Using Neural Networks to Classify 3D Scans of Museum Artifacts

Capstone Project in Machine Learning, 2021

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Research Question A

Introduction

Barbara Piccinotti Violin Maker
(Image: Roberto Cavagnoli, CC BY-SA)

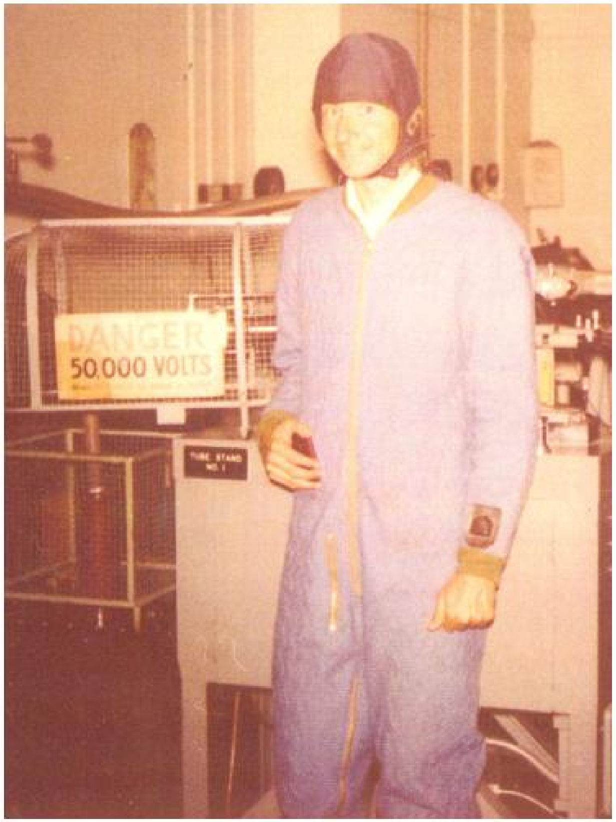
???

Glenn Casamassa, Regional Forester, USDA Forest Service (Image: Kevin Beasley, U.S. Forest Service, Pacific Northwest Region, CC0)

A metaphor:
What knowledge about forest engineering is required to make a violin?

Research Question A

How much math is necessary to apply Machine Learning (M.L.) in practice?



Michael Minovitch **solved** the "3 Body Problem" at NASA in 1961, using a computer simulation. *

???

Henri Poincaré proved in 1890
that the "3 Body Problem" **cannot be solved**.

(Image: public domain)

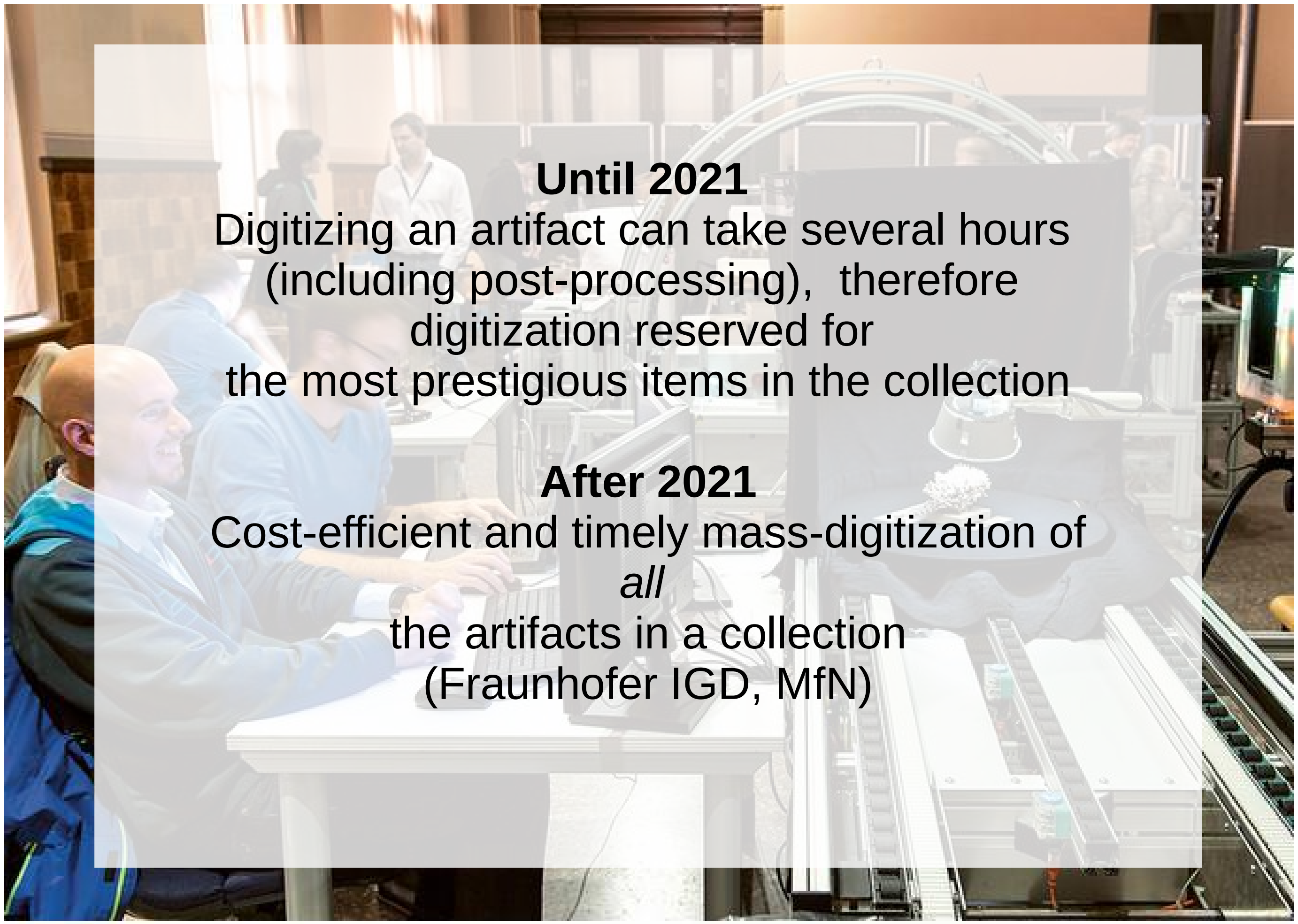
*   Minovitch, M., 1961. Alternative method for determination of elliptic and hyperbolic trajectories. *Jet Propulsion Laboratory, Techincal Memo*, pp.312-118.

3D-digitalization of archaeological or natural history artifacts

Automated 3D scanning at Museum für Naturkunde Berlin, using the CultLab3D system developed by Fraunhofer institute (Photo: Carola Radke, MfN)

Research Question B

Given the current state of digitization of cultural artifacts, what results can be expected?



Until 2021

Digitizing an artifact can take several hours (including post-processing), therefore digitization reserved for the most prestigious items in the collection

After 2021

Cost-efficient and timely mass-digitization of *all* the artifacts in a collection (Fraunhofer IGD, MfN)

Data Sources

UNIVERSITY of VIRGINIA | LIBRARY

University of Virginia, Charlottesville, USA

Musée Art & Histoire, Bruxelles, BE

ARCHEOLOGICKÉ 3D VIRTUÁLNÍ MUZEUM

INSTITUTE OF ARCHAEOLOGY OF CAS, Prague, CS

GLOBAL DIGITAL HERITAGE

Global Digital Heritage, USA / IT / ES (non-profit)

