GENERAL ARTICLE

A Viewpoint on the Computing-Art Dialogue: The Classification of Interactive Digital Artworks

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ABSTRACT

The author provides a viewpoint on the dialogue between computing and art by describing a framework for classification of Interactive Digital Artworks: information technology systems in which spectators are involved in the production of the artistic output. The author bases his approach on the input-process-output view of information systems and relates it to the "Computing as a Science" viewpoint. The framework is validated by classifying 33 interactive digital artworks presented at various international exhibitions.

Interactive Digital Artworks (IDAs) are yet another computer-mediated means of getting to know the reality outside ourselves. I use IDA to mean any artwork where digital technology is an essential factor and for which interaction with audience and environment is a necessary component to produce the artistic output. *Interactive Artwork* denotes a more general class of artistic creations, wherein the interaction between the work and the spectators contributing to the production of the artistic output occurs through and is supported by any device, not necessarily one based on digital-information technology.

IDAs can be physical artworks placed in a public and open space ("installations"), virtual artworks enjoyed on personal devices or even live performances. Digital films and videos are usually not examples of IDA, nor is digital music; both lack the contribution of the user to the content production. However, when the outcomes of video animations or music pieces are modified according to user interaction, these constitute examples of "interactive digital art." The user may be the artist herself; thus performances by the artist can also be examples of IDAs.

Unlike with the standard technological approach based on pure rationality and objectivity, IDAs allow a more subjective and emotional way of decoding and giving meaning to the world. The work of media artists dealing with interaction is thus yet another valuable form of creating social meaning obtained by interactive design and the creation of social experiences [1]. Given that our world and our lives are more and more immersed in and supported by computers, this additional viewpoint is increasingly important, and a better understanding of its language will increase the effectiveness of the computing-art dialogue.

Computing, beyond having become "the fourth great domain for making science" [2], with its own set of "Great Principles" [3], provides us with unsurpassed capabilities of processing data about the world with the aim of better understanding it. Hence, computing offers us the only hope of possibly counteracting the "epistemological inversion" (from data scarcity and depth of meaning to data plentitude and shallow interpretation—from an era where meaning outruns data to one where data outrun meaning) that confronts us [4,5], and its use in artworks is increasingly important in extracting meaning from the world.

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This paper discusses a classification framework for IDAs, providing a common background for a number of activities and actors related to IDAs:

- management and preservation, for museums and curators
- evaluation of economics and copyright issues, for anyone in the commercial area
- discussion and criticism, for all participants
- teaching, for art schools
- research, for scholars
- production, for artists.

In this respect my classification is similar to others used in the standard fine arts regarding, for example, painting techniques, materials and tools, which facilitate similar sets of activities for standard artworks.

Admittedly, classification frameworks in the art world are sometimes criticized as a form of power and a restriction of artists' individuality and creativity [6]. However, beyond the pragmatic needs they satisfy (consider for example the "Cataloguing Guide" of the DOCAM Research Alliance, defined to help new media artwork curators better manage museums' collections [7]), they represent a conceptual tool useful for building a common vocabulary for relating artworks by establishing similarities and differences. What has to be rejected is "the idea to develop THE ONE vocabulary of a specific field of knowledge" [8]. A useful analogy is that a classification framework is like a map describing a territory. One should never forget that the map is NOT the territory. Many maps can be drawn of the same territory, and one should choose the map best suiting one's goal.

From a conceptual viewpoint, classification of IDAs can help to show that the human interface is an essential part of how computer-based information systems are designed. The spreading pervasiveness of digital devices with fast and absorbing environments is increasing the importance in computer science of those areas focusing on the relationship between people and computing devices and is affecting foundational computer science in many areas. Creators of IDAs have long conducted research on human-computer interfaces, pushed by their desire for a control of computer-based tools comparable with that ensured by traditional ones [9]. "They have shown how digital processes are essential elements of the artistic creation processes" and that their outcomes "have

Fig. 1. The basic information system view of an interactive digital artwork (IDA). (© Enrico Nardelli)

often significantly influenced the commercially available products and how we interact with technology today" [10]. In fact, human-centered computing "must be as focused on quality and sensation as it traditionally has been on quantity and speed" [11]. A dialogue with the arts, which always have had a human-centered focus, is therefore essential to computer science for a successful exploitation of new developmental avenues. Maybe the coupling of rigorous computer science with an emotional artistic involvement grounded in intense firsthand practice will be able "to generate future da Vinci's who will become our next generation computer scientist" [12].

