Understanding nanoscopical images and exosomatic vision through visual literacy

A Master's Thesis for the Degree Master of Arts (Two Years) in Visual Culture

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Understanding nanoscopical images and exosomatic vision through visual literacy.

In this paper I explore the visual literacy of images produced by nanoscopes picturing objects the naked eye cannot see. In the first part of the paper I introduce three nanoscopical images supposed to be read without knowing what they are picturing, and how they are produced. Visual literacy and exosomatic vision are introduced and used to open for a discussion whether the images are read or observed, and if we can believe what we see. In the second part I explain what a nanoscope, and a nanoscopical image is, through their technical specifications, as well as exploring foundational aspects of the nanoscope such as light, and lasers, with works provided by scientists such as Vlatko Vedral, Stephen Hawking, and, inventor of the nanoscope, Eric Betzig. The technological tool is related to a cultural framework by referring to the work of Lynn Åkesson and Susanne Lundin, and their book *Amalgamations: fusing technology and culture.* In the third part of the paper I provide a deeper analyzation of the three images, connecting to the first part and comparing how my perception and visual literacy has changed by gained knowledge. This moves through a discussion of how the information provided by my sources has differed in difficulty, and how the images and their captions give credibility to the science, as well as whether this information has proved vital or not for understanding.

Keywords

Visual literacy
Nanoscope
Exosomatic vision
Vlatko Vedral
Eric Betzig

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Glossary

Diffraction limit – In this thesis referring to Ernst Abbe´s diffraction limit for microscopes. A limit for how small an object can be observed in an optical microscope.

EMCCD – Electro-multiplying charge couple device. A form of camera technology able to detect individual photons.

Exosomatic vision – Seeing with the aid of tools because the eye is insufficient.

Micrometre – A scale used in science, often written as the symbol μm, one micrometre is one millionth of a metre.

Nanometre – A scale used in science, often written as the symbol nm, one nanometre is one billionth of a metre.

PALM – Photo activated localization microscopy. Technique used for imaging beyond the diffraction limit.

QED – Quantum electrodynamics. A theory describing how light and matter interact.

STED – Stimulated emission depletion. Technique used for imaging beyond the diffraction limit.

TIRF – Total internal reflection fluorescence. A microscope enabling observations smaller than 200 nanometres.

Introduction

Objective

In this thesis I will explore how reading and perceiving an image can change based on what kind of knowledge is made accessible for the observer. Three images produced by nanoscopes are observed using visual literacy in order to see how the observers' visual literacy determines his or her understanding of the image. I will myself analyse three images in two steps, once before gaining knowledge about them, and once after to show how visual literacy can be changed. The images, as well as the tool that produces them (the nanoscope) are then thoroughly explained to increase the understanding that nanoscopical images are made differently than one might have expected at first view. Since nanoscopes produce images using lasers, both light, and lasers will be explained to increase understanding of the advanced instrument and its products. All nanoscopic images are exosomatic, meaning that they picture things we can never see with our own eyes. Therefore the images are supported by mathematical equations validating them, and giving them credibility, this will be taken into account as I consider our ability to read them. Learning about the complexity of the production, and of the tool will change the way the images are observed as I will demonstrate when the three images return for a deeper analysis.

How the new visual literacy is created using my sources will also be observed as the texts vary in difficulty and targeted readers. The texts and indications belonging to the images, or integrated within the images will also be taken into account, as will what kind of information might be lacking.

Background

If we start with a historical view we discover that light and optics has always held a great deal of fascination for the people we now call geniuses. It was experimented on by Archimedes and Da Vinci, and has its roots in ancient Greece. However, the development of optics, and

the ability to truly see light, was always held back by the slow technological progress. This lead to optics not being considered an important part of physics, or a science, until the 16th and 17th centuries, when it became accepted largely thanks to the works of Pierre de Fermat, Isaac Newton and Christiaan Huygens. [1] [2]

The nanoscopic method was invented by Eric Betzig, Stefan W. Hell, and W. E. Moerner. They each received a Nobel Prize in chemistry for their ability to produce images smaller than half a wavelength in 2014. The work to break the diffraction limit, the limit that has previously prevented us from observing anything smaller than that half wavelength of light, had begun years prior. W. E. Moerner measured the light absorption of a single molecule in 1989. Building his work on the previously Nobel Prize awarded discovery of green fluorescent protein. Eric Betzig developed the near field microscopy in the 1990´s, and Stefan Hell imaged an E-coli bacterium using a STED microscope in the year 2000.[3]

Betzig, Hell, and Moerner each continued to explore ways of enabling observations on nano-levels and had breakthroughs when discovering the use of fluorescent proteins that could light up cells from within, and could also be activated at will.[4]

With the creation of the nanoscope came the nanoscopical images. When I first laid eyes on one it did not strike me as different from any other microscopic images I had seen. It was the knowledge that it was *nano*scopical instead of *micro*scopical that changed it. I set out to understand what these images were about and how they were produced, and in the process came to study how they were read as well. Understanding something as advanced as nanoscopical images is difficult, and how we understand and read is no easy topic either.

Visual literacy has, according to historian and art critic James Elkins, been in use for over 150 years. The topic has been debated for years but no conclusion to how we read images has been reached. There is no right or wrong answer. Images change as our ability to produce them change, but in the sources I have used I have not read anything about the change of our reading.[5]

The vast background of microscopes, the predecessors of nanoscopes, light, visual literacy and lasers cannot be covered completely in this thesis. The parts of the different histories that have been chosen only serves to support the topic of how visual

[1] Vedral, Vlatko, *Modern foundations of quantum optics*, Imperial College Press, London, 2005, p. 1-2.
[2] Vedral, Vlatko, *Modern foundations of quantum optics*, Imperial College Press, London, 2005, p. 2.
[3] Fernholm, Ann, 'How the optical microscope became a nanoscope', http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2014/popular-chemistryprize2014.pdf, 2014(accessed 25 May 2016), p. 1-6.
[4] Ibid. p. 1-6.
[5] Elkins, James 'Introduction: The Concept of Visual Literacy, and Its Limitations.' in Elkins, James (red.), *Visual literacy*, Routledge, New York, 2008, pp. 1-10, here see p. 1.

literacy can change or broaden.

Relevance of the work

Based on the difficulty of finding sources for this thesis I would say the work is highly relevant. Visual literacy in scientific images has been covered before, but never in regards to nanoscopical images. In the cases where scientific images are studied as art or from cultural standpoints those images are also most often picturing space, and not bacterium.

Nanoscopical images being new complicate the study as they are difficult to find. A cultural reading of nanoscopical images have not yet been made by my knowledge.

Research question

How does the observers´ visual literacy of nanoscopical images, and their exosomatic vision change with gained knowledge about the images?

Theories and methods

The starting point for this thesis is the hypothesis that the perception of images change depending on our knowledge and understanding of them. I have performed a case study using three nanoscopical images that I have myself observed, learned about, and then observed again to see how my visual literacy can be transformed. The literary, web based, and image sources are selected qualitatively and over one moment in time, for two reasons, one being that there is no one source treating nanoscopical images from a cultural viewpoint (meaning that the closest related material needs to be chosen with care), and the other being that this study needs to be feasible within a limited timeframe (meaning that I cannot wait for new materials to be presented).

The main theory used in the case study is visual literacy. Visual literacy has its foundation in dual-coding theory, which addresses the learning of information as parted in two, image and language. Making visuals and linguistics separated.[6]

[6] Avgerinou, Maria D. & Pettersson, Rune, ' Toward a Cohesive Theory of Visual Literacy ', *Journal of Visual*

There have been discussions amongst my sources if visual literacy should be regarded as a concept, or as a theory of its own, in this thesis I am treating visual literacy as a theory. (Visual literacy is presented in greater detail in chapter three.)

Relation to current research

My relation to current research is to take on the role of merging culture and science in an interdisciplinary study of the nanoscopical images. I have yet to come across an explanation concerning nanoscopy that has cultural influences, and standpoints, and as it is non-existent I am adapting cultural viewpoints, from related subjects, for this specific topic alone. I am aiming to fill in a blank between culture and science in this new image field where science still dominates. There is no research in visual literacy in nanoscopical images yet, as I believe the images to be too new, which would make this thesis a good starting point for encouraging further studies.

Sources

The empirical materials used in this thesis were chosen based on their relevance to the topics of visual literacy, and nanoscopy. I could find no single source clearly treating nanoscopical images from a cultural standpoint meaning that what sources I have used, have had to be adapted for this topic. Their relevance lies in them being as close to the subject as possible by treating aspects of the nanoscope or aspects of reading images. I have chosen to select only a few sources treating the scientific parts of nanoscopy, light and lasers. For the nanoscope there are not yet enough credible material published concerning its development and use, while for the light and lasers there are a great amount. I have made the choice to use sources by theoretical physicists Girish S. Agarwal, Stephen Hawking, and professor of physics Vlatko Vedral. This selection was made because when researching scientific sources I discovered that the mathematical equations and the descriptions used where mostly the same, it was only the style of writing that differed from book to book. This is not surprising as a history of light and the development of lasers has been agreed on, and there is only so many

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Literacy, Volume 30, no. 2 Autumn, 2011, https://www.researchgate.net/profile/Maria_Avgerinou/publication/267988880_Toward_a_Cohesive_Theory_of_Visual_Literacy/links/54d9e8ea0cf24647581fc28b.pdf, (accessed 25 May 2016), pp. 1-19, here see p. 13.

ways that one can explain the theories of light without changing its meaning completely into something it is not.

The sources by Vedral, Agarwal, and Hawking also have the advantage of being written with different targeted readers in mind. Agarwal and his co-writers present in *Selected papers on resonant and collective phenomena in quantum optics* a selection of papers that are highly advanced in both mathematics and language. Being a big, heavy volume, it was published for scientists or ambitious students studying on a higher level. Vedral however writes for students in his *Modern foundations of quantum optics*, explaining all mathematical equations and encouraging the reader to try calculations of his or her own. Hawking is a different story; he has had help from a screenwriter and theoretical physicist, Leonard Mlodinow, and has together with him written a popular science book called *The grand design* that is both easy to read and to understand. The books represent three levels of difficulty from highly advanced to easy, where the easiest to understand book is also the easiest to acquire as it is sold as leisure reading in book stores, while the other two books needs to be borrowed from university libraries, or ordered specifically.

For the cultural part of my thesis there are several contributors, but some of the ones that I have relied most on are art critic James Elkins, Professors Susanne Lundin and Lynn Åkesson, and Doctor Maria Avgerinou. None of their texts have been very difficult to understand, they do vary in accessibility though. James Elkins books are well known, and available to buy and borrow for the general public, Lundin and Åkessons book about *Amalgamations: fusing technology and culture* however is only available to be borrowed at selected libraries across the country, and needs to be ordered specifically if it wishes to be bought. Avgerinou´s text can be found in the journal *Journal of Visual Literacy* online, making hers the easiest accessible text (provided that the reader has an internet connection).

There are two sources for my three nanoscopical images and they are both scientific journals. *Nature* is a scientific journal where scientists can publish their findings; it is highly established and has been in use since 1869. *Science* is a younger journal, being founded in 1979 but shares similar aspects and approaches as *Nature* as it also enables scientists to spread their work. Both journals are available online making them very easily accessible, however they are not as easily read and understood as they are clearly aimed towards a reader skilled in scientific languages.

Disposition

This thesis can be seen as divided into three main blocks of text. I will start of by briefly introducing exosomatic vision, and presenting my case study, the nanoscopical images. The images are observed without as little previous knowledge about them as possible creating a starting point as well as a comparison for the later deeper analyzation. The topic of visual literacy is then presented and problematized before we start to gain scientific knowledge about the images.

The middle part of this thesis is mostly focused on science, and technology. This because nanoscopy is so advanced that I felt the need to cover it as thoroughly as possible. I start this block by explaining the technical tool, the nanoscope. I then continue with how it produces images, and finish with a cultural study of technology freely adapted for nanoscopy. In the very last block the three images will return for a deeper analyzation were I will observe them using my newfound knowledge. The differences in observations will then be compared and analysed to create a conclusion about how my visual literacy and understanding of exosomatic vision has changed.

Chapter 1 Beyond the capability of the human eye

There are things in this world that our eyes cannot see. Not because our eyes are flawed, but because some things are so beyond tiny, so far away from small, that we would never be able to observe them without the help of tools. Letting a tool see for us, and creating an image for us that we can never truly validate, gives us what is called an exosomatic vision. Exosomatic vision is seeing beyond the capability of the human eye, of using more than our bodies to observe.[7]

A good example of exosomatic vision is nanoscopical images. They are produced with the help of nanoscopes, seeing beyond what even ordinary microscopes can observe, creating images with a minimal use of the human eye. What we are then able to observe as a result, as an image, can be so difficult for us to understand that the images needs constant backup from math. Mathematical equations are used to make sure that everything we see is accurately positioned, and to give credibility to the image. Without it we cannot be certain of what we are observing since our own eyes cannot convince us that what we see is fact.

Throughout this thesis I will observe and analyse three images, each of which are nanoscopical. They are advanced, and I do not expect anyone to fully grasp their complexity in form of mathematics or scientific messages. Instead what I would like to focus on is how reading changes with higher understanding of the image production. In the next chapter I will have a look at the three images without previously knowing much about them.

[7] Professor Joacim Sprung, *Introductory lecture: Histories of modern visualities*, notes taken by Susanna Ivarsson, 1 September 2015, Lund University, Lund.

Chapter 2 The images three

I would hereby like to introduce the images that I will be exploring throughout this text. The images were obtained by searching the internet for an overview of where (webpages, blogs, articles) nanoscopical images could be found and in what quality they were uploaded. The best quality of images that were also confirmed to be nanoscopical belonged to two scientific journals, *Nature*, and *Science*. *Nature* had by far the easiest captions to understand as they were written by a second party as summaries for a science fan reader, while *Science´*s captions were quite the opposite as they were written by the authors of the article, and producers of the images, Betzig et al. for a skilled scientific reader. I chose the three images below as my case studies because of how they were divided, the first as one whole image, the second as divided in two, and the third as divided in four allowing me to compare clarity, blur, colours, scales, and centre of attention. I allowed myself to forget as much as possible of the captions before I studied them for the first time, this to create a reading of the images as *images*, and not to go too deeply into science. A deeper image study will be made later on in the thesis were all information about what is pictured in my case studies will be presented.