Institutul Național al Patrimoniului

patrimoniu.ro

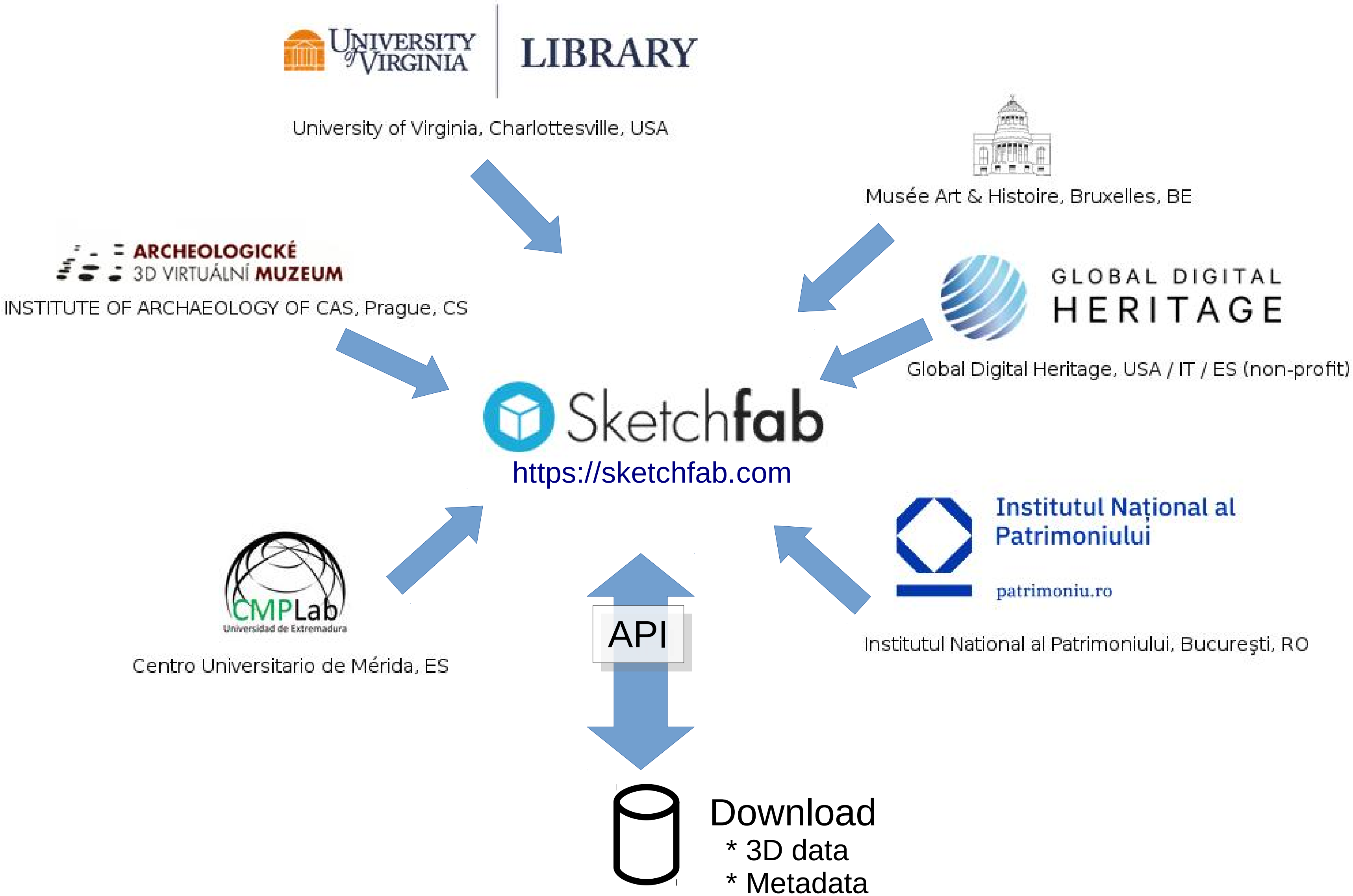
Institutul National al Patrimoniului, Bucureşti, RO

CMPLab

Universidad de Extremadura

Centro Universitario de Mérida, ES

Data Sources

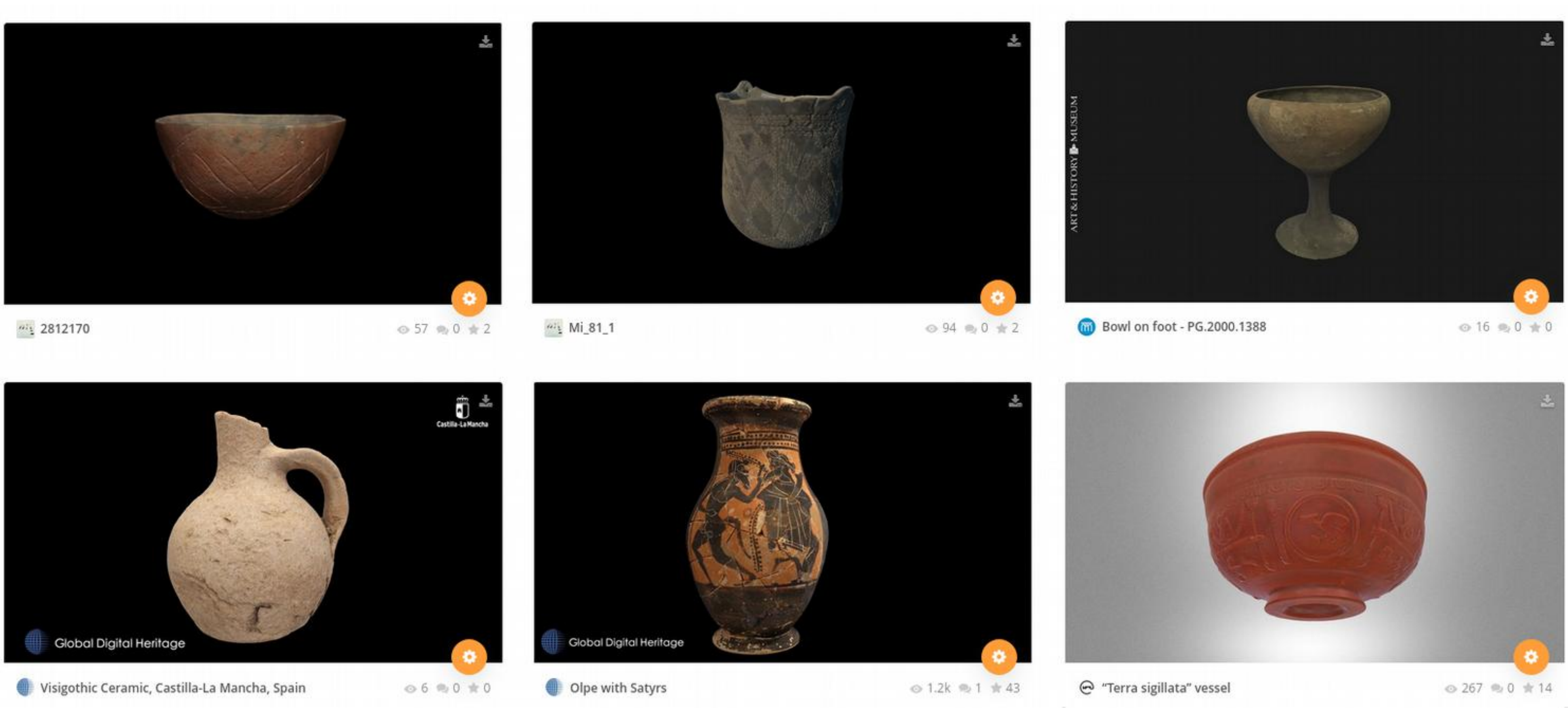


Downloaded data: Metadata

1) the name of the 3D model
2) ideally a textual description of the object, written by a museum curator
3) the API-URI where the 3D-model file can be downloaded
4) a link to the 3D-model's preview page on Sketchfab
5) the name of the museum, institution or organization that provided the digitized object
6) a link to the providers page on Sketchfab
7) the license of the 3D-model
8) the number of vertices in the 3D-model
9) tags added by the provider of the 3D-model describing the object (json)

