Connecting the dots : playful interaction with scientific image data in repositories

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Chapter 1

Introduction

1.1 Introduction (of the introduction...)

This work is about playful exploration of scientific image data in repositories. In particular, it considers playful interactions with image data from the life sciences stored in well-maintained, shareable image collections. Given the key role of images in biological research and the potential of well-maintained data repositories as sites of discovery, we are enthusiastic about the ways that interacting with image data in collections could inform the research process. Considering also the creative nature of scientific inquiry, we ponder on the types of interaction that could transform data repositories into playgrounds for scientific creativity. Interfaces to scientific image collections should foster the conditions for creative insights into one's own data, often under the light of other data and/or due to connections or associations reached. We will argue that such re-considerations of image research material could be stimulated by creating opportunities to literally play with images in repositories. Artefacts, i.e. interfaces, to exemplify and further study this notion of play for exploration are designed, developed and analysed.

This thesis is a response to context, reviewed literature and current developments in Human Computer Interaction (HCI). But the fact that you are now reading this particular response and none other is also because of own my personality and my own views, likings and dis-likings. I am of the opinion that to be productive does not always mean to be efficient. I also believe that getting lost or simply wandering is a valid way to knowing. Finally, I do maintain a soft spot for links, connections, associations, gaps to be filled in and spaces in between. That said, be assured that having preferences does not imply that the regarded topics are unsupported in the literature or unrelated to the aims and scope of the project in question; it does mean, however, that I was attracted to study them.

For the past four years, the author of this work has been struggling with concepts that stubbornly defy definitions (e.g. creativity), a common consensus (e.g. play) or a measurable outcome (e.g. exploration). This introductory chapter pins down the fundamental concepts involved in this body of work, examined under the lens and interests of this exact body of work. While no finite definitions will be attempted, a common ground in terminology and sufficient knowledge of the context of our work should be attainable. Our idiosyncratic understanding of the concepts involved as utilized throughout this thesis will also be highlighted.

1.2 On the use of images in (life) science

It all started with an image database for the life sciences. As a scientific programmer with the task to develop the web interface of the CSIDx repository (Cyttron Scientific Image Database for eXchange), I was very comfortable with concepts such as data, records and databases. However, and in the course of time, it was moving to realize how involved biologists are with their images. For a biologist, an image is just not another entry in a database; it is science.

image: *A visual entity or rendering initially captured by means of a sensor of an imaging technology*

For the purposes of this study, images can be understood as visual entities or renderings that were initially captured by means of a sensor of an imaging technology, e.g. a microscope. Our definition has been influenced by the views of imaging science as the study of images and imaging systems; after all, this research has been conducted in an imaging group of a computer science department. Beck (1993), pioneer of imaging science, explains that

> "images (including the imperfections introduced by the imaging system) may be characterized by the spatial (and possibly the temporal) distribution of properties such as light reflectance, color, brightness, or opacity/transmittance at each point- i.e., by the numerical values associated with such properties".

As such, images are registered values of some captured physical property that are rendered visible. Surely, a variety of algorithms and processes may interfere between the moment the captured energy excites the sensor and the moment a visualization is produced. Yet, we still refer to these visualizations as 'raw' images which can be further used for image processing and analysis. Considering the variety of visual representation used in scientific practice, our definition of images explicitly excludes graphical compositions such as illustrations, graphs and diagrams, all most likely to be assembled by a human agent. These diagrammatic or graphical displays are essential in conducting science but are rarely perceived as 'raw' data by the researchers, although advanced imaging techniques such as spectroscopy may challenge this distinction. The diversity of visual representations involved in scientific practice as well as the aspects that contribute to this diversity are thoroughly addressed by Pauwels (2008). With respect to his proposed framework, our understanding of images emphasizes algorithmically derived representations of subjects with a physical presence in the natural world.

The predominance of images in science often goes without saying. And, as most things that go without saying, it becomes cumbersome to trace or verify, once questioned. How are images actually used for conducting science? As already noted by Pauwels (2008), visual products must be examined with respect to their purpose. The author proposes a non-exhaustive list of possible usages and intents, including further analysis, concept development, result communication, persuasion and many more. In this study, we focus on the needs and practices of scientists engaging with biological research. Biologists, life scientists and, occasionally, bioimage informaticians are the featuring personas of this discussion. So, let us rephrase the question: How are images used for conducting science in the field of biological research?

Biological research provides an excellent example of the predominance of images in scientific inquiry. What Schaechter (2008) and Kemp (2008) describe as the 'visual turn' in microbiology is relevant to most disciplines engaging with the study of life. The production, inspection and analysis of image-based observations is an indispensable part of contemporary biological research, from molecular biology to cell biology to organismal biology. Imaging has also a major role in medical practice and research but the practices of a clinician will differ from the practices of a researcher imaging a model organism or postmortem tissues in a research lab, even if the same imaging technology is involved. An indication of the variety of imaging techniques used in biological research and of the wide field of research topics for which imaging is relevant can be found in Conn (2004a,b). Walter et al. (2010) provide an informative and up-to-date overview of the practices, challenges and trends involved in the use of image data in contemporary biology, including high-throughput imaging. More applications of bio-imaging and more computational challenges are discussed in Peng (2008). Naturally, the explosion of image data produced during biological research poses pressing demands for robust systems and for standardized practices for the storage, retrieval and sharing of these data. We will further discuss data management issues in chapter 2, where the CSIDx database system is described in depth. All in all, it should be clear that images have a central role in contemporary biological science. In the words of Evanko (2010), editor of 'Nature Methods', "biology is a visually grounded scientific discipline- from the way data is collected and analysed to the manner in which the results are communicated to others".

