Introduction

The World as Seen from Venice (1205-1533) as a Case Study of Scalable Web-Based Automatic Narratives for Interactive Global Histories

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Abstract

This introduction is both a statement of a research problem and an account of the first research results for its solution. As more historical databases come online and overlap in coverage, we need to discuss the two main issues that prevent 'big' results from emerging so far. Firstly, historical data are seen by computer science people as unstructured, that is, historical records cannot be easily decomposed into unambiguous fields, like in population (birth and death records) and taxation data. Secondly, machine-learning tools developed for structured data cannot be applied as they are for historical research. We propose a complex network, narrative-driven approach to mining historical databases. In such a time-integrated network obtained by overlaying records from historical databases, the nodes are actors, while the

links are actions. In the case study that we present (the world as seen from Venice, 1205-1533), the actors are governments, while the actions are limited to war, trade, and treaty to keep the case study tractable. We then identify key periods, key events, and hence key actors, key locations through a time-resolved examination of the actions. This tool allows historians to deal with historical data issues (e.g., source provenance identification, event validation, trade-conflict-diplomacy relationships, etc.). On a higher level, this automatic extraction of key narratives from a historical database allows historians to formulate hypotheses on the courses of history, and also allow them to test these hypotheses in other actions or in additional data sets. Our vision is that this narrative-driven analysis of historical data can lead to the development of multiple scale agent-based models, which can be simulated on a computer to generate ensembles of counterfactual histories that would deepen our understanding of how our actual history developed the way it did. The generation of such narratives, automatically and in a scalable way, will revolutionize the practice of history as a discipline, because historical knowledge, that is the treasure of human experiences (i.e. the heritage of the world), will become what might be inherited by machine learning algorithms and used in smart cities to highlight and explain present ties and illustrate potential future scenarios and visionarios.

Key words
World history, History of Venice, Computational history, Epistemology, Machine-learning, International relations

I. OLD PROBLEMS AND NEW TECHNOLOGIES: FROM THEORY TO PRACTICE IN WORLD HISTORIES

> *Historia vero testis temporum, lux veritatis, vita memoriae, magistra vitae, nuntia vetustatis, qua voce alia nisi oratoris immortalitati commendatur?*/By what other voice, too, than that of the orator, is history, the evidence of time, the light of truth, the life of memory, the directress of life, the herald of antiquity, committed to immortality? (Marcus Tullius Cicero, *De Oratore*, II, 36).

The electronic computer is one of those radical technological innovations that changed dramatically and deeply, at all levels, the way in which our society and economy work[1]. They allow us to

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[1] William Brian Arthur, *The Nature of Technology: What It Is and How It Evolves* (New York: The Free Press and London: Penguin Books, 2009).

see vast realms that could not be seen before and process the related data and information at a pace faster than ever before.[2] An interconnected world can be investigated to understand the mechanisms of convergence/divergence between local communities and international networks, placing crucial questions: how the same networks/people can bring new wealth and development, or war and poverty? Which dynamics and mechanisms operate in the world systems of cities and governments?

If we read Cicero's famous quote *historia magistra vitae* through the lens of the thermodynamic paradigm—which holds that a perfect description of a given moment or set of conditions in history would provide a knowledge of future conditions—and assume that "the new society comes into being in the womb of the old"[3]; our increasingly complex world should care as much as possible of the treasure of human experiences (THE data), to increase resilience and sustainability, and to nurture innovation.

In this scenario, the computers could do for historians what they did, for example, for mathematicians[4] and chemists[5] in the 20th century, both at the level of capacity of observation and theoretical speculation. In principle, the main benefits and improvements that the computer can provide to historical research are not new to historians. In the 1970s, the considerations made by the French historian Emmanuel Le Roy Ladurie, on which

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[2] Douglas S. Robertson, *The New Renaissance: Computers and the Next Level of Civilization* (Oxford: Oxford University Press, 1998).

[3] John Lechte, *Key Contemporary Concepts. From Abjection to Zeno's Paradox* (New York: SAGE Publications Ltd., 2003), 105–7, quotation at page 106.

[4] Douglas S. Robertson, *Phase Change: The Computer Revolution in Science and Mathematics* (Oxford: Oxford University Press, 2003).

[5] Chemists used to create models of molecules using plastic balls and sticks. Today, the modelling is carried out in computers. In the 1970s, Martin Karplus, Michael Levitt, and Arieh Warshel laid the foundation for the powerful programs that are used to understand and predict chemical processes. Computer models mirroring real life have become crucial for most advances made in chemistry today. On 9 October 2013 the Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Chemistry for 2013 to Martin Karplus (Université de Strasbourg, France and Harvard University, Cambridge, MA, USA), Michael Levitt (Stanford University School of Medicine, Stanford, CA, USA), and Arieh Warshel (University of Southern California, Los Angeles, CA, USA) "for the development of multiscale models for complex chemical systems."

implications the use of the computer would have in historical studies, made already aware that[6]

> History based on computers/information technology is not limited to a very specific category of research, but also leads to the establishment of an 'archive.' Once transferred to tape or punched cards, and after having been used by a first historian, the data can in fact be stored for future researchers, who want to find non-experimented correlations. . . What emerges is a new kind of archivist; a sort of engineer of history, very different from the great scholars trained at the *École Nationale des Chartes*. . . At the end, the duty of the historian will almost uniquely consist in thinking: which, in fact, is supposed to be his unique vocation.

And even the idea of looking at unexpected relations in the repertory of knowledge is not new, when we accept that research is not only finalized to use what we find for what it is, but also to find new possibilities of interactions among elements that initially did not have any reciprocal relationship. This concept dates back at least to Roger Bacon (ca. 1214-1294), who switched the concept of *inventio* (invention/discovery) from the search of what was already known to the discovery of the unknown.[7]

The real frontier research starts when we want to use computers to structure historical information, model historical narratives, simulate theoretical large scale hypotheses, and incent world historians to use virtual assistants and/or engage them in teamwork using social media and/or seduce them with immersive spaces to provide new learning and sharing environments, in which new things can emerge and happen: "You do not know which will be the next idea. Just repeating the same things is not enough" (Carlo Rubbia, 1984 Nobel Prize in Physics, at Nanyang Technological University on January 19, 2016). To do this Andrea Nanetti defined a research domain and proposed it as a case study to share an explicit formal specification of the domain terms and their reciprocal relationships. In one word, he felt the

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[6] Emmanuel Le Roy Ladurie, *Le Territoire de L'Historien*, vol.1 (Paris: Gallimard, 1973), 3–6.

[7] Umberto Eco, *From the Tree to the Labyrinth* (Cambridge MA/London UK: Harvard University Press, 2014), 37.

need of a new ontology—according to the definition and the methodology provided by Thomas R. Gruber[8]—to describe and design the relationships (trade, diplomacy, conflicts, etc.) among cities and governmental institutions (agents) in the intercontinental network (the system). The world as seen from Venice between 1205 and 1533 constituted his first ontology for the study of interactive global histories as a scalable solution to investigate change (i.e. the fundamental and nonlinear force of history) and to understand how and why cities and countries (seen as complex adaptive systems[9]) develop and evolve in relation to world systems.

The belief is that such a case study, with good coverage of various historical periods and geopolitical regions, is able to generate from noisy and incomplete sets of historical data and metadata *coherent narratives* that can be tested at the same level of rigor as scientific hypotheses and theories, as more data and metadata become available. The generation of such narratives, automatically and in a scalable way, will revolutionize the practice of world history as a discipline, because historical knowledge, that is the treasure of human experiences (i.e. the heritage of the world), will become what might be inherited by machine learning algorithms.