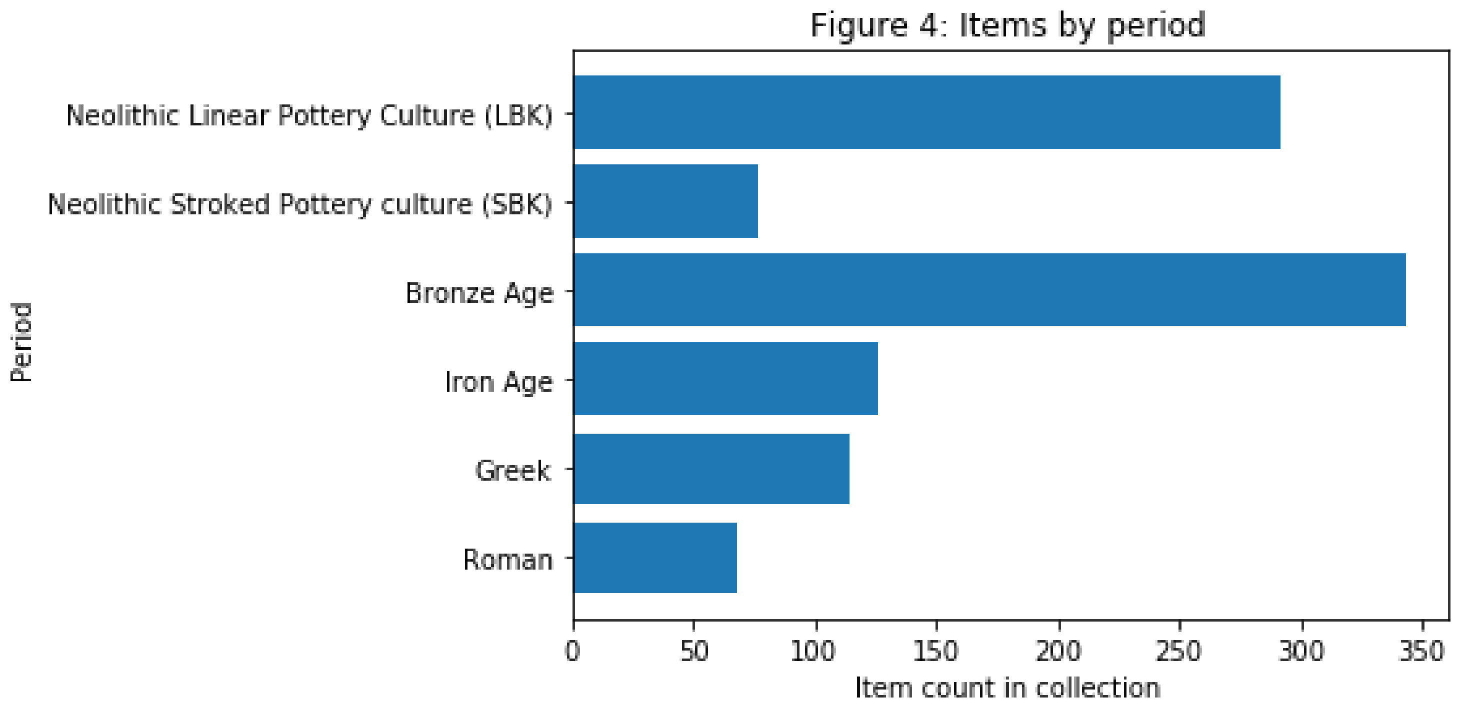
	Data Provider	Object Count
1	Archaeological 3D virtual museum	369
2	The Royal Museums of Art and History	343
3	Global Digital Heritage	180
4	Institutul Național al Patrimoniului	22
5	CMPLab	11
6	UVA3D	10
7	Other (less than 10 models each)	85

Downloaded data: Classes

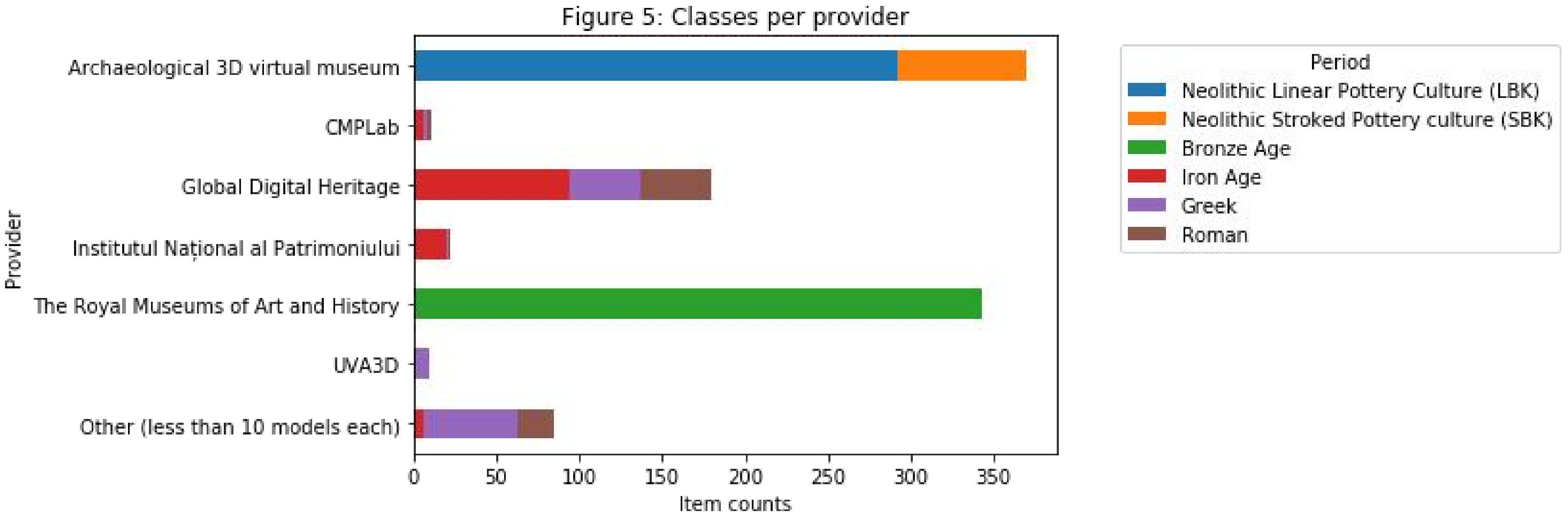


Various types of pots in the data set: Neolithic LBK vessel, Neolithic SBK mortar, Bronze Age bowl on foot, Iron Age -Visigoth- bottle, Greek Jug, Roman cup (screenshot from the Sketchfab website).

