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Abstract. Medieval and Renaissance maps of the world were and worked as knowledge aggregators. The cosmographers identified, selected, and re-edited information about hundreds of places from a variety of literary, iconographic, and oral sources, and synoptically re-organized them in place names, cartouches, and drawings to be put on a map. This selection/aggregation process transformed the *mappa mundi* into a visual encyclopaedia (i.e. an all-around learning and thinking tool), where each geographical entry was able to generate narratives as a data gateway and an information hub for customs, commodities, and rulers of different peoples of the world. If we infer that the Renaissance people asked to the cosmographers to learn about the world as we go to search engines to find what we want, the reverse engineering of these works (as exemplified in this paper for the mid-fifteenth-century world map by Fra Mauro Camaldolese) can help to draw the connection between the traditional way to aggregate knowledge as a product (e.g. Fra Mauro's *mappa mundi*) and the modern way of using search engines and related internet services (i.e. their map services) to serve a similar purpose but in a better and more dynamic manner, placing crucial question, such as: How the same networks/people can bring new wealth and development, or war and poverty? Which are the dynamics of sustainability in international mechanisms?

Keywords: World Maps, Knowledge Aggregators, Web Search Engines

1. Introduction

In this paper, we present Frau Mauro's *mappa mundi* (map of the world) as a case study of how a medieval map can be understood as a knowledge aggregator, a knowledge engineering tool that allows its user to assemble information of different kinds from different sources, guided by what the user *wants to do* with the synthesized whole. The paper is a result of the research collaboration between Nanyang Technological University (Singapore) and Microsoft Research on "Augmenting Bing Search through Automatic Narratives in the Interactive Global Histories" started in 2014-2015 and based on Andrea Nanetti's ongoing research project Engineering Historical Memory[1]. EHM aims to generate narratives on the web that can be tested at the same level of rigor as scientific hypotheses and theories. The vision is that the generation of such narratives, supported by a new coherent ontology, automatically and in a scalable way, can revolutionize the practice of historical studies using web search engines and digital maps (Nanetti, Cheong, Filippov, 2013, p. 104).

In particular, places names in Medieval and Renaissance representations of the world were understood as *loci* (i.e. topics and gateways to topics linked one to the others from a variety of literary, visual, and oral sources) that provided the intellectual structure through which the user could gain access to all sort of information and narratives: from the shape and structure of the celestial and sublunary worlds, to ethnographical descriptions of people, cities, regions, animals and wonders, but also world trade of commodities, in particular spices, gold, silver, pearls, and precious stones, including the terrestrial and maritime routes, on which and through which they circulated (Woodward, 1987; Gautier Dalché, 1996; Bouloux, 2002; Hoogvliet, 2007; Cattaneo, 2008).

Figure 1. Fra Mauro's *mappa mundi*, ink and colors on several sheets of vellum, framed in two wooden frames, 223x233 cm (the circular frame set within the square has a diameter of about 196 cm), ca. 1450. Venice, Biblioteca Nazionale Marciana. It includes texts and images. Dispersed throughout the surface are about 3.000 inscriptions, with some 115.000 characters. Of these, some 200 – the rest being single place-names – make up a large cosmographical treatise that deals with natural philosophy, description of places and people, commercial geography, history, navigation and direction of expansion, and, finally, on what we can nowadays call methodological issues. In addition, Fra Mauro's world map also includes hundreds of images, representing cities, temples, funerary monuments, streets, and ships, as well as a scene in the lower left corner representing Earthly Paradise (Almagià, 1944; Gasparrini Leporace, 1956; Winter, 1962; Falchetta, 1995; Cattaneo, 2003; Falchetta, 2006; Cattaneo, 2011).

In Section 2, we reason what Fra Mauro's intentions might be in producing the *mappa mundi*, which shows itself to be a document of great value and importance for unpacking the three principal social and cultural processes that characterize the history of Venice in this period: the development of long-distance information networks; the foundation of a global economy in which Venice served as one of the leading protagonists; and, finally, an expansion—both physically and epistemologically—into the spaces and seas that earlier were not believed to be accessible to man. These are processes in which Venice played a determining role, with consequences for all of Europe, and for the *oikoumenē* of the fifteenth century (Abu-Lughod, 1989; Milanesi, 1993; Tenenti 1994).