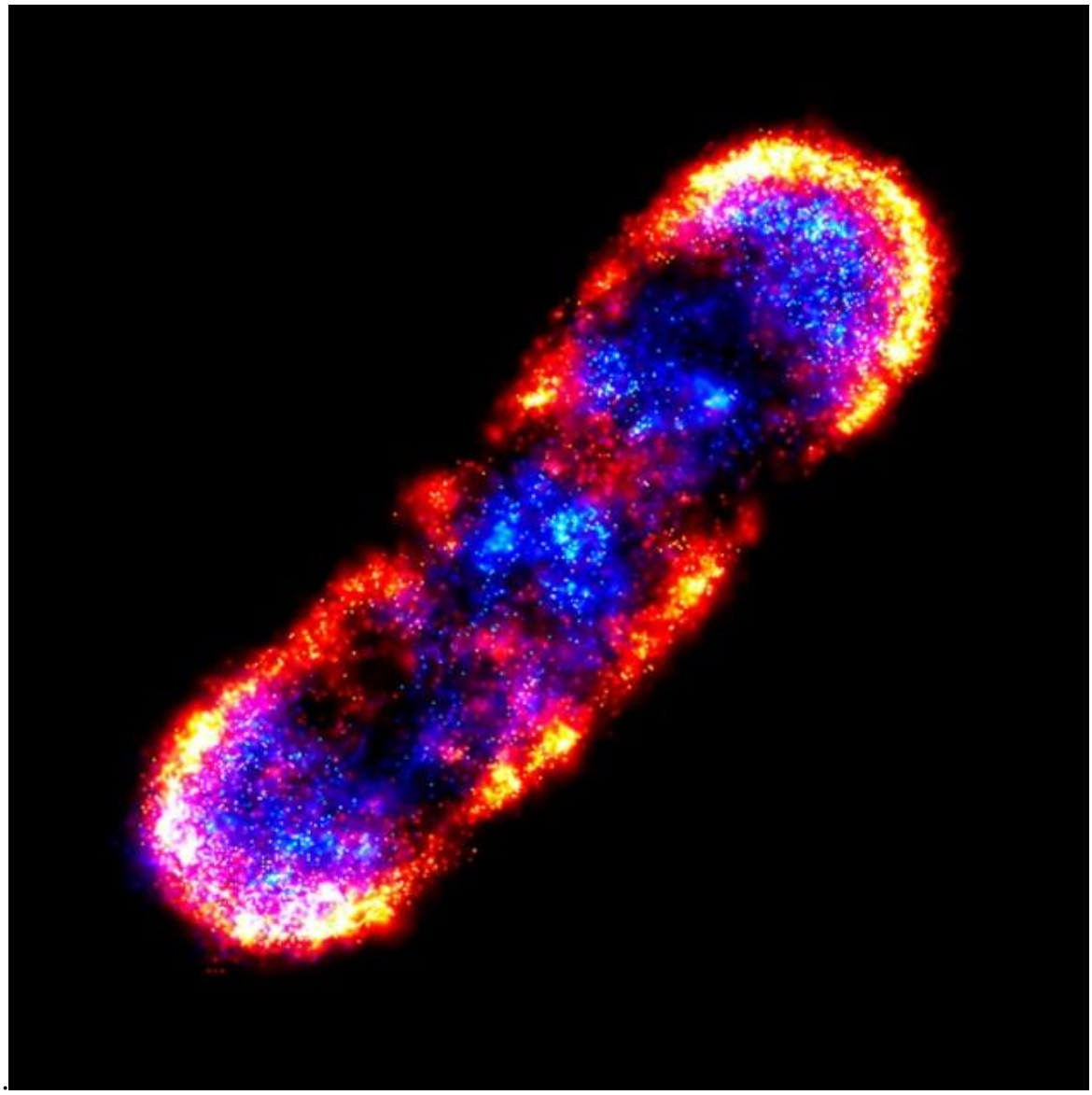

Image 1.1

No 1

The first image, to me, looks like a pill. It is tilted so that it rests diagonally in the image with the top towards the right hand corner. It is very colourful in luminescent blues, reds, yellows, orange, pinks, and whites. The colours seem to be made up of dots of different sizes; some dots are smaller and brighter while others blend together creating “clouds”. I can see the black solid background shining through the “pill” in places, making me think of it as slightly translucent. The blue colours are prominent in the centre of the “pill” while the warmer colours like the red are seen around the edges. This gives me the impression that the edges are

hot and the centre cold, because it reminds me of thermodynamic images. The “pill” does not glow outside of its edges, meaning that the light from it is not strong enough to spread or that its edges have been trimmed to look neater. I can see no indications within the image explaining its size or what it is that I am seeing, but it is very clear and my attention is drawn to the colourful elongated object immediately. I do not know what information I am supposed to see within this image, and I do not know if something is amiss. I am not a scientist, I do not know of its usage. All I see as I read the image from top to bottom is bright colours on a black background.

This objective view actually causes confusion for me, because I can see that the image is scientific. I can see that what is portrayed is most probably smaller than I can imagine, and I know from having seen similar images before in newspapers or on the internet that it probably is a bacterium that is being shown. When having viewed these types of images before I have not regarded them as something to observe. I have seen them, sure, but I have not taken the time to think about what it is that I am seeing. I have learned to identify the image as “advanced”, “difficult”, “scientific”, “colourful”, and “microscopic”. But never taken the time to reflect on how I read them, and why I just accept them the way that they are.

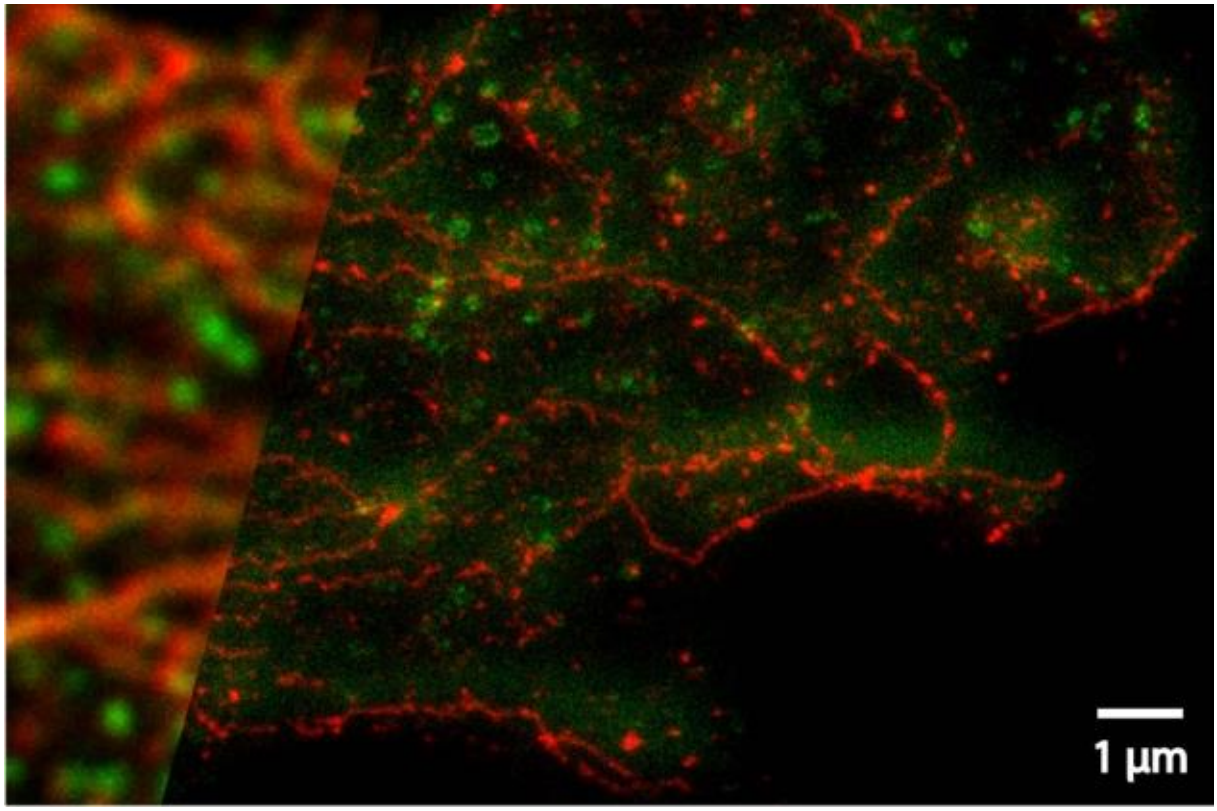

Image 1.2

No 2

The second image is a green and red network of lights on a black surface. There are threads, and clouds, as well as dots of colour. The image is divided in two, with a small part at the left side showing a blurred version of the right side. Starting with the clearer right side, the colours seem a bit more solid in this one as it looks like the green colour was painted on the black background like toxic clouds. The red lines were then drawn on like roads on a map, and the red dots added as an afterthought to mark out houses by the "roads". The slimmer left side almost gets overlooked as my eyes are drawn to the clear rather than the blurred. In the left side the red dominates over the green in the blur, but the green shines through in dots that seem much brighter than the green to the right.

There is an indication on the right side, at the bottom corner, as to the images scale, but there is no indication to the left. This makes me wonder if the whole image is at the same scale or if the scale is just for the right side. If the whole image is in the same scale, why is the left side blurred? If the parts of the images are in different scales, why is the left sides scale not marked out?

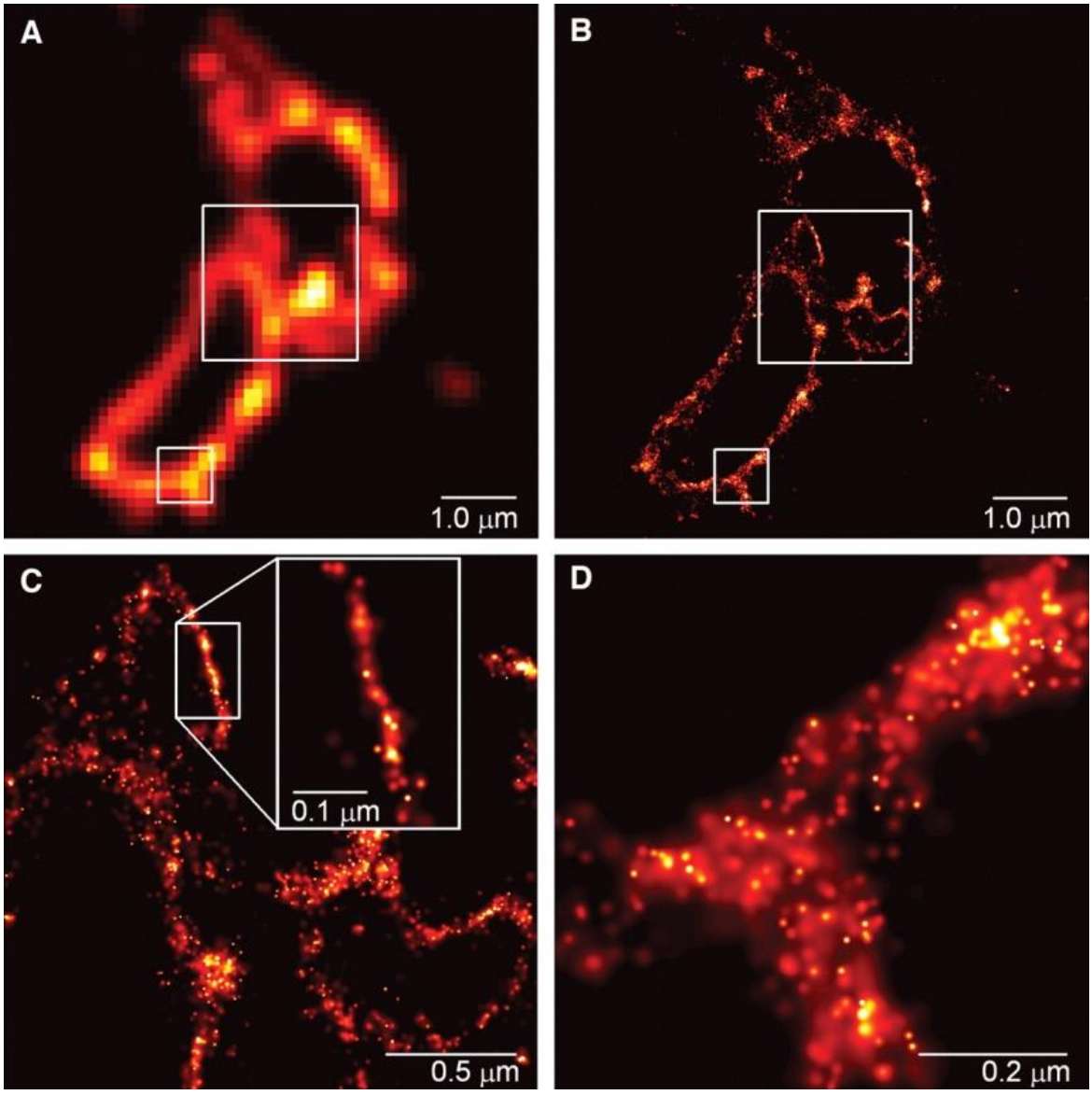

Image 1.3

No 3

The last image is a four in one. This image is interesting to me because it seems to show the process of zooming in and out of what is being portrayed. There are white squares framing the parts of the picture that we should be paying attention to, and there are clear indicators at the bottom right corner in all four images to their scale. At the top left in every image there are also the letters, A, B, C, and D, which seems to indicate in which order to look at the images. Starting at the top left we move to the right before letting our gaze drift diagonally down to

the left again, and once more ending to the right. In all four frames we see lit up shapes in red with brighter white and orange dots. There is black shining through from the background in all shapes imaged, and just like with the "pill" it makes me believe that what I am viewing is not completely solid.

