Simon Dirks (4237331)

Artificial Intelligence - MSc. Thesis

July 7th 2021

Understanding Interestingness of Artwork Relations for Art Museum Visitors based on Wikidata Metadata

Department of Information and Computing Sciences
Utrecht University

Supervisor: Prof. dr. Lynda Hardman
Second examiner: Dr. Mel Chekol

Acknowledgements

Throughout my research process, I was fortunate enough to be supported by many kind and caring individuals.

I am particularly indebted to Lynda Hardman, whose ability to understand my own work better than I did has been at times frustrating but mostly incredible. I have learned to admire and respect Lynda both intellectually and personally, and look back on her kind, patient and excellent supervision with sincere gratitude. Maia Kenney I have met as a competent and open-minded professional without whom this research would not have been possible. I thank Maia for helping me understand and appreciate art, her continuous and kind assistance throughout this study, and our newly found interdisciplinary friendship.

I appreciate Mel Chekol taking the time to be my second examiner, and am grateful for the assistance of the NDE (Dutch Digital Heritage Network) for recruiting participants, hosting data, and giving me a platform for my work. Finally, I thank Lotte Matola for her unique mix of continuous loving emotional support and genuine interest in my work, and appreciate Ivar Troost and Dylan Kruyff for their friendship and valuable feedback on various drafts of this study.

Contents

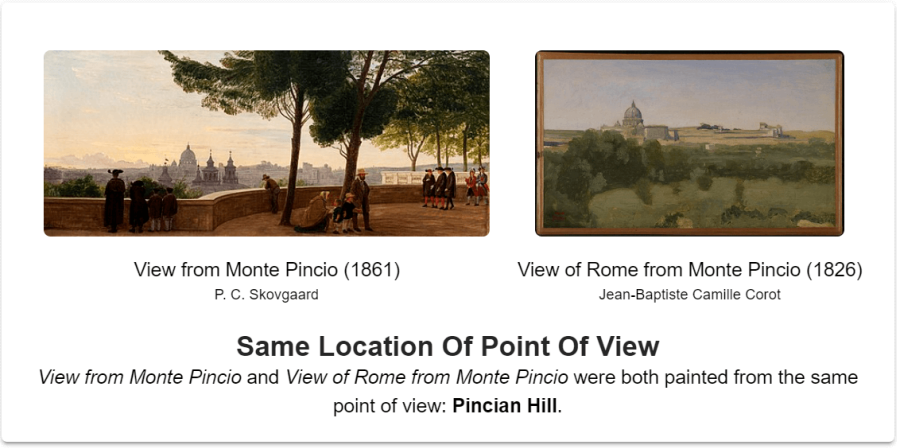


Figure 1: The artwork relation considered most interesting by 320 participants (on average).

Abstract

Art museum curators typically aim to tell stories spanning individual artworks, thereby connecting exhibited works to each other and making exhibitions greater than the sum of their parts. For art museum visitors, however, these relations are rarely explicitly clear, while learning about them has considerable potential for improving their visiting experience. Manually considering all relations between exhibited works is infeasible, however, and automatic methods for relation exploration tend to identify many relations unlikely to be of interest for museum visitors.

In this study, we took a data-driven approach to understand what makes artwork relations interesting for art museum visitors. Our contributions are as follows:

1. We create a ground truth dataset on artwork relation interestingness based on 7894 interestingness ratings from 320 participants across a selection of 136 artwork relations.
2. We present and evaluate various Wikidata-based artwork relation interestingness heuristics.
3. We show the extent to which there is a consensus on the types of artwork relations that art museum visitors consider (un)interesting.
4. We highlight several automatically identifiable artwork relation characteristics that help estimate the types of artwork relations art museum visitors consider to be interesting.
5. We confirm the considerable potential for improving the art museum visitor's experience by explicitly identifying (interesting) artwork relations.

1 Introduction

Artworks exhibited in art museums can be related in many ways, for instance by portraying similar themes, belonging to the same art-historical periods, or using similar techniques. These relationships, however, are rarely explicitly presented in museum spaces, and can be hard for visitors to discover based on visual impressions or museum labels alone. We hypothesize that for art museum visitors, learning about the relationships between artworks encountered during a museum visit provides valuable insights into the exhibition's contents and, therefore, has considerable potential for improving the museum visiting experience.

To identify relations between the specific varying artworks that individual visitors are intrinsically interested in, museum curators face a near impossible challenge. One would need to consider all possible relations between exhibited works, which grows exponentially with the number of exhibited artworks, and quickly calls for a more automatic approach.

Previous research on relationship discovery leverages the power of the Semantic Web to automatically

identify relations between a selection of objects (Heim et al., 2010), and in principle would allow museum visitors to discover relationships between encountered artworks. A problem with domain-independent approaches like these, however, is that they typically identify many relationships that are of little to no interest for museum visitors. In an exhibition space where visitors need to strategically allocate attention to competing attractions (Rounds, 2004), overwhelming visitors with long lists of uninteresting relations seems particularly detrimental to the visiting experience. We propose, therefore, that to make existing methods for (artwork) relationship discovery of value for improving the experience of art museum visitors, we first need to understand what types of artwork relations visitors are interested in, which can be used to optimally rank and/or filtered identified relations.

In this exploratory study, we present a data-driven approach to understanding what it is that makes artwork relations interesting for art museum visitors. We take a visitor-centered and experience-driven approach, following the trend of museums becoming increasingly visitor-centered (Ballantyne & Uzzell, 2011; Weil, 1999), and agreeing with the vision of large academic museum initiatives before us such as PEACH (Stock et al., 2007), CHESS (Pujol et al., 2011), EMOTIVE (Perry et al., 2017) and SPICE (Bruni et al., 2020).

1.1 Research Questions

Motivated by the reasons introduced above, the main research question that will be addressed in this study is as follows:

Main RQ: How can the interestingness of artwork relations for art museum visitors be understood?

To answer this question, we address several sub-questions. First, we aim to grasp the wide spectrum of the types of relations that could be identified between artworks (Section 3), explicitly differentiating between what professional curators might identify (Sub-RQ 1.1) and what can be automatically identified (Sub-RQ 1.2).

Sub-RQ 1. What types of artwork relations exist?

Sub-RQ 1.1. What types of artwork relations do curators identify in art exhibitions?

Sub-RQ 1.2. What types of artwork relations can be automatically identified?

Then, we create ground truth data on the extent to which art museum visitors consider various types of artwork relations to be interesting (Sub-RQ 2, Section 4).

Sub-RQ 2. What types of artwork relations do art museum visitors consider to be interesting?

After this, we research the extent to which there is a consensus on artwork relation interestingness for art museum visitors (Sub-RQ 3), representing the subjectivity of interestingness in this context.

Sub-RQ 3. To what extent do art museum visitors differ in the types of artwork relations they consider to be interesting (as identified in RQ 1.2)?

Finally, we evaluate various automatically identifiable artwork relation characteristics on the accuracy with which they can estimate art museum visitors' perceived interestingness (Sub-RQ 4, Section 5.3). In doing so, the best-performing characteristics help us understand what makes artwork relations interesting for art museum visitors, while simultaneously having immediate practical value for ranking identified relations on interestingness.

Sub-RQ 4. Which automatically identifiable artwork relation characteristics most accurately estimate the extent to which art museum visitors consider artwork relations to be interesting (as identified in RQ

1.2)?

1.2 Contributions

The contributions of this study are as follows:

1. We create a ground truth dataset on artwork relation interestingness based on 7894 interestingness ratings from 320 participants across a selection of 136 artwork relations (Section 6.1).
2. We present and evaluate various Wikidata-based artwork relation interestingness heuristics (Section 5).
3. We show the extent to which there is a consensus on the types of artwork relations that art museum visitors consider (un)interesting (Section 7.4).
4. We highlight several automatically identifiable artwork relation characteristics that help estimate the types of artwork relations art museum visitors consider to be interesting (Section 7.5).
5. We confirm the considerable potential for improving the art museum visitor's experience by explicitly identifying (interesting) artwork relations (Section 6.4).

1.3 Relevance for the field of AI

While the meaning of "interestingness" tends to be intuitive for people, the concept is inherently subjective and context-dependent, making it difficult for machines to interpret. By researching interestingness of artwork relations (for art museum visitors), we ground the interpretation of what is (un)interesting in empirical data, thereby furthering our understanding of what makes relationships interesting and contributing to the Knowledge Representation and Reasoning field of AI.

2 Related Work

2.1 Conventional interestingness measures

Measures of "interestingness" have been used in the context of data mining and/or knowledge discovery to estimate the interest in identified patterns for users exploring (large) databases. These measures have been shown to be useful for ranking and filtering long lists of identified results (Geng & Hamilton, 2006; Kontonasios et al., 2012; Mcgarry, 2005).

A distinction can be made between three types of interestingness measures: *objective* measures based on raw data, *subjective* measures based on raw data and the user, and *semantics-based* measures based on the semantics and explanations of identified patterns (Geng & Hamilton, 2006). In this study, we focus exclusively on objective measures that can estimate artwork relation interestingness for art museum visitors solely based on raw data, though we consider further research into subjective measures (taking the user into account) a desirable next step (see Section 8).

2.2 Empirically evaluating interestingness measures

Conventional interestingness measures do not necessarily measure "real human interest" (Ohsaki et al., 2004), but instead aim to *estimate* or *predict* it. As an example, eleven objective interestingness measures were shown to be good estimators for real human interest in only 35.2% of the cases (Carvalho et al., 2005). Furthermore, the performance of the selected measures varied considerably across different datasets (Carvalho et al., 2005), confirming earlier findings that there is no "one-size-fits-all" solution that performs well in all domains (Tan et al., 2002).

Empirical evaluations of interestingness measures have been conducted across various domains, such as the medical domain (Ohsaki et al., 2004), retail (Kirchgessner et al., 2016), and others (Carvalho et al., 2005). Given the visitor-centered nature of our research, it is of particular importance to ensure that the estimates of our proposed interestingness heuristic align well with what art museum visitors really consider to be interesting.

To create ground truth data, the studies mentioned above all recruited a (very) limited number of domain experts to rate identified rules or patterns on interestingness (Carvalho et al., 2005; Ohsaki et al., 2004; Kirchgessner et al., 2016). Since our targeted users were "regular" art museum visitors, we circumvented most of the pragmatic issues with finding expert users. In this sense, we took a similar approach to Harris et al. (2015), who used crowd-sourcing to retrieve interestingness rankings directly from (financial domain) users.

2.3 Artwork relation discovery and identification

One tool for relation discovery in Linked Data knowledge bases is *RelFinder* (Lohmann et al., 2010). RelFinder is domain-independent, and therefore capable of identifying artwork relations out of the box. Because of its domain-independence, however, it does not aim to exploit domain users' interests for ranking or filtering identified relations. *Explass* has similar aims as *RelFinder* and allows for exploratory search of associations between Semantic Web entities (Cheng et al., 2014). *Explass*, however, explicitly focuses on exploratory search as a complementary line of research to ranking, whereas we primarily focus on the latter as a data-driven approach for understanding what makes relations interesting.

Just as *RelFinder* (Lohmann et al., 2010), *Faceted Relator* (Hyvönen & Rantala, 2021) allows for faceted and interactive exploration and filtering of identified relations. We hypothesize, however, that this type of interaction is often too demanding for museum visitors. Instead, we aim to identify and understand museum visitors' domain-specific interests, which can be used to present only the most interesting relations between encountered artworks, minimizing the cognitive strain associated with interactively exploring identified results. In this sense, our motivation aligns more with the flat top-K list that *Explass* (Cheng et al., 2014) provides than the exploratory tools that surround it.

For domain-specific relation-finding, manually pre-defined ontological patterns can be used to prune obviously uninteresting results and allow for easy template-based generation of natural language texts (Hyvönen & Rantala, 2021; Lin & Lin, 2017). We used such an approach to create a selection of potentially interesting artwork relations for creating ground truth data on interestingness, (automatically) identifying relations based on a pre-defined selection of Wikidata properties we, together with a professional curator, considered likely to help identify interesting relations.

2.4 Interestingness of (artwork) relations for recommending purposes

Research on which semantic relations (e.g., teacherOf, birthPlace, hasStyle) were most useful for recommending artworks that were of interest to users of an "Art Recommender" system has much in common with our research (Wang et al., 2009). A key difference, however, is that we are looking back (i.e., identifying what is interesting for relations between encountered artworks) instead of looking forward (i.e., identifying what is interesting for recommending new works to users), which likely changes what users consider to be interesting and/or useful. As an example, it is generally not interesting to "learn" that two already encountered works visually look alike, but it could be of great interest to discover new artworks that visually look like a visitor's favorite works.

Outside of the cultural domain, trends in which related information users found most interesting while watching news on TV were identified (e.g., a general interest to learn more specifically about the people involved in events) (Pinzi, 2014).

To create ground truth data on which artwork relations were considered most interesting by visitors (Section 4), we took a somewhat similar approach as was used for *CultureSampo*, a cultural recommender system for which relevance predictions were empirically evaluated by comparing the system's recommendations with users' manually defined rankings (Ruotsalo & Hyvönen, 2007). We acknowledge their described difficulties when asking participants to order presented relations on interestingness, though we used a four-point interestingness scale instead of a binary ranking dichotomy.

3 Selecting 136 potentially interesting artwork relations

Before creating ground truth data on which artwork relations experiment participants considered to be interesting (Section 4), we first created a manageable list of example relations that represented the types of relations that could be manually or automatically identified between artworks.

Below, we describe a professional curator identifying artwork relations in a local art exhibition (Section 3.1), as well as how we automatically identified relations between those same artworks (Section 3.3). Then, to cover a more diverse range of relations, we used this relation-finding approach to automatically identify thousands of relations between a selection of 8364 Wikidata paintings (Section 3.4), after which we narrowed the list down to a final selection of 136 artwork relations we deemed potentially interesting (Section 3.6).

3.1 A curator manually identifying artwork relations within a local art exhibition

To obtain an impression of the various types of relations that could connect exhibited artworks to each other (RQ 1), we collaborated with Maia Kenney, a professional curator of a local exhibition on surrealism with hundreds of exhibited artworks. First, we asked Kenney to create a selection of 16 artworks (four per exhibition room) to represent the exhibition's curatorial narrative. Then, we asked her to manually identify potentially interesting relationships between the selected works, which resulted in a list of 24 artwork relations (Appendix I.1).

3.2 Creating a local art exhibition knowledge base using Wikidata

To automatically identify relations between the 16 selected case study artworks, we first saved the artworks and their respective creators in a small Linked Data knowledge base using Protégé, an easily available, "standard" ontology editor (Musen, 2015).

To maximize interoperability, we used the CIDOC Conceptual Reference Model (CIDOC-CRM) and Dublin Core (DC) Linked Data standards, after which we hosted the resulting knowledge base at a triplestore of the Dutch Digital Heritage Network (NDE).

After storing basic information such as the artwork's title (dc:title) and artists' names (foaf:givenName and foaf:familyName) in our knowledge base, we manually mapped each artwork and its respective creator to their corresponding Wikidata entities, creating new Wikidata entities for artworks or artists for which no information was available.

Finally, we queried (SPARQL query in Appendix J.1) Wikidata to retrieve all available information (e.g., an artwork's creation date, or an artist's work location) for the 16 artworks and 12 artists of our case study exhibition.

3.3 Automatically identifying artwork relations within a local art exhibition knowledge base

Within Linked Data knowledge graphs, great numbers of complex semantic associations can be identified to show how entities (e.g., artworks) are related. For scoping reasons, however, we specifically examined two types of straightforward ways in which artworks could relate to each other:

1. Artworks or artists[1] directly relating to other artworks or artists (e.g., one artist being a student of another artist).
2. Artworks or artists directly relating to the same Wikidata entity (e.g., two artworks both belonging to the same art-historical movement).

Throughout this study, we will refer to these types of straightforward relations as "1-hop" relations.

To identify these 1-hop relations (Table 1), we wrote a simple JavaScript script, though similar results could be retrieved directly through SPARQL queries (Heim et al., 2009).

Relation ID	**Entity #1**	**Entity #2**	**Property**	**Referred Entity**
afternoon-encounter-inception-1932	Afternoon (Q55420698) by Joop Moesman	Encounter (Q24061332) by Joop Moesman	inception (P571)	1932
encounter-la_joie_de_vivre-made_from_material-oil_paint	Encounter (Q24061332) by Joop Moesman	La Joie de vivre (Q27955492) by Max Ernst	made from material (P186)	oil paint (Q296955)
encounter-la_joie_de_vivre-made_from_material-canvas	Encounter (Q24061332) by Joop Moesman	La Joie de vivre (Q27955492) by Max Ernst	made from material (P186)	canvas (Q12321255)
moesman-magritte-instance_of-human	Joop Moesman (Q4040804)	René Magritte (Q7836)	instance of (P31)	human (Q5)
magritte-dalí-movement-surrealism	René Magritte (Q7836)	Salvador Dalí (Q5577)	movement (P135)	surrealism (Q39427)
magritte-dalí-manner_of_death-natural_causes	René Magritte (Q7836)	Salvador Dalí (Q5577)	manner of death (P1196)	natural causes (Q3739104)
ernst-unmarried_partner-fini	Max Ernst (Q154842)	-	unmarried partner (P451)	Leonor Fini (Q464011)
ernst-spouse-tanning	Max Ernst (Q154842)	-	spouse (P26)	Dorothea Tanning (Q234324)
ernst-fini-place_of_death-paris	Max Ernst (Q154842)	Leonor Fini (Q464011)	place of death (P20)	Paris (Q90)
...	...	...	...	...

Table 1: Examples of automatically identified 1-hop relations within the local art exhibition knowledge base. Two types of relations were identified: relations in which artworks or artists referred to the same entity, or directly to each other.

[1] Technically speaking, an "artist relation" is a (slightly) more complex semantic association than direct relations between artworks. In this context, however, we consider the ties between an artwork and the artist that created it significant enough to refer to artist relations simply as artwork relations.

3.4 Expanding the artwork knowledge base to identify more diverse relations

The relations identified between our 16 case study artworks (Section 3.3) gave a first glimpse into the types of artwork relations that could automatically be identified using Wikidata. However, the list was far from exhaustive, and did not properly represent the various types of relations that could be identified between artworks. To represent a wider range of artwork relations, we expanded our knowledge base of 16 artworks with 8364 unique artworks retrieved from Wikidata, allowing for a more diverse set of relations to be automatically identified in addition to Kenney's manually defined ones.

Specifically, we added to our knowledge base Wikidata *paintings* (*instance of* [P31[2]] *painting* [Q3305213]) that were considered a *notable work* (P800) of their *creator* (P170), and had an *image* (P18) available (SPARQL query in Appendix J.2). The choice to query specifically for paintings was made to match the 16 selected artworks by Kenney (which were all paintings), but was otherwise mostly arbitrary. We required paintings to be *notable works* (P800) to keep the number of artworks to find relations between manageable, while maximizing the likelihood of diverse metadata to be available for these artworks (assuming more metadata to typically be available for notable works than for others). Finally, we queried for artworks for which images were available to give participants in our online experiment for creating ground truth data on artwork relation interestingness (Section 4) a visual impression of what the works looked like.

3.5 Selecting 75 potentially interesting Wikidata properties for relation identification

After significantly expanding our knowledge base (Section 3.4), thousands of diverse artwork relations were automatically identified. We, together with Kenney, considered many of these relations unlikely to be of interest for art museum visitors, however, requiring us to find ways for creating a (more manageable) list of potentially interesting artwork relations.

Collaborating with Kenney, we independently made a selection of artwork and artist Wikidata properties that we believed could be used to identify potentially interesting artwork relations. For our final selection of 33 artwork and 42 artist Wikidata properties (Appendix H), we included all properties that we both agreed on, and examined the remaining properties on a case-by-case basis.

3.6 Selecting 136 potentially interesting artwork relations (of which 112 based on 75 potentially interesting Wikidata properties)

To investigate which types of artwork relations experiment participants considered most interesting (Section 4), we created a concise yet representative list of relations that covered most ways in which artworks could directly relate to each other.

Of all relations identified between the artworks in our knowledge base, we discarded all that were not based on one of the 75 potentially interesting Wikidata properties selected in Section 3.5. For many of the 75 properties, this resulted in multiple relations to choose from.

For properties for which more than one relation was identified, we initially included just the first available one. When an included relation referred to artworks or artists that were already referred to in other relations, we automatically replaced them by an alternative if available, to ensure a more diverse dataset.

To represent properties for which initially no relations were found in our knowledge base, some relations were manually identified using Wikidata. For these properties, we queried Wikidata to determine

[2]To improve readability, we exclude the wdt (http://www.wikidata.org/prop/direct/) and wd (http://www.wikidata.org/entity/) prefixes for Wikidata properties and entities respectively throughout this study.

if relations for the property existed between artworks or artists that were previously excluded from our knowledge base, such as artworks that were not a *notable work* (P800) of their creator, or had no *image* (P18) available on Wikidata. If this was the case, then we manually added these artworks or artists to our knowledge base, allowing for new relations to be identified for the property.

For the artworks for which no *image* (P18) was available on Wikidata, we manually retrieved the image files from museum websites or other online resources, and linked to them in our knowledge base.

For some properties such as *price* (P2284) or *coordinates of the point of view* (P1259), we needed to find approximate matches (e.g., artworks that sold for *approximately* the same price), which our system could not yet automatically identify. Since this only concerned a couple of properties, we did not update our application to automatically identify these relations. Instead, we queried Wikidata to find these relations manually and labeled them as "automatically identified".

After having selected one relation for each of the 75 Wikidata properties, we included additional relations for some properties. For instance, for the *manner of death* property (P1196) we included three relations referring to *natural causes* (Q3739104), *accident* (Q171558) and *suicide* (Q10737). Typically, these relations were added to later test specific hypotheses on which relations visitors would find most interesting, such as comparing common and rare values for a given property.

After adding these additional relations, we ended up with a selection of 112 potentially interesting automatically identified relations. Besides these 112, we included Kenney's 24 manually defined relations (Section 3.1), which were typically more complex, interpretative, and/or storylike, and would allow us to later compare qualitative feedback between these "richer" artwork relations and the automatically identified ones.

