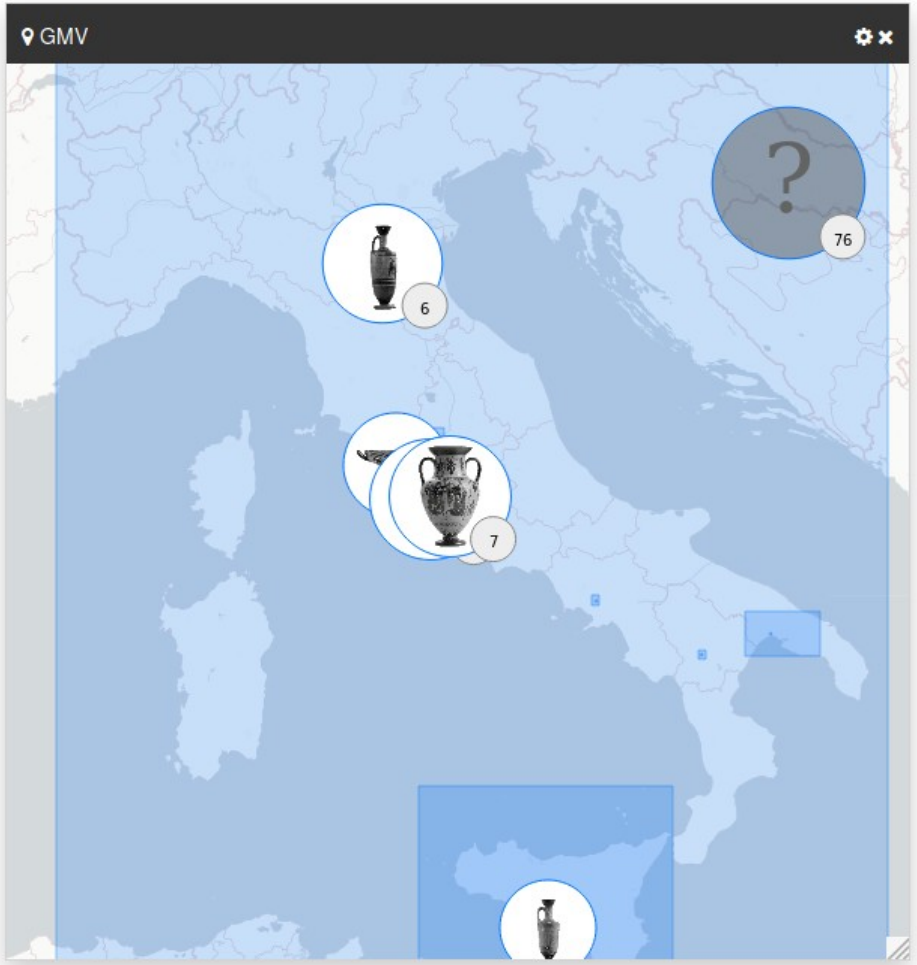
- Geographic map with object previews

Findspot View



- Geographic map with object previews
- Visual enhancement
  - Aggregation by findplace

Findspot View



- Geographic map with object previews
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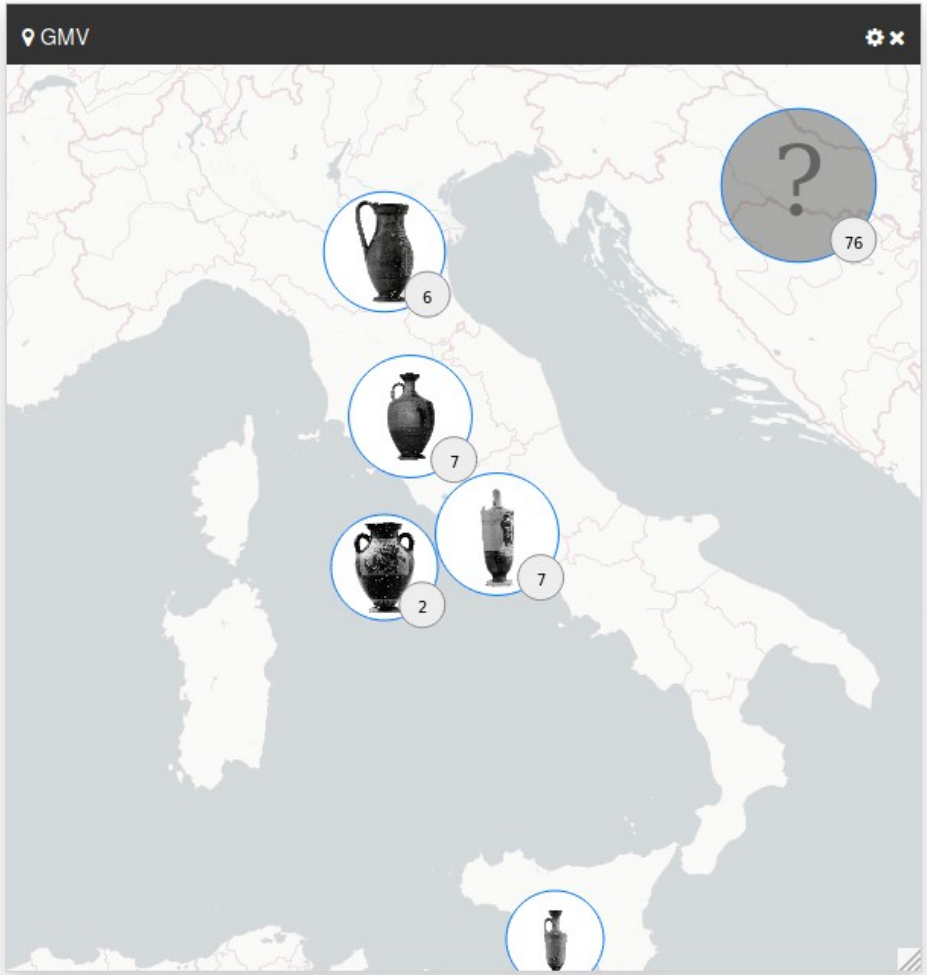
Findspot View



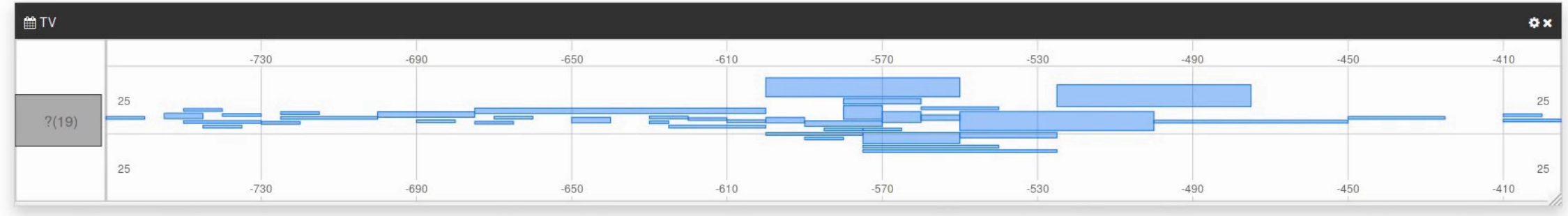
- Geographic map with object previews
- Visual enhancement
  - Aggregation by findplace
  - Collision Avoidance

Findspot View

- Geographic map with object previews
- Visual enhancement
  - Aggregation by findplace
  - Collision Avoidance
  - Separate node for unattributed objects

Timeline View

- Dating information given as (half open) interval
  - E.g. “-525 to -475”
- Objects aggregated into interval blocks
  - Thickness of block signifies the number of objects
- Layout governed by force simulation



Timeline View

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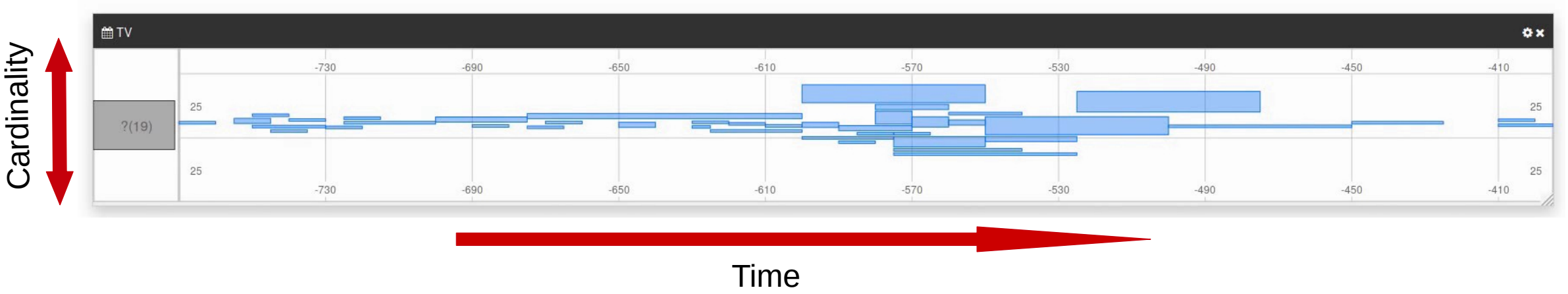


Shape Similarity Viewer

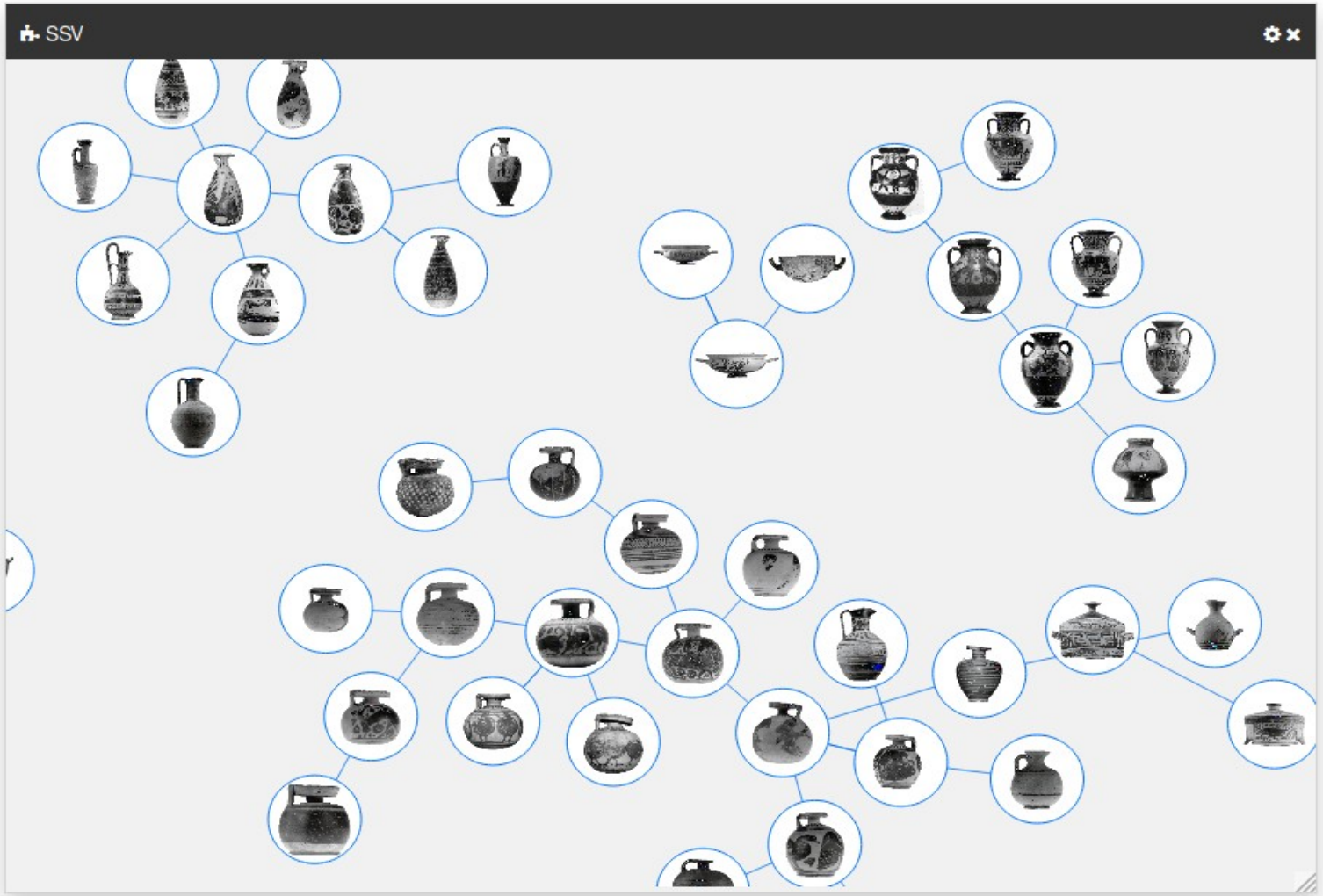
- Extract silhouettes from object depictions

- Silhouette similarities determined by *Shape Contour* Descriptor[12]

