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Network Theory and Its Applications in Arts Practice and History of Arts

Miguel Ángel Medina
University of Málaga (Spain)

Abstract
Networks pervade our world. Network theory is currently applied to different social, humanistic and natural sciences. The concept of network and the theory behind it have enormous potential of useful application in both art research and art practice. This article provides historical backgrounds of network sciences and reviews some relevant applications in arts.

1. Introduction

These first years of the XXIst Century have known the development and explosion of the *science of networks*. The birth and expansion of technological tools has contributed to popularize the term "social network", as shown by the successful paradigms of *facebook* and *twitter*. But the concept of social network is not new at all. In fact, what else is a group of friends, or a family, or a neighborhood? Furthermore, evidence clearly shows that in our world there are networks everywhere, not only man-made technological networks (as those of internet), but also natural networks. At all the scales, from the molecular to the cosmic level, natural systems organized as networks can be identified. This is the case of interacting protein networks (interactomes), metabolic and biosignaling networks, ecological networks (including food webs), and even the diffuse network connecting matter in the universe. Thus, in few years we have become aware that there are networks pervading everywhere and that these networks bring everything surprisingly very close to each other. In this point, a number of questions arise: What is a network? What have all the networks in common (if anything)? What are the main rules and general principles of organization and evolution of networks? And what have network to do with arts? To provide answers to these questions, it could be advisable to go backwards to the historical backgrounds of modern science of networks.

2. Historical background and some key concepts

It is widely accepted that the earliest precedent of modern network science goes back to the XVIIIth Century, and in concrete to the most productive mathematician in the history of mathematics, namely, Leonard Euler, who laid the conceptual bases of the scientific study of networks with the formulation of *graph theory*. Euler founded this new branch of mathematics when he solved for the first time the famous problem of Königsberg's bridges in 1735, at the age of 28. The city of Königsberg (currently, Kaliningrad in Russia) is set on both side of the Pregel river and included two islands connected to each other

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and to the mainland by seven bridges. The problem was to find a walk through the city that would cross each bridge once and only once. Euler managed to solve this problem by making an abstraction of the concrete situation (Biggs, Lloyd & Wilson, 1999; Euler, 1913), identifying each position as a point or *node* and each direct way connecting two positions as a line or *edge*. Modern network science also represents networks as graphs consisting of nodes and edges. A second essential background is related to the second most prolific mathematician in the whole history of mathematics, namely, Paul Erdös, who in cooperation with Alfred Renyi introduced the new mathematical theory of *random networks* in 1959 along eight specialized articles mentioned in (Graha, & Nesetril, 1996).

A network is any system that can be abstracted and depicted in the form of a graph in the terms introduced by Euler. Hence, any network is composed of two subsets of elements: *n* nodes and *m* edges connecting nodes. For a primer on concepts, principles and rules of network science see (Newman, 2010). Irrespectively of their nature, networks can be described by their topological features; among them their *degree* and *length*. The degree of a node in a graph is the number of edges connected to it. In random networks, the connections among nodes are established randomly, giving rise to an average degree of the network with little standard deviation. In a graph, two nodes can be connected with a number of paths and the *length of a path* is the number of intermediate nodes in this path. A *geodesic path* (or *shortest path*) is a path between two nodes such that no shorter path exists between them. The *diameter* of a graph is the length of the longest geodesic path between any pair of nodes in the network for which a path actually exists. In random networks, the diameter varies with the number *n* of nodes as *ln n*. The number of independent paths between a pair of nodes is called their *connectivity*. This can be thought of as a measure of how strongly connected those nodes are.