4 Creating ground truth data on artwork relation interestingness

Having selected a list of 136 potentially interesting artwork relations (Section 3.6), we created ground truth data on the extent to which participants of our experiment were interested in each of the selected relations.

Below, we describe the experiment through which we gathered this data, as well as the participants that successfully finished the experiment. The experiment ran for 20 days (February 18th - March 9th, 2021), during which a total of 320 participants successfully finished the experiment.

4.1 Participants

4.1.1 Sampling process

We used convenience sampling to recruit participants, sharing the experiment on our personal social media accounts (LinkedIn, Facebook and Twitter), Reddit (/r/SampleSize), and the newsletter, website and social media platforms of the Dutch Digital Heritage Network (NDE).

No compensations were given to the participants besides the gratitude of the researcher. A distribution of how participants heard about the experiment is shown in Appendix F.

4.1.2 Demographics

Age, gender, education 82% (263 out of 320) of the participants were between 18 and 34 years old (Figure 2). 175 of the participants identified as female, 129 as male, 10 as non-binary and 6 did not

answer.

The participants' highest completed education is visualized in Figure 3.

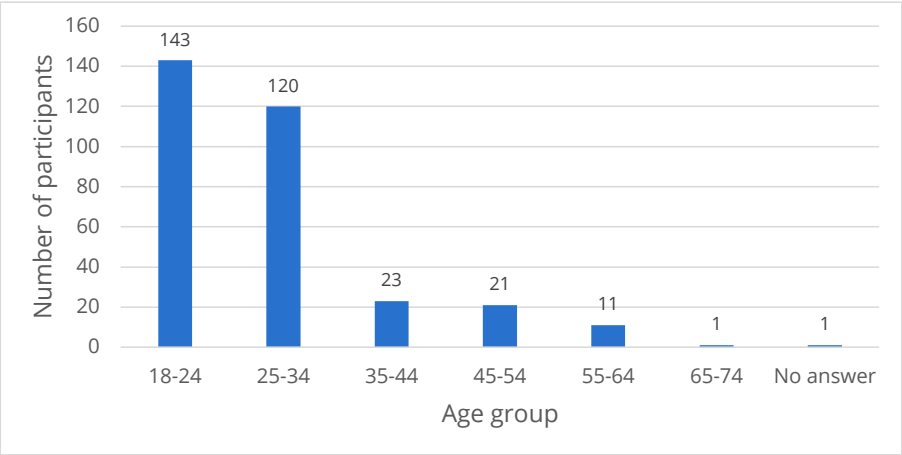


Figure 2: Age groups of 320 participants. 82% (263 out of 320) were between 18 and 34 years old.

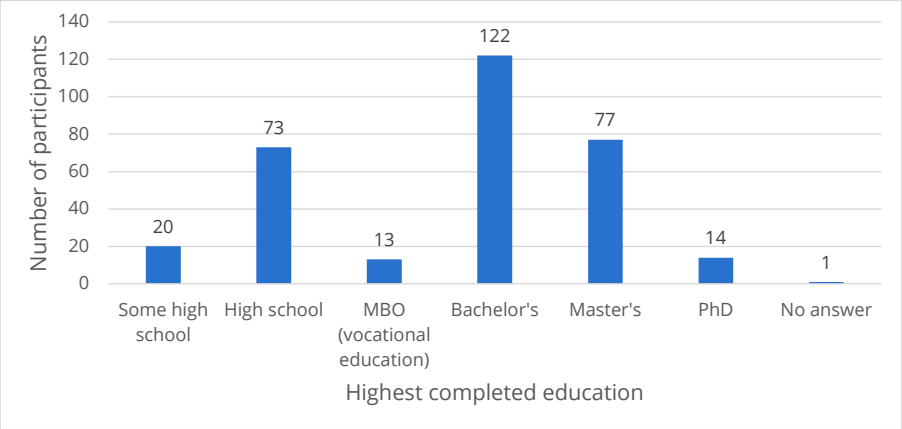


Figure 3: Highest completed education of 320 participants.

Platform used 63% (202) of the participants participated on a mobile device, and 37% (118) on a desktop device.

Art and Art Museum Interest To measure participants' interest in art and art museums (Appendix E), we included three (slightly adapted) questions from the Vienna Art Interest and Art Knowledge Questionnaire, which was developed to measure art interest and knowledge (Specker et al., 2020).

Art-historical Knowledge Participants' self-reported art-historical knowledge was measured on a five-point scale, ranging from *Very poor* to *Very good* (Figure 4).

Museum Visit Motivation To get an impression of participants' motivations for visiting museums (Figure 5), we used descriptions of the five museum-specific identities (i.e., explorer, facilitator, experience seeker, professional/hobbyist, recharger) by Falk (2006). Participants were asked to pick one of the following descriptions that matched their art museum visiting motivations best:

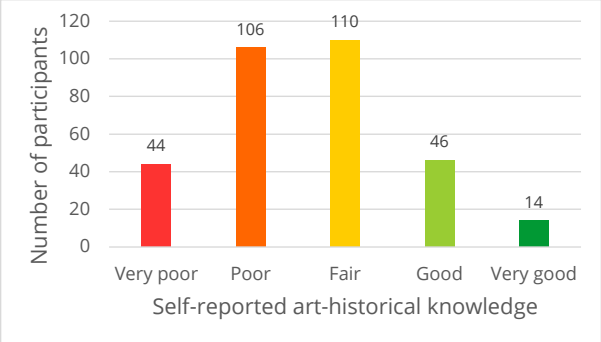


Figure 4: Self-reported knowledge of art history of 320 participants.

1. **Curiosity-driven:** When visiting art museums, I expect to find something that will grab my attention and fuel my learning.
2. **Socially motivated:** My main focus when visiting art museums is to enable the experience and learning of others.
3. **Professional or hobbyist:** I feel a close tie between the art museum's content and my personal passions. I usually have a specific goal in mind when I visit a museum.
4. **Experience-driven:** I usually visit art museums because I perceive them as an important destination. My main satisfaction derives from the fact of having "been there and done that".
5. **Restorative:** The art museum is a place to unwind for me, while being surrounded by inspiring and beautiful things.

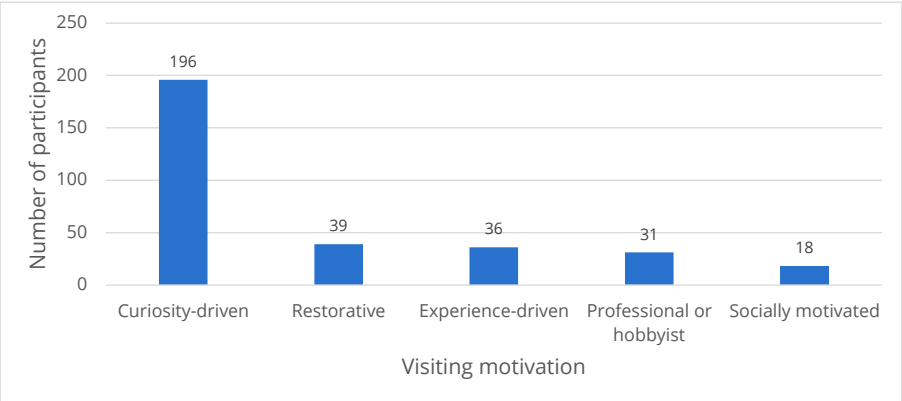


Figure 5: Art museum visiting motivation of 320 participants. The majority of our participants (61%) were curiosity-driven.

4.2 Materials

To conduct the experiment, we developed a custom web application using Angular (a widely used web development framework) and Ionic (a front-end framework). To host the website and save the results of participants remotely, Google Firebase was used, which is an online development platform offering (initially free) database and hosting functionalities.

Participants used their personal mobile or desktop devices to participate in the experiment remotely, so

an internet connection was required.

4.3 Procedure

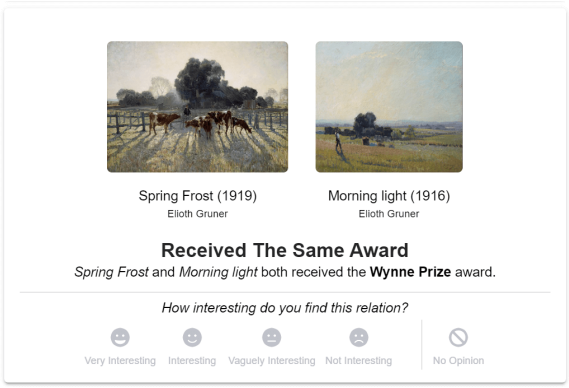
Assigning participant groups. As asking participants to rate all 136 relations would be infeasible time-wise, upon opening the experiment, participants were automatically placed in one of 11 participant groups that determined which artwork relations they would rate. The assignment of participant groups was based on the participant's incrementally assigned numerical ID, meaning that the first and twelfth participants were placed in the first group, and the second and thirteenth in the second group. During initial testing, we found that the experiment took about 10 to 15 minutes to complete when asking participants to rate a selection of 25 relations, which seemed a reasonable time commitment to ask for. As 136 was not divisible by a single number near 25, depending on the participant group, participants were presented with either 24, 25 or 26 relations (Appendix G).

Experiment introduction and consent form. First, participants were welcomed with a brief introduction of the experiment, which described how long the experiment would take, as well as the experiment's purpose and a brief overview of the experimental procedure (Appendix B.1). Then, participants were asked to sign a consent form, ensuring that they agreed to voluntarily participate, and were aware of the experiment's nature and purpose (Appendix B.2).

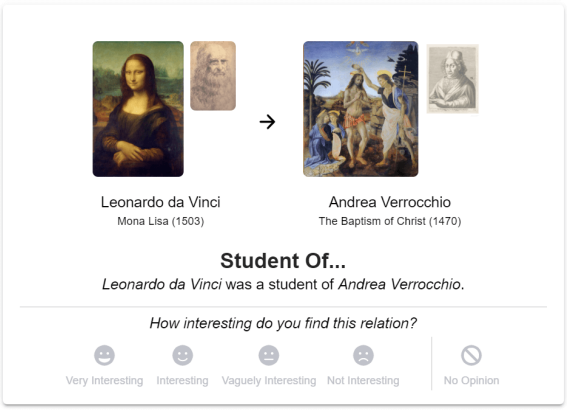
Demographics survey. After signing the consent form, participants were asked several questions concerning their age, gender, education, art-historical knowledge, museum visiting motivations, and general museum and art interest (Appendix B.3).

4.3.1 Rating artwork relations on interestingness

The core of the experiment consisted of rating 24, 25 or 26 artwork relations on interestingness, presented in a random order (Appendix B.4). For artworks or artists directly referring to other artworks or artists,



(a) Example of a relation between artworks that participants were asked to rate on interestingness.



(b) Example of a relation between artists that participants were asked to rate on interestingness. For artist relations, a small picture of the artist was shown next to the artwork's image. For relations in which artworks or artists directly referred to other artworks or artists, a small arrow was shown to indicate direction.

Figure 6: Two example relations that participants were asked to rate on interestingness.

a small arrow was shown to indicate the direction of the relationship (Figure 6b). When relations referred

to artists, a small[3] image of the artist was shown next to the artwork's image if available (Figure 6b), which was omitted when referring to artworks (Figure 6a).

The titles and descriptions for automatically identified relations were generated based on natural language templates. JSON dictionaries were used to map Wikidata properties to their corresponding templates, which were filled using JavaScript. As an example, relations based on the *award received* (P166) property were mapped to the title *"Received the same award"* and the HTML description template `<em>[first_compared_entity_name]</em> and <em>[second_compared_entity_name]</em> both received the <strong>[referred_entity]</strong> award.`

As the presented relations were pre-selected to be potentially interesting (Section 3.5), we opted for an unbalanced rating scale that allowed us to capture more nuance on the "interesting" side of the scale, and allowed participants to rate each relation as either "Very Interesting", "Interesting", "Vaguely Interesting", "Not Interesting", or "No Opinion".

4.3.2 Sharing qualitative comments on reasons for finding artwork relations interesting

After rating the presented artwork relations on interestingness, participants were asked which types of art relations they generally found most interesting.

Then, (at most) four relations that participants rated to be either "Very Interesting" or "Interesting" were again presented, after which we asked participants to elaborate on why they considered these specific relations to be interesting (Appendix B.5). When (automatically) selecting these relations, relations rated as "Very Interesting" were prioritized, meaning that relations rated as "Interesting" were only selected if participants rated fewer than four relations as "Very Interesting". If participants did not rate any relation as "Very Interesting" or "Interesting", participants were allowed to skip this section.

After elaborating on interests in (at most) four specific artwork relations, participants could indicate to what extent a smartphone application that could identify artwork relations such as the ones they had seen during the experiment would improve their art museum visiting experience.

Finally, participants could share any remaining comments, questions or thoughts regarding the experiment, after which the experiment was completed, and attributions for manually retrieved artwork or artist images were shown (Appendix B.6).

5 Understanding artwork relation interestingness based on Wikidata metadata

Having created ground truth data on artwork relation interestingness (Section 4), we used a data-driven approach to better understand the artwork relation characteristics that best estimated what participants considered to be interesting. To do this, we first retrieved Wikidata metadata for all automatically identified artwork relations and the Wikidata entities they referred to. Based on this metadata, we created various artwork relation interestingness heuristics, which we evaluated by comparing the heuristics' ranking performance with our ground truth data. Finally, to gain further insights into participants' reasons for finding relations interesting, we manually coded qualitative feedback on artwork relation interests.

[3]Since we targeted art museum visitors, we deliberately kept artist images relatively small compared to artwork images, as we considered the artworks to be an important visual clue to reconcile digitally presented information with the physical exhibition space.

5.1 Retrieving artwork relations' referred Wikidata classes for estimating artwork relation interestingness

Different artwork relations referred to different entities that were associated with different Wikidata classes. We hypothesized that participants on average might consider some of these referred Wikidata classes to be more interesting than others (e.g., artwork relations referring to *people* on average being more interesting than relations referring to *places*).

To be able to test this hypothesis (Section 6.3), we queried Wikidata to find the *instance of* (P31) classes and *subclasses* (P279) of the referred entities of our selection of 112 automatically identified artwork relations, as well as the *subclasses* (P279) thereof up to four levels deep (SPARQL query in Appendix J.3).

As an example, the relation "these two artists were both students of Leonardo da Vinci" referred to *Leonardo da Vinci* (Q762), which on Wikidata was an *instance of* (P31) *human* (Q5), which in turn was a *subclass of* (P279) *person* (Q215627). In this sense, this relation referred both to the Wikidata classes *human* and *person*, while another relation might refer to a *country* (e.g., a relation describing two artworks that were created in Italy) or a *museum* (e.g., a relation describing two artworks that were exhibited at the Louvre Museum).

After identifying the 609 unique referred Wikidata classes across all 112 automatically identified artwork relations, we saved them as dummy variables for each relation in a CSV file (Table 2).

Relation	**"park" (Q22698)**	**"location" (Q17334923)**	**"human" (Q5)**	**"painting" (Q3305213)**	**...**
Same location of the point of view: Pincian Hill	**TRUE**	**TRUE**	FALSE	FALSE	...
Same place of birth: Breda	FALSE	**TRUE**	FALSE	FALSE	
Same sitter: Emma Hill	FALSE	FALSE	**TRUE**	FALSE	...
Student of: Leonardo da Vinci → Andrea Verrocchio	FALSE	FALSE	**TRUE**	FALSE	...
Inspired by: Luncheon on the Grass → The Tempest	FALSE	FALSE	FALSE	**TRUE**	...
Same medical condition: Deafness	FALSE	FALSE	FALSE	FALSE	...
...	...		...	...	...

Table 2: Examples of artwork relations' referred Wikidata classes, which were stored as dummy variables in a CSV file.

5.2 Retrieving five Wikidata-based numerical variables for estimating artwork relation interestingness

In addition to using relations' referred Wikidata classes for estimating artwork relation interestingness (Section 5.1), we calculated five Wikidata-based numerical variables that we considered might help estimate which artwork relations participants considered to be interesting. We selected these variables to be both intuitive to interpret as well as easily retrievable.

We calculated the variables using six numerical variables retrieved from Wikidata, and one from Wikipedia:

1. **Total number of artworks.** In our dataset, the total number of paintings on Wikidata. At the time of retrieval, this was 457,088 paintings.

2. **Total number of artists.** In our dataset, the total number of people that created at least one painting on Wikidata. At the time of retrieval, this was 45,215 people.

3. **Property count.** The number of artworks or artists described using the Wikidata property that a relation was based on. As an example, the relation "these two artworks were both located in Belgium" was based on the *location* (P276) property, which was used to describe 417,996 out of all 457,088 Wikidata paintings. For this relation, therefore, the "Property count" was 417,996. An example of a relatively low "Property Count" would be the relation showing that two artworks were created from the same *point of view* (P7108), as this property was used to describe only 23 of all 457,088 Wikidata paintings (i.e., a "Property Count" of 23).

4. **Referred entity count for property.** The number of artworks or artists that referred to the entity that a relation referred to, using the property that a relation was based on. As an example, the artwork relation "these two artworks were both created using oil paint as a material" referred to the *oil paint* entity (Q296955). Of all 271,822 artworks for which the *material used* (P186) was known, 247,333 referred to *oil paint*, meaning that the "Referred entity count for property" for this relation was 247,333. An example of a relatively low "Referred entity count for property" would be the relation showing that two artworks were created from the same point of view: *Pincian Hill* (Q550215). Out of the 23 artworks for which the *location of the point of view* (P7108) property was known, only two referred to *Pincian Hill* (i.e., a "Referred entity count for property" of two).

5. **Compared entities incoming edges.** The summed number of incoming Wikidata edges for the artworks or artists that the relation compared.

6. **Compared entities outgoing edges.** The summed number of outgoing Wikidata edges for the artworks or artists that the relation compared.

7. **Compared entities Wikipedia pageviews.** The summed average daily pageviews over the last 30 days for the Wikipedia pages describing the artworks or artists that the relation compared. To retrieve these numbers, we used the Python library *WikiMapper*[4] to map Wikidata IDs to their corresponding Wikipedia pages, and the *Wikimedia Pageview API*[5] to retrieve the number of pageviews. All entities for which no corresponding Wikipedia page could be found were saved as if having 0 pageviews.

Using the numbers described above, we calculated the following five variables that we considered might help to estimate artwork relation interestingness:

1. **Property commonness** = Property count / Total number of artworks or artists. As seen in the example described earlier, the *location of the point of view* (P7108) property was only used to describe a fraction of all Wikidata paintings, meaning it had a low "Property commonness" value of 23/457,088 = 0.005%.

2. **Referred entity commonness for property** = Referred entity count for property / Property count. As seen in the example described earlier, of all 23 artworks that were annotated with the *location of the point of view* (P7108) property, two referred to *Pincian Hill*, giving this relation a "Referred entity commonness for property" of 2/23 = 8.7%

3. **Referred entity commonness** = Referred entity count for property / Total number of artworks and artists in dataset. This is a similar measure to "Referred entity commonness for property", but focusing solely on the commonness of the referred entity and disregarding the commonness of the property itself. Following the example described earlier, the "Referred entity commonness" would be 2/457,088=0.0004%

4. **Compared entities Wikipedia pageviews.** As described above.

5. **Compared entities edges count** = (Compared entities incoming edges + Compared entities outgoing edges) / Total number of artworks or artists. This is an alternative measure to "Compared entities Wikipedia pageviews", aiming to approximate an artwork or artist's popularity by measuring the (relative) numbers of incoming and outgoing edges to and from the artwork or artists that a relation compares.

[4]https://github.com/jcklie/wikimapper
[5]https://pypi.org/project/pageviewapi

5.3 Evaluating the performance of artwork relation interestingness heuristics based on Wikidata metadata

After having retrieved hundreds of categorical (Section 5.1) and five numerical (Section 5.2) variables from Wikidata for each of the 112 automatically identified relations, we researched which variables performed best for estimating the extent to which participants considered relations to be interesting. We did this by comparing relation rankings of many "interestingness heuristics" with our ground truth data, with each heuristic sorting the list of 112 artwork relations on at least one variable, and then alphabetically. As an example, one heuristic might assume relations referring to people to be considered interesting by participants, and therefore sort relations first on if they referred to the *human* Wikidata class (Q5), and then alphabetically. An example of a more complex heuristic could for instance sort first on "Property commonness", then on relations *not* referring to the *location* Wikidata class (Q17334923), and then alphabetically.

To evaluate the heuristics' performance, we calculated the Kendall tau rank distance for each heuristic, mostly because of its intuitive interpretation. To do this, we counted the (normalized) number of discordant pairs between the resulting ranked relation lists for each heuristic and the relation ranking based on our ground truth data (Section 4).

Since including higher numbers of variables lead to both a combinatorial explosion as well as diminishing returns, we evaluated heuristics including up to four variables. To further limit the computational demands of evaluating exponentially growing numbers of variable combinations, for heuristics including three variables, we evaluated a selection of the best-performing variables of 2-variable heuristics, and for heuristics including four variables, we evaluated a selection of the best-performing variables of 3-variable heuristics.

5.4 Coding qualitative comments on artwork relation interests

To gain additional insights into artwork relation interestingness, we manually coded 219 qualitative comments on the types of artwork relations our experiment's participants shared to find interesting, and similarly coded participants' shared reasons for finding the top 10 highest rated relations interesting. To do this, we examined the lists of comments in multiple passes, creating new categories based on encountered comments, and iteratively labeling previously encountered comments with newly created categories in each pass.

6 Results

We first describe the quantitative ground truth data we created on artwork relation interestingness for our experiment's participants, as well as the qualitative feedback we gathered on the same topic. Then, we present the performance of all evaluated interestingness heuristics, including the (combinations of) categorical (i.e., referred Wikidata classes) and numerical variables that best helped estimate participants' artwork relation interestingness ratings. Lastly, we report the self-reported museum experience impact of allowing participants to identify (interesting) artwork relations while visiting.