Moving from these problematic, the project Engineering Historical Memory (EHM) was born (http://www.engineeringhistoricalmemory.com and now on Microsoft Azure http://ehmazure.cloudapp.net). It constitutes an experimental methodology and an ongoing research project for the organization of historical data in the digital age, that Andrea Nanetti first theorized when he was Visiting Scholar at Princeton University in 2007, in order to develop and test new sets of shared conceptualizations and formal specifications for content

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[8] Thomas R. Gruber, "A Translation Approach to Portable Ontologies," *Knowledge Acquisition* 5, no. 2 (1993): 199-220, doi: http://tomgruber.org/writing/ontolingua-kaj-1993.htm; Thomas R. Gruber, "Toward Principles for the Design of Ontologies Used for Knowledge Sharing," *International Journal of Human-Computer Studies* 43, no. 4-5 (November 1995): 907–28, doi: http://tomgruber.org/writing/onto-design.htm

[9] For an introduction to agent based modeling as computational practice in the historical domain, see Michael Gavin, "Agent-Based Modeling and Historical Simulation," *Digital Humanities Quarterly* 8, no. 4 (2014) at http://www.digitalhumanities.org/dhq/vol/8/4/000195/000195.html#p2

management systems in historical studies. What sets it apart from other approaches is a focus on developing and applying computationally intensive techniques (e.g., pattern recognition, data mining, machine learning algorithms derived from other disciplines, and visualization solutions) to achieve this goal. It entails the creation and advancement of databases (relational, graph, and hybrid), algorithms, computational, statistical, and complexity techniques and theories to solve formal and practical problems arising from the study, interpretation, conservation, and management of historical data and information.

EHM, as an experimental methodology, is based on a few simple questions: What shall the historian do having *all* data available in a digitalized form and available in any language? What the implications will be when *all* research materials will be digitized and searchable through metadata in any language? When we know the relationship between (past) events and their (still present) traces/evidence, what kind of interpretation can be built on top of them? Are universal interpretations possible, supported by relations between events?

The preliminary sets of formal specifications and results of tests on highly cross-linked historical data have been got ready for publication by Andrea Nanetti when he was in the Faculty of Cultural Heritage Conservation at the University of Bologna (Italy), and were then published in 2008 (*urban* historical memory transmission),[10] 2010 (*world* views and networks),[11] 2011 (*regional* human-heritage-landscape dynamics),[12] and 2014 (mapping and visualizing historical data systems).[13] In particular, in his 2014

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[10] Andrea Nanetti, *Imola Antica e Medievale nella Cronachistica Cittadina di Età Moderna: Indagine Esemplare per una Ingegnerizzazione della Memoria Storica* [Ancient and Medieval Imola in Modern Chronicles of the City: A Case Study for Engineering Historical Memory] (Imola: Editrice La Mandragora, 2008).

[11] Andrea Nanetti, *Il Codice Morosini: Il Mondo Visto da Venezia (1094-1433)* [The Morosini Codex: The World as Seen from Venice (1094-1433)], 4 vols. (Spoleto: Foundation CISAM, 2010).

[12] Andrea Nanetti, *Atlas of Venetian Messenia: Coron, Modon, Pylos and Their Islands, 1207-1500 and 1685-1715* (Imola: Editrice La Mandragora, 2011).

[13] Andrea Nanetti, and Mario Giberti, *Viabilità e Insediamenti nell'Assetto Territoriale di Imola nel Medioevo: Sperimentazione Esemplare di Mappatura e Visualizzazione del Dato Storico* [Roads and Settlements in the Territory of Medieval Imola: A Case Study for Historical Data Mapping and Visualization] (Imola: Editrice La Mandragora 2014).

publication, to emphasize the unity of this method, "mapping and visualization" must be seen as a hendiadys in the investigation of historical data. The term mapping is taken here in its basic meaning of localization and description of elements, facts or phenomena that relate to a circumscribed area, historically understood at the intersection of precise space and time coordinates. The aim is to provide and test a specimen of an innovative epistemological process to visually distil historical data and information into historical knowledge (being aware of possible consequences of specific actions) and wisdom (foreseeing under which circumstances to act). Rather than a reductive representation to epitomize and/or illustrate written narratives, the visualization process is seen here as an investigative tool for the 'digital' historian to organize and discovery new relationships between objects in a continuously reloadable historical landscape, where past, present, and future can merge in a democratized whole and serve as a guide to understand under which circumstances he/she is directing his/her curiosity and selective decisions.[14]

Andrea Nanetti's early works—that used the Italian town of Imola and its territory as a case study to analyse cities, rather than empires and nations, as basic agents/units of enquiry in world history—demonstrated how a new interdisciplinary research methodology could get traditional historical data sets ready for the semantic web: (digital) maps were seen as *knowledge aggregators* and (digital) mapping was the epistemological tool to pioneer experimental narrative and non-narrative operations to associate each element of given sets of data coming from traditional disciplines (history, archaeology, anthropology, art history, etc.) with one or more elements of a range of automatically generated sets of different things of the same general type (places, people, buildings, events, dates, ideas, etc.).

This "mapping and visualization" method wants to be a first step towards the experimentation of automatic narratives to

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[14] On "digital historians" (people that do more than use Google), see also http://www.digitalhistory.uh.edu/ and http://www.digitalhistorians.org/ As for the democratization of the doing of history, see Cheryl Mason Bolick, "Digital Archives: Democratizing the Doing of History," *International Journal of Social Education* 21, no. 1 (Spring-Summer 2006): 122–34.

make history in the post-digital era. It is not a positivistic revival, but a consequence of the belief that "narrative is not just a set of materials but it is a quite specific method of organizing those materials",[15] and in this way can also be discussed a famous statement made by the Italian theorist and philosopher Benedetto Croce: "Where there is no narrative, there is no history".[16]

In 2008 Rick Altman has ironically and futuristically framed the case in the conclusions to his famous book on narrative. One last foray. If medieval physics clearly grows out of dual-focus assumptions, and its Newtonian successor develops a fundamentally single-focus cause-and-effect model, then we may perhaps recognize in Einstein's famous equation $e = mc^2$ the ultimate multiple-focus hem-naming process, recognizing for the first time that energy and matter can be treated as equals. When energy and matter, action and character, are reduced to the same entity, can the end of narrative be far behind?[17]

Rather than the end of narrative, we see here, after 6,000 years of essentially linear narratives, the beginning of non-linear narratives generated by artificial actions (i.e., human made and programmed) more and more interconnected with computational operations (i.e., completed by electronic devices able to store and process data, typically in binary form, according to instructions given to them in a variable program).

Besides that, the theory presented by Altman offers powerful potential for describing human activities, and is applicable wherever humans tell stories or implicitly refer to previously told tales. In the final conclusion (p. 338), he suggests how his theory might be used to image and explain such varied phenomena as

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[15] See Rick Altman, *A Theory of Narrative* (New York: Columbia University Press, 2008) 5, for the citation, in which the author rephrases a definition given at the height of structuralist activity by Karlheinz Stierle, "L'Histoire comme Example, L'Example comme Histoire," *Poétique* 10 (1972): [176–98] 178, referring to the "basic structure of all narrative texts" by Arthur Coleman Danto, *Analytical Philosophy of History* (Cambridge, MA: Cambridge University Press, 1965):

x *is* f *at* t1
g *happens to* x *at* t2
x *is* h *at* t3

[16] See Benedetto Croce, *La Storia Ridotta Sotto il Concetto Generale dell'Arte*, in *Primi Saggi* (Laterza: Bari 1951) [3–41], 26.