By means of both the words and images, Fra Mauro's work synthesizes and recapitulates crucial aspects of fifteenth-century culture: Aristotelian-Christian cosmology, Aristotelian-Ptolemaic cosmography of the sublunar world, the chorography and geography of peoples and commerce, nautical and Ptolemaic cartography, ethnographies (mainly Marco Polo) and travel accounts, descriptions of the principal routes for the global commerce of spices, gold, and silver, as well as the histories of the ancient conquests of Alexander the Great and the recent ones of Tamerlane. All these frames of reference are linked together and developed within the epistemological unity of the *mappa mundi* (Cattaneo, 2003; Cattaneo, 2005; Falchetta, 2006; Cattaneo, 2011).

2. Deconstructing Fra Mauro's Map of the World

2.1. Fra Mauro's Map as Visual Aggregator

Fra Mauro's *mappa mundi* is an extraordinarily rich and ecumenical synthesis of different cartographic languages, namely, the classic Medieval *mappae mundi* combination of drawings and inscriptions, the portolan charts graphic syntax, the Ptolemaic outline of the far Eastern coast, and the circumnavigable Africa drawn according to a classic ancient tradition that, in Fra Mauro's time, was followed by several cosmographers, among which Paolino Minorita (1320), Pietro Vesconte (1320), Albertino da' Virga (1414), Andrea Bianco (1436), Andrea Walsperger (1449), Giovanni Leardo (1442, 1448, 1453), and the anonymous author of the so called «Catalan Estense Map» (c. 1450). A general taxonomy of *mappae mundi* can be found in the works by Woodward (1987, pp. 295-299), Gautier Dalché (2014), and also Hoogvliet (2007). In the paragraphs that follow we deconstruct the epistemological unity of Mauro's map, by highlighting the pieces the map is composed of, and making hypotheses on the way they work and on their functions. We start our analysis from the image of the *mappa mundi* in itself, then move quickly to the images that fulfil it. First of all the *mappa mundi* shows itself as a circle inscribed into a square. Being a circle, it has a geometrical centre, a metal pinion from which Fra Mauro traced the red circle that surround the *oikoumenē* – the ecumenical border between *land* and *water*, in terms of the Aristotelian *elements* – and a symbolic centre, Jerusalem, displaced from the center. Fra Mauro felt the need to explain this in a intricate paragraph. Jerusalem, he says, is in the midst of the habitable world according to latitude, although according to its longitude it is too far west. But because the western part is more populated, Jerusalem is still in the middle according to longitude, not considering the physical space of the earth, but the number of its inhabitants. The circle, the square and the center, have a deep symbolic meaning that did not pass unnoticed by fifteenth century spectators of the *mappa mundi*. They are all fundamental religious cultural symbols (de Champeaux and Sterckx, 1972, pp. 20-45). Even if Fra Mauro has abandoned, strictly speaking, many of the structural bases of thirteenth – and fourteenth centuries *mappae mundi* – for example, referring to the subject of the traditional lines of division of the earth into three continents as 'tedious' (Gasparrini Leporace, 1956, pl. XXII, h 35) – by giving the *mappa mundi* a circular shape, by placing the earthly paradise in the left bottom corner, by placing Jerusalem – the location of Christ's incarnation – in the center, placing Noah's ark (*Archa Noè* in Gasparrini Leporace, 1956, pl. XXVIII, d 3), which is a reminder of the second birth of mankind and all living things after the Flood, Fra Mauro molded and rooted a *lay* cosmography – a cosmography that was mainly based on what Joan-Pau Rubiés defined an «unprecedented type of narrative – the lay observer's personal

observations», in the case of Fra Mauro, as will be explained later, Marco Polo's, Niccolò de Conti's, and several navigators' observations (Rubiés, 2000, p. 45)– whose origin still lied in the Christian doctrine of Creation and Redemption.

Figure 2. Text and images combine one with the other in Fra Mauro's map. Venice, Biblioteca Nazionale Marciana.