6.1 Ground truth data on artwork relation interestingness

In total, we gathered 7894 interestingness ratings across 136 artwork relations, from 320 participants (Figure 7). In the results presented below, all 135 "No Opinion" ratings were discarded.

To visualize the absolute average interestingness ratings for each of the 136 artwork relations (Figure 8) and for all 320 participants (Figure 9), categorical interestingness ratings were first mapped to numerical values (Not Interesting = 1, Vaguely Interesting = 2, Interesting = 3, Very Interesting = 4). The unique

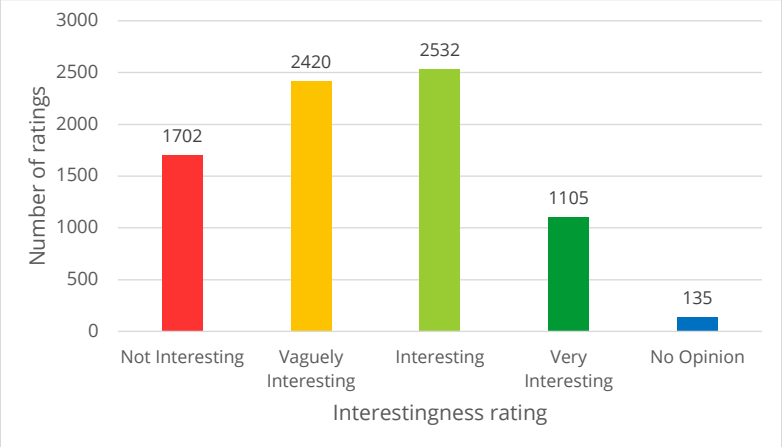
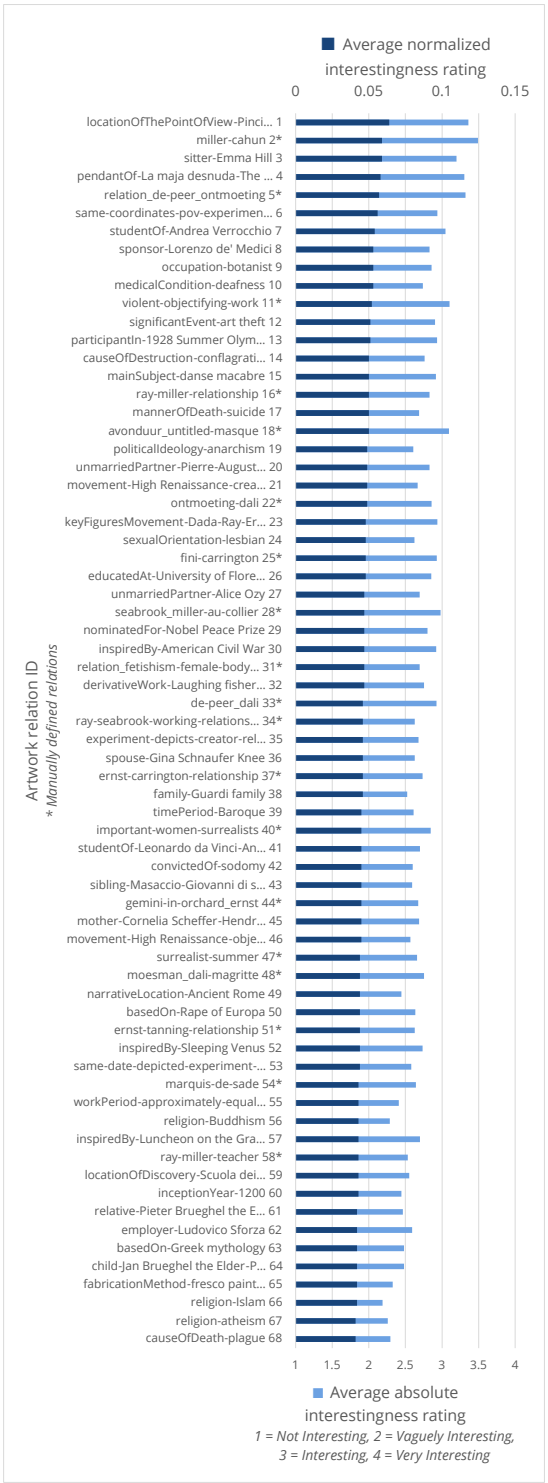


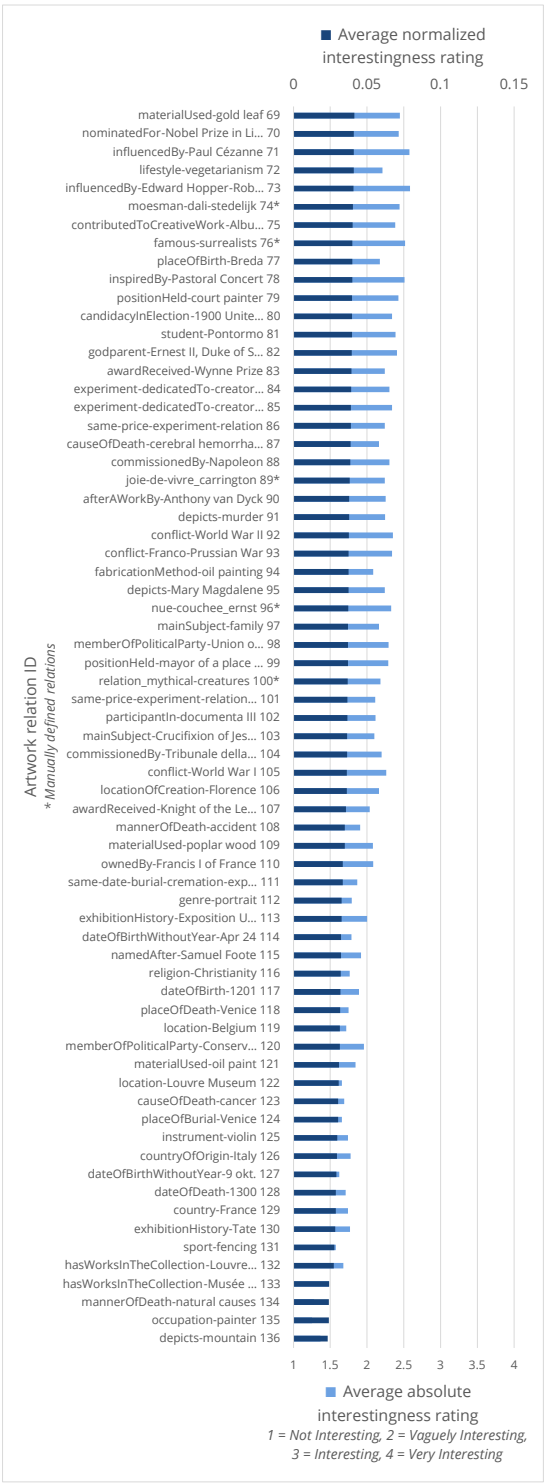
Figure 7: Distribution of 7894 interestingness ratings across 136 artwork relations, from 320 participants. For the ground truth dataset, all "No Opinion" ratings were discarded.

IDs and presented descriptions of the relations can be found in Appendix I.

As some participants were generally more critical or interested than others, we normalized all participant ratings to measure only relative differences between participants (Figure 9). For participants (Figure 9), results were sorted on average absolute ratings to highlight initial individual differences (i.e., some participants finding nearly all relations interesting, others finding nearly all relations uninteresting). For relations (Figure 8), results were sorted on average normalized ratings, which are the ratings considered ground truth. Normalization was done after removing "No Opinion" ratings, meaning that for participants who gave many "No Opinion" ratings, fewer artwork relation ratings were included. The normalized ratings for relations that these participants rated were, therefore, relatively higher, which is why normalized ratings are non-uniform (Figure 9).



(a) Ground truth interestingness ratings for artwork relations #1 - #68.



(b) Ground truth interestingness ratings for artwork relations #69 - #136.

Figure 8: Ground truth interestingness ratings by 320 participants for 136 selected artwork relations, of which 112 automatically identified, and 24 manually defined by a professional curator. Results are sorted on normalized ratings, which are considered ground truth. Bars are shown overlapping, not stacked.

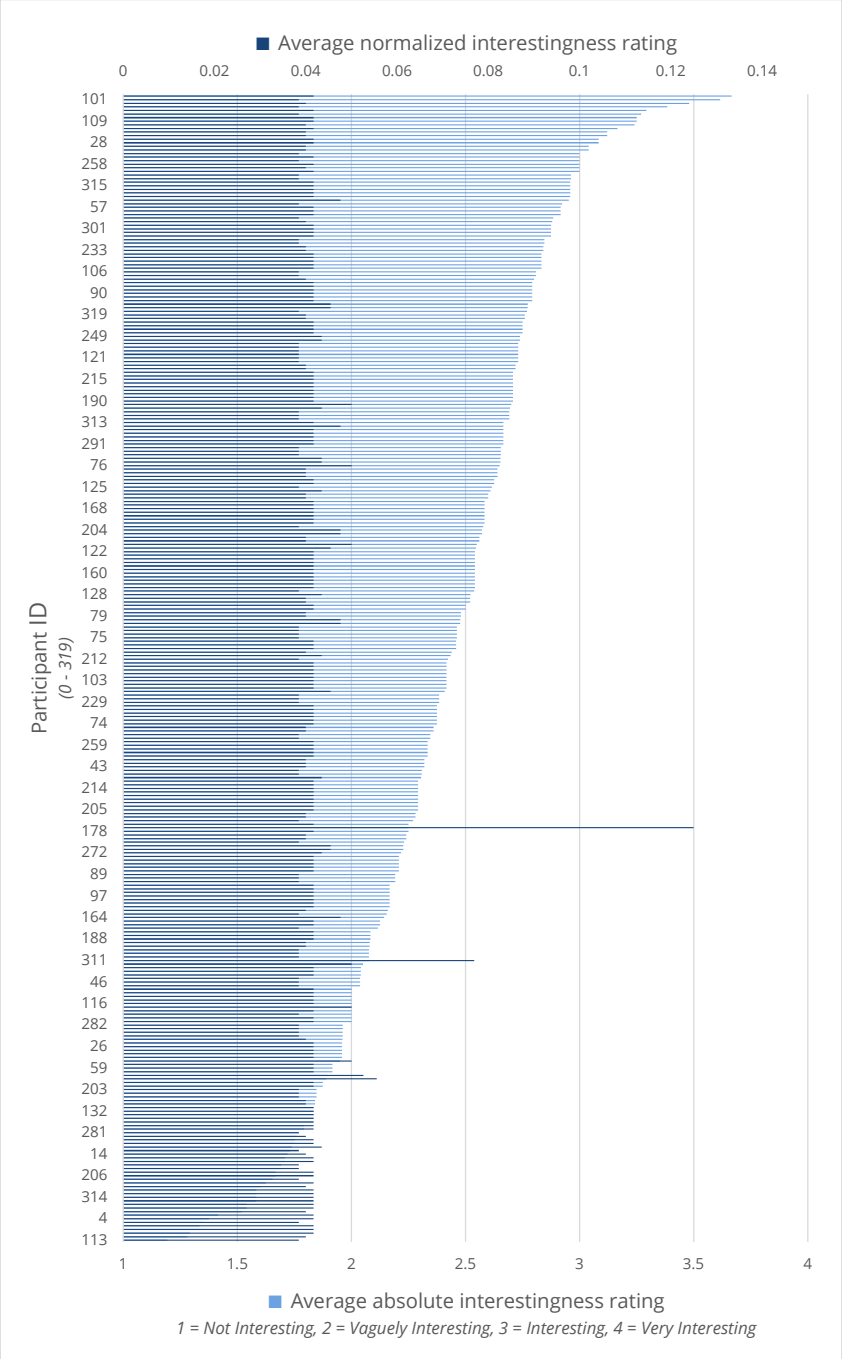


Figure 9: Average artwork relation interestingness ratings for 320 participants. Participants rated a selection of 24, 25 or 26 relations. Results are sorted on absolute average ratings, to highlight initial differences between participants (i.e., some finding nearly all relations interesting, others finding nearly all uninteresting). Normalized ratings are non-uniform because normalization was done after discarding "No Opinion" ratings; relatively high normalized participant ratings typically reflected participants giving many "No Opinion" ratings. Bars are shown overlapping, not stacked.

6.2 Qualitative comments on artwork relation interestingness

Below, we describe qualitative comments on the types of artwork relations that participants generally considered to be interesting, as well as participants' shared reasons for finding the top 10 highest rated relations interesting.

6.2.1 Reasons for finding types of artwork relations interesting

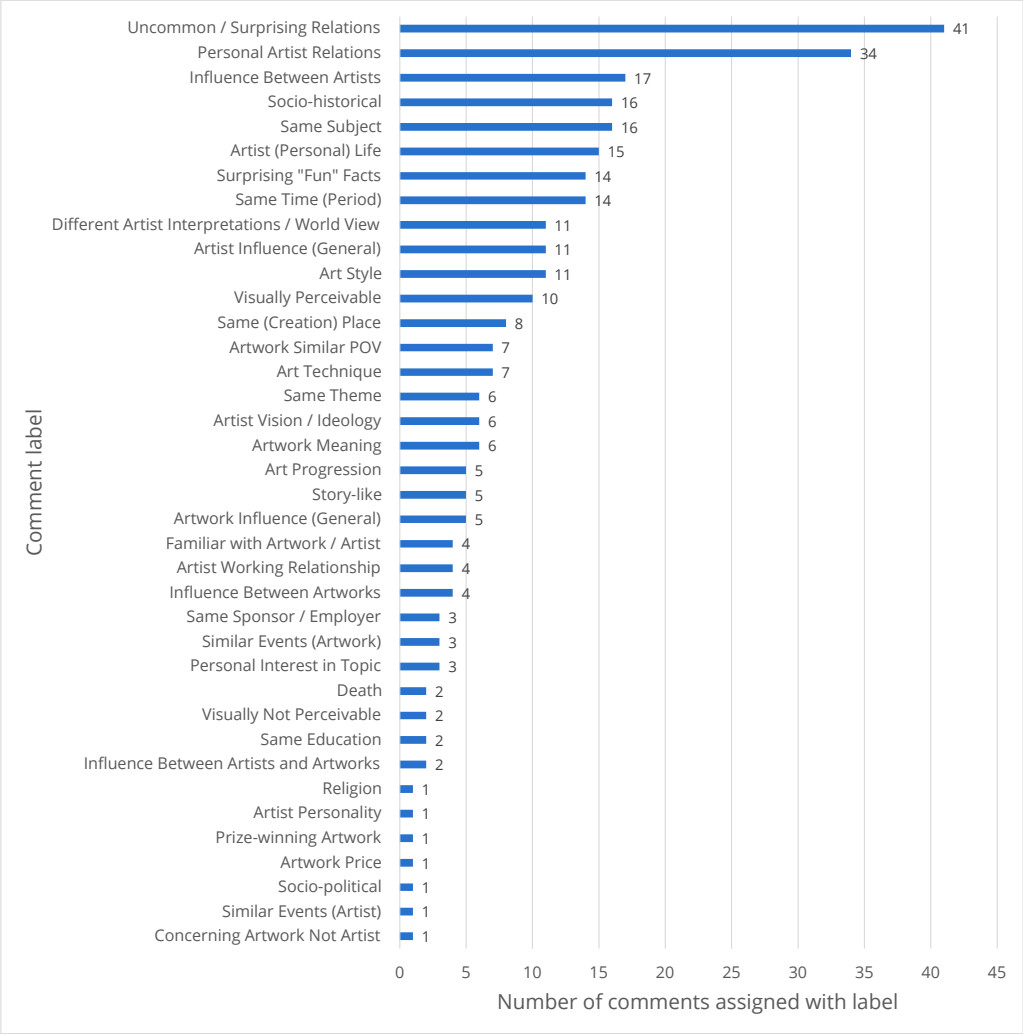


Figure 10: Coded qualitative comments on types of artwork relations considered interesting by 320 participants. The two topics recurring most often were relations being considered interesting because they were uncommon or surprising, or because they described personal relationships between artists.

Two topics specifically stood out for qualitative comments on the types of artwork relations considered to be interesting by participants (Figure 10), namely an interest in unexpected (i.e., uncommon and/or surprising) artwork relations, as well as in personal artist relations.

Out of 219 comments, 41 referred to an interest in unexpected relations. Examples are:

- "*[Relations that w]ere unexpected/not obvious (e.g. you can tell if artworks are both oil paintings, the vast majority of famous painting[s] are, so it's not interesting)*"

Relation ID	Labels for finding relation interesting
#1. Same location of point of view: Pincian Hill	- Helps to understand the artists' perspective through the artworks - Helps to understand the world
#2. Miller and Cahun	- Helps to understand the artists' perspective - Helps to understand the artworks through the artists - Helps to understand the world
#3. Same sitter: Emma Hill	- Helps to understand the artists' perspective - Helps to understand the artworks through the artists - Is unexpected
#4. Pendant of: La maja desnuda → The Clothed Maja	- Helps to understand the artists' perspective through the artworks - Helps to understand the artworks by comparing them - Is visually perceivable
#5. Color change: Ontmoeting and De Peer	- Helps to understand the artists' perspective through the artworks - Helps to understand the artworks through the artists - Helps to understand the world - Has a story element - Is visually perceivable
#6. Approximately same point of view	- Helps to understand the artists' perspective through the artworks - Helps to understand the world
#7. Student of: da Vinci → Verrocchio	- Helps to understand the artists' perspective - Helps to understand the artworks through the artists - Describes a popular artist
#8. Same sponsor: Lorenzo de' Medici	- Helps to understand the sponsor's perspective - Helps to understand the artworks through the sponsor - Is unexpected
#9. Same occupation: Botanist	- Helps to understand the artworks through the artists - Is unexpected
#10. Same medical condition: Deafness	- Helps to understand the artists' perspective - Helps to understand the artworks through the artists - Is unexpected

Table 3: Coded qualitative reasons for participants finding the top 10 highest rated artwork relations interesting. For these relations, participants were mostly interested in better understanding presented artworks, the artists that created them, or the world in which they were created. Additionally, the unexpectedness of relations was considered interesting for four out of the ten relations.

- "*It is a relation that surprises me*"
- "*When the relation was not obvious, or something I didn't already know*"

34 (out of 219) comments referred to an interest in personal artist relations. Examples are:

- "*I find connections between the people who created the artwork most interesting, compared to connections between the artwork[s] itself [sic]. It helps to humanize them.*"
- "*Personal relationships, whether romantic or professional, were something I'd gloss over. As a result, many were surprising!*"
- "*Connected the artists/pieces on a personal, human level: either between each other or to me.*"
- "*I found relations dealing with personal aspects more interesting, such as dark stories about inspiration or family ties. [...]*"

An interest in personal artist relations was additionally reflected in feedback on why participants considered several highly rated relations to be interesting. Examples of this were comments such as "*I like knowing about [artists' personal] lives*" for the second highest rated relation (i.e., Miller and Cahun knowing each other and exploring the female body from a unique point of view), or "*These two artists*

had an intimate relationship. It is interesting to compare their works. [...]" for the sixteenth highest rated relation (i.e., Ray being Miller's teacher and employer while they were in a relationship).

An interest in unexpected relations was similarly reflected in comments on specific highly rated artwork relations, examples being "*I had no idea da Vinci was a botanist*" for the ninth highest rated relation (i.e., two artists both active as a botanist), and "*It's something relatively uncommon that connects these two men.*" for the tenth highest rated relation (i.e., two artists both being deaf).

6.2.2 Reasons for finding the top 10 highest rated artwork relations interesting

We recognized various high-level reasons for finding the top 10 highest rated relations interesting (Table 3). Example comments reflecting each of these reasons for all ten artwork relations are listed in Appendix C.

6.3 Performance of artwork relation interestingness heuristics based on Wikidata metadata

Below, we present the performance of all evaluated Wikidata-based interestingness heuristics for estimating the extent to which participants considered artwork relations to be interesting.

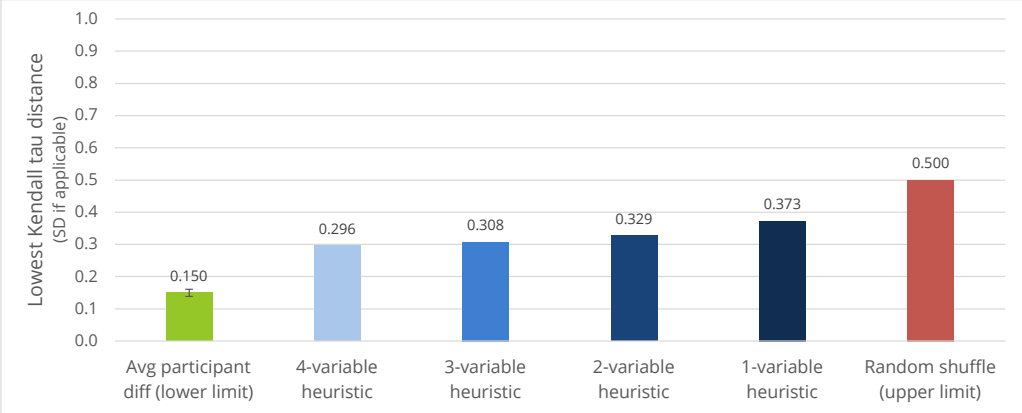
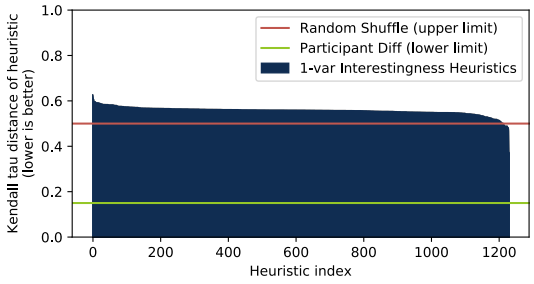


Figure 11: Performance (lowest achieved Kendall tau distance) of best-performing evaluated 1-variable, 2-variable, 3-variable and 4-variable artwork relation interestingness heuristics for estimating the extent to which participants considered relations to be interesting.