[17] See Rick Altman, *A Theory of Narrative* (New York: Columbia University Press, 2008), 339-40.

individual texts, literary and film history, social organization, religion, and political life. Many other domains might have been evoked. Whether the topic is literature, art, or epistemology, we regularly find a historical series that may be usefully described as developing from dual-focus through single-focus to multiple-focus.

In fact, as the same Altman highlighted in the first pages of his book,[18] among human endeavors, few are more widely spread or more generally endowed with cultural importance than narrative. Stories are the major vehicles of personal memory, a mainstay of law, entertainment, and history (p. 1). Historically, definitions of narrative have been tightly tied to a particular type of plot. This tendency began with Aristotle (*Poetics*, Book VI),[19] who informs us that a tragedy is impossible without action, but a tragedy may exist without characters (p. 2). Adopted from Aristotle, the notion of unity of action involves the need to built a play around a single unbroken plot thread, eschewing competing story lines, unnecessary characters, and unrelated episodes. Stories must be coherent; they must have a distinct beginning, middle, and end; they must connect their parts through clearly motivated causes; and they must expunge any material unrelated to this unity of action (p. 3).

Altman, towards the end of his work, notes that: «We circulate among characters and places, not according to our own interests but according to an itinerary fixed by the narrator». If it is inaugurated by the process of "following," the act of reading also involves a tendency toward "mapping": calling on our memory of the text at hand, as well as our prior experience of other texts, the process of mapping involves the reader in a perpetual return to the past, and a constant attempt to define the present in terms of that past, permitting eventual understanding of the present (pp. 291-292).

In a global history perspective—as Murray Gell-Mann pointed out at the international conference *A Crude Look at the Whole* (Singapore, Nanyang Technological University, 4-6 March

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[18] Rick Altman, *A Theory of Narrative* (New York: Columbia University Press, 2008), 1–3.

[19] Bywater, Ingram, *Aristotle on the Art of Poetry* (Oxford: Oxford University Press, 1909), 13.

2013) in his keynote lecture on *A Crude Look at the Whole: A Reflection on Complexity*[20]—the vision is to increase the understanding of historical processes improving, rather than simply criticizing and marginalizing, the complex way opened by the British historian Arnold J. Toynbee between 1934 and 1961 with his 12-volume magnum opus *A Study of History*, in which the author presents the development of all major world civilizations starting from a history of the Byzantine Empire.[21] For a critical review and classification of the various methodologies, which scholars have developed to think globally about the past (around the main categories of comparing, connecting, conceptualizing, and contextualizing), we can now reliably refer to *Thinking history globally*, a recent book by Diego Holstein, Associate Director of the World History Center at the University of Pittsburgh.[22]

The Nanyang Technological University research team of EHM was born following Murray Gell-Mann's inspiring thought under the auspices of the NTU Complexity Program Director, Jan W. Vasbinder. Its initial aim was to provide a new information environment to better understand the elements of the debate on the 'origins' of a world system (10th millenium BCE for Andrey Vitalievich Korotayev, 4th millenium BCE for Andre Gunder Frank, thirteenth century CE for Janet Abu Lughod, or 1450-1640 CE for Immanuel Wallerstein),[23] and to better appreciate famous and discussed theories like the one proposed by Joseph A. Tainter in *The Collapse of Complex Societies* (whose use of historical data is far beyond being comprehensive especially when he deals with the so-called 'fall' of the Roman Empire, taking into consideration Rome and Constantinople)[24]; or in *Guns,*

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[20] Unpublished paper.

[21] Arnold J. Toynbee, *A Study of History*, 12 vols. (London: Oxford University Press, 1934-1961).

[22] Diego Holstein, *Thinking History Globally* (Houndmills UK/New York: Palgrave Macmillan, 2015), 6–8.

[23] For this debate, see George Modelski ed. *World System History* (Oxford UK: EOLSS Publishers, 2004, *Encyclopedia of Life Support Systems*-EOLSS, e-books series developed under the auspices of the UNESCO) and Robert A. Denemark, Jonathan Friedman, Barry K. Gills, and George Modelski eds. *World System History. The social Science of Long-Term Change* (Abingdon: Routledge, 2000). In the context of the present case study, see Rila Mukherjee, *Networks in the First Global Age: 1400-1800* (New Delhi: Primus Books, 2011).

[24] Joseph A. Tainter, *The Collapse of Complex Societies* (Cambridge, MA: Cambridge University Press, 1988).

Germs, and Steel by Jared Diamond (whose geographical determinism does not explain for example how conquerors are conquered by the culture of the conquered, like the Romans in Greece, the Ptolemaic dynasty in Egypt, and the Mongols in China)[25]; or the one by Walter D. Mignolo in *The Dark Side of the Renaissance* (that investigates how European Renaissance was a justification and agent of colonial expansion)[26]; or the one by Daron Acemoglou and James A. Robinson that does not impute to either climate, geography, or culture, but to institutions, the fall of nations[27]; or the one proposed by Rens Bod book for a new history of humanities, which in 2016 is becoming an online journal as well[28]; or the one developed in *Sapiens* by Yuval Noah Harari (whose key concept is that the whole of history takes place within the bounds of the biological arena, which sets the basic parameters for behaviour and capacities of homo sapiens)[29]; or even the monumental research on the geography of human genes by Luigi Luca Cavalli-Sforza, Paolo Menozzi, and Alberto Piazza, for which Diamond writes,[30]

> This remarkable book approximates a history of everything about everybody, because the authors begin their accounts of each continent with a convenient summary of the continent's geography, ecology, and environment, followed by the prehistory, history, languages, physical anthropology, and culture of its peoples.

In a knowledge production perspective, the aim is to provide tools and ontologies "to explore the vast domain of the yet

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[25] Jared Diamond, *Guns, Germs, and Steel: The Fates of Human Societies* (New York and London: W.W. Norton & C., 1999).

[26] Walter D. Mignolo, *The Dark Side of the Renaissance: Literacy, Territoriality, and Colonization* (Ann Arbor: University of Michigan Press, 2003).

[27] Daron Acemoglu and James A. Robinson, *Why Nations Fail. The Origins of Power, Prosperity, and Poverty* (London: Profile Books, 2012).

[28] Rens Bod, *A New History of the Humanities: The Search for Principles and Patterns from Antiquity to the Present* (translated into English: Oxford: Oxford University Press, 2013). See https://historyofthehumanities.wordpress.com/

[29] Yuval Noah Harari, *Sapiens. A Brief History of Humankind* (London: Harvill Secker/Vintage Books, 2014).

[30] Luigi Luca Cavalli-Sforza, Paolo Menozzi, and Alberto Piazza, *The History and Geography of Human Genes* (Princeton: Princeton University Press, 1994), 429.

unknown," as Helga Nowotny would say, with an openness to uncertainty in testing already existing theories.[31]

It could also be the ideal platform to connect aspects of the historiography of science to global economic history ones, according to the problematic identified during the international conference *Globalizing History and Philosophy of Science: Problems and Prospects* (21-22 August 2014), jointly organized by the Asia Research Institute of the National University of Singapore, the Centre for Dialogue of La Trobe University Australia, and the Situating Science Strategic Knowledge Cluster in partnership with University of King's College Canada: how to shift from "the idea of organizing world history around civilizations as building blocks dominated" to the use of terms like crossroads, or connections (Sanjay Subrahmanyam), "how to globalize the history of science while taking account of the different cultural traditions? (e.g. hydraulic engineering, machine making, navigation and cartography between 1400 and 1800)" (Karel Davids), or "how does science travel?" (Axel Gelfert).