In spite of the interest of random networks, many (and the most interesting) real networks are not random. This fact postponed the scientific exploration and analysis of real networks for years. In fact, technological and natural networks only began to be studied within the framework of network science from the nineties on. In this point, it is noteworthy that the first influential scientific studies of real networks were not carried out in any of the natural sciences but in the social sciences. The first one was the experiment and study on the so-called "small-world problem" carried out by the psychosociologist Stanley Milgram (Milgram, 1967). This study, inspired by the popular expression "it's a small world", followed the path started by Ithiel de Sola Pool's group at MIT, who empirically studied the structure of social networks in the early sixties. The graduate student Michael Gurevich conducted this study under the supervision of de Sola. This work yielded the PhD dissertation "The Social Structure of Acquaintanceship Networks", which was later further formalized in mathematical terms by Manfred Kochen in a study that only was published in 1978, many years after the actual moment in which it was carried out (de Sola Pool & Kochen, 1978). In his popular 1967 paper, Milgram describes two parallel experiments designed and carried out to give an answer to the question: "How many intermediaries are there connecting two distant, randomly selected persons in the USA in an acquaintance chain?" In Milgram's study, chain varied from 2 to 10 intermediate acquaintances with the median value at five. Surprisingly, this median value had been envisioned by the Hungarian writer Frigyes Karinthy in 1929. Karinthy was convinced that technological advances in communications and travel was contributing to make friendship networks grow larger and span greater distances, thus giving rise to an ever-increasing connectedness of human beings in an shrinking world. This idea is exposed in his brief history "Chain-Links" (Karinthy, 1929), contained in the short stories' volume "Everything is Different" (1929). The quotation from this short story (translated into English) is as follows:

> *"One of us suggested performing the following experiment to prove that the population of the Earth is closer together now than they have ever been before. We should select any person from the 1.5 billion inhabitants of the Earth - anyone, anywhere at all. He bet us that, using no more than five individuals, one of whom is a personal acquaintance, he could contact the selected individual using nothing except the network of personal acquaintances. For example, "Look, you know Mr. X.Y., please ask him to contact his friend Mr. Q.Z., whom he knows, and so forth".*

Nowadays, we know that Karinthy's insight and the results provided by the above mentioned studies on social networks were the first comments and demonstrations of the so-called *small-world effect*, the fact that most pairs of nodes in most real networks (namely, those so-called small-world networks) are connected by a short path through the network, short path that is much shorter than the mean path length expected in a random network with the same size (Newman, 2003).

The idea that a chain of "friends of a friend" could be made to connect any two persons in the world in six or fewer seps envisioned in Karinthy's "Chain-Links" and experimentally supported in Milgram's experiments became worldwide popular in the nineties through the expression *"six degrees of separation"*, introduced by the playwright John Guare as the title of a Broadway play (1990), later adapted to a film with the very same title (1993). The small-worldness effect and the "six degrees of separation" expression have been repeatedly found in the analysis of many real networks.

The second milestone article in the social sciences contributing to the establishment, development and popularization of the modern science of networks was "The Strength of Weak Ties" (Granoveter, 1973). This is one of the ever most cited papers in social sciences. In this work, Granovetter describes the social world as structured into highly connected *clusters* in which everybody knows everybody else. But -and this is the critical point- these closed clusters do not remain isolated from the rest of the world thanks to a few external links (referred as "weak ties" in the title of the article) connecting them. These "weak ties" correspond to connections between acquaintances belonging to different clusters. For instance, in friendship networks, most of persons belong to relatively small closed circles of friends, but a few persons know and have firends belonging to different circles, thus contributing to maintain them connected. The kind of social networks that emerged from Granovetter's study was that of highly clusterized networks, very different to the random networks characterized by Erdös and Rényi. What is even more important, clustering is not only present in social networks, but also in many technological and natural systems so far studied. In a key article marking a before and after in network science, Duncan Watts and Steven Strogatz used the abstraction approach demonstrated extremely useful by Leonard Euler's graph theory to demonstrate very easily and elegantly how poorly connected worlds can become highly clustered worlds and collapse into small worlds (Watts & Strogatz, 1998). The most amazing finding of this work is that only a few additional links are sufficient to sharply decrease the average separation between nodes and, hence, the diameter of the network.

