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Linking science and arts: Intimate science, shared spaces and living experiments

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Abstract. We aim to move beyond the idea of art as a tool for communicating science, towards a truly interdisciplinary practice where art and public engagement are a fundamental part of the way that science is carried out as promoted by the FuturICT project. Artistic exploration can have a scientific impact when artists act as designers, catalyzers and coordinators of experiments, which scientists interpret and respond to. We propose the creation of a travelling show, consisting of a set of core exhibits and 'living experiments': interactive, evolving pieces which blend artistic experience and scientific research. We also propose the creation of a new production oriented, distributed, inter-institutional research centre, focused on developing parallel relations between artistic practice and diverse fields of science. All these initiatives will be aligned with different areas of the FuturICT project, using different aspects of the *Living Earth Simulator*, *Planetary Nervous System*, and *Knowledge Accelerator* to support the creation of rich, interactive, collaborative experiences and in close contact with the educational and participatory platforms of FuturICT.

1 Summary

In this paper, we present a distillation of our conceptualisation of the relationships between science, art and technology, and the motivations for carrying out interdisciplinary work. The development of experimental projects linking art and science offers opportunities to develop and catalyze models for new trans-disciplinary approaches to learning. These approaches are becoming more and more necessary in cutting-edge research, so proper training of future scientists is crucial to tackle the most important challenges of contemporary science. We seek to move beyond the idea of art as a tool for communicating science, and towards a truly interdisciplinary practice where

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art and public engagement are a fundamental part of the way that science is carried out; to do this we use as starting points Latour's move from science to research and "collective experiments", and Born and Barry's logics of interdisciplinarity. This is especially relevant in the context of the FuturICT project's modelling of complex social systems.

We present diverse case studies, highlighting different aspects of the interface between science and art that relate to the FuturICT vision. These include technological interventions to alter political attitudes; multimedia approaches to understanding the complex future; novel ways of looking at everyday objects; using technology to understand and track human processes and dynamics, highlight physical processes or explore artificial life; and understanding the socio-temporal geographies of knowledge creation.

From these case studies, we extract several qualities which form the basis of a set of goals for the Art and Science Link within the FuturICT project: the notion of collective experiments, where the public is part of the experiment; multilayered presentation, allowing for engagement with a range of publics without imposing a single point of view; playful experimentation, supporting micro-experiments and informal, ad-hoc hypotheses; physical and environmentally situated work, which relates to the world and engages with people's physical presence; and shared spaces with interaction between participants creating collaborative experiments.

We explore the possibilities for impacts both within and outside the scientific spheres of discourse. Artistic exploration can have a scientific impact when artists act as designers, catalyzers and coordinators of experiments which scientists interpret and respond to. Technological innovation can be nurtured by artistic approaches towards building open-source software and innovative tools in data acquisition. The first aspect to consider is that links between science and art open up possibilities of connecting with the cultural and intellectual spheres of discourse. Scientific practices have important social, ethical and political dimensions that art can help to underline, explore and resolve. Secondly, by creating a direct participatory relationship outside the scientific community, we enhance traditional science communication formats to enable more effective public engagement, making society more aware of the challenges and opportunities development of ICT brings. Additionally, science education must also adapt to this multiplicity of dimensions to have a more realistic picture of our changing world. Educational experiences for young children play a key role in their learning about science and technology and the more playful and creative perspectives offered by art and science hybridation enables participation for a range of ages and abilities. This interaction and fusion of disciplines, whose communities are often disparate, is an ideal motor to drive inquiry-based- and problem-based science education, and to facilitate the synergistic cultural change in young people's interest in science studies as distilled in the EU Rocard Report 2007 [1] and reinforced in the EU Masis Report 2009 [2].

To this end, we propose the creation of a travelling show, consisting of a set of core exhibits and projects, which blend artistic experience and experiment. These exhibits will be use different areas of emerging ICT to support the creation of rich, interactive, collaborative experiences. Participants may take on the role of different actors within a simulated socio-political system; they may experiment with setting different initial conditions, policies, and behavioural strategies for a model in order to observe the changes in the resulting system; they may become designers, envisioning novel uses of ICT.

Alongside these core pieces, we will have a large set of related exhibits and activities, to explore *co-creation* – creation considered as a collective, cooperative and self-organised process – with the wider artistic and scientific communities and the general public. By supporting collaboration between scientists and artists and the

public, we will provide a nucleation point for integrating and focusing some of the creative energy currently existing at the interface of science, art and technology.

Finally, we propose creation of a new production oriented, distributed, inter-institutional research centre, focused on developing parallel relations between artistic practice and diverse fields of science. Within this structure, consisting of artistic and scientific institutions, individuals and groups will go beyond the traditional boundaries separating domains of knowledge to work together at the interface between art, science and technology. Artistic strategies will be used to facilitate innovation, reflect on the relevant issues and discoveries, create new perspectives, and disseminate knowledge. The research centre will organize joint workshops and seminars for scientists and artists in the areas relevant to research conducted in emerging ICT development. It will also produce art, with a special focus on large-scale, performance oriented pieces in the broadly defined 'public space'.

The exhibits which form the travelling show will link into the FuturICT project, using different aspects of the *Living Earth Simulator*, *Planetary Nervous System*, and *Innovation Accelerator*. These links will allow rapid development of pieces that use cutting edge modelling and simulation techniques, as well as supporting creative exploration of the huge amount of human and social data produced. The core of exhibits will grow throughout the course of the FuturICT project, as more aspects of the research become available, and more interconnections between different areas and disciplines can be used. This creation of transdisciplinary pieces will provide a wider context for the work within FuturICT, and bring a more diverse set of ideas into play. Simulateneously, the network of institutions in the research centre will work in close collaboration with the structures of FuturICT, interacting with the research carried out within the project. The workshops and seminars organised by the research centre will target areas relevant to the various *Observatories* and *Accelerators* of FuturICT. The use of large scale art in public spaces will also form a key innovation and dissemination activity during FuturICT conferences and public events.

Section 2 sets out our vision of how to link art and science, partiularly within the context of the FuturICT project. Section 3 offers some previous experiences where several FuturICT partners/supporters have been involved, and develops goals, opportunities and challenges to be considered when linking art, science and technology. The innovation and expected paradigm shifts produced by these linkages are described in Sect. 4 alongside the core ideas: interaction with large datasets, social experiments, digital curation and geo-ethics aspects of Art and Science collaboration. Finally, expected impact and conclusions are detailed in Sects. 5 and 6.

2 Vision

Art and science are said to represent two alternative approaches through which knowledge about social reality has been acquired in recent centuries. These approaches use different tools and present the knowledge in different forms, but the systems of knowledge generated by science and art are complementary to each other. While the perspective of science offers precision and can describe social phenomena in quantitative way, art is better suited for capturing meaning and emotions related to social phenomena and provides tools to intervene in social reality. The development of full understanding of social phenomena requires the combination of these perspectives, but the differences between the approaches mean that integration is a complex task. New ICT tools, and the approaches of complexity science [3,4] offer a novel approach towards a synthesis of the perspectives of art and science.

Europe has a deeply rooted history of permeable, transdisciplinary, creative and exploratory science, leading back to Ancient Greece [5]. It can be exemplified by the

conceptual sketches and inventions of Leonardo da Vinci, which stemmed from a deep understanding of anatomy and mechanics; or Galileo Galilei who saw irregularities on the Moon's surface when using telescope as other scientists did, but his skills in drawing and perspective led him to conclude that the patterns of darker and lighter areas visibible on the moon were due to surface irregularities, which we now know to be impact craters. Other historical examples include Santiago Ramon y Cajal proposing the existence of neurons without the use of powerful microscopes and Ernst Haeckel's drawings of jellyfish and *Radiolaria*, both of which had a high impact not only in scientific community but also on the general public.

In Leonardo's time, the value of the experiment began to be appreciated and it provoked a rapid evolution of what we today mean by Science. The Art historian Martin Kemp gives a deep account of Leonardo's attitudes to art and observation as a means of distilling the scientific essence of a phenomenon [7]. As a scientist, artist and inventor, Leonardo saw Earth as a living entity with many layers and spatio-temporal scales, deeply interconnected and with self-similar properties. He observed strong similarities between rivers and human veins, and produced hydrologically plausible drawings of a turbulent flood. We can also read in his *Treatise on Painting* strong ideas about why artistic activity should be conceived of as a scientific activity:

> "[Painting] with philosophic and subtle speculation considers all the qualities of forms. Truly this is science, the legitimate daughter of nature, because painting is born of nature."

So artistic activity can be seen as a knowledge and learning process, akin to contemporary scientific research. We take this as one point of departure for the work of the Art and Science Liaison within the FuturICT flagship proposal [3].

Our synthesis conceptualises art following Leonardo's thoughts as part of scientific research. There is now a new generation of artists highly skilled in science and technology who are keen to be involved in scientific research dynamics since they already conceive art to be along the same lines and in the same spirit [8,9]. This is exemplified by the notion *Intimate Science*. A recent exhibition takes this term[1] and showcases recent works at the intersection of art, science and technology. These artists, working as *intimate scientists* are autodidactic and their methodologies are similar to those used by the open innovation and hacking movements, following a technological, engineering way of thinking. By taking heuristic and intuitive approaches to describing the physical and natural world, these artists are not constrained by any discipline and feel free to break stablished disclipinary protocols and conventions. These practices are linked to unrestricted observation and experiential learning, and hence they provide wide opportunities for the public to participate in a research process. Through their engagement with 'intimate science,' a more knowledgeable public might well be able to influence what research is supported and adopted by the larger culture, and the walls of science can become more transparent. In fact, these 'intimate scientists' are already contributing to the system of science: by breaking disciplinary boundaries and increasing the emotional and critical dimension in the conceptualisation and representation of scientific knowledge[2]. This movement from art towards science is our second point of departure, and leads to an attempt and an important opportunity to create truly transdisciplinary work within FuturICT [3].

Europe already boasts a number of agencies and institutions that have proven success in working at the intersections between science and artistic practices:

[1] Exhibition at the Miller Gallery, Carneggie Mellon University, March 2012. `http://millergallery.cfa.cmu.edu/exhibitions/intimatescience`

[2] It represents an additional perspective to that of Philip Ball in his article *"I'm going to try to be like an arts critic, but for science"* from the series *Critical Scientist* since "there are all sorts of questions to ask about science, beyond whether it's correct or not" [6].

Fig. 1. Part of the Arts Santa Mònica exhibition space called *Laboratori* of around 400 m^2 devoted to the intersection between art, technology and science. School and weekend workshops are runned within the exhibition space. Credit: Xavi Soto – Arts Santa Mònica.

igniting fresh, creative thinking and new approaches to science research, education and dissemination by considering science from a radical, creative and experimental point of view. Among these hybrid organisations are Arts Catalysts (United Kingdom), Swiss-Artists-in-labs (Switzerland), Wellcome Trust (United Kingdom), Lighthouse Bristol (United Kingdom), FACT Liverpool (United Kingdom), Kapellica Ljubljana (Slovenia), Olats-Leonardo (France), Gaité Lyrique Paris (France), Art Center of Enghien les Bains (France), Iméra-Marseille (France), Le Laboratoire (France), Medialab Prado Madrid (Spain), LABoral Gijón (Spain), Arts Santa Mònica Barcelona (Spain) shown in Fig. 1, ZKM Kalsruhe (Germany), Science Gallery-Trinity College (Ireland), Ars Electronica Linz (Austria), CIANT Prague (Czech Republic), Laboratoria Moscow (Russia), V2 Rotterdam (Netherlands). All of these and many others work between Art-Science-Technology, with a range of different styles based on their particularities and local specificities. For instance, Dublin's Science Gallery's webpage describes the center as[3]

> "an experiment in public engagement with science and technology, bringing science into dialogue with the arts through exhibitions, events and educational programming and acting as a sociable environment for face-to-face interactions and encounters between the public, scientists and the creative community coming from arts but also design."

