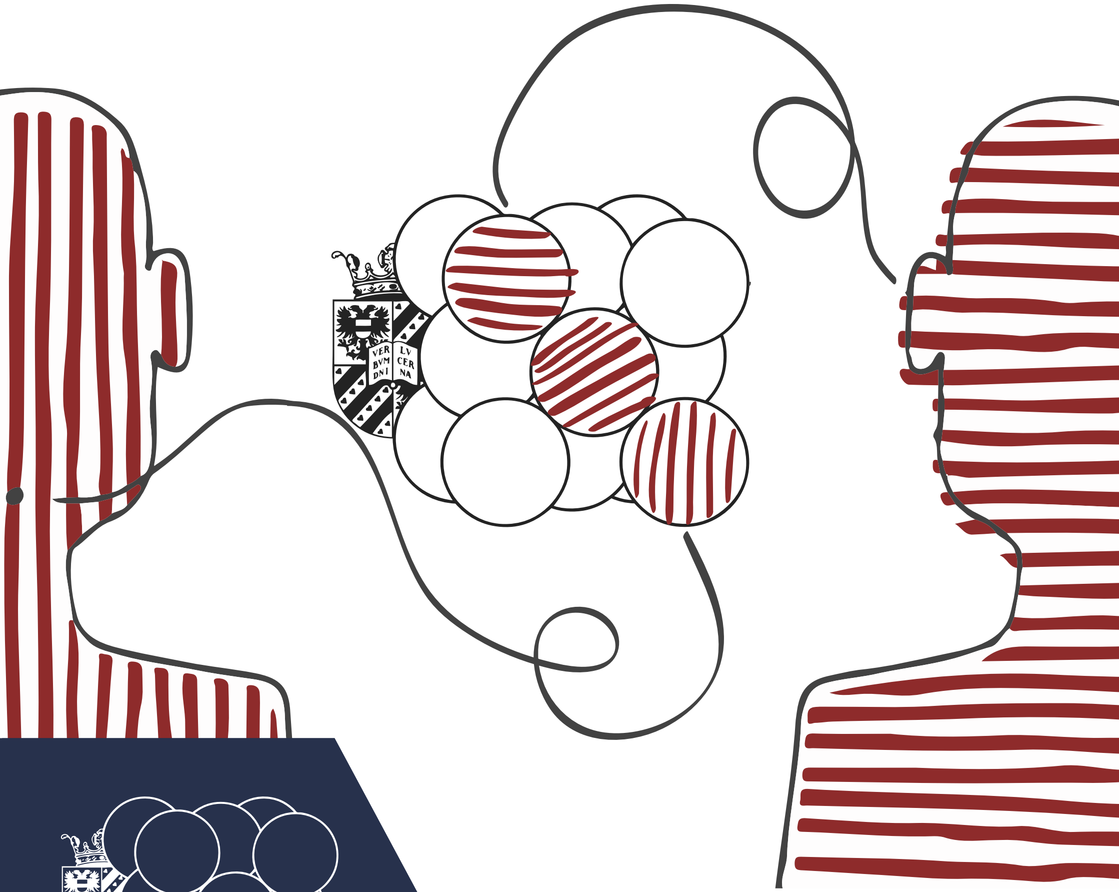
Brains and Black Holes
Limits on information and communication

Inside View
Materials Science group on tailored nanostructures

The US of Francken
The second in a trilogy of a year in America

Francken Vrij

Communication



21.2 Communication

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TOM CONSTANDSE
Program manager, Nano-Instrumentation

My main focus is on Bionanotechnology and I want to play my part in growing this interdisciplinary science at TNO. All state-of-the-art technologies people think are so cool, are right here.

Edition 21.2

Edition 21.1

Colophon

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Editorial

The theme of this edition is 'communication'. The first thing you might think now: what does this have to do with Physics? It does not sound as a topic to be treated at our faculty. However, topics such as encryption and data storage are topics closely related to communication and these have high relevance nowadays.

We only received one puzzle for our solution of the previous edition: Arjen Kramer sent us an out-of-the-box puzzle corresponding to our solution, see his solution in Figure 1 on page 36. Enjoy reading this new Francken Vrij!

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Chairman's Preface

By Anton Jansen

The academic year, as well as our board year, is well on its way. It pleases me to already be able to look back at the enjoyable and interesting activities that have taken place, as well as the personal growth both members and we as the board experienced during the year. Since this edition of the Francken Vrij is all about communication, I would like to communicate my thoughts about communication to you today.

As humans, our immense ability to communicate is the main reason we have been able to develop our society to what it is today. Although lots of species in the animal kingdom possess better senses than we (for example the sight of an eagle or the sense of smell of a dog), there is not a single animal species better at communicating than us humans. No other animal can communicate their dreams, desires, feelings and thoughts on the supply of *piekfusten* during Karakterborrels.

It is fascinating to look at how communication has evolved over time. 200 years ago, we only had speech, music and written text. Now, we have television, radio, photography, and of course the internet. Because of the omnipresence of the internet, we are always and everywhere connected to and communicating with each other. This sometimes reminds me of the Borg from Star Trek. These cyborg-like creatures are all part of a giant ever-communicating web, almost to the point where the individual does not exist anymore. Everybody can literally read everybody else's mind. In a certain sense, humans are well on their way to become cyborgs as well. We might not have biomechanical implants yet, but we do carry an "implant" with us all the time, allowing us to communicate always and everywhere: our smartphone.

The odd thing is that despite these recent advances and our inherent experience in communication, this is still the area where it most often goes wrong when trying to organize something at Francken. We as the board know all too well about that. Whether the moral of this story should be to strive to become complete cyborg-like creatures that literally read each other's thoughts is questionable, but it would be rather interesting and also quite useful when you try to plan a committee meeting for example. Anyway, I hope I have told you something interesting about communication, and I wish you all a happy reading of the new Francken Vrij!

A[nd]ton worrying about piekfust supply chains

News of the Association

By Willeke Mulder

As the 32nd week of the 32nd board 'Buitengewoon' has passed by, in which Francken members were able to enjoy the 32-weeks-board whipped cream pie, it is time for the second 'News of the Association' of this year. To give you a nice overview of all the different kinds of activities that have been organised, a summary is given in the following pages.

Klaverjas tournament

Some Francken members train for this particular event all year long. Of course I am not talking about the Tour, but about the *klaverjas* tournament. At first it seemed that the 'Morele Winnaars' would have an easy win, but after a bloodcurdling final round, they had been surpassed by two teams, with only 17 points difference between number 1 and number 3. Team 'Meli' finally won the roulade, but the members of the Fraccie, benevolent as they are, provided (consolation) meat for other teams as well.

Jamsession

Since the start of the year, Jazzcafé De Spieghel has found back its roots in the city centre of Groningen: the ideal place for the Fraccie to host their annual jamsession. The committee started the evening with sing-a-longs, and later delivered a breathtaking performance to the crowd. Every person had the opportunity to join the band as they were playing songs in genres ranging from pop and (hard)rock to jazz and ballads. You would not believe how astonishingly musical many Francken members were!

International running dinner

A new committee has come to life: the Intercie. It aims to organise activities especially for international students, so that they can blend in with the Dutch students. The first activity they organised was a running dinner through 4 *Franckenhuisjes*, each having a country as a theme, on walking distance from each other. The groups students traveled from Mexico ((Dors) tequila, wraps, nachos), via Greece (salads, homemade toast toppings and other delicious appetizers), to India (spicy curry), and eventually to Duncan's house (Russia?). Many students had a great time and a great (liquid) dinner!