It would be the ideal platform for the network framework of cultural history proposed by Maximilian Schich and his research team on *Science* Magazine.[32] The reading of cultural and historical geography through the lens of literary and philosophical works would also benefit of such a platform, because of the underground links between different sources related to the world discourse and the *worldmakers* in Modern times, as Ayesha Ramachandran would say,[33] and as we are going to demonstrate here below for the Fra Mauro *mappa mundi* as one of the earliest case studies.

In the knowledge management literature, we find the classification of human awareness into a *data, information,*

knowledge, and *wisdom* (DIKW) hierarchy.[34] According to Russell 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. This thought is not completely new, and seems to have been already familiar to the Chinese author Xun Kuang (c. 310 – c. 235 BC), as mentioned to me by Luo Shen Shen during our PhD class discussions: 不闻不若闻之，闻之不若见之，见之不若知之，知之不若行之；学至于行之而止矣 / Not hearing is not as good as hearing, hearing is not as good as seeing, seeing is not as good as mentally knowing, mentally knowing is not as good as acting; true learning continues up to the point that action comes forth (or, only when a thing produces action we can say that it has been truly learned)[35].

To do well in the world we must move up this hierarchy of knowing, and the greatest challenge we (and Fra Mauro and Antonio Morosini too, in their days in Venice) 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,[36] organizational learning,[37] and even bioinformatics,[38] and medicine.[39]

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[34] Russell L. Ackoff, "From Data to Wisdom," *Journal of Applied Systems Analysis* 16 (1989): 3-9; Gene Bellinger, Durval Castro, and Anthony Mills, "Data, Information, Knowledge, and Wisdom," accessed November 13, 2014, http://www. systems-thinking. org/dikw/dikw. htm, 47; Jennifer E. Rowley, "The Wisdom Hierarchy: Representations of the DIKW Hierarchy," *Journal of Information Science* 20, no. X (2007): 1–18. doi:10.1177/0165551506070706.

[35] See *Xunzi* by Liu Xiang (818AD), Chapter 8 *Ruxiao*.

[36] Bernard Roy, "Paradigms and Challenges," in *Multiple Criteria Decision Analysis: State of the Art Surveys*, ed. Salvatore Greco (New York: Springer, 2005): 3–24.

[37] Robert M. Grant, "Toward a Knowledge-Based Theory of the Firm," *Strategic Management Journal* 17, S2 (1996): 109–122; Janis Grundspenkis, "Agent Based Approach for Organization and Personal Knowledge Modelling: Knowledge Management Perspective," *Journal of Intelligent Manufacturing* 18, no. 4 (2007): 451–57.

[38] François Belleau, Mark-Alexander Nolin, Nicole Tourigny, Philippe Rigault, and Morissette Jean, "Bio2RDF: Towards a Mashup to Build Bioinformatics Knowledge Systems," *Journal of Biomedical Informatics* 41, no. 5 (2008): 706–16; Olivo Miotto, Tan Tin Wee, and Vladimir Brusic, "Rule-Based Knowledge Aggregation for Large-Scale Protein Sequence Analysis of Influenza A Viruses," *BMC Bioinformatics*, 9, Suppl 1 (2008): S7.

Are we forecasting the demine of the historian as yet another occupation doomed to extinction through the rise of information technology and artificial intelligence, or simply proposing the development of new tools to assist historians in their work? The answer is entirely in the universities of the present. It hangs on how they will be able to educate the future generation of historians as fully bilingual: the minds of the historians of the future will need to master the language of humanities and be able at the same time to mathematise their thoughts. Our educational vision is the development of a formal science of heritage for research and teaching purposes to answer the question of how and how much of the treasure of human experiences may be inherited by machine-learning algorithms and stored in easy-to-access knowledge aggregators. Heritage science, being able to convey the treasure of human experiences data in policy making and nurturing creativity, will educate the global citizens and civil servants of the future to prepare the next IT and social innovations that will prevent the collapse of our increasing complex society.

II. Maps as Knowledge Aggregators: From Fra Mauro's World Map to Web-based Search Engines

A medieval world map can be understood a knowledge aggregators, 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. 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 wanted to use maps to generate narratives on the web that can be tested at the same level of ri-

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[39] Udo Hahn, Martin Romacker, Stephan Schulz, "How Knowledge Drives Understanding-Matching Medical Ontologies with the Needs of Medical Language Processing," *Artificial Intelligence in Medicine* 15, no. 1 (1999): 25–51; Kirsti Malterud, "The Art and Science of Clinical Knowledge: Evidence beyond Measures and Numbers," *Lancet* 358, no. 9279 (2001): 397–400; Ellen M. McDonagh, Michelle Whirl-Carrillo, Yael Garten, Russ B. Altman, and Teri E. Klein, "From Pharmacogenomic Knowledge Acquisition to Clinical Applications: The Pharmgkb as a Clinical Pharmacogenomic Biomarker Resource," *Biomarkers in Medicine* 5, no. 6 (2011): 795–806.

gor as scientific hypotheses and theories as the research team did with chronicles.

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.[40]

Fra Mauro's *mappa mundi* 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.[41]

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[40] David Woodward, "Medieval Mappae Mundi," in *The History of Cartography*, ed. J. B. Harley and D. Woodward, vol. 1 (Chicago/London: Chicago University Press, 1987): 286–370; Patrik Gautier Dalché, "Pour une Histoire du Regard Géographique: Conception et Usage de la Carte au XVe Siècle," *Micrologus* 4 (1996): 77–103; Nathalie Bouloux, *Culture et Savoirs Géographiques en Italie au Xive Siècle* (Turnhout: Brepols, 2002); Margriet Hoogvliet, *Pictura et Scriptura: Textes, Images et Herméneutique des Mappae Mundi (XIIIe-XVe siècles)* (Turnhout: Brepols, 2007); Angelo Cattaneo, "La Cosmografia del Rinascimento: Una Storia Polifonica," in *Il Rinascimento Italiano e l'Europa*, ed. G. Ernst and A. Clericuzio, vol. IV, *Le Scienze nel Rinascimento Italiano* (Verona: Angelo Colla Editore, 2008): 551-69; Catherine Hofmann, Hélène Richard, and Emmanuelle Vagnon, ed. *The Golden Age of Maritime Maps: When Europe Discovered the World* (Buffalo, NY: Firefly Books, 2013). First published as *L'Áge d'Or des Chartes Marines* (France: Éditions du Seuil, 2012). Catalogue of the exhibition at Bibliothèque Nationale de France, Paris, October 23, 2012–January 27, 2013.

[41] Janet Lippman Abu-Lughod, *Before European Hegemony: The World System A.D. 1250-1350* (Oxford: Oxford University Press, 1989); Marica Milanesi, "La Cartografia Italiana nel Medio Evo e nel Rinascimento," in *La Cartografia italiana. Cicle de conferències sobre Història de la Cartografia. Tercer curs,* 1991, ed. Marica Milanesi, Vladimiro Valerio, Emanuela Casti Moreschi, and Leonardo Rombai (Barcelona: Institut Cartogràfic de Catalu-

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 Ptolomaic 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).[42]

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.[43] 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.[44]

Even if places names are still keys to accessing our digital world (as demonstrated, among others, by institutions like UN-GEGN, the United Nations Group of Experts on Geographical

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nya, 1993): 15–80; Alberto Tenenti, "L'Unità dell'Umano Attraverso le Scoperte Veneziane (Secoli XIV-XVI)," in *L'epopea delle scoperte*, ed. Renzo Zorzi (Firenze: Olschki, 1994): 1–16.