As a recent example, which illustrates the experiences of these organisations, we examine a very recent linkage between media art and a big scientific infrastructure [10]: the Ars Electronica Festival 2011 was called *Origin* [11] and involved a close collaboration with CERN where scientists working on the accelerator became deeply involved in the festival program. As part of this project, Julius von Bismarck is the first participant in the digital arts joint-residency program; he will be spending two months at CERN and a third month at Ars Electronica in Austria, collaborating with scientists "to create a physics-inspired artwork as part of the Collide@CERN program"[4]. The Press

[3] Extracted from `http://sciencegallery.com`

[4] `http://arts.web.cern.ch/collide`

Realease says that Von Bismarck is excited about the opportunity to combine physics and art and quotes[5]:

> "The root reason as to why I am an artist is the same as it would be for being a scientist: finding out what there is out in the world and how I can contribute to our understanding of it. In fact, I didn't know if I would study physics or art, but in the end decided to study art, reading about physics and research in my spare time. I am interested in responding to the science in my work in a sense-able way – through the body and its senses."

Von Bismarck is most famous for his invention of the *Image Fulgurator*[6], an apparatus that looks like a camera but actually projects a secret image that shows up only in other peoples' photos described in Fig. 2. He used the device when President Barack Obama spoke in Berlin, projecting a cross onto his podium that appeared in press photos, as well as at Tiananmen Square in Beijing, where tourists found their photos contained the image of a white dove over Mao Zedong's face in a prominently hanging portrait among many other situations as described in The Creator's Project webpage[7]. Von Bismarck declares in this webpage:

> "I believe that all technology that's invented should also be questioned. I believe that an invention is also a political statement. If I build a machine that can change the world, then I have to back it up as the creator. That's why every technician and every engineer also acts as a politician and as someone who is responsible for our future."

In fact, the following statement by American composer John Cage exemplifies some of the prevalent attitudes held by artists toward art and technology already in the 1960s[8]:

> "I want to remove the notion of the separation between the artist and the engineer. I think that the engineer is separate from other people simply because of his very highly specialized knowledge. If the artist can become aware of the technology, and if the engineer can become aware of the fact that the show must go on, then I think that we can expect not only interesting art, but we may just very well expect an interesting change in the social order. The most important aspect of this is the position of the engineer as a possible revolutionary figure. And it may very well come [to pass] as a result of the artists and engineers collaborating. Because the artists, for years now, have been the repositories of revolutionary thought. Whereas the engineers, in their recent history, have been employees of the economic life. But in relating to the artists, they become related to a revolutionary factor."

Some other perspectives which are relevant here include the interdisciplinary arts scholar Edward Shanken [13] from University of Amsterdam, who has recently revisited the "formidable history of artistic uses of electronic media": a history that parallels the growing pervasiveness of technology in all facets of life with the examples of more than 200 artists and institutions from more than 30 countries. Artists like the American composer John Cage hold such humanistic views on art and

[5] CERN Press Release: First Prix Ars Electronica Collide@CERN laureate announced (Geneva 6 December 2011) `http://press.web.cern.ch/press/PressReleases/Releases2011/PR24.11E.html`

[6] `http://www.juliusvonbismarck.com/bank/index.php?/projects/image-fulgurator`

[7] From `http://thecreatorsproject.com/creators/julius-von-bismarck`

[8] These comments reported in Ref. [12] were made in the context of his participation in an historic series of artist-engineer collaborations in 1966, *Nine Evenings: Theatre & Engineering*, organized by the artist Robert Rauschenberg and Billy Klüver in New York.

Fig. 2. The *Image Fulgurator* is a device that intervenes when a photo is being taken, without the photographer being able to detect anything. The manipulation is only visible on the photo afterwards. It operates via a kind of reactive flash projection that enables an image to be projected on an object exactly at the moment when someone else is photographing it. The intervention is unobtrusive because it takes only a few milliseconds. Every photo at which the *Fulgurator* is also aimed is affected by the manipulation. Hence visual information can be smuggled unnoticed into the images of others as shown in down picture taken by a tourist in Check Point Charlie in Berlin. Description source: `http://www.todayandtomorrow.net`

technology with specific commitment of science and technology community. At Bell Laboratories, the engineer and laser researcher Billy Klüver began collaborating with artists including Jean Tinguely and Jasper Johns in the late 1950s. In 1966 Klüver also co-founded the famous Experiments in Art and Technology (E.A.T.), a non-profit organization that facilitated artist-engineer collaborations internationally. And finally as contemporary example we can mention the case of Julian Voss-Andreae a physicist

transformed that has become an artist, his sculptures are heavily influenced by his work in quantum physics.

In a more general way, from a scientific perspective, Arthur I. Miller has studied the relations between artists' and scientists' imagination and creativity by putting seminal works in the context of their contemporary science, including the works of El Greco, Shakespeare, Shelley, Mondrian, Gris, Braque, Picasso, Duchamp, Rothko and many others [5]. Miller [14] also presents in a single book the creative similarities between the work and life of Pablo Picasso and Albert Einstein, making connections between the cultures of art and science. Another connection relates the possible inspiration of the artist Marcel Duchamp and the works of the mathematician Henri Poincaré [15–18].

There are many reasons to carry out inter- or trans-disciplinary work and, in particular, work which exists on the interface between art and science. Latour [19] talks of the move from science to research:

> "Science produces objectivity by escaping as much as possible from the shackles of ideology, passions, and emotions; research feeds on all of those to render objects of inquiry familiar."

He also introduces the notion of the "collective experiment", in which the public are no longer consumers of the output of science, left only to decide whether they are closed or open to the new ideas, but become a driving force within the research. Writing about the French Association for the Treatment of Muscular Distrophy (AFM) he says:

> "They took over. They tailored a science policy adjusted to what they perceived as their needs. Far from expecting certainty from science, they accepted that they must share risk in research."

Nowotny et al. [20] look at the contextualisation of the production of scientific knowledge where the context must be created through a range of interdisciplinary practices apart from the production of the science itself. Born and Barry [21] extend this to look at Art and Science as going beyond rendering science accessible or accountable. Barry et al. [22] sets out three logics behind interdisciplinary work: the logic of accountability, where the transdisciplinarity is used to break down the barriers between science and the public, to legitimize and defend the work of scientists; the logic of innovation, where transdisciplinary working allows the transformation of knowledge to best suit an intended audience; the logic of ontology, where interactions across disciplines raise questions about the fundamental conceptualisations of those disciplines (see Fig. 3 and Sect. 3.4). These logics are generally interrelated, but especially in the context of projects with a global focus, highlighting the ontological view can help provide innovative ways of engaging non experts in the practice of research. In particular, citizen scientists – people who are not necessarily scientists by trade, but volunteer to perform research related tasks – are emerging as a huge resource[9]. This represents the direction which we will pursue: the use of artistic practice and technique to bring the public at large into the experiment, not simply to communicate the results of science, but to open up ownership and direction of the research to a wider community.

[9] See for instance philosophy of Citizen Science Alliance: `http://www.citizensciencealliance.org/philosophy.html` and Ref. [24] or in the media: `http://www.guardian.co.uk/science/2012/mar/18/galaxy-zoo-crowdsourcing-citizen-scientists`, and the cooperative mapping shown in Fig. 4.

Fig. 3. *POEtic Cubes* (2006-2008), installation composed by 9 bioinspired robots responding to human presence by Raquel Paricio and Juan Manuel Moreno Aróstegui in *Cultures of Changes* show 2009. The installation can be understood as a "living experiment". Credit: Xavi Soto – Arts Santa Mònica.

2.1 Goals, opportunities, challenges

Here we consider the goals, opportunities and challenges involved in creating links between arts and science as part of the FuturICT project - the "Art Science Link" (ASL).

The first goal of the ASL is to **engage** a strong artistic community in the intersection between science, art and technology, aligned with the research spirit of FuturICT. The FuturICT initiative has the opportunity to create a framework which helps to highlight the linkages and commonalities between these organisations, and influence alignment with the spirit of the FuturICT ideas. To move towards this goal we will create a new production oriented **inter-institutional research centre**, focused on developing parallel relations between artistic practice and diverse fields of science. This centre will help to connect various Art and Science institutions interested in ASL. The network will organize workshops, seminars and artistic events in public space in the areas relevant to FuturICT. This will help to support a

FuturICT presence in Media Art festivals like Ars Electronica Linz[10], Transmediale Berlin[11], as well as others located further afield. We will also consider science festivals – some of which already include artistic collaborations, such as the Edinburgh Science Festival[12] – art and science meetings, and finally science centres or museums with an interest in the artistic perspective. Engagement with the Arts and Humanities communities is essential to the success of the FuturICT initiative, and this includes establishing active links between creative practitioners and the complexity scientists in FuturICT.

To produce strong, lasting links between art and science, we will start residency programmes, supporting artists to be embedded in scientific institutions for extended periods of time – e.g. 9 months following the example the Swiss-Artists-in-Labs experience reported in Refs. [25,26]. In these cases, artists interact with scientists, live like scientists and show their work periodically in and out of the scientific lab. We will also follow the spirit of other organisations, such as Iméra in Marseille, which break the typical structure of academic institutions and simultaneously host artists and scientists. Finally, we will also explore the possibility of offering artistic institutions the chance to host scientists for some period. This third option has not been extensively developed and we only are aware of the experience of the Institute of Contemporary Arts in London. It represents an exciting initiative, and we believe that many centres may be interested in replicating this strategy in the future, and that it will lead to new scientific research, such as studying visitor behaviours at the Louvre [27].

Our second goal is to generate a **creative and open-minded spirit** among the supporters of the FuturICT proposal. The ASL aims to break the walls of each discipline, with transdisciplinary strategies, with the notion of experimentation, with an intimate science and with a logic of accessibility of distinct knowledges developed. Both the artistic methodology and the ability to offer a critique and to open up a debate around scientific practices that can help to enhance discussion and to trigger new lines of research. This strategy of questioning and integration will also help to engage society, build **public knowledge and awareness**, and provide insights into both the outputs and processes of FuturICT research. The Ars Electronica and CERN joint initiative above and the *Image Fulgurator* shown in Fig. 2 project are representative case studies of this kind of interdisciplinary collaboration, but there are many other success stories involving FuturICT partner organisations.