Shape Similarity Viewer

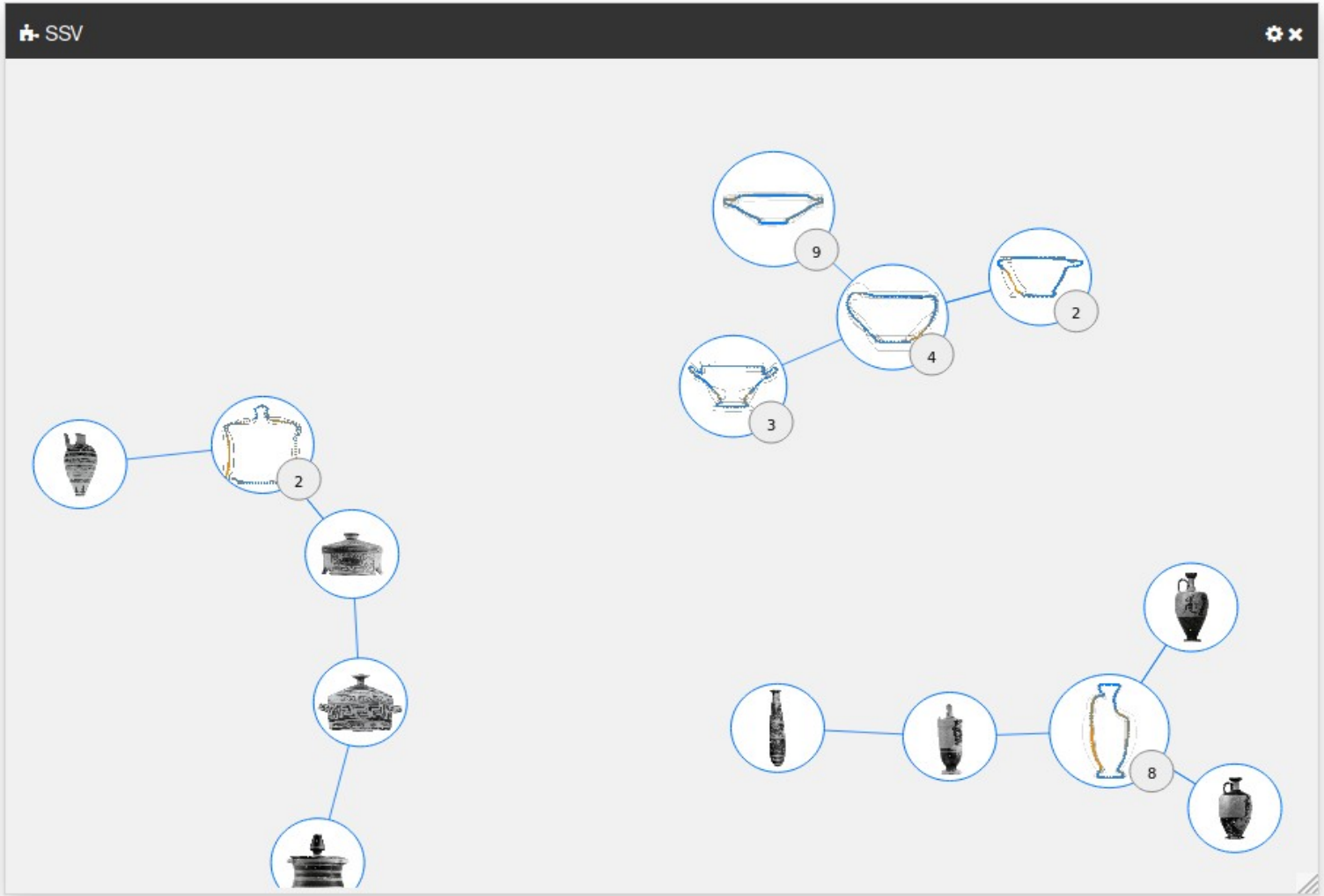
- Network visualization for shape similarity
  - Similarity indicated by connecting links
- **Issue:** Links between all nodes overconstrain the layout

Shape Similarity Viewer



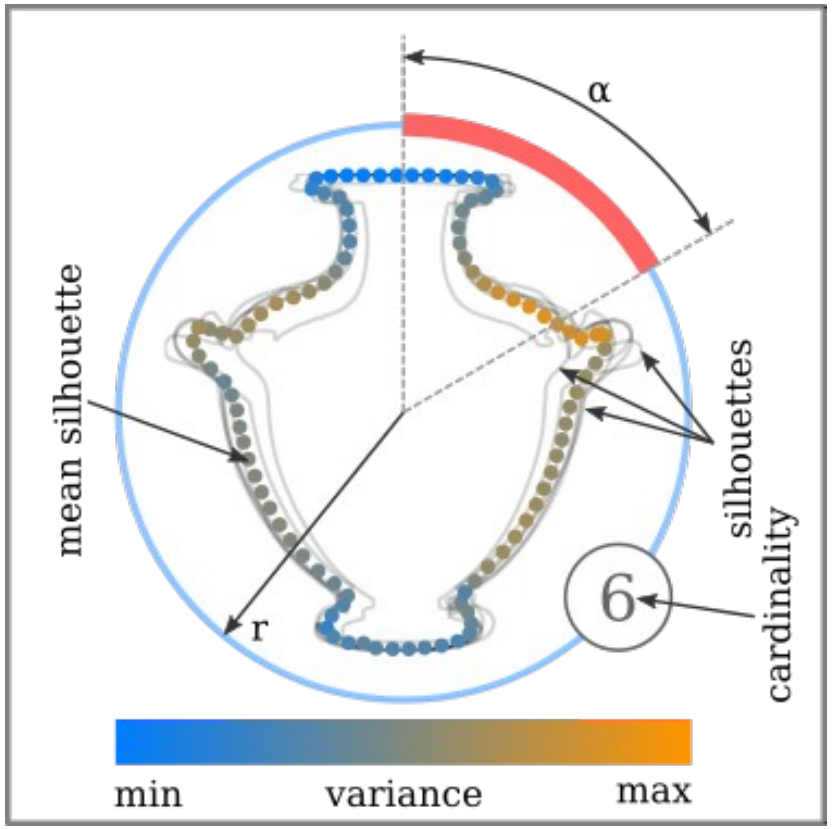
- Link sparsification[13] perserves only the *‘most significant’* links

Shape Similarity Viewer



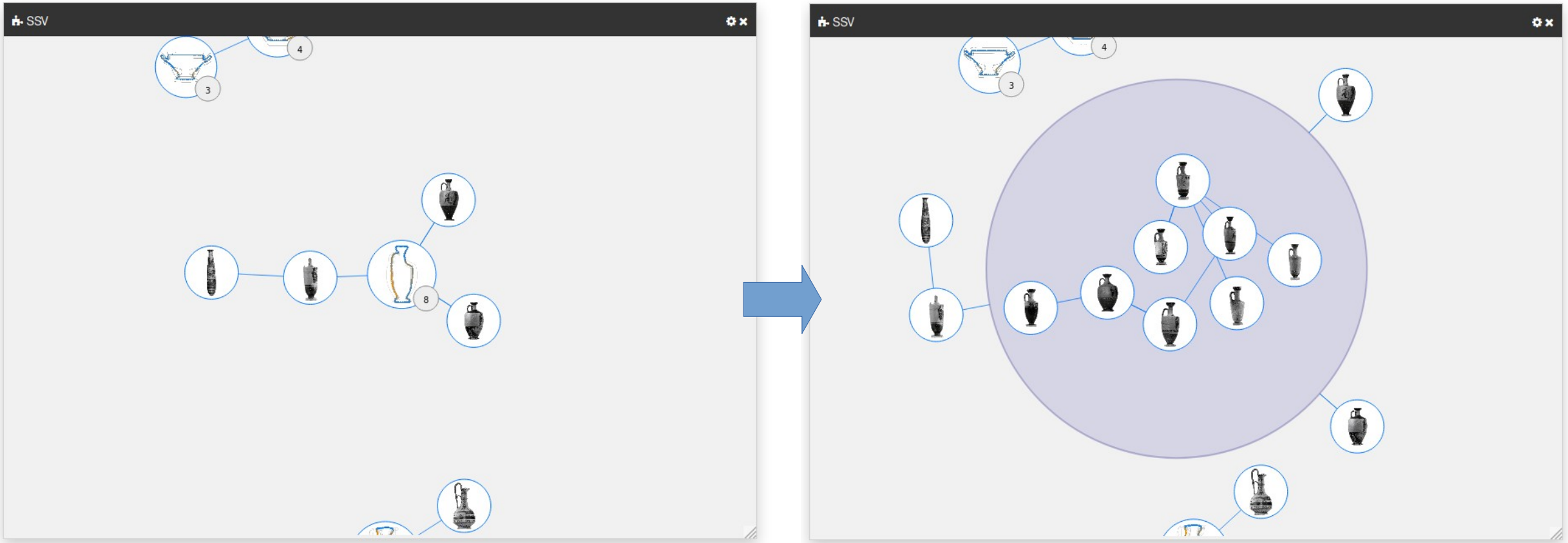
- Pairwise aggregation of objects with strongest link force

Shape Preview Surrogate

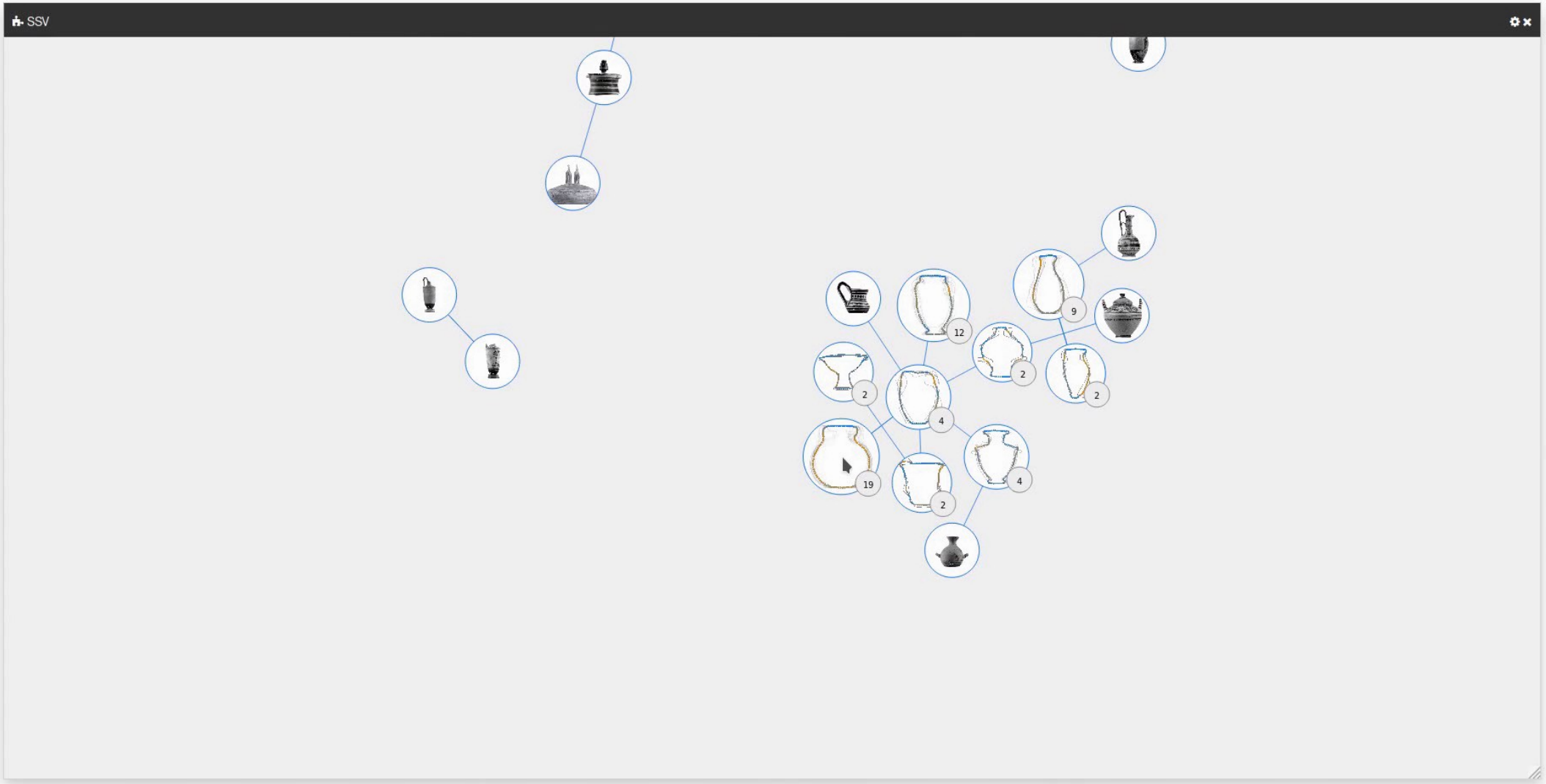


- Multi-object preview for aggregated nodes
- Silhouettes
  - All silhouettes as semi-transparent gray line
  - Mean silhouette as dotted line
    (the color encodes the local variance)
- Cardinality := # of incorporated objects
- Radius $r = r('\text{cardinality}')$