Turning to the images that fulfil the *mappa mundi*, they can be divided into ten groups: palaces, temples, churches and mosques, bridges, sepulchral monuments, ships, animals, mountains, rivers, and text. Fra Mauro constantly used and repeated these ten patterns, making an outstanding patchwork in which the function and role played by text deserve a more specific treatment. Without denying the importance of the text in terms of content, in the *mappa mundi* the text primarily plays the role of an *image*, whose function is to create and suggest the idea of a fully humanised space. From a *cosmographical* point of view, the way in which Fra Mauro disposed the text and the other images on the *mappa mundi* reveals and hints to a representation in which space has been conceptualised as completely knowable and inhabitable. What emerges is a concept of space that implies that men can leave and travel over without as much limits as implied, for example, in the original Ptolemaic cosmography (Koyrè, 1957).

The circular shape, the square frame, the center, the image of the earthly paradise, and the way in which the text is disposed on the *mappamundi*, all reflect Fra Mauro's system of beliefs, that is both his theological and cosmographical model, whose keystone was that at the beginning of the *world* there is the will of God who both reveals and at the same time conceals itself. The *earth* is part of the *world*, and the *world* is created; the will of God creates the *world* and what the eye of the cosmographer cannot see directly, can be instead known through a reading of scripture, the exegesis of writings of the church fathers, and of Christian Scholastic interpretation of the Aristotelian natural philosophy, because, in the end, they are objects of *revelation*. It follows that the macrostructure of the world, that is, *cosmography* as understood in its sub lunar and heavenly parts, is given and above all is, or can be, perfectly well known. The only space that remains undefined – and it is conjectural, not *incognitus*, unknown – is the chorographical. From a *cosmographical* point of view, in Fra Mauro's interpretation space has turned out to be completely knowable, inhabitable, and, more over it can be extensively travelled over. Fra Mauro's *mappa mundi* follows this iconological model which reveals itself to be the key for the comprehension of Fra Mauro's cosmographic vision. This model springs from and should be read in an epistemological context in which not only are there echoes of biblical cosmology and geography, but mainly

philosophical arguments that greatly affected the anthropological system that every Christian thinker considered his duty to construct on the basis of information provided by Church Fathers (St. Augustine, Boetius), by Christian Scholastic interpreters of Aristotelian natural philosophy (Aristotle, Averroës, Albertus Magnus, St. Thomas Aquinas, Auicena, Sacrobosco) as well as the interpretation of Pliny, Solinus, Pomponius Mela, and Ptolemy. When speaking of Renaissance maps as images their beauty and elegance can be easily equated with the ornamental elements and nothing more. Fra Mauro's *mappa mundi* may demonstrate that the role of the images in the *mappa mundi* and, broadly speaking, in Renaissance cartography, runs much deeper than the decorative and ornamental. Under the shape of beautiful Venetian pieces of art, the images in the *mappa mundi*, and the *mappa mundi* in itself as an image, even if they had also a celebratory role, are not decorations, but a relevant part of Fra Mauro's cosmographic discourse whose presence enforces its semantics.

Figure 3. The Earthly Paradise depicted by Leonardo Bellini in the lower left corner of Fra Mauro's *mappa mundi*, 40x60 cm, ca. 1455. Venice, Biblioteca Nazionale Marciana.

2.2. Fra Mauro's Map as Textual Aggregator

As has already been pointed out, Fra Mauro's some 3,000 textual units make up a large cosmographical treatise that deals with natural philosophy, descriptions of places and people, commercial geography, history, navigation and direction of expansion, and, finally, on what we can nowadays call methodological issues. Fra Mauro wrote his text in the form of a dialogue with his readers. The text is built around a close and continuous work of criticism, quotation, and comparison with the most significant *auctoritates* of the millenary history of natural philosophy and cosmography. Among Fra Mauro's *auctoritates*, three groups are easily recognizable. The theologians, the Fathers of the Church: St. Augustine, Bede, Boetius, Rabanus Maurus, St. Paul, St. Jerome, Damascenus, Basilius and Chrisostomus. The second group is composed of the natural philosophers, Aristotle and his Arab and Christian commentators, Avicenna, Averroës, Albertus Magnus and St. Thomas Aquinas (Grant, 1994; Grant, 1996). The last group is made of the most important thinkers in Western cosmography: Gaius Julius Solinus with his *Polyhistor* (Milham, 1960a) that, until Petrarch's rediscovery of Pomponius Mela's *Cosmographia* (Milham, 1960b), at the beginning of the fourteenth century, was the most important *auctoritas* of medieval cosmographic knowledge; then, Pomponius Mela's *Cosmographia*; and last, Ptolemy with his *Cosmography* or *Geographical Description*. There is also Euclid,

quoted with reference to the calculation of the reciprocal size of the sublunary elements.