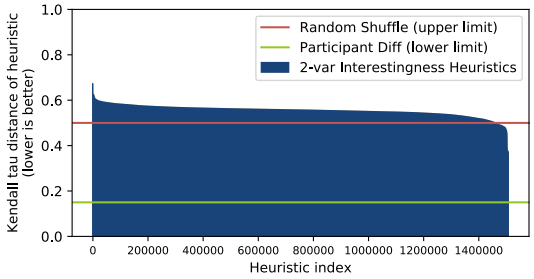
Relation rankings for each heuristic were compared with our ground truth data using the Kendall tau rank distance as a performance metric. A Kendall tau distance of 0 indicates that two ranked lists are completely identical, whereas a distance of 1 indicates complete disagreement.

A baseline heuristic sorting relations randomly (Kendall tau distance of 0.5) served as the upper limit of heuristic performance. Sorting relations alphabetically resulted in a Kendall tau distance of 0.56 in our dataset, or 0.44 when sorting in reverse (Z-A).

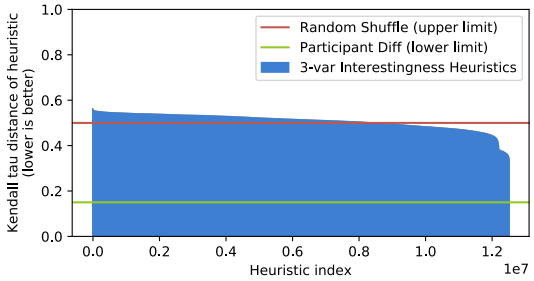
To determine a lower limit of heuristic performance, we wrote a Python script to split up participants in random halves 10,000 times, and repeatedly compared the resulting relation rankings of the two halves. On average, the Kendall tau distance between these randomly split participant groups was 0.150 across the entire dataset (SD=0.011, 7759 ratings after removing "No Opinion" ratings).



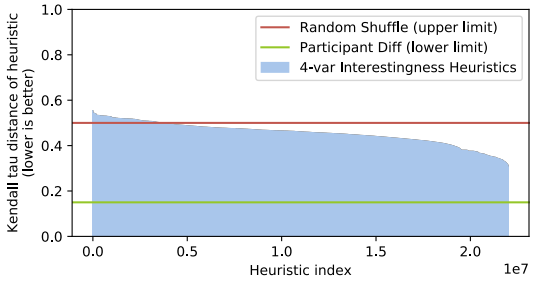
(a) Performance of 1228 evaluated 1-variable artwork relation interestingness heuristics.



(b) Performance of 1,506,756 evaluated 2-variable artwork relation interestingness heuristics.



(c) Performance of 12,486,936 evaluated 3-variable artwork relation interestingness heuristics, based on the best-performing 20% (233) variables of evaluated 2-variable heuristics.



(d) Performance of 22,005,480 evaluated 4-variable artwork relation interestingness heuristics, based on the best-performing 30% (70) variables of evaluated 3-variable heuristics.

Figure 12: Performance (Kendall tau distance) of all evaluated 1-variable, 2-variable, 3-variable and 4-variable artwork relation interestingness heuristics for estimating the extent to which participants considered relations to be interesting.

The best-performing 1-variable, 2-variable, 3-variable and 4-variable heuristics had Kendall tau distances of 0.373, 0.329, 0.308 and 0.296 respectively (Figure 11), whereas the worst-performing ones had Kendall tau distances of 0.626, 0.672, 0.559 and 0.550 respectively[6].

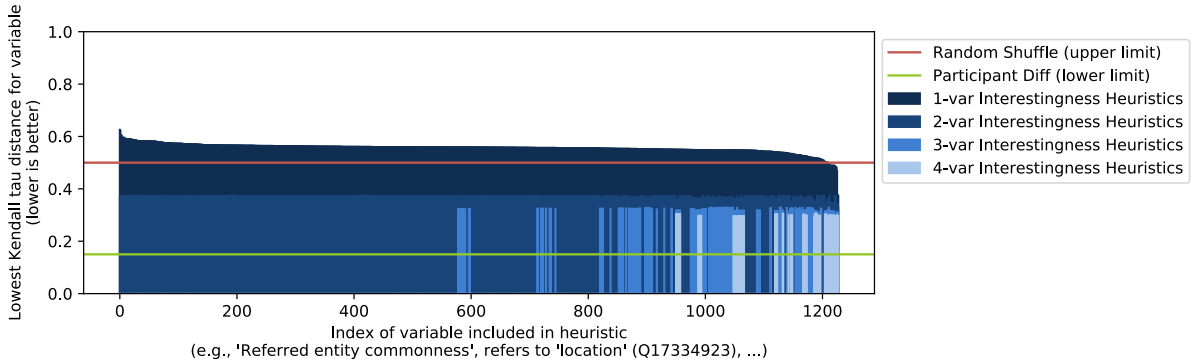
The performance of all evaluated 1-variable, 2-variable, 3-variable and 4-variable artwork relation interestingness heuristics are visualized in Figures 12a, 12b, 12c and 12d respectively. An overview of the lowest Kendall tau distance for each of the 1228 evaluated variables is presented in Figure 13a, reflecting the performance of the best-performing heuristic that each variable was included in. A zoomed-in version of this graph (Figure 13b), highlights the lowest distance of the best-performing 50 variables for 1-variable heuristics, as well as the variables' performance for 2-variable, 3-variable and 4-variable heuristics.

6.3.1 Best-performing variable for 1-variable heuristics

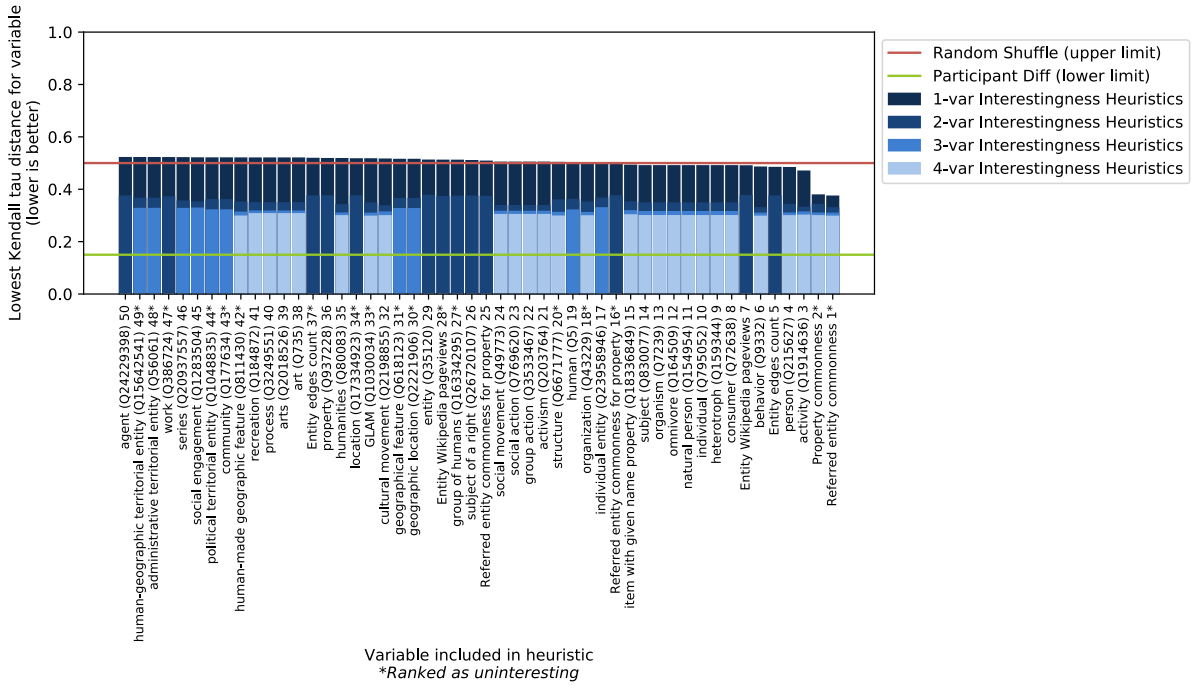
For 1-variable heuristics, 614 unique variables sorted in two directions (i.e., a total of 1228 heuristics) were evaluated.

The best-performing 1-variable heuristic (Kendall tau distance of 0.373) ranked low values of "Referred entity commonness" as most interesting. The second best-performing 1-variable heuristic was a relatively close match (Kendall tau distance of 0.377), and ranked relations based on "Property commonness" in-

[6]Note that for 3-variable and 4-variable heuristics only a selection of the best-performing 2-variable and 3-variable heuristics respectively were evaluated, meaning that the highest distance (i.e., worst performance) identified for these heuristics was naturally lower (i.e., better) compared to 1-variable and 2-variable heuristics (for which all variables were included).



(a) Best performance for the **1228** Wikidata-based variables included in artwork relation interestingness heuristics.



(b) Best performance for the **top 50** Wikidata-based variables included in 1-variable artwork relation interestingness heuristics.

Figure 13: Best performance (lowest Kendall tau distance) for the 1228 Wikidata-based variables included in evaluated artwork relation interestingness heuristics. 3-variable heuristics included only the top 20% (233) best-performing variables from 2-variable heuristics, and 4-variable heuristics included only the top 30% (70) best-performing variables from 3-variable heuristics. Bars are shown overlapping, not stacked.

stead of "Referred entity commonness".

Low values for "Referred entity commonness" were found for relations such as two artworks both having been *owned by* (P127) *Francis I of France* (Q129857), as only two out of the 457,088 included artworks were owned specifically by *Francis I of France* (Q129857).

Examples of relations with the highest values for "Referred entity commonness" were two artists both having the *painter* (Q1028181) *occupation* (P106), or two artworks using *oil paint* (Q296955) as a *material* (P186). Of all included 45,215 Wikidata artists, 42,476 (94%) had the *painter* (Q296955) *occupation* (P106), and, similarly, of all 457,088 included Wikidata artworks (i.e., paintings), 247,333 (54%) were made using *oil paint* (Q296955) as a *material* (P186).

The lowest values for "Property commonness" were found for relations describing the *cause of destruction* (P770) of two artworks (known for only 8 of the 457,088 included Wikidata paintings) or the *location of the point of view* (P7108) property (known for only 23 paintings).

Relations with the highest values for "Property commonness" were relations such as two artists both *having works in the same collection*[7] (P6379), or two artists having the same *occupation* (P106), as these properties were commonly known for artists included in our dataset.

6.3.2 Best-performing variables for 2-variable heuristics

For 2-variable heuristics, 1,506,756 combinations of 614 unique variables (sorted in two directions) were evaluated.

The best-performing 2-variable heuristic (Kendall tau distance of 0.329) ranked low values for "Referred entity commonness" and subsequently relations referring to the *behavior* Wikidata class (Q9332) as most interesting. The second best-performing 2-variable heuristic (Kendall tau distance of 0.330) ranked low values for "Referred entity commonness" and subsequently relations referring to the *activity* Wikidata class (Q1914636) as most interesting.

11 out of the 112 evaluated relations referred to the *behavior* Wikidata class (Q9332), examples being two artists both *identifying as* (P91) *lesbian* (Q6649), or two artists that were both *convicted of* (P1399) *sodomy* (Q206426). 19 out of the 112 evaluated relations referred to the *activity* Wikidata class (Q1914636), some of which overlapping with relations referring to the *behavior* class (e.g., two artists both identifying as lesbian), other examples being two artworks that both *depicted* (P180) *murder* (Q132821), or two artists that both had the *painter* (Q1028181) *occupation* (P106).

6.3.3 Best-performing variables for 3-variable heuristics

For 3-variable heuristics, 12,486,936 combinations of 233 unique variables (sorted in one direction) were evaluated. For these heuristics, only the best-performing 20% (233 variables) of 2-variable heuristics were evaluated, sorted in the best-performing direction.

The best-performing 3-variable heuristic (Kendall tau distance of 0.308) ranked low values for "Referred entity commonness", then relations referring to the *behavior* Wikidata class (Q9332), and finally relations referring to the *GLAM* Wikidata class (Q1030034) as most interesting.

Six out of the 112 evaluated relations referred to the *GLAM* Wikidata class (Q1030034), examples being two artworks that were both *exhibited* (P608) at *Tate* (Q430682), or two artists both having *exhibited* (P6379) works at the *Exposition Universelle of 1889* (Q957317).

6.3.4 Best-performing variables for 4-variable heuristics

For 4-variable heuristics, 22,005,480 combinations of 70 unique variables (sorted in one direction) were evaluated. For these heuristics, only the top 30% (70 variables) best-performing Wikidata classes of 3-variable heuristics were evaluated, sorted in the best-performing direction.

[7] When querying for the number of artists for which this property was known, this was the only property for which Wikidata repeatedly timed out. Therefore, we expected this property to be extremely common, and assumed this property to be known for all artists in our dataset.

The top 21 tied best-performing 4-variable heuristics (Kendall tau distance of 0.296) all ranked a combination of the following variables:

1. Referred entity commonness (low values ranked as interesting).
2. The *behavior* (Q9332) Wikidata class (relations referring to this class ranked as interesting).
3. The *Olympic Games* (Q5389), *Summer Olympic Games* (Q159821), *competition* (Q476300), *international competition* (Q44637051), *multi-sport event* (Q167170), *recurring sporting event* (Q18608583), *sports competition* (Q13406554) Wikidata classes (relations referring to these classes ranked as interesting).
4. The *GLAM* (Q1030034) Wikidata class (relations referring to this class ranked as uninteresting).

In the four tied second best-performing heuristics (Kendall tau distance of 0.297), the following additional two variables were included:

1. The *structure* (Q6671777) Wikidata class (relations referring to this class ranked as uninteresting).
2. The *human-made geographic feature* (Q811430) Wikidata class (relations referring to this class ranked as uninteresting).

Within our dataset, only one relation referred to Wikidata classes associated with the Olympic Games, 16 to the (high-level) *structure* (Q6671777) class (e.g., relations referring to museums, religions, family or countries), and six to the *human-made geographic feature* (Q811430) Wikidata class (five of which referring to museums or exhibitions).

6.3.5 Key clusters of best-performing referred Wikidata classes

Some referred Wikidata classes described the exact same relations in our dataset. As an example, the relation "these two artworks were created from the same point of view: Pincian Hill" referred to *Pincian Hill* (Q550215), which on Wikidata was an *instance of* (P31) *hill* (Q54050) and *park* (Q22698), where *park* was a *subclass of* (P279) *green space* (Q22652). As we included only one relation referring to a hill, park or green space in our dataset, the performance for estimating artwork relation interestingness of these three variables was identical.

Alternatively, some referred Wikidata classes described *almost* the same relations, thereby typically performing (very) similarly. Examples of this were the *museum* (Q33506) and *art museum* (Q207694) Wikidata classes, where the *art museum* (Q207694) class described three relations referring to the *Louvre Museum* (Q19675) and *Tate* (Q430682), and the *museum* (Q33506) class described one additional relation referring to *Musée de la civilisation* (Q1705530), which is not an art museum.

After examining the best-performing 15 variables for 1-variable (Appendix D.1), 2-variable (Appendix D.2), 3-variable (Appendix D.3) and 4-variable heuristics (Appendix D.4), we identified three key "clusters" of similar-performing referred Wikidata classes.

1. **Artwork relations referring to people.** These relations were ranked as interesting, and referred to classes such as *person* (Q215627), *consumer* (Q72638), *heterotroph* (Q159344), *individual* (Q795052), *natural person* (Q154954), *omnivore* (Q164509), *organism* (Q7239), *subject* (Q830077), *creator* (Q2500638) and *item with given name property* (Q18336849). Example relations were two artworks both having the same *sitter* (P2634), or *da Vinci* (Q762) being the *student of* (P1066) *Verrocchio* (Q183458).
2. **Artwork relations referring to human behavior.** These relations were ranked as interesting, and referred to classes such as: *activity* (Q1914636), *behavior* (Q9332), *cultural movement* (Q2198855), *art movement* (Q968159), *social movement* (Q49773), *humanities* (Q80083), *activism* (Q203764), *social action* (Q769620) and *group action* (Q3533467). Example relations were two artists both *identifying* (P91) as *lesbian* (Q6649), or two artists both having *anarchism* (Q6199) as a *political ideology* (P1142).

3. **Artwork relations referring to museums.** These relations were ranked as uninteresting, and referred to classes such as: *GLAM* (Q1030034), *museum* (Q33506), *art museum* (Q207694), *museum of culture* (Q28737012), *organization* (Q43229), *tourist attraction* (Q570116), and *human-made geographic feature* (Q811430). Example relations were two artists both *having works in the collection* (P6379) of the *Louvre Museum* (Q19675), or two artworks both having been *exhibited* (P608) at *Tate* (Q430682).

6.4 Museum experience impact of enabling visitors to identify (interesting) artwork relations on-site

We report the participants' self-reported museum experience impact of using a smartphone application to identify (interesting) artwork relations during a museum visit (Figure 14). We saw no significant differences on the museum experience impact (Figure 15) across participants who visited art museums rarely (e.g., almost never) or frequently (e.g., once per week or more often).

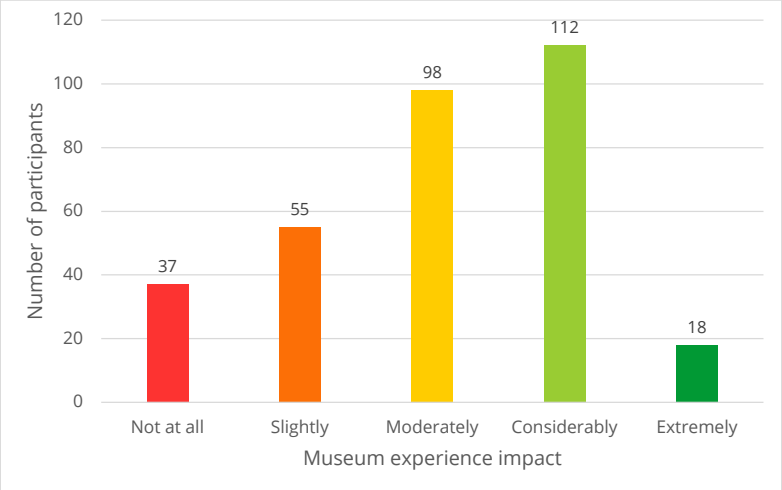


Figure 14: Self-reported museum experience impact of using a smartphone application to identify (interesting) artwork relations during a museum visit for 320 participants.

7 Discussion

7.1 Main RQ: How can the interestingness of artwork relations for art museum visitors be understood?

We took a data-driven approach to understand artwork relation interestingness, identifying various automatically identifiable artwork relation characteristics that effectively estimated what participants considered to be interesting. In this sense, we were not merely interested in identifying ways to optimally estimate the extent to which participants considered artwork relations to be interesting (i.e., heuristics as a black box for estimating relation interestingness), but instead longed to interpret why these characteristics performed well in this regard (i.e., heuristics as a means to understand characteristics of interestingness).

Below, we discuss our approach and findings, structured by the (sub-) research questions addressed in this study. First, we discuss the various types of artwork relations that exist, and reflect on the differences and overlap between our 1-hop automatically identified relations and Kenney's (typically more "rich") manually defined ones. Then, we discuss our ground truth data on the types of artwork relations that our experiment's participants considered to be interesting. Next, we briefly reflect on the extent to which there was a consensus on artwork relation interestingness between participants of our experiment.

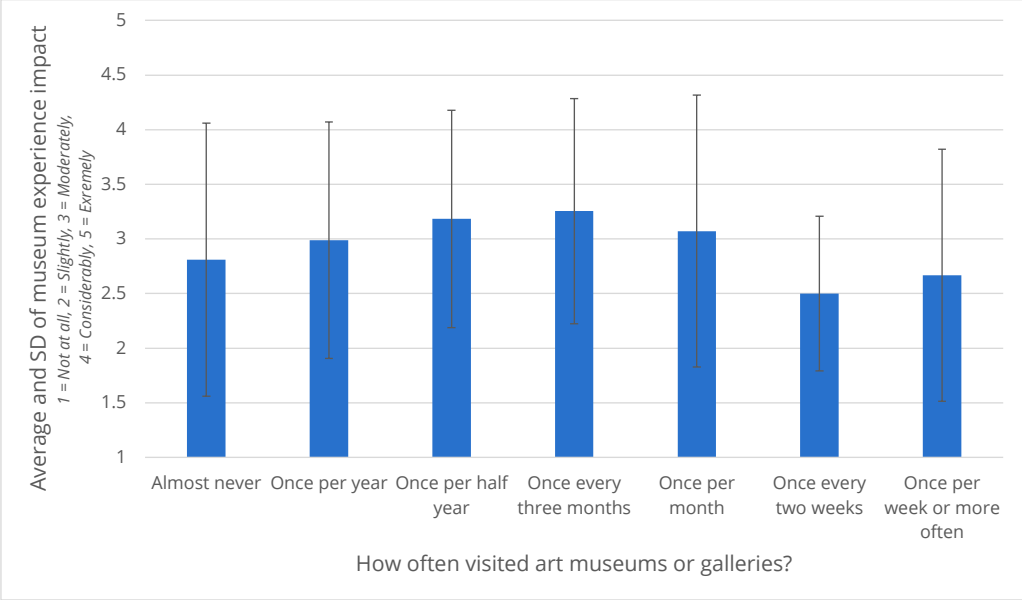


Figure 15: Average and SD of self-reported museum experience impact of using a smartphone application to identify artwork relations during a museum visit for participants visiting art museums or galleries at different rates.

Finally, we discuss and reflect on a number of identified artwork relation characteristics that most accurately estimated what participants considered to be interesting in our ground truth dataset, thereby facilitating a better understanding of the meaning of interestingness in this context.

Throughout this discussion, we consider all participants of our experiment to (potentially) be "art museum visitors". Though a number of participants indicated to "almost never" visit art museums, we considered them a key group to better understand given the public nature of museums as inclusive and participatory institutions, and did not exclude them from our dataset. In addition to this, the self-reported museum experience impact of being able to identify (interesting) artwork relations while visiting did not differ significantly for this group from participants who visited more often, making the practical implications of this research (i.e., being able to highlight interesting relations between encountered artworks) perhaps particularly valuable for encouraging these participants to start visiting art museums.