Masters of Engineering symposium

This year, the Masters of Engineering was a full day symposium with several interesting lectures around the theme 'Explore Energy'. The lectures focused on technical challenges that concern topics like smart grids, energy storage both on a small and large scale, future energy distribution, etc. There were presentations by Tesla, Nuon, Senfal, Enexis and Prof. dr. A.J.M. van Wijk.

Tour de Francken

This year's Tour de Francken started from *Franckenhuisje* 1, passed through the city of Doetichem towards the Vaalserberg, climbed in Switzerland and ended in the capital of 'Franckrijk'. Due to the excellent TdF system, the brave and combative participants were able to reach the finish line in three hours, whereas the Domino's deliverer was not able to find the Nijenborgh. Team 'WAANZIN' has once more managed to maintain the yellow hat unitl the end, and with that prolonged their title. Pieter Wolff has won the individual combativity tournament.

Christmas dinner

As Francken members we all love eating, and it would be a sad waste of opportunity to eat badly. For this and many more reasons, the Christmas dinner appears to be a success year after year. The whole evening everybody could enjoy, among others, homemade hamburgers, Italian risotto, delicious wraps and a nice bowl of soup accompanied by a glass (or more) of wine.

> *The members of the Fraccie, benevolent as they are, provided (consolation) meat.*

Freshmen dinner

Since the start of the year, Freshmen active at Francken have joined the Sjaar(s)cie. In January they had their first activity, the Freshmen Dinner. With the use of lanterns, pink tablecloths and rose leaves, the hallway of 'Gebouw 13' (not to be confused with the beer of the same name) was transformed into the main theme of the evening: 'Fairy tale'. The committee, dressed as princes and princesses, made a three course

fairy tale dinner.

Ice Skating

As the ice skating activity organised by the Sportcie has been a great success in the last years, the committee decided to again give Francken members the opportunity to join an ice skating clinic taught by TJAS. The clinic was primarily focussed on the crossover turn technique. Afterwards, participants could reheat while having dinner at Huize Maas.

Practice sessions

After the great success of the very first Mechanics practice session this year, hosting 108 participants, the Practice Session Committee of T.F.V. 'Professor Francken' successfully organised eight other practice sessions in the first two periods of this academic year. With preparation exams made by the committee, freshmen and seniors are able to benefit from the knowledge of older Francken members. As everybody knows, there is always plenty of free coffee, tea and cake. Hats off (*dik chapeau*) to the committee!

Materials Science Group: Tailored Nanostructures

By prof. dr. J.Th.M. De Hosson

Modern technology depends critically on the availability of advanced materials and tailoring these materials with a desirable set of structural and functional properties has always been a dream of materials scientists. The research efforts of the Materials Science group are devoted to make this dream come true. Our group of enthusiastic and talented researchers of different nationalities from all over the world comprises a strong international team of physicists and engineers who collaborate in multi- and interdisciplinary research projects. Our mission is to carry out innovative and pre-competitive research in the field of nanoscience and nanotechnology with particular emphasis on: Nanostructured materials: nano-clusters, nano-foams, nano-objects, heterophase and homophase interfaces produced by high power lasers and advances in microscopy, in particular in situ scanning- and transmission electron microscopy for applications in areas such surface technology, transportation, communications, and data processing (for details see *http://materials-science.phys.rug.nl/*).

Since properties of nanostructured materials are strongly affected or even controlled by the presence of solid interfaces between similar and dissimilar materials, a considerable part of our research programme concentrates on experimental and theoretical work of the characterization of hetero- and homophase interface structures with advanced in–situ electron microscopy methods over various length-scales. The following two examples are illustrative for recent BSc & MSc projects in our group.

Question 1: What about classical Newtonian mechanics? Does it break down in solids?

Many laws in phenomenological materials physics are based on the concept that a constant force or driving force will lead to a response which is constant in time. In fact, the entire framework of solid state mechanics, founded by Isaac Newton himself, is based on this principle. For example, a constant force per unit of area will lead to a particular deformation response everywhere and at any time in the material; also: a constant driving force will lead to a certain velocity at each point of an interface and to recrystallization and transformation kinetics well described by various phenomenological models.

In our recent work with PhD & MSc students (in particular with MSc student Maxens van Daalen, currently at Fraunhofer Dresden for his internship and Gerrit Zijlstra/Leo de Jeer as PhD students and Dr.ir. Vašek Ocelík MK staff member) we concentrated on the dynamics of phase transformations in time as a function of temperature. The Russian mathematician Kolmogorov and American metallurgists Johnson and Mehl and Avrami independently formulated the first mathematical descriptions of isothermal solid-state phase transformation kinetics (see your Materials Science Bachelor class Callister book, 9th edition, p. 396) :

$$f = 1\text{-}exp(\text{-}kt^n), \qquad (1)$$

where *k* and *n* are time-independent constants for a particular reaction. Note that *k* cannot be considered a frequency factor as its unit depends on the value of the exponent *n*. In fact it would be better to formulate the exponent as $(kt)^n$ with *k* per unit of s^{-1}. Nevertheless, this modification will not affect the analysis as Eq. (1) is developed for a constant value of *n*. The resulting model is nowadays known as the Johnson-Mehl-Avrami-Kolmogorov (JMAK) equation.

More important is to realize that these essentially equivalent models predict the volume fraction *f* converted as a function of time *t* in a very large specimen, i.e. boundary effects are ignored and it follows that crystallites nucleate homogeneously throughout the bulk and grow at a constant rate under interfacial control. These models represent the kinetics of a solid state phase transformation as a process of nucleation and growth of a product phase at the expense of the parent phase. The original approach is only valid for random homogeneous nucleation and isotropic growth, but in modified form was shown to be applicable for continuous cooling and heterogeneous nucleation.

Nevertheless, this concept has been used very successfully but it breaks down under critical examination, for non-diffusional transformation or under thin film conditions. Also, in recent times it has been demonstrated convincingly, albeit not systematically, that in many situations of phase transformations such a simple Newtonian concept does not apply and possibly interfaces do not move continuous in time but in a jerky-type fashion, i.e. not in accordance with Eq. (1). It should be pointed out that the experimental conditions required to observe jerky-type motion are most demanding since criteria of high spatial and time resolution have to be met. It is therefore not surprising that the details of the jerky nature of the transformation has gone unnoticed for a long time.

With the novel developments in instrumentation it is relevant to revisit the JMAK equation again and ask the question whether and when it will break down and at which length scales? Recent evolution of this setup on the speed of in-situ signal processing, allow us to study the dynamics of phase changes with increased temporal resolution. In our work we combine a heating stage and Electron-Back Scattering Diffraction (EBSD), resulting in in-situ observations of microstructural changes. The strength of Electron Backscatter Diffraction (EBSD) is the accurate determination of the phase front within sub-micron error, com-

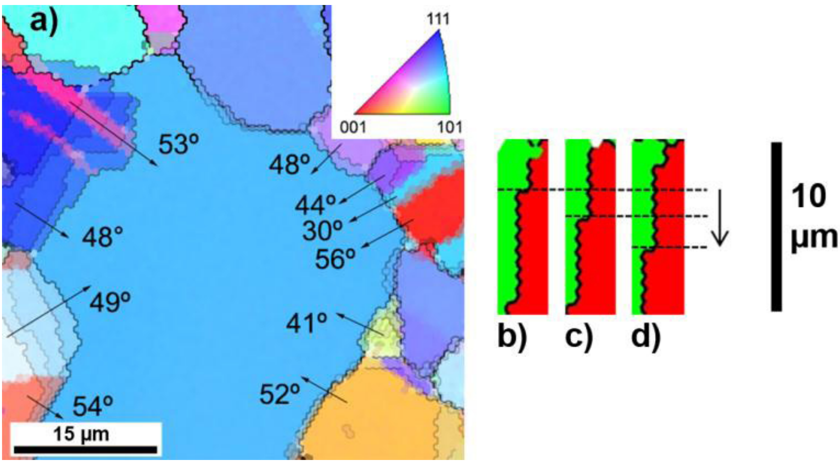

Figure 1: a) Overlaid [001] inverse pole figure maps indicating phase boundary growing directions and misorientation at a constant temperature of 840 °C. The large grain in the center is bcc, and surrounded by new fcc grains. b), c), d): Section of the 49° misorientation phase boundary at 840 °C. Time between scans is 65 seconds. Step size of scan 0.75 µm; recorded movement of the boundary in the parallel direction of 1.5 µm.