From the variety of functions and roles of images in the research workflow and scientific discourse of the biologist, we will mainly focus on images as primary data to be further analysed by human inspection. Based on our experience with collaborative, imaging projects with researchers in the life sciences, we adopt the following, simplified take on biological imaging for research purposes: Biologists make images in order to study biological phenomena; they design experiments and image their samples in order to test hypotheses, to track biological entities or processes or to model test organisms. Image data are to be observed, discussed, reflected upon and further tested by designing new or refined experiments. Note that the processes involved are primarily social and collaborative. They may also require comparing or contrasting the acquired image data to other reference images. Via such processes, image data become significant signposts in directing research and decision-making. Then again, for discoveries to be made, images need to be quantified: It is unlikely that a discovery will be granted on the basis of visual evidence only. Thus, we see image-based observations as an intermediate but fundamental step in the process of scientific inquiry. Eventually, and once discoveries are made, images will be turned into communication tools, functioning as the means to communicate findings to fellow scientists.

A word of caution is now due. Generally speaking, visuals in sciences are treated as evidence of credible persuasive power. Yet, their objectivity should not be taken for granted. This remark does not attack the scientific integrity of practising scientists but is a reminder of the constructed nature of scientific images and of the often unsaid assumptions of scientific practice. Historians of science, sociologists of science and philosophers of science have led the discussion on the risks of uncritically accepting visuals and images as objective representations of nature. Lynch (1988), Knorr-Cetina and Amann (1990) but also Kemp (2006), among others, have examined the practices involved in the production of scientific imagery. Regarding the images featuring in this work, it is worth remembering that computer-generated imagery is not free from inscribed decisions, often hard-coded in the algorithmic system involved, despite its seemingly 'self-evident' nature. On the contrary, and possibly even more that any other type of visuals, images resulting from algorithmic processes challenge the relation between the subject depicted and the visualization rendered and exploit our susceptibility to visual evidence. Eventually, visual studies will have a saying in the type of discourse that is unconsciously implied or deliberately communicated by the use of images in scientific communication. While a complete examination of the philosophical implications of image-based science is out of the scope of this work, we feel that any work that deals with scientific images should at least acknowledge the issues.

So, images are fundamental and frequent in the process of biological research, but where do these images actually reside? One will find biological images of non-finalized research residing on the hard disks of researchers, circulating around the corridors of research institutes and laying on the tables of research meeting rooms. Occasionally, they find their way into databases.

data repository, data collection: *A structured set of entities (e.g. images) available for access and distribution*

Scientific practice is the yet another human activity that accumulates data; if not the chief one. Apart from any epistemological implications involved in our society's need to accumulate data in repositories, structured collections have straightforward practical benefits for managing and sharing research data. For the purposes of this study, a data repository (also referred to as data collection) is a structured set of entities/tokens of information available for access and distribution. Clearly, our interest lies in collections of images of a biological subject matter. In the life sciences domain, the '-omics' revolution has familiarized biologists with the need to access large volumes of well-maintained data. An impressive number of databases for biological purposes have spawned in the last couple of decades; see Chiang (2004) or the inventory of database resources maintained by the prestigious 'Nucleic Acids Research' (NAR) journal. Image databases are yet to reach a similar status of popularity. Martone et al. (2007) suggest that image databases are yet to become useful and meaningful for biologists because of the computation difficulties in the analysis of image data. Nonetheless, significant biological image database projects exist. We acknowledge the need for image data to be stored in well-maintained repositories and endorse the benefits for biological discovery as described by Swedlow et al. (2009), i.e. management, sharing, remote access, interoperability and integration. However, in the research described in this thesis, we wish to shift focus from the practical benefits of image repositories and discuss the benefits of a well-maintained image repository in terms of its potential to stimulate scientific creativity.

1.3 Why exploration?

The first proposition of this study is that exploration as an open-ended information activity can be beneficial for scientific practice for it can excite the small discoveries and insights that fuel scientific creativity. This section will overview various aspects of scientific creativity (cf. subsection 1.3.1) and of discovery in data repositories (cf. subsection 1.3.2) that motivate and inform our appeal for exploration. The open-ended, exploratory, possibly procrastinating interaction we are after should be crystallized by the end of this section; for lack of a better term, we abbreviate it as exploration.

1.3.1 On scientific creativity

Science is a creative endeavour. No doubt scientists regularly "come up with ideas or artefacts that are new, surprising and valuable", conforming to most definitions of creativity. The quoted fragment is derived from Boden (2004, chapter 'In a nutshell') and her definition of creativity as "the ability to come up with ideas or artefacts that are new, surprising and valuable". Similarly, Sternberg (1999, chapter 1) defines creativity as "the ability to produce work that is novel and appropriate". While the qualifiers given deserve further consideration, it is clear that such definitions of creativity are inclusive of the fruits of science, i.e. scientific theories and scientific discoveries. Even more importantly, science is a creative endeavour because scientists will often need to resort to creative thinking when weaving their way through research. Scientific practice, including both the formulation of worthwhile problems, i.e. problem-finding, and the struggle to solve them, i.e. problem-solving, frequently calls for the scientist's creative toolbox. There is nothing mystical or romantic here, no muse visitations or bursts of inspiration: Scientific practice is creative for it "involves slow, methodical work, with mini-insights occurring everyday" (Sawyer, 2006, chapter 14). Such mini-insights vary from new ideas to new observations to new realizations and new inferences and may be based on or derived by scientific data.

Creativity is a complex phenomenon. It is notoriously difficult to define, has multiple aspects, i.e person, process, press, and product (Rhodes' scheme, discussed in Runco, 2004), and can be researched via various methodologies, from psychological to biological to computational. Mayer (1999) provides a good overview of the various research streams in creativity research, while Kozbelt et al. (2010) summarize some of the most prominent theories of creativity. We tackle only a small portion of the phenomenon, i.e. creativity as a property of thinking (Nickerson, 1999), and observe that creative thinking as both the capacity to generate ideas and "the capacity to bring together previously unconnected 'frames of reference' " (Nickerson, 1999) is relevant for everyday scientific practice. Some of the processes that appear to be involved in the cognition of creative thinking, such as synthetic and analytic thinking, remote associations and concept combination, among others, include a notion of synthesis by links and associations which we find particularly relevant.