The white squares framing parts of the images are seen in A, B, and C only. C also has two scales, one for the whole image, and one for the white frame which is in a smaller scale. Images B, and C, which are very clear, looks to me like the earth at night, like roads and villages lit up by streetlights, while A, and D, which are more blurred, are harder to compare to anything I might have seen before. All in all the scales, and squares help me understand how to read the image, but I still do not know exactly what it is that I am viewing.

Reading without knowing.

What I have just done is reading without knowing. When I look at images, and try to figure out their meanings, usage, what they are showing, how they were produced, I start to see things in them and imagine things about them. When I have no previous knowledge about what I am viewing, and might not have seen an image like it before, I try to solve the problem. For my three case studies I continuously drew a blank while trying to figure them out but that does not matter. What is important is that I start to think about what I see, and how I see it. For instance, I have realized that I read the images from right to left, left to right, and top to bottom. For every image my eye movements were different. I have also realized that I pay a lot of attention to colours, while I reflect very little on shapes (especially when the shapes are thread like), and that I question what is pictured in scientific images very little.

There is a concept for how we read images, and it is called visual literacy. In the following chapter I will explain more about what it is in order to enable a deeper understanding of how I might change my reading for the second image analysis.

Chapter 3 Visual literacy.

Professor of occupational education Lynna J. Ausburn means that visual literacy has come to involve more disciplines than its original one, education. Since visual literacy can be considered as a language and its main focus is intentional messages sent and received with purpose it has been a concept happily adapted to fields like art, philosophy, and semantics.[8]

Doctor of educational technology Maria D. Avgerinou supports this in her studies of the writings about visual literacy in the years 1969 to 1999. She has identified main points recurrent in most disciplines incorporating visual literacy. Her conclusion, which has, according to herself, been supported by several researchers such as A-M Barry, Roland Barthes, Donis A. Dondis, Rune Pettersson, and Edward H. Sewell states that visual language does exist and is parallel to verbal language. Visual literacy does not have to be exclusive for the sensory of sight; it can be integrated with for instance touch as well, and its skills should be able to be taught, learnt, and improved upon.[9]

According to art historian James Elkins, the editor of *Visual Literacy*, visual literacy has been in use for over 150 year, but has not gotten the attention it deserves.[10]

In *Visual Literacy* several authors contribute to the topic, but I have chosen four, W. J. T. Mitchell, Henrik Engquist, Matthias Bruhn, and Vera Dünkel, because of their topics´ relation to my study of nanoscopes and their images.

W. J. T. Mitchell is a professor of English and art history at the University of Chicago in America, and he starts of by comparing the act of reading images to the act of reading text. He states that we immediately know that reading a text is a much more difficult thing to do than looking at an image. He also says that in order to be able to read a language, one must already know how to speak it, and claims that languages which are ideographic or pictographic, like Chinese, must have their characters fully learned before reading and writing

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[8] Ausburn, Lynna J. & Ausburn, Floyd B., 'Visual Literacy: Background, Theory and Practice' , *Innovations in Education & Training International*, Volume 15, Issue 4, 1978, published online Summer 2006, http://www.tandfonline.com.ludwig.lub.lu.se/doi/abs/10.1080/0033039780150405, (accessed 25 May 2016), pp. 291-297, here see p. 291.

[9] Avgerinou, Maria D. & Pettersson, Rune, ' Toward a Cohesive Theory of Visual Literacy ', *Journal of Visual Literacy*, Volume 30, no. 2 Autumn, 2011, https://www.researchgate.net/profile/Maria_Avgerinou/publication/267988880_Toward_a_Cohesive_Theory_of_Visual_Literacy/links/54d9e8ea0cf24647581fc28b.pdf, (accessed 25 May 2016), pp. 1-19, here see p. 4.

[10] Elkins, James 'Introduction: The Concept of Visual Literacy, and Its Limitations.' in Elkins, James (red.), *Visual literacy*, Routledge, New York, 2008, pp. 1-10, here see p. 1.

can begin. For his first statement I feel he has missed out on recognition without reading. Let me explain, in the Asian languages where signs are used instead of words (as we know them) we could learn to recognize a character without being able to read it. Many people, me included, have Chinese signs in our homes as decorative pieces of art, framed on our walls. I, and many with me, cannot read them but I have learned to recognize them. Mitchell fails to explain that using the word reading and relating images to text also relates visual literacy very strongly to verbal language, and he seems to be having trouble defining how reading can be adapted from text to image, therefore I feel that he is talking about two different forms of reading for the text and the images, where the images are observed and the texts read.[11]

Quoting professor of literacy studies, James Gee: '"Language" is a misleading term; it too often suggests "grammar."' [12]

For Mitchell´s second statement I do not believe that we have to be able to speak a language fully before we learn to read it. Anyone who has ever studied a language in their life knows that you combine reading and speech, and that some people learn the text faster than the phonetics, and vice versa. Maria Avgerinou, and Rune Petterson quotes S. E. Moriarty in their article ' Toward a Cohesive Theory of Visual Literacy ' in *Journal of Visual Literacy* saying that children learn to communicate visually before verbally. Thinking about it, it does make sense as children are often asked to point and identify objects (in for instance board books) long before they try to match said objects with words. Also drawing upon the works of M. L. Zimmerman and G. W. Perkin they write that people not knowing how to read look at images differently from people being literate, for my study of nanoscopical images this is interesting. I tried to forget as much of the captions to my images as possible and read them as someone who does not understand what it is I am seeing. Granted, I am not illiterate, but for my case studies I have tried to create a bit of illiteracy for the scientific understanding of the images. This to get a better comparison of how my reading changes with gained knowledge.[13] [14]

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[11] Mitchell, W.J.T, 'Visual Literacy or Literary Visualcy?' in Elkins, James (red.), *Visual literacy*, Routledge, New York, 2008, pp. 11-13 here see p. 11-13.

[12] Gee, James P., 'Literacy, discourse, and linguistics: introduction', *Journal of education*, Volume 171, no. 1, 1989, http://jamespaulgee.com/geeimg/pdfs/Literacy%20and%20Linguistics.pdf, (accessed 25 May 2016) pp. 5-17, here see p. 5.

[13] Moriarty, S. E. 1994, cited in Avgerinou, Maria D. & Pettersson, Rune, ' Toward a Cohesive Theory of Visual Literacy ', *Journal of Visual Literacy*, Volume 30, no. 2 Autumn, 2011, https://www.researchgate.net/profile/Maria_Avgerinou/publication/267988880_Toward_a_Cohesive_Theory_of_Visual_Literacy/links/54d9e8ea0cf24647581fc28b.pdf, (accessed 25 May 2016), pp. 1-19, here see p. 8.

[14] Zimmermann, M. L. & Perkin, G. W. 1982, cited in Avgerinou, Maria D. & Pettersson, Rune, ' Toward a Cohesive Theory of Visual Literacy ', *Journal of Visual Literacy*, Volume 30, no. 2 Autumn, 2011,

Returning to Mitchell who continues with reading in relation to the ability to see, pondering on the use of sight after having been blind your whole life. He does not believe that sight will be of any use to a blind as it would be too late to learn how to see. For Mitchell it seems to make a valid point for the difficulty of learning new languages at an older age, but for me it becomes problematic. Because if getting your eyesight back would mean not being able to use it on the grounds that you have never used your vision before, then losing your eyesight would mean not being able to use your hands to "see" as you have never used them for that purpose before. Yet we know of people who have learned to read and "see" with their hands after having lost their vision. Personally, I believe that humans are nothing if not adaptable, and believe that we can learn anything at any age.[15]

Mitchell has presented his opinions using knowledge that he himself believes to be generally taken for granted. This makes him someone that I cannot fully agree with for I do not take any of the things he said to be the general idea. I do not believe that we learn languages the way that he describes, and I do not believe that a blind person would be forever visually illiterate. What I have learned, however, from disagreeing with him is that visual literacy is hard to define in terms of reading and seeing. Mitchell seems too focused on reading as in reading texts, and loses focus on the ability to read images, as he writes about phonetics and iconographic languages. The ability to see as a premise for the ability to read is another topic that we have both argued for, and both become none the wiser as a conclusion. Mitchell, writing from a cultural viewpoint and for a cultural reader delivers arguments that need to be adapted before being relevant for the study of nanoscopical images. Not that scientific images necessarily needs to be separated from other images, but there is a gap in the lighter way Mitchell writes and the advanced way the nanoscopes are described scientifically.[16]

Next up on the topic of images in health care, is Henrik Enquist. He has explored how x-ray images, and other images produced within health care can help communication between doctors and patients in the form of visual aids. Claiming that there is a great amount of medical images stored away, globally, in hospitals, that only gets used by researchers and doctors when the drawings, images, and photographs could also be of benefit for the patient. Enquist does not believe that a patient has to understand an image in order to find it helpful,

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https://www.researchgate.net/profile/Maria_Avgerinou/publication/267988880_Toward_a_Cohesive_Theory_of_Visual_Literacy/links/54d9e8ea0cf24647581fc28b.pdf, (accessed 25 May 2016), pp. 1-19, here see p. 8.

[15] Mitchell, W.J.T, 'Visual Literacy or Literary Visualcy?' in Elkins, James (red.), *Visual literacy*, Routledge, New York, 2008, pp. 11-13, here see p. 13.
[16] Ibid. p. 13.

and believes that medical images should be shown more often.[17]

So far I could not agree more. Images are known to increase understanding when language is failing, and I believe that the doctor´s is one place where you want to be truly understood. Doctor Michael Winkelman is one author who has touched upon this importance of being understood. He writes in his book *Culture and health: applying medical anthropology*, about how culture should be studied more by doctors to increase good health care. He means that by studying culture doctors would get a higher understanding for their patients, and by this enable a reduction of differences between themselves and their clients. Winkelman points out that the gaps between doctors and patients and misunderstandings could affect treatments and consultations, as doctors might try to cure a pain located or described inaccurately by the patient. For instance, people refer to body parts or areas of the body differently than doctors do. Winkelman uses the example of the stomach, which to doctors is a limited, small area, while to patients it could be any area of the abdomen from just below the chest to the pelvis.[18]

The nanoscope and its images are used in basic research and would not be used in a health centre or at your local hospital for treatments. But the understanding of messages sent and received between medical practitioners and "common folks" can be adapted for the nanoscopes. As with the doctor – patient relationship, the relation between scientists and the man on the street can be full of misunderstandings. One area, of any one of the images in my case study is not the same to me as it is to a scientist, and if I and the scientist were to discuss the images from our different standpoints I would not be too surprised if we miscommunicated, and misunderstood each other completely.

Returning to Enquist, we discover that he argues against himself as he says that seeing an x-ray image of your broken leg would be useless as you already know that it is broken. It is curious that he would think that the image of the broken bone is useless, when he has said that all images are important because it is about seeing, not what you see.[19]

Images of broken bones are the ones that I perceived to be the most commonly used, and shown to patients, and it strikes me as odd that Enquist would brush them off as unimportant while arguing for the importance of *all* medical images. An x-ray image could tell a patient a number of things, one of which being the extent of the injury. Sure, it feels like

[17] Enquist, Henrik 'Bridging the Gap between Clinical and Patient-Provided Images.' in Elkins, James (red.), *Visual literacy*, Routledge, New York, 2008, pp. 145-164, here see p. 145-146.
[18] Winkelman, Michael, *Culture and health: applying medical anthropology*, 1st ed., Jossey-Bass, San Francisco, 2009, p. 75, 84, 174.
[19] Enquist, Henrik 'Bridging the Gap between Clinical and Patient-Provided Images.' in Elkins, James (red.), *Visual literacy*, Routledge, New York, 2008, pp. 145-164, here see p. 147.

your leg is broken, but a crack in the bone could be just as painful to a sensitive person. Maybe, it is not completely broken, or maybe it is but the two pieces of bone are still close enough together (as oppose to one part of the bone sticking out through your skin) to be healed rather quickly. If I broke my leg I would like to see for myself how bad the break is, and would also need the information to know how long it would take for me to heal.

Engquist takes his leave and we are left with our last two contributors Matthias Bruhn and Vera Dünkel. They start of by saying that thanks to media, being visual has become one of the most important aspects of society. But the spread of visuals has also lead to more advanced images being released to the public who has not yet required itself a proper training in reading them. This makes the images closer to symbols and representations, giving them other meanings than what they were originally produced for.[20]

For our study of nanoscopical images this is indeed very interesting. We see images everywhere, every day. We know that we do, even if most of the images are perceived subconsciously. To release scientific images, and more specifically, nanoscopic images to the general public as representations are problematic. The images are very advanced but could be perceived as something closer to simple. As I searched for my own three images for my case study I had difficulties finding images of a good quality that was confirmed to be nanoscopical, and in several instances the text related to them was so advanced I had more trouble understanding what I was seeing after reading it.