In social, technological and natural networks, those nodes contributing to maintain connected different clusters within the same web are extremely important components for the structural stability of the networks. These nodes are called *connectors* and use to have a much larger link number than the average connectivity of the network. Furthermore, in many real network one or at most a few of these connectors have an extremely high number of connections. These privileged nodes are called *hubs*. In fact, if we analyze the distribution of connectivity values for the whole set of nodes of a real network, very frequently this distribution follows a negative power law, with many poorly connected nodes and very few highly connected nodes or hubs (Newman, 2010). Those networks with negative power law distribution of their node's connectivity values are called *scale-free* networks. The topological analysis of many different real networks within this century has shown that scale-free networks are ubiquitous.

Thus far we have seen that real networks are far from being "equalitarian" ones, since connection distributions follow power laws. This means that, as it occurs with the distribution of wealth in human societies, only a few privileged nodes hoard most of the connections. Even more, dynamic studies have shown that highly connected nodes tend to become more and more connected in growing networks, following the principle "rich get richer" (Bianconi & Barabasi, 2001). Nonetheless, there is a second way for a node to become a privileged one: as important as or eve more important than the number of connections is the "quality" of these connections. A node with very few connections (in fact, as few as only 2) can be very important if these connections represent the only way to maintain connected two subnets within a network. In network science the concept of *betweenness* has been introduced as a way to measure the mean "importance" of a node's connections. In the history of the art of the XXth Century, the giant figure of Pablo Picasso would represent in an ideal and not yet well characterized network of XXth Century artists a node with both high connectivity (in fact, it is a hub) and high centrality (betweenness), since his immense artistic work is the origin and point of communication for many different artistic tendencies and means of artistic expression.

During the last years of the last century and the first years of the present century there has been a great progression in the development of the science of networks, with key contributions to a renewed systemic approach within the areas of molecular biology integrated in the new so called systems biology (Medina, 2013). After the initial study of metabolic networks and *interactomes* (Jeong, Tombor, Albert, Oltvai & Barabasi, 2000; Uetz *et al.*, 2000), other complex biological networks, such as *disease-omes*, have been studied more recently (Goh, Cusik, Valle, Childs, Vidal & Barabasi, 2007; Reyes-Palomares, Rodríguez-López, Ranea, Sánchez-Jiménez & Medina, 2013; Zhang, Zhu, Hacomy, Lu & Jegga, 2011). Furthermore, since living beings are intrinsically dynamical systems, the first serious attempts to capture dynamic changes within the framework of network science have also been carried out within the domain of biology (Han *et al.*, 2004).

3. Applications of network theory in Arts

The concept of network and the theory behind it have enormous potential of useful application in the domain of Arts (Levy, 2009), as it has been already proven in the domains of sociology and natural sciences. In fact, networks can be applied to both *art research* and *art practice*. Hence, networks can be useful for both artists and academic researchers and professors in the area of arts. Bibliographies, museum inventories and different kinds of arts/artists databases can be exploited by using the rules and tools of network science. The emergence and evolution of artistic canons, movements and poetics, as well as the evolution of communities of art practitioners are relevant dynamical processes that can be studied within the framework of network theory. From the "Kevin Bacon is God" anecdote (extensively commented in Barabasi, 2002) based on the small-world property of the community of Hollywood actors and actresses and the subsequent "Oracle of Bacon" webtool (http://www.oracleofbacon.org), cinema is perhaps the performing art most frequently approached up to now by using network science tools and rules. This is the case of a reflection on networks in films by Vivien Silvey and a couple of assays by Breda Mc Carthy (Mc Carthy, 2006; Mc Carthy & Torres, 2005; Silvey, 2009). This is also the case of a more recent analysis of statistically validated networks in bipartite complex systems that includes the IMDB movie co-appearance network as one of these bipartite complex systems, along with the networks of organisms and the network of financial stokes (Tummimello, Miccichè, Lillo, Piilo & Mantegna, 2011). Recently, the IMDB network (http://www.imdb.com) has been revisited (Gallos, Potiguar, Andarde Jr & Makse, 2013), unveiling its fractal and modular properties.