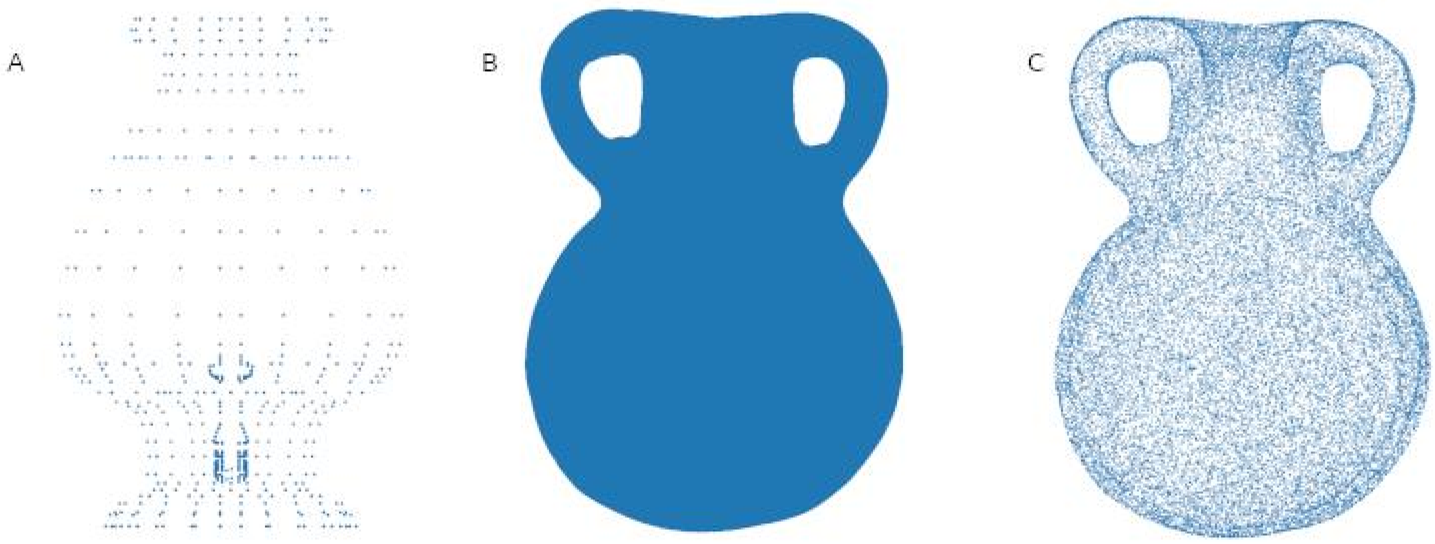
Caveat 1: Data is imbalanced by source



Caveat 2: Data is imbalanced by class

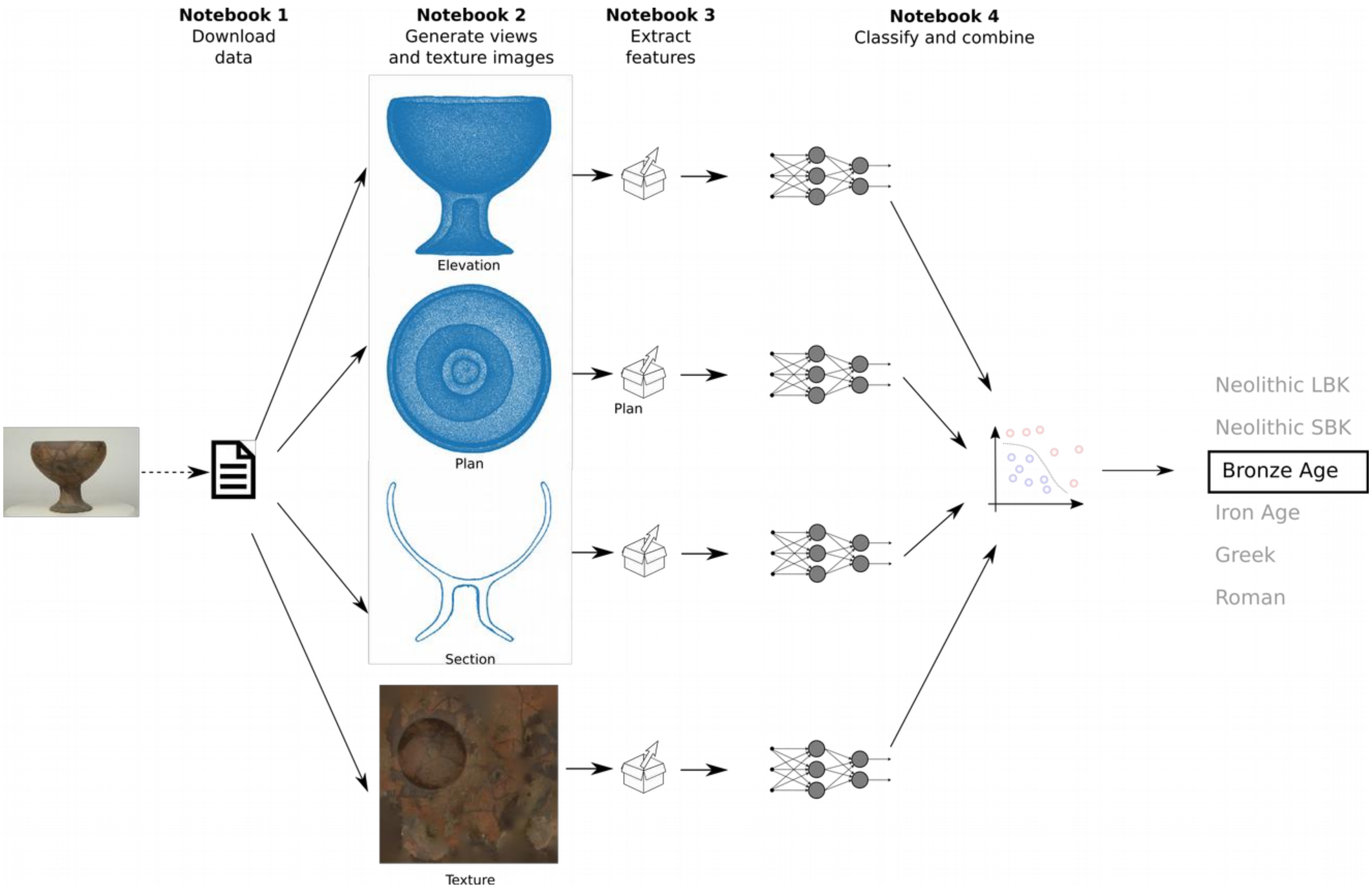


Caveat 3: Downloaded 3D models are not homogeneous



The 3D-model with the least vertices (A), with the most vertices (B), the model with the most vertices sub-sampled to 37532 vertices (C)

Machine learning setup



Preprocess 3D-models

A Greek jug (A), its 3D point cloud (B), its texture image (C).

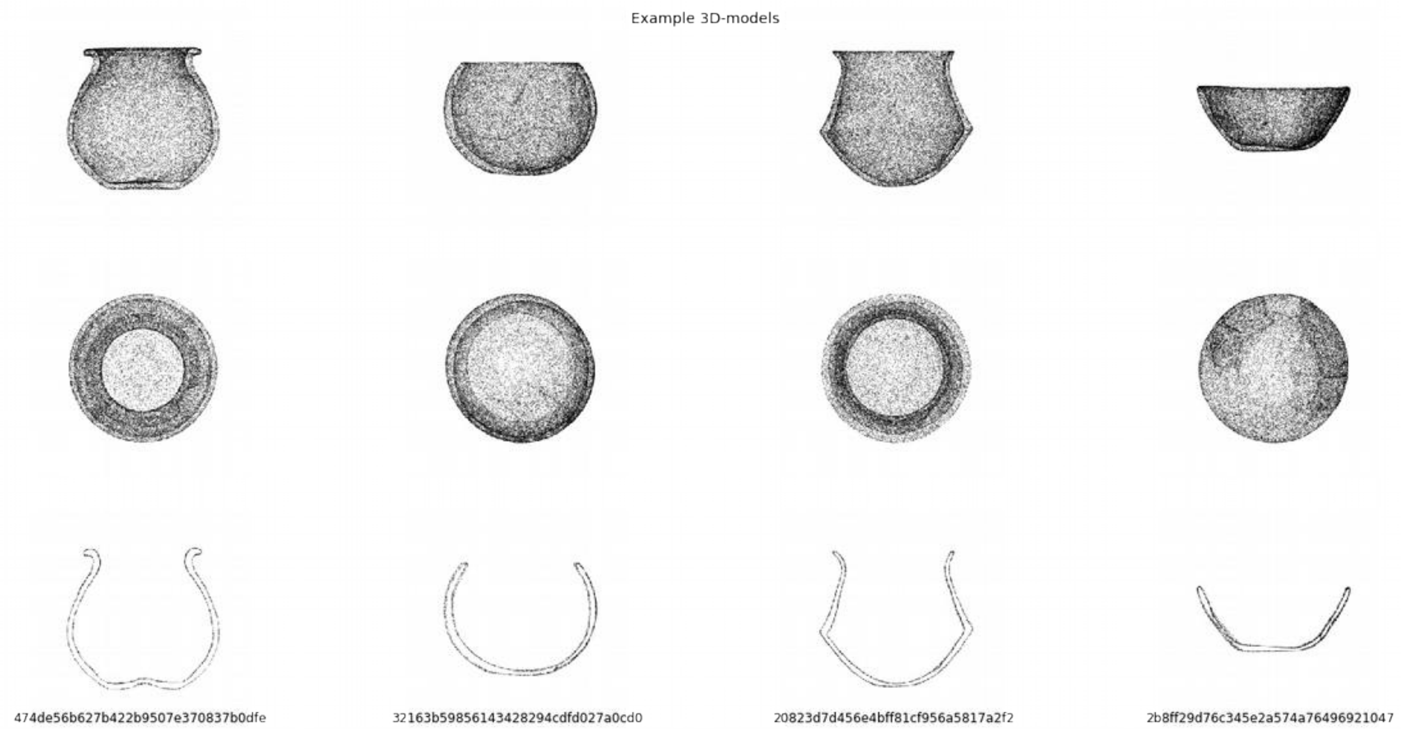
Point clouds

1) sub sample point cloud data so that the number of vertices is the number computed in the EDA in notebook 1, i.e. 37838 vertices
2) rotate the point cloud to generate an elevation (side) view
3) generate plan (top) and cross-section views by rotating the elevation view
4) render the views as images
5) save the pixel data of the flattened images into a npz file