Hierarchic Balloons



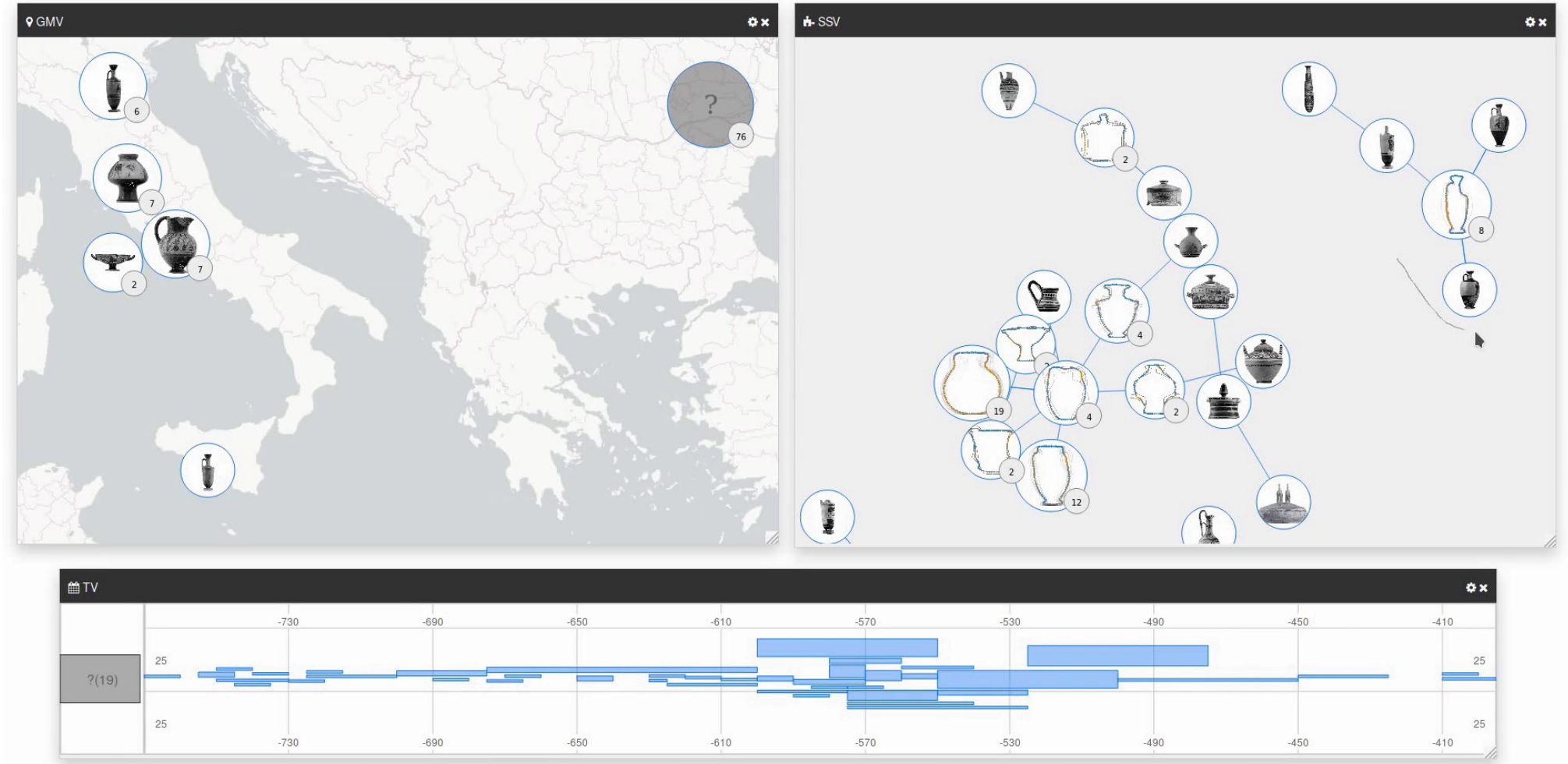
Hierarchic Balloons



Intra-View Highlighting

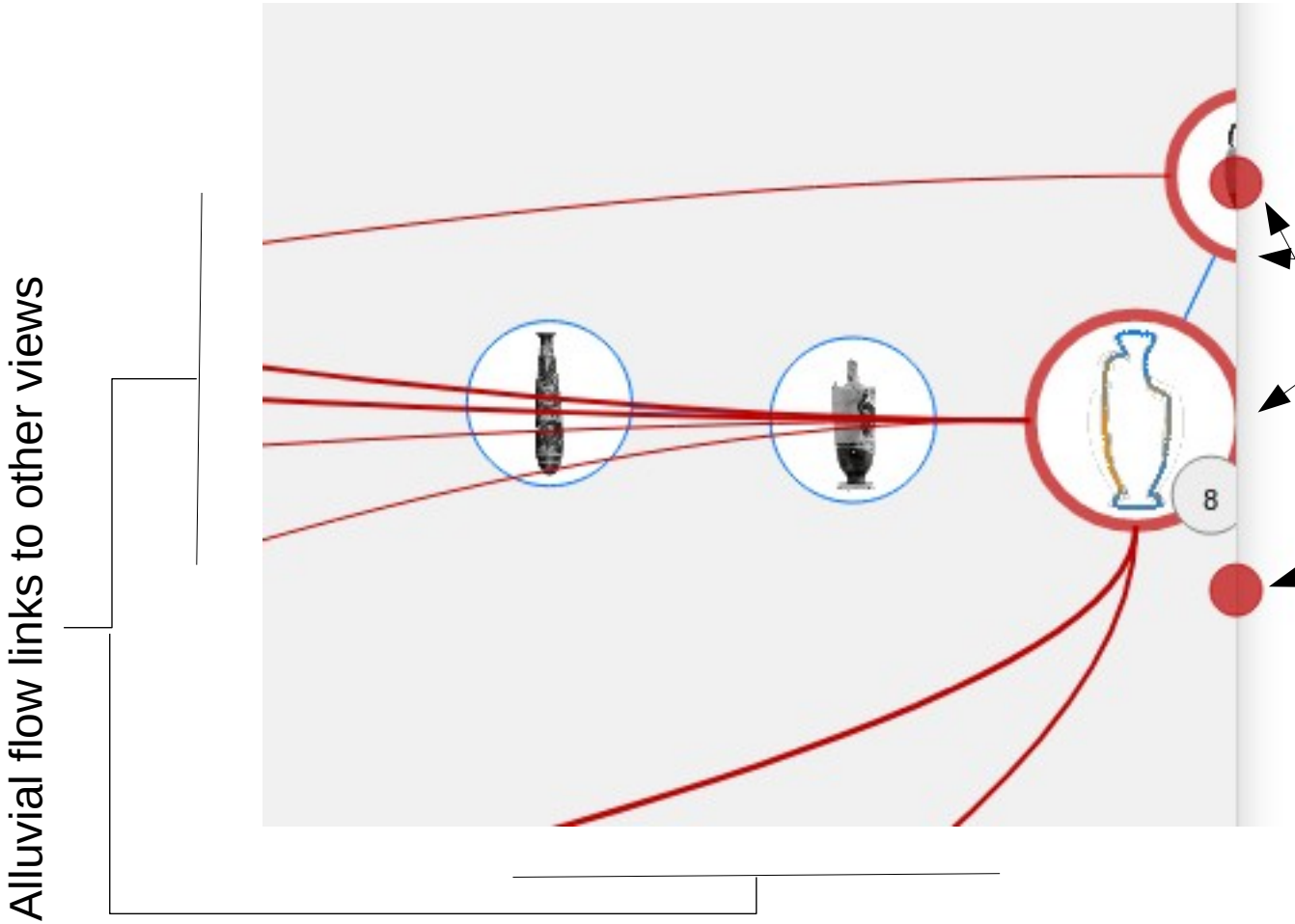
- Highlighting ob object subsets reveals the attribute relations
- Red border around a node indicates a highlight
- Subset selected though lasso selection

Intra-View Highlighting



Highlighting based on user selection

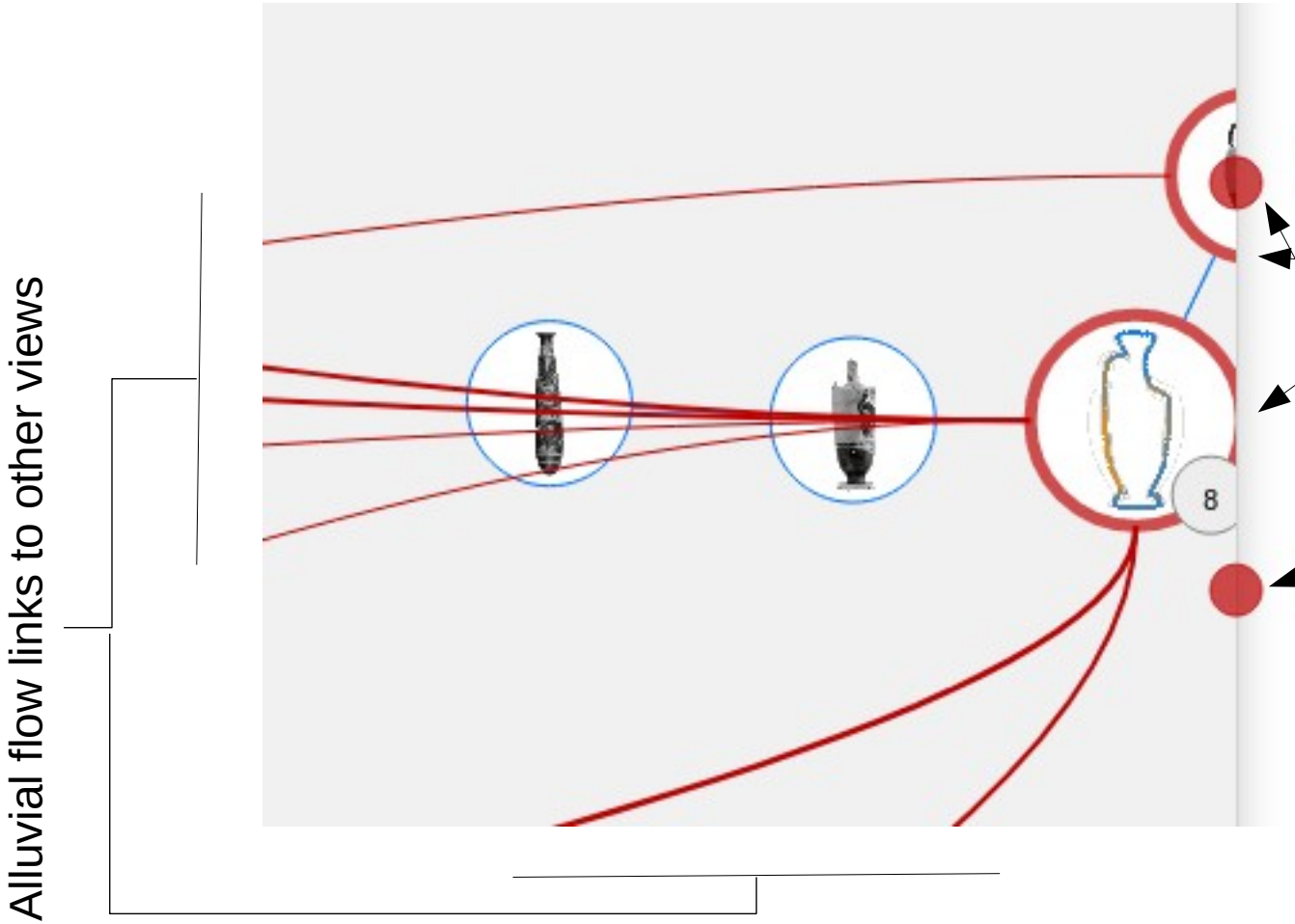
Intra-View Highlighting



Selected Objects marked with red color

Landmarks for selected Objects outside the currently displayed section

Intra-View Highlighting



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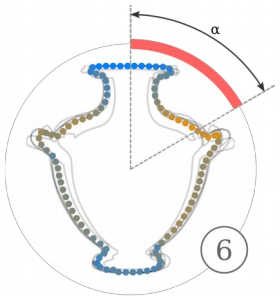
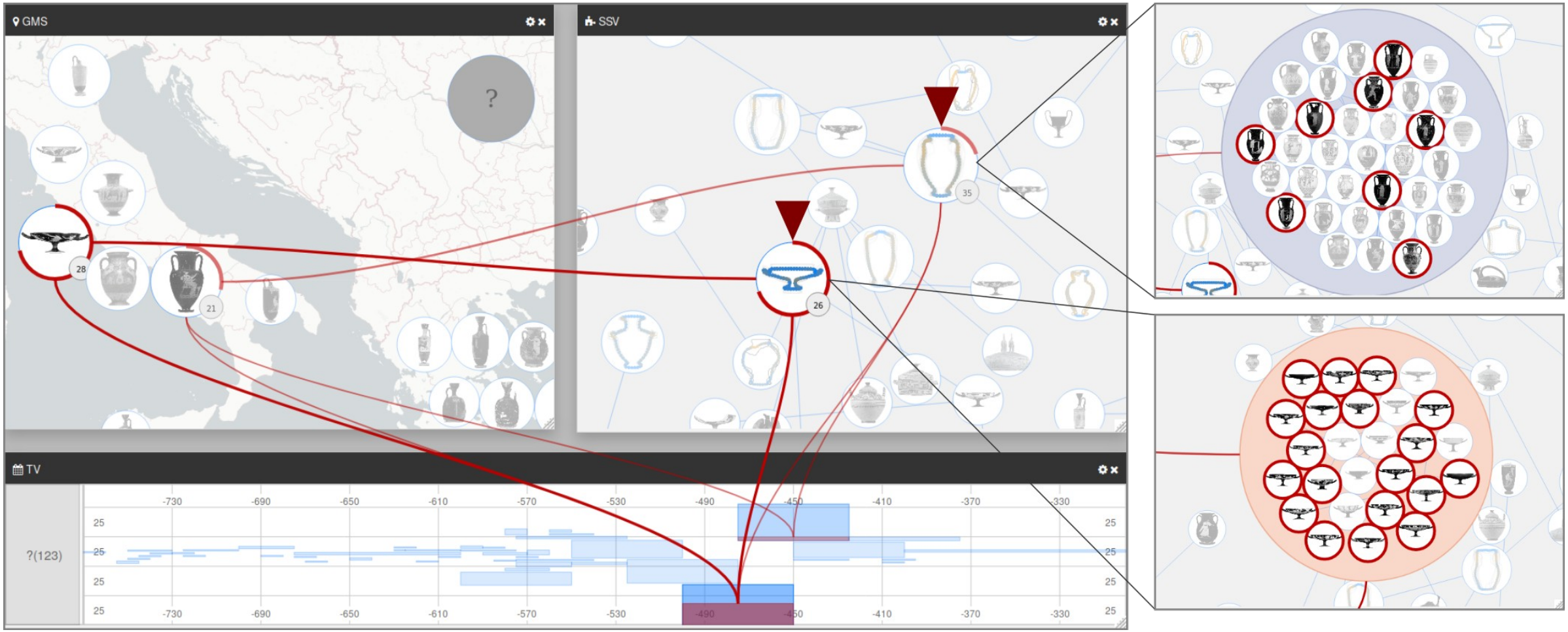


Partial highlight for aggregated node

Expert Feedback

Which dating is related to *aryballoi* shape? → Which other objects belong to the same period?

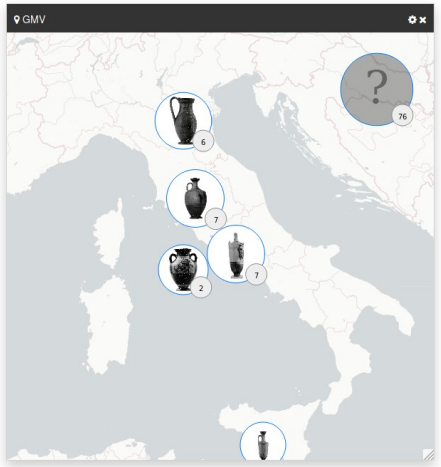
Intra-View Highlighting



`Most significant' links determined by Intra-view cross-correlation

Limitations / Future Work

- Extend and adapt views for additional modalities



- Collection
- Fabric

- Texture
- Decoration
- Motif depictions

Limitations / Future Work

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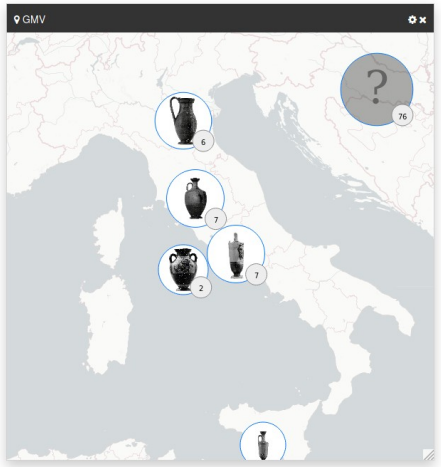

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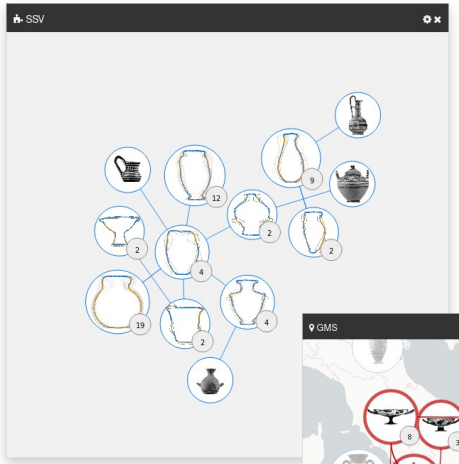

