

Universal Multi-Expert Measures *for Quantitative Visual Art Analysis*

Applied Quantitative Solutions for Complex Systems

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Advances and Challenges in Modern Computer Vision and Image Processing

- Recent advances made possible development of automated systems for medical image analysis, face recognition, reconstruction of 3D objects from multiple views, and other applications.
- While some applications are more developed due to possibility of well-defined formalization of the problem, generic category recognition is still very difficult task without any prospect of universal solution in the near future.
- For example, while computers can accurately reconstruct 3D shape from images taken from different views, they cannot name all the objects and animals in the picture even at the levels of a 2-year-old child.
- None of the existing computer vision systems could approach performance level of a 2-year-old child in generic category recognition. The main obstacles for performance improvement in this area is great variability within the same class.

Challenges of Quantitative Analysis of Visual Arts

- Computerized visual art analysis is facing much greater challenges than standard recognition tasks, because objective is not just identification and classification of objects in the painting.
- The most challenging objectives in visual art analysis is capturing much less obvious and hard-to-quantify features that could relate considered piece of art to a particular famous painter, school of visual art or epoch.
- Even the same object or scene can be represented in a wide variety of styles by different painters or schools of art. Therefore, variability in such problems could create much more serious challenges than in more standard problems of generic category recognition.
- Similar to more developed areas of computer vision, certain problems of computerized visual art analysis are more quantifiable. These include applications dealing with the analysis of certain aspect of style used by artist.
- For example, quantitative characterization of brushstrokes in paintings by van Gogh has been shown to be useful for detection of forgeries. Other computer-based systems for analysis of perspective, shading, color and form have also been used for identification of artists and styles.
- Unique style signatures of talented artists cannot be fully captured by a single feature. Typically, personal style of an artist consists of complex combination of features. There is no universal way for optimal choice of such features and for their quantification.

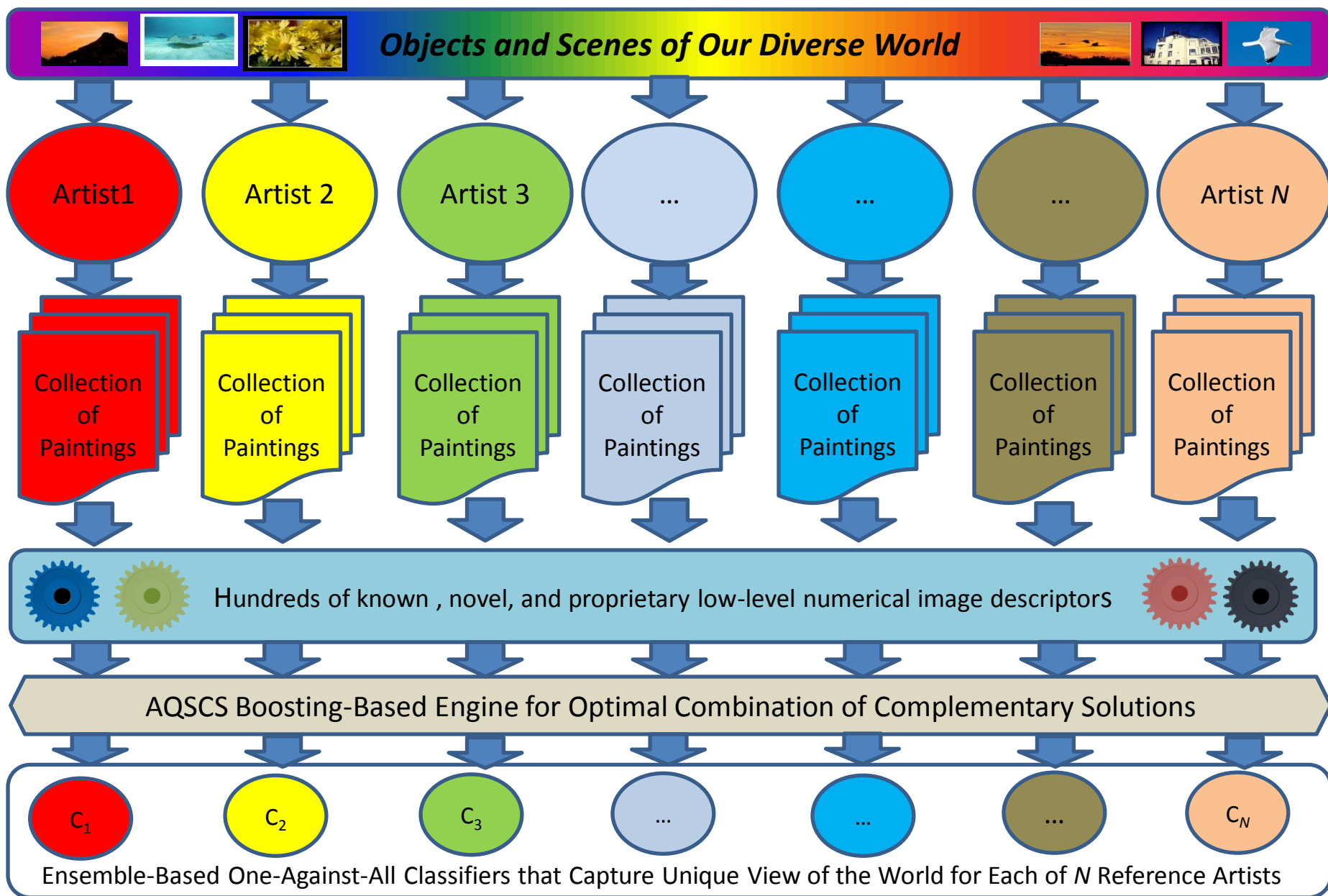
Capturing Implicit Multi-Feature Signatures of "High Art" that are Hard to Explain, Formalize, and Quantify.