Textures

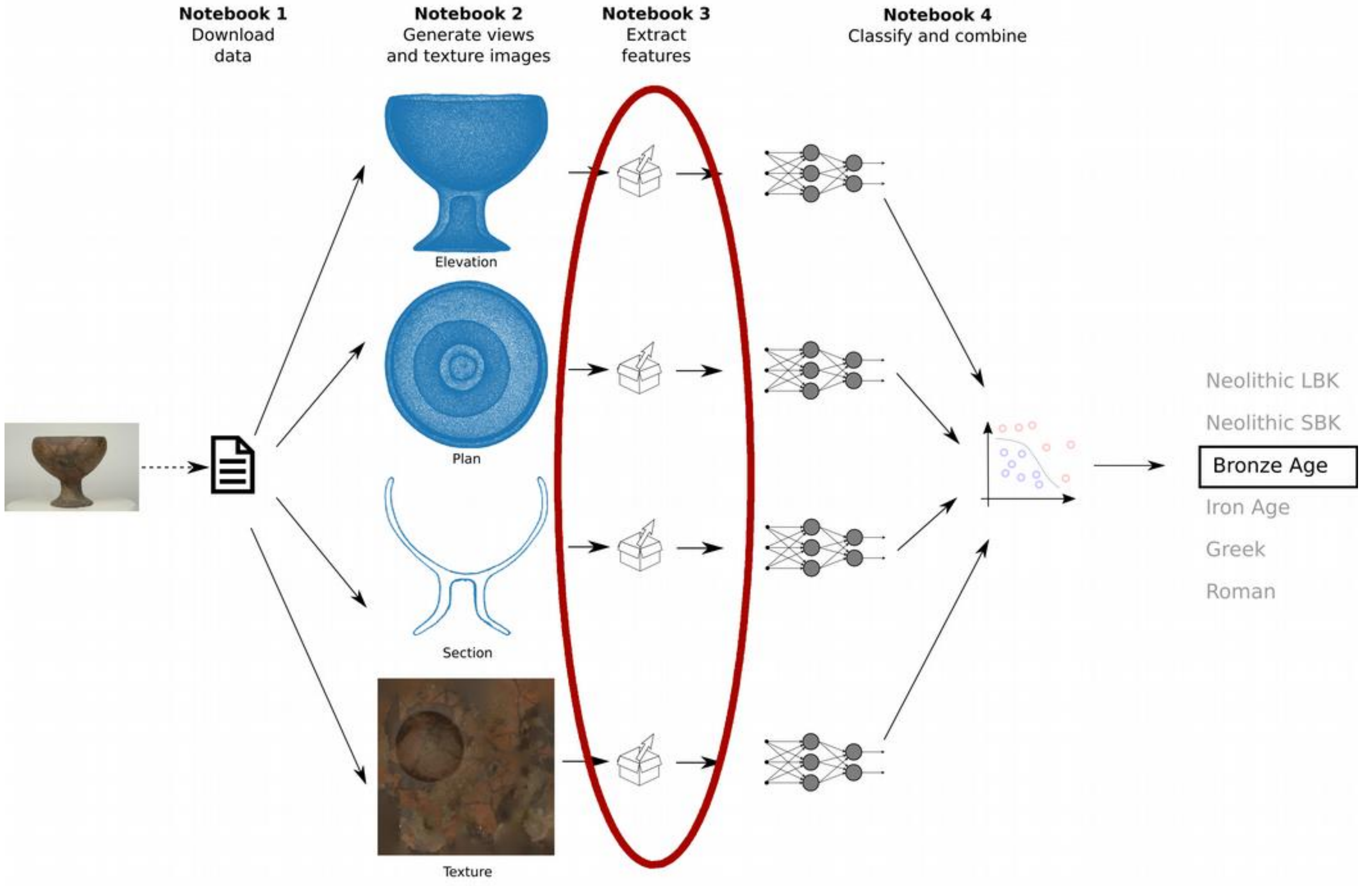
6) resize the texture image to the size expected by the data extraction model, i.e. 299x299 pixels RGB
7) save the textures as flattened images into a npz file

Split data into "train", "validate" and "test" datasets

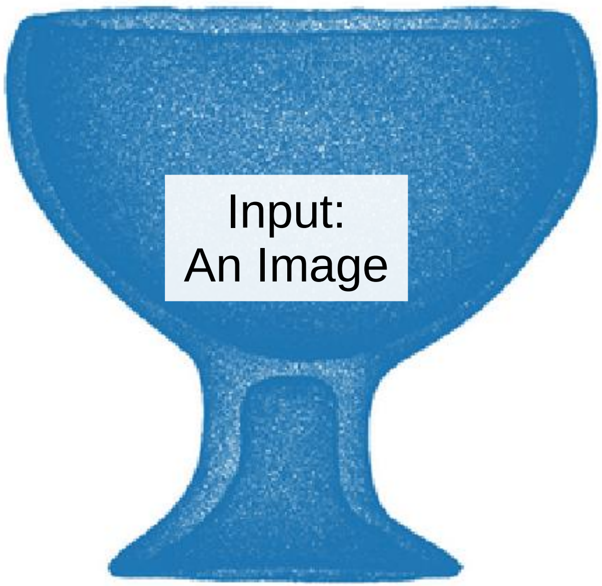


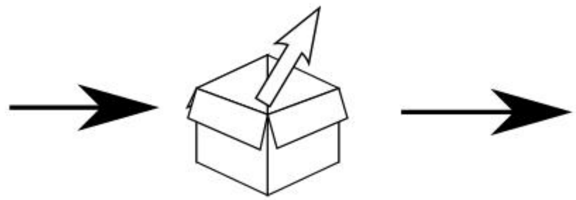
- Training dataset (70%)
- Validation dataset (20%)
- Test dataset (10%)