The novelty of this proposal with respect to previous work is its explicit basis in the standard input-process-output view of standard computer-based Information Systems (ISs). A traditional IS is created by information technology developers within a particular organizational context. People in such a context interpret data representations produced by the system (which outputs them by manipulating data representations received as input from people or the environment) and give data representations meaning. Therefore an IS is a tool mediating communication and information exchange both between human beings and between them and external reality. Hence IDAs can be considered as ISs and analyzed from this viewpoint [13].

A traditional IS is designed, implemented and operates with an underlying rationality framework, allowing the mind to rationally process its output representations, obtaining an objective viewpoint on the reality around us. An IDA acts in much the same way, receiving input representations and producing output representations by means of some processing, but it appeals to our emotional processes [14] to infer from its output representations a meaning about reality. Indeed, our emotional capabilities can be better instruments for grasping and focusing on some aspects of the world than our rational ones [15]: Neurobiology has recently acknowledged that emotions are essential for human rational capabilities to work effectively and efficiently [16].

The current view of computing as "the study of information processes, natural and artificial," where "an information process is a sequence of representations," and information processes are found, beyond informatics, in biology, physics, chemistry, economics and the social sciences [17], raises the questions: What do we mean by a representation? What is a computational format for a representation? What is not a representation? [18] And what is information? [19] If any definition of information necessarily involves, beyond its objective constituents (the physical signs and the material or immaterial entities represented by signs), a subjective component (the meaning for the receiver, i.e. the linkage between the sign and the represented entity defined by an intellectual sense-maker or interpreter) [20], then classification of IDAs by considering them as ISs appears well grounded and capable of providing benefit to computing itself.

I have presented a preliminary version of this classification [21] and discussed it elsewhere [22]. Here it is thoroughly revised, extended and validated against a sample of IDAs presented in major international digital art exhibitions in 2010.

The Classification Framework

An information system is conventionally seen as a system that **processes** a given **input** to produce a desired **output**. I likewise consider an IDA as a system receiving a certain input (*content*) and producing as a result the output intended by the IDA's creator (Fig. 1).

The dimensions of the classification are:

- **content providers**: those who produce the raw material processed by the IDA
- **processing contributors**: the sources affecting the processing
- **processing dynamics**: the type of variability of the processing itself
- **input channels**: those through which content providers and processing contributors give their input to the IDA
- **output channels**: through which the IDA produces its output.

It is helpful to consider the process producing the intended output as a mathematical function $Y = f(X)$, transforming inputs X into outputs Y according to its mathematical specification f:

$$output = transformation(input) \qquad (1)$$

An IDA receives two types of inputs: the *content* transformed by the processing function, and the parameters (input provided by *contributors*), which change the behavior of the processing function (Fig. 2). The distinction between **content providers** and **processing contributors** is an important conceptual differentiation because it distinguishes between what the artist considers the raw material to be processed and what she considers "parameters" that change the basic be-

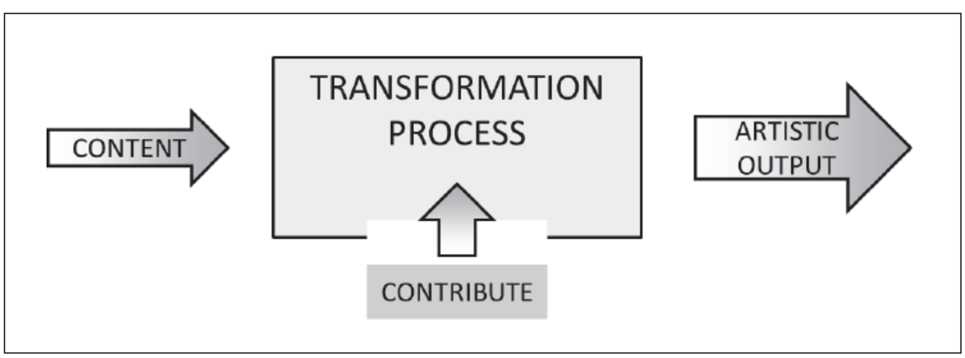


Fig. 2. The information system view of an interactive digital artwork (IDA), distinguishing various kinds of inputs. (© Enrico Nardelli)

havior of the processing function, that is, change the way the raw material is manipulated by the processing function. We therefore rewrite Equation (1) in more conceptual terms:

artistic_output
= transformation(content, contribute)