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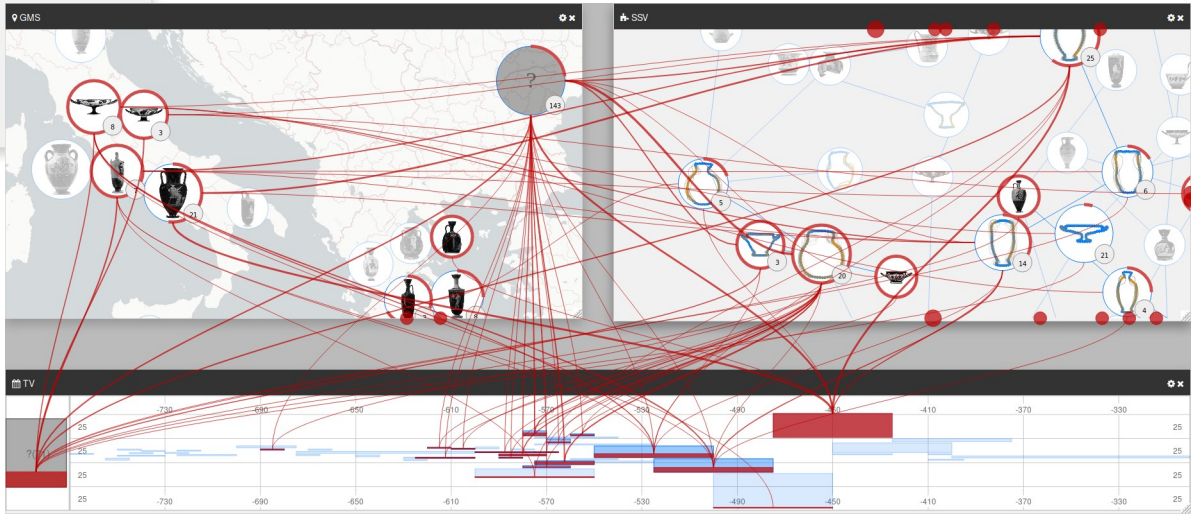
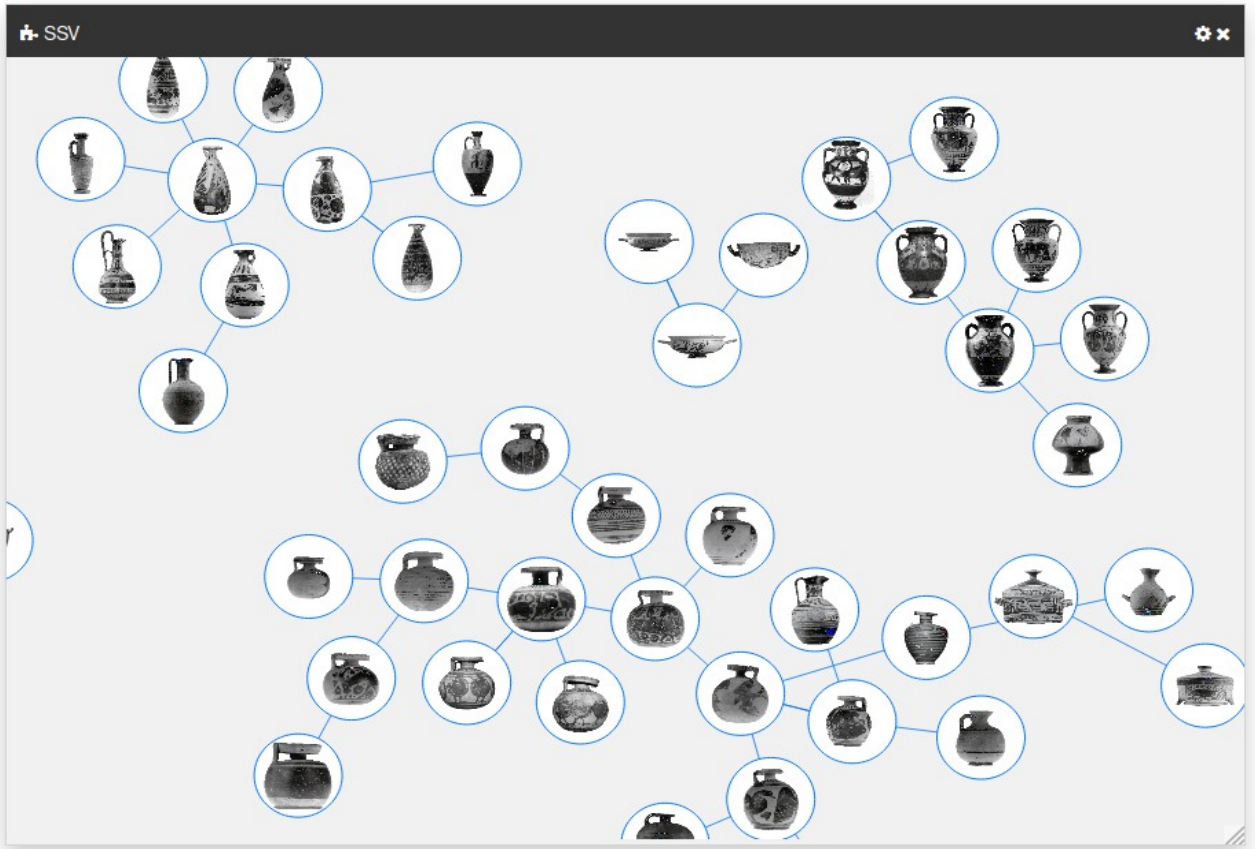


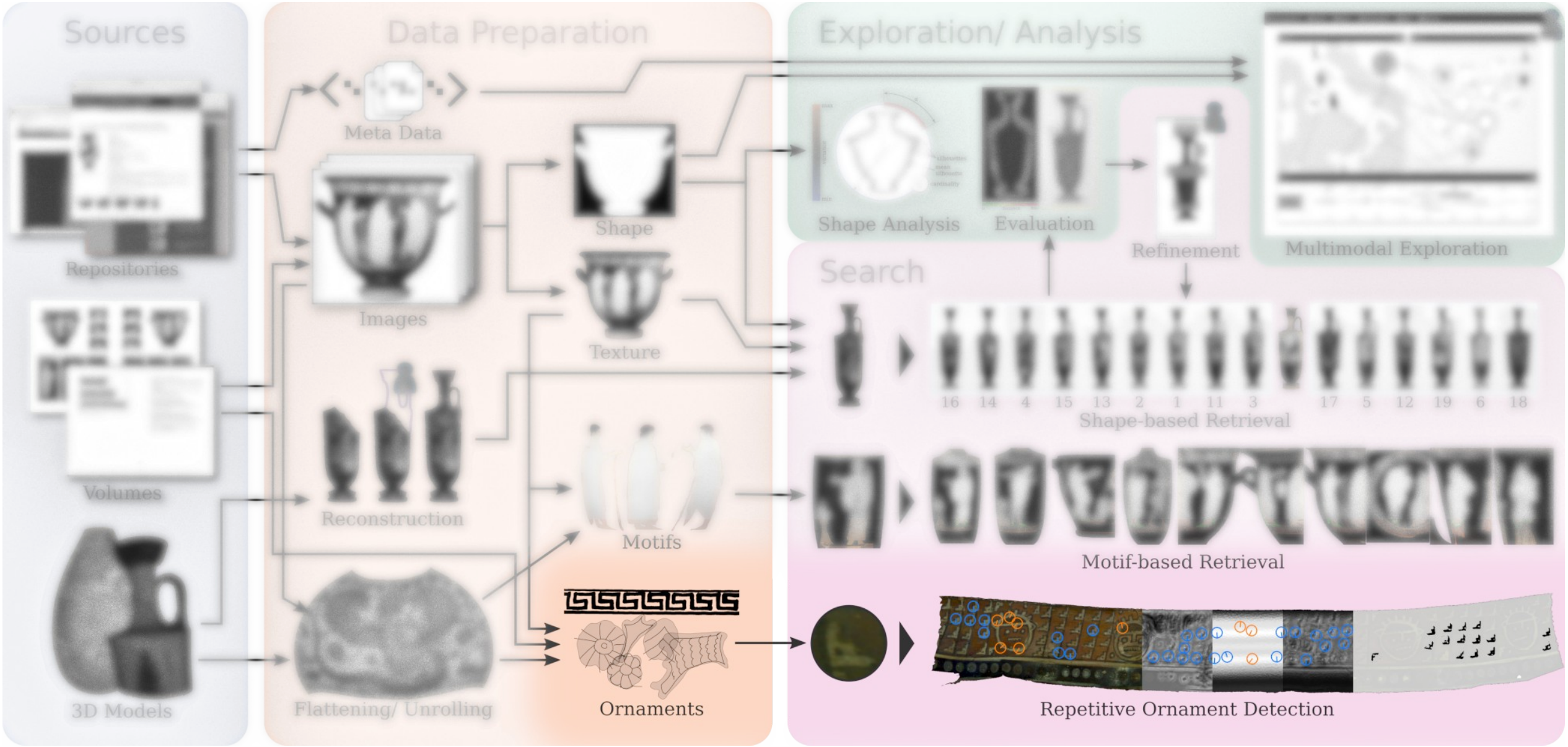
- Optimize link bundling/routing

Questions?

Lengauer, S., Komar, A., Labrada, A., Karl, S., Trinkl, E., Preiner, R., Bustos, B. and Schreck, T., 2019. Motif-driven Retrieval of Greek Painted Pottery. In *Eurographics Workshop on Graphics and Cultural Heritage* (pp. 91-98). Eurographics-European Association for Computer Graphics.



Lengauer, S., Komar, A., Karl, S., Trinkl, E., Sipiran, I., Preiner, R., and Schreck, T., 2020. Visual Exploration of Cultural Heritage Collections with Linked Spatiotemporal, Shape and Metadata Views. *Proc. VMV,* 137-144.


Sources
Repositories
Volumes
3D Models
Data Preparation
Meta Data
Images
Reconstruction
Flattening/ Unrolling
Shape
Texture
Motifs
Ornaments
Exploration/ Analysis
Shape Analysis
Evaluation
Refinement
Multimodal Exploration
Search
16 14 4 15 13 2 1 11 3 17 5 12 19 6 18
Shape-based Retrieval
Motif-based Retrieval
Repetitive Ornament Detection

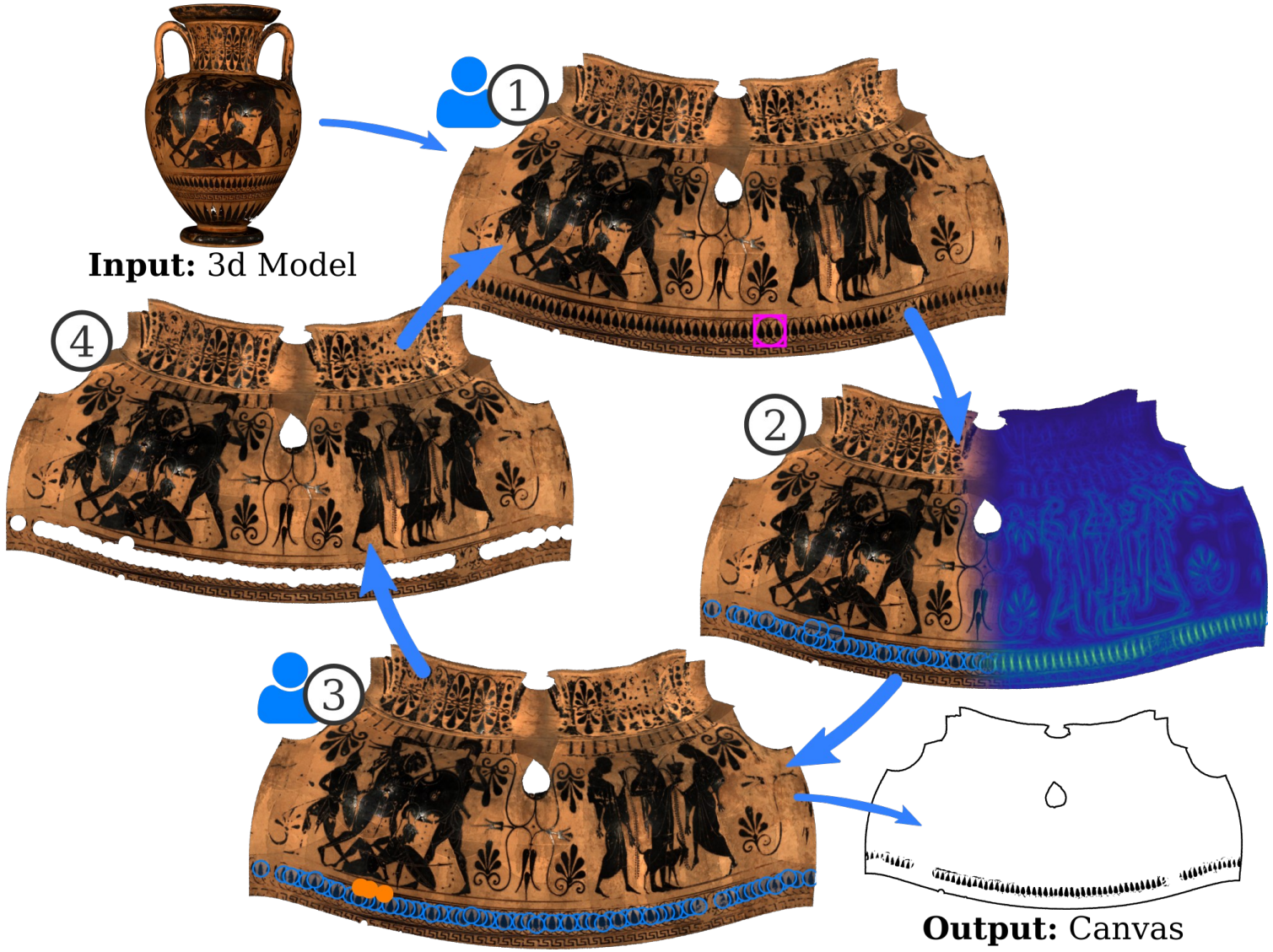
Workflow

Input: 3d model

Iterative dissection of the flattened[1] surface:

1) Query selection
2) Self-similarity detection
3) Results refinement
4) Surface subtraction