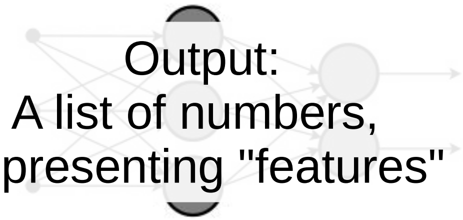
Extract features by transfer learning



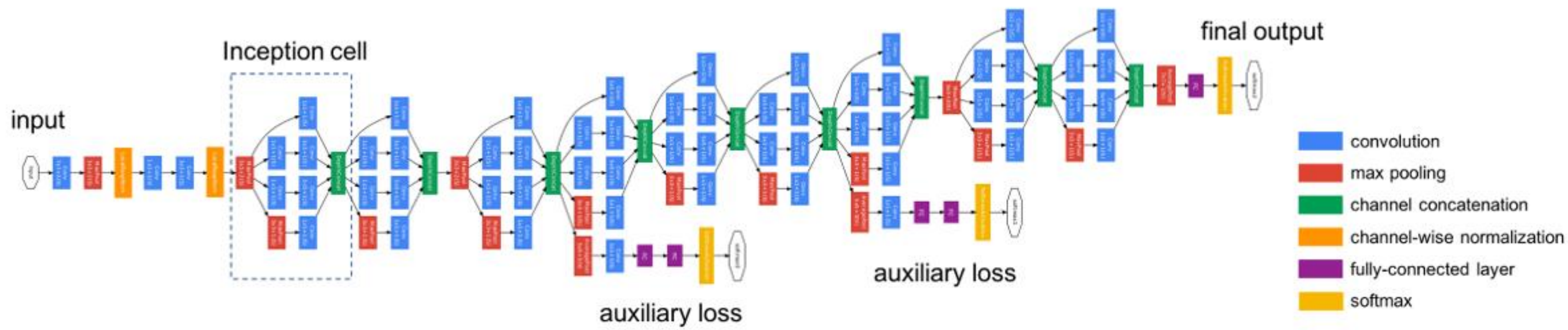
Extract features by transfer learning







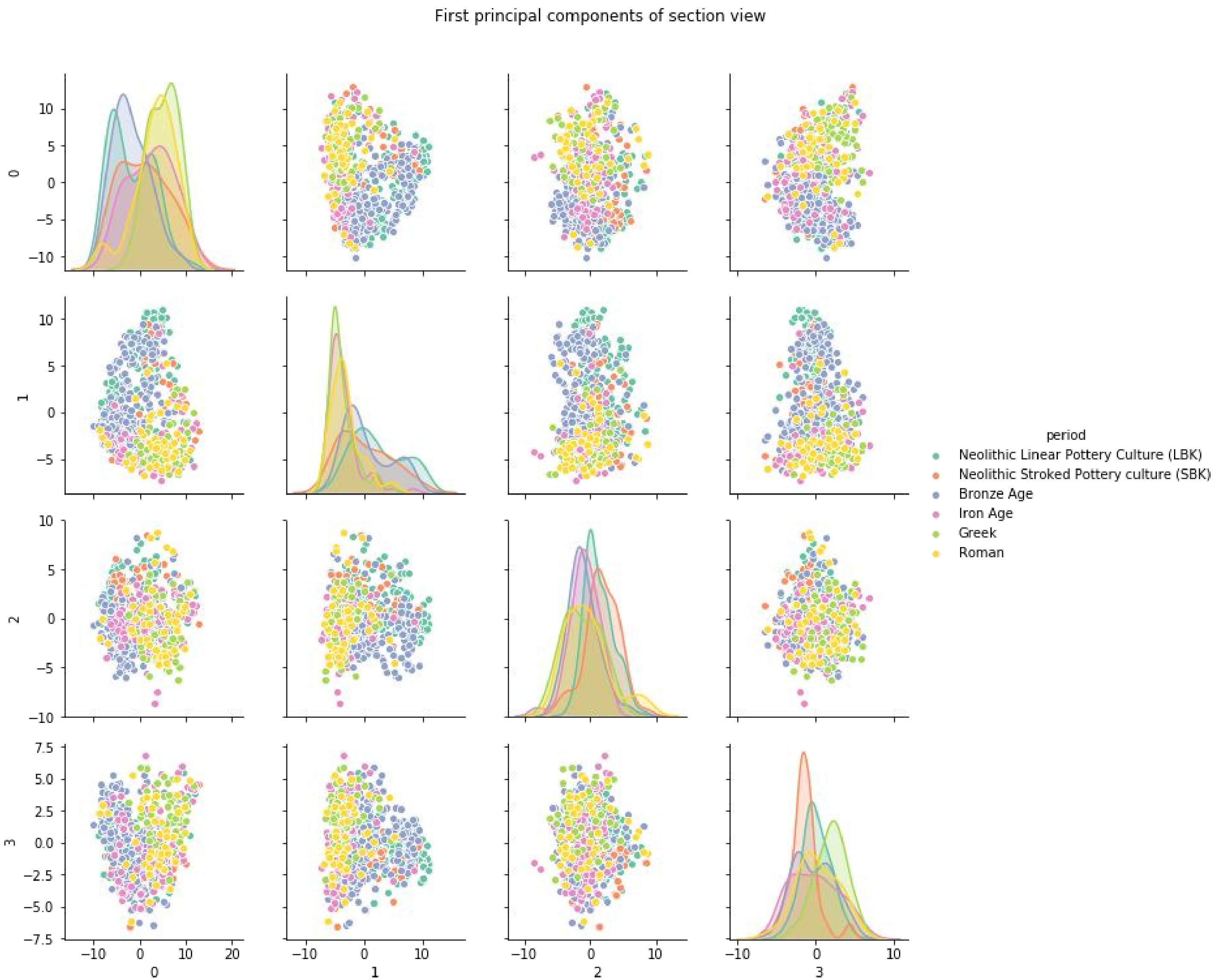
What's inside the box?



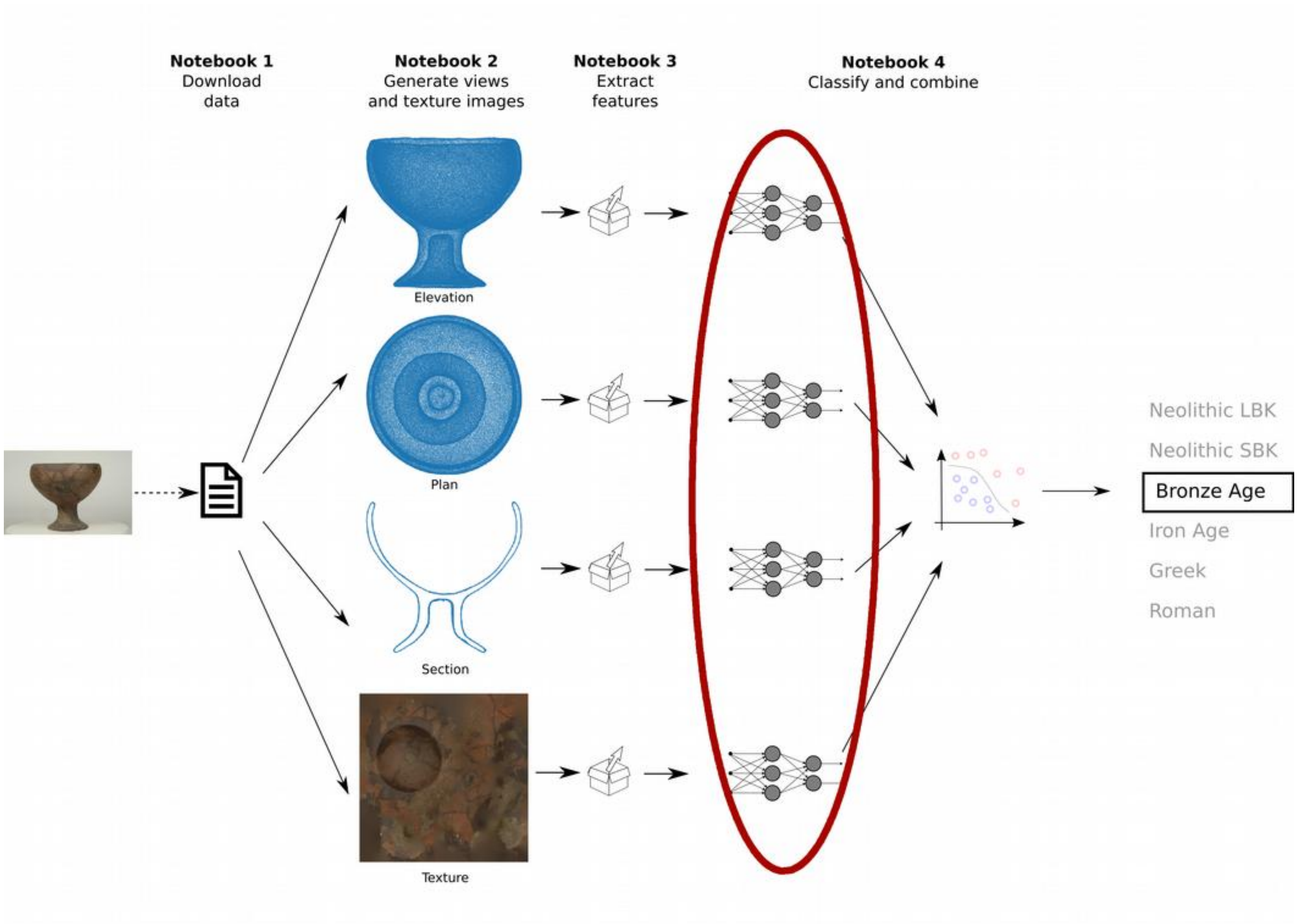
Inception v3 model, trained on "ImageNet" dataset (14.197.122 images) on Google Cloud

Christian Szegedy, Vincent Vanhoucke, Sergey Ioffe, Jonathon Shlens, Zbigniew Wojna: "Rethinking the Inception Architecture for Computer Vision", 2015.