As a further clarification of this point, let us consider a software program for listening to Internet radio on a PC. The program can be seen as a mathematical function transforming input bits into acoustic waves. All bits processed by this function are input bits, but some make up the sound bitstream to be transformed into acoustic waves and others specify how to process the sound bitstream by means of the various audio filters. The former are the raw data; the latter are the parameters.

In the following sections we will look at the feasible values or labels for each dimension, as summarized in Table 1; additional comments and examples appear in the online supplemental Appendix [23].

In Table 1 and in the following, *artist* denotes the person or team who has invented and realized the IDA, *audience* denotes the human beings actively and consciously providing any kind of input to it, and *environment* denotes any passive or not-conscious entity present in the environment surrounding it.

Content Providers

The source providing content can be *artist* or *audience* or *environment,* and an artwork can be labeled with one, two or all of these values. *Artist* means the IDA processes the raw data specified by the artist and incorporated inside the IDA before its "release." This set of data is fixed, independent of the IDA's physical location or the passage of time, even if the artist may have decided to select different subparts of it depending on space/time or other conditions. *Audience* and *environment* refer to what the IDA finds, after its release, in the venue of its placement.

Processing Contributors

The parameters driving content processing can be self-contained in the IDA (what the *artist* has put directly within the artwork affects the processing by changing the basic behavior of the processing function), or these elements can arrive within the IDA through interaction with the context the IDA is placed within (the processing function also receives input parameter values modifying how the content is processed). In the latter case, *audience* or *environment* can be providers of these values, and an artwork can receive one, two or all labels. Note that when the artist, as a human being, interacts with her IDA to produce the desired output, then *audience* is used as the label.

Processing Dynamics

The processing function of an artwork can be constant or changing with the passage of time. Changes considered here are the intrinsic changes in the processing function the artist has designed and implemented in construction of the IDA, not the changes in raw data or in the parameters of the processing function itself. Depending on the artist's choices, however, raw data and parameters may determine, partly or wholly, such intrinsic changes.

Labels for changing processing functions are as follows:

- *predefined change,* when changes follow the plan defined by the artist, even if specific choices may be driven by values from the audience or from the environment
- *casual change,* when changes derive from random choices, even where the set or the domain of possible choices has been completely predefined by the artist
- *evolutionary change,* when changes follow an unpredictable path defined by the evolution (in a biological sense) of the processing function itself.

Unchanging functions are termed *static.*

An IDA is usually labeled with exactly one of these four values, but it can receive more than one value, since an artist can realize an IDA showing different processing dynamics in its different parts or at different times during the exhibition.

To clarify what this dimension describes, let us consider again the previous example of a software program for listening to Internet radio on a PC. Now, however, assume that such a program has been realized with two processing functions: One is the standard digital-to-analog acoustic conversion, while the other converts the raw data input into a visual output. Whenever certain bit patterns are found in the raw data input, the current processing function is switched from the one producing acoustic output to that producing a visual output and vice versa. This is a case of **processing dynamics**:*predefined change.*

Input and Output Channels

We take into account here the sensory channels by means of which IDA and its context interact. We do not consider issues related to hardware and software, either in terms of the IDA development environment or the environment where the work is viewed, since both these issues are too dependent on the current state of technology development. We define the values for these dimensions using a "human senses" viewpoint, which is rather stable and time invariant.

When the value for **content providers** or **processing contributor** is *environment,* any physically measurable phenomenon can be a provider of input values to IDAs (e.g. atomic particles, acceleration, humidity). To make our classification ro-

Table 1. A summmary view of the classification framework. *Labels* are the possible values to assign to an IDA under the various dimensions.