bined with the measured crystal orientation of the parent and daughter grains. Our MSc student Maxens van Daalen (famous scene director and producer of Francken promotion movies, see Francken 30th Anniversary) has developed a novel analytical method to derive the velocity of the phase interface from the EBSD phase maps. Fig. 1 presents a typical result where a phase boundary between fcc/bcc (face-centered cuboc/body-centered cubic) is growing at a constant temperature of 840 °C in situ in the scanning electron microscope- electron back scatter diffraction.

These in-situ EBSD experiments are conducted in a Tescan Lyra FEG/FIB Dual beam microscope, equipped with an OIM system by EDAX including a Hikari super camera which can achieve a maximum of 1400 indexed points per second. Annealing inside the microscope can be performed with a heating module, which contains a ceramic resistance heater. The module is calibrated for optimal performance at high temperatures with a maximum of 1500 °C. The temperature can be maintained within a fluctuation of 0.1 °C through a coupled temperature controller.

It should be pointed out that the experimental conditions required to observe jerky-type motion are most demanding since criteria of high spatial and time resolution have to be met simultaneously. To put the in-situ EBSD-SEM observations in perspective let us define the spatio-temporal resolution δ_{ST} as the product of spatial and resolution in time:

$$\delta_{ST} = \delta_S \otimes \delta_T \, . \qquad (2)$$

In our current FEG-Lyra Tescan microscopes the spatial resolution is of the order of nanometer when using accelerating voltages ranging between 15 and 30 kV. Although we have employed a Hikari super camera, the first one operational in Europe, which can achieve a maximum of 1400 indexed points per second, the actual EBSD processing speed may still suffer if the indexation time per spot increases due to decreasing signal quality. A conservative number is indexation of 50 spots per second, with a typical step size of sub micrometer, this results in $\delta_{ST} = 8.10^{-9}$ m.s.

The observations in time of ragged and straight interfaces, like in Fig. 1 indicate a jerky-type phase boundary movement mechanism, i.e. observations reveal a segmental motion of the interface, with segment length, stagnation period and maximum local velocity may vary. We ask ourselves: What determines the characteristic time scale and what affects the characteristic length scale in these transformation?

It turns out that the 'disorder' of ledges, kinks along the heterophase interface and of 'roughness' along general (not special, neither favored) grain-boundaries are the principal cause of jerkiness, i.e. not continuous in time on a microscale as the Johnson-Mehl-Avrami-Kolmogorov (JMAK) Eq. (1) would predict at the macro-scale.

Figure 2: Left: Zacharias Jan(s)sen, living in Middelburg, credited with inventing the microscope. Right: Reproduction of first compound (2 lenses) microscope made by Hans and Zacharias Jan(s)sen, circa 1590. From the National Museum of Health and Medicine, Washington, D.C.

In physical terms we can say that providing the Gibbs energy change per unit of volume is much larger than the fluctuations in the interface boundary energy between the bcc and fcc per unit of lattice step height, a continuous motion is expected as long as the driving force is very large. In the opposite case, jerky motion is expected. We have proved that the mean velocity (order of nm per second) depends on the correlation length along the transformation front, which can be regarded as correlating with the length of a local ledge or roughness correlation length. Deviation of simple Newtonian mechanics/Avrami equation are due to non-linear effects of the correlation length on the actual jump distance and on the time lapse involved. In fact, so far we conclude that linear dependence between the velocity and Gibbs energy change per unit of volume as predicted by a classical thermodynamics are far too simple at a nanometer scale. We need clever BSc/MSc students to explore this further in other systems, including a hot topic of 'high-entropy alloys'.

Question 2: What about 2D observations and 3D reconstructions in electron microscopy?

In Materials Science we are used to say: '*seeing is believing*'. Historians attribute the

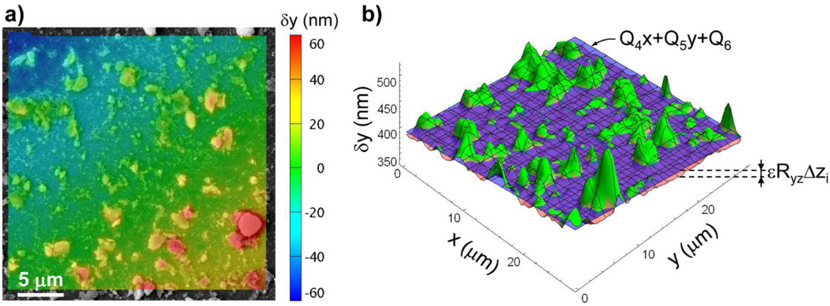

Figure 3: (a) Map of digital image correlation data obtained and (b) 3D reconstruction.

invention of the first microscope to Hans and Zacharias Janssen (sometimes spelled like Jansen) in the 1590s, see Fig. 2. In 1610, a year after his interest in the telescope, Galileo turned his telescope upside down and started to work on the microscope. The then new field of science, called "microscopy", opened up the unsuspected world of the ultra-small. The discovery by later scientists, in particular Antonie van Leeuwenhoek in Delft, of the existence of bacteria prompted the sterilization of surgical equipment taken for granted today, saving millions of lives ever since. Interestingly, almost exactly like Galileo also our 1st (!) Nobel Laureate Frits Zernike (1888-1966) started in astronomy being assistant of Jacobus Cornelius Kapteyn in Groningen (1851-1922) before he turned to (phase contrast optical) microscopy. It goes without saying that optical microscopy has made a substantial contribution to mankind but that is equally true for electron microscopy in the development of new materials.

'Seeing is believing': that's all fine but there is a serious problem with that statement, namely : in any micrograph we get a projection of an object in 2D but we are interested of course in an object defined in 3D. There are several proposals in literature to tackle this issue but they all rely on information about the microscope itself and suffer from severe calibration problems.

Recently in Materials Science we have designed a novel procedure to obtain 3D surface reconstructions from scanning electron microscopy images acquired at different angles. The main advantage is that no a priori information about the imaging equipment is needed, and therefore complex calibrations of the equipment can be avoided. The method can be directly applied to any set of three or more images obtained while changing the tilting angle between images. The theoretical background has been presented in E.T. Faber, D. Martinez-Martinez, C. Mansilla, V. Ocelík, J.Th.M. De Hosson, Calibration-free quantitative surface topography reconstruction in scanning electron microscopy, Ultramicroscopy, 148 (2015) 31-41, *http://dx.doi.org/10.1016/j.ultramic.2014.08.009*, together with two different methods to reach a unique solution. Three different cases have been selected for a critical validation of the concept for different situations of imaging and tilting. The method was patented in 2015 by the applied-physics materials science group and trademark TopoSEM, Patent number WO/2015/185538,EP14170815.6, PCT/EP2015/062231.