- The visual analysis of art is highly complex cognitive task. Different elements of visual art such as colors, shapes, and boundaries are processed by different pathways and systems in the brain designed to interpret each aspect of the art.
- fMRI and EEG analysis indicated that experienced painter uses his brain in a different way than the non-painter. There are functional and topographical differences between artists and non-artists when performing visual perception of paintings, suggesting that artists perceive visual art in a different cognitive manner compared to non-artists.
- These observations provide additional objective support for existence of "high art". Works of true artists are capable of capturing viewer attention on deep psycho-emotional level, rather than mechanical visual representation of the surrounding scenes that lacks such "magical" effect.
- Intuitively, potential quantitative measures capable to identify such subtle effects of "high art" and to differentiate between different artists and schools should be based on optimal combination and interrelation of many different features capable of capturing style of the true artist.
- The most objective way for comprehensive capturing of hard-to-explain signatures of artist style would ignore direct analysis of objects and scenes, but rather use thousands low-level numerical image content descriptors that reflect different aspects of the visual content in paintings.
- Optimal representation with multi-scale and multi-type low-level image descriptors could potentially capture hard-to-explain psycho-emotional content of the painting.

AQSCS Universal Multi-Expert Metrics for Visual Art Quantification, Identification, and Comparison: Summary

- Representations based on optimal combinations of multiple low-level image descriptors could be very useful in providing objective quantitative support and interpretation for opinions expressed by art experts who may have intuitive ability to grasp complex multi-level visual information implicitly encoded in the art work.
- Such multi-expert quantitative measures could also consistently discover effects which could be difficult or impossible to notice even for the most experienced human experts.
- These multi-expert metrics should be able to include hundreds or even thousands of complementary image descriptors and demonstrate robust out-of-sample performance on the same time. Combination of these two requirements could be prohibitive for the most of standard approaches.
- Generic AQSCS framework for multi-expert discovery of model, indicators, and strategies has demonstrated its effectiveness for many challenging problems in biomedical, quantitative finance and other applications.
- AQSCS boosting-like ensemble learning algorithm with proprietary regularization techniques is capable of taking into account thousands of base models, measures and other quantitative information and discover stable multi-expert solution with robust out-of-sample performance.
- Our first efforts to adopt AQSCS framework for discovery of generic multi-feature measures capable of consistently detecting subtle differences in visual art pieces resulted in very encouraging results.