Dimension	Definition	Labels
content providers	those who produce the raw material processed by the IDA	artist, audience, environment
processing contributors	the sources affecting the processing	artist, audience, environment
processing dynamics	the type of variability of the processing itself	static, predefined change, casual change, evolutionary change
input channels	those through which content providers and processing contributors give their input to the IDA	ph2, acoustic, visual, other_em, haptic, brain
output channels	through which the IDA produces its output	sight, hearing, smell, taste, haptic, brain

bust with respect to the large variety of possible choices, we use *ph2 (physical phenomenon),* which can then possibly be annotated with further description of the actual phenomenon being measured. When the value is *audience* then the possible labels are the possible sensory channels used to receive input from human beings: *acoustic, visual, other_em, haptic. Acoustic* refers to anything the IDA receives from human beings through acoustic waves, *visual* to anything it receives through the visible spectrum of electromagnetic waves, *other_em* to anything in the non-visible spectrum of electromagnetic waves, *haptic* to anything resulting from direct bodily interaction between the human being and the IDA. To these we add *brain,* referring to channels connected directly to the brain, as in the quickly developing area of brain-computer interfaces [24]. An artwork can receive one or more of the six labels, even if *brain* would likely be exclusive of the other ones.

The possible output values are directly related to the five human senses: *sight, hearing, smell, taste, haptic.* Visual and acoustic interfaces are the oldest and most-used ones. Olfactory interfaces [25] are much less used, and taste-based ones even less so ("Taste is the last frontier of virtual reality" [26]) but still possible as an IDA's output channel. We use *haptic* to encompass any other physical sensation one gets through the body: It can take the form of any cutaneous or kinesthetic feeling (e.g. pressure, heat, movement), depending on the specific hardware used [27]. To these we add, as above, *brain.* An IDA can receive one or more of the six labels, again with *brain* probably excluding the others.

Comparison with Previous Work

This section sets out the foundations for a comparison (detailed in the online supplemental Appendix) between this classification framework and some of those previously documented and reports the outcome of this process. I focus on the most relevant papers, referring the reader for further details to the works by Kwastek [28] and Graham [29] on the evolution of the concept of interactive art.

Edmonds et al.

Previous work related to our classification goal was done by Cornock and Edmonds [30] as early as 1973 and later revised by Edmonds, Turner and Candy [31]. Grounding their approach on the distinction between process-oriented art and object-oriented art, they provided a categorization of the relationships between the artwork, artist, viewer and environment and suggested the term "participant" instead of "viewer" or "audience."

This work was the first in trying to systematize the various classifications of interaction in artworks and in this respect has a wider applicability beyond digital artworks. Edmonds et al. discuss four categories of increasingly interactive artworks:

- *Static:* there is no interaction and the artwork does not respond to its context
- *Dynamic-Passive:* the artwork response may be modified by environmental factors through a mechanism completely defined by the artist such that its behavior is predictable
- *Dynamic-Interactive:* an extension of the previous category for artworks where the human presence and/or actions (purposeful or not) change the output of the artwork, whose processing rules are static
- *Dynamic-Interactive (Varying):* an extension of the previous category for artworks where the processing rules used by the artwork to produce its output are modified by an agent (the artwork software or a human).

Sommerer and Mignonneau

The distinction between process-oriented art and object-oriented art was also the foundation for the 1999 paper by Sommerer and Mignonneau [32] that somewhat foreshadowed the IDA as Information System viewpoint. They stressed that the key concept in interactive digital art is processing capability provided by computers over and above the actual interaction between devices and human beings.

Elaborating on this approach, instead of focusing their discussion on a true classification framework, they clearly differentiated between two kinds of interaction. They distinguished:

- *Pre-Designed:* the viewer can choose her path of interaction among a set of limited and predefined possibilities
- *Evolutionary:* the artwork's processing rules are linked to interaction so that the artwork behavior becomes unpredictable.

Trifonova et al.

