A Complex Network Approach for Museum Services
A Model for Digital Content Management

Filippo Eros Pani, Simone Porru, Matteo Orrù and Simona Ibba
Department of Electrical and Electronic Engineering, University of Cagliari, Piazza d'Armi, Cagliari, Italy

Keywords: Knowledge Management, Complex Network, Knowledge Base, Museum Services.

Abstract: In a globalized economy, cultural heritage is a strong attractor. Thanks to ICT, it is possible to trigger new development dynamics. For cultural heritage, the contribution of new technologies can offer the highest degree of distribution and access opportunities. A modern museum can actually be seen as a complex ICT system, deeply interconnected, with typically a large quantity of data to manage, extremely dynamic due to ever-changing temporary exhibitions, and with applications that feature a high level of usability for a higher visitor involvement. The aim of this position paper is to create an approach geared to provide aggregated information on the nature, range and articulation of the belongings of the museum, through a paradigm based on the concept of complex network. Applying the complex network model, it will be possible to map a corpora of items made of works of art, artifacts and any object of interest for a museum. The implications derived from the adoption of this approach are multifarious: for example, a curator could evaluate partnership opportunities in the organization of temporary exhibitions, guided paths or catalog editing through an analysis of the relations between the items in their museum and the ones in other museums.

1 INTRODUCTION

The cultural heritage sector has an enormous potential for innovation, with astounding development prospects. This evolution scenario is of special interest to countries owning a rich cultural heritage. Such a wealth can also be relevant as an economic asset, with very interesting and varied consequences and characteristics.

Museums are known for the large quantity of data they need to manage, and show an extreme dynamism, for example due to temporary exhibitions. Its applications must possess a high level of "usability" so that a higher number of visitors can be involved in the most "intense" way possible. It is implied that the use of digital technologies in the museum sector offers many opportunities for innovation (Pani et al., 2014). Thanks to the use of the Internet and to the new forms of interaction with information systems, the ways in which museums can be enjoyed are expanding, for information and communication management systems as well as for increasingly "bold" opportunities leading to a new type of museum, namely an interactive one (Kelly, 2014) (Sahba, 2014) (Chianese and Piccialli, 2014).

The aim of our proposal is to provide aggregated information on the nature, the extension and the articulation of the belongings of museums. The information related to each artifact needs to be managed through a paradigm based on the concept of complex network, integrating "punctual" information (as related to a single item, like in a traditional catalog) with another type of information related to the connections among the different items that are hosted by the museum (gallery, exhibition, etc.). This second type of information is of a "topological" nature.

The paper is structured as follows: Section Two shows an overview of the complex networks and in Section Three we propose our approach In Section Four some possible applications to museum services in real world scenarios are presented. Lastly, Section Five includes the conclusions and some reasonings about our work.

2 RELATED WORK

In the recent years there has been a surge of interest and an increasing number of studies on complex networks (Newman, 2003).These systems are found in natural sciences, for example in proteomics and in neurophysiology, in social sciences (i. e., social

Pani, F., Porru, S., Orrù, M. and Ibba, S..
A Complex Network Approach for Museum Services - A Model for Digital Content Management.
In *Proceedings of the 7th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management (IC3K 2015) - Volume 3: KMIS*, pages 216-221
ISBN: 978-989-758-158-8

networks like Facebook), in technology and computer science (i.e., Internet and the Web). The increasing number of scientific works published on prestigious journals such as Nature, Science and PNAS shows that the subject has become one of the most important in statistical physics and science in general. We live in an age where information is the ultimate source of meaning, as well as economic value, and the information is propagated and is processed through their complex networks.

It has been found that networks of different nature share some properties (Valverde et al., 2002) (Valverde and Sole, 2003) (Concas et al., 2013). Many different kind of complex networks have been proved to present the small-world property. Reported for the first time by Milgram (Milgram, 1967) it has been then popularized as “six degree of separation”. This networks present small values for average shortest paths and high value of the clustering coefficient. This implies that network nodes are highly connected and that the number of “hops” that separates two pairs of nodes are on average small if compared to a random network of the same size. As a result it is possible to find a path that connects two nodes with a relatively small number of edges, but also to change a path in case of edges being removed.

In general, in complex networks, the distribution of the nodes' in (out) degree is represented by an exponential function. This kind of network usually presents few nodes that are highly connected, with a far greater number of connections, whereas, on the contrary, the vast majority of nodes present just few connections with the rest of the network. This property has practical implications: for example if one considers the reliability of a network, that results robust to the random failure but vulnerable to failure involving the highly connected nodes or hubs.