To illustrate the impact of our method: Upon using secondary electrons, contrast variations in scanning electron microscopy (SEM) are caused by the topography of the sample. However, the extraction of topographical information from SEM images is rather complex. Different approaches have been defined in order to find a solution to that problem. However, they require specific equipment or complex calibration procedures. In addition to those, so-called stereographical methods have been reported in literature. The most important ones can be grouped in feature-based (based on edge detection) and area-based methods (based on image correlation). The latter ones bear the advantage of obtaining a high density of points and circumvent problems when operating with rather in- homogeneously distributed features .This type of approach is very versatile, and has been applied to different materials such as inorganic particles or biological specimens]. Nevertheless, several publications do not provide a clear comparison between the original images and the 3D reconstructions, and/or they do not include information about the range of values in the depth direction. In other cases, geometrical information is a prerequisite.

Our new approach aims at recovering the topographical information hidden in the contrast of the SEM pictures, avoiding the necessity of calibrations and other complex geometrical considerations. On the contrary, the only requirement to obtain the 3D reconstruction in practice is the acquisition of at least three images of the surface region under study at different tilt angles, without further information about details of the tilting parameters. In fact, the method can be applied on sets of images acquired without knowledge of the imaging and/or rotation conditions. Thus, the sample will be just slightly tilted in the SEM equipment, but there is no need of a fine control of the direction and magnitude of rotation. The consequence of tilting is the displacement of the points of the image. However, the magnitude of this displacement varies depending on the z-coordinate of the point.

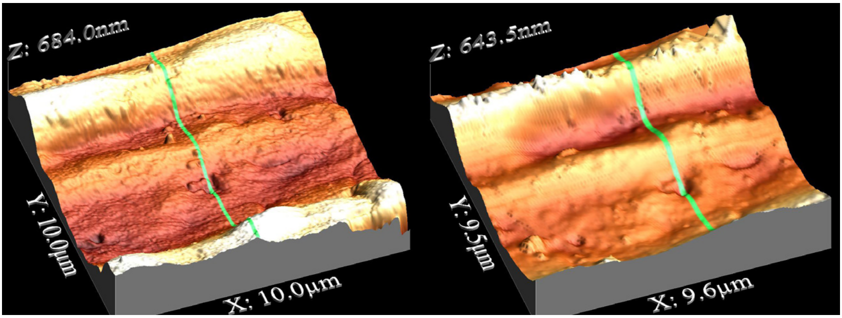

Figure 4: left: Atomic Force Microscopy and right: TopoSEM.

As a consequence, by evaluating the displacement of every point in the images after tilting, it will be possible to reconstruct the z-coordinates. This evaluation has been carried out by conventional 2D digital image correlation (DIC) between the images before and after the tilting (Fig. 3).

For Francken students Lesson #n, n>>1: when you have designed a new methodology it is crucial to confront these novel ideas to an already existing technique. Fig.4 convincingly shows that the new Materials Science method in SEM can compete with existing methods as far as resolution is concerned (such as AFM based on atomic force profilometry) but bypass these existing method in a spectacular way because of the combi of resolution and analytical (chemical & crystallographic) capabilities of SEM. The agreement is excellent, and even small features (particularly holes) can be seen at the same place. The topic requires immediate input from BSc/MSc students applying it to different materials systems at various length scales.

If you are interested to work with us as a BSc or MSc student at the forefront of tailored nanostructures using novel advances in microscopy, for further information please contact: prof.dr. J.Th.M. De Hosson (room 5113.0043), Dr.Ir. V. Ocelik (room 5113.0023), Dr. D.I. Vainchtein (room 5113.0026).
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SpyGEM

By Kathinka Frieswijk

In 2016, the University of Groningen participated again in the International Genetically Engineered Machine (iGEM) competition and I was one of the team members. The purpose of the iGEM competition is that groups of students build their own genetically engineered biological systems over the summer and eventually present their work in Boston, USA (yes, Joran's current location).

The project of the team of 2016 was 'secret communication', which is why 'SpyGEM' (a wordplay on iGEM) would have been the perfect name for our project (and has been the name for several months). But alas, at the last second the project supervisor suggested the name 'CryptoGErM' and subsequently the biologists (major part of the team) opted for this choice of name, "since sending secret messages has nothing to do with spies" according to them. That the term 'crypto germ' already exists and is in fact a nasty parasite that causes diarrhea, was deemed completely irrelevant. Thus, we ended up with a team name that translates as 'shitty germ'. Sometimes, democracy is overrated (#Trump).

But I am drifting off. Far more interesting than the name of our team is of course the content of our project. By introducing a sequence into the DNA of bacterial spores, one of the most durable and resilient forms of life, we designed a novel and safe data storage and transmission system. The idea is to send a key and a message in two separate spore systems of *Bacillus subtilis*. Digital and biological protection layers ensure that unauthorized parties do not have

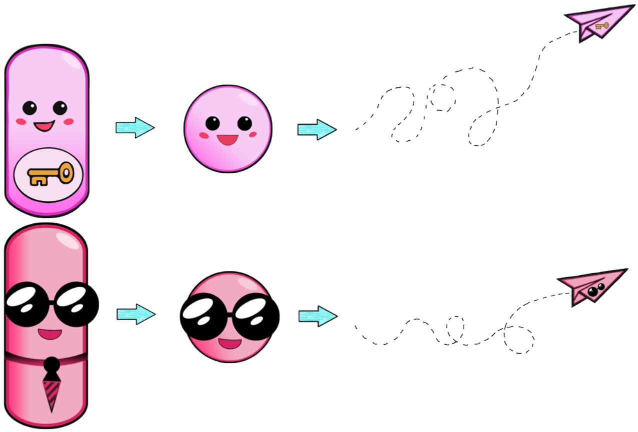

Figure 1. Bacillus subtilis forms highly resistant endospores, which can easily be shipped.

access to the information. The message is protected by computational encryption, while the key can only be accessed by using the right growing conditions. If the recipient fails to do so, the message is lost forever.

Step 1: Encryption

The original message is encrypted into a new message (the ciphertext) by using the Rijndael algorithm [1], which was developed in 1998 by two Belgian cryptographers, Joan Daemen and Vincent Rijmen. In November 2001, this algorithm was selected by the U.S. National Institute of Standards and Technology (NIST) as the new Advanced Encryption Standard (AES) [2]. Since then, it has been adopted by the U.S. government to secure highly classified data and has been used worldwide.

After encryption, the message will be converted into a binary message, by making use of the American Standard Code for Information Interchange (ASCII). ASCII encodes characters into integers, which can be represented as sets of binary digits.

The encrypted binary message is translated into a sequence of the nucleotides ACTG by using the following translation scheme. The binary pair 00 will be represented as A, 10 as T, 01 as C and 11 as G (see Table 1). Subsequently, the obtained string of nucleotides is integrated into the DNA of

00	A
10	T
01	C
11	G

Letter	H	e	l	l	o		w	o	r	l	d
ASCII	072	101	108	108	111	032	119	111	114	108	100
Binary	0100 1000	0110 0101	0110 1100	0110 1100	0110 1111	0010 0000	0111 0111	0110 1111	0111 0010	0110 1100	0110 0100
DNA	ATAC	CCTC	AGTC	AGTC	GGTC	AATA	GCGC	GGTC	TAGC	AGTC	ACTC

Table 1. Translation scheme: pairs of binary digits are represented by nucleotides.

Table 2. The message 'Hello world' is translated into a sequence of nucleotides ACTG.

Bacillus subtilis, which will serve as the carrier organism for our secret message.
For example, Table 2 shows the translation of the plaintext 'Hello world' into a sequence of nucleotides (encryption is not applied in this example). The same strategy is applied to the encryption key.

Step 2: Integration in B. Subtilis
The key and message sequence are stored in the DNA of *Bacillus subtilis*, a gram-positive, nonpathogenic, rod-shaped catalase positive bacteria, usually found in soil and gastrointestinal tracts. It is one of the most well studied gram-positive microbe and the integration of DNA sequences into its genome is well known.