Tapping into the topic of the public's reception of images is Max Liljefors in *Legitimizing ESS: Big Science as a collaboration across boundaries* edited by Thomas Kaiserfeld and Tom O´dell. In this text about the ESS (European Spallation Source) there is the problem of not delivering factual information to the public, but rather sharing information that will instead make the mind form some kind of understanding. Metaphors are used to describe the ESS, comparing it to, for instance, a microscope, when it is not. Microscopes are just the closest related thing that the general public knows well enough to be able to visualize what ESS might be, and become. Visualization also seems to be the key to understanding, I have used it plenty myself in this thesis and the reader will notice many metaphors and comparisons throughout that are present to create pictures, and imaginations. Although it creates as many problems as it does solutions to use metaphors, I for one still believe them to be more than helpful. It is difficult for us to make up our minds with nothing to go on, and to create relations to previously used tools can help. That being said it is also good to reflect on

[20] Bruhn, Matthias & Dünkel, Vera, 'The Image as Cultural Technology' in Elkins, James (red.), *Visual literacy*, Routledge, New York, 2008, pp. 165-178, here see p. 165.

what kind of understanding I create for you when explaining visualisation, images, and text the way that I do.[21]

Using a language full of metaphors and similes gives my text a cultural relation and interpretation that might not agree with all readers. Basically what I am doing with these metaphors is creating an understanding that is valuable for this thesis only. This breaches the training of the spectators eye, as Bruhn and Dünkel interjects is rarely incorporated in publications anymore. In scientific texts, and especially texts regarding microscopes, there used to be instructions for the reader on how to frame and interpret observations. Now the reader has to make up his mind largely on his own based on the poetic, colourful or vivid language of the author.[22]

But what have I learned of visual literacy from all this? I have learned that it is difficult to label observations of images as reading since reading is so strongly connected to text. I have learned that images are a great visual aid even when not understood, and I have learned that the intentional messages sent and received in regard to the nanoscopical images can be misinterpreted (partly due to the metaphors used in relation to them). My ability to read text also affects how I read images, and this shows in my visual literacy of nanoscopical images. Because I was not able to fully understand all captions related to my case studies it made me close to scientifically illiterate, making me read the images differently from someone understanding the text. This is why I also set out to learn the scientific part of the technical tool and the production of the images, to change my reading. In the following chapter I will explore the invention of the tool that produced my three images, the nanoscope, because it is, to use (delightfully flawed) metaphors, our microscope, our camera.

[21] Liljefors, Max; 'Believing in the ESS: Scale, vision and pioneering' in O´Dell, Tom & Kaiserfeld, Thomas, *Legitimizing ESS [Elektronisk resurs] : Big Science as a collaboration across boundaries*, Nordic Academic Press, 2014, pp. 187-203 here see p. 187, 189, 190.
[22] Bruhn, Matthias & Dünkel, Vera, 'The Image as Cultural Technology' in Elkins, James (red.), *Visual literacy*, Routledge, New York, 2008, pp. 165-178, here see p. 167-168.

Chapter 4 The nanoscope.

It is now time for us to gain some knowledge about how the images came to be. I am starting this journey by studying the creation of the nanoscope. Being the development of microscopes nanoscopes are new and still fairly hard to grasp, and to explain, especially without comparing them to their predecessors. I have made a good attempt though of not intertwining the invention of nanoscopes with the history of microscopes.

The journeys of three inventors.

In order to understand the technical instrument I have chosen to explore how the nanoscope was invented. For this I used the article published by *Nobelprize.org* (in cooperation with The Royal Swedish Academy of Sciences) explaining in an easily read, popular science way the background of the invention, and its inventors. Interestingly there are two texts available regarding this topic. One is the popular science one, a seven page article with easy to understand illustrations, the other a seventeen pages long text with mathematical equations, illustrations and charts. The easier article that I have chosen is also the one being made available as a suggestion for further reading in relation to the press release announcing the Nobel Price winners.

Eric Betzig, Stefan W. Hell, and William E. Moerner are the three men responsible for inventing the nanoscope, earning them a Nobel Prize in chemistry each in 2014. By realising that shining a light on an object you wish to observe is fruitless if you also wish to see objects smaller than half a wavelength of light they manged to create a new way of overcoming the obstacle holding them back. As it is all about reaching the inside of the cells, they came up with the idea of lighting cells up from within using fluorescent genes.[23]

Stefan Hell made way for the STED (stimulated emission depletion) microscope when he realized, while reading about spontaneous emission, that it could be possible to scan over samples using a kind of nano-flashlight. In STED microscopy a laser scans over a cell

[23] Fernholm, Ann, 'How the optical microscope became a nanoscope', http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2014/popular-chemistryprize2014.pdf, 2014(accessed 25 May 2016), p. 1.

prepared with a fluorescent gene twice, once to put out all fluorescence in the cell except those on the tiniest nanometre level, and a second time to register the positions of the glowing lights that are left. Because the scientists know exactly where the light of the laser meets the cell, they can calculate the position of the small glowing dots in the cell. Using this Hell managed to image an E-coli bacterium at a resolution never before seen in the year 2000. [24]

The other awarded principle created by Eric Betzig and W. E. Moerner independently is the single-molecule microscopy. Here the cell that you wish to observe is inserted with fluorescent proteins at an even distance of 0.2 micrometres. This spacing has been chosen because 0.2 micrometres is roughly the same as half a wavelength of light. A weak light pulse makes the fluorescent proteins glow, and they are let to glow until faded. The procedure gets repeated over and over at new subgroups of proteins until the whole cell has been lit up. The blurred images taken are then mathematically calculated using probability theory, and selected thereafter, before being superimposed into one high resolute image of a cell. This principle creates a higher resolution by merging several images into one.[25]

The first to measure the light absorption of a single molecule in the year of 1989 was W. E. Moerner. While other scientists focused on studying a vast amount of molecules at once, Moerner wished to get to the single molecule as a means of making the molecules less average. Building his work on the previously Nobel Prize awarded discovery of green fluorescent protein he was able to mark single cells revealing their exact positions. The green protein was extracted from a jellyfish and inserted to other proteins using gene technology, and the fluorescent protein was successfully used because it would make proteins inside living cells visible without harming or killing the cell (which was a problem for previous attempts). [26]

A version of the green fluorescent genes could also be activated, and re-activated at will as Moerner discovered. He shone light of different wavelengths at the protein before coming to the conclusion that light of wavelength 488 nanometres would make it glow, and that light of wavelength 405 nanometres would recharge it. Recharging did not make the fluorescent protein glow however, the protein needed to be exposed to the light of wavelength 488

[24] Fernholm, Ann, 'How the optical microscope became a nanoscope', http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2014/popular-chemistryprize2014.pdf, 2014(accessed 25 May 2016), p. 2-3.
[25] Fernholm, Ann, 'How the optical microscope became a nanoscope', http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2014/popular-chemistryprize2014.pdf, 2014(accessed 25 May 2016), p. 4-6.
[26] Fernholm, Ann, 'How the optical microscope became a nanoscope', http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2014/popular-chemistryprize2014.pdf, 2014(accessed 25 May 2016), p. 3-4.

nanometres again for that to happen. The protein was then put in a gel, spaced out at a distance wider than 0.2 micrometres (which is the diffraction limit, the limit for how small an object a microscope can observe). With this distance between the glowing proteins even a regular microscope could achieve a higher resolution than previously before thought possible.[27]

The spacing of the protein means that the glowing fluorescent dots do not get obscured by each other. They are separated and easier to observe than they would have been if appearing to be clustered together.

Eric Betzig, working on something similar to Moerner started off in the 1990´s by developing near-field microscopy. In near-field microscopes the extremely thin tip was placed as close to what was being observed as possible, usually just a few nanometres from the object. This also broke the diffraction limit but would not produce images that showed structures deeper within the cell, and it could not be improved that much further.[28]

Betzig then contemplated making molecules glow in different colours. The colours would separate the molecules from each other without causing confusion or make the image too obscure. One image per colour was produced before being merged into one whole complete view of the cell. The fluorescent proteins of every colour were spaced out much in the same way as Moerner had, at 0.2 micrometres, so that when the images of the different colours were put together as one the result was higher than the diffraction limit. Betzig´s real breakthrough came in 2005 when he discovered a fluorescent protein that could be activated at will, much like the one Moerner discovered, making him realize that the small glowing dots did not have to be in different colours at all, it was simply enough for them to light up at different times.[29]

It became obvious to me from this description of the nanoscope and how it was invented that I need to understand how light, fluorescence, and lasers work (at least in some basic sense) before I can understand how the images are produced. In the following chapter I will summarize some of the aspects of light that I found most important to understand to be able to grasp the complexity of the nanoscope.

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[27]Fernholm, Ann, 'How the optical microscope became a nanoscope', http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2014/popular-chemistryprize2014.pdf, 2014(accessed 25 May 2016), p. 4.
[28] Fernholm, Ann, 'How the optical microscope became a nanoscope', http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2014/popular-chemistryprize2014.pdf, 2014(accessed 25 May 2016), p. 4.
[29] Fernholm, Ann, 'How the optical microscope became a nanoscope', http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2014/popular-chemistryprize2014.pdf, 2014(accessed 25 May 2016), p. 4-6.

Chapter 5 Light.

My three images are produced by light interacting with light, by lasers scanning over fluorescence, quenching it or making it glow. This is why light is so important for my understanding of how the images are made. For this chapter I have chosen to weigh up the scientific explanations provided by professor of physics Vlatko Vedral, and theoretical physicist Girish S. Agarwal (et. al) with the more pedagogical and popular science explanations provided by theoretical physicist Stephen Hawking and his co-writer physicist, and screenwriter Leonard Mlodinow. Vedral´s book *Modern foundations of quantum optics* is a book for students, Agarwal´s *Selected papers on resonant and collective phenomena in quantum optics* is a highly complex collection of papers best understood by other scientists, and Hawking and Mlodinow´s *The grand design* is a book available to buy for the general public as leisure reading at the nearest Pocket Shop.

The properties of light

To start with, light likes to travel the shortest distance possible, meaning, preferably, in a straight line. As it travels it encounters obstacles (like lenses, windows and such), these obstacles are called refractive surfaces, they do not hinder the light but instead serves to make it extremized, meaning that the light could become either minimized or maximized from passing through it. The extrimization is an uncertainty principle keeping the options open for the lights speed to change either which way. This means that light interacts with whatever it might pass through and also that the obstacle changes it in some way. Being able to mathematically calculate the speed of light and how it travels helps positioning of for instance stars, but in a way also of glowing molecules in a nanoscopical image.[30]

Another property of light is spreading. Spreading is exactly what it sounds like; it means that the light, although preferring to travel in a straight line, does not stay completely straight. It bends around corners and creates, as one could say, rays or cones, widening as the distance increases.[31]

[30] Vedral, Vlatko, *Modern foundations of quantum optics*, Imperial College Press, London, 2005, p. 4-5.
[31] Vedral, Vlatko, *Modern foundations of quantum optics*, Imperial College Press, London, 2005, p. 6-7.

The spreading would easiest be explained by lights wavelike qualities. The mathematician and physicist Christiaan Huygens believed that if light were not a wave, and instead made up of particles, then those particles would collide when beams were crossed. As it is they simply pass through each other. Physician Thomas Young then created the famous double slit experiment to observe why nothing happens when two beams meet. He noticed dark and light patterns emerging on the screen he had placed behind his lit up slits.[32]

In order to understand how theses rings appear I have relied on the explanation provided by Steven Hawking and Leonard Mlodinow in their popular science book *The grand design*. All waves can be identified by their hills and valleys, and light waves are no different. When the waves meet and collide the hills and valleys either reinforce or cancel each other out, which is called interference. If the interfering waves are both at a hill they create a larger wave, and if a hill meets a valley they cancel each other out. If we make positive charges (hills) 1, status quo ante bellum (calm water) 0, and negative charges (valleys) -1 we get the familiar equations 1 + 1 = 2 (for constructive interference), and 1(+) - 1 = 0 (for destructive interference).[33]

It would be easy to assume that the particles and waves only occur when the photons are plenty, as in a beam of light, but that has been shown not to be the case. Even when photons are fired singularly, they have been known to travel in waves, up and down hills and valleys. This shows that photons do not just go with the flow, or fall under peer pressure; they actually prefer to travel that way even individually.[34]

Understanding that light moves in waves have led to a series of important discoveries, one of which is that light is also an electromagnetic wave. The reasoning behind the discovery, thought up by scientist Michael Faraday, was that if an electric current could bring about a magnetic field, then the opposite should be possible as well, a magnetic field should be able to bring about an electric current.[35]

According to Hawking and Mlodinow electromagnetism is not just responsible for all of chemistry and biology, but is also one of the four founding forces of nature together with gravity, weak nuclear force and strong nuclear force. This makes it important for us to know that light is part of the electromagnetic force. The general behaviour of electromagnetism is the same as that of magnets. Remember how you tried to merge two magnets with the same polarization, and how it never worked? That is just how electromagnetism is. Opposites

[32] Vedral, Vlatko, *Modern foundations of quantum optics*, Imperial College Press, London, 2005, p. 5.
[33] Hawking, S. W. & Mlodinow, Leonard, *The grand design*, Bantam, London, 2011, p. 73.
[34] Hawking, S. W. & Mlodinow, Leonard, *The grand design*, Bantam, London, 2011, p. 90.
[35] Hawking, S. W. & Mlodinow, Leonard, *The grand design*, Bantam, London, 2011, p. 113, 116.

attract while similarities rejects. On a smaller scale, like the ones we are interested in, electric forces between for instance molecules dominate. While electric forces (even though they are long-range and much stronger than gravity) between larger bodies like planets would simply cancel each other out.[36]

Electromagnetism also happens to be the first force to be quantised in the war-torn years of the 1940s in what is called quantum electrodynamics (or QED for short). In quantum theories we take things even deeper, make them more detailed. It is here that we discover that light is made up of particles behaving like waves.[37] [38]

It is time to add another aspect of quantum physics to our understanding of light, the uncertainty principle. The term first formulated by Werner Heisenberg in 1926 tells us that we cannot measure all forms of data at once. For instance, we cannot measure speed and position simultaneously with precision.[39]

Much as light prefers to travel in short somewhat "straight" rays we now have to consider the paths taken to reach each destination. According to physicist Richard Feynman a particle samples every possible way it can travel from A to B. When sampled the paths each get a collected number, this is called a phase. All information from all phases is added together before being squared to reach the right probability, the probability that B will be reached.[40]

For quantum theories everything is made more difficult because of the fact that all information, no matter how detailed, powerful or precise, cannot be predicted with an absolute certainty. The uncertainty principles do help to widen our views concerning conditions and possibilities, but they do also undermine the outcome in some ways. It is like adding a question mark in 1 + 1 = 2, or a maybe between yes and no.[41]

Quantum physics also does us a great favour by recognizing that observations can be interactions. We shine a light on all that we wish to see, regardless of its size, and this gets effects. When light is shone photons are fired. Photons are force carriers (bosons) that get absorbed by whatever they hit, changing its route. For a larger object not much changes, just as you probably would not fall to the ground if someone threw a single blueberry at you, but for a smaller particle there is a documented effect. The effect is also more prominent using