Our third goal is to engage with society in a different way than traditional science communication by including the notion of the **"collective experiment"**, in which the public are no longer consumers of the output of science, left only to decide whether they are closed or open to the new ideas, but become a driving force within the research [28]. It is then necessary to consider particular events, not talks, where participants could also interact in real time which eventually serve to provide more data for scientific research purposes [23,29]. A good example is the recent experiment performed in 2011 by some FuturICT partners, investigating the issue of possible network effects on the emergence of cooperation[13] illustrated in Fig. 4. This experiment involved over 1200 final year high school students, from over 40 high schools in the Aragón region of Spain. The scale of the experiment allowed for meaningful conclusions to be drawn, which would not be possible with the usual number of subjects in behavioral economics experiments [30–32], and this can be facilitated by the use of artists to enhance participation and public awareness. Therefore, use and reuse of data for scientific research in the strong sense is an innovative outcome [33], which we

[10] http://www.aec.at
[11] http://www.transmediale.de
[12] http://www.sciencefestival.co.uk/
[13] http://dilema.ibercivis.es

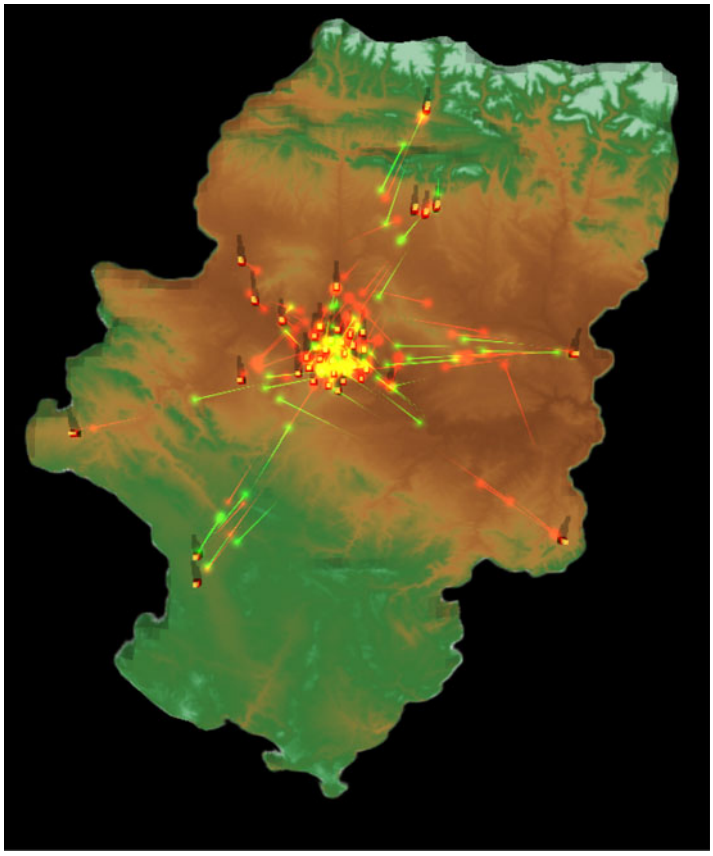

Fig. 4. Map of cooperative activity during the prisonner's dilemma experiment performed in Aragón (Spain) last December 20, 2011 in order to study how cooperation emerges in society. 1,230 students from 42 schools participated in a large on line social-economic experiment. This experiment was conducted by Ibercivis Foundation and the Institute of Biocomputing and Physics of Complex Systems in collaboration with the University Carlos III of Madrid. Credit: Ibercivis.

make possible by: (a) creating a set of experiment/experiences, which can form the core of an exhibition and (b) exploring strategies for co-creation where contents and ideas arise from a bottom up, self-organised and participatory dynamics – in other words, as a complex system by itself.

To this end, we also propose the creation of a **travelling show**, consisting of a set of core projects, which blend artistic experience and experiment. These exhibits will be based on different areas of the FuturICT project, using different aspects of the *Living Earth Simulator* [34], the *Planetary Nervous System* [35], and *Knowledge Accelerator* [33,36] to support the creation of rich, interactive, collaborative experiences. Participants may take on the role of different actors within the socio-political system; they may experiment with different initial conditions, policies, behavioural strategies, demographic models and so on to observe the changes in the resulting system; they may become designers, envisioning novel uses of FuturICT in the future. This core of exhibits will grow throughout the course of the FuturICT project, as more aspects of the simulation and data become available, and more interconnections can be modelled. Alongside these core pieces, we will have a set of related exhibits and activities, to explore co-creation with the wider artistic and scientific

communities and the general public [23]. This will provide a wider context for the work within FuturICT, and bring a more diverse set of ideas into play. By supporting **collaboration between scientists and artists and the public**, we hope to provide a nucleation point for integrating and focusing some of the creative energy currently existing at the interface of science, art and technology. Additionally the final form of each exhibition will come out from a participatory and co-creative dynamics as a bottom-up self-organised process. We therefore consider collaboration with a range of creative practitioners such as designers and architects, not only artists, working within this spirit.

3 State of the art

Here we report several projects in which FuturICT supporters have been involved in one way or another, with a range of different styles, directions and philosophies. Some of them correspond to a particular exhibition project stressing ideas relevant to FuturICT; others introduce participatory dynamics to engage society using new technologies and describing dynamics of complex systems: emergent properties, synchronicity, chaos, self-organization, simulation and so on; another group introduce, through artistic practices, a critique aiming to shift perception of society with respect to particular issues; finally some of them involve technology and science research and apply this research to innovative methods, techniques, software, interfaces and products. In this way, all these projects are at the interface between science, technology and art, and we try to tease out successful aspects to guide future developments.

3.1 Conflict, trauma, art

In 2008 in a seminar *Conflict, trauma, art* occurring in the Warsaw School for Humanities and Social Sciences led by an artist Krzysztof Wodiczko and a psychologist Andrzej Nowak, several artists and scientists presented the results of their research on conflict. The presentations made it clear that scientists and artists study the same phenomena in the area of conflict and that the perspectives of art and science can inspire and complement each other. Wodiczko, for example, in his works *Hiroshima* and *Tihuana* used interviews with victims of conflict and violence projected into buildings to present an emotional dimension of conflicts and convey an intuitive understanding of the sources and dynamics of conflicts [37]. Scientists, in contrast, presented results of empirical studies showing the mechanisms and patterns of escalation, for example how the complexity of information processing decreased in conflicts or how political campaign associated with national elections increased the salience of stereotypes. With respect to the conflict that is often manifest on the Internet, scientists described the dimensions of conflict and patterns of escalation, while artists presented a shocking film in which Internet posts from a "flame war" – an inflammatory, invective filled exchange – were read by an actor. What seemed to be usual in written text acquired a shocking meaning in verbal expression.

Social reality is constructed by interactions between individuals, and sustained by social interactions. In contrast to physical phenomena, properties of social reality depend more on the social process than on their objective properties. Even such seemingly objective social institutions as marriage are the result of social construction. Social constructs are thus the results of human decisions rather than objective reality. The meaning created in social interactions has causal effect; it determines the shape of social processes and their course. Art has ways to transform meanings and thus to change the dynamics of groups and societies.

For example, art can provide a means to intervene in conflict. In Mozambique, as the country was emerging from a genocidal conflict, an initiative called *Guns into art* helped to change the culture of the society from war-oriented to peace-oriented. In this initiative artists used guns as materials to construct sculptures of peaceful objects such as chairs or trees. More than 200,000 guns have been collected and destroyed in this initiative[14].

Joanna Rajkowska, in her work *Oxygenator*, created a pond surrounded by benches, in the area of Warsaw that was associated with war-related traumatic memories, which was a centre of tension between different social groups. The pond has become a rest area for the inhabitants of nearby houses, transforming an area of conflict into a peaceful zone. Rajkowska has also placed a huge artificial palm tree in front of the former Polish Communist Party headquarters building, using absurdity to disarm the grave atmosphere of Poland's old seat of government. In summary, artists can change the course of conflict by transforming the structures of meanings associated with conflicts.

Social reality arises in interaction between people and objects, and people generate meanings from objects: interpretations, stories, memories etc. Meanings become consolidated and may be transformed into a material form. Monuments are a perfect example of this process. Monuments solidify particular interpretation of events. Once created, material objects generate new meanings. Objects and meanings thus form a feedback loop where each component reinforces the other. Artistic intervention can be aimed either at the object or the meaning associated with the object. Wodiczko, for example, has used video projections of content incompatible with the official meaning of monuments to change the social perception of the monuments in an attempt to break up the feedback loop.

3.2 Extremely rare events

Art and science can complement each other in explorations of social dimensions of complexity research and in communicating the results of the research to public and policymakers. As an example, in August 2009 the Center for Contemporary Art (CCA) in Ujazdowski Castle, Warsaw, ran an exhibition called *Extremely Rare Events*. Parts of this exhibition were also shown during the Big Step dissemination conference of the Global System Dynamics project[15] in Brussels in 2010.

CCA's strategic mission is research and presentation of the most current tendencies in contemporary art, understood in a very wide, interdisciplinary sense to include visual arts, performance, theatre, film, music and more. CCA supports and stimulates exchanges between artists and the public; this includes investigation into the processes of participation, the reception of art, and the relations between art and other cultural areas (social sciences, new technologies, etc.). These exchanges aim at the development of interaction, site-specific production, collaboration, and new forms of network circulation. As a process and experiment oriented institution, CCA has already experience in developing cutting edge projects based on collaboration between Art and Science.

The discovery of the importance of rare events for the dynamics of natural and social phenomena is at the foundation of complexity science. Art has often concentrated on what is unusual and exceptional. Bringing together the two perspectives creates new values beyond those contained in each of the perspectives separately. Science reveals the mechanisms underlying the power of rare events, such as: autocatalytic processes where the process acts as a catalyst for itself; exponential growth

[14] http://news.bbc.co.uk/2/hi/africa/1764173.stm

[15] http://www.globalsystemdynamics.eu/

which greatly magnifies all initial differences; multiplicative relations etc. Art conveys the importance of uniqueness, illustrates the effects of randomness, and shows how discoveries of science translate into human experience. As an example, the futility of prediction is illustrated by Agnieszka Kurant in her work *Future Anterior*. Predictions of what will happen in 2020 were used to produce a copy of New York Times supposedly printed in 2020. To show how uncertain the predictions were, the newspaper was printed with temperature sensitive ink. The print disappears when the temperature rises, for example as the result of a group of people gathering around trying to read the newspaper, to reappear when the temperature drops again. The prediction of the future is elusive, it appears to be in firm print, but it can disappear as one tries to subject it to more careful examination. Another aspect of this exhibition presented computer simulations as video art pieces. Lukasz Ronduda, a curator of visual art, worked with scientists who specialize in computer simulations of social processes in the same way that he works with video artists. As a result, several films were created, which on the one hand present the idea of the simulation model and on the other can be seen as video art.

3.3 Combining art and urban design: Warsaw as emergent structure

Expectative, in 2009 in Warsaw was a series of six related events intended to juxtapose the scientific and artistic views of specific phenomena, and create a dialogue between art and science. For each event an artist invited a scientist for a collaborative project which resulted in a book. The perspective of complexity science was represented by the project of Aleksandra Wasilkowska and Andrzej Nowak, called *Warsaw as Emergent Structure*. The project researched the conflict and interaction between top-down planning and bottom-up spontaneous organization in urban space. During the event participants had experiences related to various aspects of emergent urban processes, for example, how the meaning of different areas of urban space is created in interactions between city inhabitants. During the event the participants could combine subjective experiences relevant to living in a city, produced by participatory art, with the scientific, complexity based knowledge concerning the same phenomena. The edited book [38] contains texts of architects (Aleksandra Wasilkowska, Yona Friendman), philosopher Manuel de Landa, complexity scientists Sorin Solomon and Andrzej Nowak, and scientists adopting complexity science to study urban dynamics, Dirk Helbing and Andrzej Nowak.