In another recent study, networks have been used to visualize the evolution of rock music (Lu & Akred, 2014). In the Digital Humanities 2014 Conference held in Lausanne (July 8th-12th, 2014)) several contributions made use of netowrk science, including a network analysis of Spanish research on Arts history and a network analysis of the Venetian "Incanto" system (http://dh2014.org/program/abstracts).

Not trying here to offer a comprehensive coverage of so far published studies on arts within the framework of networks, I would like to comment at least two remarkable initiatives: *Banquet* ("Banquete" in its original Spanish version) and *Arts, Humanities and Complex Networks*.

4. Banquet-Nodes and Networks

Banquet (Ohlenschläger & Rico, 2009) is the third and last part of an editorial trilogy, outcome of the Banquet Project to explore relationships among biological, social, technological and cultural processes. In the first part of the Banquet Project (2004) correspondences between forms of life and forms of communication were studied by exploring analogies between *metabolism* and *communication* from the starting point that both can be understood as processes of transformation of energy, matter and information. In the second part of the Banquet Project (2005), the evolutionary features of both life and communication were stressed. In contrast, *Banquet- Nodes and Networks* (2009) explores the underlying network structure of biological, social and cultural systems. As in the two previous parts of the trilogy, *Banquet- Nodes and Networks* gives voice to remarkable and well known artists, architects, biologists, engineers, philosophers, economists and sociologists. They contribute with their reflections and both research and artistic projects related with the dynamics, patterns and processes that drive both tangible and intangible fluxes of matter, energy and information (Ohlenschläger & Rico, 2009).

The publication is structured in 4 sections, whose contents can be understood as nodes of a network without a defined or compulsory linear reading. The first section, entitled *"Info-nano-bio-socio"*, shows how the pattern of this network connects and crosses different spatiotemporal scales and contexts. The second section, entitled *"Info-socio-cogno"*, explores and links the informational, cognitive, social and cultural dimensions defining the emergent paradigm of *Networked Society*. The third section, entitled *"Info-socio-urban"*, explores the urban dimension as a context with a catalyzing role for the emergence of interactions among social, informational and cultural processes. Finally, the fourth section, entitled *"Info-socio-eco"*, points toward the ecosystem and planetary-scale networks affected by the current global exchanges, as well as to their sociocultural, economical and ecological implications.

In the context of the present essay on the potential and usefulness of the concept and the theory of networks in arts, *Banquet- Nodes and Networks* includes 31 individual or group contributions by artists, describing an artist project, performance or creation, as the cases of the contributions of the well known artists Daniel Canogar and Joan Fontcuberta. There is also a reflection *"On the network"* by the aesthetics thinker José Luis Brea (Brea, 2009). Finally, Ramon Folch contributes with an essay connecting sciences, networks and arts (Folsch, 2009).

5. Arts, Humanities and Complex Networks

This is an amazing editorial experience promoted and carried out by *Leonardo* (the journal published by the International Society for Arts, Science and Technology) encompassing updated contents regarding complex networks in the fields of arts and humanities within an experimental container adopting the form of an evolving multimedia e-book and web companion project (Schich, Meirelles & Malina, 2012). This e-book is par of the *Leonardo* initiatives at the University of Texas, Dallas ATEC Art and Technology Program (http://utdallas.edu/atec/x/). As explained by Roger Malina (current *Leonardo*'s Emeritus Editor-in-Chief), the journal co-sponsored the *Metamorphosis* conference in Prague as part of the *Leonardo* 40th anniversary celebrations in 2007. One of the keynote speakers in that conference was Albert-Laszlo Barabási, who urged to pay attention to how the emerging area of complex networks could be used in the context of the arts and humanities. This led to a fruitful collaboration with Max Schich and Isabel Meirelles to chair from 2010 on the annual Leonardo Day at the Network Science (NETSCI) Conferences. In its third edition release, dated May 2013, the AHCN e-book contains a Preface, an Introduction and communications structured into six parts, devoted to: 1) Networks in culture. 2) Networks in arts. 3) Networks in humanities. 4) Art about networks. 5) Research in network visualization. 6) The AHCN 2013 abstracts. Most of this work is *transdisciplinary* in nature, since their methods and tools freely migrate and are translated between arts, humanities and science. Many of the included contributions are related to arts. Herein, I will mention only some of these works to illustrate the potential of the application of complex network science in the research and practice of arts.