[36] Hawking, S. W. & Mlodinow, Leonard, *The grand design*, Bantam, London, 2011, p. 132-133, 139.
[37] Hawking, S. W. & Mlodinow, Leonard, *The grand design*, Bantam, London, 2011, p. 133-134.
[38] Vedral, Vlatko, *Modern foundations of quantum optics*, Imperial College Press, London, 2005, p. 9.
[39] Hawking, S. W. & Mlodinow, Leonard, *The grand design*, Bantam, London, 2011, p. 91.
[40] Hawking, S. W. & Mlodinow, Leonard, *The grand design*, Bantam, London, 2011, p. 99.
[41] Hawking, S. W. & Mlodinow, Leonard, *The grand design*, Bantam, London, 2011, p. 92.

bright light than faint and lasers, as you will see, is nothing if not bright.[42]

The properties of lasers

Laser, being short for Light Amplification by Stimulated Emission of Radiation, is a highly intense light, about 10^8 (that is 100 000 000) times higher than that bulb in your kitchen lamp. It is the primary light for production of nanoscopical images, and the light that has been most important to understand the interaction between light and matter. Laser light is bright, of nearly one single colour, short, easy to direct to where you want it, and coherent meaning able to be connected (not physically) between points in waves. There are two different forms of coherence, spatial and temporal. If I should explain the two then temporal is walking along a garden path twice at different times and notice that the rock that you stumbled over the first time is still there at the same place to make you trip a second. Spatial however is to have a friend with you walking along another path, as you reach that rock that keeps making you fall your friend trips over a stone as well, at the same time but in a different pathway.[43] [44]

Lasers can be described as a box with mirrors containing moving atoms. However unlike our kitchen lamp, where light pours out of the bulb every which way almost completely uncontrolled, the laser makes all phases the same, enabling it to be controlled. This means that lasers have the ability to interact with matter, such as a cell, with great precision.[45] [46]

What lasers are able to do is to make light more and more compact. It eventually becomes so compact that no more light can be absorbed by the atoms, resulting in the light starting to shine right through. In this case the laser is turned off and the atoms are allowed to release the energy through what is called spontaneous emission before being able to be used again. Emission and absorption of light is fairly easily explained using quantum mechanics. Imagining two levels with an atom at the first level, stimulated absorption would mean it moves to the second level by absorbing light. If the atom then emits a photon it goes back to the ground level in what is called stimulated emission.[47] [48]

[42] Hawking, S. W. & Mlodinow, Leonard, *The grand design*, Bantam, London, 2011, p. 103-105.
[43] Vedral, Vlatko, *Modern foundations of quantum optics*, Imperial College Press, London, 2005, p. 17-18.
[44] Vedral, Vlatko, *Modern foundations of quantum optics*, Imperial College Press, London, 2005, p. 46.
[45] Vedral, Vlatko, *Modern foundations of quantum optics*, Imperial College Press, London, 2005, p. 14, 18.
[46] Vedral, Vlatko, *Modern foundations of quantum optics*, Imperial College Press, London, 2005, p. 46.
[47] Vedral, Vlatko, *Modern foundations of quantum optics*, Imperial College Press, London, 2005, p. 111.
[48] Vedral, Vlatko, *Modern foundations of quantum optics*, Imperial College Press, London, 2005, p. 40-43.

When creating intensity it needs to be known that an amount of atoms give out a number of waves at different times. This results in different phases, meaning that even though the frequency is the same, the intensity will be low. Enabling light to be seen better is phase matching, phase matching match all waves of a frequency together, creating a stronger light. For lasers one can also use mode-locking to get small pulses of light at high intensities. Mode-locking can be made actively by charging the losses through the mirrors and passively by creating a bending that absorbs within the cavity.[49] [50]

Like speed and volume in the theories of light, electric and magnetic fields cannot be measured simultaneously. It also means that a photon is not a particle as we are used to understanding them as a photon is not so easily localized and positioned. Photons are also part of what is called bosons, bosons are one of the two types of particles in nature, they are the ones which bunch together while the other type of particles, called fermions, are the ones which anti-bunches (as Vedral describes it).[51] [52]

In lasers there is such a thing as a beam splitter sending the photon through the cavity, at the beam splitter the photon has two choices, left or right. There is a fifty percent chance of the photon going either which way, and it both can and does go both.[53]

The timespan for photons and atoms to interact is set by the charged atoms and is depending on how long they can stay excited. If the light wave is longer than the lifetime of the atom, the atom interacts with the wave several times giving a greater understanding of time in regards to the given fluorescent radiation. The fluorescent glow emitted from an atom can also be observed even when the atoms lifetime is only some tens of nanoseconds, and thanks to tunable dye lasers it is possible to observe spectres with narrower expanse than what has been considered natural.[54] [55]

There are several other aspects of lasers that could be valuable to know, but I have chosen to present a brief (and very simplified) summary of the information that I thought most vital. This selection was made to get an overview of what lasers are, and perhaps can be. Before moving on to florescence I will finish this section by listing of the last aspects of lasers

[49] Vedral, Vlatko, *Modern foundations of quantum optics*, Imperial College Press, London, 2005, p. 80.
[50] Ibid. p. 69, 70.
[51] Ibid. p. 151.
[52] Ibid. p. 132, 138.
[53] Ibid. p. 149.
[54] Hong, C. K. & Mandel, L., 'Theory of parametric frequency down conversion of light' in Agarwal, Girish S. (red.), *Selected papers on resonant and collective phenomena in quantum optics*, SPIE Optical Engineering Press, Bellingham, 1995, pp. 145-154, here see p. 145.
[55] Fougères, A; Mandel, L. & Noh, J. W., 'Measurement of the Quantum Phase by Photon Counting' in Agarwal, Girish S. (red.), *Selected papers on resonant and collective phenomena in quantum optics*, SPIE Optical Engineering Press, Bellingham, 1995, pp. 168-171, here see p. 168.

that I found important. Spectrums of light are dependent on time. Atoms cannot emit photon after photon without being recharged. There is energy in the light field even when there are no photons around, and light and matter interact by exchanging charges.[56] [57] [58] [59] [60]

Fluorescence.

It is thanks to the fluorescent genes that the diffraction limit was circumvented and it was the fluorescent genes that made microscopy into nanoscopy.[61]

Most often used in a similar fashion as Hell used it for his STED microscope, all fluorescence that is not wished to be observed tends to be quenched by a laser beam, making the remaining glow much clearer.[62]

In a much more technically advanced description of the nanoscope found in the scientific journal *Science*, we learn that the fluorescence is beyond helpful in positioning proteins, but that the proteins are still limited by the ever so annoying diffraction limit. If a group of glowing molecules are tightly packed together within the resolution limit of a microscope they first need to be separated by distinguishing optical characteristics. The position of one single molecule is then determined more precisely by finding its centre of fluorescent emission with the help of a calculation of the measured photon distribution in relation to the resolution limit of your instrument.[63]

Thinking about this I believe that it is not as complicated as it sounds. Let us say that you are lying in your bed at night, your glasses at the bedside table, and your near-sighted

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[56] Vedral, Vlatko, *Modern foundations of quantum optics*, Imperial College Press, London, 2005, p. 141.
[57] Vedral, Vlatko, *Modern foundations of quantum optics*, Imperial College Press, London, 2005, p. 157.
[58] Kien, Fam Le; Pernigo, M. & Schleich, W., 'Nonclassical state from two pseudoclassical states' in Agarwal, Girish S. (red.), *Selected papers on resonant and collective phenomena in quantum optics*, SPIE Optical Engineering Press, Bellingham, 1995, pp. 172-187, here see p. 175.
[59] Siegman, A. E., 'Excess spontaneous emission in non-Hermitian optical systems. II. Laser oscillators.' in Agarwal, Girish S. (red.), *Selected papers on resonant and collective phenomena in quantum optics*, SPIE Optical Engineering Press, Bellingham, 1995, pp. 203-207, here see p. 207.
[60] Boyd, W. R. & Gaeta, A. L., 'Quantum Noise in Phase Conjugation' in Agarwal, Girish S. (red.), *Selected papers on resonant and collective phenomena in quantum optics*, SPIE Optical Engineering Press, Bellingham, 1995, pp. 208-211, here see p. 211.
[61] Fernholm, Ann, 'How the optical microscope became a nanoscope', http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2014/popular-chemistryprize2014.pdf, 2014 (accessed 25 May 2016), p. 1.
[62] Fernholm, Ann, 'How the optical microscope became a nanoscope', http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2014/popular-chemistryprize2014.pdf, 2014 (accessed 25 May 2016), p. 2.
[63] Betzig, Eric, et al., 'Imaging Intracellular Fluorescent Proteins at Nanometer Resolution', *Science*, Vol. 313, Issue 5793, Autumn, 2006, http://science.sciencemag.org/content/313/5793/1642.full, (accessed 25 May 2016), pp. 1642-1645.

gaze directed towards the ceiling. In the ceiling there are a couple of hundred luminous stars. Some of them are bigger, and some are smaller; some are close together, and others are not. There is one that you like to look at in particular; it is a small star that glows orange. However you cannot make it out because it is in a cluster of other glowing stars, so you reach for your glasses. With your glasses on you find the orange star, using the first step in positioning, separating the star from the others by its characteristics. Then you narrow your eyes so that you can make out the centre more clearly, that is where the orange glow is the strongest, this is the second step. You know that you can only see so far, even with your glasses on, so the star is not that far away. This is the third step, the limit of your tool. Using your logical part of the brain you quickly figure out that the photons emitted from your favourite star in mathematical relation to your sight using the glasses can help you figure out the stars exact position in your ceiling. However, the hour is late and the calculation is an advanced one, you decide to stick with counting sheep.

Chapter 6 Producing nanoscopical images.

In the scientific journal *Science* published by the American Association for the Advancement of Science, Eric Betzig, et al. presents a much more difficult explanation of how a nanoscope works.

I have tried to see if I can produce an image in a nanoscope, in theory, using their descriptions. The first thing I would need is something to observe, I think a cell would be preferable. I then need to decide if I wish to have a look at the whole cell or a cryosection. I went with the whole cell for simplicity. We now apply a fluorescent protein near the surface of the cell in parts measuring $\sim 50 - to\ 80\ nm$. Because it is possible to detect up to 10 000 photons from a single fluorophore I need to eliminate background noise as not to be distracted. The best way to get rid of the disturbances such as the background noise or auto fluorescence is to have the cell imaged by TIRF (total reflection fluorescence) microscopy onto an EMCCD (electro-multiplying charge couple device) camera.[64]

When all preparations are done I start the process of making the fluorescence glow. Depending on how sparsely I have distributed my protein within the cell, I have to redo the action of exciting, measuring and bleaching the fluorescent protein in about 10 000 to 100 000 image frames until we have reached the highest results. In general the time for each frame is $\sim 0{,}5\ to\ 1{,}0s$, meaning that it would take me two to twelve hours to get a complete set of images ready to be superimposed. When all of my best images are turned into one I can see up to 1 000 000 localized molecules.[65]

For knowing the small glowing dots exact position there is a quite advanced technique called photo activated localization microscopy (PALM). I have decided to quote it below as it serves as an example of the difference in information provided for readers. In the texts covering popular scientific explanations of the topic this mathematics is not even present, while in the article 'Imaging Intracellular Fluorescent Proteins at Nanometer Resolution' in *Science* written for fellow scientists it is thoroughly explained.

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[64] Betzig, Eric, et al., 'Imaging Intracellular Fluorescent Proteins at Nanometer Resolution', *Science*, Vol. 313, Issue 5793, Autumn, 2006, http://science.sciencemag.org/content/313/5793/1642.full, (accessed 25 May 2016), pp. 1642-1645.

[65] Betzig, Eric, et al., 'Imaging Intracellular Fluorescent Proteins at Nanometer Resolution', *Science*, Vol. 313, Issue 5793, Autumn, 2006, http://science.sciencemag.org/content/313/5793/1642.full, (accessed 25 May 2016), pp. 1642-1645.

> When the xy frames from any such image stack are summed across time t, the molecular signals overlap to produce a diffraction-limited image […] similar to that obtained by conventional TIRF, in which all molecules emit simultaneously […]. However, when the data are plotted in a multidimensional volume xyt […], the signal from each molecule m is uniquely isolated and can be summed at each pixel and across all of the frames in which it appears. This result […] is then fitted using a robust nonlinear least squares algorithm to an assumed Gaussian PSF of free center coordinates x_o, y_o […], yielding coordinates x_m, y_m for the location of the molecule, with a position uncertainty $(\sigma x,y)_m$. Finally, each molecule is rendered in a new xy frame as a Gaussian of standard deviation $(\sigma x,y)_m$ (rather than the much larger standard deviation s of the original PSF), centered at x_m, y_m […] and normalized to unit strength when integrated over all xy space. Thus, the superresolution image obtained by summing the rendered Gaussians associated with all localized molecules in the original image stack […] provides a probability density map where brightness is proportional to the likelihood that a PA-FP molecule can be found at a given location. [References to figures not included in the thesis deleted][66]

There is a problem with this form of imaging though. Choosing to light up fewer molecules increases the ability to position each glowing dot, and makes the images clearer, but also creates images with less complete information. Imagine that you are at a concert, sitting in a seat high up in the stands, looking down at the crowd. If we chose to only light up every other person or so in the crowd, the crowd would look smaller than it really is. You as an observer would get a clearer view of what kind of people are present, but you would also miss out on a lot of knowledge about the part of the audience that are currently not visible.[67]

There were of course different colours tested in the making of the nanoscopical images. For imaging cellular structures Betzig et al. focused on yellow colours because they were easier to see, brighter and clearer. The colour and protein was also easier to separate from background noise and other disturbances, and did not interfere as much with the cells structure or function.[68]

Betzig and his cowriters have in the article in *Science* included ideas for future works

[66] Betzig, Eric, et al., 'Imaging Intracellular Fluorescent Proteins at Nanometer Resolution', *Science*, Vol. 313, Issue 5793, Autumn, 2006, http://science.sciencemag.org/content/313/5793/1642.full, (accessed 25 May 2016), pp. 1642-1645.