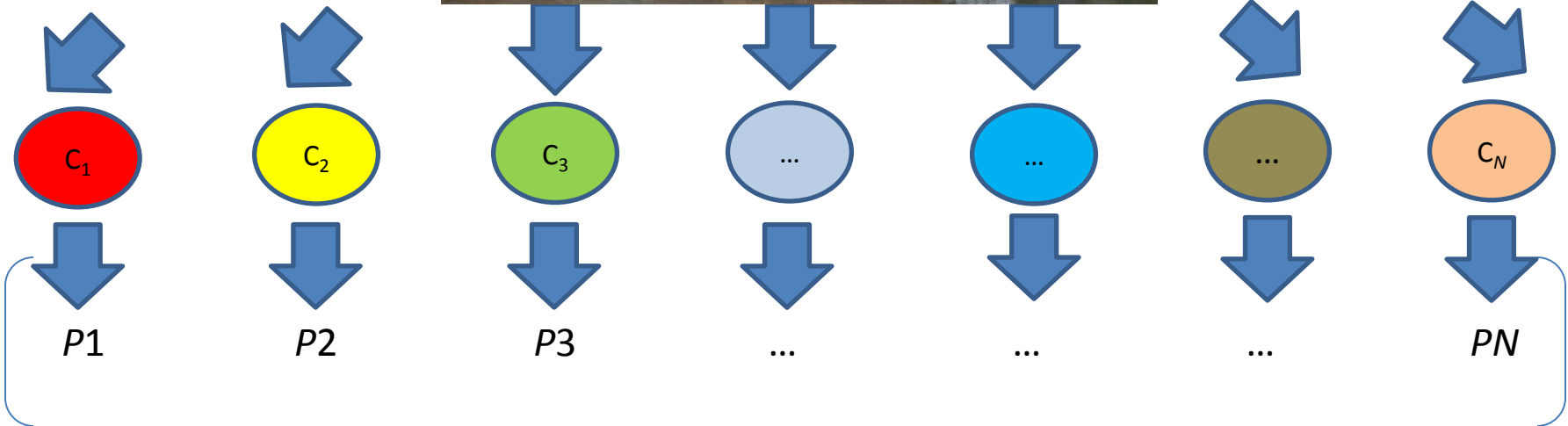
AQSCS Universal Multi-Expert Metrics for Visual Art Quantification, Identification, and Comparison: Discovery/Calibration Phase



AQSCS Universal Multi-Expert Metrics for Visual Art Quantification, Identification, and Comparison: Application Phase