Output: ‘Canvas’ with detected and extracted ornaments



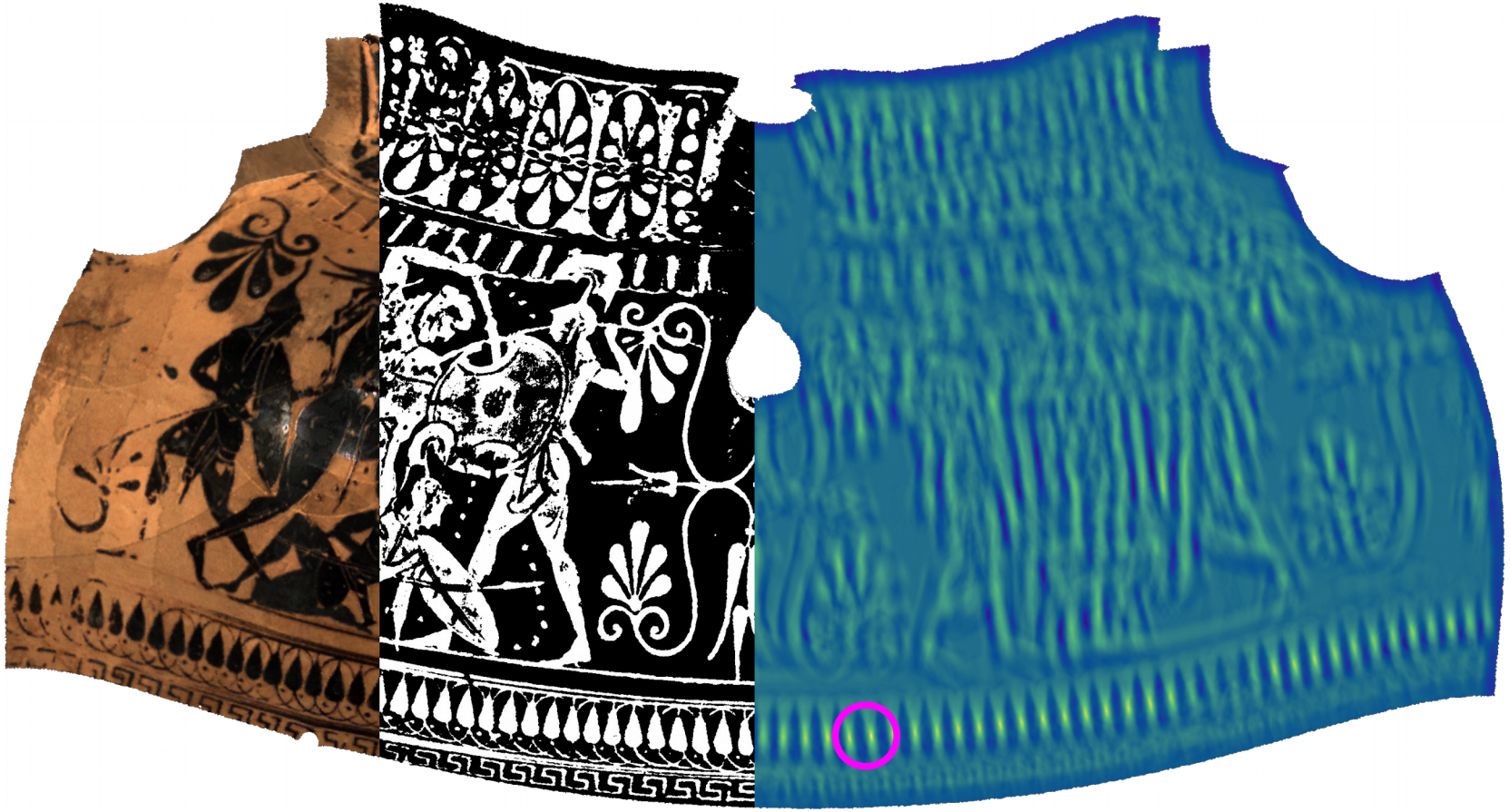
Self-similarity Detection

Flattened
3d model

Self-similarity Detection

Flattened
3d model

Self-similarity Detection



Query

Flattened 3d model

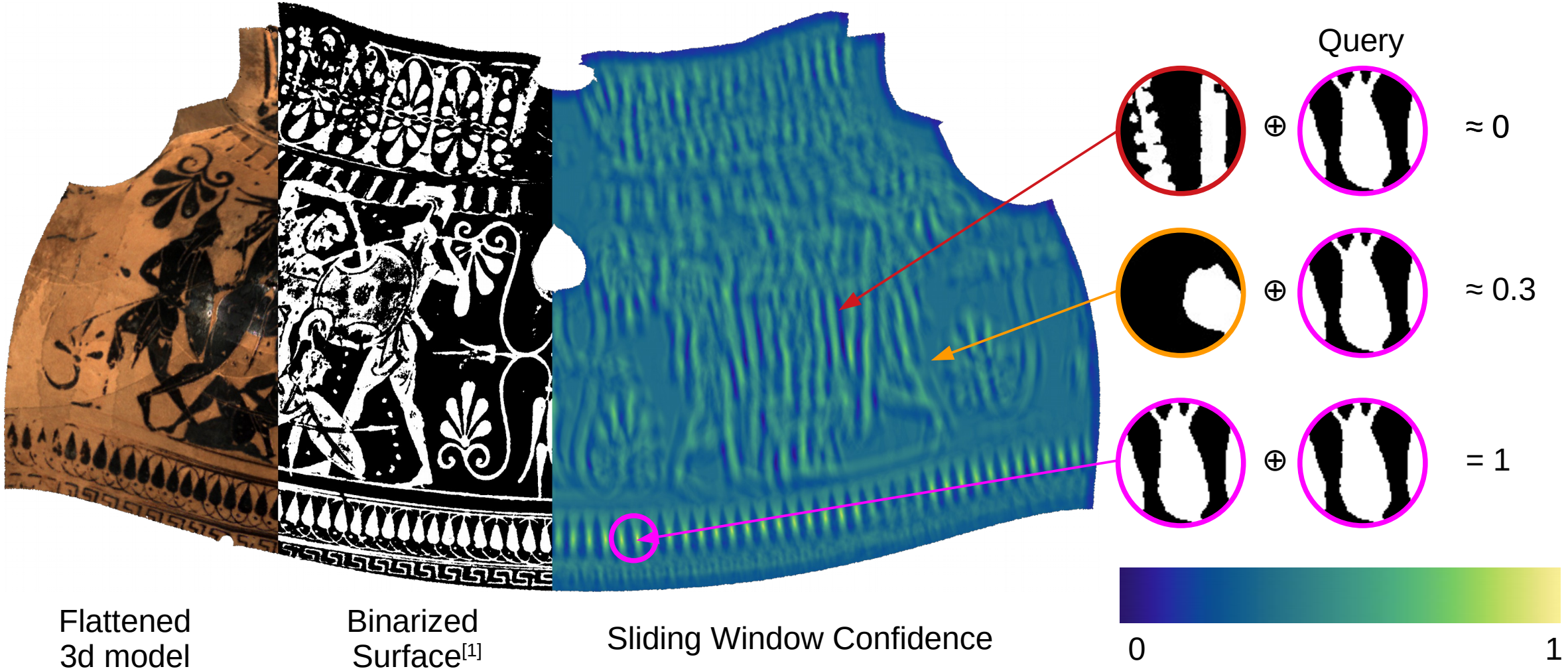
Binarized Surface[1]

Sliding Window Confidence

0

1

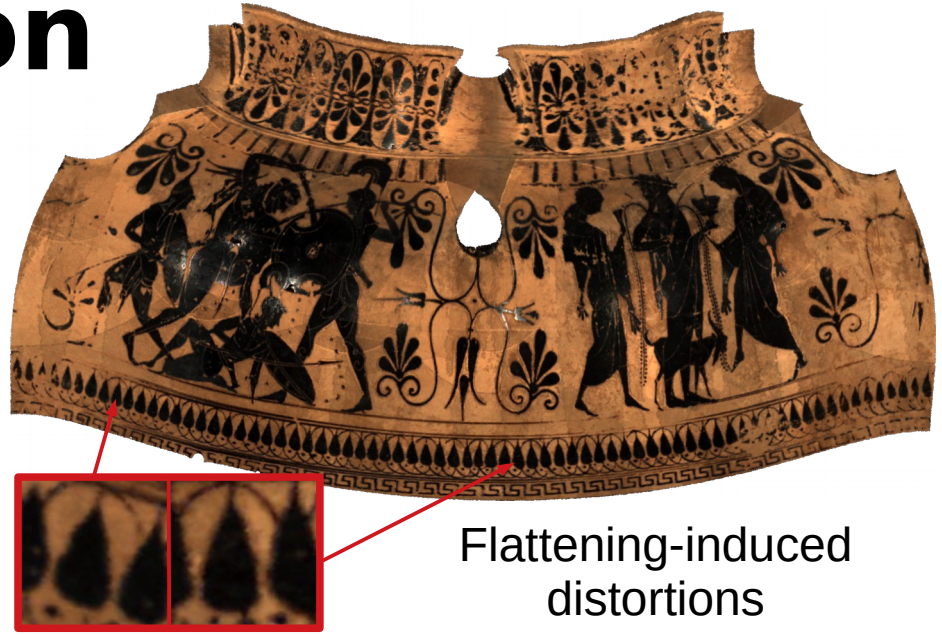
Self-similarity Detection



Self-similarity Detection

- Rotation invariance required

Alternating orientation of ornaments

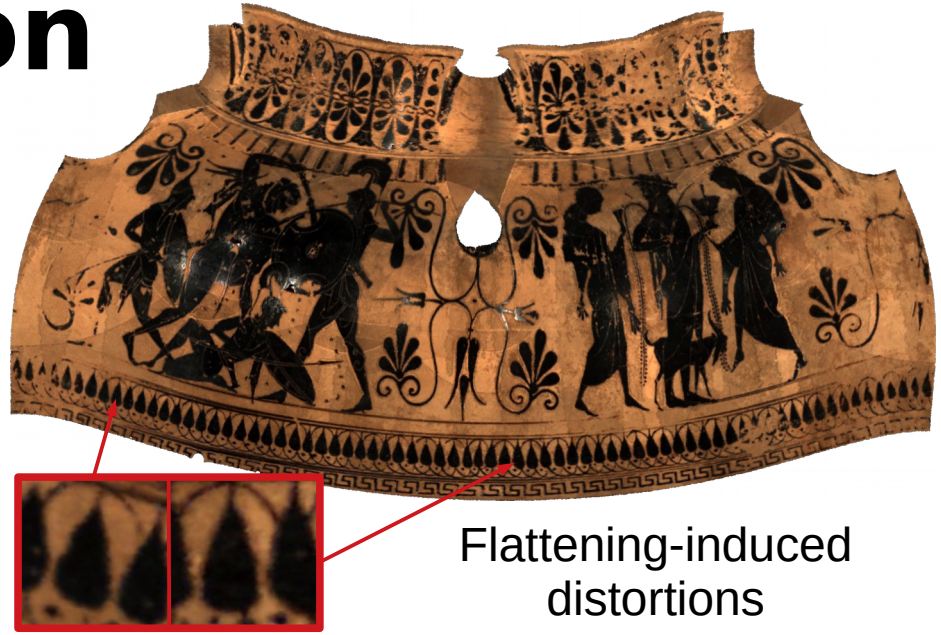


Flattening-induced distortions

Self-similarity Detection

- Rotation invariance required

Alternating orientation of ornaments



Flattening-induced distortions

$$C_{sw} = \max_{\theta} \left\{ \; , \; , \; \ldots , \; \right\} =$$

$\theta = 0$ $\quad \theta = \frac{2\pi}{K}$ $\quad \theta = \frac{2\pi(K-1)}{K}$

Self-similarity Detection

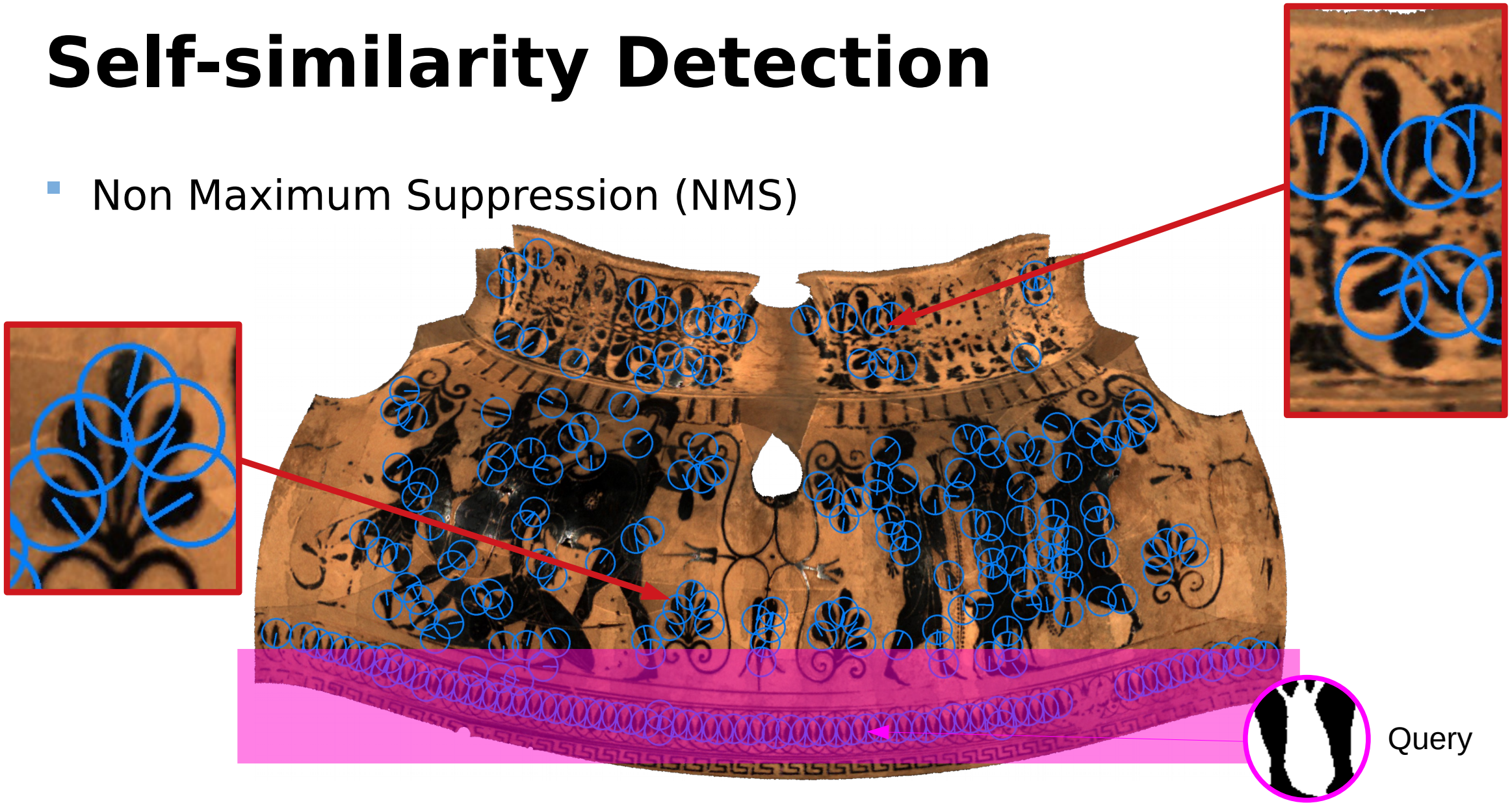
- Non Maximum Suppression (NMS)

Self-similarity Detection

- Non Maximum Suppression (NMS)

Self-similarity Detection

- Non Maximum Suppression (NMS)



Refinement with Isohypses Map

- **Assumption:** Repeating ornaments are arranged in ornamental bands around the rotational axis of the solid of revolution.