Principal component analysis

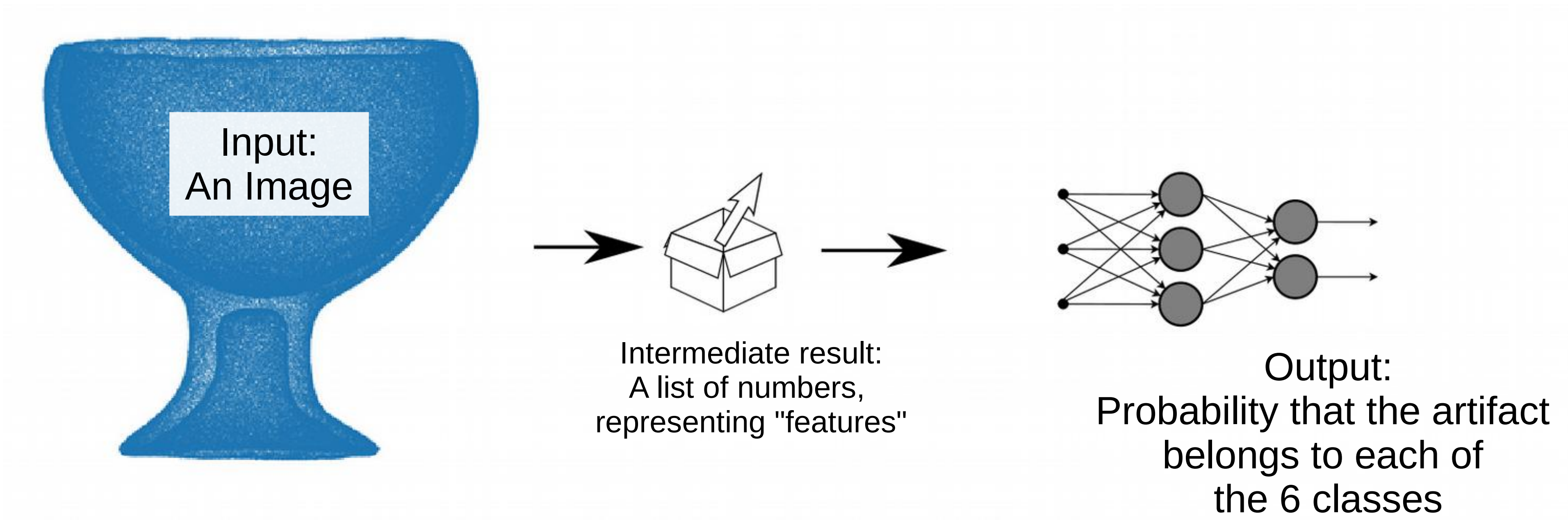


Classify



Notebook 1
Download data
Notebook 2
Generate views and texture images
Notebook 3
Extract features
Notebook 4
Classify and combine
Elevation
Plan
Section
Texture
Neolithic LBK
Neolithic SBK
Bronze Age
Iron Age
Greek
Roman