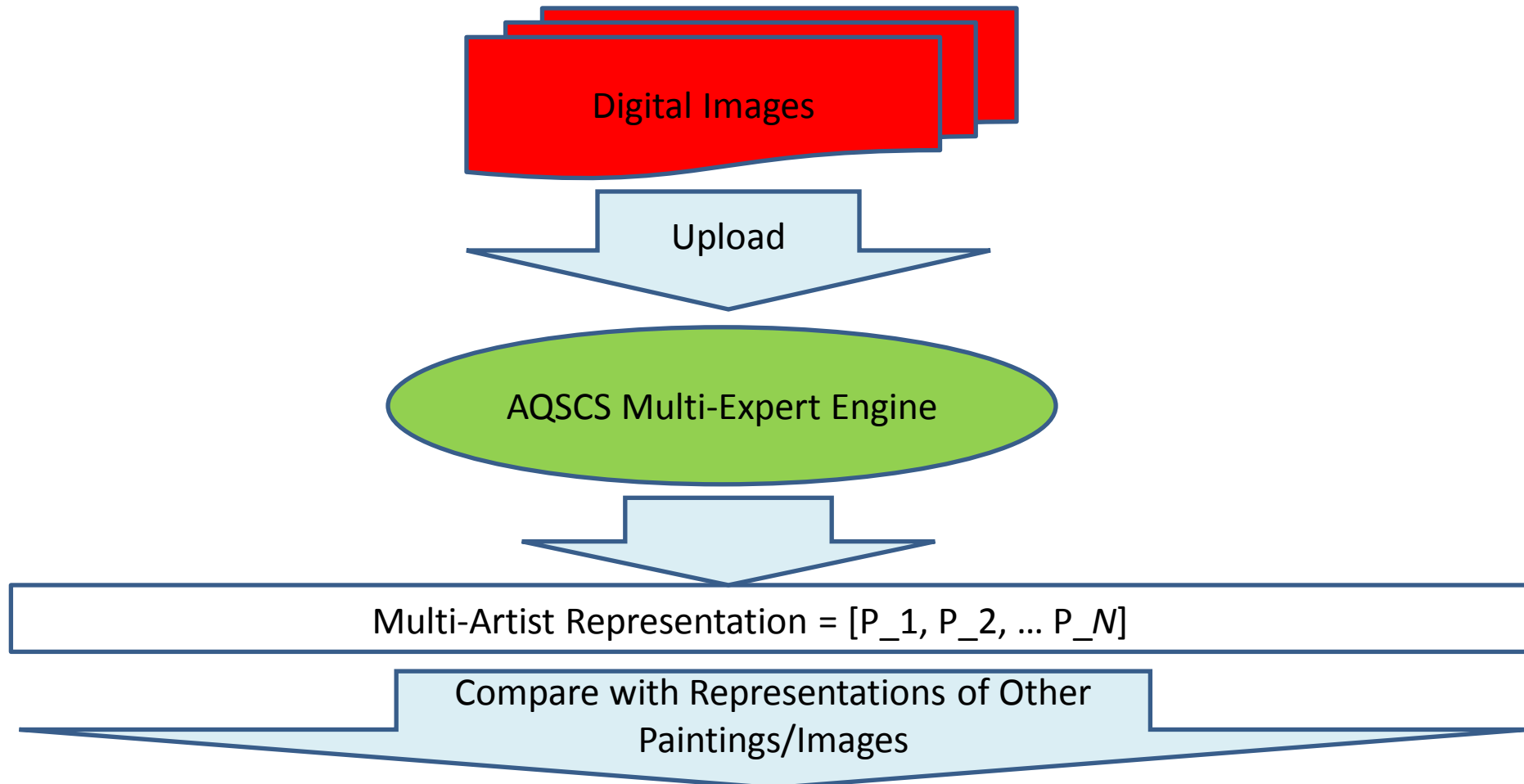


← Digital image of analyzed painting



- For any painting, probabilities P_i or similarities to Artist 1, Artist 2, ... Artist N are computed
- Probability vector creates generic representation by similarity
- Tested painting is quantified by its multi-feature similarity to N famous artists of different art schools and epochs
- Any two paintings or collections can be compared using distances between their similarity (probability) vectors
- Metrics can be used for any painting/artist/school not included in the training set, i.e. no retraining is necessary
- Representation can be easily expanded by adding new reference artists without retraining of already existed classifiers