The classification proposed by Trifonova, Jaccheri and Bergaust [33] addresses "interactive installation art": On one hand it hence considers a narrower set of works (installations alone and not artworks experienced on personal devices), and on the other it is constructed by focusing solely on interactivity as the main aspect of IDAs. They consider three dimensions:

- **Interaction Rules**: whether the rules controlling the interaction are *Static* (unchanging during the artwork's life) or *Dynamic* (they may change)
- **Triggering Parameters**: whether the interaction rules depend only on *Human Presence* or require some form of *Human Action,* or *Nature/Environment* controls them
- **Content Origin**: whether what the artwork shows is *Predefined by the artist,* is provided as *User Input* or is *Generated* by the software, possibly through some *Evolutionary Algorithm.*

Kwastek

Kwastek developed a taxonomy for interactive artwork in the context of a research project at the Ludwig Boltzmann Institute Media.Art.Research [34,35] and used as a case study the submissions for the annual competition of the Prix Ars Electronica. She defined four dimensions (called "perspectives") in her classification, with various categories addressing specific aspects within each perspective:

- **Formal—**featuring three categories:
  — *form of artwork:* describing the physical manifestation of the artwork
  — *range of artwork:* giving information on its spatial characteristics
  — *interaction partners:* specifying the possible form of interactions.
- **Aesthetic—**this dimension uses verbs to allow for a clearer description of the direction of the actions executed during the interaction process:
  — *the visitor (performer) does:* the action(s) executed by the participant
  — *the work (project) does:* the action(s) executed by the artwork.
- **Technical—**this perspective deals with the various technological elements:
  — *media:* which physical support is used to embody the artwork and implement the interaction
  — *processing technology:* characterizes the technical aspects of how participants' input is processed by the artwork.
- **Contextual—**describing the character and the specific genre of the artwork:
  — *catchword:* terms, often technical, used to denote a distinct nature of the artwork
  — *topic:* societal areas/issues relevant for the artwork.

Novelty and Validation of the Proposed Framework

Novelty

My classification framework is the only one fully taking into account in a detailed way the different flavors of computation performed by the processing function and the different conceptual natures of its inputs. This descends from considering IDAs as ISs, allowing us to look at an IDA as the transformation from one representation to another, under the guidance of yet another representation (i.e. the processing function).

This connects IDAs to the modern view of computation, seen as a process transforming data from representation to representation under the control of a processing representation that can in its turn be transformed as if it were data. A novelty element considered in this approach is how the transformation of the processing representation happens.

Moreover, with the adopted focus on the "processing" part, we can distinguish between the raw data transformed by the processing function and the parameters changing the basic behavior of the processing function. The differentiation between these two kinds of inputs is not present in other approaches and is yet another novelty of my approach.

The novelty of my approach is further elaborated by discussing how some examples of IDAs are classified under the various frameworks. Values for my classification are provided in the order in which the dimensions are discussed in Table 1.

In *Flesh for Fantasy* (Appendix ID #3—see the online supplemental Appendix) [36], the spectator's silhouette before the IDA is projected onto a screen. Moving the arms makes the projected silhouette appear to fly.

In *The Janus Machine* (#4) [37] a 3D scan of the spectator's face is taken and an outline is built, which is then shown on screen in relation with other previously scanned faces.

Both works are classified as *interactive* according to the Edmonds et al. approach, while my classification shows that while in *The Janus Machine* (#4) [*audience, artist, static, visual, sight+hearing*] the audience provides only the raw data to the processing function, in *Flesh for Fantasy* (#3) [*audience, audience, static, visual, sight*] the audience also provides the value of parameters that change its basic behavior, which is otherwise static. These same IDAs are not differentiated by the Sommerer and Mignonneau approach either, since they have the same classification label *pre-designed*.

Cycles—Arc One (#11) [38] visually merges the appearance of the spectator's hand with the representation of a simulated organism. This merging creates a hybrid entity that evolves through a life cycle depending on hand position.

Ocean of Light: Surface (#26) [39] is a 3D cubic array of lights populated by autonomous virtual entities, which react to the surrounding level of sound by visualizing colored light waves rippling across the array itself and by triggering luminous blasts. Both effects are accompanied by output sound.