[67] Betzig, Eric, et al., 'Imaging Intracellular Fluorescent Proteins at Nanometer Resolution', *Science*, Vol. 313, Issue 5793, Autumn, 2006, http://science.sciencemag.org/content/313/5793/1642.full, (accessed 25 May 2016), pp. 1642-1645.

[68] Betzig, Eric, et al., 'Imaging Intracellular Fluorescent Proteins at Nanometer Resolution', *Science*, Vol. 313, Issue 5793, Autumn, 2006, http://science.sciencemag.org/content/313/5793/1642.full, (accessed 25 May 2016), pp. 1642-1645.

that will improve nanoscopic image making. They suggest exploring methods for speeding up the time-consuming process by using brighter molecules, to use more types of fluorescence, and to work actively for photo stability. Also noticed is the problem of having a non-uniform background which makes it harder for scientists to position molecules and in addition they wish to suppress a phenomenon called blinking.[69]

On the bright side of nanoscopes, as opposed to the things that needs to be worked on, there is the ability to adapt the already existing tools to make them break the diffraction limit. All that is needed is a TIRF-capable microscope, appropriate lasers, filters, an EMCCD camera, acquisition, localization, and image rendering software.[70]

From this text I get a much better understanding of how a nanoscopical image is made. I suddenly understand how long it takes for an image to be made, how many components that needs to work, how many molecules I can actually see in an image (between 100 000 and 1 000 000) and I start to understand the nanoscopes flaws as well. I realize that just like I made a selection of information presented in this thesis scientists have had to make a selection of molecules to be lit up. It is quality over quantity.

In the next chapter I will consider the technological tool from a cultural point of view in order to understand the use of the nanoscope.

[69] Betzig, Eric, et al., 'Imaging Intracellular Fluorescent Proteins at Nanometer Resolution', *Science*, Vol. 313, Issue 5793, Autumn, 2006, http://science.sciencemag.org/content/313/5793/1642.full, (accessed 25 May 2016), pp. 1642-1645.

[70] Betzig, Eric, et al., 'Imaging Intracellular Fluorescent Proteins at Nanometer Resolution', *Science*, Vol. 313, Issue 5793, Autumn, 2006, http://science.sciencemag.org/content/313/5793/1642.full, (accessed 25 May 2016), pp. 1642-1645.

Chapter 7 Technology and culture.

I am moving away from the literacy and the science and onto the subject of technology in relation to culture. For this I have the help of Susanne Lundin and Lynn Åkesson who in their book *Amalgamations: fusing technology and culture* have problematized how we see technology.

Lundin and Åkesson, with the aid of Per-Markuu Ristilammi, explain that technological tools get their own personalities and independence. This almost making them into subjects rather than objects has influence on how we talk about the tools. The technological metaphors changes parallel to technological progress, and it is claimed by the authors that each historical period, and invention, had its own influence on speech; using the example of the brain which is still referred to as a hard drive or computer storing data.[71] [72]

I believe this to be happening with our nanoscope as well. The prefix nano was already in use, and have been in use for several years within the field of science. The prefixes micro and nano then got transferred and transformed when adapted to everyday speech. When talking outside the frames of science the words micro and nano are often used as an exaggeration describing something small, for instance in a joking manor like: your dog is so small it is microscopical.

An interesting aspect of technology, brought up in *Amalgamations: fusing technology and culture* is the idea of new technology as neutral. Lundin and Åkesson disagree with this idea and states that the divisions between the sexes, the generations and the classes can become completely transformed with the launch of a new technological tool. People can also be separated on the basis of who is involved in the making or use of the tool, and who is not. In fact, a lot of technology is seen as something that can be moved freely from wherever to wherever without causing any changes. In reality, though, all technology has to relate to

[71] Lundin, S. & Åkesson, L., 'Introduction. The Amalgamation of Technology and Culture' in Lundin, Susanne & Åkesson, Lynn (red.), *Amalgamations: fusing technology and culture*, Nordic Academic Press, Lund, 1999, pp. 7-17, here see p. 8-9.
[72] Ristilammi, P-M., 'The Bodily Eye. Reflections on the Era of the Stereoscope' in Lundin, Susanne & Åkesson, Lynn (red.), *Amalgamations: fusing technology and culture*, Nordic Academic Press, Lund, 1999, pp. 105-115, here see p. 105.

economic, moral, religious, and juridical systems.[73]

Thinking of our technological tool, the nanoscope, I would say that the questions and thoughts brought up by Lundin and Åkesson gives us a new dimension of contemplation. Most of us know that computers, smartphones and tablets have divided generations, but what of nanoscopes? Surely there must be some kind of division within the world of science, where older scientist might experience difficulties understanding or using such a tool, while younger scientists might adapt easier, but I do not know for sure. Division between genders are also interesting since the nanoscope was invented by three men. It is not a tool exclusively made for men, but I have in my research not come across many mentioning's of women using the nanoscope, none taking part in the invention, and very few to none writing about the topic (one of the few females writing about this is Jennifer Lippincott-Schwartz who *contributed* to the article about nanoscopes in *Science*).

Lundin and Åkesson, now together with Orvar Löfgren and Magnus Wikdahl, continue with the launch of new technology. When the technology is brand new there is an openness enabling users to play with the object. Both amateurs and experts are allowed to experiment with the tool, creating new uses or new perceptions about it. After some time though the new tool become mainstream and common, it gets integrated into everyday lives and loses that first exciting openness. Here Lundin and Åkesson are mostly referring to technological tools like cell phones, but for our nanoscopes, which are not designed to be used by the everyday man, there is another strong point, namely that some technologies are almost invisible and thought of as unproblematic by pretty much everyone except its users.[74] [75]

So, thinking about our nanoscope again makes me wonder if there ever was a play with its possibilities by anyone else than the scientists. I would dare say that nanoscopes are part of the technological tools that are quite invisible. It is not a tool that you can buy in any local shop, and many might not even be able to picture what a nanoscope looks like. Scientists are the chosen few who know what they are, but even amongst them there must be divisions (because there is more than one field that you can be a scientist in) with subgroups depending on how well you know the tool. In the research I have made for this thesis I have not come

[73] Lundin, S. & Åkesson, L., 'Introduction. The Amalgamation of Technology and Culture' in Lundin, Susanne & Åkesson, Lynn (red.), *Amalgamations: fusing technology and culture*, Nordic Academic Press, Lund, 1999, pp. 7-17, here see p. 9.
[74] Löfgren, O. & Wikdahl, M., 'Domesticating Cyberdreams. Technology and Everyday Life.' in Lundin, Susanne & Åkesson, Lynn (red.), *Amalgamations: fusing technology and culture*, Nordic Academic Press, Lund, 1999, pp. 40-62, here see p. 50-51.
[75] Lundin, S. & Åkesson, L., 'Introduction. The Amalgamation of Technology and Culture' in Lundin, Susanne & Åkesson, Lynn (red.), *Amalgamations: fusing technology and culture*, Nordic Academic Press, Lund, 1999, pp. 7-17, here see p. 11.

across a single private individual talking about the nanoscope, and its use. By that I mean that I have not come across any blogs, Tumblr posts or YouTube videos posted by non-scientists, and non-journalists, sharing their opinions of the tool in the way that you might see when for instance a new iPhone is launched.

While we in the previous chapter focused on the technical aspects of the images, and reading them, we have in this chapter learned more about the tool and its accessibility. Part of understanding the images is understanding the tool that produced them. Interestingly it seems as though it is not a priority for the man on the street to know exactly what a nanoscope looks like, and exactly how it works, it is good enough if we can picture something somewhat similar based on the metaphors we are fed as explanations. Although I do not mind metaphors because I believe them to be helpful, they are still difficult to relate to at times simply because one thing describes another.

Chapter 8 A deeper image study.

After having learned about visual literacy, the nanoscope, how the nanoscopical images are produced and how technological tools can be seen from a cultural standpoint I am now going to view my images once more. The images can be found either in the beginning of this thesis under chapter two or in the appendix. I will again tell you about what I can see and will then compare how my perceptions and visual literacy has changed. In this analysis I will also add the information about what the images really are picturing, as well as what kind of information was present in relation to them and where they were found.

No 1

The first image (**image 1.1**) that I studied, the one I called the "pill", is in fact an Escherichia coli bacterium. It was imaged by Eric Betzig at the Howard Hughes Medical Institute in Ashburn, Virginia, and shows receptor proteins in the E. coli. The image was taken from an article called 'Through the nanoscope: A Nobel Prize gallery' in the scientific journal *Nature*. It was chosen by me for its bright colours and its misleading simplicity, with one object pictured. The image also has a high quality and is confirmed to be nanoscopical which was a minimum requirement. The caption for the image was not difficult to understand and the article contained no other text worth mentioning as it was a picture gallery.[76]

Just knowing what the image is showing (an E.coli) changes my opinion of it. The bright, harmless, glowing dots suddenly transforms into something that could be potentially very harmful for my health. The colours that I would generally see as positive, happy colours are transformed into something more hostile. Like their glow has become a warning.

The size of the bacterium is also increasingly worrying now that I know what it is. Having something that is generally seen as negative enlarged makes me see it as much more of a threat. This single giant bacterium seems like it could wreak havoc with my entire well-being, even though I am well aware that it would take many more than just one E. coli to

[76] Van Noorden, Richard, 'Through the nanoscope: A Nobel Prize gallery', *Nature News*, article published as stand-alone on webpage, Autumn 2014, http://www.nature.com/news/through-the-nanoscope-a-nobel-prize-gallery-1.16129#/b1, (accessed 25 May 2016)

affect my health.

Having also learned that every single glowing dot is a molecule needing to be mathematically verified, as to establish their position makes me see the amount of work put into the making of the image, this E. coli bacterium is imaged using PALM (the technique for positioning the molecules as quoted on page 38). Because there is an uncertainty in all positioning the small dots that we are observing might actually not be in that exact position at all making me wonder how far off it could be possible for them to be.

The time it takes to produce a nanoscopical image is two to twelve hours because of the need to excite and re-excite the fluorescence in molecules, and also because every single glowing dot needs to be measured thoroughly. This image was not just taken and shared like any photograph. Having learned all this I start to look deeper into the image, trying to see the molecules, trying to grasp their number. There seems to be an infinite amount, but I know that there is likely not more than a million. My eyes search for the smallest glowing dot, but I cannot find one that I believe to be smaller than any other.

I still see the image as clear and not blurred, but with my new understanding the clarity gets deeper meaning. Before it meant that I could see the "pill" better, now it means that every single glowing dot is visible, and I start to see the exosomatic vision because I know that this clarity in an image of something so tiny is produced by a tool. My centre of attention drifts from reading the image from top to bottom to looking straight into the E. coli, ignoring the black background, and the shape.

The colours are also understood differently because I know that they are different spectra used to enable the nanoscopic view. The image was made by picturing one colour at the time and then submerged into one full image with all colours visible. I cannot say what kind of software was used in the making of the image, and if the colours are really enhanced or not, but I would say that it is most likely that they are. It would also explain the lack of glow around the edges of the bacterium if it was trimmed to look neater.

The image still does not hold any indication to scale other than the fact that it is nanoscopical, but I have learned that nano in this sense means so small it can barely be verified by the math it relies on. The relationship between math and image in this case is problematic because the math contains question marks and possibilities in the form of uncertainty and the image cannot be validated with anything else. So the math proves the image, and the image proves the math in return.[77]

[77] Elkins, James, *Six stories from the end of representation: images in painting, photography, astronomy, microscopy, particle physics, and quantum mechanics, 1980-2000*, Stanford University Press, Stanford, Calif.,

No 2

The second image (**image 1.2**) is a human brain tumour pictured by Stefan Hell using both a confocal microscope and a STED microscope. The blurred part to the left of the image is the confocal microscope while the much sharper part to the right is the STED. This image is taken from the same article as **image 1.1**, the E. coli, above.[78]

Looking at this image a second time I interpret the red threads differently. Before I thought of them as closer to roads, now I relate them to nerves, and veins. What they are exactly is not mentioned in the caption.

My attention moves from left to right taking in the difference between the blurred part of the image and the clear. Elkins states in *Six stories from the end of representation: images in painting, photography, astronomy, microscopy, particle physics, and quantum mechanics, 1980-2000*, that blur is something always tried to be removed, making the slimmer left side of my image a representation of something that should be avoided. As the parts of the image are actually produced by two different microscopes it makes me see the development from old methods to new. There is still no explanation for if the scale visible in the lower right corner of the clear side of the image is the same as for the blurred side, but I would assume that it is. It would make sense to have the same scale for both parts, but to have the parts imaged using different tools. The scale 1 µm actually means one micrometre. It is hard to really grasp how small this is but in somewhat easier to understand terms it would mean that the image is shown in a scale that is one thousandth of a millimetre.[79] [80]

The colours do not gain any new meanings in themselves for this image, as I see them as neither hostile nor particularly friendly. The choice of red and green could probably have been made because they are primary colours complementary to each other, increasing clarity, but there is no explanation for why these two colours were used.

2008, p. 91.

[78] Van Noorden, Richard, 'Through the nanoscope: A Nobel Prize gallery', *Nature News*, article published as stand-alone on webpage, Autumn 2014, http://www.nature.com/news/through-the-nanoscope-a-nobel-prize-gallery-1.16129#/b1, (accessed 25 May 2016)

[79] University of Wisconsin-Madison, MRSEC Educational Group, 'Size and scale', http://education.mrsec.wisc.edu/36.htm, 2016, (accessed 25 May 2016).

[80] Elkins, James, *Six stories from the end of representation: images in painting, photography, astronomy, microscopy, particle physics, and quantum mechanics, 1980-2000*, Stanford University Press, Stanford, Calif., 2008, p. 57.