The analysis of the contexts reveals that in Fra Mauro's *mappa mundi* there are four main and distinct discourses involving *auctoritates* (i.e. the authority of 'classic' authors): the cosmological discourse, the cosmographic discourse, the chorographic discourse and, finally, what we would nowadays call a methodological discourse. Each discourse is based upon specific groups of sources and authors: cosmology is based upon the authority of the theologians, Saint Augustine and Saint Thomas, in particular (Cattaneo, 2011, pp. 224-275); Aristotle's *De coelo et mundo* and *De Generatione et corruptione* Arab as well as Medieval Scholastic commentators are the principle sources for Fra Mauro's cosmography, that is the description of general structure of the world and, more specifically, the structure of the sublunary world; for the chorography, Fra Mauro quotes Solinus' *Polysthor*, Pomponius Mela's *Cosmographia*, and travellers, such as Marco Polo and Niccolò de Conti. Regarding to the methodological discourse, the most important of Fra Mauro's sources is Ptolemy (Cattaneo, 2005; Gautier Dalché, 2007; Gautier Dalché, 2009). The place-names and the inscriptions of Asia are almost entirely derived from Marco Polo's travel account, with at least 160 direct and open quotations, and from Niccolò de' Conti, with at least 10 direct and open quotations, mainly on the navigability of the Indian Ocean, Taprobana, and the Andraman Islands (Cattaneo, 2004; Cattaneo, 2005; Falchetta, 2006; Cattaneo, 2011, pp. 185-225). This is evidently an impressive store of authors and books that together constitute the bulk of natural philosophy knowledge available to men of good culture in the first half of the fifteenth century. Anyway, in the case of Fra Mauro, this knowledge is enriched by the fact that it was achieved in Venice, one of the cultural as well international capitals of the fifteenth century. In fact, Fra Mauro had the possibility to complete this *written* culture with the cosmographical *oral* knowledge that circulated in Venice as the outcome of encounters of sailors, merchants, foreigners who arrived in Venice from all parts of the *oikoumenē*. Beside the *auctoritates*, we can still hear the live voices, outstandingly transcribed by Fra Mauro, of ancient travellers.

		Authors quoted	Discourses
1	Theologians	St. Augustine, St. Jerome, Bede, Boetius, Damscenus, Basilius and Chrisostomus, Rabanus Maurus;	Cosmology: description of the general structure of the universe and its meaning

2	Natural philosophers	Euclide; Aristotle and his Arab and Christian commentators, Avicenna, Averroës, Albertus Magnus, St. Thomas Aquinas	Cosmography: description of the general structure of the sublunary world
3	Classical cosmographers and medieval travellers	Pliny, Soline, Pomponius Mela, Ptolemy, Marco Polo, Odorico da Pordenone Piero Querini, Niccolò de' Conti anonymous travellers (e.g. Ethiopian monks, Portuguese navigators)	Chorography: description of regions, cities, people, commodities, trade routes
4	Classical cosmographers	Ptolemy	"Methodology": critical discussion of Ptolemy's *Geography*

Table 1. *Auctoritates* and discourses in Fra Mauro's cosmographic text.