Refinement with Isohypses Map

- **Assumption:** Repeating ornaments are arranged in ornamental bands around the rotational axis of the solid of revolution.

Isohypsal Mapping

Refinement with Isohypses Map

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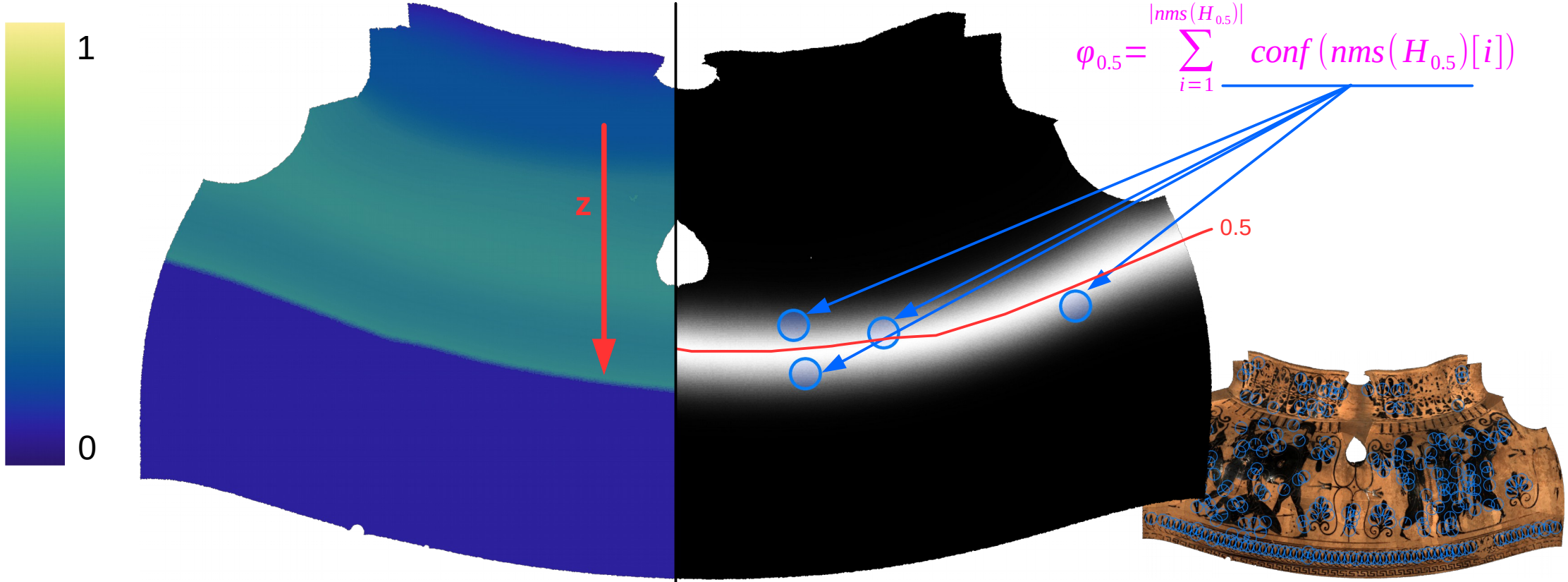
Isohypsal Mapping

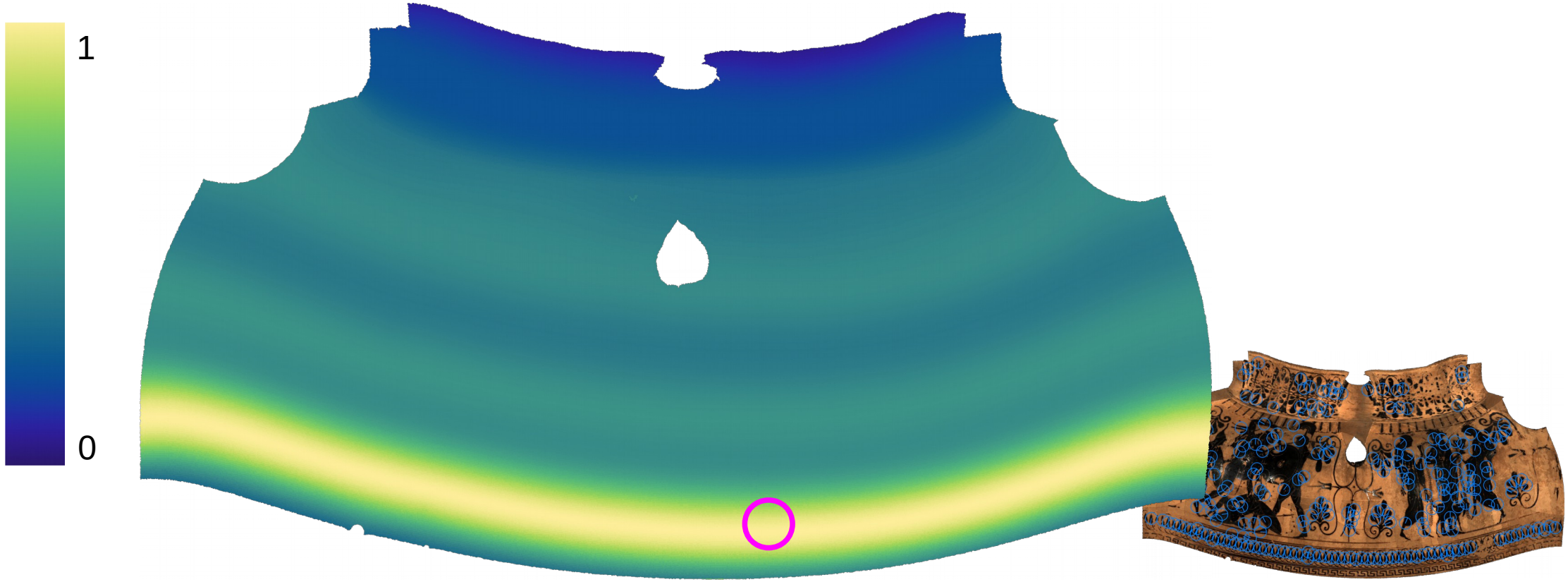
Refinement with Isohypses Map



Ishoypsal Confidence $C_{ih} = \sum H_z \varphi_z$

Ishoypsal Mask $H_{0.5} = N(0.5, \sigma^2)$

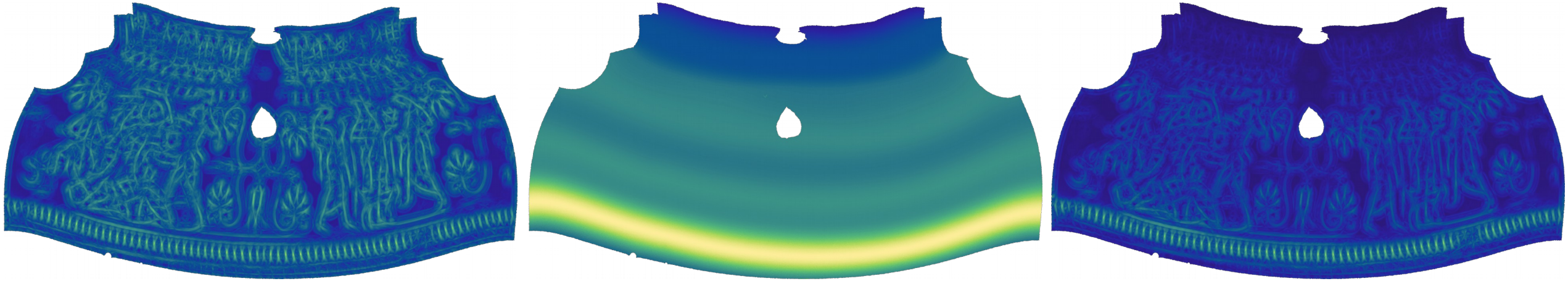
Refinement with Isohypses Map



Isohypsal Confidence C_{ih}

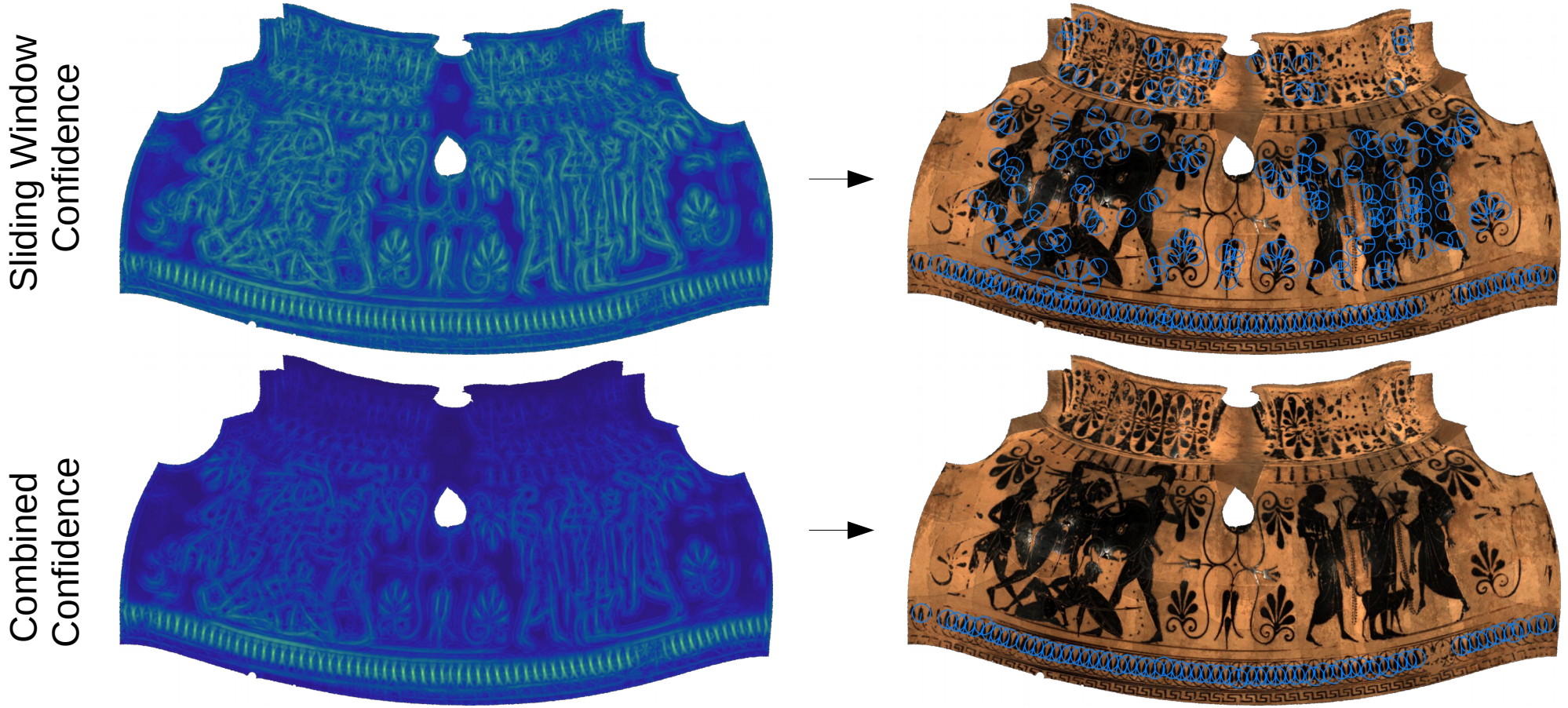
Refinement with Isohypses Map

- Refined confidence map results from element-wise multiplication of sliding-window and isohypsal confidence



Sliding Window Confidence C_{sw} $\odot$ Isohypsal Confidence C_{ih} = Combined confidence C