No 3

The third, and final, image (**image 1.3**) is from another scientific journal called *Science*. The image was published in an article called ' Imaging Intracellular Fluorescent Proteins at Nanometer Resolution', and like the previous two images it was chosen for its high quality and it being confirmed to be nanoscopical. The caption and the text of the article were very advanced and difficult to understand as they were written by scientists having themselves first-hand experience in producing the image. It contained details about what was being shown that my other case studies did not.[81]

The image is divided into four and labelled A, B, C, and D. Thanks to the caption I know that A and B are both picturing the same thing, namely a section within a cell. A is however a TIRF image while B is a PALM. The parts framed by white squares in B are enlarged in C, and D, where the larger square becomes C, and the smaller square becomes D.[82]

There are four different scales available in this image. Sections A and B both have the same scale of 1.0 µm, meaning that the TIRF and PALM images are pictured at a thousandth of a millimetre. Image C however is imaged at 0.5 µm, making it equal to 500 nanometres, and considering that a nanometre is a millionth of a millimetre it is pretty tiny. The framed part of C is imaged at 100 nanometres, and D is finally imaged at 200 nanometres.[83]

The differently scaled images serve as to show specific parts of the cell at different magnitudes. This shows progress in four steps, from blur to clarity, and beyond diffraction limits. The first blurred image, according to me, basically only serves to show the brilliance of the other three, because without the blur, the clarity would not seem as special.

There was no indication in the text to why the colour is red. It does say in the article that experiments have been made with different colours, and that the colour, or maybe I should say fluorescent protein, used on this cell is called PA-FP Kaede, but I was under the impression after having read the article that this would make the cell glow yellow. However, this could be a misunderstanding caused by the advanced wording of the text and me not

[81] Betzig, Eric, et al., 'Imaging Intracellular Fluorescent Proteins at Nanometer Resolution', *Science*, Vol. 313, Issue 5793, Autumn, 2006, http://science.sciencemag.org/content/313/5793/1642.full, (accessed 25 May 2016), pp. 1642-1645.
[82] Betzig, Eric, et al., 'Imaging Intracellular Fluorescent Proteins at Nanometer Resolution', *Science*, Vol. 313, Issue 5793, Autumn, 2006, http://science.sciencemag.org/content/313/5793/1642.full, (accessed 25 May 2016), pp. 1642-1645.
[83] Convention-metric.org, 'um to nm Conversion Micrometre to Nanometre', http://www.conversion-metric.org/length/micrometer-to-nanometer, 2016, (accessed 25 May 2016).

having a scientific background. Nevertheless, the colours are not explained in a way that is for everyone to understand.[84]

For this image my centre of attention is, after gaining knowledge, more drawn to the last section, section D, than any of the others. This because D shows the clearest glowing molecules, which is what I am looking for in the image. Before I might not have been aware of what I was supposed to see, but now I know. I am supposed to see these tiny little glowing molecules, and understand that they are what the scientists have been trying to get at.

Comparing before and after, how do I read the images differently?

To start with I no longer consider myself scientifically illiterate (still not an expert either though). Gaining knowledge has helped me understand not just the images, but more importantly the texts related to the images. In some cases, like in the article for *Science* or in the book by Agarwal, I do not believe I would have understood more than half without learning about light and lasers. Maria Avgerinou makes a very valid statement when she says that the languages used by scientists, and specialists are not meant to be understood by the man on the street. The sections about light, and lasers were also mostly added to create an understanding for the advanced captions and texts directly related to the nanoscopical images, and, at first, not as much for the image analysis itself. However, all parts of the thesis affect my visual literacy, and the sections about light could advantageously be integrated for a more scientific observation of the images if one wishes.[85]

When comparing my first reading of my case studies and my second one, I realize that I have moved my focus from the main shape and colours to the glowing molecules. As I have learned that the image is made up of somewhere between 100 000 and 1 000 000 fluorescent molecules and that it is several images merged into one, I see the layers instead of the whole. I also try to look deeper, to find individual molecules instead of regarding them as “clouds” or “clusters”. My eyes move less over the images as well; I am more focused and know what to look for. Granted, I have seen the images before which makes it easier for me to focus on one specific part, as I have not completely forgotten where that part is, or how the image looks.

[84] Betzig, Eric, et al., ‘Imaging Intracellular Fluorescent Proteins at Nanometer Resolution’, *Science*, Vol. 313, Issue 5793, Autumn, 2006, http://science.sciencemag.org/content/313/5793/1642.full, (accessed 25 May 2016), pp. 1642-1645.

[85] Avgerinou, Maria D. & Pettersson, Rune, ' Toward a Cohesive Theory of Visual Literacy ', *Journal of Visual Literacy*, Volume 30, no. 2 Autumn, 2011, https://www.researchgate.net/profile/Maria_Avgerinou/publication/267988880_Toward_a_Cohesive_Theory_of_Visual_Literacy/links/54d9e8ea0cf24647581fc28b.pdf, (accessed 25 May 2016), pp. 1-19, here see p7.

Avgerinou again makes a good point by drawing upon the works of Alain Berthoz, stating that what we actually see in images is dictated by our expectations of what we will observe.[86] [87]

I knew that the images where small, but it was not until I found a definition for micrometre, and nanometre that I understood just how tiny. Compared to a metre a micrometre is one millionth of a metre and a nanometre is one billionth of a metre. This makes the images containing indications to scales much more interesting. I can easily navigate through **image 1.3** as it zooms in to specific sections of a cell, and the difference between blur and clarity is much more interesting when I realize that they are at the same scale. Having a blurred and clear image in the same scale next to each other puts the technical tool in a higher focus. It means that I can see what progress have been made for the production of the image.[88]

As for the intentional messages sent out by my case studies, I have found no clear confirmation of what they should be. Scientific images of this kind is not as clear in what they wish to say as for instance an advertisement image of a can of soup. The message sent and received for the can of soup would most probably be "buy this soup", there is no such easy message in my nanoscopical images. At least not one that I have received. All messages that I have received have in fact been followed by questions and question marks. Even after gaining an understanding I cannot say for sure what the three images wish to tell us. For this Avgerinou says that how we understand the messages also affects how we see their source. Seeing the images as something only partly understandable therefore also makes me see the nanoscope and the science involved in its creation as not fully understandable. Meaning that I get a feeling of being excluded.[89]

Having noticed the colours less during my second observation, I feel the need to consider them once more here. Quoting Avgerinou and Pettersson, here referring to L. J. Kensicki, in their article in *Journal of Visual Literacy,* 'Photographs and bright, warm colors

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[86] Betzig, Eric, et al., 'Imaging Intracellular Fluorescent Proteins at Nanometer Resolution', *Science*, Vol. 313, no. 5793, Autumn, 2006, http://science.sciencemag.org/content/313/5793/1642.full, (accessed 25 May 2016), pp. 1642-1645.

[87] Avgerinou, Maria D. & Pettersson, Rune, ' Toward a Cohesive Theory of Visual Literacy ', *Journal of Visual Literacy*, Volume 30, no. 2 Autumn, 2011, https://www.researchgate.net/profile/Maria_Avgerinou/publication/267988880_Toward_a_Cohesive_Theory_of_Visual_Literacy/links/54d9e8ea0cf24647581fc28b.pdf, (accessed 25 May 2016), pp. 1-19, here see p. 7.

[88] University of Wisconsin-Madison, MRSEC Educational Group, 'Size and scale', http://education.mrsec.wisc.edu/36.htm, 2016, (accessed 25 May 2016).

[89] Avgerinou, Maria D. & Pettersson, Rune, ' Toward a Cohesive Theory of Visual Literacy ', *Journal of Visual Literacy*, Volume 30, no. 2 Autumn, 2011, https://www.researchgate.net/profile/Maria_Avgerinou/publication/267988880_Toward_a_Cohesive_Theory_of_Visual_Literacy/links/54d9e8ea0cf24647581fc28b.pdf, (accessed 25 May 2016), pp. 1-19, here see p. 12.

confer credibility to an organization.'[90] Also stating that images should be of good quality or not used at all they make me think of what the colours and quality could say about the nanoscope, and the science. I have previously focused on their brightness, and on the colours coming from glowing proteins, but I have not thought of what they can say about the images sources. The colours in all three case studies are certainly bright, and saturated. Looking at the nanoscopical images I would say that **image 1.2** and **image 1.3** have the highest credibility based on their colours. The red and green in them are colours that, according to me, seems to be frequently used in science (at least they were the colours used most when I searched for nanoscopical images). **Image 1.1** though has a series of very bright colours that does not seem natural, meaning that I start to doubt that the colours are created by proteins. All images are of good quality though, and all in all I would say that the images colours do strengthen my belief in science even if the E. coli can make me doubt.[91]

Images might have a negative influence though, according to Avgerinou and Pettersson. There is a point where they become distracting as opposed to helpful. Usually this point is reached when too many images are presented, but I believe that images could also become unhelpful when they do not have a clear relation to their caption, article or text. They also seem unhelpful when there is a gap between the image and the text in understanding. I am once again thinking about **image 1.3** which was taken from a very difficult to understand, scientific article. The images and the texts were not helping each other at all but only served to cause confusion. What I believed the image to be did not match with what the caption said that it was.[92]

It is mentioned in the article written by Betzig et al. that some form of software is needed to process the images. What software, though. is not clearly specified neither is it mentioned what it would do. James Elkins writes in *Six stories from the end of representation: images in painting, photography, astronomy, microscopy, particle physics, and quantum mechanics, 1980-2000* about the problems of altering an image using software. He states that it would be highly unfortunate to change an image in any way without stating

[90] Avgerinou, Maria D. & Pettersson, Rune, ' Toward a Cohesive Theory of Visual Literacy ', *Journal of Visual Literacy*, Volume 30, no. 2 Autumn, 2011, https://www.researchgate.net/profile/Maria_Avgerinou/publication/267988880_Toward_a_Cohesive_Theory_of_Visual_Literacy/links/54d9e8ea0cf24647581fc28b.pdf, (accessed 25 May 2016), pp. 1-19, here see p. 12.
[91] Avgerinou, Maria D. & Pettersson, Rune, ' Toward a Cohesive Theory of Visual Literacy ', *Journal of Visual Literacy*, Volume 30, no. 2 Autumn, 2011, https://www.researchgate.net/profile/Maria_Avgerinou/publication/267988880_Toward_a_Cohesive_Theory_of_Visual_Literacy/links/54d9e8ea0cf24647581fc28b.pdf, (accessed 25 May 2016), pp. 1-19, here see p. 12.
[92] Avgerinou, Maria D. & Pettersson, Rune, ' Toward a Cohesive Theory of Visual Literacy ', *Journal of Visual Literacy*, Volume 30, no. 2 Autumn, 2011, https://www.researchgate.net/profile/Maria_Avgerinou/publication/267988880_Toward_a_Cohesive_Theory_of_Visual_Literacy/links/54d9e8ea0cf24647581fc28b.pdf, (accessed 25 May 2016), pp. 1-19, here see p. 11.

clearly that you have done so or to have had the image altered by someone who does not know about the mathematics involved. It is also said in the same book that one must know what the goal of the change should be as well as when to stop editing. He also mentions that scientific images can be transformed into other representations than visual because they could also be mathematical equations, enabling them to be worked with in an entirely different manner. Usually this would mean no need for inaccurate information in the form of enhanced colours or cropped images.[93] [94] [95]

Having images changed almost artistically could open for interesting discussion about how scientists plan proportions and colours. I do not know how a scientist composes his images, but I would love to know if they consider geometrics, or beauty, if they ever think of mediating a feeling to the observer. I would say that it could decrease credibility to be too artistic, but at the same time it could serve as making scientific images into pieces art, and perhaps even masterpieces. Although, there has been negative feedback from the art world regarding the spread of beautiful scientific images. Elkins provides some thoughts about this phenomenon; this time in his book *Visual practices across the university*, saying that the bright hallucinogenic art of the 1960´s has influenced the colour choices for astronomical images. Meaning that choices of colour are not random, they are influenced by trends and art history.[96] [97] [98]

Finally for the exosomatic vision, I can now see its presence in the case studies. Before I did not have an understanding for that what I was observing could *never* be seen by my own eyes. This makes my visual literacy over all changed in terms of its flaws in reading nanoscopical images having been made present to me. My visual literacy did not decode my three images correctly without the help of text, and language. The messages that I received where more suitable as messages regarding microscopic images than nanoscopical, and

[93] Betzig, Eric, et al., 'Imaging Intracellular Fluorescent Proteins at Nanometer Resolution', *Science*, Vol. 313, no. 5793, Autumn, 2006, http://science.sciencemag.org/content/313/5793/1642.full, (accessed 25 May 2016), pp. 1642-1645.
[94] Elkins, James, *Six stories from the end of representation: images in painting, photography, astronomy, microscopy, particle physics, and quantum mechanics, 1980-2000*, Stanford University Press, Stanford, Calif., 2008, p. 128-129, 214.
[95] Elkins, James, *Six stories from the end of representation: images in painting, photography, astronomy, microscopy, particle physics, and quantum mechanics, 1980-2000*, Stanford University Press, Stanford, Calif., 2008, p. 60.
[96] Gettings, Fred, *Att förstå konst*, Rabén & Sjögren, Stockholm, 1988, p. 9, 17, 25.
[97] Elkins, James, 'Introduction' in Elkins, James (red.), *Visual practices across the university*, Wilhelm Fink Verlag, München, 2007, pp. i-liii, here see p. v.
[98] Elkins, James, *Six stories from the end of representation: images in painting, photography, astronomy, microscopy, particle physics, and quantum mechanics, 1980-2000*, Stanford University Press, Stanford, Calif., 2008, p. 87.

although visual literacy has been in use since the dawn of day, and scientific images have been studied in relation to it before, there is still a gap between the two.

Chapter 9 Conclusion

I started out by introducing exosomatic vision and my three case studies before learning about visual literacy and the art of reading visuals. I then studied the nanoscope, light, lasers, fluorescence, how the images were produced, and related the technological tool to culture. I then studied the three nanoscopical images again, and compared the differences in my thoughts regarding them.

It has become clear to me that gaining knowledge has made me equally sure, and uncertain. Because I know how to read a nanoscopical image now, but I also know how much more there is to it than I can understand. There more I know the less I understand.