2.3. Fra Mauro's *mappa mundi* and its Knowledge

We have noted what works were read by Fra Mauro. But how did he read them? When we compare passages from the books mentioned by Fra Mauro with the conclusions that he drew therefrom, we invariably find discrepancies of serious proportions. Any attempt to consider these books as 'sources' in the mechanical sense of the term collapses before the originality of Fra Mauro's reading and interpretation. More than the sources quoted in the cartouches, then, what is important are the keys to his reading, a filter that he placed between himself and the printed page. This filter underlined certain concepts while obscuring others, and gave importance to certain specific issues while, quite surprisingly, forgot certain others, apparently, at least to our eyes, more important. And this screen, this key to his reading, continually leads us back to a culture that is different from the one expressed in the Latin manuscript pages of his sources—one based also on an oral tradition and oral culture, expressed in the vernacular. It was the encounter between the written culture in *Latin* – St. Augustine, St. Isidore, Albertus Magnus, Pomponius Mela, Solinus, Ptolemy – and the *vernacular* oral culture of sailors, and merchants, who reached Venice from the most far regions of the *oikoumenē* that led Fra Mauro to formulate his vision of the world and that much probably made it so *special* and interesting to the Portuguese crown that commissioned a copy in 1457, as well as to our eyes. Fra Mauro's *mappa mundi* is an interesting example of a circular and reciprocal influence between vernacular oral and written culture and learned high culture, which perfectly fits in the framework of the paradigm of the so called 'vernacular

science' as quite properly and convincingly described and analysed by Carlo Maccagni (1996).

3. The Future of Maps as Knowledge Aggregators

In the knowledge management literature, we find the classification of human awareness into a *data, information, knowledge,* and *wisdom* (DIKW) hierarchy (Ackoff, 1989; Berlinger et al., 2004; Rowley, 2007). According to Ackoff (1989), data are merely symbols that we associate with specific features in the outside world, information is contextualized data that allows us to answer questions, knowledge is proceduralized information that allows us to act on and solve problems, and wisdom is knowing under which situations to act. To do well in the world we must move up this hierarchy of knowing, and the greatest challenge we (and Fra Mauro too, in his days) face is the fragmentation of knowledge and information. In other words, the problem we have to overcome is the problem of *knowledge aggregation*, encountered in decision science (Roy, 2005), organizational learning (Grant, 1996; Grundspenkis, 2007), and even bioinformatics (Belleau et al., 2008; Miotto et al., 2008) and medicine (Hahn et al., 1999; Malterud, 2011; McDonagh et al., 2011).

The chief limitations of Fra Mauro's *mappa mundi* as a knowledge aggregator are that firstly, the map has to be 'finished' before it can be useful to someone else. Once it is 'finished' it cannot be updated to reflect new information. This is the paradox facing old media: the product becomes outdated the moment it is produced. Secondly, the *mappa mundi* cannot adapt to its user. In contrast, online maps like Google Maps and Bing Maps are always works in progress. This allows new information to be added as they become available, and ultimately all old information stored in a timeline. However, they do not provide narratives produced by experts or drawn from Wikipedia.

Built on top of online maps such as Google Maps or Bing Maps, the future knowledge aggregator that we envisage will start by showing its user a map with minimal information, like country or state names. When the user moves the mouse over a location, and double clicks it, then additional information widgets appear, as shown in the example in *Figure 4*. The automatic selection of these information widgets are based on user action statistics collected by either the map-based knowledge aggregator, or the associated search engine, very much like the related searches suggested by search engines like Google and Bing. Correlations between user actions can also help to crudely define narratives, like the grouping of Grand Century Place and Ladies' Market into a 'shopping' narrative, and the grouping of Occupy

Central news, images, and videos into a 'protest' narrative. When the user clicks on one of the information widget, it opens up a full-height side panel on the knowledge aggregator. This allows the user to view the full contents of the information widget, as well as interact with other information widgets that might be embedded. As we have illustrated, contents are not proprietary, but are drawn from various online sources, such as the British Broadcasting Corporation and YouTube.

Figure 4. When the user double clicks on Mongkok in Hong Kong, the most popular follow-up information widgets pop up, organized roughly into two narratives. The first narrative concerns Mongkok as a shopping district (Grand Century Place, Ladies' Market), whereas the second concerns the late-2014 Occupy Central protest (online news, image, YouTube video).

Our ultimate vision is not for the map-based knowledge aggregator to combine only contemporary sources, but also draw on historical associations through curated as well as crowd-sourced timelines. In *Figure 5*, the map zooms out to show Beijing and London after the user consistently clicked on information widgets associated with the 'protest' narrative. This presents two related narratives, the 1989 Tiananmen Incident in Beijing, and Hong Kong political reforms initiated by Chris Patten, the last Governor of Hong Kong.