Potential Applications of AQSCS Multi-Expert Metrics Implemented as Web-Based Service



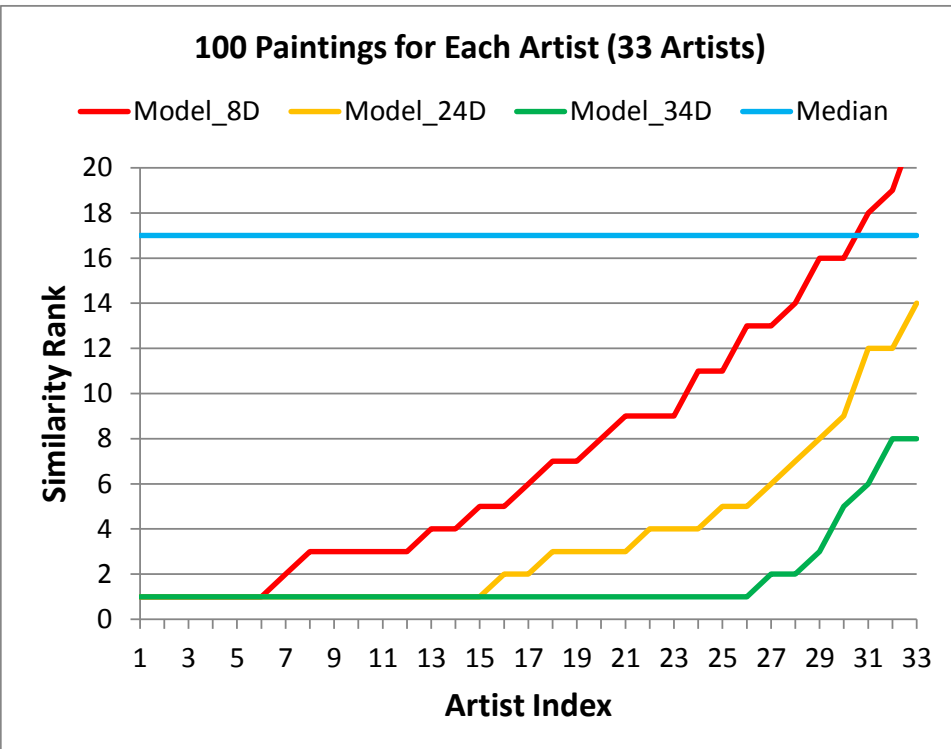
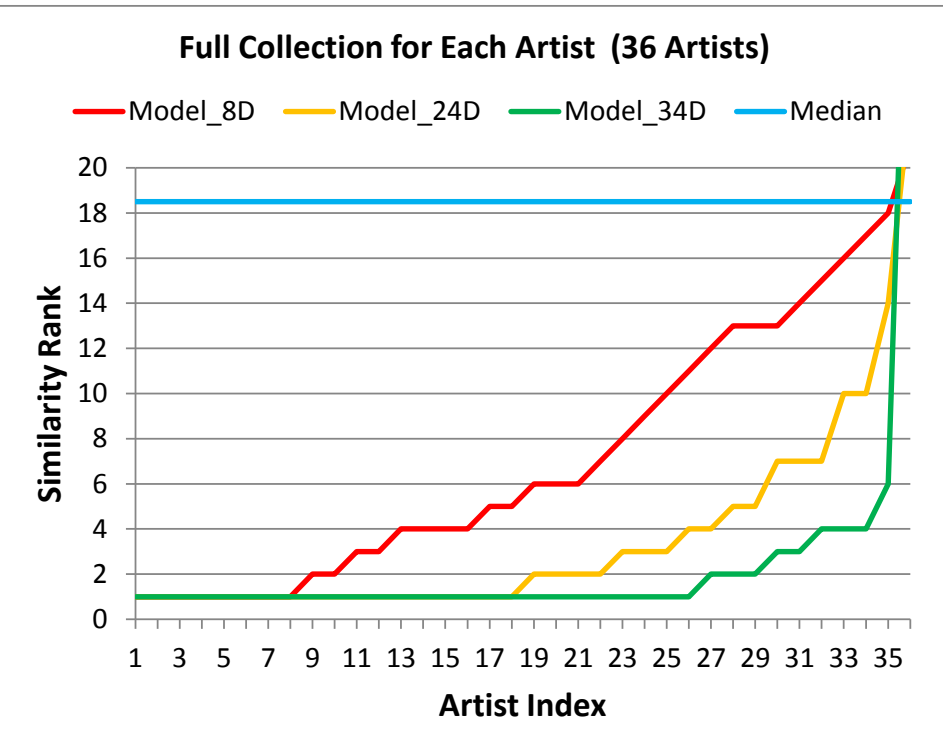
- Identification of art pieces with fully automated generation of detailed report describing best matches by artist, school, epoch, and specific paintings using our comprehensive reference database.
- Objective indication of subtle and/or slow style changes of the same artist in time
- Early detection of emerging talented artists which could be used as investment indicator
- Provide quantitative diversity measures for art portfolios (for collectors or art funds)
- Classification of emotional or aesthetic content of any image (painting or photograph)