Step 3: Storing and Sending
When environmental factors do not favour survival or reproduction, highly resistant endospores are formed. Bacterial endospores are tough, non-reproductive structures that have a central cytoplasmic core where the DNA and ribosomes are protected by an impermeable and rigid coat. They are highly resistant to aging, radiation, heat and chemical damage. In fact, viable spores formed by *Bacillus subtilis* have been recovered from a 250 million year old salt crystal [3]. These properties make them the ideal storage medium for data in DNA.
The most effective method for long-term storage of *Bacillus subtilis* spores appears to be freeze-drying [4]. During freeze-drying, water is removed from a substance.

To make it especially hard for unauthorized parties to obtain the key sequence, the key-spores will be sent in a mixture of decoy spores. The decoy is present in a much higher ratio than the key-spores. The key-spores have to be recovered using a specific selection mechanism. Unauthorized parties have no idea how to select the spore that is 'The One' (see Figure 2).

Step 4: Treatment

The spores have to receive the right treatment during germination, otherwise the key and message sequences cannot be recovered. If you are interested in these biological security layers, visit our website *'http://2016.igem.org/Team:Groningen'.*

Step 5: Decoding

After the receiver has received both the message and the key spores, he can sequence both of them. The message is (of course) decoded by using the key.

Last October, we presented our project at the Jamboree and won the track award: 'Best Information Processing Project'.

We also won a gold medal (or golden sticker, since the cheapskates did not actually give us a medal), plus were nominated for the 'Best Software Tool', 'Best Education & Public Engagement' and 'Best Wiki'. All in all, a good haul.

On a side note, universities are relentless in competing with each other, which allows iGEM to raise the entrance fee to an

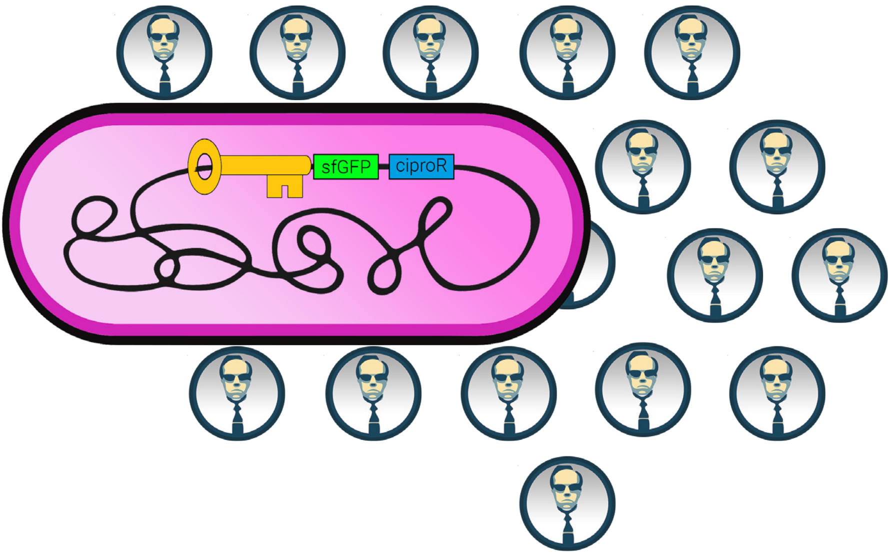

Figure 2. Bacillus subtilis carrying the key sequence, and decoy spores.

Figure 3. iGEM Groningen 2016 at the Jamboree in Boston.

enormous amount since universities will join anyway "because their prestige is on the line". Whether iGEM is still a nonprofit-organization is thus questionable.
As a student, I nevertheless had an awesome experience. I had a lot of fun while working on the project and I'd absolutely recommend joining an iGEM-team to anyone.

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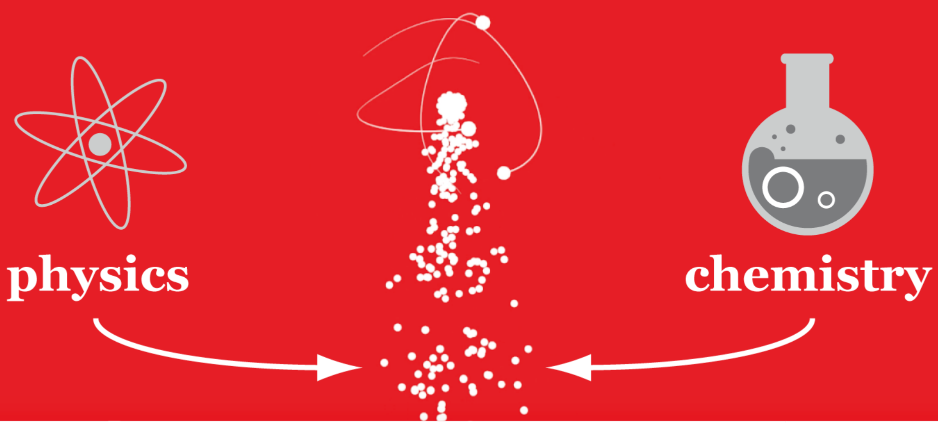

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On Brains and Black Holes

Limits on Information and Communication

By Remko Klein

Let's say you are studying for an exam - probably at the very last moment - and you are desperately trying to cramp as much information in your brain as you can, in as little time as possible. Whenever I find myself in this situation, it's like I simply can't transfer the information from a book to my brain in the rate I want to achieve. In addition, at some point it just seems my head is full of information and not a single additional bit can be squeezed in without some other information getting lost or my brain overheating. I'm sure most of you are familiar with the feeling…

This of course has some biological reason and has to do with how our brains work, but assume that somehow we could overcome these biological shackles of the brain. Now, one way we could potentially free ourselves from our biological limits, is to enhance the brain with some (as of yet unknown) technology of some kind. Would we then be able to store unlimited amounts information in your brain and also be able to transfer information (in other words: communicate) at arbitrary rates?

It turns out that the answer is no. Even if we go full cyborg mode, we are still chained by fundamental laws of physics, both in terms of information storage as well as communication. As we will see, you can't cramp unlimited amounts of information into a certain volume, without infinitely increasing the amount of energy stored in that volume, much resembling our overheating brain. A logical consequence of this is that you also can't just communicate at arbitrary rates without having to supply an infinite amount of energy.

Anyway, before going into more details we have to have a good physical definition of information and communication.

Entropy and information

Let's make explicit what we usually mean with information, which I think warrants a reminder on (or, if you are a freshman, a lightning introduction to) the concept of entropy.

To this end, consider what we call a macroscopic system: a system that's built up out of many microscopic particles. As an illustration, consider this macroscopic system to be a gas of some kind. Now, this system can have all kinds of macroscopic properties such as a certain volume, temperature, energy and pressure.

If we were to know these quantities, we would know all there is to know about this gas, at least macroscopically. However, there is more to the system than just its macroscopic properties: it consists of many microscopic particles, all randomly moving around. Together these random motions will lead to the macroscopic quantities such as temperature and pressure we usually associate to a gas.

Now, many different microscopic states will lead to the same macroscopic properties. Thus if we only know the macroscopic quantities, we are actually quite ignorant about the precise microscopic state the gas is in. In other words, we are unsure about the precise positions and velocities of all the particles the gas is made out of. A measure of this ignorance is what we call the entropy S of the system, which basically is just the logarithm of the number of microscopic states, Ω, corresponding to the macrostate, multiplied with Boltzmann's constant:

$$S = k \log \Omega$$

From this we can define the information, I, of a given macrostate: it is simply the number of bits we need in order to be able to count to the number of microstates corresponding to this macrostate. In terms of the entropy this gives

$$I = \frac{S}{k \log 2}$$

This quantity thus gives you the total number of bits a certain macroscopic system can, in theory, store. Finally, one can now define the rate of communication as being the flux of information, i.e. the amount of bits of information that passes through a certain area per unit time.