One of the most interesting property of complex networks is that they present a community structure (Girvan and Newman, 2001), (Fortunato, 2010). Inside a network, a community is a subnetwork whose nodes present denser connections to each other, if compared to the connection with nodes outside the community. Researchers of different background tackled the problem of determining the best division in communities for a network, using different approaches (statistical, algorithmical, etc). Finding a community structure implies finding the elements that present the highest interaction, meaning that they likely belong to the same social group or share some meaningful features.

Recently some scholars began to study the hierarchical aspects of complex network. The Louvain algorithm, as a matter of fact, is already a multilayer algorithm. Clauset et al. (2007, 2008) proposed a method to find the hierarchical structure of a network using a Monte-Carlo Markov Chain approach. The hierarchical structure retrieved has been shown to be useful to detect missing links between nodes.

Future applications of the use of complex networks in museums include producing and providing visitors with customized navigation environments, capable of leveraging the nowadays ubiquitous handheld devices. The interest on the use of mobile devices as a means for enhancing users' experience in museums has been increasing lately (Rubino et al., 2013). In the work of Rubino, mobile interactive guides, tailored for children and adults, are the final product of the proposed MusA framework. This framework also leverages a vision-based indoor positioning system, capable of providing location based services such as customized visit paths.

Several articles has also been produced on visitor circulation patterns (Bitgood, 2006), often focusing on the benefit/cost ratio as the determing factor in visitor's path choices. While some general visitors' preferences are not linked to the exhibit's quality and/or typology (e.g., right-hand side circulation, preference for limited choice points instead of multiple choice, one-sided visiting pattern in two-sided exhibitions), others can be heavily dependent on the differences between perceived exhibits' values. Thus, understanding how movement patterns change according to different exhibits positioning can be regarded as an effective way to reveal the items' perceived value.

Providing visitors with a customized navigation environment is also a primary goal for recommender systems. In the case of cultural sites, especially when they contatin Points Of Interests (POI), classical recommendation techniques have been used in conjunction with context-aware services to provide users with a dynamic visiting path, which therefore changes according to the mutable needs of the users (Bartolini et al., 2014).

The exploitation of collaboration between museums, and thus metadata standardization, is also another topic of interest that is regarded as a major factor in producing disruptive applications in the cultural heritage scenario (Skinner, 2014). To this respect, leveraging smartphones and Web 2.0 technologies can represent a means to detect whicth context-aware metadata can be used for standardizing user-generated knowledge (Flanagan and Carini, 2012).

3 THE PROPOSED APPROACH

The proposed approach is based on the concept of complex network (or graph), that is a structure with two main separate elements: nodes, which represent the basic elements of the graph, and node connections, called branches or arches. An example of a network we face every day is the road network. We could associate cities to nodes, and roads connecting cities to branches. The complexity is intrinsic to the networks as their size increases, that is to the number of involved elements (nodes and branches), to the point that it becomes extremely complex to understand its structure, its behavior, and its evolution. For this reason, in order to study complex networks, tools, methods, and algorithms coming from a multidisciplinary knowledge corpus (statistical physics, sociology, etc.) are used, a corpus that has been gradually built over the years.What makes complex networks interesting is the fact that they constitute a mathematical model that can represent facets and artifacts of human life, and several natural phenomena. Networks of different origin and nature (from electric networks to metabolic ones) possess the same properties. It is possible to apply the same concept of network to human knowledge. In this case, the term knowledge network is used. An example of knowledge network is represented by bibliographic networks created from author collaboration (co-authorship) information or quotations appeared in reference sections.

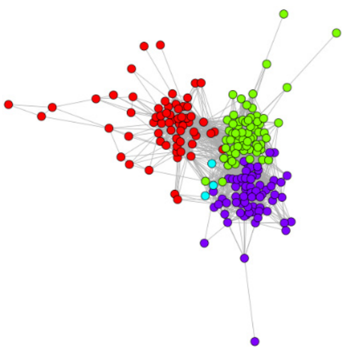

Figure 1: Collaboration network of jazz musicians. Each node is a Jazz musician and an edge denotes that two musicians have played together in a band (Gleiser and Danon, 2003). Different colors represent the community retrieved with the FastGreedy Algorithm (Clauset et al. 2004).