Current Version and Back-Testing Summary

- Digitized paintings for ~60 famous artists of different art schools and epochs. Database is constantly expanding.
- Up to several hundred paintings for each artist: Total number of images > 10,000
- Metric for representation by similarity based on up to 60 reference artists
- Robust identification of artists which are not included in the metrics
- Robust identification of different periods of the same artist
- Encouraging preliminary results for classification of the emotional content of the nature's photographs not included in the metrics based on reference artists.

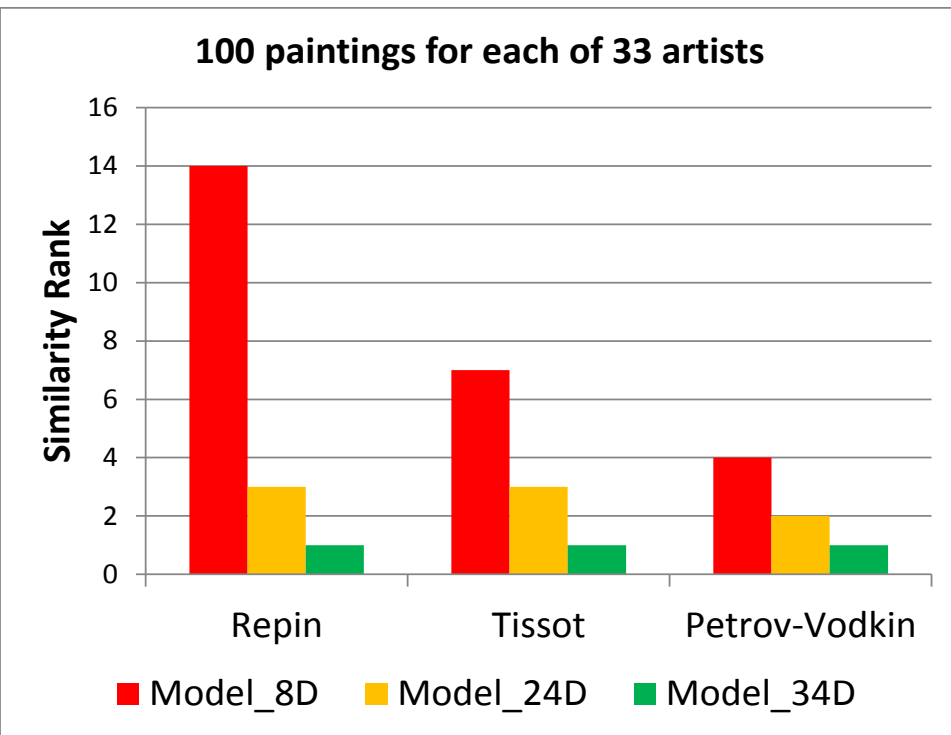
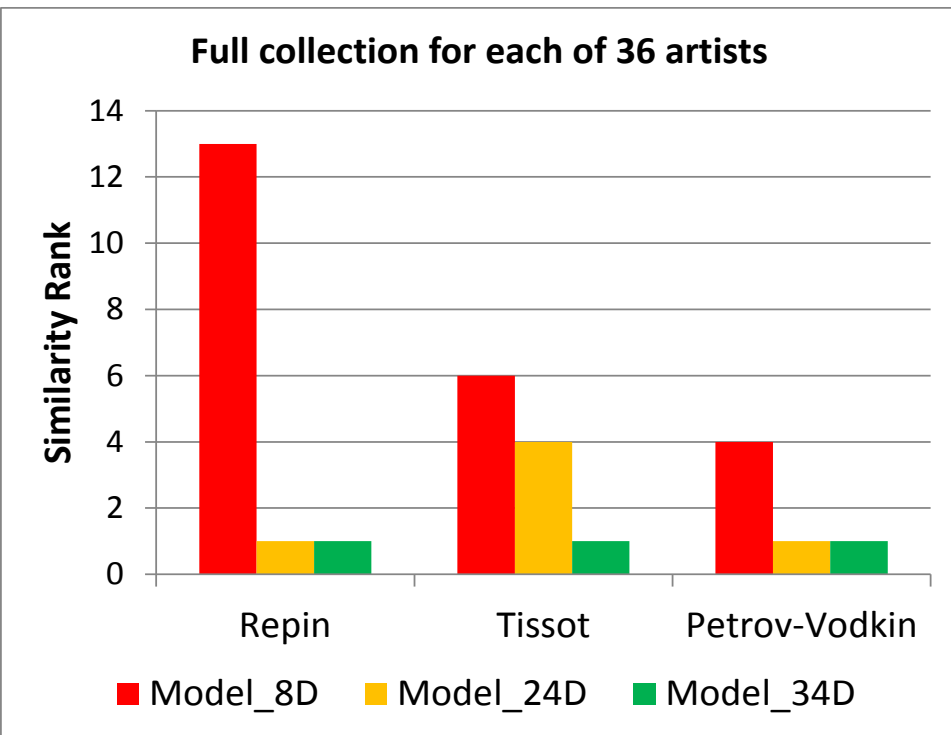
Performance: Overall Accuracy for Identification of the Artist