Black holes and the Bekenstein bound

Having lain the groundworks, let's examine the claim that both information storage capacities and communication rates are bounded by fundamental laws of physics. To this end, remember that there is something called 'the second law of thermodynamics, which states that the entropy of a closed system can never decrease. This is one of the most fundamental principles we have in physics and the general guiding rule is that if you come up with a physical the-

ory, it better not violate this law.
Now, the physicist Bekenstein realized that demanding general relativity to be compatible with this second law, leads to what is now called the Bekenstein bound on information. The argument is actually not too difficult, so let's review it. One starts off by noting that general relativity predicts the existence of black holes, and that a black hole turns out to have an entropy that is proportional to its mass squared:

$$S_{BH} = \frac{4\pi k}{\hbar c} M^2$$

Next, consider a closed system involving a black hole with mass M and entropy S_{BH}, and some other object A with mass m, radius r and entropy S_A. The total system thus has entropy $S = S_{BH} + S_A$. What one can do is lower object A into the black hole, destroying it in the process, thereby increasing the mass of the black hole with \$m\$. The final system thus consists of just the, heavier, black hole and its entropy is (to first order) given by

$$S' = S'_{BH} \approx S_{BH} + \frac{8\pi k G}{\hbar c} Mm$$

which according to the second law should be larger than the original entropy. Using this leads to the following inequality:

$$S_A \leq \frac{8\pi k G}{\hbar c} Mm$$

We now note that this argument only works if the dimensions of the black hole, as captured by its mass *M*, are sufficiently large with respect to the dimensions of the object *A*, namely *r* and *m* (or rather its energy *E*). Picking *M* to be just large enough one can show that the inequality reduces to its most strict form:

$$S_A \leq \frac{2\pi k}{\hbar c} rE$$

This thus gives us a bound on the entropy that any object with energy *E* and radius *r* can have. Since as we have seen, information is related to entropy, this inequality also gives a bound on the amount of information such an object can store.
From this we can also see that there is a limit on the rate of communication. We first note that a volume with a certain energy density, and hence with a certain maximal information density, cannot move faster than the speed of light due to relativity, and hence there is a limit to the amount of volume that can pass through a certain area. That is, the volume flux is bounded due to the speed of light. Therefore, the information flux - which is nothing but the volume flux times the information density - is also bounded, since both the volume flux and the information density are bounded.

Going to the Limit

We are now ready to plug in some numbers. Using the average mass energy of a

human brain, one concludes that it can actually store up to around 10^{42} bits. This is quite a lot indeed: the total number of bits of information ever stored on computers up to now is estimated to be a measly 10^{21} bits! Hell, even an ant brain, with an upper bound of 10^{30} bits, could potentially store this amount a billion times over!
Of course, in practice this bound is not nearly achieved: the vast majority of the possible microstates that the particles in your head could be in, do not constitute anything remotely resembling a brain. For sure, the number of microstates that lead to an actually functioning brain (and one that hosts precisely your personality and not some random other one) is only a minute fraction of the total number of microstates. This number, nowhere near the physical bound, is the actual biological limit on the number of bits the brain of a person can store.
Next, consider the cyborg scenario where we are freed of these biological bounds. We now know that even in this case, we will run into problems. This because if we keep on adding information to a volume, the energy density of the volume will rise and rise. Eventually something quite catastrophic will happen: the energy density will reach the critical value needed to form a black hole. So if we cramp too much information in our brains, they will actually eventually become black holes!*
Let me wrap up by noting that physically, the real bottleneck is information storage and not so much communication. This because the maximal possible information flux is very high since it's proportional to the speed of light (which of course is very large) times the information density. Thus, if you would somehow be able to push it to the limit and squeeze as much information through your eyeballs as physically possible, your brain will actually almost instantaneously reach the critical energy density and form a black hole. Anyway, enough of these admittedly ridiculously hypothetical scenarios... Bij deze rust de theoreet zijn koffer.

*Remarkably, the brains of some of the students I've given classes over the years, actually seem to resemble black holes: I put a lot of information in their brains an entire semester, but at the final exam none of it seems to come out...

**Again remarkably, this situation seems to occur whilst interacting with some of the students: they ramble on at such a rate, that my head feels like it wants to implode to form a black hole…

Study at MIT

By Joran Böhmer

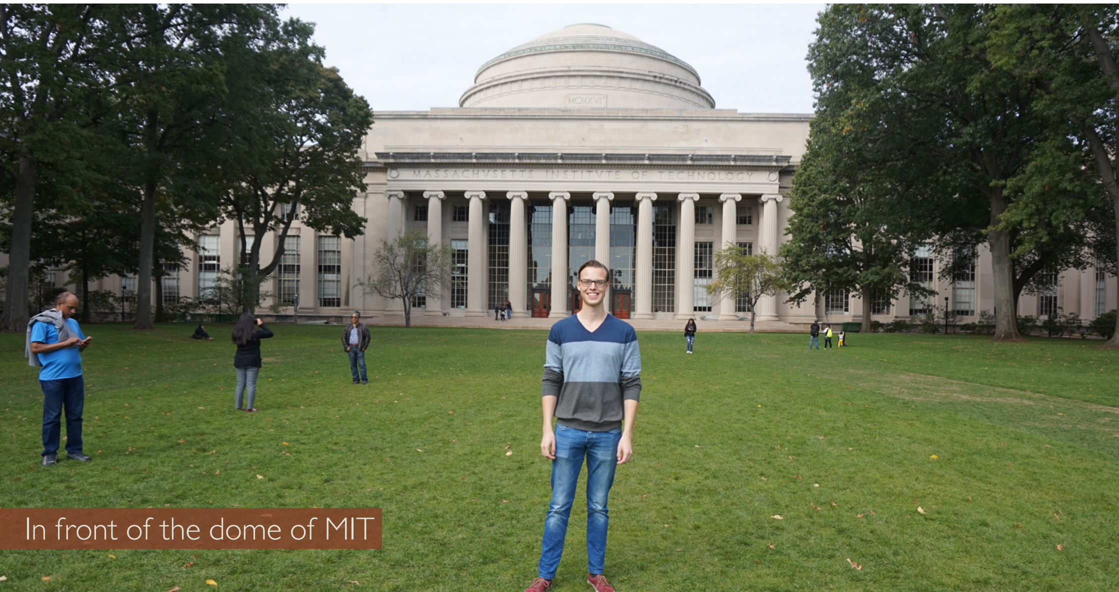

Indian summer (google it!) at White Mountains

I'm already over halfway of my time here, a nice moment to write the second part of my 'Studying Abroad' trilogy. In this part I'll take a different perspective than the first as I'll be focusing on the university itself. I'll try to answer the seemingly more important questions like "What's it like to be at MIT and do research over there?". As an added bonus, my girlfriend has been here in the meantime for a total of three weeks, which means I have an extensive photo collection of which I can share a few with you.