What exactly is the relation between scientific creativity and scientific discovery? Some scholars seem to use the terms interchangeably (see e.g. Meheus and Nickles, 1999); after all, they both refer to the production and recognition of something new and valuable. Others suggest that aspects of the process of scientific discovery may be performed creatively. To quote Langley (1987, chapter 1), "we have characterized discovery as a sequence of steps, each of which represents a small advance from an initial state of knowledge to a new state of knowledge and all, some or none of which, taken individually, might seem creative". Most likely, it is again a matter of one's preferred view on creativity and/or discovery.

The cognition of scientific discovery is equally fascinating and puzzling. The phenomenon of scientific discovery has been argued by both cognitive scientists and philosophers of science. Once again, the approaches taken in researching scientific discovery vary. An overview and comparison of research methodologies and of prominent theories is provided by Klahr and Simon (1999). How scientists discover and how scientists reason are two distinct but overlapping questions. An introduction to the broader topic of scientific thinking and reasoning is provided by Dunbar and Fugelsang (2005). Of particular relevance to the scope of this thesis is the *in vivo* research of Dunbar (1995) on scientific reasoning. The author monitors real-world laboratories, in particular molecular biology laboratories, to comment on the mechanisms active during scientific practice. His research highlights, among others, the importance of analogy, which he further distinguishes to local, regional and long-distance analogy, and the importance of social interaction within a research group.

An illuminating study on the topic of scientific creativity with respect to information systems is given by Bawden (1986). The author identifies topics related to scientific creativity that can be coupled to issues of access to information. Both the type of information required and the means to it are discussed. His observations on the nature of scientific creativity, namely

- the role of chance
- the value of analogies
- the importance of identifying inconsistencies and anomalies in patterns
- the damaging effect of false knowledge

- the value of interdisciplinary contact

have shaped our understanding on how creativity may inform scientific research. Furthermore, we are confident that activities such as "the relating of ideas generally held to be quite distinct" and "the recognition, or creation, of patterns" can potentially be stimulated by exploring data in repositories. The role of connections is also prominent in O'Connor (1988) and his examination of creativity in bibliographic systems. The author views creativity as a process of "reconciliation or reformulation" of existing concepts into new ones. As such, the creative process can benefit from a "readiness for catching similarities" and from openness to free associations, even illogical ones. The author also discusses creative browsing as navigation for "the discovery of new knowledge, of new syntheses" which he relates to three different types of connections:

- connections between 'attributes of documents'
- connections between 'concepts in the user's knowledge store (with document attributes as catalyst)'
- connections between 'the user's concepts and attributes of documents'

The production of new knowledge by a synthesis of existing concepts as facilitated by data in collections will be central in our approach.

Next to the domain of information sciences, the field of HCI has also been attentive to issues of creativity with respect to computer interfaces. Shneiderman (2007) notes that the new challenge for HCI researchers and interface designers is to design tools that support creativity, discovery and innovation. More specifically, the author is calling for tools that will be supportive of the cognitive processes involved in the creative process. As a matter of fact, Shneiderman (2000) proposes a four- stages framework for the 'generation of excellence': Collect (existing knowledge), relate (with peers), create (potential solutions), donate (results). His framework and similar others (e.g. Hewett, 2005) focus on creativity as a problem-solving process often to be facilitated in its entirety by a computerized platform. Our research scope is far less ambiguous. We note, though, that some of the activities Shneiderman (2000) proposes as worthwhile, namely searching and browsing digital libraries, visualizing data and processes and thinking by free associations, are directly related to interacting with data in repositories.

1.3.2 On small discoveries and insights

to discover: *to arrive at something (item, association or realization) that is new or interesting*

Science is all about discoveries but we confine our discussion to the small discoveries and insights that can be facilitated by data in repositories. In the context of data repositories, we understand discovering as arriving at something (item, association or realization) that is new or interesting. Discoveries in repositories may occur at various levels:

- At the item level, when reaching a valuable, interesting or unexpected item or entry
- At the association level, when establishing a new or thought-provoking connection between items
- At the dataset level, when making assessments about the whole of a dataset

Any of these small discoveries may inform the process to actual scientific discoveries. Many of these discoveries can be understood as serendipitous, either in the sense of being accidental (what van Andel (1994) calls an 'unsought finding') or in the sense of being surprising. Since much has been said about the role of serendipity in scientific discoveries, let us further examine the notion of serendipity with respect to information systems.

There is a nice and often-repeated story on the origins of the word 'serendipity' (van Andel, 1994): English writer and man of the letters Horace Walpole coined the word 'serendipity' in 1754 in one of his letters to Horace Mann, British diplomat with whom Walpole maintained correspondence for 45 years (Encyclopædia Britannica Online, 2012b). The word was inspired by the adventures of 'The three princes of Serendip', the heroes of a Persian fairytale who were travelling the world making "discoveries, by accidents and sagacity, of things which they were not in quest of"[1]. Generally speaking, serendipitous discoveries are discoveries not looked for. However, 'discoveries not looked for' come in many flavours: There are things to be found at unexpected moments or places, there are unexpected (odd and surprising) things to be found and there are unexpectedly valuable things to be found. Foster and Ford (2003) observe that a feeling of serendipity stems from either the impact of new information, i.e. due to unexpected value, or the chance encountering of information, i.e. due to unexpected location. Moreover, van Andel (1994) highlights that serendipity appears either as a surprising fact/relation, that may lead to insight, or as a surprising way to reach insight (pseudo-serendipity). The positive role of serendipity in the creative process is well-articulated and so is the need to consider serendipity within digital information systems. In information retrieval (IR) literature, browsing is considered the typical information

[1] A part of the story that often goes unsaid is that Walpole invented the word 'serendipity' in need to describe his own small serendipitous discovery.

behaviour for serendipity; we elaborate on the characteristics of browsing in the next subsection. Serendipitous information retrieval is also examined in the work of Erdelez (1999) on 'information encountering', the work of Toms and McCay-Peet (2009) on 'chance encounters' and the work of Williamson (1998) on 'incidental information acquisition'. These studies remind us that there exist valued information behaviours that differ from traditional information seeking. Serendipitous information retrieval often centres around the notion of chance, blind luck or even pure randomness but chance is only one part of the story. As van Andel (1994) emphasizes, for serendipity to be meaningful, a successful abduction must be reached. Similarly, André et al. (2009) note that if we are to support serendipity in information systems, we must consider the processes that govern a successful response to an unexpected finding, i.e. the processes that allow one to connect the unexpected finding to the relevant problem or to already available pieces of information. In our work, we welcome the idea that discoveries do not necessarily arise from searching and remain attentive to options other than simple exposure to chance encounters.