- Comparison of full collections with different number of paintings for 36 famous artists (left plot) and equal-size sub-collections of 100 paintings for 33 artists (right plot).
- Similarities between any two collections are measures as medians of all painting-to-painting distances according to AQSCS multi-expert metrics based on 8 (red line), 24 (yellow line), and 34 (green line) reference artists.
- For each collection, its distance to all other collections (including itself) is ranked from minimum distance or highest similarity (rank 1) to maximum distance or lowest similarity (rank 36 or 33).
- Red, yellow, and green lines present rank of each collection to itself for all considered artists.
- AQSCS multi-expert metrics demonstrate impressive performance in self-identification test: ranking is 1 or just slightly above 1 for majority of artists. As expected, performance improves with increasing number of reference artists (from 8 to 34) used in representation by similarity.
- Performance of our multi-expert metrics is drastically better than random metric which would have comparable number of rankings above and below median ranking (blue line).



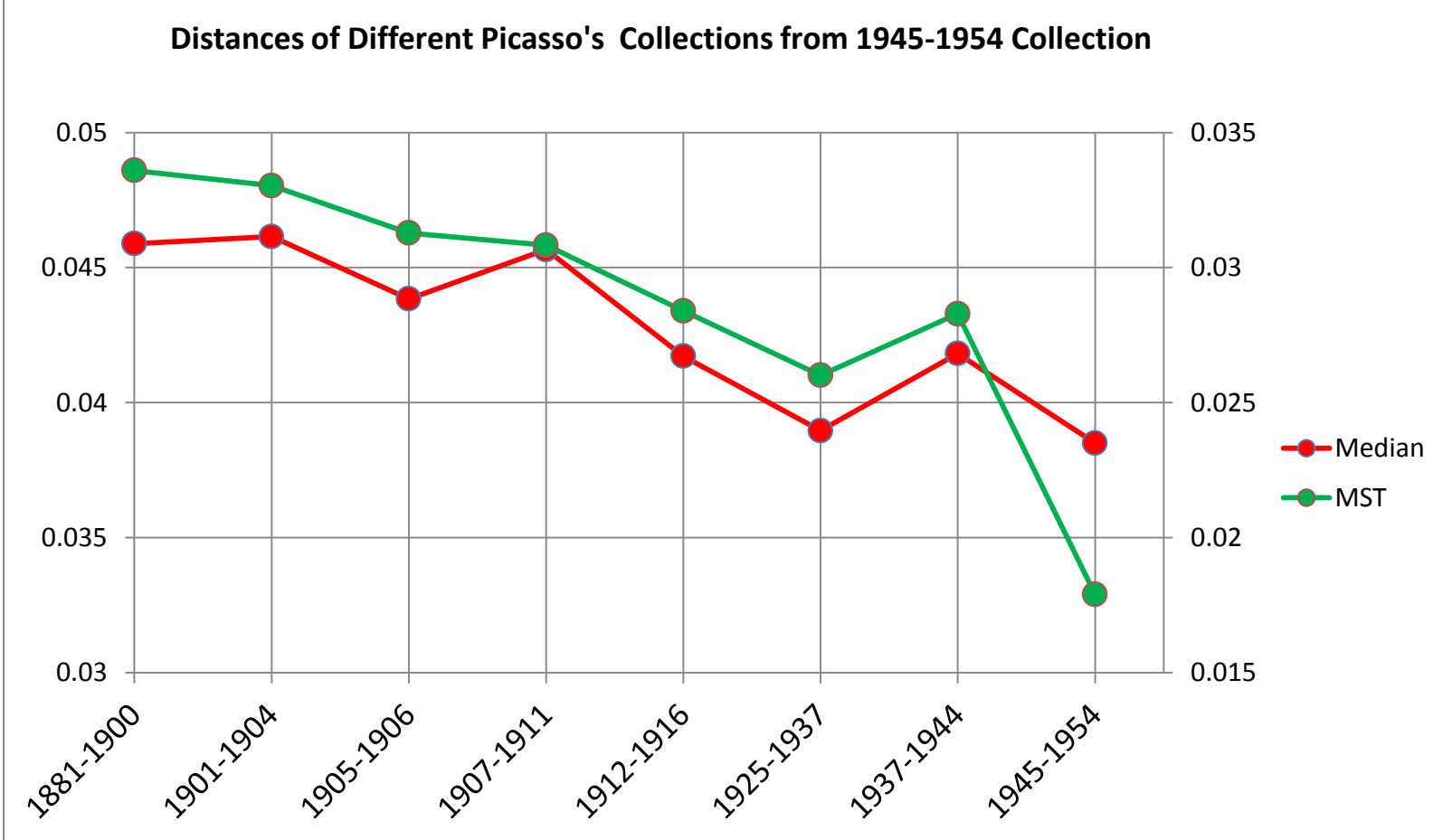
Performance: Universal Representation of any Artist/Style not used for Model Calibration

- The main advantage of the generic representation by similarity is its ability to quantify and compare paintings of any artist which is not included in the reference set of artists.
- No additional training/calibration of the multi-expert model is necessary.
- Painting of any artist is represented by its similarity to unique styles and world views of the reference set of artists.
- Accuracy of such representation is expected to increase with wider coverage of different art schools and individual styles in the reference set of artists.
- Using the same data as in figures from previous slide, we show self-ranking of the painting collections of artists not used in reference set for any of the models.
- We see that rankings are close to 1 (i.e. the correct or almost correct self identification) when large enough number of reference artists (24 or 34) are used for representation.