3.4 Cultures of change: Social atoms and electronic lives

Cultures of change. Social Atoms and Electronic Lives[16],[17] was the second exhibition conceived by the Laboratori space directed by Josep Perelló (physicist and Associate Professor in Universitat de Barcelona) inside Arts Santa Mònica, a cultural space located in Barcelona (see Fig. 1). The space has been working for three years by way of a collaboration agreement with the Universitat de Barcelona. The aim of the space is to open up laboratories of scientific research to those areas of artistic creativity that are eager for new themes and content, new tools and new science-related languages. As such, it provides an exemplar of the collaborative dynamics which can be created in art-science centres, and demonstrates an organisational structure allowing close working with academic institutions.

[16] Images: `http://www.flickr.com/photos/artssantamonica/tags/culturesdelcanvi`

[17] Videos: `http://www.youtube.com/playlist?list=PL33157ACBDFD26394&feature=plcp`

The exhibition project *Cultures of Change. Social Atoms and Electronic Lives* (from 11th December, 2009 to 28th February, 2010) curated by Pau Alsina and Josep Perelló accommodated a number of experimental simulations; a set of videos; and set of artistic installations and design prototypes, produced jointly and equally by scientists, designers, artists and technologists. The exhibition project was inaugurated during the celebration of the International Conference *Cultures of Change – Changing Cultures* in Barcelona, part of the NEST PathFinder initiative called *A Topological Approach to Cultural Dynamics* under the auspices of the European Commission's 6th Framework[18].

The *Cultures of Change* (CoC) show examines social and cultural dynamics from a highly multidisciplinary perspective the complexity sciences and digital technologies as described in Ref. [39]. ICT makes it possible to quantify and monitor, process and display aspects of our society and our culture in ways that were unthinkable until recently. The CoC project had an intense program of activities, including workshops and talks. Additionally, students were aways present within the exhibition space to act as facilitators, keen to start up a conversation with visitors. We believe that this conversational, peer-to-peer interaction is a key point for this style of exhibition project. Arts Santa Mònica collaborated with the publisher Actar-Birkhauser to print and distribute a high-quality 128-page book. Actar-Birkhauser has a wide distribution – their products can be found in artistic centres such as the Tate galleries (London) or MOMA (New York) – which helped to disseminate CoC ideas to a much wider and non-expert public than would not be reached through traditional science communication channels [39].

Within the CoC show, *POEtic Cubes* (2006–2008) is a physical installation or a sculptural set-up composed of 9 autonomous robots able to self-organize, driven by stimuli coming from the environment, as shown in Fig. 3. It is the result of a collaboration between Raquel Paricio, an artist, and Juan Manuel Moreno Aróstegui, an engineer from Catalonia Politechnic University. In the installation, the visitor interacts with the artificial organism composed of cubic, luminous robots. The robots perceive the presence of the visitor, they move around the visitor and change their colour based on the visitor's movement. The interactions both between visitor and robot and among the individual robots is based on bio-inspired models. The installation allows visitors to perceive and interact with adaptative emergent processes, and has also been used in several dance performances. The resulting project is a multidisciplinary research challenge to the artist, but also for the scientist who needed to innovate and experiment in a very different context, that of an art exhibit.

Goldsmiths College from London was presented two different prototypes coming from design rather than arts departments, representing a strongly transdisciplinary approach. The Pi Studio presented the *News Telescope*[19], a technological device that allows users to explore the globe through a telescope that internally projects digital content, extracted from places like blogs, youtube or news sites, instead of the surrounding landscape. As shown in Fig. 5, the user in Barcelona points for instance to Paris he/she is then able to observe real time news happening in the French city. Part of what makes the piece unique is it's physicality, and the connection to furniture design. A similar theme can be seen in the *Drift Table*, an electronic coffee table that displays slowly moving aerial photography controlled by the distribution of weight on its surface. The project belongs to Interactive Design Studio a group led by Prof Bill Gaver that "pursues practice-based research on new roles for interactive technology"[20]. As shown in their website, "recent work has focused on the home, exploring

[18] `http://www.atacd.net`

[19] `http://www.newstelescope.co.uk`

[20] `http://www.gold.ac.uk/interaction`

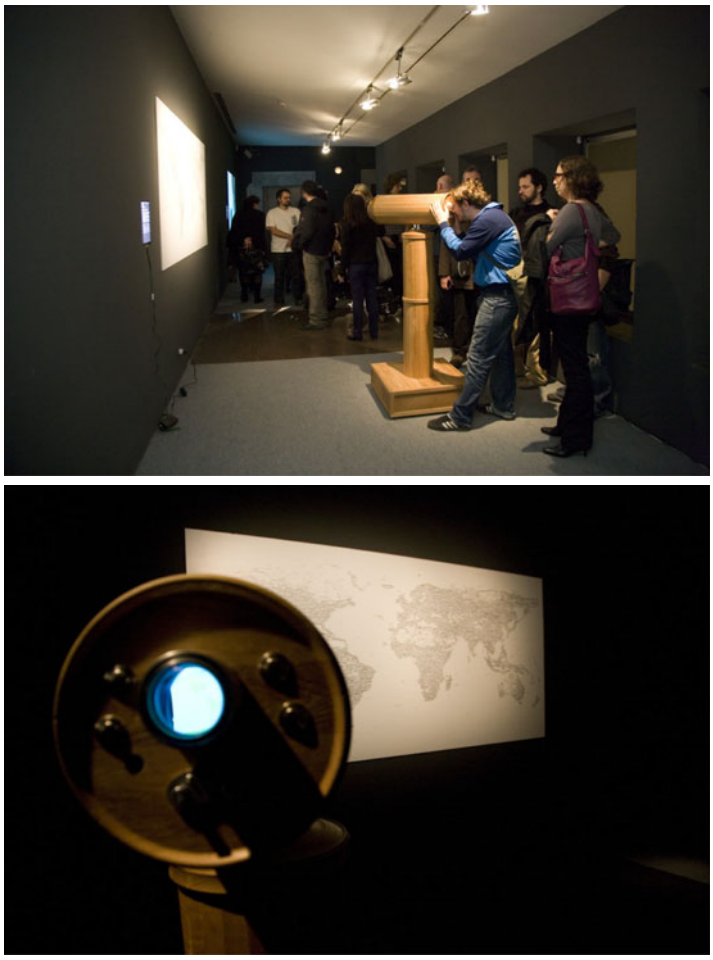

Fig. 5. *News Telescope* in *Cultures of Changes* show (2009) by Pi Studio: Rosenberg, Terry E., Waller, Michael, Fairfax, Duncan, Weatherhead, Andrew and Rogers, Pete. Credit: Xavi Soto - Arts Santa Mònica.

electronic furniture and fittings that provoke curiosity and allow exploration of new views within and outside the domestic setting". A committed focus to *making* has also produced methodological and conceptual innovations and as mentioned in their website:

> "A series of methods for engaging with users, from early explorations of the context for design all the way to the assessment of long-term field trials, stress the value of multiple, unresolved narratives in understanding the meanings of technology. This is complemented by conceptual work that explores topics such as play, ambiguity and interpretation in design."

The *Drift Table* has been showcased in several contexts and spaces around the world and recieved extensive coverage in the press as well as in specialized journals [40,41].

Another project, specially developed and produced for the exhibition, was *Change and Time*[21] shown in Fig. 6. This project was designed and conducted by Bestiario[22]

[21] `http://www.culturesdelcanvi.com`

[22] `http://www.bestiario.org`

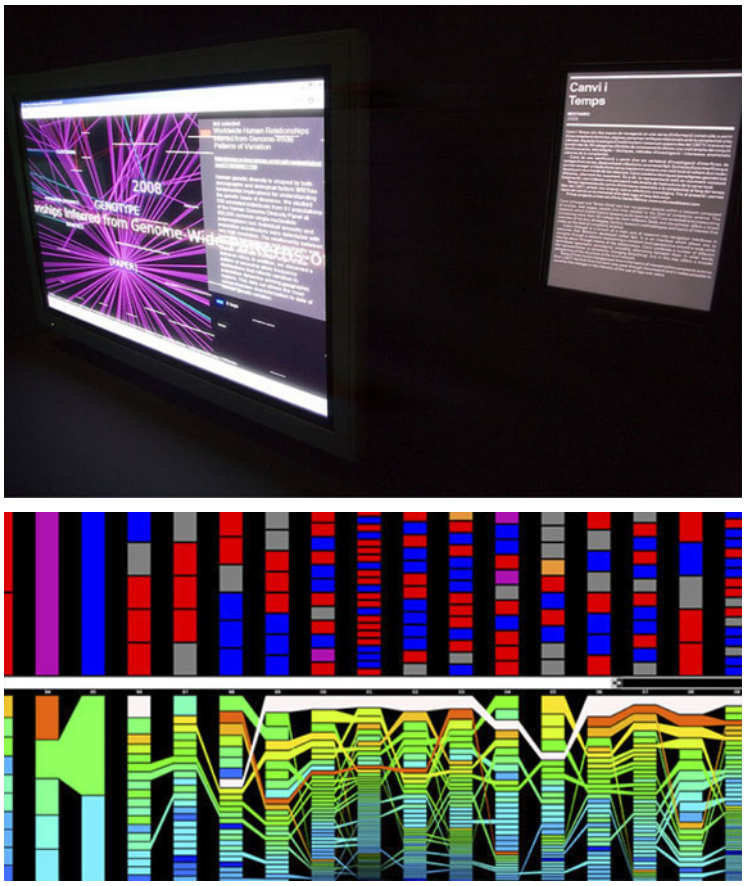

Fig. 6. *Change and Time* project by Bestiario in *Cultures of Changes* show (2009). Visit also `http://www.culturesdelcanvi.com`. Top picture shows *Change* browsing space as was presented in *Cultures of Change* show. Visit http://www.culturesdelcanvi.com/canvi. *Time* visualisation is shown in down picture as it can be seen when visiting the `http://www.culturesdelcanvi.com/temps` browsing space. Credit: Xavi Soto – Arts Santa Mònica.

a Barcelona/Lisbon-based company dedicated to data visualisation and to the creation of spaces for the collective creation of knowledge. The company combines art and science to design and create interactive information spaces based on graph theory, topological algorithms, physical models, and geometrical and geographical representations. The *Change and Time* project was commissioned by Arts Santa Mònica and Universitat de Barcelona. Ten students from Master's Programmes in which Complexity Science plays a key role spent several months feeding a `delicious.com` bookmark page with various data sets relating to the topic of complexity in science, including articles, pages, persons and links. As described in its webpage, "*Change* and *Time* are two network browsing spaces. These respectively *transversal* and *historical* visualisations offer access to the collection of approaches, strategies and tactics, research methods and interests in Complexity Science". *Time*[23], with citations since 1927, highlights the interest in representing changes associated with Complexity Science through time. *Time* allows to see changes on the usage intensity of the tags through time, and includes an interactive time slider bar and mouse hovering actions to access

[23] `http://culturesdelcanvi.com/temps`

more detailed information. *Change*[24] uses more than 30 categories of fields of knowledge, to provide an interface based on browsing a connected web of tags, allowing visitors to move through the network of their relations. *Change* combines different techniques (so-called geometric paradigms), subtly alternating between nodes and links. This alternation means that the "visual representation of the network is in constant, gently rhythmic, pulsating movement, offering a broader perception of the local network" as described in its website.