4 MUSEUM SERVICES

It is possible to apply the complex network model to map a corpus of items, along the same lines as bibliometric studies, but which is larger and more varied than bibliographic heritage, including works of art, artifacts, and any items of interest to a museum. The way howartifacts can be associated to each other on the basis of some of their features is actually intuitive. For example, sets of artifactscan be considered connected if they belong to the same artistic movement, or to the same historical period, or school, or location, author, type, subject, etc.

The implications derived from such an approach are multifarious for curators. Curators could, for example, analyze the nature of the relations between the items in their museums and items belonging to other museums, and evaluate potential partnerships when organizing temporary events, guided paths, creating catalogs.

Starting from information included in catalogs, a complex network with items and their relations (aggregated and at different granularity levels) will be created. It will include a visual representation, in a synthetic form, explorable at a glance, and it will allow to investigate the complexity of the relations between items.

That network is, in fact, a mathematical model on which it will be possible to apply different algorithms to the collection of network metrics and perform statistical analysis. It will be possible to, for example, obtain information on the nature and strength of the connections between items through the use of clustering or community-detection algorithms. It will be possible to follow the evolution of the items over time, or associate information on the items to information of another nature (for example, pertaining to location of origin). It will be also possible to filter the elements of the network according to several parameters (period, artistic school, author, etc.), to analyze only the subnetworks of relevant elements.

The enhanced capabilities of museum resources as parts of a complex network could also be leveraged for enhancing on-site visitors' experience, providing them with different alternative paths to fully enjoy their visit. For instance, a visitor could choose among a “chronological”, “paintings by artist”, or a “stylistic” path, by simply selecting their choice through a dedicated mobile application, specifically designed to work with the complex network associated to the resources in the exhibition. This could also mean that, by studying the visitors' preferences with regard to the different visiting paths (performed through the analysis of the data collected via the mobile app), it will also be possible to place the resources according to the most popular path (e.

g., visitors might be more interested in seeing a certain artist's paintings first, then ones from another, and so on, in a “paintings by artist” fashion).

In Fig. 2 an explicative diagram illustrating the interaction between a visitor and a dedicated mobile app is reported, so as to provide an example of how new information could be added in a complex network for resources in a museum. According to the proposed diagram, a visitor might use the museum application to explore the suggested predefined visiting paths, that is, paths where museum resources (e. g., paintings, sculptures) are shown to the visitor in a predefined order, such as a chronological order, or a “by artist” order.

Since the museum app communicates with a server, the visitor's choice will be recorded on the system. Thanks to the recording of such information, it will be possible to see which kind of suggested path is the most popular among visitors and, observing their behavior after that choice (i. e., if they followed that path or decided to leave it very soon during their visit), to check if it seems to satisfy the user's needs and meet their expectations. Each deviation from the chosen suggested path could also show the preferences of common visitors more clearly. For example, if many visitors show interest toward a particular piece of art, and read its description (e. g., through a QR-code placed next to the item, which upon acquiring it will send a request to the server for obtaining the object's information) instead of following the predefined path, it could be useful to insert the said piece of art in a list of “suggested items” among those next to the visitor.