A nice example of the direct application of complex network approaches to a research in the field of History of Art is a contribution in which the authors analyze the network of the Hispanic baroque paintings in the 3-century period expanding from 1550 to 1850 (Suárez, Sancho & De la Rosa, 2012). The authors made use of a PostgreSQL web-based database, containing more than a hundred thousand topics, with its information organized according to a formal ontology. By splitting the complete dataset into 12 sections, each covering a 25-year period, the authors could represent for each section a network, in which artworks are the nodes and common descriptors are weighted edges. The comparison of the 12 visualized networks allowed the authors to get insights on their evolutionary patterns.

The network approach illuminates the contribution by Sara Angel, in which the *Mnemosyne Atlas* by Aby Warburg is revisited and 18 elements of Warburg's oeuvre (including 9 of the panels included in the Mnemosyne Atlas) are analyzed as a distributed object in the form of a directed network in which Mnemosyne Atlas' panel 79 emerges as the most highly connected node (Angel, 2011).

In another contribution, it is suggested that network science tools can be useful to document artistic work susceptible to be understood as networks. In fact, it is proposed and demonstrated that ensembles by the late artist Anna Oppermann (1940-1993) are complex networks (Warnke & Wedemeyer, 2011).

Close to the aforementioned studies on actor/actress networks, there is a study of the networks of contemporary popular musicians using two kinds of edges: collaboration links and similarity links (Park, 2012). This work is somehow linked to the aforementioned study on the visualization of rock music with network approaches (Lu & Akred, 2014).

Although not exactly a research work on arts, Salah and Leydesdorff make use of graph representations based on co-citation analysis and bibliographic coupling to study the journal-journal citations published in *Leonardo* in the period 1974-2008 (Salah & Leydesdorff, 2012). Interestingly, it is demonstrated that *Leonardo* is mainly cited by journals outside the arts domain (for instance, in journals of neurophysiology and physics). In contrast, articles published in *Leonardo* cite journals from many different specialties, but with a main focus on arts. the authors of this work provide hyperlinks to two animations of citing and cited papers, thus visualizing 35 years of the recent history of the journal from a network perspective.

In the AHCN e-book there are two nice examples regarding artworks based on the concept of network. Jane Prophet, from the Computing Department at the University of London, describes the design and development of an art installation called *Net Work* based on a mathematical model of how stem cells function in the adult human body (Prophet, 2011). On the other hand, Anna Dumutriu, from the School of Arts at the University of Brighton, and Blay Whitby, from the Department of Informatics at the University of Sussex, present and describe the transdisciplinary art project *Cybernetic Bacteria 2.0*, in which they and other collaborators investigate the relationships of bacterial communication to our own digital communication networks (Dumutiu & Whitby, 2011).

The 4th and 5th (up to date the most recent) *Leonardo* Satellite Symposia on Arts, Humanities and Complex Networks took place at the DTU (Technical University of Denmark) in the outskirts of Copenhagen (June 4th, 2013) and at the University of California, Berkeley (June 3rd, 2014). Three keynote lectures and 8 short selected talks were included in the Copenhagen program. As in previous editions, one of the supporters of the Symposium was *Studiolab*, a 3-year European initiative (funded by the EC 7th Framework Program in 2011) that merges the artist's studio with the research lab in a synergistic network providing a platform for creative projects bridging the artificial gaps between science, art and design (http://studiolabproject.eu). A keynote lecture and 8 short selected talks were included in the Berkeley program, including a talk on the network landscape of Western classical music.