A related project is *Impure*[25] by Bestiario; although not present in the above mentioned show, is a more recent, award-winning project which also deserves attention. *Impure* is a visual programming language aimed to gather, process and visualise data. Among its possible sources we can highlight social media data, real time or historical financial information, images, news, or search queries. *Impure*, using Bestiario's words,

> "is a tool that allows people to be in touch with data around the Internet, to deeply understand it. Its modular logic interface allows the user to quickly link information to operators, controls and visualisation methods, bringing power and comprehension of information and knowledge to the non-expert user who wants to work with information in a professional way".

3.5 Control.Burble.Remote

Arts Santa Mònica presented an urban performance with collective participation dynamics being a closure event of *Cultures of Changes* show with over 12,000 people of attendance. *Control.Burble.Remote*[26],[27] by the artist and architect Usman Haque was premiered in Barcelona in 27th of February of 2010. See some pictures from the performance in Figs. 7 and 8. This was a new version of *Open Burble* project. The improved version allows for interaction with the public by using any IR remote control: video remotes, TV remotes, etc. Remote controls are usually eperienced by us as instruments of confinement since they require us to adopt strict, home-bound and consumption-oriented relations to our technological devices, appliances and gadgets. Haque considers them as individualistic but domestic objects that control us more than we control them. In the *Control.Burble.Remote* performance this relationship is turned inside-out in a public space and in a large-scale event.

Control.Burble.Remote was an urban spectacle in which all citizens were invited to take part. This project, half installation, half action, had the objective of setting free a structure of almost a thousand helium balloons in a crowded and public space near the Port of Barcelona. Each of the balloons in this huge floating cloud contained an electronic illumination device with four colour LEDs. The aerial sculpture was 25 metres high by 14 metres across and it was built with a network of carbon fiber. After the difficult and risky take-off operation, the network of balloons came to life through the direct participation of the public, who could manipulate the light colour of each balloon. Participants had to bring along any kind of remote control, through which they could control, influence and "paint" hundreds of balloons, by activating their internal transmitters and switching their four different LED light colours. The public became the performer of the spectacle and the relationship of people to their remote controls became externalised, communal, and urban. Additionally, balloons

[24] `http://culturesdelcanvi.com/canvi`
[25] `http://www.impure.com`
[26] Watch the event in: `http://youtu.be/GJT5YbYxWhU`
[27] Photos: `http://www.flickr.com/photos/artssantamonica/tags/usmanhaque`

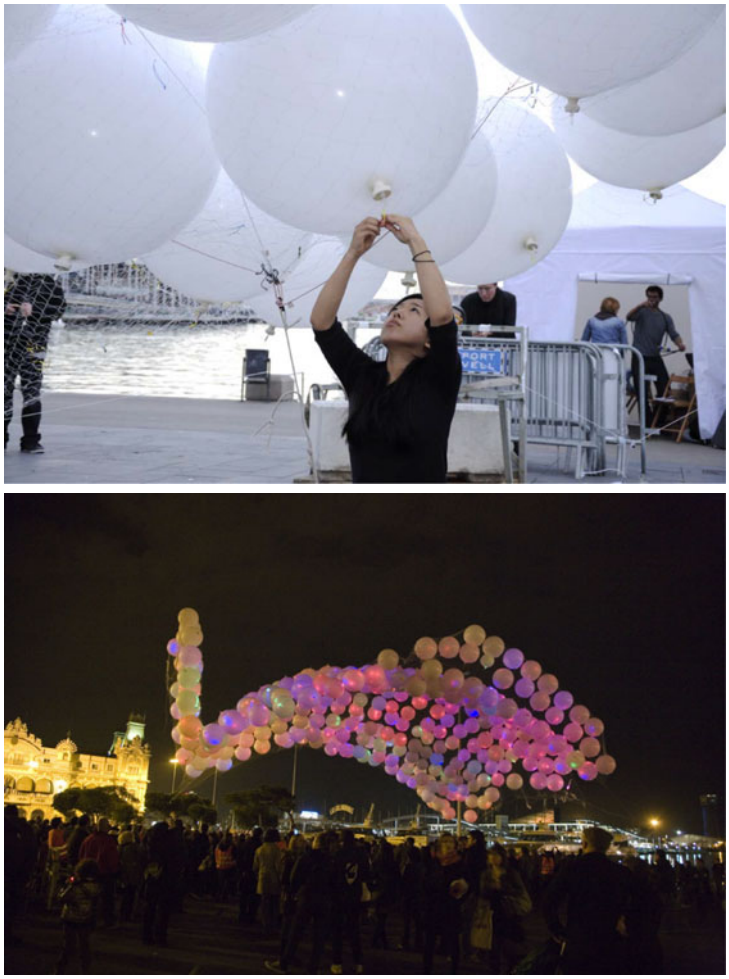

Fig. 7. Preparation and final stage of the *Control.Burble.Remote* performance by Usman Haque an urban performance with collective participation dynamics, 27 February 2010. Credit: Arts Santa Mònica.

were also transmitting their own colour and frequency vibration mode to their nearest neighbours. The whole sculpture was following complex behavioural patterns from a bottom up dynamics triggered by a large number of individual (12,000 people with their own remote controls). The result displayed fascinating and endless forms, similar to those emerging in strongly coupled springs with external noise, or the spontaneous synchronization effect of fireflies flashing in forest. The whole system had several response modes, and it was designed to be capable of displaying long range effects along the whole structure, triggered by a simple colourr change made by a single person. Cascades and contagion of colours could occur from one side of the piece to the other while other parts were showing strongly chaotic colour or flashing behaviour.

Here the audience is the artist and the artist acts a designer of a given collective experiment. This action is part of a series of participation experiments that Usman Haque has been carrying out over the last years: *Sky Ear* in London, Fribourg and Berlin (2003/4), *Open Burble* in Singapore (2006) and, *Burble* in London, which opened the London Fashion Week in 2007. *Control.Burble.Remote* was complemented

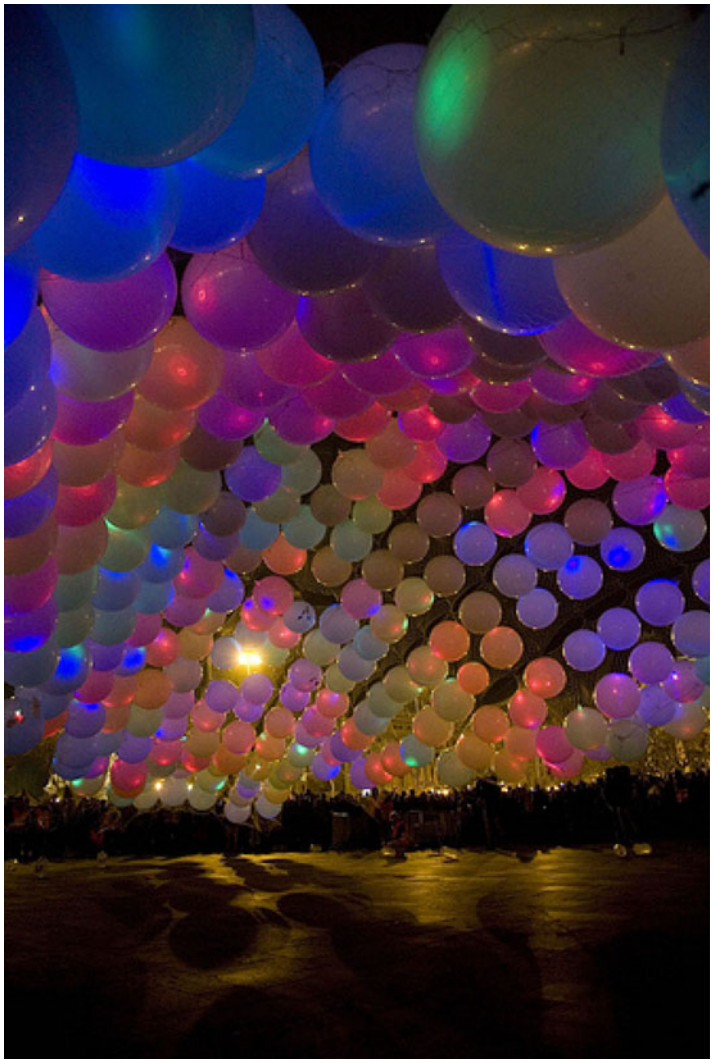

Fig. 8. Right before the difficult and risky taking off operation of the *Control.Burble.Remote* sculpture by Usman Haque, 27 February 2010. The network of balloons came to life through the direct participation of the public. Credit: Arts Santa Mònica.

by three popular science activities (*Balloonometry: Geometry+Balloonigami*, *LEDs, Lights and Drawings in the Air*, *Mobiles, Transverse Waves and Polarizers*).

Collective experiments should consider events like *Control.Burble.Remote*, applying the ideas coming from complexity sciences paradigms to social dynamics. It is also worth mentioning that the event was performed at night; during the day leading up to the launch, several dozen volunteers were engaged in preparing the carbon fiber net; constructing and testing the electronic devices with their own transmitters and LED colours; inserting the devices into the balloons; and finally, inflating and launching the network of balloons. The participatory dynamics approach brings the public at large into the experiment, engaging with a wide audience about the technical and scientific issues of the event. Artistic practice and techniques are use not simply to communicate the results of science, but to open up ownership and direction of the research to a wider community. To make crowd experiments even more meaningful,

the results of any of these social experiments should be fed back into science research and influence the development of ICT tools.

3.6 Musical acts, musical agents

The *Musical Acts, Musical Agents (MAMA)* project [42,43], is a scientific project that examines an artistic area: using multi-agent systems as a tool to analyse the process of musical interaction. The intention is both to provide a better insight into the ways which humans make music, and to improve the ability of virtual or computational musicians to work with human performers. There is a long and rich history of cross-fertilisation between music and computer science, starting with Mozart's Musical Dice Game in which dice are used to generate waltzes by combining pre-constructed material (see Edwards [44] for a recent history of algorithmic composition). Many aspects of musical behaviour have been tackled scientifically, for example computationally tractable representations of the processes used in composition or performance (e.g. Mazzola and Milmeister [45] and Pachet [46]) or a psycho-musicological understanding of musical performance [47,48]. However, musicking[28] [49,50] is also a deeply human activity – we have emotional and physical responses to listening and performing, and individual aesthetics for judging the quality of music. It is this relationship between the formalisable and the human which makes music a fascinating but frustrating aspect of study, and an appropriate area of inquiry for Art and Science.

MAMA was initiated to help understand the interactive nature of music making, in contrast to traditional computational approaches to music that tend to focus on the music which has already been produced rather than the ways in which musicians go about organising their playing. Here we want to examine music as a communicative process: to look at the interactions which take place when people play music together, and understand the patterns which allow musicians of different backgrounds and skill levels to engage in a mutually satisfying musical experience [51].

In the absence of a general theory of musical improvisation which could be implemented computationally, we take inspiration from the (arguably) related discipline of linguistics, in particular pragmatics [52] and Speech Acts [53]. Speech Acts give a logical formalisation for understanding certain types of speech, in particular phrases which have an effect on the world, such as marriage vows or declaring war, which has supported the creating of formal agent communication languages which allow for agents to reason about the intentions and beliefs of others[29]. We aim to construct a set of communicative actions for music (*Musical Acts*) along similar lines to speech acts, in order to create a computational analysis of music as played and help artificial musicians to play with their human counterparts.