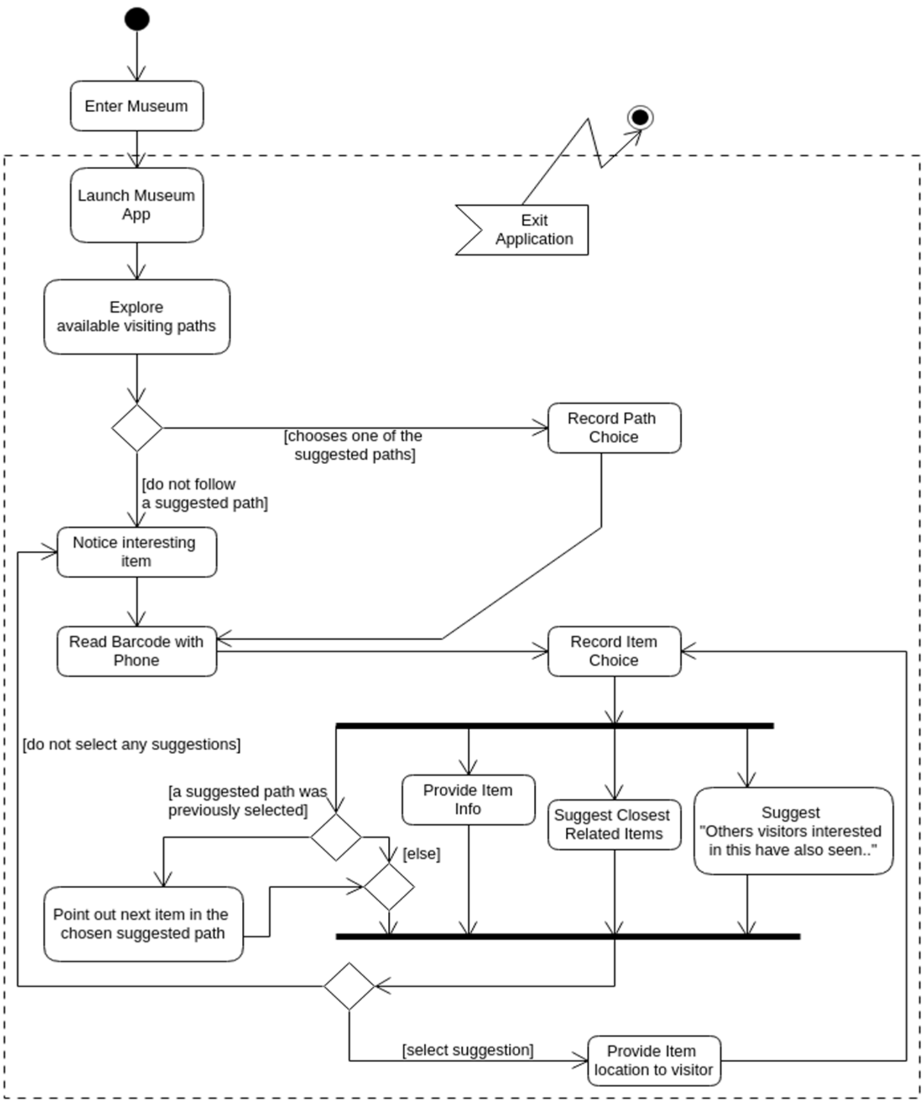

Figure 2: A possible interaction between visitors and a dedicated mobile app.

following the predefined path, it could be useful to insert the said piece of art in a list of "suggested items" among those next to the visitor.

After collecting enough data concerning the order in which items were actually seen by the visitors, and which suggestions they were prone to accept the most, it will be possible to enrich the information contained in the resources' complex network, and then design a so-called "optimal path" for visiting the museum. The museum could then easily adapt to its visitors' preferences, that is, learn from previous experiences.

5 CONCLUSIONS

In this paper we proposed an innovative approach to exploit the resources hosted on a museums and the like, by leveraging ITC technologies on one side, and a powerful statistical model called complex network on the other. We described several ways in which this integration might take place.

The enhanced capabilities of museum resources as parts of a complex network could be leveraged for enhancing on-site visitors' experience, providing them with different alternative paths to fully enjoy their visit. For instance, a visitor could choose among a "chronological", "paintings by artist", or a "stylistic" path, by simply selecting his/her choice through a dedicated mobile application, specifically designed to work with the complex network associated to the resources in the exhibition. This could also mean that, by studying the visitors' preferences with regard to the different visiting paths (performed through the analysis of the data collected via the mobile apps), it will also be possible to place the resources accordingly to the most popular paths (e. g., visitors might be more interested in seeing paintings first from an artist, than from another, and so on, in a "paintings by artist" fashion). As indoor localization services are currently a trending topic (Mighali et al., 2015) in the tourism industry, succeeding in leveraging the resources which a museum holds for improving cultural experience and indoor localization technologies represents a fairly attractive opportunity for both research and industry.

Museum resources could also be described through metadata associated to visitors' paths preferences, which will be used for characterizing a binary relationship between resources (e. g., two paintings could be linked together when most of the visitors prefer to see them one after the other), thus revealing connections that were previously hidden or not apparent.

Studying the relationship between path preferences and the so-called 'hypercongestion' (i. e., the number of visitors exceeds musem's physical space capacity) will also serve as an indicator of how visitors react to a more crowded environment, as a similar study on this subject (Yoshimura et al., 2014), conducted on the Louvre museum, has tried to understand.

REFERENCES

Bartolini, I., Moscato, V., Pensa, R. G., Penta, A., Picariello, A., Sansone, C. and Sapino, M. L. (2014). Recommending multimedia visiting paths in cultural heritage applications. In *Multimedia Tools and Applications*, pp. 1-30, DOI: 10.1007/s11042-014-2062-7.