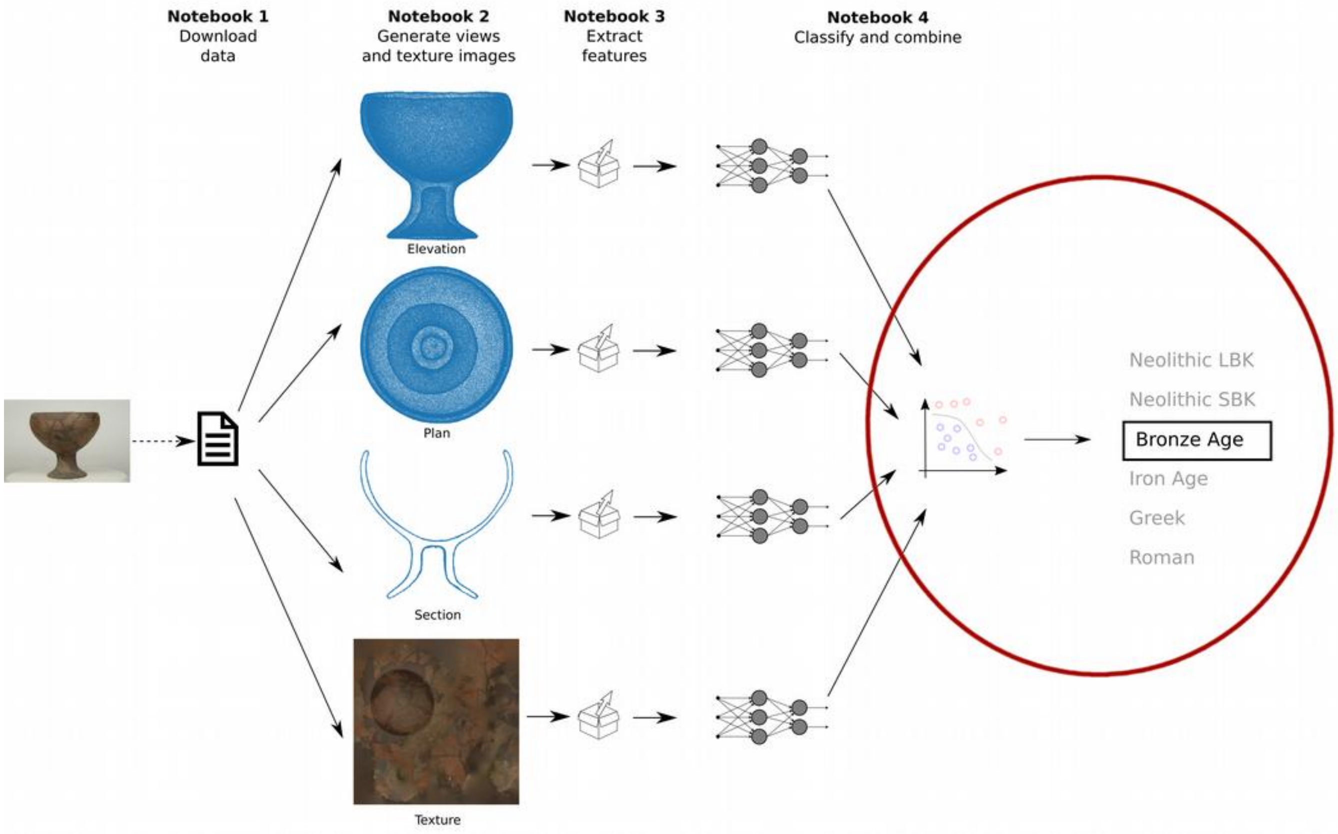
Classify



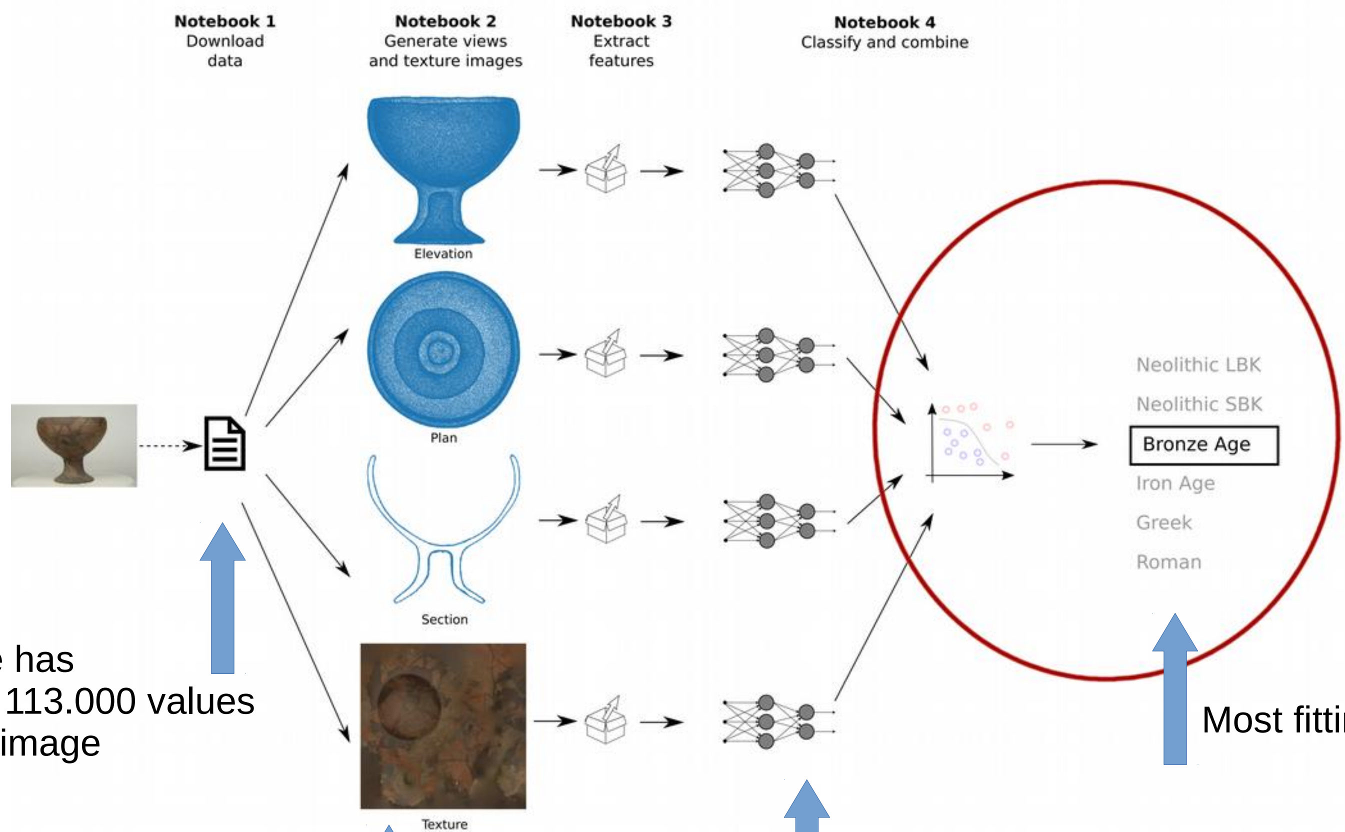
Example:
For the first artifact, for the "elevation view"

Neolithic LBK	50%
Neolithic SBK	40%
Bronze Age	80%
Iron Age	70%
Greek	20%
Roman	60%

Classify and combine



Classify and combine



Each file has
37838 3D points ≈ 113.000 values
+ surface image

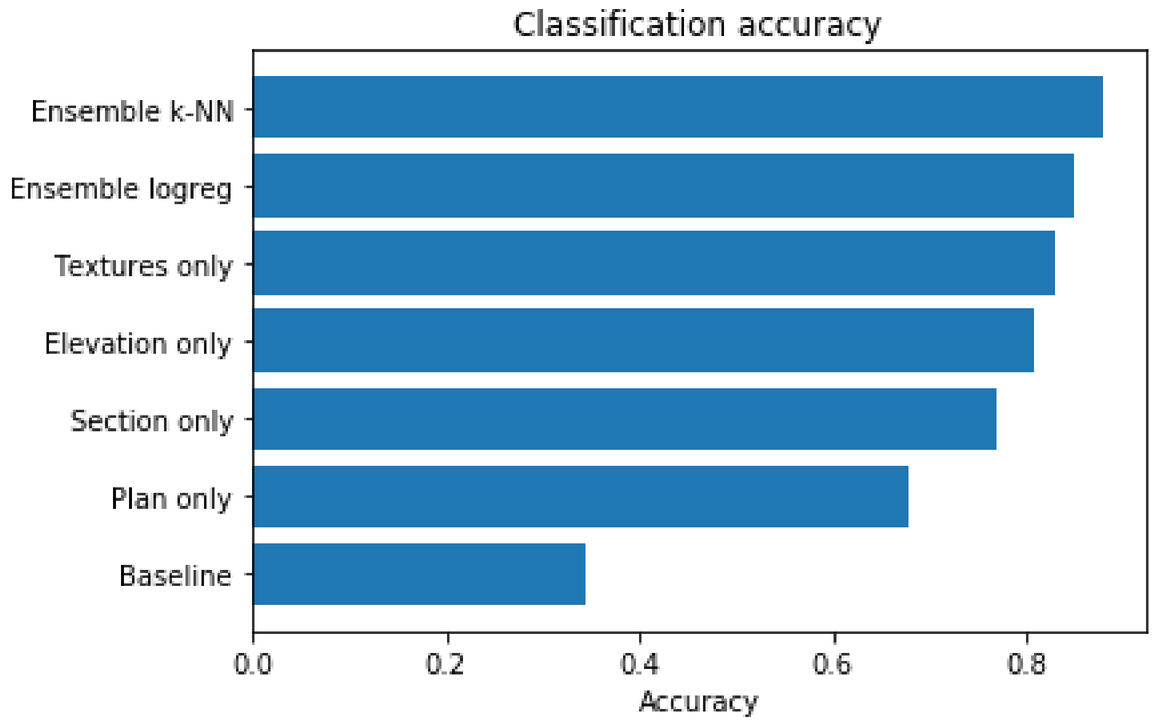
3 rendered views, 1 color texture, 299x299 pixels
≈ 54.000 values

4 sets of 2048 features
≈ 8000 values

4 sets of 6 probabilities
= 24 values

Most fitting class: 1 value

Results: Accuracy



Results: confusion matrix

		Predictions					
		Bronze Age	Greek	Iron Age	Neolithic Linear Pottery Culture (LBK)	Neolithic Stroked Pottery culture (SBK)	Roman
True class	Bronze Age	97 %	0 %	0 %	3 %	0 %	0 %
	Greek	0 %	87 %	3 %	0 %	0 %	0 %
	Iron Age	7 %	0 %	83 %	0 %	0 %	0 %
	Neolithic Linear Pottery Culture (LBK)	0 %	0 %	0 %	100 %	0 %	0 %
	Neolithic Stroked Pottery culture (SBK)	10 %	0 %	0 %	40 %	50 %	0 %
	Roman	0 %	14 %	43 %	0 %	0 %	43 %

Evaluation

RQA: How much math is necessary to apply M.L. in practice?

- *Choice of model*:
  Understand your models, investigate several suitable alternatives.

- *Apply corrections*
  Expect data to be unbalanced or non-homogeneous data, know how to handle these data.

- *Expect incomplete data*
  Keep up with library developments, as newer versions of scikit learn probably offer better imputer objects for missing data

- *Transfer learning*
  Transfer learning does improve the results on small data sets considerably.

- *Optimize the training strategy*:
  In this setup, training the whole setup in one go instead of each classifier in parallel could potentially improve the results, but would most certainly also require more powerful hardware

RQB: Given the current state of digitization of cultural artifacts, what results can be expected?

- *Larger data set*
  Around 1000 3D-models do not seem to be enough for supervised learning

- *Choose a suitable scanning method for ML from the onset*
  While point clouds with tens of thousands points have enough resolution,
  missing textures certainly are a problem. Therefore 3D-scanning methods that provide a texture should be preferred.