And what about 'insights'? Strictly speaking, an insight is a discovery characterized by suddenness or "the experience of suddenly realizing the solution to a problem or of grasping a familiar situation in a new or more productive way" (Nickerson, 1999). Schooler et al. (1995) observe two different usages of the term 'insight' in the cognitive sciences as either a "state of understanding" or "a sudden emergence of an idea into conscious awareness". The field of information visualization, a field dedicated to gaining insight over data, takes a more casual view on insight as a "unit of discovery" and as "a non-trivial discovery about the data or, as a complex, deep, qualitative, unexpected, and relevant assertion" (Yi et al., 2008). Insight is frequently associated with a notion of reformulation. In the cognitive sciences, it is often suggested that insight may arise from a restructuring of the problem's representation. Davidson (1995) proposes the following possible mechanisms of problem restructuring:

- Selective encoding, i.e. the identification of non-obvious features
- Selective combination, i.e. the combination of elements in non-obvious ways
- Selective comparison, i.e. the establishment of non-obvious relations between new and past information

Information visualization literature also hints at a similar aspect of reformulation or, to quote, "suddenly seeing something that previously passed unnoticed or seeing something familiar in a new light" (Saraiya et al., 2005).

Reaching unexpected but useful items or reaching useful items unexpectedly (serendipity), establishing associations between items (connections), making assessments about a dataset as a whole (patterns), re-viewing or re-considering an item under a new light (insight), these are only a few of the ways that interacting with data in collections can promote understanding, fuel creativity and inform everyday scientific practice. It is such small increments in understanding that our ‘small discoveries and insights’ refer to.

1.3.3 Exploration as an open-ended information activity

If data repositories hold a multiplicity of opportunities for small discoveries, what kind of tools will we need to actually mediate them? This is a battle that can be fought at many fronts. We believe that, when interacting with data in repositories, discoveries can be stimulated by means of the interface. That is to say that, next to the sustainable body of research to improve the underlying representations and access mechanisms to data, e.g. content-based image retrieval, clustering and classification, knowledge discovery, semantic reasoning and more, the interfaces that provide access to the repositories should also be considered. Not only do we need usable, well-designed interfaces for the user to make the most out of the capacities of the repository. We also need interfaces that will encourage and engage the user to explore.

The aim of this study is to design interfaces to data collections that will nurture the conditions for small discoveries, insights or creative responses to occur, always in the context of data collections and within the broader frame of scientific practice. In the previous subsections, we encountered several elements of creativity and discovery that share a notion of establishing associations between existing concepts or between existing and new/newly encountered concepts. Furthermore, we identified various activities with data that can be of relevance for scientific creativity:

- Reaching unexpected but useful items or reaching useful items unexpectedly (serendipity)
- Establishing connections between items (connections)
- Making assessments about a dataset as a whole (patterns)
- Re-viewing or re-considering an item under a new light (insight)

Note that none of these activities corresponds with query-based search and fact-finding. Most lack an explicit goal or information need and some imply a notion of movement across information points. Within the field of IR, strategies such as browsing, exploratory search and the use of information visualizations for IR are successful examples of interactions that differ from the predominant keyword search paradigm.

Browsing: Browsing is a major information seeking strategy that is distinct from keyword search. Most definitions of browsing stress its casual and exploratory nature: Baeza-Yates et al. (1999, Glossary) define browsing as an "interactive task in which the user is more interested in exploring the document collection than in retrieving documents which satisfy a specific information need", while 'to browse' according to Reitz (2012) is "to look through a library collection, catalogue, bibliography, index, bibliographic database, or other finding tool in a casual search for items of interest, without clearly defined intentions". A comprehensive survey of various understandings of browsing is provided in Chang and Rice (1993), while differences between browsing and keyword searching are summarized by Hearst (2009, chapter 3). It is useful to repeat here that browsing is often undirected, i.e. without a clearly defined goal. For example, Bawden (1986) reports two undirected types of browsing, namely 'capricious' browsing as "the random examination of materials without a definite goal" and 'exploratory' browsing as the search of inspiration.

Exploratory search: Exploratory search is a search paradigm that emerged out of the need to facilitate information needs of an "open-ended, persistent, and multi-faceted" character (White and Roth, 2009). In particular, exploratory search targets searches of a high degree of uncertainty, when searchers are "unfamiliar with the domain of their goal or unsure about the ways to achieve their goal... and/or even unsure about their goals" (White and Roth, 2009). Successful implementations of the exploratory search paradigm can be found in faceted search, i.e. search by combination of known, usually hierarchical metadata of a dataset, and in dynamic queries, i.e. search that allows direct manipulation of a visual representation of the dataset. More examples are discussed in Crawford (2006). Exploratory search, as envisioned by Marchionini (2006), is relevant for it reminds us that searches are not conducted only for question answering but also for learning and investigation. What is more, it promotes a cooperation between information retrieval and the field of HCI toward interfaces that would better cater for these needs.