[42] Angelo Cattaneo, "Scritture di Viaggio e Scrittura Cartografica: La Mappamundi di Fra Mauro e i Racconti di Marco Polo e Niccolò de' Conti," *Itineraria* 3–4 (2004–2005): 157–202; Piero Falchetta, *Fra Mauro's World Map* (Turnhout: Brepols, 2006); Angelo Cattaneo, *Fra Mauro's Mappa Mundi and Fifteenth-Century Venice* (Turnhout: Brepols, 2011).

[43] Aniket Kittur, Ed H. Chi, Bryan A. Pendleton, Bongwon Suh, and Todd Mytkowicz, "Power of the Few vs. Wisdom of the Crowd: Wikipedia and the Rise of the Bourgeoisie," *World Wide Web* 1, no. 2 (2007): 19; Aniket Kittur and Robert E. Kraut, "Harnessing the Wisdom of Crowds in Wikipedia: Quality through Coordination," in *Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work* (2008): 37–46.

[44] Andrea Nanetti, Siew Ann Cheong, and Mikhail Filippov, "Interactive Global Histories: For a New Information Environment to Increase the Understanding of Historical Processes," in *Proceedings of the International Conference on Culture and Computing 2013* (Los Alamitos, CA: IEEE Computer Society, 2013): 104–10.

Names[45]), and can be understood as *loci* like in Medieval and Renaissance representations of the world (i.e. topics and gateways to topics linked one to the others from a variety of literary, visual, and oral sources), 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: in 2013 Henson et al. 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.[46] 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, and apply the methodology which Fra Mauro used to create the map and propose a way 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

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[45] See the United Nations Programs on Global Geospatial Information Management http://unstats.un.org/unsd/geoinfo

[46] Cory Henson, Payam Barnaghi, and Amit Sheth, "From Data to Actionable Knowledge: Big Data Challenges in the Web of Things," *IEEE Intelligent Systems* 28, no. 6 (2013): 0006–11.

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.

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. 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 Digital Atlas of Roman and medieval Civilizations edited by Michael McCormick, Leland Grigoli, Gio-

vanni Zambotti, et al.,[47] the British Broadcasting Corporation, and YouTube.

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 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).

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 here not only helps us better understand the Renaissance world placing it in a more flexible global context, but can also potentially help us understand ourselves and our world. In this way, maps continue to be storytelling devices that provide a point of view

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[47] Michael McCormick, Leland Grigoli, Giovanni Zambotti, et al. ed. *Digital Atlas of Roman and Medieval Civilisations*, http://darmc.harvard.edu/icb/icb.do.

by filtering information, but according to the user's needs instead of an author(ity)'s proposal. 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 the living with each other?[48]

III. The Time Period 1205-1533: World History and Quantitative Data

The starting date 1205 is emblematic for Late Medieval and Early Modern world history (Figg. 1 and 2): it was the year, just after the Fourth Crusade and the conquest of Constantinople (1201-1204), when the Venetians and the Western barons started to settle in the territories of the former Eastern Roman Empire and Genghis Khan made his first small-scale raids into Western Xia. The year 1533 is more related to the contingency of the main historical source used to start this research: the Venetian Diaries. All in all, it is the time period in which the Western European newly born nations tightened by the spirit of Renaissance started their sea-based expansionism in the Mediterranean sea and in the Oceans colonizing languages, memory, space, and knowledge.[49]

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[48] Andrea Nanetti, Angelo Cattaneo, Siew Ann Cheong, and Chin-Yew Lin, "Maps as Knowledge Aggregators: From Renaissance Italy Fra Mauro to Web Search Engines," *Cartographic Journal* 52, no. 2 (May 2015): 159–67.

[49] Caspar Hirschi, *The Origins of Nationalism: An Alternative History from Ancient Rome to Early Modern Germany* (Cambridge, MA: Cambridge University Press, 2012): 119–42; Wallace K. Ferguson, *The Renaissance in Historical Thought: Five Centuries of Interpretation* (Boston: Houghton Mifflin, 1948): xi-xv; Walter D. Mignolo, *The Darker Side of the Renaissance*: *Literacy, Territoriality, and Colonization*, 2nd ed. (Ann Arbor: University of Michigan Press, 1995, and 2003): i–xxii and 427–63; William N. West, "Encircling Knowledge," *Renaissance Quarterly* 68, no. 4 (Winter 2015): 1327–40.
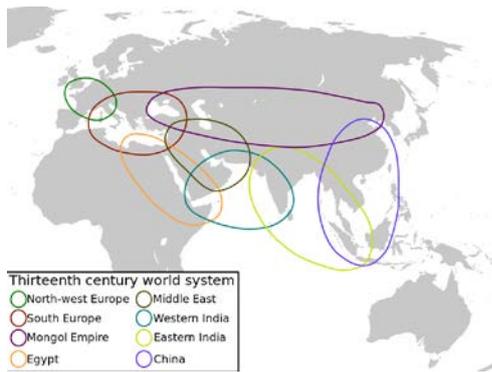
Figure 1. The eight circuits of the thirteenth-century world system; based on Abu-Lughod 1989: 34 [50]. Source of the image: *Wikipedia*.
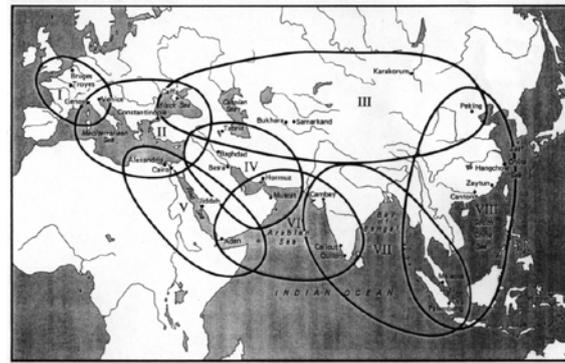

Figure 2. Abu-Lughod 1989: 34 [51] eight circuits of the thirteenth-century world system. Source of the image: https://lxsmuchxs.files.wordpress.com/2012/02/il1.gif .

The time period 1205-1533—besides its historical importance for having reshaped the world systems on land and sea both in the West (with the rise of nations, Humanism, Renaissance, geographical discoveries, etc.) and in the East (with the Mongol-led Yuan Dynasty, the Empire of the Great Ming, etc.)[52]—is significantly interesting from a data point of view as well, because there is just enough but not too much historical evidence for feasible tests of new ontologies to organize texts, images, and sounds in a relational database suitable to develop a systemic approach to the study of complex interactions between key subjects of the historical landscape.

For this same reason of providing just enough but not too much historical evidence, the choice of this time period facilitates also the scalability across the entire range of world histories in the experimental drawing of interaction layers among Europe, Africa and Asia. Indeed, from a world histories perspective, the results of this case study can help investigations in levels of intercontinental connectivity, whether less documented, like the diffusion of technologies or overwhelmed by documentation like the European expansion on the oceans in Modern Times.