Refinement with Isohypses Map



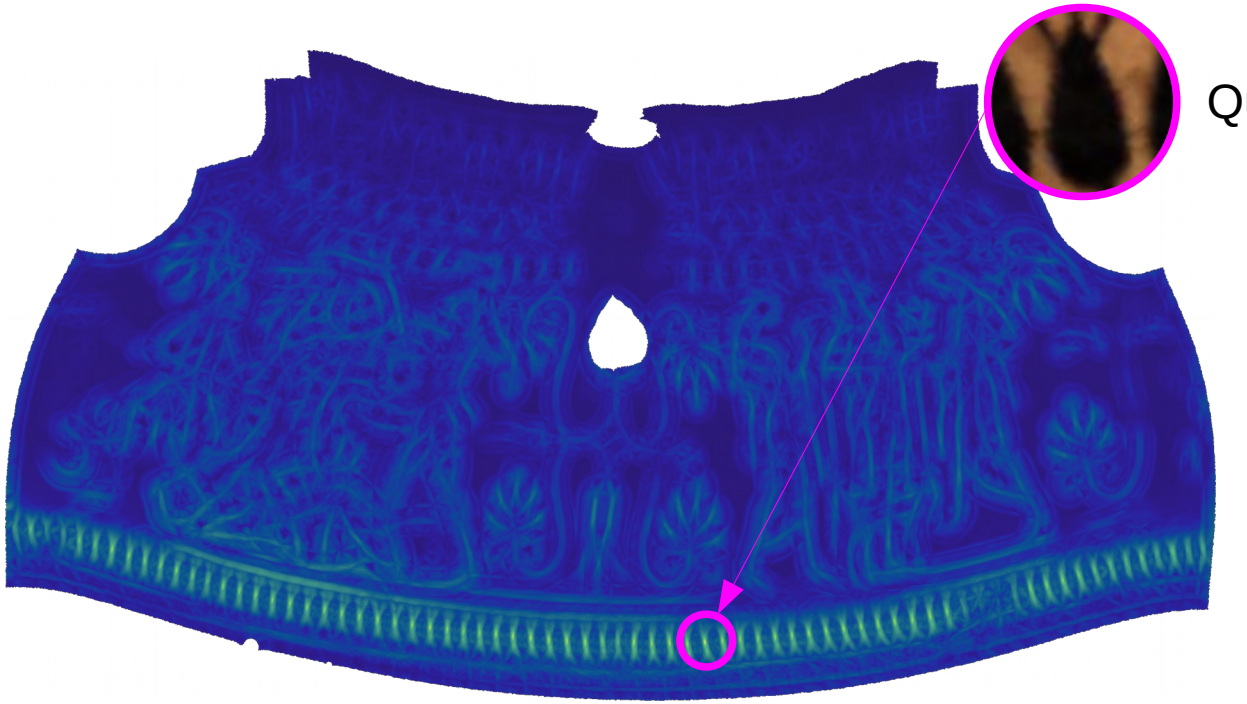
Confidence Maps

Candidates after NMS

Experimental Results

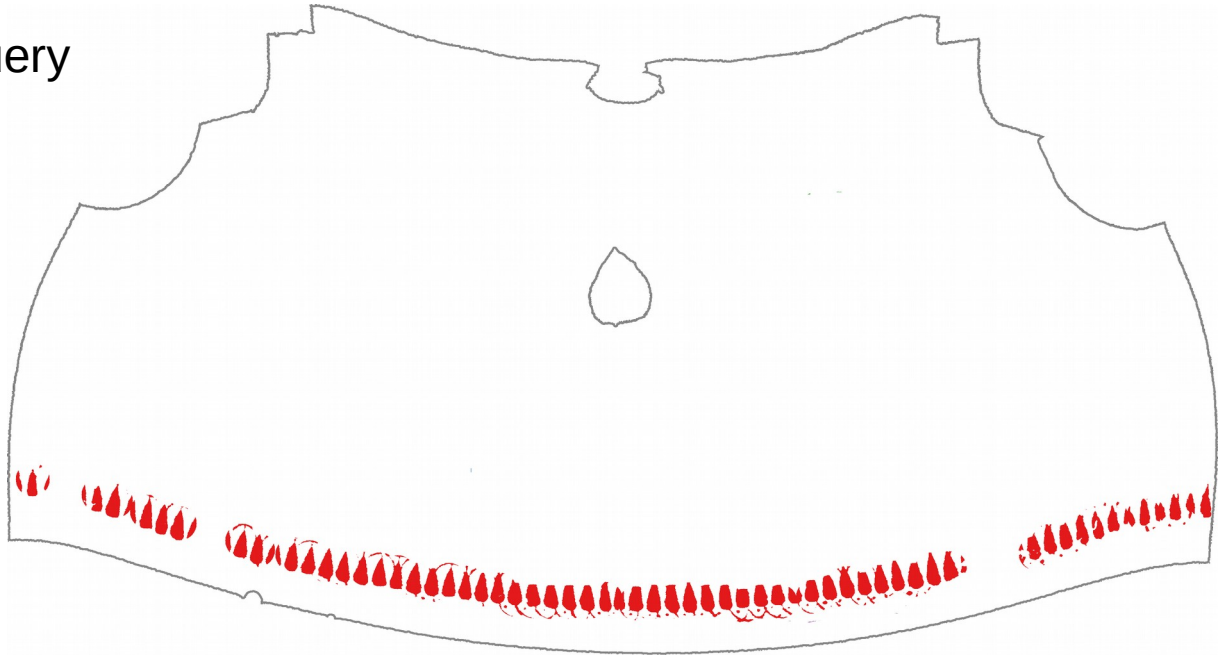
Experimental Results

- Attic black-figured amphora (Kunsthistorisches Museum, Vienna)



Query

Combined Confidence



Canvas

Experimental Results

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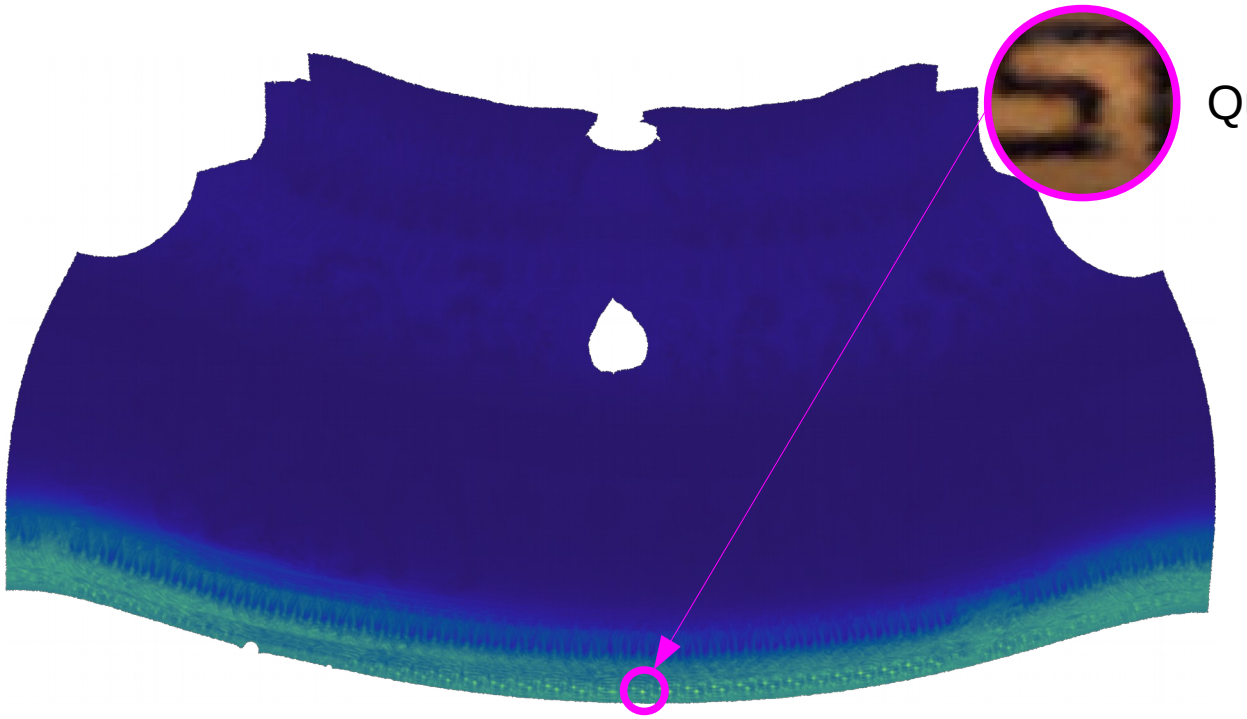
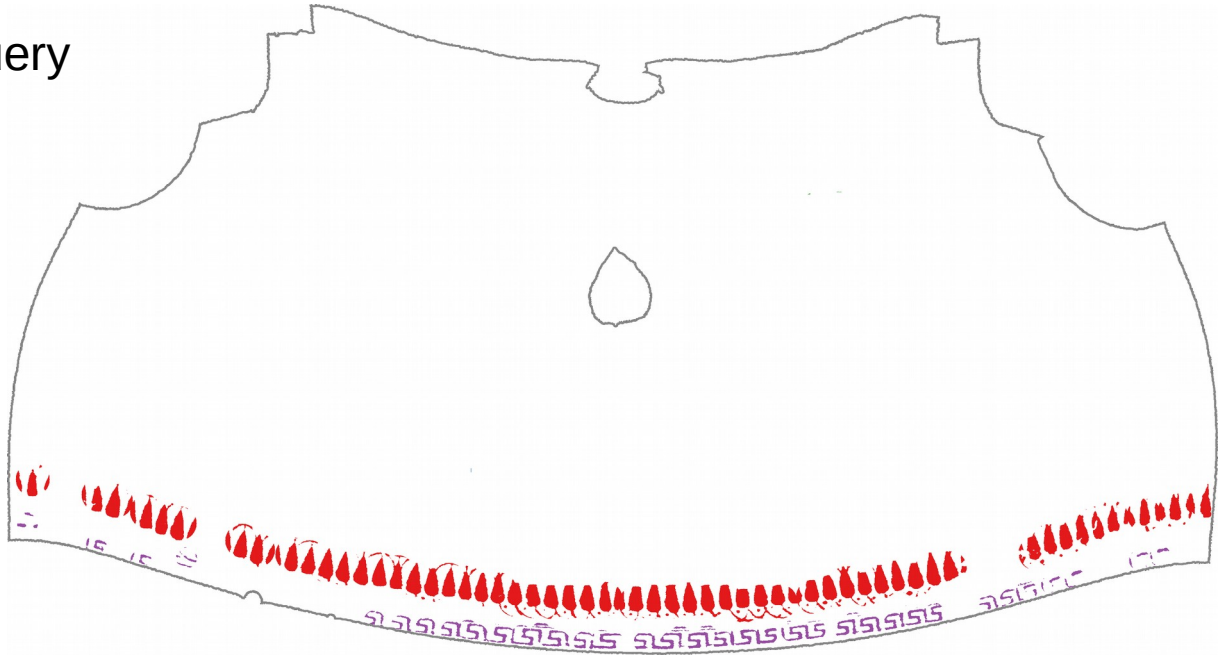


Query

Combined Confidence



Canvas

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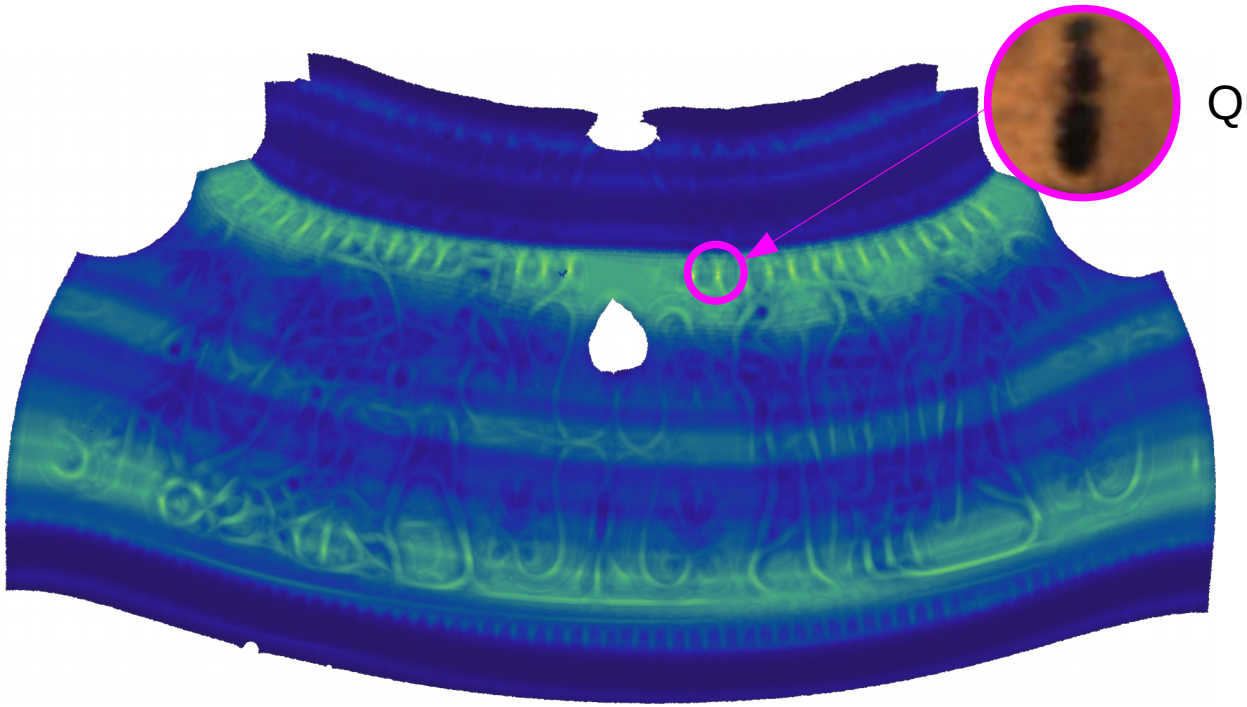
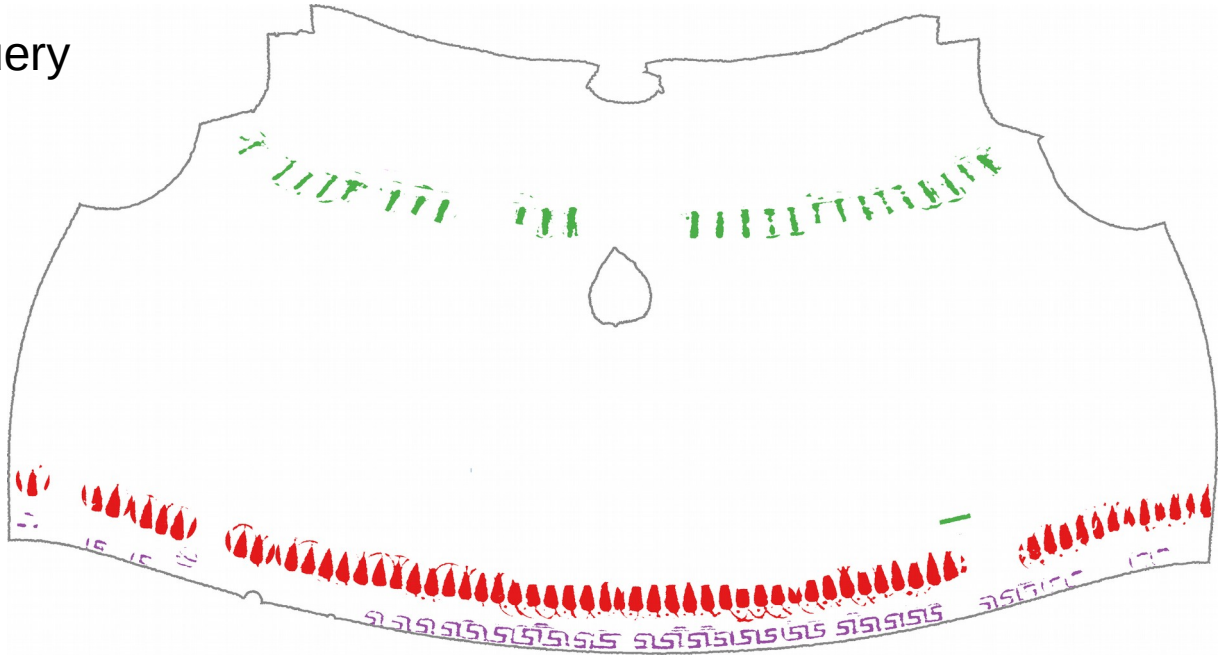