Information Visualization and IR: Information visualization, as "the communication of abstract data... through the use of interactive visual interfaces" (Keim et al., 2006), provides a considerable solution to the problem of information overload and a valid way to amplify understanding by using the visual capacities of humans. If we describe data repositories as nominal datasets, then data repositories are valid subjects for visualization; typical information visualization tasks will support manipulation and exploration of the dataset. If we approach data repositories as IR systems, then information visualization is again of relevance. As noted by Song (2000), all components of a traditional IR system can be presented visually, from the user data to the query to the query results. Additionally, various user tasks in interacting with the IR system can be visually facilitated, from goal-setting to querying to evaluating results. The visualization of search results has received considerable attention particularly with respect to web search. Kules et al. (2008) identify several design patterns in visualization-based web search tools, such as classification (hierarchical, faceted, automatic or social), results organization (in lists or in 2D and 3D space) and several more. More web- and visualization-based systems are reviewed by Turetken and Sharda (2007). Most IR-related visualizations are not limited to a static presentation of the result sets but also provide the visual means for query formulation and reformulation, for navigation and/or for browsing.

to explore: *to examine and investigate data, their location and their properties, may potentially stimulate small discoveries and insights*

The aforementioned strategies, i.e. browsing, exploratory search and the use of information visualizations for information retrieval, have informed our understanding of exploration in the context of data repositories. In particular, we envision interactions that are of an open-ended and casual nature (cf. browsing) yet combined with an alert consideration of entities, their attributes and the structure they belong to (cf. information visualization). What is more, we deliberately sheer away from searches (cf. exploratory search) and consider ways to engage with data that stem from notions of associations and reformulations, as also motivated by cognitive aspects of creativity, discovery and insight. Although we acknowledge the role of browsing and navigation, we emphasize that insights and discoveries occur not by simply visiting or encountering entities but when reconsiderations or useful associations are reached.

Common understandings of exploration, i.e. outside of the domain of IR, are also worth mentioning. Stebbins (2001) discusses four distinct meanings of the verb 'to explore' which he couples to distinct types of exploration [2]:

[2] Stebbins (2001) examines 'exploration' in order to better understand the exploratory research paradigm in the social sciences. Exploratory research is a particular research methodology which should not be confused with the practices proposed here. Nevertheless, the author's observations on the usage of the word 'exploration' are relevant.

1. Investigative exploration, when studying, examining, analysing, or investigating something
2. Innovative exploration, when becoming familiar with something by testing its properties
3. Exploration for discovery, when travelling for the purpose of discovery
4. Limited exploration, when searching systematically for something

We consider the exploration of images in the investigative sense and the exploration of repositories as exploration for discovery. In fact, a spatial metaphor for data repositories can provide us with a useful mental model. Data collections are information spaces to be travelled and explored. On the way, and by investigating data, their location and their properties, discoveries and insights may occur. Furthermore, we expand this spatial metaphor by emphasizing that insights and discoveries occur not by simply visiting entities but when reconsiderations or useful associations are reached.

1.4 Why playful?

An invitation to play is an invitation to explore. Or is it vice versa? Play and exploration are concepts so intertwined that, at moments, we wonder if we have been trapped in yet another chicken-or-egg question: Does one explore when playing or play when exploring? As far as this study is concerned, it is sufficient to acknowledge that play and exploration both feed and nourish each other. Play as exploration and exploration as play maybe just two expressions of what one could describe as adopting a playful attitude. Playfulness can be understood as the inclination to be less serious and more experimental; as such, it caters for the open-mindedness we find essential when exploring in collections. Playfulness as curiosity or the ability to toy with options and alternatives is also a highly desirable attitude. Finally, playfulness as simply playing and enjoying is equally desirable even if it is only for reasons of engagement with the task.

The second proposition of this study is that designing for play and playfulness is a valid way to design for exploration. As a matter of fact, we will take this idea literally: Playing with data in collections is a means to exploring data in collections. In effect, our work attempts to enrich our interactions with images by incorporating aspects of play. Our initial orientation towards play has been driven by notions of exploration: Openness, playfulness and positive affect are essential components of an attitude that favours exploration. Yet, our orientation towards play and our take on playful and game-like interfaces have sprouted amid a fast-growing interest of the HCI community in play and playfulness. As we shall see, this work is not the first one to propose a pollination of interfaces with ideas from play and games. Still, we approach, study and prototype this concept from within a particular domain, i.e. interfaces to scientific image collections, and with a particular agenda, i.e. collection exploration. What is more, we have been open to various modes of play and examined a wide range of what game-like or playful interfaces to collections may be like. In the following chapters you can find out what happens when an HCI researcher with a particular agenda messes with the idea of play. For now, let us provide a necessary context by summarizing views on play as derived from the field of game studies and views on the closely related issues of fun and pleasure. But mainly, let us expand on the meeting points of such topics with HCI and interface design.

1.4.1 Homo ludens: The fundamentals

Delineating the notion of play is a difficult task and any attempt to do so will unavoidably start from the seminal writings of Johan Huizinga (1842-1945) (Encyclopædia Britannica Online, 2012a) and Roger Caillois (1913-1978). Note that there is an overwhelming body of research on children play which we will not consider here; our focus is on attempts to formally define the notion of play.

Huizinga was one of the first theorists to consider the significance of play for human culture. In his classical work “Homo ludens” (translated as “Man the Player”), Huizinga (1955, chapter 1) provides the following, widely cited and argued, list of characteristics to define play:

> “Summing up the formal characteristic of play, we might call it a free activity standing quite consciously outside ‘ordinary’ life as being ‘not serious’ but at the same time absorbing the player intensely and utterly. It is an activity connected with no material interest, and no profit can be gained by it. It proceeds within its own proper boundaries of time and space according to fixed rules and in an orderly manner. It promotes the formation of social groupings that tend to surround themselves with secrecy and to stress the difference from the common world by disguise or other means”.