7.2 Sub-RQ 1. What types of artwork relations exist?

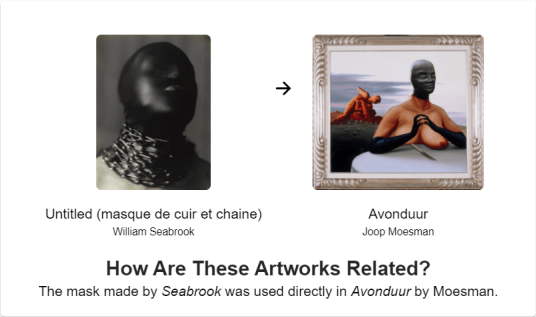
7.2.1 Sub-RQ 1.1. What types of artwork relations do curators identify in art exhibitions?

Though far from an exhaustive review, the 24 relations identified by Kenney (Section 3.1) helped us understand the types of artwork relations that professional curators might identify in art exhibitions, and inspired us to distinguish between two types of 1-hop relations (i.e., direct relations from artworks/artists to other artworks/artists, and artworks/artists relating to the same Wikidata entity).

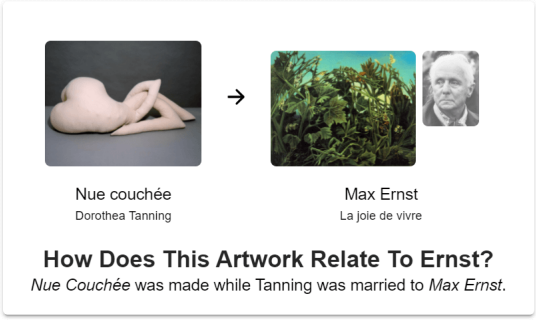
7.2.2 Sub-RQ 1.2. What types of artwork relations can be automatically identified?

We exclusively focused on the automatic identification of 1-hop artwork relations, as we considered ground truth data on "simple" relations a prerequisite step for evaluating the interestingness of more complex relations.

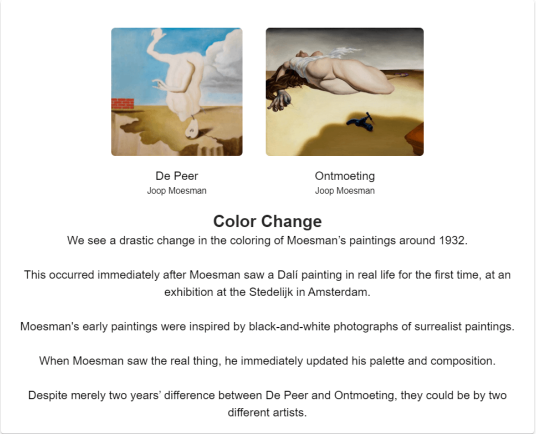
Though in doing so we did not get close to automatically identifying relations such as the ones manually defined by Kenney, below, we reflect on the extent to which Kenney's manually defined relations could potentially be automatically identified in future work.



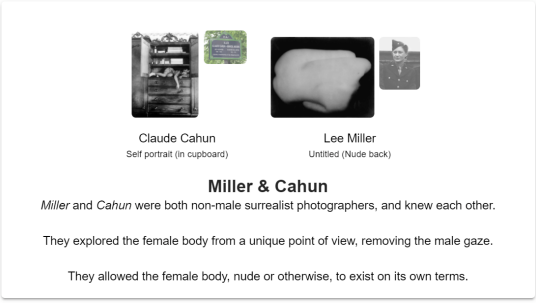
(a) Example of a manually defined relation that could be easily automatically identified using methods such as described in this study.



(b) Example of a manually defined relation that is feasible to automatically identify by combining information from multiple triples.



(c) Example of a manually defined relation that is more complex and storylike, and therefore much harder to automatically identify.



(d) Example of a manually defined relation of which the semantic meaning is intuitive for human readers to understand but hard to model as Linked Data (therefore challenging to automatically identify).

(e) Example of a manually defined relation that seems feasible to automatically identify using computer vision approaches.

Figure 16: Examples of various manually defined relations that could potentially be automatically identified in future work.

Some of Kenney's relations (Figure 16a) could in Linked Data-terms be modeled as simple triples (i.e., Avonduur *depicts* [P180] Untitled (masque de cuir et chaine)), thereby easily being automatically identifiable using methods such as described earlier in this study (Section 3.3).

Other relations (Figure 16b) were a bit less straightforward, but still very feasible to automatically identify by combining information from multiple triples (i.e., when was Nue couchée made, and when were Ernst and Tanning married?), or by using a rule-based approach (Hyvönen & Rantala, 2021; Lin & Lin, 2017).

Some of Kenney's relations (e.g., Figure 16c) were much more complex and storylike than the straightforward relations we focused on. Though modeling the individual events described in these types of relations (e.g., Moesman seeing a Dalí painting around 1932 at the Stedelijk in Amsterdam) as Linked Data would be fairly straightforward, tying these events together to form a coherent whole is a far more complicated semantic storytelling challenge that we did not tackle in this study.

Another challenge is represented by some of Kenney's more interpretative relations (Figure 16d). In this example, the semantic meaning of "allowing the female body to exist on its own terms" might be intuitive for human readers, but seems challenging to explicitly model as Linked Data.

Lastly, one of Kenney's relations (Figure 16e) seems quite feasible to automatically identify, but calls for a different approach altogether. Given the visual nature of this relation, it begs for a Machine Learning approach, such as the work by Saleh and Elgammal (2015) who use a metric learning approach to approximate style similarity between fine-art paintings.

7.3 Sub-RQ 2. What types of artwork relations do art museum visitors consider to be interesting?

We first briefly discuss participants' qualitative comments on artwork relation interestingness, after which we compare Kenney's manually defined relations and our automatically identified 1-hop relations. Otherwise, this question was mostly addressed by the ground truth data presented in Section 6.1.

7.3.1 Qualitative comments on artwork relation interestingness

In participants' qualitative comments, we recognized a shared interest in unexpected artwork relations. "Surprisingness" or unexpectedness is one of the nine criteria for determining a pattern's interestingness (Geng & Hamilton, 2006), and the connection between unexpectedness and interestingness has been extensively documented and discussed in existing literature (Geng & Hamilton, 2006; Kontonasios et al., 2012; Mcgarry, 2005). In this sense, we confirm the relevancy of this interestingness measure within the context of artwork relations for art museum visitors.

7.3.2 Comparing interestingness of manually defined and automatically identified relations

Comparing Kenney's 24 manually defined relations and our 112 automatically identified relations, it is worth noting that Kenney was constrained to find relations between 16 artworks from a local art exhibition, whereas automatic methods could identify relations between the world's most famous artworks (e.g., da Vinci's Mona Lisa and Picasso's Guernica). In this sense, direct quantitative comparisons would be unfair, though we noticed that Kenney's relations did not underperform in terms of perceived interestingness, two of them being the second and fifth highest rated relations overall. It seems likely, therefore, that having allowed Kenney to identify relations between any artworks in the world, her relations would have been considered more interesting than they were in this experiment.

7.4 Sub-RQ 3. To what extent do art museum visitors differ in the types of artwork relations they consider to be interesting (as identified in RQ 1.2)?

The lower limit of what a one-size-fits-all heuristic might achieve within our dataset (Kendall tau distance of 0.150) represented the individual differences between our experiment's participants, and the subjective nature of interestingness.

Most importantly, this lower limit showed that, though individual interestingness preferences did differ within our dataset, there was to some extent a general consensus within our participant group with regards to the types of artwork relations they considered most (or least) interesting. With no such consensus existing, we would have expected this number to be closer to 0.5 (the random baseline), which would have meant that further research into adapting the notion of interestingness to individual preferences (i.e., user modeling) would be an essential next step.

7.5 Sub-RQ 4. Which automatically identifiable artwork relation characteristics most accurately estimate the extent to which art museum visitors consider artwork relations to be interesting (as identified in RQ 1.2)?

To better understand artwork relation interestingness for art museum visitors, below, we discuss and interpret the various evaluated numerical (e.g., "Referred entity commonness") and categorical (i.e., referred Wikidata classes) variables for estimating artwork relation interestingness, as well as participants' reasons for finding the top 10 highest rated relations interesting.

7.5.1 Interpreting best-performing Wikidata-based numerical variables for estimating artwork relation interestingness

Out of the five evaluated Wikidata-based numerical variables, low values for "Referred entity commonness" and/or "Property commonness" best estimated participants' perceived interestingness. Below, we reflect on why we believe these numerical variables were most effective for estimating artwork relation interestingness, and elaborate on the similarities between "Property commonness" and "Referred entity commonness", as well as the differences between "Referred entity commonness" and "Referred entity commonness for property".

Interpreting performance similarities between "Property commonness" and "Referred entity commonness" "Property commonness" and "Referred entity commonness" were relatively closely related in terms of performance, especially for 1-variable heuristics. One explanation for this is that "Referred entity commonness" was calculated using the number of occurrences of a referred entity (e.g., oil paint) for a given property (e.g., material used). If a given property was more commonly available in the dataset (i.e., higher "Property commonness"), the probability that this property (e.g., material used) referred to a specific entity (e.g., oil paint) naturally increased as well to some extent (i.e., higher "Referred entity commonness").

Interpreting the performance of "Property commonness" and "Referred entity commonness" We recognize two (mutually inclusive) ways in which artwork relation interestingness heuristics effectively ranked relations on interestingness:

1. Prioritizing (i.e., assigning high ranks to) artwork relations deemed interesting by participants.
2. Pruning (i.e., assigning low ranks to) artwork relations deemed uninteresting by participants.

Heuristics based on "Property commonness" and "Referred entity commonness" seemed to mostly perform well in the latter category, effectively pruning "obvious" relations with the highest values for "Property commonness" and/or "Referred entity commonness" (e.g., two artists with the same occupation, or two artworks that were both made with oil paint), thereby causing "unexpected" relations that participants indicated to find interesting (Section 7.3.1) to be ranked relatively higher.

Given that we recognized an interest in unexpected relations through these two numerical variables as well as in participants' qualitative data and existing literature (Section 7.3.1), we consider the connection between unexpectedness and interestingness to be particularly noteworthy in this context.

Interpreting performance differences between "Referred entity commonness" and "Referred entity commonness for property" One participant shared that as the majority of famous paintings are made using oil paint, it was not interesting to learn that two artworks were both made using oil paint. In this sense, it seemed that "Referred entity commonness" would be a good measure for pruning these types of clearly uninteresting or "obvious" results, as many (54%) of the included artworks were created using oil paint. For this specific example, however, "Referred entity commonness for property" would have been an even better measure, as for all the 457,088 included paintings for which the *material used* (P186) was known, 91% used *oil paint* (Q296955) as a material.

The difference between "Referred entity commonness" and "Referred entity commonness for property" is best illustrated when looking at a Wikidata property that was often not known for included artworks, such as *cause of destruction* (P770). This property was only known for 8 out of the 457,088 included artworks, and referred to *conflagration* (Q168983) 4 out of 8 times. In this case, "Referred entity commonness for property" measured that, given that an artwork was destructed, it occurred due to conflagration (fire) relatively often (50% of the times). "Referred entity commonness", however, approximated the *absolute* probability of an artwork being destructed in a fire, which was rarely documented on Wikidata (4 times for 457.088 artworks). By taking the commonness (in this case: rareness) of the property itself into account, "Referred entity commonness" would, therefore, rank this as a much more exceptional (and therefore more interesting) event.

Given that "Referred entity commonness" performed better than "Referred entity commonness for property", we conclude that art museum visitors were more interested in the overall rareness or commonness of a relation, as opposed to the relative rareness or commonness of a referred entity (e.g., conflagration) given a property (e.g., cause of destruction).

7.5.2 Interpreting key clusters of best-performing referred Wikidata classes for estimating artwork relation interestingness

Some of the best-performing 4-variable heuristics ranked relations on whether or not they referred to Wikidata classes associated with the Olympic Games (e.g., *Summer Olympic Games* [Q159821], *multi-sport event* [Q167170], *sports competition* [Q13406554], etc). Given that there was only one (relatively highly rated) relation in our dataset that referred to the Olympic Games (i.e., two artists that were both participants in the 1928 Summer Olympics), these heuristics seemed to have overfitted, which is why we did not include these variables in the identified clusters.

Artwork relations referring to people or human behavior In the qualitative data (Section 6.2), participants indicated to be interested in personal artist relations. Furthermore, nine out of the ten most highly rated artwork relations were (partly) considered interesting because they helped to better understand the perspective of the people that created (or sponsored) compared artworks (Table 3). Given that heuristics ranking on referred Wikidata classes associated with "people" and/or "human behavior" were additionally good data-driven estimators for artwork relation interestingness, we confirm a high-level interest of art museum visitors in artwork relations referring to people.

7.5.3 Interpreting the interestingness of the top 10 most interesting relations

The identified connection between furthering understanding (i.e., of artworks, artists or the world) and interestingness within the top 10 highest rated relations seemed to align well with unexpected relations being considered interesting (7.5.1). We hypothesize that relations that were *not* unexpected (i.e., "obvious") typically contributed no new knowledge, thereby failing to facilitate understanding. Examples of these types of relations can be found in the ten relations considered least interesting, such as two artworks both *depicting* (P180) a *mountain* (Q8502), two artists that both had the *painter* (Q1028181) *occupation* (P106), or the *manner of death* (P1196) of two artists being *natural causes* (Q3739104).

We hypothesize that the highest rated relation (i.e., same location of point of view: Pincian Hill, Figure 1) was mostly considered interesting because it catered to two different types of interests. Some participants showed an interest in the presented artworks as a representation of the world in which it was created (i.e., two artworks showing how Rome has changed over time), whereas others showed an interest in the artworks as representations of how their creators perceived the world (i.e., the two artworks showing how different artists interpreted the same place). Participants shared a similar reasoning for the sixth highest relation (i.e., two artworks created at *approximately* the same point of view, within 12km of each other), though in this case the proximity of the point of view was not visually perceivable, which might explain the lower interestingness ratings.

Overall, nine out of the ten most highly rated artwork relations were (partly) considered interesting because they helped understand the artists' (or sponsor's) perspective in some way. The one relation that was not considered interesting for this reason (i.e., da Vinci and Carus both being botanists) seemed mostly to be considered interesting because of its unexpectedness (7.5.1), the effect of which might have been amplified because of da Vinci's popularity.

7.6 Limitations

Firstly, some level of overfitting is to be expected for the best-performing interestingness heuristics, especially for heuristics sorting on multiple variables. Within the scope of this study, however, no cross-validation step was performed, which we consider future work and would provide further insights into the generalizability of the heuristics evaluated in this study.

Secondly, due to the COVID-19 pandemic, we conducted our experiment remotely (i.e., online) instead of in a physical (museum) space, which likely changed the way in which presented artworks and relations between them were perceived, thereby potentially impacting the types of artwork relations participants considered interesting. Additionally, considering that most of our experiment's participants were between 18 and 34 years old and curiosity-driven, our ground truth data might be biased towards a younger curiosity-driven audience. Due to insufficient data, we did not verify the extent to which the notion of artwork relation interestingness differed across demographic groups.

Lastly, when selecting potentially interesting Wikidata properties for artwork relation identification, we, together with Kenney, independently made selections that were merged afterward. For the coding of qualitative comments, however, no third party independently confirmed or evaluated the final categorization, making a bias in this regard more likely.

8 Future Work

8.1 Generalizability to other domains

We specifically investigated the interestingness of relations between paintings for art museum visitors, but expect our findings to generalize well to artistic (sub)domains in which there is a clearly defined

relation between an artwork and its creator (i.e., the artist), and in which entities are described using similar Wikidata properties as the ones we used for creating our ground truth data (Appendix H.1). The automatically identified relations between artists identified in our dataset were mostly based on properties applicable to people in general (Appendix H.2, e.g., *cause of death* [P509], *child* [P40], *political ideology* [P1142], *sexual orientation* [P91]), with only a few exceptions such as *has works in the collection* (P6379) and *movement* (P135). Therefore, similar relations could in principle be identified for people within non-artistic domains, though further research is needed to verify the extent to which the interestingness of relations between people remains consistent across different domains. As an example, within an art museum context, it was considered relatively uninteresting that two artists both played the violin. In another context, such as the identification of relations between celebrities, this might be considered a more interesting "fun fact".

Some of the Wikidata properties used to automatically identify relations between artworks in our dataset (Appendix H.1) were mostly applicable to (visual) artworks (e.g., *depicts* [P180], *date depicted* [P2913], *sitter* [P2634]) such as paintings, photographs or sculptures. Others (e.g., *award received* [P166], *movement* [P135], *time period* [P2348]) were less specific, and could be of use for identifying relations within domains such as literature (i.e., books) or architecture (i.e., buildings). In this sense, we expect that the degree to which our findings generalize to other domains is partially related to the extent to which entities within that domain are (or can be) described using similar Wikidata properties as we used within our dataset.

8.2 Adapting what is "interesting" to visitor groups sharing similar interests

We researched one-size-fits-all heuristics, exploiting generic interests of art museum visitors. Given the subjective nature of interestingness, however, we hypothesize that groups (or "stereotypes") of visitors sharing similar artwork relation interests could be identified. As an example, in an art museum space, inexperienced adolescents might find different artwork relations interesting than professional art historians. Within these groups of adolescents and art historians, however, people might generally agree with each other to a much greater extent. Though we collected this kind of demographic data (e.g., age, education, art interests and knowledge), we could not verify our hypothesis due to a lack of data across (demographic) groups. If groups of visitors sharing similar interests could be (automatically) identified, however, it would be worthwhile to further explore user modeling techniques to automatically adapt the notion of what is interesting to visitor groups, as is often done in existing systems aiming to personalize the museum experience (Antoniou et al., 2016; Ardissono et al., 2012; Pujol et al., 2011).

8.3 Evaluating alternative interestingness measures

We discussed the performance of artwork relations' referred Wikidata classes for estimating the extent to which art museum visitors considered artwork relations to be interesting. As an example, within our dataset, artwork relations referring to people were (on average) considered more interesting than relations referring to museums, which facilitated a better understanding of human interests in this context. Besides these categorical variables, we additionally evaluated five numerical variables for similar reasons, such as the average daily Wikipedia pageviews of the artworks that a relation compared, or the relative frequency ("commonness") with which Wikidata properties were used to describe artworks. Though outside the scope of this study to evaluate, more of these numerical "interestingness measures" exist, such as the ones evaluated by Carvalho et al. (2005) across other domains. Further work is needed to implement and evaluate these measures within the context addressed in this study (i.e., artwork relations and art museum visitors).

9 Conclusion

In this study, we aimed to understand what makes relations between artworks interesting for art museum visitors. We created ground truth data on artwork relation interestingness for a selection of 24 manually defined and 112 automatically identified relations. This allowed us to identify a (partial) consensus on artwork relations deemed interesting or uninteresting by participants, meaning that despite the subjective nature of interestingness, there were some characteristics that participants agreed on. We identified these characteristics of interesting artwork relations by taking a data-driven approach, comparing the ranking performance of various interestingness heuristics with ground truth data. Based on both quantitative and qualitative results, we confirmed a connection between unexpectedness and interestingness in this context, which aligns well with existing literature on the topic (Geng & Hamilton, 2006; Kontonasios et al., 2012; Mcgarry, 2005). We additionally found that relations referring to (Wikidata classes associated with) *people*, *human behavior* and *museums* most effectively estimated participants' perceived (un)interestingness of artwork relations. The identified participants' interest in people was furthermore confirmed by qualitative data highlighting interests in personal artist relations, as well as by nine out of the ten highest rated relations being considered interesting because they helped to understand the artists' (or sponsor's) perspective.

Evaluating qualitative feedback on why participants considered the highest rated ten artwork relations to be most interesting, we identified particular interests in relations helping to better understand presented artworks, the artists that created them, or the world in which they were created. This emphasis on understanding, however, might have been caused by most of our participants being curiosity-driven museum visitors, meaning further research is needed to confirm the extent to which these findings hold for other types of visitors.

We have confirmed the considerable potential for improving the art museum visitor's experience by allowing them to explicitly identify (interesting) artwork relations during their visit. In this sense, the automatically identifiable interestingness characteristics for artwork relations we identified not only helped to better understand the meaning of interestingness in this context, but are additionally likely to have practical value for automatically identifying interesting relations within art museum spaces (though further empirical research is needed to confirm this).

Overall, we see two main directions for future work. Firstly, we hypothesize that groups (or "stereotypes") of visitors sharing similar artwork relation interests could be identified, which, if confirmed to be the case, would provide further insights into the meaning of interestingness across individuals, and could verify the value of user modeling techniques for adapting the notion of interestingness to specific (sub-)groups. Secondly, to highlight the differences and overlap of interestingness across domains, further research could investigate the generalizability of our findings to other artistic domains such as photography, sculpture, literature, or architecture, or non-artistic domains such as people (e.g., celebrities) or historical events.

Appendix A Prototype for identifying artwork relations within the museum space

In this study, we did not evaluate the museum experience impact of allowing visitors to use a smartphone application to identify (interesting) artwork relations in a physical museum space. We did, however, create a prototype for this purpose, which we briefly describe below.

A.1 Scanning artworks using a smartphone's camera

Using the prototype application, visitors of an art exhibition could use their smartphone's camera to scan artworks they were interested in, after which they were presented with a list of relations between the scanned work and previously scanned works.

We implemented two methods for scanning artworks. Firstly, we implemented a visual recognition proof of concept that allowed visitors to directly take pictures of artworks to scan them. We developed a basic Node.js server for this, hosted on Heroku. To predict which artwork was scanned, we used a pre-trained MobileNet model (@tensorflow-models/mobilenet) and a K-Nearest Neighbors image classifier (@tensorflow-models/knn-classifier) that was trained on 50 example images per artwork, extracted from 5 second videos. The alternative (and most commonly used) method to scan artworks was to make use of QR codes. The scanning logic for this was implemented using the *@zxing/ngx-scanner* Angular component.