Notice that I said the 'seemingly' more important questions. It's all in the name 'MIT' that makes it seem more important. Now don't get me wrong. I certainly feel privileged to walk around here, especially in the first few weeks. The main building is a piece of art and has libraries where you can study inside the famous dome or sit down in a big relaxing chair, while enjoying the view over the river Charles. Of course this is not what I usually do, because my office is in a place where we physicists know physics places to be all too well. Yes, that will be in the basement of the main building, the place where they don't care about hiding pipes from sight or installing air ventilation in an office. But I wasn't done praising this university yet. As a student you can benefit

My office is in a place where we physicists know physics places to be.

from a lot of facilities like a beautiful gym with sauna included or an Olympic swimming pool. You can also decide to join one of the many clubs out there that range from a sail or skydive club to a beehive or Quidditch club. There are also clubs for if you're interested in training people skills or if you're just interested in a social club with people that have similar interests. I for instance spend quite some time with people I met via the poker club through which I have the possibility to play some (home) games



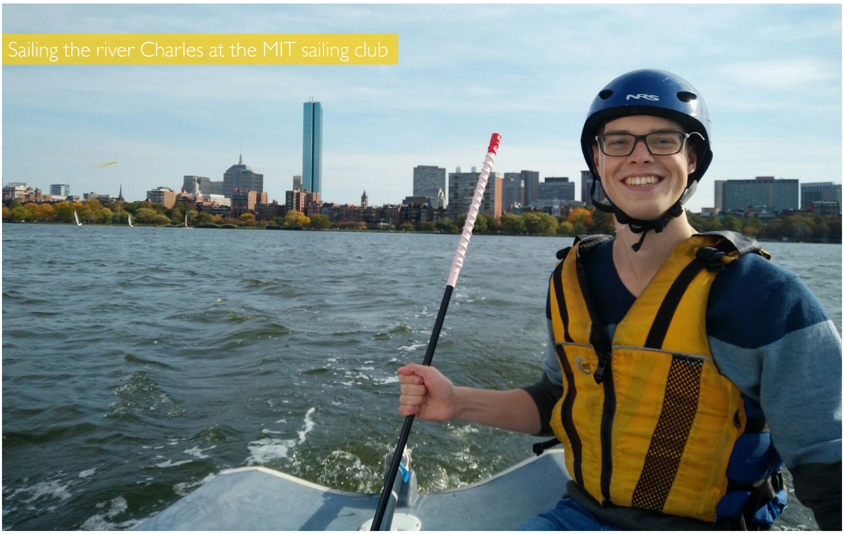
In front of the dome of MIT

or go to casinos. They basically have a club for everything. And it's all "free", because you've paid for it in terms of a registration fee that is higher than a Dutch tuition fee. Ok, now I'm done.

The beautiful main building with crappy basements is in a way a nice example of the way research is being done and how the board likes to invest in the university. It all has to look good on the outside, while an inside view may reveal some contradictions. MIT has a certain title they eagerly want to keep and one of the aspects that will be assessed is of course the research. Now if you want to have the best research at your university, you need to have the best people. So MIT scouts them from all over the world and offers great deals to those who truly are the best for them to study or research at the prestigious university. This does lead to some groundbreaking research that makes it look like the research is top of the notch in every way. Together with the best people you would need to have the best laboratories. Here's where we come to the first contradiction. Laboratories are being used by many people that come from all different groups. Nobody really feels responsible for the well-being of a lab and the people in charge lose control of what happens in the labs. If new equipment is bought for a lab, the quality will degrade quickly because of this. All this results in mostly dirty and messy labs with equipment that's far from optimal. As an example our office's box of PDMS had been stolen twice in a row even though it had been labeled with our name. In the same lab I heard one of the women in charge cursing about a chemical cabinet of which 60-90% of the components were falsely registered. Researchers have to pay internal fees to use each other's equipment. This only impedes cooperation between groups. People stack up on paperwork and circulate money, while in the end they break even. Apparently it doesn't seem to help the state of the labs.

As scientists move up along the ladder of MIT, they need to deal with the 'bullshit show' as a postdoc in our office likes to refer to it. Everything is being pushed towards patents by people at the top of the ladder. It's all that matters and the competition is killing. There's no time to completely understand every aspect of the research you do or tend to do. You come up with an idea and present it to someone higher up the ladder. At that point it's either a hit or a miss and if it's a miss you need to come up with a new idea quickly and forget about the rest. It's all about glorifying your research and some people even steal each other's ideas to get there. People won't make it if they're not running many hours and the salaries (at least for PhDs and postdocs) are outright low. Luckily, I don't have to deal with all of this as a Master's student.

Down the ladder the work environment is more pleasant. I get to determine the amount of hours I put in and don't have to deal with the sales pitches to glorify my research. I'm stimulated to get as much out of this experience as possible besides doing research. And they're right, because that should be the reason you study abroad. You don't have to do it for the experience and training in research itself, not even at MIT. Although it does seem important.

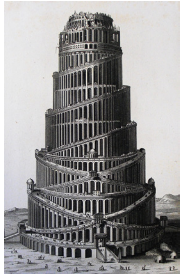


Sailing the river Charles at the MIT sailing club

Comic

By Kathinka Frieswijk

Puzzle



By Steven Groen

As A[nd]ton already pointed out, humans have an exceptional ability to communicate with one another. However, (presumably) because of the unfortunate audacity of the constructors of the tower of Babel (pictured on the top right), there is more than one language in this world. This can cause a lot of ambiguity and confusion. One of the most popular contemporary tools to overcome this is Google Translate. One might point out that Google Translate is not a perfect translator, but then what would be a perfect translator? Who could assess that? Is there an inevitable indeterminacy in any translation, as according to Quine? Those are some interesting questions in the philosophy of language, and also a theme in this puzzle. The descriptions or definitions of words have been translated by Google into a number of languages, and eventually back to English. Boxes with the same number contain the same letter. Vertically, in green, the name of a philosopher of language can be read. If you tell us this name, you can win a puzzle.

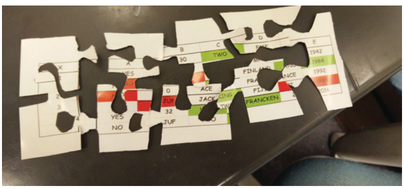


Figure 1: A puzzle to the previous solution.

1. Games, trial games. Part of the support structure, of course, management.
2. Little star of the solar system.
3. Summary of cheek hair color, but the animals and take them.
4. Beer, you can sell it.
5. All stars and galaxies public with a natural process, such as planets, each other. Light as energy and mass, cause and effect, is by all forms of energy.
6. Beer is the most important region. The largest city in North Holland.
7. Eighteen students have enough magic legendary British eleven.
8. Transfer to understand and accept the legal advice, nor much.

9. Food, seed, orange, leaves, red, white and blue.
10. Standard Australian Semiaquatic Egg Climate, Australia Mammals.
11. Cats, communicating with the dead, because he was alive, and not only because there is still a temporary international superposition.
12. The wife of the governor of his right hand.
13. All of the capital, "180 million people in four cities in Austria and Australia.
14. High speed electronic scanning images of crime in this production. The test for the topographic data, a different electrical signals design of thrust contact between atoms.
15. Neil theory mathematics, and the first book in 1687. issued on the basis of Mechanics ancient philosophy. Light and Leibniz, he helped to pioneer the development of both.
16. -Saidheans Scotland, anthropologist, author and security in mind, the first researcher to make sure you get the call.
17. India minutes.
18. Technical Institute Groningen, Training Groningen.

1.					13	22	5	5	21	16				
2.					11	16	14	4	22	14	12			
3.					1	16	24	14	9					
4.						1	14	16	8	16	14	12		
5.					3	14	24	20	10	2	24	2	10	7
6.			3	14	7	17	10	17	3	16	17			
7.						6	7	3	8	24	14	2	26	
8.			4	7	11	11	22	17	10	4	24	2	10	7
9.				4	24	14	14	7	2					
10.						13	21	24	2	12	13	22	26	
11.	26	4	6	14	7	9	10	17	3	16	14			
12.						19	22	16	16	17				
13.					20	10	16	17	17	24				
14.									26	16	11			
15.						17	16	8	2	7	17			
16.								1	16	21	21			
17.									10	13	24			
18.						23	14	24	17	4	25	16	17	

Life After Francken

By Jasper Compaijen

And then came the email with the honorable question if I wanted to write a 'Life after Francken'-item. Honestly, I didn't really expect this question, nor did I anticipate that it would be asked so soon already. It doesn't feel like I have been away from the university for a very long time, but, looking back, I realize it has been a year and a half already.