Caillois’s equally influential work “Les jeux et les hommes” (translated as “Man, Play and Games”) lists a comparable set of characteristics. Play, according to Caillois (2001, chapter 1), is an activity that is

- free, i.e. not-obligatory

- separate, i.e. circumscribed in time and place
- uncertain, i.e. with unforeseeable outcome
- unproductive, i.e. creating neither goods nor wealth
- governed by rules, i.e. with rules that are different from everyday life
- make-believe, i.e. accompanied by the awareness of a different reality

Caillois (2001, chapter 2) further suggests that play activities span across a continuum between two types of play, namely ludus, i.e. ruled-governed activities, and paidia, i.e. improvised activities. The voluntarily and self-fulfilling nature of play is an element reoccurring in various writings and theories about play. Walther (2003) summarizes Gregory Bateson's theory of play and fantasy as follows: "Bateson further states that playing is autopoietic (self-generating) and autotelic (self-motivating), and finally he suggests that play is not the name of some empirical behaviour, but rather the name of a certain framing of actions". We will return to this idea of framing when considering 'playfulness' as a state of mind.

Discussions on the notion of play are soon followed by discussions on the notion of game. What is a game and how does it compare to play? Loosely speaking, a game is play that is structured and goal-oriented. But scholars in the domain of game design, the core subject of which is games and play, have more to comment about. Juul (2005) proposes a classical game model according to which a game is:

- a rule-based formal system
- with variable and quantifiable outcomes
- where different outcomes are assigned different values
- where the player exerts effort in order to influence the outcome
- the player feels emotionally attached to the outcome
- the consequences of the activity are optional and negotiable

Definitions are to be debated and expanded; and they are meant to leave some scholars unsatisfied. As this work is not about formally defining the notions of play or game, we will gladly adopt the definitions provided by Salen and Zimmerman (2004). The authors compile and compare both the common language usages and the major formal definitions of play and game. Eventually, they propose the following definition of a game (digital or other):

> "A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome".

Interestingly, the authors suggest two possible relationships between the notion of games and play: Games as a subset of play activities, in one hand, and play as a component of games, on the other hand. Confronted with the ambiguity of play, the authors propose three families of activities, each a superset of the previous:

- Game play, i.e. activities that involve games as described above
- Ludic activities, i.e. activities commonly understood as play
- Playful activities, i.e. ordinary activities exercised in a playful manner

Eventually, they propose a definition of play as

> "free movement within a more rigid structure".

This definition, complemented with the above-mentioned families of play-related activities, should provide a sufficient framework for the purposes of this thesis.

playfulness: *the inclination to be less serious, i.e. more humorous, or more experimental or looking for fun and amusement*

The proposition that play emerges out of a playful attitude rather than out of specific characteristics of an activity is particularly interesting. Playfulness can be understood as the inclination to play; as such, however, it does not further contribute to our discussion about play. Seen as the inclination to be less serious, i.e. either more humorous or more experimental or looking for fun and amusement allows us to reconsider what engaging in play may amount to. To quote Fullerton et al. (2008, chapter 4), "a playful approach can be applied to even the most serious of difficult subject because playfulness is a state of mind rather than an action". Note that we consider playfulness as an attitude, not as a personality trait, and one that can be induced. We will be using the term 'playful' as in playful interface/playful interaction to refer to interfaces that are both an invitation to play and an invitation to adopt a playful attitude. However, it should be mentioned that the notion of 'playful interfaces' is not without its cultural baggage within the field of HCI. Kuts (2009) reviews HCI literature on 'playful interfaces' and reports the following notion of playfulness within HCI: "The definition of playfulness in user experience can be crystallized as elements of a design that engage people's attention or involve them into activity for play, amusement, or creative enjoyment". Identified aspects of playful interfaces are, among others, creative enjoyment, exploration, customization, curiosity, fantasy and metaphor.

Not surprisingly, most understandings of play and playfulness assume some sort of satisfaction or pleasure involved. Positive emotions such as fun, amusement, joy, delight are often associated with play and playfulness. We can fairly assume that play pleases us but how exactly play pleases us is a subject of further study. Costello and Edmonds (2007) propose a framework of thirteen pleasure categories of play, namely creation, exploration, discovery, difficulty, competition, danger, captivation, sensation, sympathy, simulation, fantasy, camaraderie and subversion. While particular to playful interfaces in the context of interactive art, their framework provides a useful synthesis of various theories on play and pleasure experiences. Korhonen et al. (2009) propose a 'Playful Experience framework' of twenty playful experience categories validated versus the subjective experiences of video game players. Coming from a game design perspective, Hunicke et al. (2004) propose a vocabulary of eight kinds of fun to describe the fun in playing games, namely sensation, fantasy, narrative, challenge, fellowship, discovery, expression and submission. Finally, the highly influential work of Csikszentmihalyi (1975, 1991) on flow, i.e. a state of absolute absorption in an activity, and his model of flow state as a balance of skill and anxiety have been repeatedly applied to explain the experience of a player as well as to guide game design.

In the next section, we further examine the notions of fun and enjoyment from an HCI perspective.

1.4.2 HCI ludens: Intersections and cross-pollinations

The rise of the enjoyable interface

Is playfulness and enjoyment relevant for HCI? In 1988, this suggestion might have been considered a joke: "Fun" is a 1988 SIGCHI bulletin article by Carroll and Thomas (1988) discussing the importance of fun for human computer interaction. In fact, it is one of the pioneering calls within HCI to seriously study the impact and nature of fun. The authors of the article end their discussion with the following contemplation: "We realize that many people will read this article as a sort of joke. To this extent, we are the victims of our own analysis: there are risks in being serious about fun". Today, it is well-acknowledged that HCI needs to seriously take fun into consideration.