They are both classified **Interaction Rules**:*dynamic* and **Triggering Parameters**:*human action* by the Trifonova et al. approach, while my approach provides a distinction between spectators providing both raw data and parameters in *Cycles—Arc One* (#11) [*artist+audience, artist+audience, dynamic evolutionary change, visual, sight*] and spectators providing only the latter in *Ocean of Light: Surface* (#26) [*artist, audience+environment, dynamic predefined+random change, acoustic, sight+hearing*]. They are differentiated according to the Kwastek approach by the large set of keywords used for choosing labels for categories, but there is no keyword indicating that the change of processing function is *evolutionary* in *Cycles—Arc One* (#11) while it is *predefined* with *random* elements as well in *Ocean of Light: Surface* (#26).

I stress that the above considerations do not indicate a superiority of the classification framework proposed here and are reported only to help the reader fully grasp the difference in viewpoints in the various approaches and the novelty of this one.

Method and Data

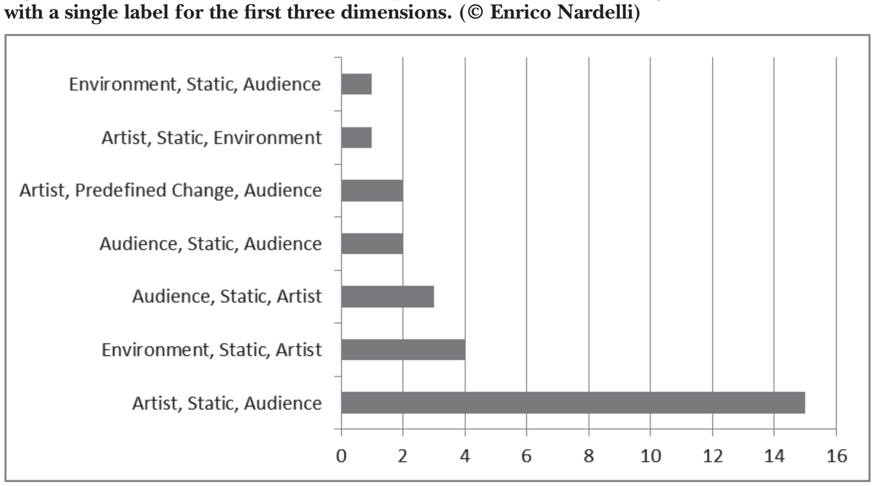
To validate this extended and revised classification I have used a set of 33 IDAs presented at two major international exhibitions (Ars Electronica and ISEA) during 2010 (see the online supplemental Appendix). For each work, beyond its classification within my framework, with some comments if needed, a synthetic description and an online reference are given. This is the almost complete set of all IDAs presented in 2010 in these two exhibitions and therefore offers good support for the validity of this approach.

I have visited both these international exhibitions and personally observed each IDA discussed in the Appendix, interacting with them at length. During this process, which also included reading presentation material and discussions with the IDA artists (if present), I decided on labels for each IDA and noted these on each IDA's card together with its short description. These cards contain a synthesis of label definitions, so that I could select the proper ones in front of the IDA without resorting to memory. Moreover, colleagues attending the same exhibitions and aware of this classification framework were asked to comment on the proposed labels while viewing the IDAs.

Results

I was able to employ all the labels I had developed for the various dimensions, except that **output channels:** *smell* and *taste* values were not present in these works, given that the related technology is still very rarely used or available. Of the 33 IDAs considered, 28 have a single label for the first three dimensions (Fig. 3). Of these, 15 are

Fig. 3. Distribution of the classification triples for the 28 interactive digital artworks (IDAs) with a single label for the first three dimensions. (© Enrico Nardelli)



classified as [**content providers**:*artist,* **processing dynamics**:*static,* **processing contributors**:*audience*], confirming that this is in some sense the "typical" or "mainstream" IDA. The next-widest used classification triples are [*environment, static, artist*], with 4 instances and [*audience, static, artist*] with 3.

These three most-used triples suggest that the artist, in an understandable desire to retain some control of the output while allowing for the richness allowed by interaction, both uses a static processing function and keeps complete control either of input data or of contributing parameters. This is not of course a required course of action, merely a record of the current situation.

The distribution of labels for the input (Fig. 4a) and output (Fig. 4b) channels shows how, in the former, *haptic* and *other_em* have almost the same frequency as *visual,* while the latter is highly concentrated on *sight* and *hearing*.