The main thrust of this project illustrates one of the ways to approach the intersection of science and art: using scientific methods to understand an existing artistic process, and attempting to model or replicate it. However, this is only part of the story designing and implementing the necessary computational and conceptual frameworks posed questions about how people relate to computers, and suggested new forms of interaction. In particular, the need for a more direct, immediate interface than that provided by a mouse and a screen was clear, and this led to the construction of

[28] The work *musicking* was coined by Small [49]: "To music is to take part in any capacity in a musical performance. That means not only to perform, but also to listen, to provide material for performance – what we call composing – to prepare for a performance – what we call rehearsing or practicing – or any other activity connected with the performance. We should certainly include dancing…"

[29] See e.g. Foundation for Intelligent Physical Agents Agent Communication Language, `http://www.fipa.org/repository/aclspecs.html`

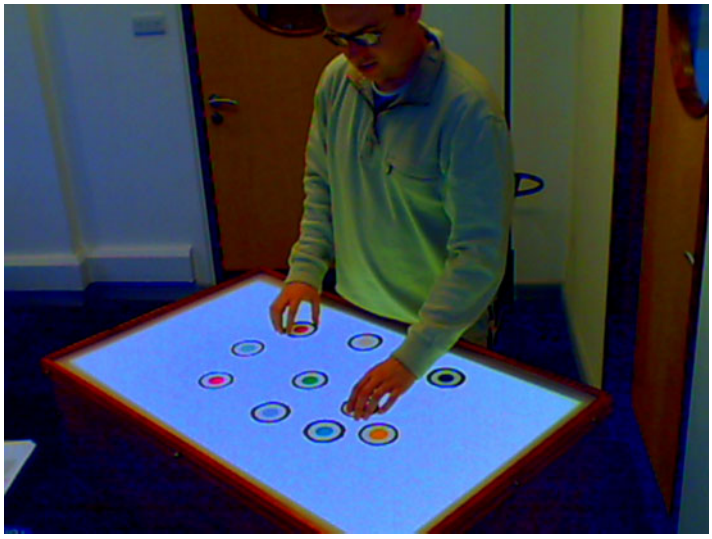

Fig. 9. *Musical Acts, Musical Agents (MAMA)* project [42,43]. Credit: Dave Murray-Rust.

a tangible interface which allowed people to manipulate many agents at the same time.

A set of agents is given material from Terry Riley's *In C*, which consists of a list of small musical fragments; each musician (or agent) starts playing the first fragment, repeatedly, and gradually moves through the list according to their own volition, but attempting to be within a few fragments of the other players. The agents are arranged within a two-dimensional space, with the position defining the loudness and stereo position of the sound made by the agent. Each agent has a natural speed of progression through the piece, but they attempt to match their position in the piece relative to the other agents, with emphasis given their closer neighbours.

A set of coloured disks represented agents, which collaborators could position on an illuminated surface. By arranging, adding and removing the disks, a mix of different agents could be created; also, agents could be separated into groups, whose playing would gradually diverge, or lines along which the choice of material could diffuse.

In this case, it was when people were confronted with the working system that they became engaged: the system provided an experience which was intuitively understandable, and hence provoked a stronger reaction than the abstract concepts in the theory were giving rise to. Both elicited and observed responses could then be used to improve the interface, generate new ideas for human-computer interactions and refine the Musical Act theory. In contrast, another part of the project used a more traditionally scientific approach, setting up an experiment with pianists who played duets (which contained an improvisatory component) with the system, and filled out questionnaires about the quality of interaction. There were several problems with this: the limited set of people who could take part due to the skill requirements led to a small data set; the quantitative nature of the results removed a lot of depth from the responses by compressing a musical interaction down to a set of numeric responses; and the formalised nature of the process did not allow for exploration of anything the participants found interesting. Here the value of allowing a more general public to play in an open ended manner with the system was readily apparent as shown in Fig. 9.

Fig. 10. *ChaoDependant* by Murray-Rust, Papadakis and Green (2010). Credit: Parag Mital, Agelos Papadakis.

3.7 ChaoDependant – science and sound-art

An alternative direction of approach is represented in *ChaoDependant* shown in Fig. 10. This is an example of scientists, technologists and artists collaborating to create an art piece that is based on several scientific principles. The piece centres around a magnetic pendulum, and a collection of blown glass pods, containing magnets, lights and sensors. The pendulum has long been a source of inspiration for Art and Science work, including Foucault's striking experimental design to demonstrate the rotation of the earth (e.g. Somerville [54]) and the Harmonographs and related devices used to draw pleasing curves [55] using harmonic motion. Here, the interest was in exploring the chaotic motion produced when the pendulum moves through the invisibly structured space created by arranging a set of magnets below it. Although the motion in itself is intriguing, to create a more complete piece and encourage different kinds of interaction, the lights and sensors were added. When the pendulum passes over a pod, it triggers a light, and sends a signal to an interactive soundscape

generator, which plays a recognisable sound, and contributes to a background sound field that responds to the state of the system; rapid sequences of events increased the internal feedbacks, leading to denser and more chaotic output.

The use of technology allowed for multiple levels of appreciation and interaction. People could passively observe the motion of the system (as long as someone would set it in motion), or they could alter the setup of the pods to explore the patterns and rhythms that could be generated. Adding the visual and sonic triggers gave an intuitive indication of the chaotic behaviour, with changes in orbit resulting in changes in the melody produced, giving an open ended avenue for exploration of the physical processes. By having multiple processes layered together – i.e. by not being a scientific demonstration of a single phenomenon – a general audience could engage with whichever aspects they found fascinating. From talking with and observing visitors to the *Kinetica Art Fair*, we saw: small children being mesmerised by the idea of something that you push away which comes back; older children using it as a coordination artefact for play, setting up patterns and games with the pendulum; people arranging the system to play melodies; many ad-hoc experiments, where attempts were made to enhance or isolate a behaviour; questions about the physics, and questions about the technology used to highlight it. In the end, the most rewarding aspect was that it was open ended, and multi-layered. There was not a strong communicative or disseminative principle; rather it was a space for exploration, and the questions were generated by the visitors.

3.8 Living systems. Christa sommerer and Laurent Mignonneau

Christa Sommerer and Laurent Mignonneau, based in University of Linz, "are two of the most renowned and innovative artists on the international media-art and interactive-art scene" [56]. In a natural and intuitive way, their work develops interactive interfaces that apply principles of the theory of living systems related to ecology, artificial life and complexity sciences [57]. *Living Systems. Christa Sommerer and Laurent Mignonneau*[30], curated by Josep Perelló and Irma Vilà, is a production by Arts Santa Mònica and represents the first retrospective exhibition of these two artists. The show offered the possibility of experimenting in a participative way with important issues linked to the study of living systems: *Eau de Jardin*, *Phototropy*, *Life Spacies II*, *Mobile Feelings* and *A-Volve*. Ricard Solé, an ICREA researcher of complex systems in Universitat Pompeu Fabra from Barcelona, has collaborated with Josep Perelló on the compilation of the scientific vocabulary necessary to understand the artists' virtual ecosystems. A series of activities and workshops make it possible to study in even greater depth the behaviour and modelling of complex living systems in which the beings interact each other and with the environment. The exhibition had also an activity program and an education program, as well as an exhibition book being broadly distributed by the publisher Actar-Birkhauser [57].

We here report in detail two of these pieces. As Sommerer and Mignonneau describes in Ref. [57], "*Eau de Jardin* developed in 2004 in Tokyo is an interactive installation that transports visitors into the imaginary world of virtual water gardens" as shown in Fig. 11. Inspired by Monet's later Water Lilies paintings and their panoramic setting at the Musée de l'Orangerie in Paris, Sommerer and Mignonneau constructed in Barcelona a projection screen that forms a triptych. As described in their exhibition book [57],

[30] Living systems output:
Videos: `http://www.youtube.com/playlist?list=PL546D55BEAB4E46A3&feature=plcp`
Photos: `http://www.flickr.com/photos/artssantamonica/sets/72157626897044368`

Fig. 11. *Eau de Jardin* by Christa Sommerer and Laurent Mignonneau where plants on screen grow following a fractal algorithm. *Living Systems* show (2011). Credit: Xavi Soto – Arts Santa Mònica.

> "the wide horizontal screens immerse the viewers mentally into a virtual picture of the water garden. Up to eight amphorae hang from the ceiling of the room. When the visitors approach the amphorae, their presence is recognized by the plants, causing virtual water plants to be drawn on the large projection screens. The electrical potential differences (voltage) between the user's body and the real plants are captured by the plants and interpreted as electrical signals that determine how the corresponding virtual plants grow on the projection screen following fractal algorithms which also serves to model real plant growing. The more visitors interact with the real plants, the more the virtual scene of aquatic plants builds up all changes in the their interactions are translated and interpreted, leading to constantly new water garden images. The virtual pond in *Eau de Jardin* becomes a mirror of the 'reality' of virtuality. Just as Monet succeeded in creating two layers of virtuality by blurring the borders between "real" interpreted plant images and their reflected image in the water's surface, *Eau de Jardin* tries to create several layers of virtuality by blurring the borders between real plants, virtual plants on the screen and their reflected virtual image in the virtual water's surface."

Fig. 12. *A-Volve* by Christa Sommerer and Laurent Mignonneau based on Prey-Predator models. *Living Systems* (2011). Credit: Xavi Soto – Arts Santa Mònica.

A-Volve, shown in Fig. 12 is an interactive environment with artificial creatures living in a water-filled glass pool [57]. The virtual creatures are initially created by visitors. By designing any kind of shape with their finger on a touch screen, visitors create three-dimensional creatures that are automatically alive and swim in the water of the pool. The creatures compete by trying to get as much energy as possible from other living creatures. Predators hunt prey, trying to eat them and get more energy. The fittest creature survives the longest and will have more chance of mating and reproducing. The newly born offspring lives in the pool with the rest of the members of this ecosystem. The creatures also react to visitors' hand movements in the water. If a visitor tries to catch a creature, it will try to flee or it will stay still if it is caught. The visitor is thus able to influence the system by, for instance, protecting prey from predators. *A-Volve* is a pioneering work that has been exhibited worldwide and received the 1995 Inter Design Award of the Japan Inter Design Forum, the 1995 Ovation Award of the Interactive Media Festival in Los Angeles, the 1994 Multi Media Award of the Multi Media Association, Tokyo an the 1994 Golden Nica Award of the Prix Ars Electronica 1994 in Linz.

3.9 Places & Spaces

The international *Places & Spaces: Mapping Science*[31] exhibit was first shown in 2005, and introduced a range of maps of science. These maps contextualise science across the globe in both space and time, in support of the navigation, management, understanding, and communication of data, knowledge, and expertise. As of 2011, the exhibit features 70 maps by 189 authors from 11 countries. Each year, a new themed set of 10 maps is added via an open call for maps and peer review by the exhibit advisory board and invited experts. Over the last 7 years, the exhibit has been on display at more than 200 venues in 19 countries on 6 continents.