The reasons for HCI to research fun have been multiple. Consider for example, the three cases identified by Draper (1999) when fun is actually a software requirement:

- Software with fun as the main function
- Software with learning as the main function
- Software with high learnability requirements

From 1999 onwards, Draper's cases have become increasingly relevant. It has been often remarked that, as technology moves from the workplace to everyday life, including leisure and entertainment, the design of products or experiences must deal with issues of fun, enjoyment and pleasure. On the other hand, many scholars claim that traditional application software can benefit from incorporating fun, in terms of both learnability and user engagement. As Carroll (2004) points out, "people must want to use a system, and must continue wanting to use the system" and fun, he continues, may provide an answer to this challenge. The author further comments that usability, if understood as simplicity and ease of use, is not the only relevant aspect for the success and adoption of application software; correspondingly, he recommends towards an expanded notion of usability that will include fun and other aspects of the user experience. Similar shifts from standard usability to issues of fun, enjoyment and the user experience have been articulated within the 'funology' movement, an initiative in the early 2000s (Monk et al., 2002; Blythe et al., 2004). Furthermore, studies on pleasurable products as well as studies on the impact of aesthetics on the interaction have also contributed to this shift. Today, user experience research is a prominent subject within HCI. As summarized by Hassenzahl and Tractinsky (2006), current user experience research is engaging with non-instrumental human needs, the role of affect and emotions in the interaction and the nature of experience. Not surprisingly, the authors conclude with a vision of HCI as being able to "contribute to our quality of life by designing for pleasure rather than for absence of pain", the latter being often understood as the predominant contribution of standard usability.

The understanding, promotion and evaluation of the fun component in the interaction is, by now, a relevant topic of HCI research, but what is actually fun in HCI terms? For Draper (1999) fun is "playing for pleasure" and a form of intrinsic motivation. Carroll (2004) finds fun in things that "attract, capture, and hold our attention by provoking new or unusual perceptions, arousing emotions in contexts that typically arouse none, or arousing emotions not typically aroused in a given context". The author also considers a play component when assigning fun to things that "present challenges or puzzles to us as we try to make sense and construct interpretations". Shneiderman (2004) talks about "fun-filled experiences" as "playful and liberating" and distinguishes between fun-in-doing and fun-in-not-doing. Marcus (2007) associates fun in the user experience with play, games and humour but is careful to remind us that fun is a complex cognitive and emotional issue. Taking a more experiential approach, Blythe and Hassenzahl (2004) distinguish between fun as distraction and pleasure as absorption, the latter being closely related to the concept of flow. At the end, what all scholars seem to share is the belief that we can achieve a feeling of euphoria during or via an interaction, be it fun, enjoyment or pleasure. However, the means to reach such a state are various and will vary across tasks, environments and people.

It should be clear that there are no recipes for enjoyable interfaces. It is worth examining, though, the suggestions and guidelines that have been articulated so far. Shneiderman (2004) requires that fun interfaces respect the task at hand and safeguard usability and reliability before they are spiced up with fun features. His toolkit of fun features consists of graphics, animations, sounds, alluring metaphors and compelling content. In our view, the toolkit is strongly oriented to enhancing the aesthetic appeal of the user interface component of an application. While this is a valid strategy, we ponder about the possibility to evoke enjoyment by devising activities that are actually fun in themselves. To paraphrase Overbeeke et al. (2004), "emphasis should shift from a beautiful appearance to beautiful interaction, to engaging interaction. And this should not be a glued on quality": Replacing 'fun' or 'playfulness' in place of 'beauty' should clarify our point. Other guidelines draw inspiration from play and playfulness. Malone (1982), in a classical work, proposes heuristics for the design of enjoyable interfaces by examining how players of video games experience fun. His heuristics, namely challenge, fantasy and curiosity, were originally conceived for the analysis of instructional environments, and as such, they predominantly focus on stimulating motivation. Graphics or sounds are considered only as stimulating to curiosity and less as elements of an aesthetic experience. Kuts (2009), in her examination of playful interfaces, reports on aspects of the interface that are considered playful, such as exploration, customization and feedback, and proposes a set of user interface components to promote them. Eventually, her proposal suffers from the same 'spicing up' strategy. Finally, Kim (2008) proposes designing fun application software by incorporating common video game mechanics, such as collecting, earning points, receiving feedback, exchanging and customizing. The speaker's ideas are representative of a now blooming trend in interaction design, i.e. the gamification of application software, which will be discussed in depth in the next sub-section.

Finally, a word of mention is due to the notion of 'ludic interfaces' as envisioned by Gaver (2002). The author borrows the term 'ludic' (as in Huizinga's 'homo ludens') to raise a case for interfaces that are playful as in being ambiguous and open to interpretation and appropriation. The author views playfulness as curiosity and exploration, clearly opposes game and play, the latter being free and unbound to rules, and advocates the need to engage with technology and technological artefacts in ways that are open-ended, interpretative and non-task oriented. His suggestion is that similar principles should propagate into our methodologies for designing artefacts and interfaces. The notion of 'ludic interfaces' may be truer to the needs of a 'playing man' than any other notion of play-full and game-full (cf. gamification) interaction within HCI. It may also be truer to the needs of a 'playing researcher', i.e. of both the target user group of this thesis as well as myself.

HCI and games: A marriage of convenience

The work of Malone (1982) was one of the early encounters between HCI and video games. In the meantime, the video game market has expanded significantly and interest in video games has increased enormously. HCI is yet another discipline flirting with video games but, as Jørgensen (2004) observes, the exchange between HCI and games can be bidirectional.

Video games are pieces of software that perfectly qualify as a study subject for the field of HCI. Traditional HCI methodologies, such as usability evaluation and user testing, can be directly beneficial for the development of video games. Numerous examples are provided in Jørgensen (2004); Barr et al. (2007) and Zaphiris and Ang (2007). Moreover, as Barr et al. (2007) advocate, methods that are specific to video games need to be devised. On the whole, HCI research can deliver considerable contributions to the field of video games. On the other hand, given the success and popularity of video games, HCI is attentive for ideas and opportunities that may inform the design of traditional application interfaces. The idea that good video games can teach us how to make good interfaces is not new: Malone (1982) proposed his heuristics for the design of enjoyable interfaces as early as 1982. Links between HCI and games were put forward for discussion in conference workshops in 1994 (Pausch et al., 1994) and 1997 (Cherny et al., 1997). More recently, Dyck et al. (2003) derived aspects of game interfaces that can be relevant for the design of traditional interfaces. On a side note, their work is notable for it examines potentially useful interaction techniques rather than ways to stimulate fun and enjoyment. More encounters between HCI research and games have sprung: A delightful historic overview is provided by Turner and Browning (2010). As most of our bibliography tagged by [hci][games] features in this report, we will refrain from repeating the same timeline here. Still, we wish to set this tradition against a few recent developments in the quest for enjoyment and engagement by means of gaming or game elements, namely gamification, serious gaming and games with a purpose.