Crucial validations are required by the time period in historical studies. In an Indian Ocean and South East Asia perspec-

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[50] Janet Lippman Abu-Lughod, *Before European Hegemony: The World System A.D. 1250-1350* (Oxford: Oxford University Press, 1989), 34.

[51] Ibid.

[52] David Northrup, "Globalization and the Great Convergence: Rethinking World History in the Long Term," *Journal of World History* 16, no. 3 (Sept. 2005): 249–67, 255.

tive, the consolidation of empires seems to have helped also to circumvent middle-traders.[53] As Geoff Wade wrote in 2010, the 15th century remains enigmatic in the overall history of Southeast Asia.[54]

> The crises, which ended the classical age of temples and inscriptions in the region during the 13th and 14th centuries, have been studied by a number of scholars, as has the period of European expansion which began with the 16th. However, the 15th century, which linked these phenomena, and its nature as a transitional period, continue to be infrequently examined and poorly understood. This volume is intended to partially redress this lacuna. It posits the great changes, which the region we know today as Southeast Asia underwent during the 15th century were to certain degree influenced by the politics and actions of Ming China.

Wang Gungwu in his foreword to the book edited by Tagliacozzo and Chang on *Chinese* circulations, states his surprise at the lack of early documentation about Chinese seagoing vessels competing with those coming from South and Southeast Asia[55]:

> The Chinese seemed to have been content to travel on foreign bottoms when they sailed to and from the Indian Ocean. Nevertheless, I speculated that the proto-Chinese Tue peoples of what became the southern coastal provinces of Fujian, Guangdong, and Guangxi were engaged in the maritime trade, and that their Chinese descendants eventually led the way as late Tang (ninth century), Wudai (907-959), and Song (960-1279) China increasingly launched their own ships to compete against well-established Muslims fleets. By the time of Zheng He's Indian Ocean banal expeditions in the fifteenth century, the Chinese were posed to dominate the southern seas. But, continental power prevailed and that initiative did not go any further. For much of the next six centuries, without state support, Chi-

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[53] Thomas Suárez, *Early Mapping of Southeast Asia: The Epic Story of Seafarers, Adventurers, and Cartographers Who First Mapped the Regions between China and India* (Singapore, Hong Kong, Indonesia: Periplus Editions, 1999).

[54] Geoff Wade and Sun Laichen, ed., *Southeast Asia in the Fifteenth Century: The China Factor* (Singapore/Hong Kong: National University of Singapore Press and Hong Kong University Press, 2010), 3.

[55] GungWu Wang, "*Foreword*," in Eric Tagliacozzo, and Wen-Chin Chang (eds.), *Chinese Circulations: Capital, Commodities, and Networks in Southeast Asia* (Durham NC: Duke University Press, 2011), xi–xiii.

nese private merchants operated in the interstices of European trading empire.

In our data perspective, every new book is a layer of metadata with an author, which has to be validated. For all of them, as Fra Mauro did for his map, we need workflow tools (provenance tools) to trace back how the authors came to certain conclusions. Our vision is to train AI to decode the semantics on which they based their knowledge, that is differentiate disparate data, trace back information, and present them in a synoptic visual report which will work as gateway to academic literature and primary sources.

IV. THE MOROSINI CODEX (1205-1433) AT THE INCEPTION OF A NEW ONTOLOGY FOR THE INTERACTIVE STUDY OF WORLD HISTORIES SEEN FROM DIFFERENT HISTORIOGRAPHICAL TRADITIONS

The Morosini codex (1205-1433) is the first successful example of Venetian historical diary dealing with the whole known world and represents the model for the following Venetian vernacular historiography, which will lead to Girolamo Priuli's work for the years 1494-1512 and to the most famous 58-volume *Diarii* (1496-1533) by Marin Sanudo the Younger.[56] Providing information on all the empires and cities having marketplaces in the known world, it represents one of the most important international historiographical texts for late medieval European and Mediterranean history. It deals with thousands of first-hand political and economical information taken mainly from merchants' (news)letters and the official deliberations of the Venetian councils. During the second half of the nineteenth and the twentieth centuries, in the Venetian diaries many scholars have been 'fishing' by excerpts the documents, on which the academies of Italy, Slovenia, Hungary, Croatia, Bosnia-Herzegovina, Serbia, Montenegro, Greece, Turkey, Russia, Cyprus, Syria, Lebanon, Israel, Egypt, Libya, Tunisia, Algeria, Morocco, Spain, and France, met

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[56] Marin Sanudo il Giovane, *Diarii*, vol. 58, ed. R. Fulin, F. Stefani, N. Barozzi, G. Berchet, M. Allegri (Venezia: Stabilimento Visentini cav. Federico Editore: 1879-1902).

together studying the history of the societies that appeared at the Mediterranean and at the Black Sea window from Medieval Times onwards, through the eye of Venice. Last, but not least the Mediterranean Basin is the longest and best-studied record of the ways in which human activities have transformed the world.[57]

Andrea Nanetti between 2010 and 2012 digitized the 1400-1423 portion of the Morosini codex and created a relational database as co-PI of a strategic research project hosted by Gherardo Ortalli at the University of Venice Ca' Foscari. The database provides both data (text-image links for the Morosini codex) and metadata for a first set of primary contents (linked geographical locations, governmental entities, and attributions), with a customized Web interface for data input and retrieval. Since then, a college of experts (Andrea Nanetti, John Melville-Jones, Alan Stahl, Sergej P. Karpov, Giovanni Caniato, and Andrea Rizzi) is responsible for the translation into English and the constant update of the critical edition in the database.

In 2010 and 2011, around the idea of the database took place a series of seminars led by Andrea Nanetti at the European Center for Living Technology of the same University of Venice, using the ideas about organization thinking developed in the first chapter of the ISCOM book by David Lane (one of the dissemination activities of the EU project ISCOM 'Information Society as a Complex System', 2002-2006)[58] to develop models of 'kinds of world,' which could be used to distinguish Morosini's from 'earlier' (or just 'different') kinds. That is a way of doing inference on the kind of material that the Morosini's diary represents, making rigorous what historians often treat in a completely anecdotal and suggestive way, without using "all" the material available, but only selecting fragments that illustrate their particular interpretations.

As a very basic example, the above mentioned Venetian diaries need to be fully indexed, parsed, and translated into English by a college of experts to become highly attractive and relia-

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[57] David Abulafia, *The Great Sea: A Human History of the Mediterranean* (New York: Oxford University Press, 2011), i-xxxi.

[58] David Lane, Sander van der Leeuw, Denise Pumain, and Geoffrey West, ed., *Complexity Perspectives in Innnovation and Social Change* (New York: Springer, 2009).

ble for the historians' international community as a whole. But the scholars have to be able to interact with the critical edition, translation, and data parsing as authors/users in an ongoing flow of *addenda & corrigenda* to ensure increasing collaboration to the project (e.g. the review by Sergej P. Karpov of the Morosini codex edition[59]).

The project is developing and testing tools (technologies and processes) to be readily adopted by users to visualize high volumes of data through maps, timelines, tag clouds, and/or interconnected graphs on different scales. Because, not only highly qualified scholars, but also artists, students, and all sorts of other users will create and share their narratives, by tagging, connecting and recognizing links among elements of the historical landscape.

The tag cloud can act as a link between relational and graph database solutions, suggesting case-by-case tests according to the primary differences between the two kinds of databases. Relational database structure allows keeping regular, relatively simple, structure. Graph databases, in turn, provide visualization and simplify information extraction through maps, timelines, etc. In a graph database, the relationships are stored at the individual record level, while in a relational database the structure is defined at a higher level (e.g. the table definitions).