I chose to repeat the same three case studies to be observed a second time and compared the change in my visual literacy using images I was therefore already familiar with. For further studies there is the possibility of studying different images before and after to document the change in reading images never before seen (by the observer). I am also only one singular person meaning that I have none other than myself to compare results with. It would be beneficial to use more than one observer as to get a wider range of how visual literacy can change, with more observers there is also the possibility of using people with different scientific, cultural, linguistic or other backgrounds. The information I have presented is also a selection of a vast range of information available concerning light, lasers, visual literacy, and microscopes. Information about the nanoscope and its images however are quite exclusive. There were difficulties creating a balance between the information and adapting text to make it valid for my case. It needs to be noticed that the information I have chosen as supportive is not specifically written to treat nanoscopes, and therefore new sources may appear with time that will be better suited for a study like the one I have made in this thesis.

For my theory visual literacy I have discovered that it is flawed in determining if observations are the same as reading or not. It is also not yet clear on how language and visuals should interact. There needs to be further studies between text and image, especially for images like the nanoscopical images because they are dependent on their captions, and their captions are dependent on them.

The conclusion for my initial research question of how the observers' visual literacy of nanoscopical images, and their exosomatic vision changes with gained knowledge about the images is that the reading moves from the surface of the image to its depth. Just like nanoscopes moves to a deeper field of study. Colours, and shapes gets put aside as molecules and fluorescence gets more attention.

Appendices

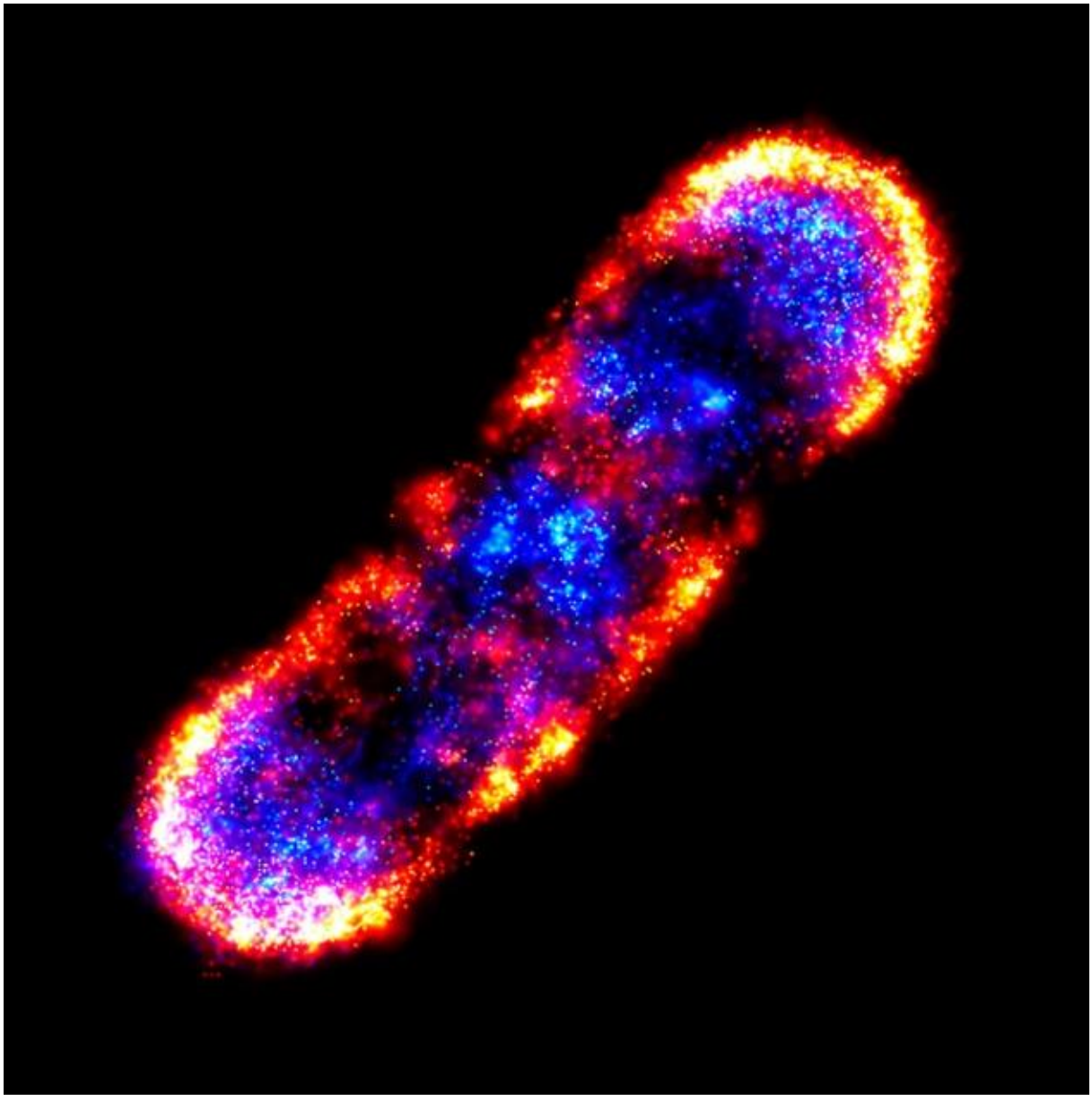

Image 1.1 Escherichia coli bacterium imaged by Eric Betzig.

Van Noorden, Richard, ‘Through the nanoscope: A Nobel Prize gallery’, Nature News, article

published as stand-alone on webpage 10 October 2014, http://www.nature.com/news/through-the-nanoscope-a-nobel-prize-gallery-1.16129#/b1, (accessed 25 May 2016)

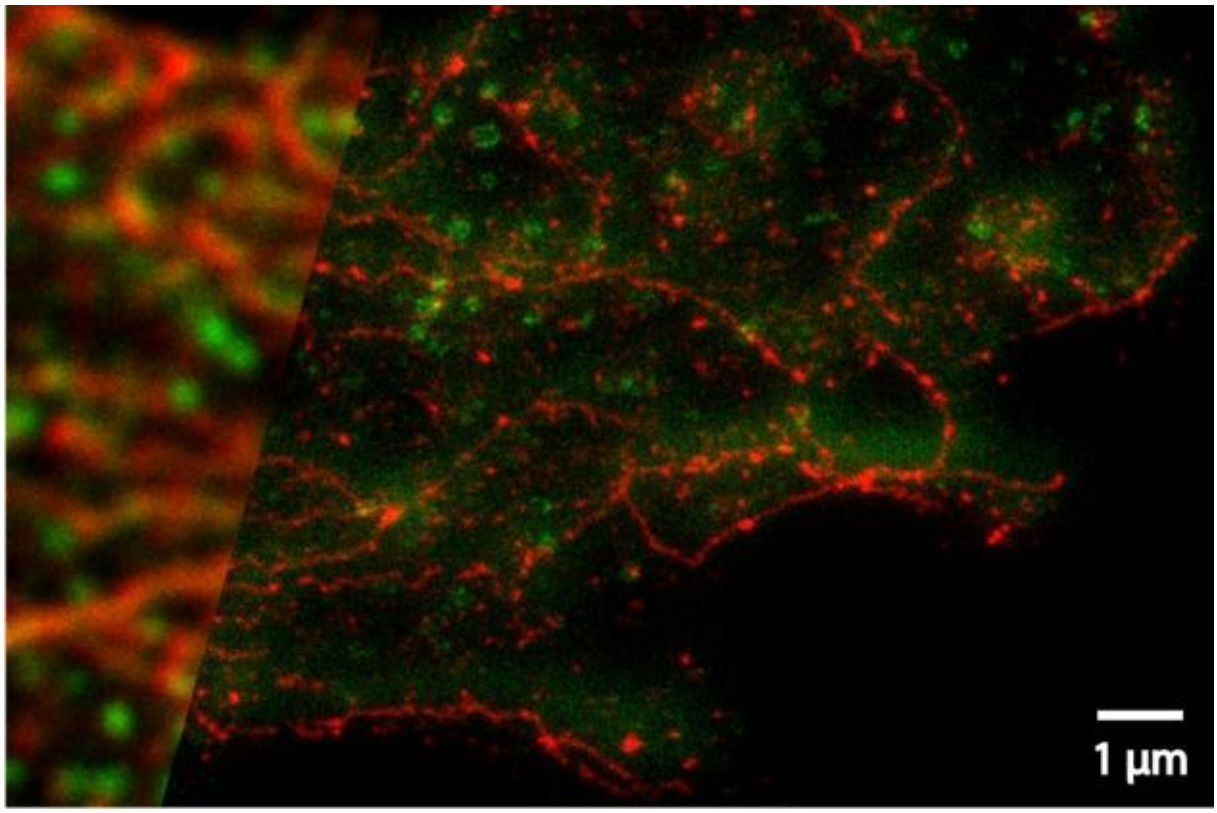

Image 1.2 Human brain tumour imaged by Stefan Hell.
Van Noorden, Richard, 'Through the nanoscope: A Nobel Prize gallery', Nature News, article published as stand-alone on webpage 10 October 2014, http://www.nature.com/news/through-the-nanoscope-a-nobel-prize-gallery-1.16129#/b1, (accessed 25 May 2016)

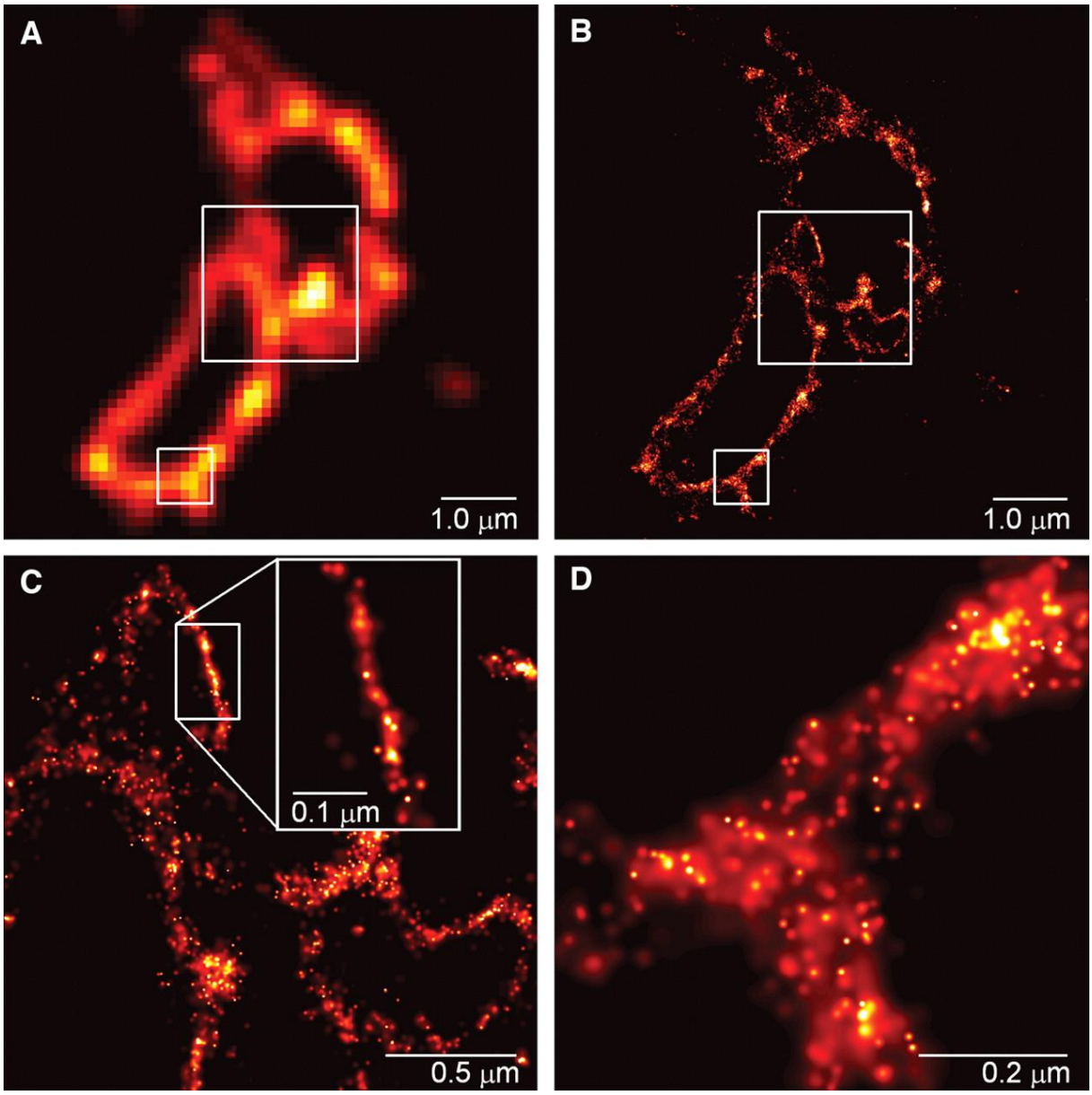

Image 1.3 TIRF and PALM images of the same section of a COS-7 cell.

Betzig, Eric, et al., 'Imaging Intracellular Fluorescent Proteins at Nanometer Resolution', *Science*, Vol. 313, Issue 5793, Autumn, 2006, http://science.sciencemag.org/content/313/5793/1642.full, (accessed 25 May 2016)

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University of Wisconsin-Madison, MRSEC Educational Group, ‘Size and scale', http://education.mrsec.wisc.edu/36.htm, 2016, (accessed 25 May 2016).

Internet; digital image

Image 1.1 Escherichia coli bacterium imaged by Eric Betzig.
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Image on its own accessible via:
http://www.nature.com/polopoly_fs/7.20690.1413309976!/image/01.%20SPL-PALM-C0049785-E.jpg_gen/derivatives/landscape_630/01.%20SPL-PALM-C0049785-E.jpg
(accessed 25 May 2016)
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Image on its own accessible via:
https://d2ufo47lrtsv5s.cloudfront.net/content/sci/313/5793/1642/F2.large.jpg (accessed 25 May 2016)
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