Gamification: Gamification as "the use of game design elements in non-game contexts" (Deterding et al., 2011) is a relatively new development in the design of application software. While a new kid in town, the idea may be not much different from previous attempts to learn from existing knowledge and practices from video games in order to increase user engagement. Deterding et al. (2011) acknowledge that gamification nears the tradition of 'playful interfaces' but they are confident that gamification can serve as a research topic of its own sake. The trend has already been heavily criticized by game scholars and game designers alike, who observe a tendency to superficially gamify applications. Much too often, application designers have advocated gamification of applications by means of extrinsic rewards resulting in an abuse of game elements such as points and badges. At present, the HCI community remains active in discussing and better understanding the issues around gamification, especially the issue of motivation via game elements.

In principle, neither gamified applications nor playful/enjoyable interfaces (cf. subsection 1.4.2) are actually games. A significant exception is the work of Chao (2001), who created a pure first-person shooter for the administration of computer processes. The author relates to the term game-like interface, a notion we endorse and comment upon in chapter 3. But actual, full-scale games have also been appropriated within HCI:

Serious games: Serious games are games for purposes other than mere entertainment (Susi et al., 2007; Alvarez and Michaud, 2008). The underlying idea is that educational or other objectives can be successfully conveyed via the medium of video games. Serious games have found applications in a variety of fields and industries such as education, marketing, training and social awareness but their success and quality varies. For example, instruction games with drill and practice exercises have been heavily criticized as 'the worst of two world', i.e. bad education and bad gameplay (Charsky, 2010). On the contrary, simulations and games that train the corresponding skills, be it motor skills or problem solving skills, may have more promising potential.

Games with a purpose: Games with a purpose (von Ahn, 2006) are games that harvest human effort during play. As such, they provide an effective mechanism to utilize humans for traditionally challenging areas of computation. The underlying idea is that we can engage humans in tedious tasks, and bring human computation and crowd-sourcing to a new level, if we transform these tasks into games. The paradigm has been applied successfully at numerous occasions for problems that are either computationally challenging or simply tedious. For example, the 'ESP game' (von Ahn and Dabbish, 2004) was a pioneering example in producing semantic image annotations, i.e. annotations about the content of an image, via game play. Siorpaes and Hepp (2008) review more game examples relevant to the field of semantic web technologies, an area that traditionally requires painstaking effort in capturing human knowledge. Another significant example of human computation via play can be found in the domain of biological sciences. The game 'fold-it' is a puzzle game for predicting protein structures. Players of the game have collectively outperformed state-of-the art algorithms while, at the same time, suggesting new solution strategies (Cooper et al., 2010).

All of the above developments share an interest in tapping the popularity and success of video games. Games work, at least well-designed ones do, so, naturally, many disciplines consider the applicability of gaming for their own purposes, be it learning, computation, engagement or improved user experience. We are confident that engaging instances of playful work and of useful play, of games that 'do more' and of applications that are more playful can be delivered. We acknowledge that ideas from gaming can be useful and applicable to a variety of domains often irrelevant to gaming itself and that application interfaces can benefit from the positive effect of fun and play. Then again, our outputs are not *per se* serious games nor applications gamified. First and utmost, our outputs are platforms to actively engage with and contemplate about scientific images. Hopefully, we have explored a tiny bit of that "vast and utterly neglected territory of possible systems that are really neither work nor fun" (Sengers, 2004).

1.5 Structure of the thesis

The coming chapters document our attempts to better understand how play for exploration could be catered for. Via case studies and reviews, we flesh out particular elements of play for exploration and implement artefacts that exemplify instances of playful interaction with image research material in collections.

Chapter 2 introduces the CSIDx database system (Cyttron Scientific Image Database for eXchange). The system and its data management approach, in particular the extensive use of ontology annotations, are discussed in depth. An understanding of the scope and intentions of the CSIDx system should further illuminate some of the requirements put forth in this introduction. Connectivity across microscopy techniques, users and subject matters is one of the foundation stones of the Cyttron project; as such, the context provided by Cyttron has strengthened our interest in connections and associations. With respect to the notion of playful exploration, we discuss information visualization features of the CSIDx web interface that are supportive for exploration.

Chapter 3 presents Onto-Frogger, a video game prototype developed for the CSIDx image database. In chapter 3, we elaborate on the use of gaming for exploration: Onto-Frogger implements a form of playing with images that is clear-cut gaming. What is more, we introduce a new concept, that of games as 'executable' information visualizations, and suggest that games may materialize structure and existing connections when encoding them in their game logic. Our produced game is heavily oriented towards images, their annotations and the connections implied by these annotations. Onto-Frogger implements a way to literally play with images that exposes the users/players to the underlying structure of the data collection by challenging them to identify, predict and resolve existing connections for the needs of the game.

Chapter 4 takes a step away from the CSIDx database to question what lessons can be learned from existing practices in popular image collections and from existing games involving digital images. In chapter 4, we review image-based gaming activity as exercised in the Flickr photo sharing system. The work presented contributes a first scouting of the Flickr ecosystem and a first categorization of the gaming activity present. But mostly, it contemplates on the exploratory qualities of the found activity to derive potentially promising ideas to further support playful and exploratory interactions with images in collections.

Chapter 5 presents LABBOOK, a collaborative storytelling game for biologists and their images. In chapter 5, we investigate storytelling as a form of playing with images. In effect, and in response to our findings in chapter 4, we divert from rule-based play in favour of play that is more creative and more unstructured. The work presented in this chapter attempts to probe creative responses to images by confronting the players with the challenges of story composition. LABBOOK implements a way to literally play with images that challenges the users/players to imagine connections and devise explanations for the needs of the game. The game is also an invitation for social exchange and conversation.

Chapter 6 concludes this trip.