A relational database is much faster when operating on huge numbers of records and using minimum storage space for it. At the same time, in a graph database, each record is examined individually during a query in order to determine the structure of the data, what make sense when there are a lot of variations in the relationships between records. According to these characteristics either structure could be used to provide necessary service: to store heterogeneous data types, as a platform for crowd sourcing, to mine data and metadata for coherent narratives.

Historian's theories select events and explain the processes that give to those events a meaning. Here historians can develop and test their theories of change, that are the main instruments

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[59] Sergej P. Karpov, "Review of The Morosini Codex," *Srednie Veka/The Middle Ages* 73 (2012): 361–64 (in Russian).

by which they provide explanations to how and why history has evolved; being the highest scientific and theoretical challenge of the project at this stage to offer an automatic narrative generation engine as part of the suite of tools on Interactive Global Histories.

Once the ontologies were ready, the research team started to work on other contemporary historiographical traditions, beginning with the Ming Shi Lu (明实录), from Ming Dynasty China (1368-1644 CE), and, presently, we are in the process of incorporating other chronicles, from the Middle East, India, and Southeast Asia. With this, we started our Interactive Global Histories project and we are now looking forward to adding Arab, Persian, Malay and other historiographical texts to the database. The database has also migrated from a rudimentary WordPress platform to Microsoft Azure, a cloud-based platform that allows us to run more powerful analytics on the data, moving form MySQL to graph databases and from PHP to Java Script.

We are now able to invite other scholars to upload into the database on Microsoft Azure other contemporary (1205-1533) historiographical traditions related to intercontinental networks, in order to let interact the world as seen from Venice and Ming China, with the world as seen from other perspectives. Other historians are also interested in this period, and they are similarly employing complex system approaches to understand historical developments at the regional to continental scales. In particular, Johanes Preiser-Kapellar has done a lot of work applying complex adaptive system and complex network approaches to gain new insights into the histories between 7th and 15th centuries. Together with Falko Daim, he recently edited a journal special issue under the theme of *Harbours and Maritime Networks as Complex Adaptive Systems*, exploring interactions between harbours in the Mediterranean, the Northern and Baltic Seas, and other inland waterways,[60] and is also getting ready to publish a book on the role of Constantinople in the intercontinental trade network between 1282 and 1402.

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[60] Johanes Preiser-Kapeller and Falko Daim (editors), *Harbours and Maritime Networks as Complex Adaptive Systems*, *International Journal of Nautical Archaeology* 45.1 (2016): 213-14.

Immediately, we ran into problems and challenges. Firstly, the same place may be known by different names in different sources, and the same name in different sources may refer to different places. The same name may also be used to refer to a village, a region, a people, or the ruler of the people. This requires us to think hard at how to do disambiguation, or even to do it at all. In the end, we came up with an author-toponym framework to handle this problem.

More importantly, once the EHM database is complete, with regional chronicles covering all the way from China to Venice, it would contain too much data for a historian to exhaustively study. This led us to develop the method of automatic narratives, which we will describe in greater details in the section on AUTOMATIC NARRATIVES FOR HISTORICAL DATABASES, after introducing our readers to complex systems and complex networks in the section on COMPLEX SYSTEMS & COMPLEX NETWORKS. The method of automatic narratives aims to apply data mining techniques to produce digests and hypotheses, that the historian can assess, and decide whether these are meaningless or worthy of in-depth exploration.

However, presenting all these digests to the historian at once is still too much. We need to filter out most information, and present only a small selection to the historian, and show more information as and when it is clear the historian will be interested in these. We realized the best interface to present this information is through an interactive digital map. After we explained the data, information, knowledge, and wisdom (DIKW) hierarchy and its relevance to the historical sciences in the section on THE DATA-INFORMATION-KNOWLEDGE-WISDOM HIERARCHY, we will argue in the section on DIGITAL MAPS FOR INTERACTIVE GLOBAL HISTORIES that in the past, the map was also the medium of choice to aggregate and summarize knowledge. We then describe how an interactive digital map can serve this knowledge aggregator role, and help historians study historical data in a scientific way.

V. Complexity, World Histories, and Automatic Narratives Generation

In the words of John H. Holland[61] and William Brian Arthur,[62] complex systems are characterized by their dependence on contingencies, for example, event B happens because event A happened in the past, but not event C. These contingencies, also called path dependences, make the study of global histories highly bewildering, because of the concatenation of conditional probabilities.[63] Here, instead of relying on theories and interpretations about levels and networks of world connectivity, we want to test how, when, and by whom the (potential) intercontinental network (which changes across time accordingly to accidents like plagues, conflicts, natural calamities, and so on) has been used according to specific case studies, analyzed one by one and added to the database as interactive layers of documented circulations of objects (ceramics/porcelain, silk and other fibers, textiles, glass, paper, etc.), individuals and groups (e.g. accounts of specific travels by land and/or sea), technologies (production and diffusion of white and blue porcelain, pottery kilns, weaving and dyeing, lost-wax casting bronze productions, etc.), rituals, dances, and so on, including all aspects of tangible and intangible cultural heritage sees as the treasure of human experiences. Seeing history not as a linear progression of events, but as a complex, nonlinear network of contingencies gives us the correct frame of mind to respond to the issues raised by William A. Green in his article on world history periodization.[64]

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[61] John H. Holland, *Emergence: From Chaos to Order* (Oxford: Oxford University Press, 2000).

[62] William Brian Arthur, *Increasing Returns and Path Dependence in the Economy* (Ann Arbor: University of Michigan Press, 1994).

[63] Bak, Per and Maya Paczuski, "Complexity, Contingency, Criticality," *Proceedings of the National Academy of Sciences of the United States of America* 92 (1995): 6689–96.

[64] William A. Green, "Periodizing World History," *History and Theory* 34, no. 2 (May 1995): 99–111, 99. See also the larger work by the same William A. Green, "Periodization in European and World History," *Journal of World History* 3 (1992): 13–53; and Jerry H. Bentley, "Cross-Cultural Interaction and Periodization in World History," *American Historical Review* 101, no. 3 (June 1996): 749–70.

Periodization is rooted in historical theory. It reflects our priorities, our values, and our understanding of the forces of continuity and change. Yet periodization is also subject to practical constraints. For pedagogical reasons, world historians must seek reasonable symmetry between major historical eras despite huge discrepancies in the availability of historical data for separate time periods and for different areas of the world.

Our proposed solution to delimit time periods is to move away from focusing on main individual events, but to look instead at intensity in the flow of events in societies' natural non-linear perception of time.

While historical texts have long been subject to critical analysis, the formal and historical problems posed by graphic representations of time have largely been ignored. "This is no smaller matter: graphic representation is among our most important tools for organizing information" (and yet retrieving it using search engines algorithms).[65]

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[65] Danile Rosenberg and Anthony Grafton, *Cartographies of Time: A History of the Timeline* (New York: Princeton Architectural Press, 2010): 10–25, and note 1 at p. 248, which provides the essential bibliography for interdisciplinary perspectives on graphic representation, epistemology, and aesthetics. Yet, little had been written about historical charts and diagrams before this book. And, for all of the excellent work that has been recently published on the history and theory of cartography, we have few examples of critical work in the area of what Eviatar Zerubavel has called *Time Maps: Collective Memory and the Social Shape of the Past* (Chicago: University of Chicago Press, 2003). For time in cartography, see footnote 2 at p. 248. Mark Greengrass and Lorna Hughes, ed., *The Virtual Representation of the Past* (Farnham UK/Burlington USA: Ashgate, 2008), defined as a "comparative exercise in representation" (Mark Greengrass, p. 1), opened the series *Digital Research in the Arts and Humanities* collecting the results of seminars held in 2005 and 2006, which deals essentially with digitalization of artifacts and their purposes.