6. Concluding remarks

Currently, the network paradigm pervades scientific, sociological, cultural and artistic reflection, research and practice. However, it is evident that the degree of development and the number of applications of network theory in both the sociological and the scientific domains far exceed those within the cultural and artistic domains. Perhaps the most impacting research in humanities conducted within the framework of network science is that recently published in *Science* on a network framework of cultural history (Schich *et al.*, 2014). In this very important article, the authors reconstruct what they call "aggregate intellectual mobility" over two thousand years thorugh the data of birth and death location for more than 150,000 notable individuals. The current self-emerging interest in networks within the field of arts explores three different directions: 1) The use of the network paradigm in academic research in arts (including art history). 2) The research in network visualization to be applied to projects concerning arts. 3) Art practice regarding networks. Much more efforts and exploratory ideas should be expected in these areas in the near future.

References

Angel, S. (2011). The Mnemosyne Atlas and the meaning of panel 79 in Aby Warburg's oeuvre as a distributed object. *Leonardo, 44,* 266-267.

Barabasi, A.L. (2002). *Linked.* Cambridge, Massachussetts, USA: Perseus.

Bianconi, G., & Barabasi, A.L. (2001). Bose-Einstein condensation in complex networks. *Physical Review Letters, 86,* 5632-5635.

Biggs, N.L., Lloyd, E.K., & Wilson, R.J. (1999). *Graph Theory 1736-1936.* Oxford, United Kingdom: Oxford University Press.

Brea, J.L. (2009). On the networks (some random thoughts), (in Spanish). In K. Ohlenschläger & L. Rico *Banquete- Nodos y Redes* (pp. 206-209). Madrid, Spain: SEACEX.

de Sola Pool, I., & Kochen, M. (1978-9). Contact and influence. *Social Networks, 1,* 5-51.

Dumitriu, A., & Whitby, B. (2011). Cybernetic bacteria 2.0. *Leonardo, 44,* 264-265.

Euler, L. (1913). *Opera Omnia.* Basel, Switzerland: Birkhäuser.

Folsch, R. (2009). Science, networks and art: plastics and ecology (in Spanish). In K. Ohlenschläger & L. Rico *Banquete- Nodos y Redes* (pp. 293-299). Madrid, Spain: SEACEX.

Gallos, L.K., Potiguar, F.Q., Andarade Jr., J.S., & Makse, H.A. (2013). IMDB network revisited: unveiling fractal and modular properties from a typical small-world network. *Plos ONE, 8,* e66443.

Goh, K.I., Cusik, M.E., Valle, D., Childs, B., Vidal, M., & Barabasi, A.L. (2007). The human disease networks. *Proceedings of the National Academy of Sciences USA, 104,* 8685-8690.

Graham, R.L., & Nesetril, J. (eds.). (1996). *The Mathematics of Paul Erdös.* Berlin, Germany: Springer Verlag.

Granoveter, M. (1973). The strength of weak ties. *American Journal of Sociology, 78,* 1360-1380.

Han, J.D.J., Berlin, N., Hao, T., Goldberg, D.S., Berritz, G.F., Zhang, L.V., Dupuy, D., Walhout, A.J., Cusick, M.E., Roth, F.P., & Vidal, M. (2004). Evidence for dynamically organized modularity in the yeast protein-protein interaction network. *Nature, 430,* 88-93.

Jeong, H., Tombor, B., Albert, R., Oltvai, Z.N., & Barabasi, A.L. (2000). The large-scale organization of metabolic networks. *Nature, 407,* 651-654.

Karinthy, F. (1929). *Chain-Links.* Available online: http://djjr-courses.wdfiles.com/local..files/soc180%3Akarinthy-chain-links/Karinthy-Chain-Links_1929.pdf (accessed on 5th February 2013).

Levy, E.K. (2009). Classifying Kubler: between the complexity of science and art. *Art Journal, 68,* 88-98.

Lu, S., & Akred, J. (2014). Visualizing the evolution of rock music. *Big Data, 2,* 2-4.