Places & Spaces: Mapping Science is a project that is meant to inspire cross-disciplinary discussion on how to best track and communicate human activity and scientific progress on a global scale. It has two components: the physical part displays

[31] `http://scimaps.org`

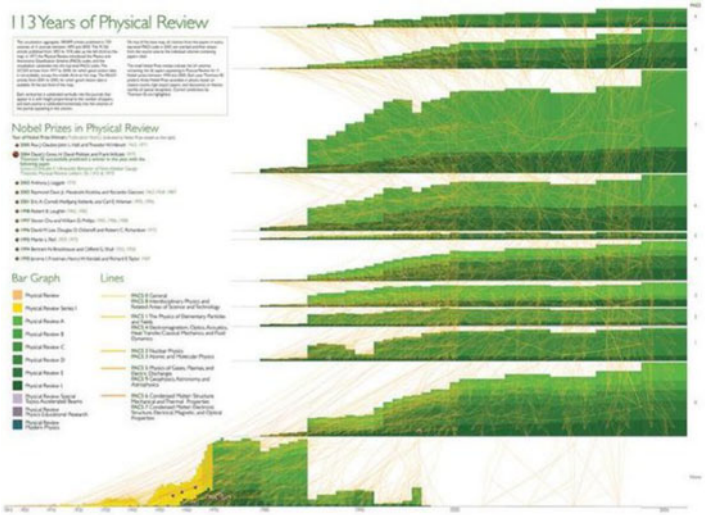

Fig. 13. The *113-year Physical Review* dataset by research programmers Bruce W. Herr II and Russell J. Duhon, graphic designer Elisha F. Hardy, data analyst Shashikant Penumarthy, and information scientist Katy Börner. The visualisation aggregates 389,899 articles published in 720 volumes of 11 journals between 1893 and 2005 using the Physics and Astronomy Classification Scheme (PACS) codes introduced in 1975. Source: `http://scimaps.org`

high quality reproductions of maps for display at conferences and education centres; the on line counterpart provides links to a selected series of maps and their makers along with detailed explanations of how these maps work. The exhibit is a 10-year effort. Each year, 10 new maps of whatever data one might imaging are added resulting in 100 maps total in 2014. For instance, one of the maps is a visualisation of international collaboration that occurred between 2005 and 2009. See for instance Fig. 13.

Katy Börner from Indiana University is behind this cross-disciplinary project, which in fact has a counterpart inside academia and in scientific journals [58,59]. *Places & Spaces: Mapping Science* and other related projects where Börner has been involved have been reviewed by journals like Science [60], Nature [61], American Scientist [62], SEED magazine [63]. The New York Times [64] documents a particularly interesting example: *Life: A Cosmic Journey* is a multimedia presentation shown at the Morrison Planetarium at the California Academy of Sciences, which relies not just on computer animation techniques, but on a wealth of digitized scientific data as well. The New York Times says:

> "The planetarium show is a visually spectacular demonstration of the way computer power is transforming the sciences, giving scientists tools as important to current research as the microscope and telescope were to earlier scientists. Their use accompanies a fundamental change in the material that scientists study."

The same article takes Katy Börner's words to describe what is a "macroscope"

> "It is a new class of computer-based scientific instruments to which the new planetarium's virtual and physical machine belongs. These are composite tools, with different kinds of physical presences that have such powerful and flexible software programs that they become a complete scientific workbench that can be reconfigured by mixing and matching aspects of the software to tackle

> specific research problems. [...] 'Macroscopes' provide a vision of the whole, helping us synthesize the related elements and detect patterns, trends and outliers while granting access to myriad details. New software-based scientific instruments make it possible to uncover phenomena and processes that in the past have been too great, too slow or too complex for the human eye and mind to notice and comprehend."

There exists a huge potential to consider artists and graphic designers in building up these software-based scientific instruments. The final users can be the general public exploring an installation; scientists improving research results through a better visualisation; or stakeholders and policymakers getting a better understanding of scientific research [65]. It could be extremely useful to blend scientific interests with Data Aesthetics initiatives most of them with artists and graphic designers involved and compiled in several books for the general public [66] and nicely reported in Nature [65]. Just as a final example, *Visualizar*[32] is an annual meeting taking place for the last 11 years in Medialab Prado Madrid[33]. The latest of these focused on *Understanding Infrastructures* and used a workshop format to tackle the theme of making infrastructures visible, ranging from those that produce and transfer energy and water to those that make possible global communication and mobility.

3.10 Common themes and lessons learnt

We have presented a range of case studies and examples exploring the links between science, technology, art and indeed culture. There are different approaches, from applying scientific method to understanding the process of artistic creation (*MAMA*) to using art to explore the impact of technology on everyday life (*Control.Burble.Remote*). However, there are some features in common which are part of the motivation for their creation and the reason for their success. In all cases, the inspiration is not to communicate or justify science; often, it is to bring the public into the laboratory or the laboratory to where public is. That is, the projects are not based solely on making science accessible by explaining it to the public, but use the artistic impetus to modify and enhance the scientific component of the work (i.e. using the logics of innovation and ontology). *Places & Spaces*, *News Telescope* and *Drift Table*, through its investigation of methods to present the spatio-temporal components of knowledge generation, goes beyond communicating what was done: it creates new understanding about how knowledge is created and helps suggest and answer questions about the process through the juxtaposition of multiple methods of presentation and visualisation.

The interactive nature of several of these works allows the construction and testing of immediate ad-hoc hypotheses. For example, *Living Systems* allowed experimentation with different forms of artificial life which then feeds back into the construction of a scientific vocabulary. These micro-experiments are therefore a rich source of inspiration to the development of science – especially science that is concerned with humans and their behaviour, as illustrated for example by watching interactions with the *MAMA* system. In many cases, the playful and direct nature of the interactions was key: in some of the interventions in *Conflict, trauma, art*, for example, art used playfulness to engage with serious issues without these being painful or traumatic for the participants. Extremely Rare Events uses the mischievous notion of words that disappear when more attention is paid to them to illustrate the ephemeral nature of future prediction.

[32] `http://medialab-prado.es/visualizar`
[33] `http://medialab-prado.es`

Similarly the ability to reach out and "touch" the system – to get "covered in pixels" – encourages creativity on the part of the visitor, and provides the main avenue for increasing understanding for both the system's creators and its public. *ChaoDependant*, *A-Volve* or *POEtic cubes* invite visitors to interfere with a physical system while in motion, and understand the disturbances; *Oxygenator* prompts people to change their behaviour by using the benches and pond provided, to foster interactions with each other; *Control.Burble.Remote* allows participants to paint gigantic swathes of colour in the sky. Finally, it is often the shared nature of the interaction which gives it its power: the balloons of *Control.Burble.Remote* introduces a physical component visible to others; *ChaoDependant* allows the construction of games between participants; *Conflict, trauma, art* uses the location of the pieces to create interventions in shared spaces.

Based on this, we suggest the following qualities and principles as being valuable for work linking science and arts, such as the FuturICT ASL [3]:

- collective experiments, which bring a wider public into the scientific process,
- multiple overlapping styles of presentation and engagement,
- supporting playful experimentation,
- physical components, making use of the surrounding environment,
- shared spaces and interaction between participants.

4 Innovation and expected paradigm shifts

The main aim of the FuturICT Art Science Link is to create a cascade of artistic interest and activity around the FuturICT ideas and project. It is important to support artists in using existing tools and data from complexity science. This will enable artists to enhance new research lines and discover new uses for the existing technologies, and inspire future directions. Participating artists in FuturICT will be considered as experimentalists and researchers of a lively and intimate science. The expected innovations and paradigm shifts can be grouped into four main areas: (i) interaction with large datasets; (ii) social experiments, storytelling and serious games; (iii) digital curation and living experiments; and (iv) geo-ethics.

4.1 Interaction with large datasets

Visualisation has always gone hand in hand with big data and data mining; meanwhile significant effort has gone into the exploration of techniques for interacting with large datasets [65]. This is a highly interdisciplinary field, as design and art techniques are fundamental to acquiring knowledge from these large datasets. However, the use of these systems is typically the preserve of the scientist, engineer or statistician, so we should reconsider these roles along the "macroscope" concept provided in Sect. 3.9 and the ideas from artists like John Cage and Julius von Bismarck, presented in Sect. 2.

Within FuturICT, the *Living Earth Simulator* [34] *Planetary Nervous System* [35] and *Global Participatory Platform* will generate huge amounts of data, which will be explored using cutting edge techniques elsewhere in the project. The *Art and Science Link* section of FuturICT will build on this, to work with a range of alternative techniques, to create works which engage with different publics. Some particular areas of interest are around ubiquitous computing and "calm" computing [67,68] which give alternative approaches to interacting with data and technological systems; "ambient interfaces" [69] can be used to embed data into the physical environment for

example the DerivArt[34] Financial Landscapes which sonifies[35] stock market data, or audiovisual mapping onto buildings[36] can be used to translate individual interactions into larger shared and public spaces; ludic[37], playful interfaces [40,41] take a whimsical approach to interactions with information and data [38]); computational systems can provide increasingly natural ways to work with multidimensional data, e.g. OverCoat[39] which allows for a painterly approach to 3D modelling, and is developed by a FuturICT supporter. OverCoat technique generalizes the 2D painting metaphor to 3D that allows the artist to treat the full 3D space as a canvas. Strokes painted in the 2D viewport window must be embedded in 3D space in a way that gives creative freedom to the artist while maintaining an acceptable level of controllability.

Working within the context of FuturICT will provide a long term framework for the development and assessment of these emerging technologies and methodologies alongside more traditional techniques. By using multiple approaches to explore and present the same datasets and simulations, we will gain a greater understanding of which approaches are most useful for engaging with different publics and different data. The experimental, playful, engaging techniques used within the ASL will cross-pollinate with the more direct visualisation methods used elsewhere in the project, giving a spectrum of approaches from highly directed tools to open-ended experiences. This will allow the data created by FuturICT to be extremely open to public inspection: not only will we provide the data, we will create a set tools and experiences which allow different sections of the public to explore the data in ways which are meaningful to them.

4.2 Social experiments, storytelling and serious games

The *Innovation Accelerator* [33,36] provides a forum to share knowledge, and through this sharing and collaboration, to enhance the generation of new knowledge, leading to innovation. By creating a parallel Art Accelerator, we can use this knowledge, and the *Living Earth Simulator* [34], to support a range of artistic projects examining and contributing to FuturICT themes in very different ways.

The artist becomes a social-experiment designer – an intimate scientist or a "macroscope" – carrying out large-scale participatory experiments with strong public and social engagement. These experiments provide windows onto the future, allowing crowd-sourced exploration of future scenarios and for reflection on the role of ICT and FuturICT technologies in a changing world. Serious games [70] are maturing, and making use of current technology, particularly from computer games [71], and provide a huge opportunity for dissemination and engagement around FuturICT. A range of forms is possible: digitally mediated collaborative storytelling where particpants work together to create plausible futures and their reactions to those futures [74]; group economic simulations were participants use alternative currencies to explore economic mechanisms; simulated crises where a group of people must respond to emergency situations.

[34] `http://www.derivart.info`

[35] Turns into sound or music.

[36] See for instance PlayModes audiovisual mapping on buildings. Closing event of Catalan Culture capital in Figueres, Spain (`http://vimeo.com/8749914`), Kernel Festival Dessio, Italy (http://vimeo.com/26047200), Albacete,Spain (`http://vimeo.com/11007507`), Theatre's re-opening of El Molino, Barcelona, Spain (`http://vimeo.com/16481605`).