Figure 3. The 6 W's of a narrative, and how they relates to the key actors, key events, key periods, key locations, key factors, and key actions in historical analysis. Source of the image: Nanetti et al. 2013.[66]
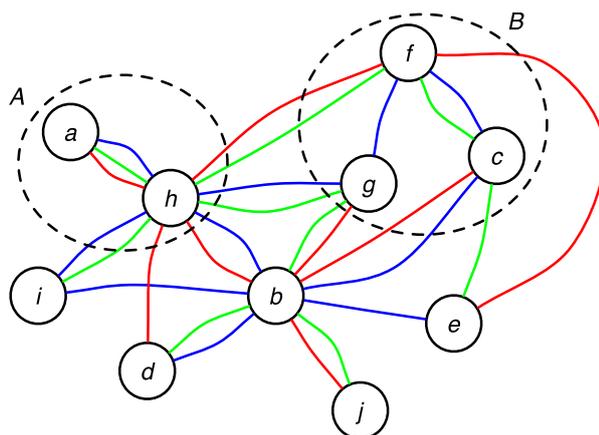

Figure 4. A complex network of historical actors (*a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, *i*, *j*), connected by different link types (blue, green, and red, and possibly others as well), which represent different kinds of socio-political relations (trade, diplomacy, conflicts, etc.). Among other higher-level information we can extract from this complex network are power blocs, shown here as the clusters *A* and *B*. Source of the image: Nanetti et al. 2013.[67]

Marten Scheffer's research team recently used eco-systems as a showcase to point out that complex systems theory associates regime shifts as critical transitions with higher intensities of events.[68] Building on his insights, we decided to mine the complex network of intercontinental trade, diplomacy, conflicts and other interactions among cities, nations and continents during Late Middle Age and Early Renaissance (1205-1533 CE) to identify time and geography of such transitions.

As Fra Mauro's map of the world connected geographical worlds not so far critically compared in one picture (Ramusio in 1550 recommended it to the pilgrims as "one amongst the various miracles of Venice"[69]) and the Morosini codex reorganized

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[66] Andrea Nanetti, Siew Ann Cheong, and Mikhail Filippov, "Interactive Global Histories: For a New Information Environment to Increase the Understanding of Historical Processes," in *Proceedings of the International Conference on Culture and Computing 2013 (Kyoto, Ritsumeikan University, Sept. 16-18, 2013)* (Los Alamitos, CA: IEEE Computer Society, 2013), 107.

[67] Ibid.

[68] Marten Scheffer, Jordi Bascompte, William A. Brock, Victor Brovkin,Stephen R. Carpenter, Vasilis Dakos, Hermann Held, Egbert H. van Nes, Max Rietkerk, and George Sugihara, "Early-Warning Signals for Critical Transitions," *Nature* 461, no. 7260 (2009): 53–59.

[69] Giovanni Battista Ramusio, *Primo Volume delle Navigationi et Viaggi* (Venetia: Appresso gli Heredi di Lucantonio Giunti, 1550).

the news arriving in Venice from its worldwide network (a vast accumulation of facts with little relationship among them), the idea is to compare historiographical worlds not associated yet: chronicle, diaries and travel accounts in vernacular Venetian, Chinese, Arab, Persian, Malay, and Javanese. Using Fra Mauro's syntax and grammar (aggregating and comparing contradictory ancient authorities visualizing them in one picture), we can experiment the sea between 1205 and 1533 as a global commercial network connecting pre-existing networks already partially overlapping as Ferdinand Freiherr von Richthofen first enounced in two talks given at the Geological Society in Berlin in 1876[70] for the maritime networks and in 1877 for the land ones,[71] where he presented the first results of what would have been later published in his monumental *China* between 1877 and 1912.[72]

Such a kind of enriched knowledge aggregation can provide the ontologies for interactive spatial reconstructions and reorganizations of historical knowledge in interactive narratives on flat screens (e.g. Microsoft World Wide Telescope[73] and Rich Interactive Narratives[74]) or in dome screens as we are experimenting in the School of Art, Design and Media at Nanyang Technological Singapore (e.g. The Silk Road, by Andrea Nanetti and NTU University Scholars Programme, animated by Luo ShenShen, NTU-ADM PhD student).

We believe that this case study on the period 1205-1533, seen and experimented as a lab (isolated in time as a closed physical system), and the use of such interactive aggregation tools will allow us to create a history laboratory for e-science to organise the data, distill relevant information, make test hypoth-

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[70] Ferdinand Freiherr von Richthofen, "Über den Seeverkehr nach und von China im Altertum und Mittelalter," *Verhandlungen der Gesellschaft für Erdkunde zu Berlin* (1876), 86–97.

[71] Ferdinand Freiherr von Richthofen, "Über die zentralasiatischen Seidenstrassen bis zum 2. Jh. n. Chr," in *Verhandlungen der Gesellschaft für Erdkunde zu Berlin* (1877): 96–122.

[72] Ferdinand Freiherr von Richthofen, *China: Ergebnisse Eigener Reisen und Darauf Gegründeter Studien*, 5 vols., and Atlas (Berlin: Reimer, 1877–1912); Daniel C. Waugh, "Richthofen's 'Silk Roads:' Toward the Archaeology of a Concept," *Silk Road* 5, no. 1 (Summer 2007): 1–10.

[73] http://www.worldwidetelescope.org/

[74] Kenji Takeda, Graeme Earl, Jeremy Frey, Simon Keay, and Alex Wade, "Enhancing Research Publications Using Rich Interactive Narratives," *Philosophical Transactions of the Royal Society A*, 20120090. http://dx.doi.org/10.1098/rsta.2012.0090

eses, and validate evolutionary processes theories, first of all for cities (recognised as the basic knots in the intercontinental network system). In this way history can be used in smart cities today to highlight and explain present ties and illustrate potential future scenarios. Is the future written in the data that the present still provide us about the treasure of historical human experiences? Can AI be smarter than humans in knowledge transmission processes?

With these questions in mind, we are building up our heritage science laboratory to test the already published history books narratives and provide prototyping, solutioning, and proofs of concept for new research hypotheses. The vision is to kick off a historical analysis at the world scale, through the digital assembly of historical sources into a cloud-based database on Microsoft Azure, where machine-learning techniques can be used to summarize the database into a time-integrated actor-to-actor complex network.

The first deliverables of the laboratory, run in collaboration with Microsoft Research, will be the diagnosis and discussion of potential problems and real difficulties inherent to the current experimental project, focusing of provenance and validation issues. The disclosure of these reflections will continue to be done in international journals, conferences, and workshops to benefit a growing community of researchers that we welcome to join our project, seen as an open work at the frontiers of knowledge, as Umberto Eco would say.

All historians of goodwill can be part of the research team, individually or involving the research institutions to which they are affiliated. They can participate at different levels, from sharing their databases of transcribed and translated historical sources, to benefiting of the search tools, to joining or co-organizing conceptual and methodological sessions for the definition of the structure of the metadata and the future developments of the research project.