For future work, though the scanning logic for QR codes is typically more easily implemented, the preferred option for visitors would be to pursue a visual recognition approach (Wein, 2014).

A.2 Presenting artwork relations

At the top of the application (Figure 17a), visitors can see the artwork they have just scanned. Below, a list of relations between the scanned artwork and previously scanned artworks is shown, which could be ranked based on the results of our study.

A.3 Recommendation module

Though we preferred visitors to scan artworks exclusively out of intrinsic interest, we also experimented with a basic recommender module to provide suggestions for which artworks a visitor might like to scan next (Figure 17b). Though we mostly steered away from features that guided visitors in how they explored the exhibition's physical space, we nonetheless considered this a feature worth exploring for overwhelmed visitors that did not know where to start.

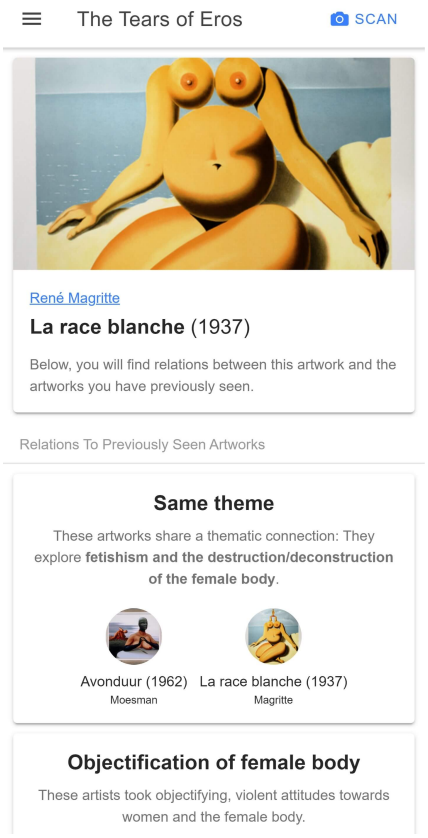
In this prototype, recommendations for which artworks visitors might like to scan next were solely based on which of the exhibition's unscanned artworks had the highest number of relations with the visitor's previously scanned artworks. Obviously, the number of relations between artworks was not necessarily indicative of the quality of those relations, meaning this was an inherently flawed measure. In future work, using the results of this study, an alternative measure of the summed interestingness of all relations between artworks could be calculated to predict which artworks visitors might like to scan next.

Appendix B Experimental procedure

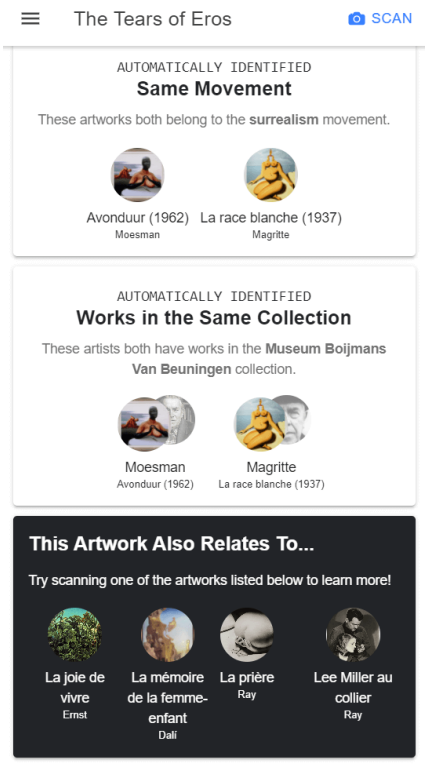
Below, we report the texts and instructions presented to participants of our experiment on artwork relation interestingness.

B.1 Experiment: Introduction text

Welcome to this experiment on understanding what types of artwork and artist relations museum visitors find most interesting.



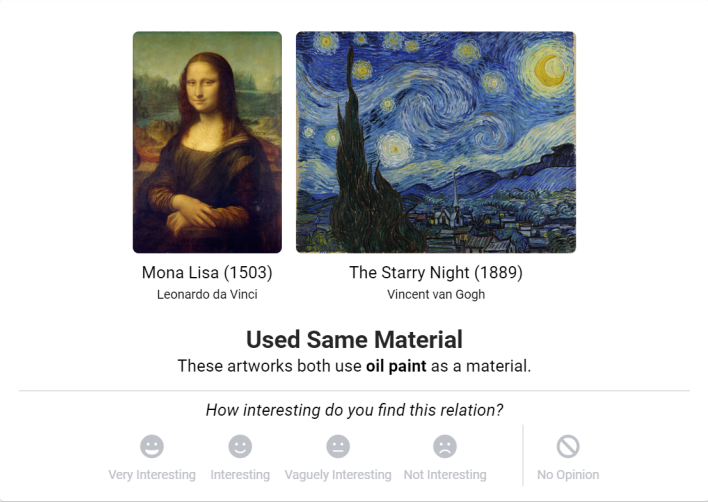
(a) Prototype application interface, showing the scanned artwork and two manually identified relations between the scanned work and previously scanned works.



(b) Prototype application interface, showing automatically identified relations between the scanned work and previously scanned works, as well as recommended artworks the visitor might like to scan next.

Figure 17: Screenshots of our web-based prototype smartphone application for identifying artwork relations in a physical museum space.

During the experiment, you will be presented with a list of relations between artworks and/or artists. **We would like you to judge how interesting you find each relation.** As an example, consider the artwork relation below between the Mona Lisa by Leonardo da Vinci and The Starry Night by Vincent van Gogh:



How interesting do you find this relation?

You can use the smiley faces below each relation to indicate how (un)interesting you found the presented information, or the "No Opinion" button if you are indifferent. After seeing approximately 25 example relations, we will ask you a few questions about your favorite relations, and why you found them interesting.

The Experiment

- The session will take around **10 to 15 minutes**.
- Please use a modern browser like **Chrome, Firefox, Edge or Safari** to view the questions. *Internet Explorer is not supported.*
- After signing a consent form we will ask you a few questions about who you are.
- Your responses will only be used if you have successfully finished the experiment.

Thank you for taking the time to participate in this experiment!

Simon Dirks, MSc student UU, [E-MAIL ADDRESS REDACTED].
Supervised by Lynda Hardman, CWI & UU.

[GO TO CONSENT FORM BUTTON]

B.2 Experiment: Consent form

The data that is collected in this experiment will be used to research what types of artwork/artist relations people find most interesting.

All collected data is saved **anonymously**. Please read the consent form below carefully before participating.

- I voluntarily agree to participate in this research study.
- I understand that even if I agree to participate now, I can withdraw at any time or refuse to answer any question without any consequences of any kind.
- I have had the purpose and nature of the study explained to me in writing.
- I understand that I will not benefit directly from participating in this research.

- I agree that information I provide in this study will be anonymously saved and used for research purposes.
- I understand that all information I provide for this study will be treated confidentially.
- I understand that I am free to contact the people involved in the research to seek further clarification and information by sending an e-mail to [REDACTED].
- By checking the checkbox below, you agree to have read all of the above information and voluntarily consent to participate in this study.

[ ] I voluntarily consent.

[GO TO SURVEY BUTTON]

B.3 Experiment: Demographics survey questions

Please answer all of the questions below before starting the experiment.
How did you hear about this experiment?

- Directly from the researchers (Simon and Lynda)
- Referred by friends / family / colleagues
- Netwerk Digitaal Erfgoed (NDE)
- Reddit
- LinkedIn
- Facebook
- Twitter
- Not listed (enter below)
- ...

What gender do you identify as?

- Female
- Male
- Prefer not to answer
- Not listed (enter below)
- ...

To which age group do you belong? *You must be at least 18 years old to participate in this experiment.*

- 18 - 24 years old
- 25 - 34 years old
- 35 - 44 years old
- 45 - 54 years old
- 55 - 64 years old
- 65 - 74 years old
- 75 - 84 years old

- 85+ years old
- Prefer not to answer

What is the highest degree or level of education you have completed?

- Some High School or equivalent
- High School or equivalent
- MBO (vocational education) or equivalent
- Bachelor's degree or equivalent
- Master's degree or equivalent
- Ph.D. or higher
- Prefer not to answer

How would you rate your knowledge of art history?

- Very poor
- Poor
- Fair
- Good
- Very Good

Which description matches your motivations for visiting art museums best?

- **Curiosity-driven:** When visiting art museums, I expect to find something that will grab my attention and fuel my learning.
- **Socially motivated:** My main focus when visiting art museums is to enable the experience and learning of others.
- **Professional or hobbyist:** I feel a close tie between the art museum's content and my personal passions. I usually have a specific goal in mind when I visit a museum.
- **Experience-driven:** I usually visit art museums because I perceive them as an important destination. My main satisfaction derives from the fact of having "been there and done that".
- **Restorative:** The art museum is a place to unwind for me, while being surrounded by inspiring and beautiful things.

How often did you visit art museums or art galleries on average before the COVID-19 pandemic?

- (Almost) never
- Once per year
- Once per half-year
- Once every three months
- Once per month
- Once every two weeks
- Once per week or more often

How often do you (virtually) visit events about art or art history (seminars, projects, festivals, etc.)?

- (Almost) never
- Once per year
- Once per half-year
- Once every three months
- Once per month
- Once every two weeks
- Once per week or more often

How often do you read books, magazines or catalogues about art?

- (Almost) never
- Once per year
- Once per half-year
- Once every three months
- Once per month
- Once every two weeks
- Once per week or more often

Do not refresh or reload the page after starting the experiment to avoid LOSING ALL THE RESULTS.

[START EXPERIMENT BUTTON]

B.4 Experiment: Rating artwork relations (introductory text)

Below you will find a number of relations between artworks and/or artists.

We would like to know your opinion about the presented relation, not about the individual artworks or artists it connects. This means that:

- If you encounter an uninteresting relation between your favorite artworks, we would like you to give it a low rating.
- Alternatively, if you see an interesting relation between two artworks that you dislike, we would like you to give it a high rating.

There are no right or wrong answers! Rate each relation based exclusively on how interesting you find the presented relation. Please use the four smiley faces below each relation to indicate how (un)interesting you find each relation, or use the "No Opinion" button if you are indifferent.

[24, 25 or 26 artwork relations were shown here, which participants could rate on interestingness ("Very Interesting", "Interesting", "Vaguely Interesting", "Not Interesting", or "No Opinion").]

[GO TO FINAL QUESTIONS BUTTON]

B.5 Experiment: Reasons for finding relations interesting page

You are almost done!

To complete the experiment, we would like to know **why you found certain relations interesting.**

Below, you will find a selection of relations that you found interesting.

Please use the text boxes below each relation to briefly explain why you found these particular relations interesting. You are allowed to leave text boxes blank.

Interesting Relations
Looking back on the artwork and artist relations you have seen, which types of relations did you generally find most interesting?
[A text box was shown here]

[(At most) four specific artwork relations that participants indicated to find "Very Interesting" or "Interesting" were shown here. For each of these relations, participants were presented with a text box, through which they could share why they found the relation to be interesting]

Identifying relations during a museum visit
Artwork and artist relations, such as those you have just seen, can also be identified during a museum visit. **If you could use your smartphone to identify artwork/artist relations such as those you have just seen, to what extent would that improve your museum visiting experience?**

- Not at all
- Slightly
- Moderately
- Considerably
- Extremely

Other Comments
If you have any other comments, questions or thoughts with regard to this experiment, please share them with us using the text box below.
[A text box was shown here]

[**FINISH EXPERIMENT BUTTON**]

B.6 Experiment: Finished page

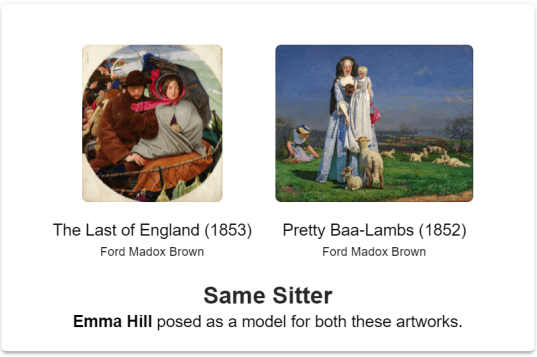
You have successfully completed the experiment. Thank you for participating!

You can now close this window.

[Image sources/attributions were shown here.]

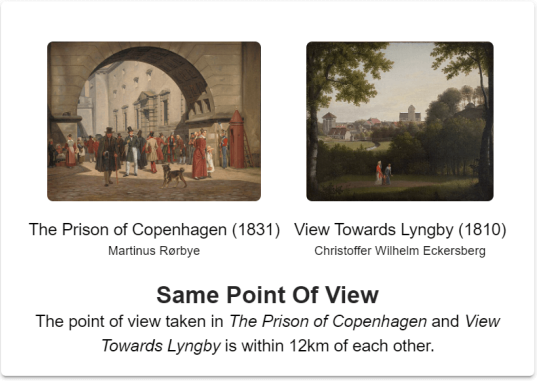
Appendix C Coded participant reasons for finding top 10 highest rated relations interesting

Participants of our experiment on artwork relation interestingness shared various reasons for finding the top 10 highest rated relations interesting. A coded overview of these reasons, including example quotes for each assigned label, is presented below.



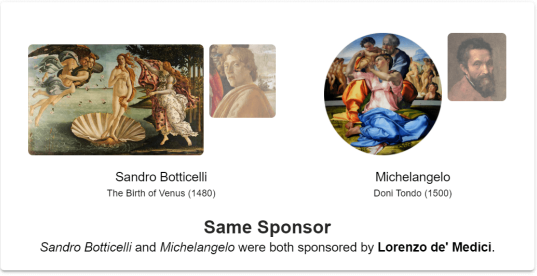
(a) The relation ranked as the third most interesting artwork relation.

(b) The relation ranked as the fourth most interesting artwork relation.

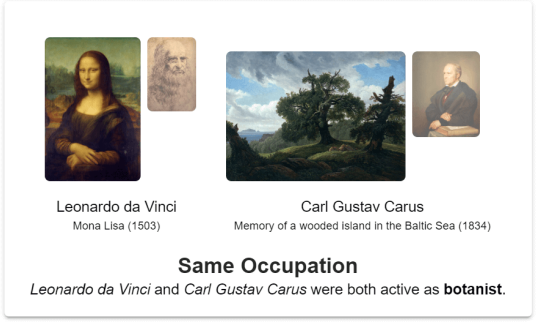


(c) The relation ranked as the sixth most interesting artwork relation.

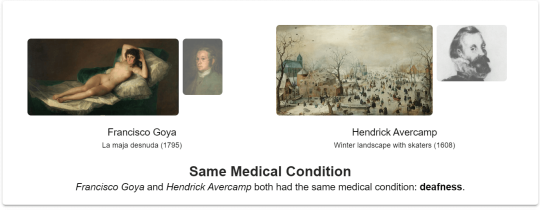
(d) The relation ranked as the seventh most interesting artwork relation.



(e) The relation ranked as the eighth most interesting artwork relation.



(f) The relation ranked as the ninth most interesting artwork relation.



(g) The relation ranked as the tenth most interesting artwork relation.

Figure 18: Relations included in the top 10 (out of 136) most interesting artwork relations, as ranked by 320 participants.

1. Same location of point of view: Pincian Hill (Figure 1). This relation was considered interesting for two main reasons:

1. The relation helped to understand the world. Example comments that reflected this were:
    - "Because of the similarity in point of view, the two paintings offer a nice opp[o]rt[u]nity to compare the view of the city of Rome in two different years."
    - "I love the contrast between the two paintings, showing the development of the area over the span of 40 or so years."
    - "It was interesting to see how much the world changed."
2. The relation helped to understand the artists' perspective through the artworks. Example comments that reflected this were:
    - "interesting [to] see how t[w]o people can form a totally different view of the world"
    - "I found this relation interesting because it shows how one location can be so differently interpreted and visualized."

2. Miller and Cahun (Figure 16d). This relation was considered interesting for three main reasons:

1. The relation helped to understand the world. Example comments that reflected this were:
    - "it explained the social-historical context a little bit"
    - "It tells a lot about their intentions and also about what female artists dealt with in the 1920/1930[s]"
2. The relation helped to understand the artists' perspective. Example comments that reflected this were:
    - "It shows different artists' views on the same subject."
    - "It tells something about their look on female bodies"
    - "I like knowing about artists['] personals [sic] lives"
3. The relation helped to understand the artworks through the artists. Example comments that reflected this were:
    - "I learned something about the artists that helped me understand how to interpret the work"

3. Same sitter: Emma Hill (Figure 18a). This relation was considered interesting for three main reasons:

1. The relation was unexpected. Example comments that reflected this were:
    - "[. . .] I might not have guessed it by looking at the two paintings."
    - "It's an interesting titbit relevant to the artwork that i would not have picked up on on my own."
2. The relation helped to understand the artworks through the artists. Example comments that reflected this were:
    - "i like to see how the same painter interpreted the same model differently."
3. The relation helped to understand the artists' perspective. Example comments that reflected this were:
    - "I suppose it gives me the idea that Brown and Hill had a good working relationship knowing that a painter would work with the same model multiple times.
      It makes me want to find out if they did even more together and why."

Note that for this relation, some people thought the two artworks were created by different artists, which might have influenced how interesting they considered this relation to be. This was reflected in comments such as:

- "It is interesting to see how a different artist painted the same person (different expression). [. . .]"

- "I found this relation interesting because you could compare them to see how the artists interpreted the model differently"

4. Pendant of: La maja desnuda → La maja vestida (Figure 18b). This relation was considered interesting for three main reasons:

1. The relation was visually perceivable. Example comments that reflected this were:
   - "I could see the relationship between the two pieces of art in a single glance."
   - "I thought it was interesting because I didn't know these paintings looked so similar. [...]"
   - "[...] I thought it was cool that they were of the same woman"
2. The relation helped to understand the artworks by comparing them. Example comments that reflected this were:
   - "I found this relation interesting because it implied that one artwork could be better understood by seeing the other one."
   - "It's interesting that the second is based on the first."
   - "I always like how a piece of art "evolves". I will always, for instance, watch the original movie after (or before) watching a remake, same with songs, etc."
3. The relation helped to understand the artists' perspective through the artworks. Example comments that reflected this were:
   - "It makes you look back and forth between the two paintings to see the relationship and how the artist must have been seeing the subject."

5. Color change: Ontmoeting and De Peer (Figure 16c). This relation was considered interesting for five main reasons:

1. The relation helped to understand the world. Example comments that reflected this were:
   - "reminded me that there was a time you couldn't go on the internet and find hi-res pictures of everything"
2. The relation had a story element. Example comments that reflected this were:
   - "[...] A great story with clearly the start, and result. So, not only a story, but you can clearly see the before and after."
   - "you can see the progression of the painter, and it adds a story element"
3. The relation was visually perceivable. Example comments that reflected this were:
   - "The difference is clearly visible [...]"
   - "[...] you can clearly see the before and after."
4. The relation helped to understand the artworks through the artists. Example comments that reflected this were:
   - "It gives a detailed account of the evolution of this artist, which makes me view the artwork in a new light"
   - "I found this relation very interesting as you would not imagine them to be from the same painter. they are very different in colours and style, which makes it very interesting to know that they are actually only 2 years apart. it's very interesting to see the development of someone's work."
5. The relation helped to understand the artists' perspective through the artworks. Example comments that reflected this were:
   - "It is interesting to see the development that an artist makes in his own work"

6. Approximately same point of view (Figure 18c). This relation was considered interesting for two main reasons:

1. The relation helped to understand the world. Example comments that reflected this were:
   - "the paintings show the place in 2 perspectives. You have the busy streets, yet a tranquil forest path far from the city."
   - "Gives a fuller view of one place"
2. The relation helped to understand the artists' perspective through the artworks. Example comments that reflected this were:
   - "I found this relation interesting because it shows how one location can be so differently interpreted and visualized."
   - "two individual perspectives of the same area."

7. Student of: da Vinci → Verrocchio (Figure 18d). This relation was considered interesting for three main reasons:

1. The relation described a popular artist. Example comments that reflected this were:
   - "da Vinci is an artist whose name I recognize [...]"
2. The relation helped to understand the artworks through the artists. Example comments that reflected this were:
   - "Interesting to see that Leonardo da Vinci has a similar way of portraying people like his teacher"
   - "you can see the influences of the teacher on his student"
3. The relation helped to understand the artists' perspective. Example comments that reflected this were:
   - "da Vinci is an artist whose name I recognize, and contextualizing the other one as his mentor makes me more interested in him"

8. Same sponsor: Lorenzo de' Medici (Figure 18e). This relation was considered interesting for three main reasons:

1. The relation was unexpected. Example comments that reflected this were:
   - "I guess you rarely think about things such as "who sponsored this" when you're looking at a painting."
   - "I never think about the patrons behind great works!"
2. The relation helped to understand the artworks through their sponsor. Example comments that reflected this were:
   - "I found this interesting because patronage is very relevant for the development of art, and it is interesting to see how art is influenced by its sponsors."
3. The relation helped to understand the sponsor's perspective. Example comments that reflected this were:
   - "this shows what kind of art Lorenzo de'[]Medici sponsored, in the sense to know what kind of art caught his eye."

9. Same occupation: Botanist (Figure 18f). This relation was considered interesting for two main reasons:

1. The relation was unexpected. Example comments that reflected this were:

- "I knew about da Vinci, but Carus I had no idea, that's cool"
- "that sounds rare"
- "A very cool fact! I like this one a lot because it is something quite obs[c]ure to link these two artists."
- "This isn't a commonly known fact of either artist (meaning, it wouldn't exactly be in the elevator pitch version of their life stories)"
- "I had no idea da Vinci was a botanist"

2. The relation helped to understand the artworks through the artists. Example comments that reflected this were:
    - "The lack in detail of the trees for da Vinci and the depth of detail in the trees (obviously because it's the main focus there) for Carus somehow intrigues me"
    - "would explain why they paint plants so well"

10. Same medical condition: Deafness (Figure 18g). This relation was considered interesting for three main reasons:

1. The relation was unexpected. Example comments that reflected this were:
    - "Again, not very common or predictable. From the paintings you wouldn't know the artists were deaf."
    - "It's something relatively uncommon that connects these two men."
    - "uncommon link"
2. Relation helps to understand the artworks through the artists. Example comments that reflected this were:
    - "There is a lot of detail in both paintings, maybe they have more attention for detail due to being deaf?"
    - "I think it's interesting to see how such a disability would reflect on their art, and it makes comparing the two pieces a bit more fun"
3. Relation helps to understand the artists' perspective. Example comments that reflected this were:
    - "This [is] not necessarily connected to the painting, more towards the way and understanding of how these painters perceived their worlds. Can be fascinating."
    - "I would imagine that would greatly impact their art style and/or personal perception of the world, giving a unique perspective of their subjects."