CONCLUSIONS

This paper has provided a viewpoint on the dialogue between computing and art by describing a framework for the classification of Interactive Digital Artworks (IDAs). The novelty of this classification scheme results from its being based directly on the input-process-output view used in the informatics field for discussing information systems (ISs), allowing it to provide evidence to the different flavors of computation performed by the processing function and the differing conceptual natures of its inputs.

While aware that, like other classifications of artworks, this one will be criticized, I am convinced that any such framework helps in structuring the discussion around artworks themselves and in discovering heterogeneity and identifying relations. I also hope that this classification, like others, might stimulate exploration of not-yet-realized combinations of classification values.

I have argued that this viewpoint is of interest for a fruitful dialogue between computing (seen as the fourth domain for making science) and art (seen as an important approach for the better understanding of reality). Because IDAs can be seen as ISs transforming input data representation to output data representation under the control of a processing representation, which is the current characterization of computing, they can be considered as yet another embodiment of computing, albeit one appealing to the emotional side of the brain. Continuing speculations on this theme, it may be worthwhile to ask, "How can artists help computer scientists in realizing Artificial Intelligence?"

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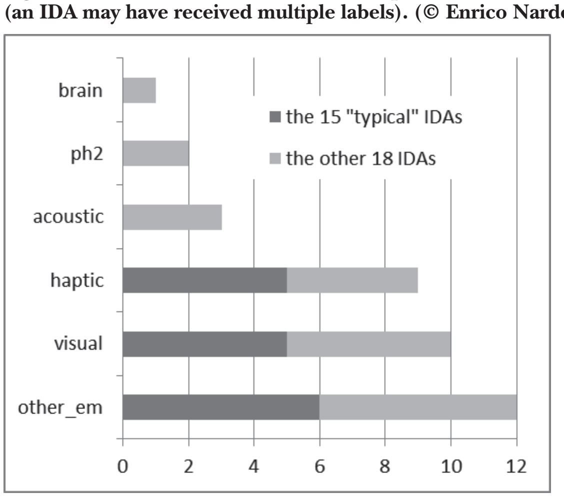
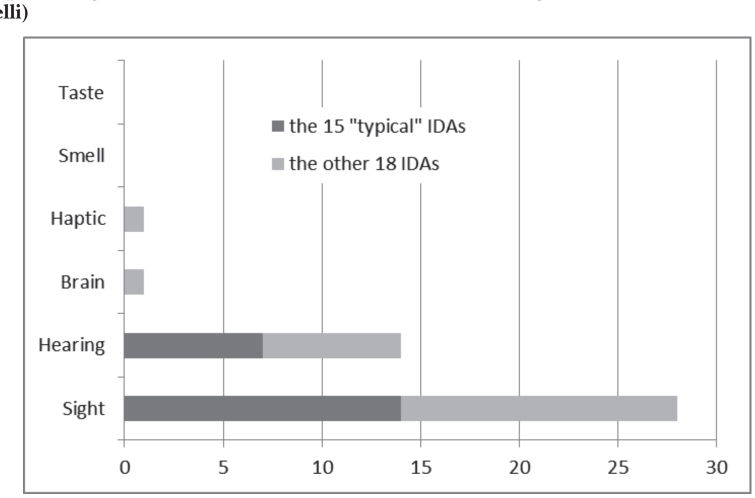
Fig. 4. Distribution of the labels for the input (a, left) and output (b, right) channels for the 33 examined interactive digital artworks (IDAs) (an IDA may have received multiple labels). (© Enrico Nardelli)





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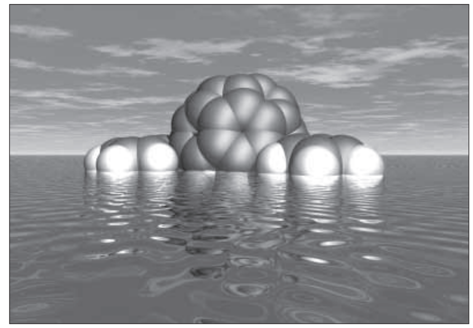

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ANNOUNCING

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