Query

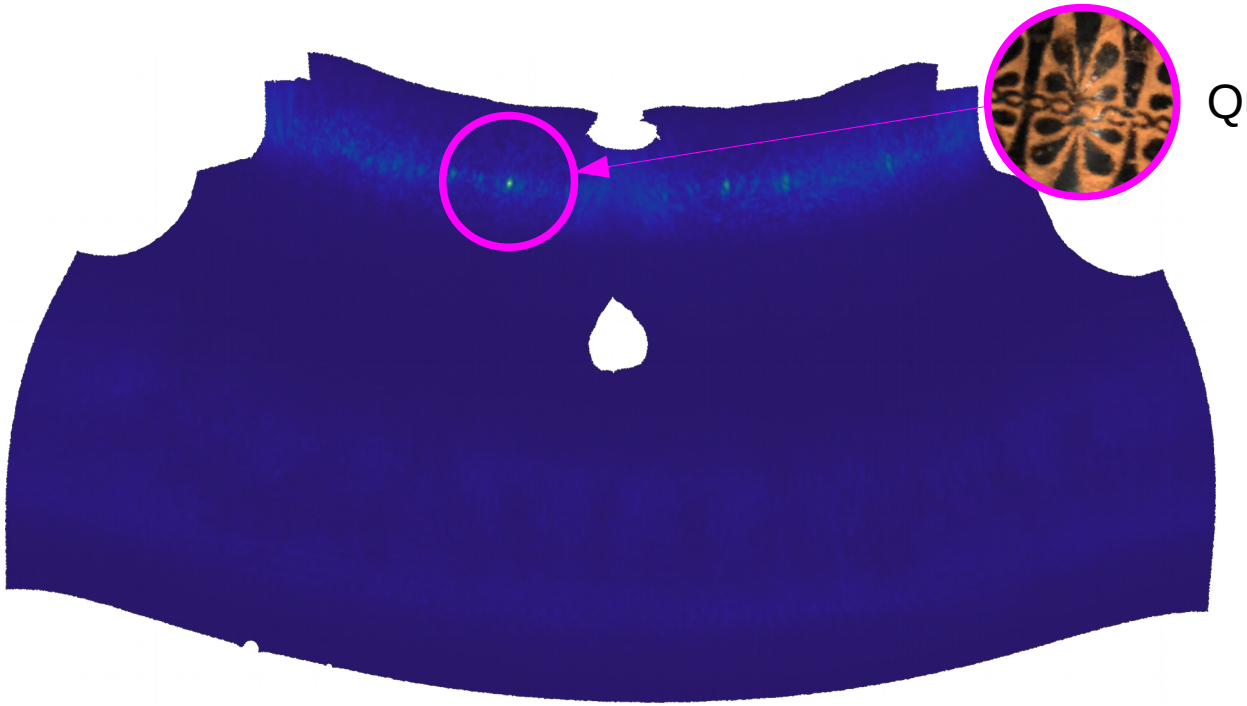
Combined Confidence



Canvas

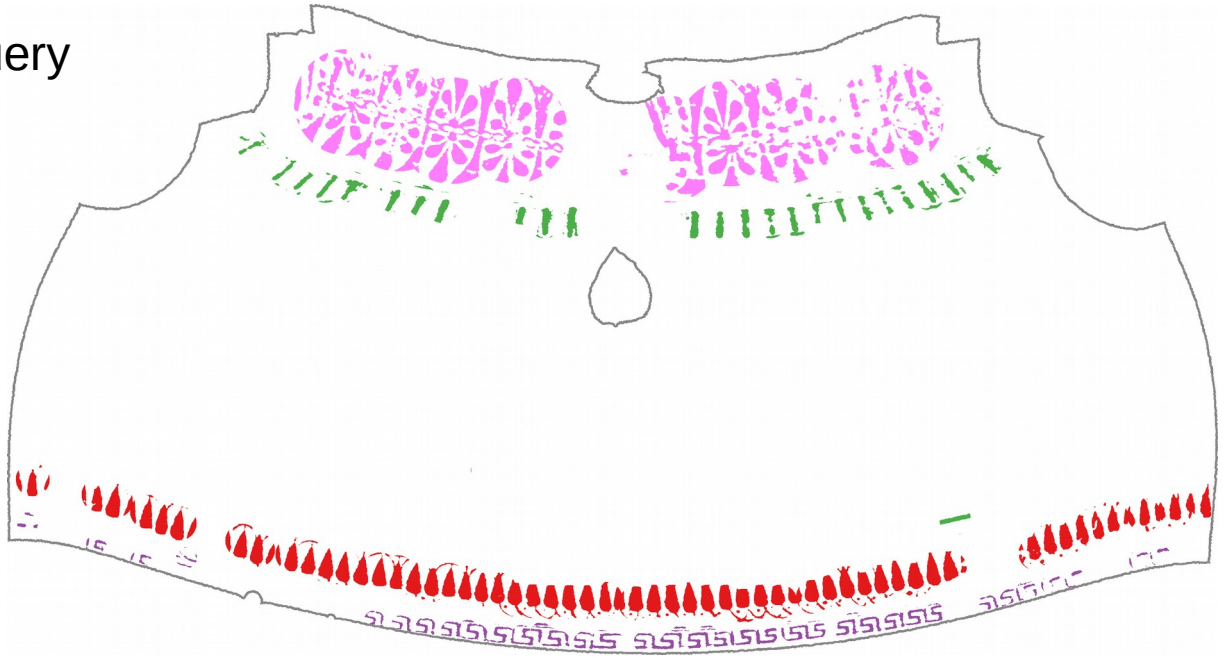
Experimental Results

- Attic black-figured amphora (Kunsthistorisches Museum, Vienna)



Query

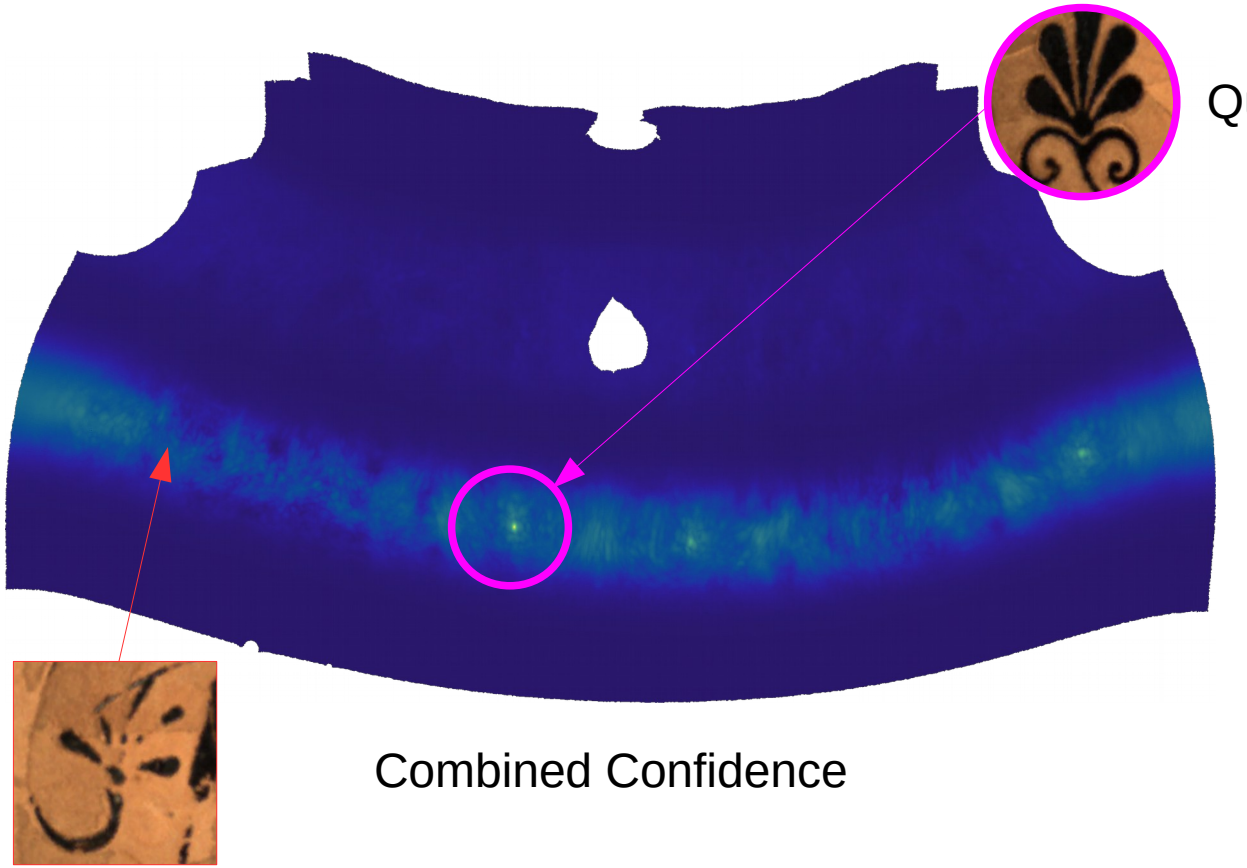
Combined Confidence



Canvas

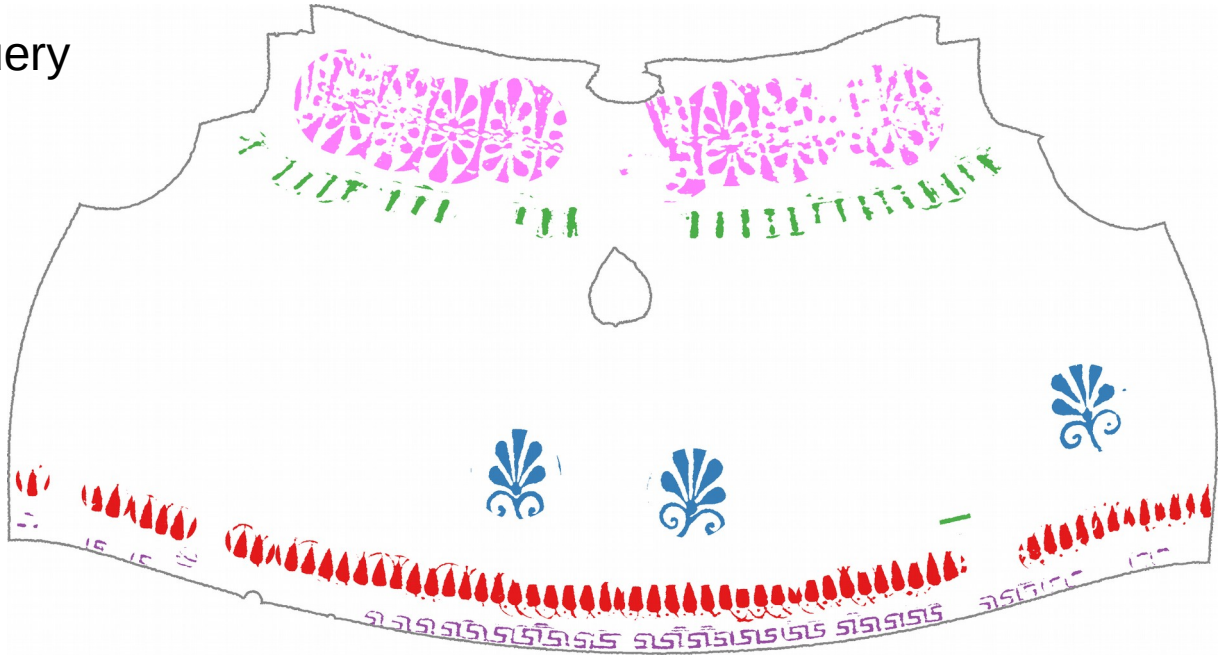
Experimental Results

- Attic black-figured amphora (Kunsthistorisches Museum, Vienna)



Query

Combined Confidence



Canvas

Experimental Results

- Pre-Columbian pots (Josefina Ramos de Cox museum, Lima, Peru)

Experimental Results

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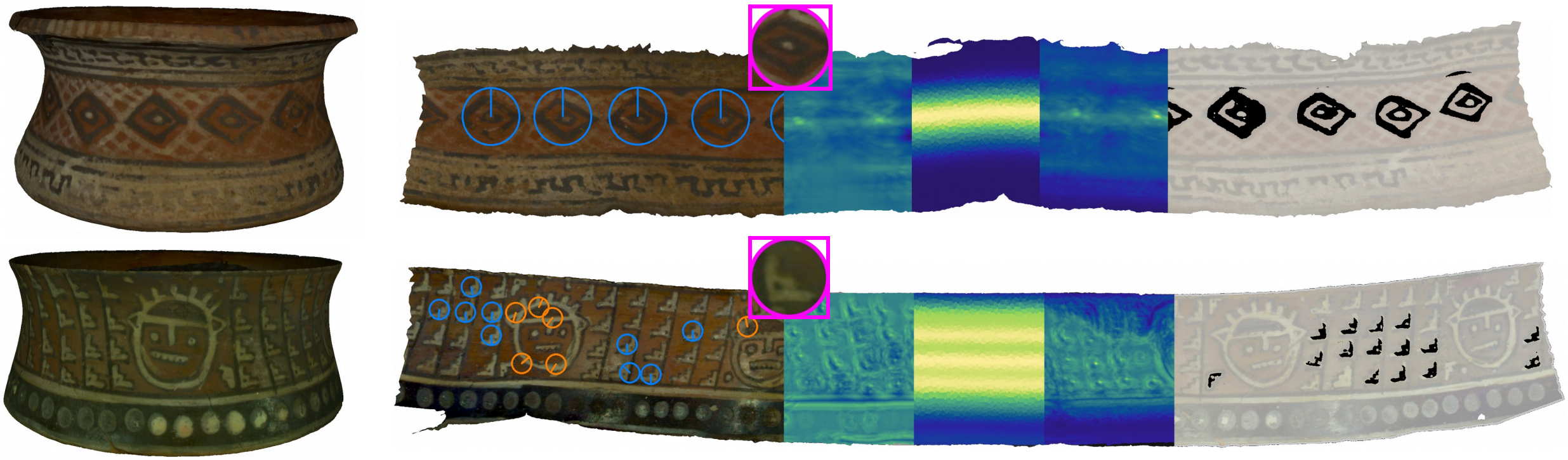

3d model

Flattened Surface $\rightarrow$ $C_{sw} \odot C_{ih} = C$ $\rightarrow$ Resulting Canvas