Appendix D Best-performing variables for evaluated artwork relation interestingness heuristics

The best performance (i.e., lowest achieved Kendall tau distance) for each of the top 15 Wikidata-based variables included in 1-variable, 2-variable, 3-variable and 4-variable heuristics is listed below.

D.1 Best-performing 15 variables for 1-variable artwork relation interestingness heuristics

1. Referred entity commonness (ranked as uninteresting): 0.373
2. Property commonness (ranked as uninteresting): 0.377
3. activity (Q1914636, ranked as interesting): 0.469
4. person (Q215627, ranked as interesting): 0.482
5. Entity edges count (ranked as interesting): 0.483
6. behavior (Q9332, ranked as interesting): 0.484
7. Entity Wikipedia pageviews (ranked as interesting): 0.489

8. consumer (Q72638, ranked as interesting): 0.489
9. heterotroph (Q159344, ranked as interesting): 0.489
10. individual (Q795052, ranked as interesting): 0.489
11. natural person (Q154954, ranked as interesting): 0.489
12. omnivore (Q164509, ranked as interesting): 0.489
13. organism (Q7239, ranked as interesting): 0.489
14. subject (Q830077, ranked as interesting): 0.489
15. item with given name property (Q18336849, ranked as interesting): 0.491

D.2 Best-performing 15 variables for 2-variable artwork relation interestingness heuristics

1. Referred entity commonness (ranked as uninteresting): 0.329
2. behavior (Q9332, ranked as interesting): 0.329
3. activity (Q1914636, ranked as interesting): 0.33
4. cultural movement (Q2198855, ranked as interesting): 0.336
5. activism (Q203764, ranked as interesting): 0.337
6. group action (Q3533467, ranked as interesting): 0.337
7. social action (Q769620, ranked as interesting): 0.337
8. social movement (Q49773, ranked as interesting): 0.337
9. humanities (Q80083, ranked as interesting): 0.34
10. Property commonness (ranked as uninteresting): 0.341
11. person (Q215627, ranked as interesting): 0.341
12. art movement (Q968159, ranked as interesting): 0.343
13. consumer (Q72638, ranked as interesting): 0.347
14. heterotroph (Q159344, ranked as interesting): 0.347
15. individual (Q795052, ranked as interesting): 0.347

D.3 Best-performing 15 variables for 3-variable artwork relation interestingness heuristics

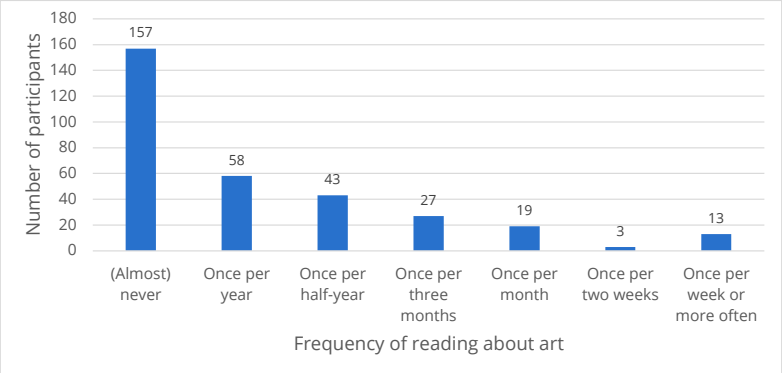
1. Referred entity commonness (ranked as uninteresting): 0.308
2. GLAM (Q1030034, ranked as uninteresting): 0.308
3. behavior (Q9332, ranked as interesting): 0.308
4. Property commonness (ranked as uninteresting): 0.308
5. person (Q215627, ranked as interesting): 0.308
6. humanities (Q80083, ranked as interesting): 0.308
7. organization (Q43229, ranked as uninteresting): 0.31
8. museum (Q33506, ranked as uninteresting): 0.31
9. tourist attraction (Q570116, ranked as uninteresting): 0.31
10. structure (Q6671777, ranked as uninteresting): 0.311
11. human-made geographic feature (Q811430, ranked as uninteresting): 0.312
12. art museum (Q207694, ranked as uninteresting): 0.312
13. museum of culture (Q28737012, ranked as uninteresting): 0.312
14. activity (Q1914636, ranked as interesting): 0.312
15. cultural movement (Q2198855, ranked as interesting): 0.312

D.4 Best-performing 15 variables for 4-variable artwork relation interestingness heuristics

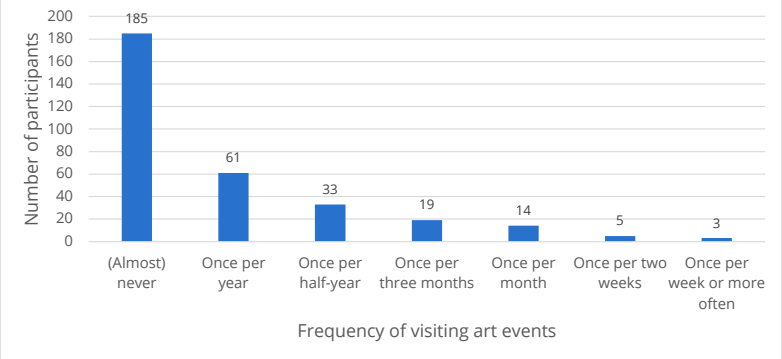
1. Referred entity commonness (ranked as uninteresting): 0.296
2. GLAM (Q1030034, ranked as uninteresting): 0.296
3. behavior (Q9332, ranked as interesting): 0.296
4. Olympic Games (Q5389, ranked as interesting): 0.296
5. Summer Olympic Games (Q159821, ranked as interesting): 0.296
6. competition (Q476300, ranked as interesting): 0.296
7. international competition (Q44637051, ranked as interesting): 0.296
8. multi-sport event (Q167170, ranked as interesting): 0.296
9. recurring sporting event (Q18608583, ranked as interesting): 0.296
10. sports competition (Q13406554, ranked as interesting): 0.296

11. structure (Q6671777, ranked as uninteresting): 0.297
12. human-made geographic feature (Q811430, ranked as uninteresting): 0.297
13. biologist (Q864503, ranked as interesting): 0.297
14. creator (Q2500638, ranked as interesting): 0.297
15. erudite (Q20826540, ranked as interesting): 0.297

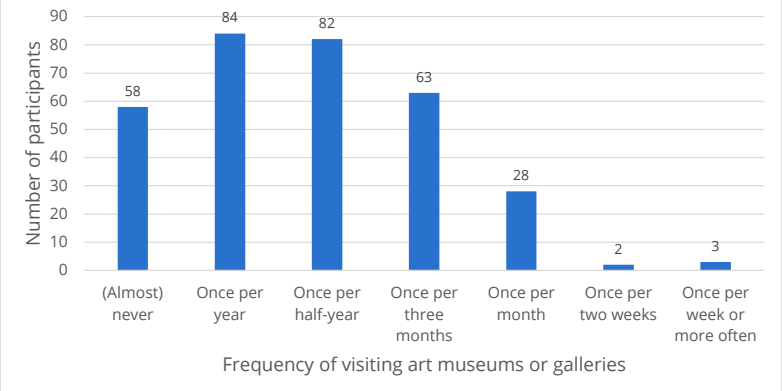
Appendix E Participant interest in art and art museums



(a) Frequency with which participants read books, magazines or catalogues about art.



(b) Frequency with which participants (virtually) visited events about art or art history (seminars, projects, festivals, etc.).



(c) Frequency with which participants visited art museums or galleries before the COVID-19 pandemic.

Figure 19: Distribution of participant answers to three questions concerning interest in art and art museums.

Appendix F Distribution of how participants heard about our experiment

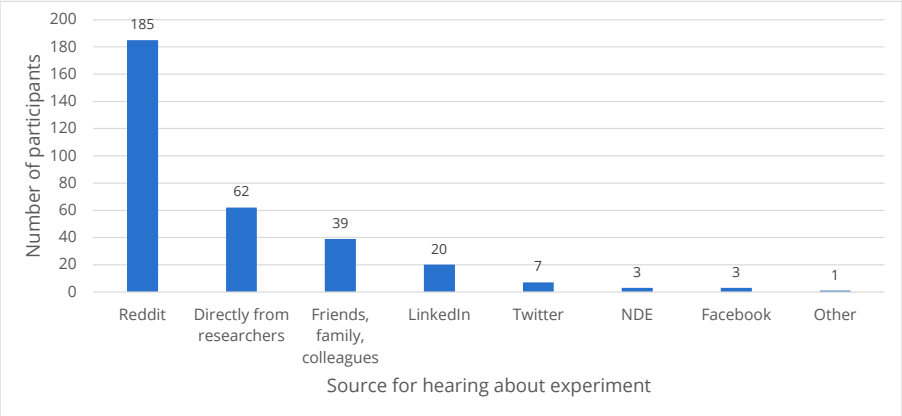


Figure 20: Distribution of how participants heard about our experiment on artwork relation interestingness. Participants from Reddit joined from /r/SampleSize. NDE stands for "Netwerk Digitaal Erfgoed", the Dutch Digital Heritage Network, who included a link to the experiment on their website and in their newsletter.

Appendix G Presented relations for 11 participant groups

Participants of our experiment were placed in one of 11 participant groups, which determined the presented artwork relations they were asked to rate on interestingness. An overview of the (number of) relations that each group rated is presented below.

Group #1 (26 relations): Relations #1 - #26.
Group #2 (26 relations): Relations #14 - #39.
Group #3 (26 relations): Relations #27 - #52.
Group #4 (26 relations): Relations #40 - #64.
Group #5 (24 relations): Relations #53 - #76.
Group #6 (24 relations): Relations #65 - #88.
Group #7 (24 relations): Relations #77 - #100.
Group #8 (24 relations): Relations #89 - #112.
Group #9 (24 relations): Relations #101 - #124.
Group #10 (24 relations): Relations #113 - #136.
Group #11 (25 relations): Relations #125 - #136 & #1 - #13.

Appendix H 75 selected potentially interesting artwork and artist Wikidata properties for relation identification

We, together with a professional curator (Kenney), did not consider all Wikidata properties likely to be of use for identifying interesting artwork relations. The lists of pre-selected Wikidata properties that we deemed likely to help identify potentially interesting artwork (or artist) relations are presented below.

H.1 33 selected potentially interesting artwork Wikidata properties for relation identification

1. after a work by (P1877)

2. award received (P166)
3. based on (P144)
4. cause of destruction (P770)
5. commissioned by (P88)
6. coordinates of the point of view (P1259)
7. country (P17)
8. country of origin (P495)
9. date depicted (P2913)
10. dedicated to (P825)
11. depicts (P180)
12. derivative work (P4969)
13. exhibition history (P608)
14. fabrication method (P2079)
15. genre (P136)
16. inception (P571)
17. inspired by (P941)
18. location (P276)
19. location of creation (P1071)
20. location of discovery (P189)
21. location of the point of view (P7108)
22. main subject (P921)
23. material used (P186)
24. movement (P135)
25. named after (P138)
26. narrative location (P840)
27. owned by (P127)
28. pendant of (P1639)
29. price (P2284)
30. religion (P140)
31. significant event (P793)
32. sitter (P2634)
33. time period (P2348)

H.2 42 selected potentially interesting artist Wikidata properties for relation identification

1. award received (P166)
2. candidacy in election (P3602)
3. cause of death (P509)
4. child (P40)
5. conflict (P607)
6. contributed to creative work (P3919)
7. convicted of (P1399)
8. date of birth (P569)
9. date of burial or cremation (P4602)
10. date of death (P570)
11. educated at (P69)
12. employer (P108)
13. family (P53)
14. godparent (P1290)
15. has works in the collection (P6379)
16. influenced by (P737)
17. instrument (P1303)
18. lifestyle (P1576)
19. manner of death (P1196)
20. medical condition (P1050)
21. member of political party (P102)
22. mother (P25)
23. movement (P135)
24. nominated for (P1411)
25. occupation (P106)

26. participant in (P1344)
27. place of birth (P19)
28. place of burial (P119)
29. place of death (P20)
30. political ideology (P1142)
31. position held (P39)
32. relative (P1038)
33. religion (P140)
34. sexual orientation (P91)
35. sibling (P3373)
36. sponsor (P859)
37. sport (P641)
38. spouse (P26)
39. student (P802)
40. student of (P1066)
41. unmarried partner (P451)
42. work period (P2031 and P2032)

Appendix I Overview of 136 potentially interesting artwork relations included in ground truth dataset

Below, we list the unique IDs of all 136 artwork relations included in our ground truth dataset, along with their respective descriptions as presented to participants of our experiment.

I.1 Overview of 24 manually defined artwork relations by Kenney

Relation ID	**Relation description**
avonduur_untitled-masque	The mask made by Seabrook was used directly in Avonduur by Moesman.
de-peer_dali	In De Peer, Dalí's influence can be seen in the flat, pale, featureless landscape with its floating figure and seemingly random elements such as the pear.
ernst-carrington-relationship	Max Ernst and Leonora Carrington were in a working and personal relationship between 1937-1939. They lived in Saint Martin d'Ardeche together and painted several portraits of each other.
ernst-tanning-relationship	Max Ernst and Dorothea Tanning married in 1946, and were in a working and personal relationship from 1942-1976 (when Ernst died). They painted several portraits of each other.
famous-surrealists	Man Ray and Max Ernst are two of the most famous surrealists.
fini-carrington	Leonora Carrington and Leonor Fini were close friends, often working together.
gemini-in-orchard_ernst	In this painting you see the technique of frottage, which was repopularized by Ernst and almost certainly passed on to Carrington through him. Carrington and Ernst were in personal relationship, but not when this painting was made.
important-women-surrealists	Leonora Carrington and Leonor Fini belong to the list of surrealism's most important woman painters.
joie-de-vivre_carrington	Max Ernst created this artwork for Leonora Carrington.
marquis-de-sade	Leonor Fini and Hans Bellmer were obsessed with Marquis de Sade.
miller-cahun	Miller and Cahun were both non-male surrealist photographers, and knew each other. They explored the female body from a unique point of view, removing the male gaze. They allowed the female body, nude or otherwise, to exist on its own terms.
moesman_dali-magritte	Moesman is known to have purchased several Surrealist magazines, such as the Belgian Surrealist publication Varietes. In the January 1929 special issue, Moesman encountered photographic reproductions of Surrealist works by Dalí, Ernst, Magritte, di Chirico, Roy, etc. These famous surrealists had an immediate effect on Moesman, who began to experiment with avant-garde composition, inserting surrealist tropes into his budding oeuvre.

moesman-dali-stedelijk	Moesman saw paintings by Dalí and Magritte at the Stedelijk museum's 1932 traveling Surrealist exhibition.
nue-couchee_ernst	Nue Couchée was made while Tanning was married to Max Ernst.
ontmoeting-dali	Dalí's work had a direct influence on Ontmoeting and is recognizable in visual cues such as the used color scheme or the flatness of the landscape.
ray-miller-relationship	Man Ray and Lee Miller were in a relationship between 1929-1932.
ray-miller-teacher	Man Ray was Lee Miller's teacher and employer while they were in a relationship from 1929-1932.
ray-seabrook-working-relationship	Man Ray and William Seabrook worked together.
relation_de-peer_ontmoeting	We see a drastic change in the coloring of Moesman's paintings around 1932. This occurred immediately after Moesman saw a Dalí painting in real life for the first time, at an exhibition at the Stedelijk in Amsterdam. Moesman's early paintings were inspired by black-and-white photographs of surrealist paintings. When Moesman saw the real thing, he immediately updated his palette and composition. Despite merely two years' difference between De Peer and Ontmoeting, they could be by two different artists.
relation_fetishism-female-body-destruction	These artworks share a thematic connection: They explore fetishism and the destruction/deconstruction of the female body.
relation_mythical-creatures	Again, the gemini are in the orchard and La Bergère des sphinx both display mythical creatures.
seabrook_miller-au-collier	Seabrook designed and made the collar Lee Miller is wearing, and is also in the picture himself.
surrealist-summer	Salvador Dalí and René Magritte met in Paris in 1929. In August of the same year, at Dalí's invitation, Magritte travels to Cadaqués, the Spanish painter's home base. This surrealist summer - which also includes visits by Éluard, Miró and Buñuel - will prove decisive.
violent-objectifying-work	Hans Bellmer and Joop Moesman took objectifying, violent attitudes towards women and the female body.

Table 4: IDs and descriptions of 24 artwork relations manually defined by Kenney.

I.2 Overview of 112 automatically identified artwork relations

Relation ID	**Relation description**
afterAWorkBy-Anthony van Dyck	Prince Rupert of the Rhine? and Katherine Manners were both strongly inspired by a work by Anthony van Dyck.
awardReceived-Knight of the Legion of Honour	Henri Félix Emmanuel Philippoteaux and Jean Auguste Dominique Ingres both received the Knight of the Legion of Honour award.
awardReceived-Wynne Prize	Spring Frost and Morning light both received the Wynne Prize award.
basedOn-Greek mythology	The Triumph of Bacchus and Amor Vincit Omnia were both based on Greek mythology.
basedOn-Rape of Europa	Rape of Europa and The Abduction of Europa were both based on Rape of Europa.
candidacyInElection-1900 United Kingdom general election	Winston Churchill and Leverton Harris were both candidates in the 1900 United Kingdom general election.
causeOfDeath-cancer	John William Waterhouse and Lee Miller both died because of: cancer.
causeOfDeath-cerebral hemorrhage	Leonardo da Vinci and Carl Larsson both died because of: cerebral hemorrhage.
causeOfDeath-plague	Andrea del Sarto and Giorgione both died because of: plague.
causeOfDestruction-conflagration	Officers of the Amsterdam guild of gold- and silversmiths in 1627 and Water-Lily Pond were both destructed because of conflagration.

child-Jan Brueghel the Elder-Pieter Brueghel the Elder	Jan Brueghel the Elder was the child of Pieter Brueghel the Elder.
commissionedBy-Napoleon	The Coronation of Napoleon and Bonaparte, Premier Consul were both commissioned by Napoleon.
commissionedBy-Tribunale della Mercanzia	Fortitude and Charity were both commissioned by Tribunale della Mercanzia.
conflict-Franco-Prussian War	Édouard Manet and Pierre-Auguste Renoir both experienced: Franco-Prussian War.
conflict-World War I	Adolf Hitler and Winston Churchill both experienced: World War I.
conflict-World War II	Adolf Hitler and Winston Churchill both experienced: World War II.
contributedToCreativeWork-Album amicorum of Jacobus Heyblocq (1623-1690), rector of the Latin school in Amsterdam	Rembrandt and Jan van de Cappelle both contributed to the same work: Album amicorum of Jacobus Heyblocq (1623-1690), rector of the Latin school in Amsterdam.
convictedOf-sodomy	Elmyr de Hory and Simeon Solomon were both convicted of sodomy.
country-France	The Crowning with Thorns and Liberty Leading the People are both currently located in France.
countryOfOrigin-Italy	Virgin and Child with Saint Anne and Madonna and Child were both created in Italy.
dateOfBirth-1201	Dietisalvi di Speme and Maestro di San Martino were both born in the year 1201.
dateOfBirthWithoutYear-9 okt.	Holger Drachmann and Simeon Solomon were both born on 9 okt. [sic].
dateOfBirthWithoutYear-Apr 24	Leonardo da Vinci and Cornelis Dusart were both born on Apr 24.
dateOfDeath-1300	Master of Saint Francis and Rinaldo da Siena both died in the year 1300.
depicts-Mary Magdalene	Braque Triptych and Pietà of Villeneuve-lès-Avignon both depict: Mary Magdalene.
depicts-mountain	The Madonna of the Rabbit and Napoleon at the Battle of Rivoli (January 14, 1797) both depict: mountain.
depicts-murder	Grabow Altarpiece and The Death of Marat both depict: murder.
derivativeWork-Laughing fisherboy (pastiche)	Laughing Fisherboy and Left-handed violin player in a dune landscape are both derivative works of Laughing fisherboy (pastiche).
educatedAt-University of Florence	Leonardo da Vinci and Michelangelo were both educated at University of Florence.
employer-Ludovico Sforza	Leonardo da Vinci and Giovanni Ambrogio de Predis were both employed by Ludovico Sforza.
exhibitionHistory-Exposition Universelle of 1889	Lola de Valence and Olympia were both exhibited at Exposition Universelle of 1889.
exhibitionHistory-Tate	Light and Colour (Goethe's Theory) – The Morning after the Deluge – Moses Writing the Book of Genesis and Dedham Lock and Mill were both exhibited at Tate.
experiment-dedicatedTo-creator-relationship-alt	Hommage to Delacroix is dedicated to Eugène Delacroix.
experiment-dedicatedTo-creator-relationship-van-gogh-gauguin	Self-Portrait Dedicated to Paul Gauguin is dedicated to Paul Gauguin.
experiment-depicts-creator-relationship	The Balcony depicts the French painter Berthe Morisot.
fabricationMethod-fresco painting	The Battle of the Milvian Bridge and The Women of Darius's Family before Alexander the Great were both fabricated using the same method: fresco painting.
fabricationMethod-oil painting	Circe Offering the Cup to Ulysses and The Oath of the Horatii were both fabricated using the same method: oil painting.