[37] Game-like, from *ludus*.

[38] See Fig. 14 for an example from DerivArt who work at the intersection of technology, finance and art. There are also interesting links which can be drawn to Ref. [31].

[39] `http://zurich.disneyresearch.com/OverCoat/`

Fig. 14. The *Burbujometro* (Bubble-o-Meter) is an interactive visualisation from DerivArt of Spanish real state prices. It shows, in real-time, the prices of apartments in different Spanish cities in the form of bubbles. The user controls the installation with an infrared gun, and as he or she shoots the bubbles these burst and display the prices of apartments. The piece promotes reflection on the socioeconomic dynamics of bubbles, housing, and the Spain of the 2000s. Source: DerivArt.

What is new here is the strong connection to a growing body of knowledge and data – the *Planetary Nervous System* [35] – and interlinked simulations – the *Living Earth Simulator* [23]. By tying into this framework, artists have ready access to a range of supporting material and technology which means that games can be constructed with realistic responses, and the implications of decisions and outcomes can be computed across a range of different subject areas. For example, when participants in a collaborative storytelling exercise make an economic decision, the ramifications of that decision can be modelled, and fed back into the storylines. This will allow for the rapid creation of highly contextualised works, with detailed mechanics, that can be used to explore interconnected systems from many viewpoints while maintaining coherence. At the same time, the actions of participants in these serious games and social-experiments will produce a large volume of behavioural data which can be analysed, and used to improve the models within the Living Earth Simulator, giving a novel bi-directional interaction between models and the people who are modelled.

4.3 Digital curation: Living experiments

Curation of digital art is an emerging issue [75], and an important trend in the history of art and media art, with the new discipline of Digital Archaeology dedicated to the memory and presentation of digital and data art[40]. The rapid change of technologies has generated the problem of preserving artistic pieces, both in terms of the evolving nature of the work, and at the mundane level of maintaining the technology required to reproduce it.

Some pieces are purposefully ephemeral, while others develop through their interactions with visitors: for example, *A-Volve*, mentioned earlier evolves populations

[40] See for instance the *Botaniq* project: `http://botaniq.org`

of virtual creatures in response to user input. Many pieces are "living experiments", where artists fix the initial conditions and observe how the system evolves based on visitor's and user's interaction. The system is alive only with the presence of visitors and the piece can be seen as a natural, or field-work experiment. The FuturICT ASL will provide a home for pieces in this style: the length of the project allows it to act as a living repository for archival and maintenance and gives a focus that extends beyond the immediate presentation of a work, supporting its future life.

At the same time, integration with the *Living Earth Simulator* [23] will allow for pieces which tap into a continuing, dynamic, shared world. This will allow for a longer unfolding over time than is usually possible; each time a work based on the *Living Earth Simulator* is shown it will connect to a world which has evolved and changed. In turn, through interaction with the public, it can affect the shared state of simualtions, leading to interactions between different pieces, across a large span of time.

4.4 Geo-ethics

There is a strong impetus in contemporary digital art to explore the intersection between digital technology, geography and ethics. This can range from intercepting and decoding digital signals as hown in Fig. 15[41] or other forms of "hacktivisim" to highlighting the pervasiveness of CCTV[42] [72,73]. Artists have created work to visualise communities with bad reputations or low visibility, such as taxi drivers in New York or Mexico City, or prostitutes in Spain and the Sahara (Antoni Abad, 2006-2011). In 2006, the Spanish artist Abad received a Golden Nica in the category of "digital communities" for a project showing the parts of Barcelona inaccessible to wheel-chairs.

The FuturICT project has its roots in digital and communications technology, so this investigation into ethics and place – geo-ethics – has a strong resonance, and many opportunities for innovation. This can be seen as a consequence of the previous directions: developing knowledge about real people and real places requires an understanding of the ramifications of this knowledge, in particular by projecting it back into the world. The idea of relating scientific knowledge to the physical world is not new, but the scale of FuturICT and the integrated data which it generates enables projects working over large spatial scales, and using a variety of themes coherently in a way which was not previously possible. At the same time, since FuturICT is concerned with the development of future technology and a greater understanding of social systems, it gives rise to a range of questions about digital ethics. What are the effects of giving voters high-quality, personalised information about their government? How do our responsibilities and responses to a system change once we can model it? How do people change their personal ethics as their understanding of the effects of their actions grows? An interesting response to these issues is the play by Roger Bernat called *Pending votation* (Pendiente de Voto, 29 February to 4 March 2012) of Centro Nacional Dramático Madrid. The theatre is transformed into a parliament where each of the spectators, armed with a remote control with which voting rules in the theatre chamber. In Bernat's words: "Theater immersion? Rather, an emerging scene".

Again, these questions are not novel in themselves. The novelty lies in being able to construct these questions in the context of a system which can model them, and thus in being able to show people the results of a course of action, allow them to

[41] Orbitando Satélites exhibition, LABoral Gijón 2011. `http://www.laboralcentrodearte.org/es/exposiciones/orbitando-satelites`

[42] See for instance the *Inside Out Project*: `http://www.insideoutproject.net`

Fig. 15. The artist Alejo Duque based in Zurich catching satellites signal passing over Barcelona the 18th of November 2011 with the project *Orbiting Satellites* led by Pedro Soler. Credit: Arts Santa Mónica.

understand it and observe how their behaviour changes and then immediately feed it back into the models. By providing a coherent, living simulation of a broad class of social systems, we can support a participatory exploration of digital and social ethics, and their larger repercussions.

5 Impact

The impacts of art on science dissemination are rather immediate, and take different forms. Firstly there is the traditional dissemination channel in the press and media, whose impact will be through set exhibitions and collective experiments. This approach will be of interest to the regular science journalists, and also to journalists

working in cultural and art sections of publications. Press coverage of innovative outputs, particularly those addressing political and ethical issues triggered from artistic collaborations, will drive curiosity about scientific processes and outputs, leading to impacts on wider society. To give some indication of this, the Arts Santa Mònica exhibitions *Cultures of Change* and *Living Systems* have been mentioned more than a hundred times by the press, radio and TV. Additionally, the *Cultures of Changes* show has been receiving approximately 800 visitors per day – up to 40,000 visitors over the course of the exhibition – with special events such as the crowd experiment by Usman Haque receiving more than 12,000 participants: the potential social and media reach of these projects is very large. Data access and visualisation projects such as MySociety[43] have helped to redefine the relationship between society and government, affecting the wider society by increasing transparency, accountability and understanding of the mechanisms of society. The participatory methods used in the Art and Science Liaison proposal here have the potential to engage with a wide range of society, both in terms of the science within FuturICT, and of knowledge about the wider issues which are being modelled. The engagement produced with interactive simulations and installations, coupled with the expected audience numbers, has the capability to affect the attitudes of a large number of people, as well as providing a valuable education resource. Finally, due to the breadth and timescale of FuturICT, and the open nature of the "travelling show", the general public can experience science as a process, and can be part of directing the research and watching knowledge and understanding improve over time.

The collaborative and crowdsourced experiments, which form the core of the travelling show and fundamental parts of the FuturICT flagship, will provide an unparalleled "living" dataset. While similar data has been collected in the past, this has typically only looked at one area of the social sphere at a time. The FuturICT dataset will be coherent across a wide range of human activities, and relating the dynamic, participatory methods proposed here to this kind of data will highlight new and emerging ways of doing science. Further impacts include the use of artist's residencies, the discussions enhanced by artists, the inclusion of research projects within a show, and the scientist residences as innovation accelerator tools and mechanisms for enhancing the scientific process within the project.

FuturICT scientific practices have important social, ethical and political dimensions that art can help to underline. We move beyond classic science communication formats to enable more effective public engagement and societal awareness of FuturICT challenges. In this sense, we believe that informal educational activities during exhibitions and collective experiments are also crucial. New science education must adopt this multiplicity of dimensions carried out by the connection with Arts and ICT in order to have a more realistic picture of our changing world. Educational experiences for young children play a key role in their learning about science and technology; the more playful and creative perspectives offered by art and science hybridisation enables participation for a range of ages and abilities (see also Ref. [76]). This interaction and fusion of disciplines, whose communities are often disparate, is an ideal motor to drive inquiry-based- and problem-based science education and facilitate the synergistic cultural change in young people's interest in science studies as distilled in the EU Rocard Report 2007 [1] and reinforced in the EU Masis Report 2009 [2]:

> "A stronger interaction between teaching sectors and research centres should be supported by activities of orientation, communication and by new institutions. Science [and technology] is also a matter of *closeness* and accessibility,

[43] `mysociety.org`

> and close contact with it is necessary in order to dispel the image of laboratories as remote, inaccessible and alien spaces."

To meet future societal, economic and scientific challenges, the adaptation of education systems tailored to modern needs across all EU Member states is urgently required to provide a legacy of creative, flexible, science literate citizens along the FuturICT spirit. As referenced in the EC 2010 Innovation Union Communication[44],

> "...innovation is now needed in almost all walks of life: schools must ensure that all young people are ready..."

Finally, in terms of innovation, the ASL proposal provides a very robust tester of new software and hardware technologies since the artistic experiences can lead to the discovery of new needs, weak points and new possibilities of these technologies. There are many examples of artists working and designing new open-source software platforms, doing things like tracking satellites in real time and therefore making us conscious of the dense population of satellites sorrounding us (e.g., *Orbiting Satellites* 2011). As a further example, Flowing Data[45] and Bestiario provides a constant stream of innovative data visualisation techniques. Although their initial aim was simply to use this data for media art installations or websites, the innovative ways of accessing and visualising data that this project makes possible can have a deep transformative effect on technology and society. Therefore, the "travelling show" concept provides an incubator for novel technology, which can be envisaged, prototyped and explored as a living, public experiment, and has the potential to produce diverse technological innovations with very little risk. The inter-institutional research centre will promote and contribute to FuturICT through artistic formats and strategies, creating a flexible, expanded mirror structure, allowing for reflection, investigation and dissemination of research and developing new interdisciplinary practice.

6 Conclusion

In this discussion paper, we have presented a very brief distillation of our conceptualisation of the relationship between science and art, and the motivations for carrying out interdisciplinary work in this area, facilitated by ICT. We have presented several diverse case studies, highlighting different aspects of the interface between science and art. From these case studies, several qualities were extracted which will form the basis of goals for the Art-Science Link of the FuturICT project: collective experiments, multilayered presentation and engagement, playful experimentation, physical and environmentally situated work, and shared spaces with interaction between participants. We propose the preparation of a large "travelling show", a set of experiments/installations, which is seen itself as a living complex system, starting from co-creative dynamics in its design and ending up as data source for scientific and technological research. We have also proposed creation of an inter-institutional research centre that will connect scientific and artistic institutions, acting as a liaison between art and science to facilitate reflection on research activities and acquired knowledge; facilitate innovation; and create artistic pieces and events to disseminate the knowledge acquired by FuturICT.

We have also highlighted four areas where the FuturICT project can support innovation in the Art and Science area: interactively visualising and presenting large datasets as part of ongoing simulation; curating and archiving coherent multimedia works; supporting group exploration of current linkages and future possibilities; and

[44] `http://ec.europa.eu/research/innovation-union`
[45] `http://www.flowingdata.com`

examining the development of geo-ethical issues around developing ICT. Finally, we have explored briefly the possibilities for impacts both within and outside the scientific sphere of discourse.

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