McCarthy, B. (2006). Building and sustaining trust in networks: lessons from the performing arts. *Irish Marketing Review, 18,* 47-57.

McCarthy, B., & Torres, A.M. (2005). A study of network typology in relation to the performing arts. *Entrepreneurship and Innovation* 168-175.

Medina, M.A. (2013). Systems biology for molecular life sciences and its impact in biomedicine. *Cellular and Molecular Life Sciences, 70,* 1035-1053.

Milgram, S. (1967). The small-world problem. *Psychology Today, 1,* 61-67.

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

Newman, M.E.J. (2010). *Networks - An Introduction.* Oxford, United Kingdom: Oxford University Press.

Ohlenschläger, K., & Rico, L. (2009). *Banquete- Nodos y Redes* (in Spanish). Madrid, Spain: SEACEX.

Park, J. (2012). Networks of contemporary popular musician. *Leonardo, 45,* 78.

Prophet, J. (2011). Model ideas: from stem cell simulation to floating art work. *Leonardo, 44,* 262-263.

Reyes-Palomares, A., Rodríguez-López, R., Ranea, J.A.G., Sánchez-Jiménez, F., & Medina, M.A. (2013). Global analysis of the human pathophenotypic similarity gene network merges disease module components. *Plos ONE, 8,* e56653.

Salah, A.A.A., & Leydesdorff, L. (2012). The development of the journal environment of *Leonardo*. *Leonardo, 45,* 88.

Schich, M., Meirelles, I., & Malina, R. (eds.). (2012). *Arts, Humanities and Complex Networks.* Cambridge, Massachussetts, USA: MIT Press e-books.

Schich, M., Song, C., Ahn Y.Y., Mirsky, A., Martino, M., Barabasi, A.L., & Helbiong, D. (2014). A network framework of cultural history. *Science, 345,* 558-562.

Silvey, V. (2009). Not just ensemble films: six degrees, webs, multiplexity and the rise of network narratives. *Forum 8.* Available online: http://www.forumjournal.org/site/issue/08 (accessed on 5th July 2013).

Suárez, J.L., Sancho, F., & de la Rosa, J. (2012). Sustaining a global community: art and religion in the network of Baroque Hispanic-American paintings. *Leonardo, 45,* 281.

Tumminello, M., Miccichè, S., Lillo, F., Piilo, J., & Mantegna, R.N. (2011). IMDB network revisited: unveiling fractal and modular properties from a typical small-world network. *Plos ONE, 6,* e17994.

Uetz, P., Giot, G., Cagney, G., Mansfield, T.A., Judson, R.S., Knight, J.R., Luckshon, D., Narayan, V., Srinivasan, M., Pochart, P., Qureshi-Emili, A., Li, Y., Godwin, B., Conover, D., Kalbfleisch, T., Vijayadamodar, G., Yang, M., Johnston, M., Fields, S., & Rothberg, J.M. (2000). A comprehensive analysis of protein-protein interactions in *Saccharomyces cerevisiae*. *Nature, 403,* 623-627.

Warnke, M., & Wedemeyer, C. (2011). Documenting artistic networks: Anna Oppermann's ensembles are complex networks! *Leonardo, 44,* 258-259.

Watts, D., & Strogatz, S.H. (1998). Collective dynamics of small-world networks. *Nature, 393,* 440-442.

Zhang, M., Zhu, C., Jacomy, A., Lu, L.J., & Jegga, A.G. (2011). The orphan disease networks. *American Journal of Human Genetics, 88,* 755-766.

Miguel Ángel Medina is a Doctor in Biology and a Graduate in History of Arts currently working as Full Professor of Biochemistry and Molecular Biology at the University of Málaga (Spain). He is the author of more than 180 research articles in science and a member of the editorial boards of several international scientific journals. He has also published essays, criticism and exhibition reviews in the field of arts. As both a scientist and a graduate in History of Arts, he is mainly interested in the interdisciplinary and transdisciplinary connections between both disciplines. Network theory is a transdisciplinary framework enabling this kind of connections.