Bitgood, S. (2006). An analysis of visitor circulation: Movement patterns and the general value principle. In *The Museum Journal*, Vol. 49, Issue 4, pp. 463-475.

Chianese, A., and Piccialli, F. (2014). Designing a smart museum: when Cultural Heritage joins IoT. In *Eighth International Conference on Next Generation Mobile Apps, Services and Technologies (NGMAST), IEEE*, pp. 300-306.

Clauset, A., Moore, C. and Newman, M. E. J. (2007). Structural Inference of Hierarchies in Networks. In *Airoldi, E. M. et al. (Eds.): ICML 2006 Ws, Lecture Notes in Computer Science* 4503, pp. 1-13. Springer-Verlag, Berlin Heidelberg.

Clauset, A., Moore, C. and Newman, M.E.J. (2008). Hierarchical structure and the prediction of missing links in networks. In *Nature* 453, pp. 98-101.

Concas, G., Monni, C., Orrù, M. and Tonelli, R. (2013). A study of the community structure of a complex software network. In *Proceedings of the 2013 ICSE Workshop on Emerging Trends in Software Metrics, WETSoM '13,* San Francisco, CA, USA, pp. 14-20.

Flanagan, M. and Carini, P. (2012). How games can help us access and understand archival images. American Archivist, Vol. 75, Issue 2, pp. 514-537.

Fortunato, S. (2010).Community detection in graphs. In *Physics Report*, 486:75-174.

Girvan, M. and Newman, M. E. J. (2001). Community structure in social and biological networks. In *Proc. Natl. Acad. Sci.* U. S. A., 99(cond-mat/0112110):8271–8276, 8 p.

Gleiser, P. M. and Danon, L. (2003). Community structure in jazz. In *Advances in Complex Systems*, 6(4):565-573.

Kelly, L. (2014). The Connected Museum in the World of Social Media. In *Museum Communication and Social Media: The Connected Museum. Ed. Kirsten Drotner and Kim Christian Schrøder.* New York-London: Routledge, pp. 54-71.

KONECT, May 2015. Jazz musicians network dataset - KONECT.

Mighali, V., Del Fiore, G., Patrono, L., Mainetti, L., Alletto, S., Serra, G., andCucchiara, R. (2015). Innovative IoTaware Services for a Smart Museum. In *Proceedings of the 24th International Conference on World Wide Web Companion*, pp. 547-550). International World Wide Web Conferences Steering Committee.

Milgram, S., The small world problem (1967). In*Psychology Today* 2, pp. 60-67.

Newman, M. E. J. (2003). The structure and function of complex networks. In *SIAM REVIEW*, 45:167-256.

Pani, F. E., Concas, G., Porru, S., (2014). An Approach to Multimedia Content Management. In *Proceedings of the 6th International Conference on Knowledge Engineering and Ontology Development, KEOD 2014,* 21- 24 October, Rome, Italy.

Rubino, I., Xhembulla, J., Martina, A., Bottino, A., and Malnati, G. (2013). MusA: using indoor positioning and navigation to enhance cultural experiences in a museum. In *SENSORS*, Vol. 13, Issue 12, pp. 17445-17471. ISSN: 1424-8220.

Sahba, F. (2014). Museum automation with RFID. In *World Automation Congress (WAC)*, IEEE, pp 19-22.

Skinner, J. (2014). Metadata in Archival and Cultural Heritage Settings: A Review of the Literature. In *Journal of Library Metadata*, Vol. 14, Issue 1, pp. 52-68. DOI: 10.1080/19386389.2014.891892.

Sahba, F. (2014). Museum automation with RFID. In *World Automation Congress (WAC)*, IEEE, pp 19-22.

Valverde, S., Cancho, R. and Sole, R. V. (2002). Scale free networks from optimal design. In *Europhysics Letters*, 60, 2002.

Valverde, S. and Sole, R. V. (2003). *Hierarchical small worlds in software architecture*. arXiv:cond-mat/0307278v2.

Yoshimura, Y., Sobolevsky, S., Ratti, C., Girardin, F., Carrascal, J. P., Blat, J., & Sinatra, R..(2014). An analysis of visitors' behavior in The Louvre Museum: a study using Bluetooth data. In *Environment and Planning B: Planning and Design*, 41(6), pp.1113-1131.