family-Guardi family	Francesco Guardi and Giacomo Guardi both belong to the Guardi family.
genre-portrait	La maja desnuda and Adele Bloch-Bauer II both belong to the portrait genre.
godparent-Ernest II, Duke of Saxe-Coburg and Gotha-Princess Alice of the United Kingdom	Ernest II, Duke of Saxe-Coburg and Gotha was the godparent of Princess Alice of the United Kingdom.
hasWorksInTheCollection-Louvre Museum	Leonardo da Vinci and Jean Auguste Dominique Ingres both have works in the collection of the Louvre Museum.
hasWorksInTheCollection-Musée de la civilisation	Francisco de Zurbarán and Jacques-Louis David both have works in the collection of the Musée de la civilisation.
inceptionYear-1200	Six Persimmons and Madonna with child were both created in the year 1200.
influencedBy-Edward Hopper-Robert Henri	Edward Hopper was influenced by Robert Henri.
influencedBy-Paul Cézanne	Vincent van Gogh and Amedeo Modigliani were both influenced by Paul Cézanne.
inspiredBy-American Civil War	Between the Lines and Nearing the End were both inspired by American Civil War.
inspiredBy-Luncheon on the Grass-The Tempest	Luncheon on the Grass was inspired by The Tempest.
inspiredBy-Pastoral Concert	Luncheon on the Grass and The Madonna of the Rabbit were both inspired by Pastoral Concert.
inspiredBy-Sleeping Venus	Venus of Urbino and Resting Venus were both inspired by Sleeping Venus.
instrument-violin	Jean Auguste Dominique Ingres and Paul Klee both played the violin.
keyFiguresMovement-Dada-Ray-Ernst-creator-relation	Max Ernst and Man Ray are both considered key figures of the Dada movement.
lifestyle-vegetarianism	William Blake and Adolf Hitler were both associated with the same lifestyle: vegetarianism.
location-Belgium	Arnolfini Portrait and The Descent from the Cross. were both located in Belgium at some point in time.
location-Louvre Museum	The Fife Player and Olympia were both located in Louvre Museum at some point in time.
locationOfCreation-Florence	Visitation of Carmignano and Saint Bernardino of Siena Preaching were both created in Florence.
locationOfDiscovery-Scuola dei Laneri	Disputation of St Stephen and The Stoning of St Stephen were both discovered at the same place: Scuola dei Laneri.
locationOfThePointOfView-Pincian Hill	View from Monte Pincio and View of Rome from Monte Pincio were both painted from the same point of view: Pincian Hill.
mainSubject-Crucifixion of Jesus	Crucifixion and The Yellow Christ both explore Crucifixion of Jesus as a subject.
mainSubject-danse macabre	The Dance of Death and Dance of the Death (Lübeck) both explore danse macabre as a subject.
mainSubject-family	The Family of Philip V and Marie Antoinette and Her Children both explore family as a subject.
mannerOfDeath-accident	Umberto Boccioni and Ivan Aguéli both died because of: accident.
mannerOfDeath-natural causes	Hans Bellmer and Lee Miller both died because of: natural causes.
mannerOfDeath-suicide	Vincent van Gogh and Rosso Fiorentino both died because of: suicide.
materialUsed-gold leaf	Portrait of Adele Bloch-Bauer I and The Kiss both use gold leaf as a material.
materialUsed-oil paint	Harlequin with Mask and A Deacon both use oil paint as a material.
materialUsed-poplar wood	Assumption of the Virgin and Virgin with the Seated Child both use poplar wood as a material.

medicalCondition-deafness	Francisco Goya and Hendrick Avercamp both had the same medical condition: deafness.
memberOfPoliticalParty-Conservative Party	Leverton Harris and Winston Churchill were both members of the same political party: Conservative Party.
memberOfPoliticalParty-Union of the Russian People	Viktor Mikhailovich Vasnetsov and Mikhail Nesterov were both members of the same political party: Union of the Russian People.
mother-Cornelia Scheffer-Hendrik Scheffer	Cornelia Scheffer was the mother of Hendrik Scheffer.
movement-High Renaissance-creators	Titian and Andrea del Sarto both belong to the High Renaissance movement.
movement-High Renaissance-objects	The Last Supper and The Virgin and Child with Saint Anne both belong to the High Renaissance movement.
namedAfter-Samuel Foote	Samuel Foote and Samuel Foote (1720-1777) (after Reynolds) were both named after Samuel Foote.
narrativeLocation-Ancient Rome	The narratives of these works both took place in Ancient Rome.
nominatedFor-Nobel Peace Prize	Adolf Hitler and Nicholas Roerich were both nominated for the Nobel Peace Prize.
nominatedFor-Nobel Prize in Literature	Winston Churchill and Rabindranath Tagore were both nominated for the Nobel Prize in Literature.
occupation-botanist	Leonardo da Vinci and Carl Gustav Carus were both active as botanist.
occupation-painter	Max Ernst and Leonor Fini were both active as painter.
ownedBy-Francis I of France	Mona Lisa and The Virgin and Child with Saint Anne were both owned by Francis I of France.
participantIn-1928 Summer Olympics	Max Liebermann and Isaac Israëls were both participants in the 1928 Summer Olympics.
participantIn-documenta III	Max Ernst and Hans Bellmer were both participants in the documenta III.
pendantOf-La maja desnuda-The Clothed Maja	La maja desnuda is the pendant of The Clothed Maja.
placeOfBirth-Breda	Pieter Brueghel the Elder and Louis de Moni were both born in Breda.
placeOfBurial-Venice	Titian and Giambattista Pittoni were both buried in Venice.
placeOfDeath-Venice	Francesco Guardi and Jacopo Tintoretto both died in Venice.
politicalIdeology-anarchism	John Cage and Ivan Aguéli both share the same political ideology: anarchism.
positionHeld-court painter	Diego Velázquez and Titian both held the same position: court painter.
positionHeld-mayor of a place in the Netherlands	Gerard ter Borch and Isaac van Swanenburg both held the same position: mayor of a place in the Netherlands.
relative-Pieter Brueghel the Elder-Pieter Coecke van Aelst	Pieter Brueghel the Elder was a relative of Pieter Coecke van Aelst.
religion-atheism	Leonardo da Vinci and Pablo Picasso both shared the religious views of atheism.
religion-Buddhism	Muqi and Bada Shanren both shared the religious views of Buddhism.
religion-Christianity	The Virgin and Child with Saint Anne and Madonna with child both belong to the same religion: Christianity.
religion-Islam	Nasreddine Dinet and Ivan Aguéli both shared the religious views of Islam.
same-coordinates-pov-experiment-relation	The point of view taken in The Prison of Copenhagen and View Towards Lyngby is within 12km of each other.
same-date-burial-cremation-experiment-relation	Cornelis Bol and Frans Hals were both buried or cremated in 1666.
same-date-depicted-experiment-relation	The Burning of the Houses of Lords and Commons and The Eruption of the Great Geyser in Iceland in 1834 both depict the year 1834.

same-price-experiment-relation	Nu couché (sur le côté gauche) and Adele Bloch-Bauer II were both sold for approximately $150 million in 2018 and 2016 respectively.
same-price-experiment-relation-alt	The King's birthday. The Royal Guard in red gala in Østergade and View through a door to running figures were both sold for 2.1 million Danish krone (approximately $340.000) in 2017.
sexualOrientation-lesbian	Rosa Bonheur and Claude Cahun both identified as lesbian.
sibling-Masaccio-Giovanni di ser Giovanni Guidi	Masaccio was a sibling of Giovanni di ser Giovanni Guidi.
significantEvent-art theft	Light and Colour (Goethe's Theory) – The Morning after the Deluge – Moses Writing the Book of Genesis and Impression, Sunrise were both involved in a significant event: art theft
sitter-Emma Hill	Emma Hill posed as a model for both these artworks.
sponsor-Lorenzo de' Medici	Sandro Botticelli and Michelangelo were both sponsored by Lorenzo de' Medici.
sport-fencing	Aniello Falcone and Joanni Maurice Perronet both played the same sport: fencing.
spouse-Gina Schnaufer Knee	Alexander Brook and Ward Lockwood were both married to Gina Schnaufer Knee.
student-Pontormo	Leonardo da Vinci and Andrea del Sarto both taught Pontormo.
studentOf-Andrea Verrocchio	Leonardo da Vinci and Pietro Perugino were both students of Andrea Verrocchio.
studentOf-Leonardo da Vinci-Andrea Verrocchio	Leonardo da Vinci was a student of Andrea Verrocchio.
timePeriod-Baroque	The Milkmaid and Girl with a Pearl Earring both belong to the Baroque time period.
unmarriedPartner-Alice Ozy	Thomas Couture and Gustave Doré were both in a relationship with Alice Ozy.
unmarriedPartner-Pierre-Auguste Renoir-Frédérique Vallet-Bisson	Pierre-Auguste Renoir was in a relationship with Frédérique Vallet-Bisson.
workPeriod-approximately-equal-experiment-relation	Per Lindhberg and Otto Boetticher were active during the same period, during 1851 - 1858 and 1851 - 1857 respectively.

Table 5: IDs and descriptions of 112 automatically identified artwork relations.

Appendix J SPARQL queries

J.1 SPARQL query for retrieving available metadata for Wikidata entities

```
SELECT ?object ?objectTitle
?propLabel ?propValue ?propValueLabel
?qualifierLabel ?qualifierValueLabel WHERE {
  VALUES ?object {
    wd:Q219831 # Example: The Night Watch by Rembrandt
  }
  ?object rdfs:label ?objectTitle.
  FILTER((LANG(?objectTitle)) = "en")

  ?object ?p ?statement.
  ?statement ?statementProp ?propValue.
  ?prop wikibase:claim ?p;
    wikibase:statementProperty ?statementProp.
  OPTIONAL {
    ?statement ?q ?qualifierValue.
    ?qualifier wikibase:qualifier ?q.
```

```
  }
  SERVICE wikibase:label { bd:serviceParam wikibase:language "en". }
}
ORDER BY (?prop) (?statement) (?propValue)
```

J.2 SPARQL query for retrieving Wikidata paintings that were notable works of their creator, and had an image available

```
SELECT ?painting ?paintingLabel ?creator ?creatorLabel
WHERE
{
  ?painting wdt:P31 wd:Q3305213 . # Instance of: Painting
  ?painting wdt:P170 ?creator . # Painting was created by... a creator
  ?creator wdt:P800 ?painting . # Painting is a "notable work" of this creator
  ?painting wdt:P18 ?image . # Painting has an image
  SERVICE wikibase:label {
    bd:serviceParam wikibase:language "[AUTO_LANGUAGE],en".
  }
}
```

J.3 SPARQL query for retrieving artwork relations' referred Wikidata classes

```
SELECT DISTINCT ?referredEntity ?referredEntityLabel ?instanceClass ?instanceClassLabel
?instanceSubclass ?instanceSubclassLabel ?instanceSubclass2 ?instanceSubclass2Label
?instanceSubclass3 ?instanceSubclass3Label ?directSubclass ?directSubclassLabel
?directSubclass2 ?directSubclass2Label ?directSubclass3 ?directSubclass3Label
?directSubclass4 ?directSubclass4Label WHERE {
  VALUES ?referredEntity {
    wd:Q12418 # Example: Mona Lisa by da Vinci
  }
  OPTIONAL {
    ?referredEntity wdt:P31 ?instanceClass.
    OPTIONAL {
      ?instanceClass wdt:P279 ?instanceSubclass.
      OPTIONAL {
        ?instanceSubclass wdt:P279 ?instanceSubclass2.
        OPTIONAL { ?instanceSubclass2 wdt:P279 ?instanceSubclass3. }
      }
    }
  }
  OPTIONAL {
    ?referredEntity wdt:P279 ?directSubclass.
    OPTIONAL {
      ?directSubclass wdt:P279 ?directSubclass2.
      OPTIONAL {
        ?directSubclass2 wdt:P279 ?directSubclass3.
        OPTIONAL { ?directSubclass3 wdt:P279 ?directSubclass4. }
      }
    }
  }
  SERVICE wikibase:label { bd:serviceParam wikibase:language "[AUTO_LANGUAGE],en". }
}
```

References

Antoniou, A., Katifori, A., Roussou, M., Vayanou, M., Karvounis, M., & Pujol-Tost, L. (2016). Capturing the Visitor Profile for a Personalized Mobile Museum Experience: An Indirect Approach, 11.

Ardissono, L., Kuflik, T., & Petrelli, D. (2012). Personalization in cultural heritage: The road travelled and the one ahead. *User Modeling and User-Adapted Interaction*, *22*(1-2), 73–99. https://doi.org/10.1007/s11257-011-9104-x

Ballantyne, R., & Uzzell, D. (2011). Looking Back and Looking Forward: The Rise of the Visitor-centered Museum: The Visitor-centered Museum. *Curator: The Museum Journal*, *54*(1), 85–92. https://doi.org/10.1111/j.2151-6952.2010.00071.x

Bruni, L. E., Daga, E., Damiano, R., Kuflik, T., Lieto, A., Gangemi, A., Pescarin, S., Mulholland, P., Peroni, S., & Wecker, A. (2020). Towards Advanced Interfaces for Citizen Curation, 6.

Carvalho, D. R., Freitas, A. A., & Ebecken, N. (2005). Evaluating the Correlation Between Objective Rule Interestingness Measures and Real Human Interest [Series Title: Lecture Notes in Computer Science]. In D. Hutchison, T. Kanade, J. Kittler, J. M. Kleinberg, F. Mattern, J. C. Mitchell, M. Naor, O. Nierstrasz, C. Pandu Rangan, B. Steffen, M. Sudan, D. Terzopoulos, D. Tygar, M. Y. Vardi, G. Weikum, A. M. Jorge, L. Torgo, P. Brazdil, R. Camacho, & J. Gama (Eds.), *Knowledge Discovery in Databases: PKDD 2005* (pp. 453–461). Springer Berlin Heidelberg. https://doi.org/10.1007/11564126_45

Cheng, G., Zhang, Y., & Qu, Y. (2014). Explass: Exploring Associations between Entities via Top-K Ontological Patterns and Facets [Series Title: Lecture Notes in Computer Science]. In P. Mika, T. Tudorache, A. Bernstein, C. Welty, C. Knoblock, D. Vrandečić, P. Groth, N. Noy, K. Janowicz, & C. Goble (Eds.), *The Semantic Web – ISWC 2014* (pp. 422–437). Springer International Publishing. https://doi.org/10.1007/978-3-319-11915-1_27

Falk, J. H. (2006). An Identity-Centered Approach to Understanding Museum Learning. *Curator: The Museum Journal*, *49*(2), 151–166. https://doi.org/10.1111/j.2151-6952.2006.tb00209.x

Geng, L., & Hamilton, H. J. (2006). Interestingness measures for data mining: A survey. *ACM Computing Surveys*, *38*(3), 9. https://doi.org/10.1145/1132960.1132963

Harris, G., Panangadan, A., & Prasanna, V. K. (2015). Learning of Performance Measures from Crowd-Sourced Data with Application to Ranking of Investments [Series Title: Lecture Notes in Computer Science]. In T. Cao, E.-P. Lim, Z.-H. Zhou, T.-B. Ho, D. Cheung, & H. Motoda (Eds.), *Advances in Knowledge Discovery and Data Mining* (pp. 538–549). Springer International Publishing. https://doi.org/10.1007/978-3-319-18038-0_42

Heim, P., Hellmann, S., Lehmann, J., Lohmann, S., & Stegemann, T. (2009). RelFinder: Revealing Relationships in RDF Knowledge Bases [Series Title: Lecture Notes in Computer Science]. In D. Hutchison, T. Kanade, J. Kittler, J. M. Kleinberg, F. Mattern, J. C. Mitchell, M. Naor, O. Nierstrasz, C. Pandu Rangan, B. Steffen, M. Sudan, D. Terzopoulos, D. Tygar, M. Y. Vardi, G. Weikum, T.-S. Chua, Y. Kompatsiaris, B. Mérialdo, W. Haas, ... W. Bailer (Eds.), *Semantic Multimedia* (pp. 182–187). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-10543-2_21

Heim, P., Lohmann, S., & Stegemann, T. (2010). Interactive Relationship Discovery via the Semantic Web [Series Title: Lecture Notes in Computer Science]. In D. Hutchison, T. Kanade, J. Kittler, J. M. Kleinberg, F. Mattern, J. C. Mitchell, M. Naor, O. Nierstrasz, C. Pandu Rangan, B. Steffen, M. Sudan, D. Terzopoulos, D. Tygar, M. Y. Vardi, G. Weikum, L. Aroyo, G. Antoniou, E. Hyvönen, A. ten Teije, ... T. Tudorache (Eds.), *The Semantic Web: Research and Applications* (pp. 303–317). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-13486-9_21

Hyvönen, E., & Rantala, H. (2021). Knowledge-based Relational Search in Cultural Heritage Linked Data [Publisher: Oxford University Press]. *Digital Scholarship in the Humanities (DSH)*.

Kirchgessner, M., Leroy, V., Amer-Yahia, S., & Mishra, S. (2016). Testing Interestingness Measures in Practice: A Large-Scale Analysis of Buying Patterns [arXiv: 1603.04792]. *arXiv:1603.04792 [cs]*. Retrieved May 13, 2021, from http://arxiv.org/abs/1603.04792

Kontonasios, K.-N., Spyropoulou, E., & Bie, T. D. (2012). Knowledge discovery interestingness measures based on unexpectedness [_eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/widm.1063]. *WIREs Data Mining and Knowledge Discovery*, *2*(5), 386–399. https://doi.org/https://doi.org/10.1002/widm.1063

Lin, F.-T., & Lin, Y.-C. (2017). An ontology-based expert system for representing cultural meanings: An example of an Art Museum. *2017 Pacific Neighborhood Consortium Annual Conference and Joint Meetings (PNC)*, 116–121. https://doi.org/10.23919/PNC.2017.8203531

Lohmann, S., Heim, P., Stegemann, T., & Ziegler, J. (2010). The RelFinder user interface: Interactive exploration of relationships between objects of interest. *Proceedings of the 15th international conference on Intelligent user interfaces - IUI '10*, 421. https://doi.org/10.1145/1719970.1720052

Mcgarry, K. (2005). A survey of interestingness measures for knowledge discovery. *The Knowledge Engineering Review*, *20*(1), 39–61. https://doi.org/10.1017/S0269888905000408

Musen, M. A. (2015). The protégé project: A look back and a look forward. *AI Matters*, *1*(4), 4–12. https://doi.org/10.1145/2757001.2757003

Ohsaki, M., Kitaguchi, S., Okamoto, K., Yokoi, H., & Yamaguchi, T. (2004). Evaluation of Rule Interestingness Measures with a Clinical Dataset on Hepatitis [Series Title: Lecture Notes in Computer Science]. In D. Hutchison, T. Kanade, J. Kittler, J. M. Kleinberg, F. Mattern, J. C. Mitchell, M. Naor, O. Nierstrasz, C. Pandu Rangan, B. Steffen, M. Sudan, D. Terzopoulos, D. Tygar, M. Y. Vardi, G. Weikum, J.-F. Boulicaut, F. Esposito, F. Giannotti, & D. Pedreschi (Eds.), *Knowledge Discovery in Databases: PKDD 2004* (pp. 362–373). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-30116-5_34

Perry, S., Roussou, M., Economou, M., Young, H., & Pujol, L. (2017). Moving beyond the virtual museum: Engaging visitors emotionally. *2017 23rd International Conference on Virtual System & Multimedia (VSMM)*, 1–8. https://doi.org/10.1109/VSMM.2017.8346276

Pinzi, V. (2014). Enriching news for supporting users information needs using schema-driven classification of entities and relations, 12.

Pujol, L., Roussou, M., Poulou, S., Balet, O., Vayanou, M., & Ioannidis, Y. (2011). Personalizing interactive digital storytelling in archaeological museums: The CHESS project, 15.

Rounds, J. (2004). Strategies for the Curiosity-Driven Museum Visitor. *Curator: The Museum Journal*, *47*(4), 389–412. https://doi.org/10.1111/j.2151-6952.2004.tb00135.x

Ruotsalo, T., & Hyvönen, E. (2007). A Method for Determining Ontology-Based Semantic Relevance [ISSN: 0302-9743, 1611-3349 Series Title: Lecture Notes in Computer Science]. In R. Wagner, N. Revell, & G. Pernul (Eds.), *Database and Expert Systems Applications* (pp. 680–688). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-74469-6_66

Saleh, B., & Elgammal, A. (2015). Large-scale Classification of Fine-Art Paintings: Learning The Right Metric on The Right Feature [arXiv: 1505.00855]. *arXiv:1505.00855 [cs]*. Retrieved May 21, 2021, from http://arxiv.org/abs/1505.00855

Specker, E., Forster, M., Brinkmann, H., Boddy, J., Pelowski, M., Rosenberg, R., & Leder, H. (2020). The Vienna Art Interest and Art Knowledge Questionnaire (VAIAK): A unified and validated measure of art interest and art knowledge. *Psychology of Aesthetics, Creativity, and the Arts*, *14*(2), 172–185. https://doi.org/10.1037/aca0000205

Stock, O., Zancanaro, M., Busetta, P., Callaway, C., Krüger, A., Kruppa, M., Kuflik, T., Not, E., & Rocchi, C. (2007). Adaptive, intelligent presentation of information for the museum visitor in PEACH. *User Modeling and User-Adapted Interaction*, *17*(3), 257–304. https://doi.org/10.1007/s11257-007-9029-6

Tan, P.-N., Kumar, V., & Srivastava, J. (2002). Selecting the right interestingness measure for association patterns. *Proceedings of the eighth ACM SIGKDD international conference on Knowledge discovery and data mining*, 32–41.

Wang, Y., Stash, N., Aroyo, L., Hollink, L., & Schreiber, G. (2009). Semantic relations for content-based recommendations. *Proceedings of the fifth international conference on Knowledge capture - K-CAP '09*, 209. https://doi.org/10.1145/1597735.1597786

Weil, S. E. (1999). From being about something to being for somebody: The ongoing transformation of the American museum [Publisher: JSTOR]. *Daedalus*, *128*(3), 229–258.

Wein, L. (2014). Visual recognition in museum guide apps: Do visitors want it? *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14*, 635–638. https://doi.org/10.1145/2556288.2557270