Figure 5. After the user has consistently picked actions belonging to the 'protest' narrative, the map zooms out to show Beijing and London in relation to Hong Kong. If the user clicks on the Tiananmen or Chris Patten images, he/she will be led to narratives from the two different perspectives.

Using this example, we illustrate what a map-based knowledge aggregator would look like, and how it presents aggregated information to the user in the form of interrelated narratives. More importantly, not all information is made available to the user, because they would be overwhelming. Instead, the user navigates the information widgets one at a time, and as his/her course of action becomes more consistent, more relevant information would be presented to him/her. By consolidating courses of actions by previous users, the map-based knowledge aggregator will increasingly be able to predict the interests of the current user (i.e. what a recommendation engine does).

4. Conclusion

Although the idea of a knowledge aggregator was first mooted close to 20 years ago, we believe its potential is not yet fully exploited. By far the most successful present-day knowledge aggregator, Wikipedia showed us how information communication technology (ICT) allows us to tap the wisdom of the crowds (Kittur et al., 2007; Kittur and Kraut, 2008). Inspired by the success of Wikipedia, many collaborative web tools were created (Cress and Kimmerle, 2008). One may also argue that modern search engines like Google and Bing are also knowledge aggregators, although their outputs (lists of hits) are much less useful compared to Wikipedia pages (Nanetti, Cheong, Filippov, 2013).

In contrast, modern geographical information system (GIS) maps, including Google Maps and Bing Maps, are not knowledge aggregators. Despite being data-rich, they are merely information aggregators, as their GIS namesake implies. When we compare these modern online maps to Fra Mauro's *mappa mundi*, we realized that the former are missing two key features that are present in the latter: (1) purpose-driven information filtering; and (2) multimodal narratives. In our opinion, these modern online maps are also not exploiting the fact that they can be continually updated.

We envisage a future where online maps are once again knowledge aggregators, in some Fra Mauro meets ICT way. This is not merely nostalgia: Henson et al. (2013) explained that as we move into the era of Big Data, data is generated so quickly that we would drown in it if we do not have knowledge aggregators to help us navigate. Our aim is to draw connection of what we wrote about Fra Mauro and then create a modern day Fra Mauro, as a digital assistant, by meshing up various internet services (e.g. to illustrate what a version of Fra Mauro's *mappa mundi* would be looked like if we build it over Bing, Bing Maps, Wikipedia, and all other possible reference sources), just to recreate it in a modern way and make it interactive to users as we have described in the paper. After that, we can draw upon what we have learned on analyzing Fra Mauro's work, its significance and implications, as described in *Section 1* and *Section 2*, and apply the methodology which Fra Mauro used to create the map and propose a way, as shown in *Table 1*, to organize knowledge but with modern technologies.

In fact, most of the behaviours of the future map-based knowledge aggregator we describe in this paper can already be implemented using present-day technologies (existing mostly in search engines). What is yet to be done is the clustering of courses of actions, and recognizing that these clusters are the results of the users following through specific narratives. With more and more data collected on what sequences of information users want the

map-based knowledge aggregator to present to them, we will eventually be able to make this knowledge aggregation fully automated, and also fully user-driven.

When Fra Mauro created his *mappa mundi*, he had intentions in mind. He wanted to provide sense to a world that was expanding and changing very quickly. He did not want to be just a passive spectator of these processes: he wanted to change his world. For what greater purpose shall we ascribe to the future map-based knowledge integrator? If we browse through the events since 1900, we see a growing intensity of strife and conflicts. As the world become more interconnected through travel and media, our cultures and knowledge of each other remains highly fragmented, mostly because media companies decide (mostly on grounds of profitability and ratings) what news stories to present to the masses. Modern ICT can change this imbalance resulting from media companies being self-interested knowledge aggregators, by giving the power to aggregate knowledge to individual users. We suppose it would be presumptuous to claim that an enhanced Google or Bing map can make the world a more peaceful place. Nevertheless, we believe the future map-based knowledge aggregator we describe in this paper not only helps us better understand the world, but can also potentially help us understand ourselves. For example, for the same global issues, how many narratives will emerge? Will these narratives be antagonistic? We can also ask how local communities can converge or diverge when we place in their hands this tool to make sense of the world (past and present). More importantly, with a tool to understand themselves and others, can people finally learn the art of living with each other?

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