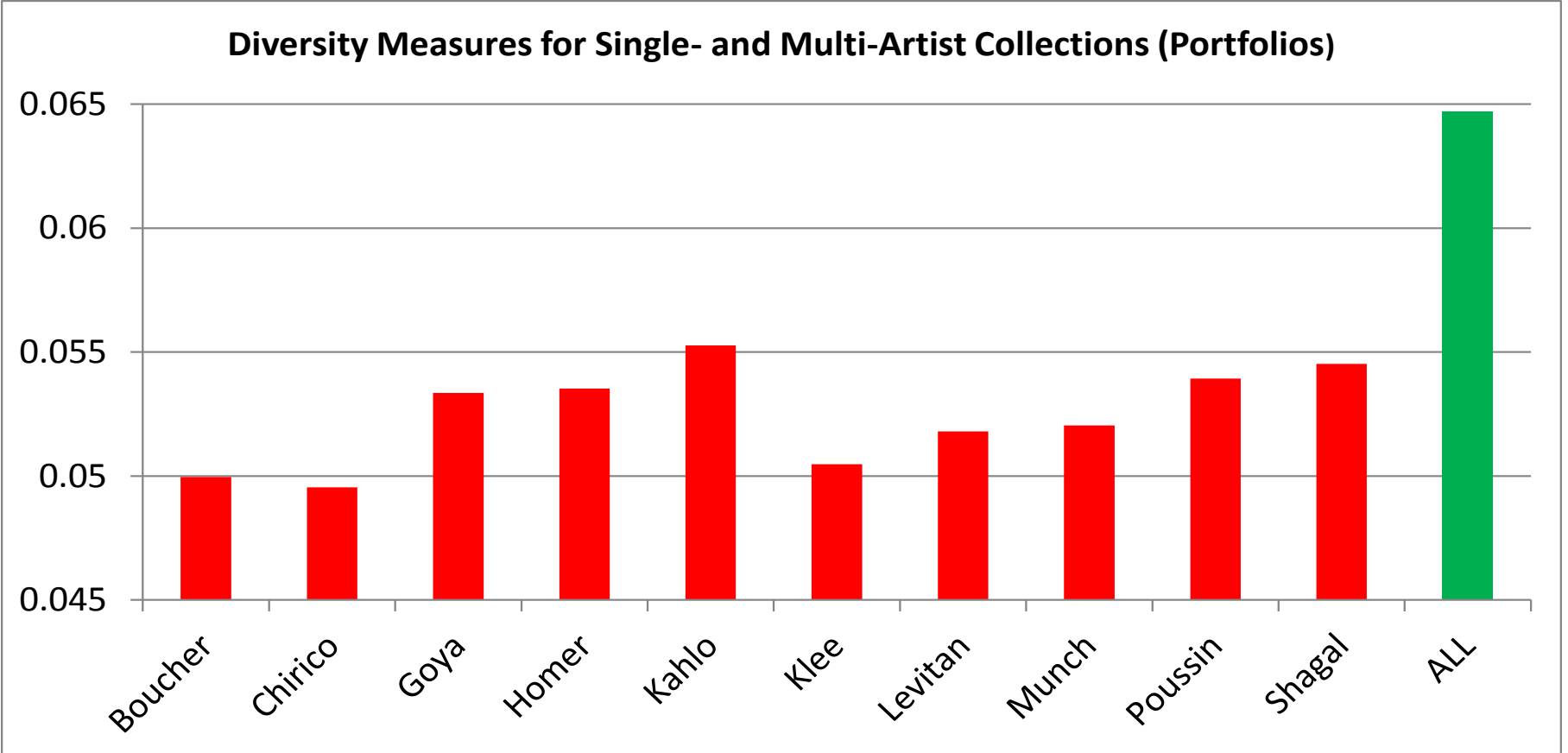
Performance: Detection and Comparison of Different Periods (Sub-Styles) of the Same Artist

- AQSCS multi-expert metrics implicitly captures large number of fine-grain details of the styles used in visual arts
- This allows to use this universal metrics not only for differentiation between different artists, but also for differentiation between different periods or sub-styles of the same artist.
- This is demonstrated for collections of paintings created by Picasso in different periods.
- The median distance (according to AQSCS metrics) from each of the collections to 1945-1954 collection is shown by red line. More accurate representation with the use of topological (MST-like) de-noising of cross-distance matrix instead of simple median of the painting-to-painting distances is shown by green line.
- As expected, the distance to 1945-1954 collection almost monotonically increases when period of the collection moves further away.



Performance: Universal Diversity Measures for Optimal Selection of Visual Art Investment Portfolios

- AQSCS multi-expert metrics can be used for measuring diversity of visual art portfolios that can be used in decision support systems for art investment.
- Diversity of the paintings' portfolio is an averaged distance between paintings according to our multi-expert metrics. The most robust diversity measure is minimum spanning tree (MST) length of the portfolio.
- Presented example compares diversity of 10 portfolios of paintings of single artists (100 paintings per portfolio) and portfolio with paintings from each of these artists (in equal proportion).
- It is evident that diversity of the combined portfolio dramatically increases compared to portfolios of individual artists.



Performance: Identification of aesthetics, emotional and other hard-to-quantify contents in images

- Quantitative description of an aesthetic and emotional content of an arbitrary image is very hard problem without known universal solution.
- One of the reasons is that notions of aesthetic and emotions are quite subjective leading to difficulties in explicit formalization of the problem.
- However, AQSCS multi-expert metric implicitly captures subjective world views of many famous artists which also includes aesthetic and emotional components.
- Therefore, it is reasonable to assume that our metric may be useful for differentiation of images with different subjective content such as aesthetic or emotion.
- Our preliminary results are encouraging as shown in the plot. Here our multi-expert metrics based on different number of reference artists are capable to differentiate between nature photographs with positive and negative emotional content.
- Here positive emotions are represented by photographs with lakes, rivers, mountains and other nature scenes in good weather conditions. Negative emotions are represented by photographs of tornado, hurricane, sea storms, fire and other disturbing scenes.
- It is important to note that none of considered photographs have been used in calibration of our metrics which were based solely on paintings of reference artists.