Maybe, before I start describing my life and career, a brief introduction is at place. I am not part of the great subset of members which might call themselves *'wijze heeren'*, I have not been active in all committees you can possibly think of and I never got a highscore on the infamous *'reeelste borrelaar'*-ranking. However, I have had a great time at Francken. I became a member during the introduction period and did spent a large amount of time in the Francken room. I have had the honor to organize the Engineer symposium in 2008, and the SLEF excursion to Japan and South Korea in 2010. And, last but not least, I was at the very start of the great Ribcie-committee (is sparerib-tuesday still a thing?).

nedap
technology that matters

Anyway, after a bachelor in theoretical physics (which I started in 2006), I enrolled for the master programme in Nanoscience. During my master research in the theoretical condensed matter physics group of Jasper Knoester, I got offered a PhD position to continue the research. For 4 years I got the opportunity to completely dive into a topic, to try to understand as much as possible and try to tackle any problem which we came across along the way. I am sure all of you can imagine how much fun I had. About a year ago, in March 2016, I successfully defended my thesis titled 'Energy transport and plasmon dispersion in linear arrays of metal nanoparticles'. For those of you who are not so familiar with these terms, basically the research was about the behaviour of light in waveguides which are much smaller than the wavelength of the light itself.

During my PhD research I was in doubt whether I should pursue a career in science, or step away from the university and work in industry. I enjoyed doing science a lot, and discovering new effects and trying to understand and describe things which are still unknown surely is very satisfactory. Furthermore, I was always mostly interested in the theoretical and mathematical sides of the research and had the habit of calling applied physics students 'bicycle repairmen'. On the other hand, in real life, I actually really like building and repair stuff, and some 'bicycle repairmen' are actually very cool (check Monty Python's sketch!).

At the Beta Business Days of 2015 I joined a session of a company called Nedap, which by then I only knew because one of my fellow students, Hilbert Dijkstra (which you all know of course), worked there. During the session I was actually quite impressed with the amount of interesting projects and challenges they were working on. Hilbert told me that they do most of their research & development in-house and that he would be happy to invite me over for a tour of the company. During this visit, I quickly realized that this was the kind of company that I could see myself work for: nice and easygoing atmosphere, hardworking people and many interesting products and technologies. Also, the company is big enough to have a lot of possibilities, but feels small enough to get to know a lot of people across the different departments.

Trying to understand and describe things which are still unknown is very satisfactory.

During the visit I had a chat with the team captain of the R&D group of the Retail department of Nedap. He told me that over the past year the group focused mostly on product development, which had the consequence that the research part had been neglected a bit. Also, he could use someone who had a feeling for radio waves and antennas. You can imagine that this sounded very nice and all, but … I was trained as a theoretical physicist and specialized in nano-optics. Radio waves are like a bazillion times bigger. The good thing about Maxwell's equations is that is doesn't matter so much. Depending on the thing you are after, you either just multiply or divide by a billion and everything is well and fine. So I decided this would be a nice opportunity for me to see how it is to work in industry and in October 2015 I started my official working life.

You may recall that I mentioned that I finished my PhD in March 2016, so by the time I started working I was still writing my thesis. Although this is not uncommon, I will not recommend it to anyone, unless you want to really experience the few amount of hours in a day and how much sleep you actually need to function properly. Another complication was the location of Nedap, Groenlo (you know, Grolsch territory). Groenlo is in the so-called Achterhoek, of which 'Behindcorner' seems a perfectly fine translation which covers the most important thing: far away from everything. We decided to trade the beautiful city of Groningen for the actually-also-quite-beautiful city of Deventer, which resulted in a reasonable travelling time to work, but also being well connected to the rest of the country.

Traditionally, Nedap Retail is the manufacturer of 'Electronic Article Surveillance' products, in other words: the gates that make this annoying beeping sound if you are trying to leave a shop without paying for the articles that you have put in your bag. This system is based on 8 MHz radio transmission. Attached to each item is a label which basically consists of a partly double sided aluminum coil on some dielectric material. Of course the applied physicists among us immediately realize that this is in fact an inductor and a capacitor connected, forming a resonator (see Fig.1). The gates are antennas which transmit an 8 MHz signal, the labels are resonant at this frequency and an oscillating current starts running through the label. The radiation emitted by the moving charges in the labels is received by the antennas and BEEP!!! Although the working principles are very straightforward, it is in reality quite complicated to make a decent working product out of it, since it requires huge sensitivity and it is very receptive for noise sources.

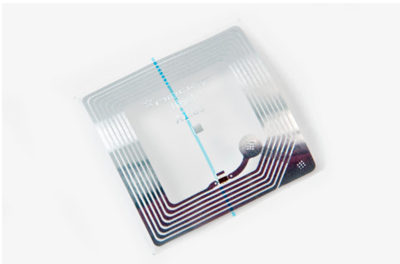


Figure 1: 8MHz EAS label.

The newer generation of products we are making is based on quite a different technology, namely UHF RFID. Here, UHF stands for Ultra High Frequency, which is 900 MHz, still mammoth sizecompared to optics but a slight improvement. The important part of the technology is the last

Figure 2: UHF RFID label. The black dot in the middle is the chip.

two characters: ID. The labels have a little chip inside which is able to communicate an identification code (see Fig. 2). This is very relevant because it allows you not only to signal that something is being stolen, but also tells you which item has been stolen. In fact, you can even make much more relevant stuff than theft protection. Being able to find a unique product ID remotely, allows you to do a very fast, accurate and efficient inventory round. Since radio waves propagate through lots of materials, it is possible to take the IDs of pile of jeans or a rail of shirts, without having to touch them. At the moment my work mainly consists of researching and prototyping to bring this technology one step further: Is it possible to build a high-performance, fully automated inventory system? How can we optimize the system to become low-cost and easy installable? And will our systems affect (and be affected by) the growing number of wireless connections in our day-to-day lives? While writing this I feel honored that I have been given the possibility to develop commercial products that are operating on the edge current technology, just as a simple theoretical physicist.

Figure 3: The SLEF 2010 committee.

Could I have a triple vanilla shot pumpkin spice frappuccino?

Thank you SO MUCH!

By Rob Jagt

California is the sunshine state of long beaches with white sand, hipsters with well-maintained beards and very diverse landscapes (it is possible to go surfing in the morning and be on your skies in the snow in the afternoon). Currently, I am halfway through my research project at Caltech. A good time to step back from the research for a moment and to compare the USA and Europe. In this second episode: The tiny differences between Europe and America.

The famous car scene in *Pulp Fiction* states it nicely. John Travolta: "You know what the funny thing is about Europe? They have the same shit over there, but theirs is just a little different. " Samuel L. Jackson: "Example. "

The USA as a salad bowl

My time here at Caltech is like living in a bubble inside another bubble. The difference between different parts of the USA and Los Angeles are huge. This is best exemplified by my daily bicycle trip to Caltech. When I cycle under a bridge I pass a couple of homeless people, whereas after 5 min I drive through a fancy neighborhood with Maserati's parked in front of the houses.

Soon America will become a majority minority country, in which one or more racial and/or ethnic minorities (relative to the whole country's population) make up a majority of the local population. The idea initially was that this would converge to a melting pot in which the heterogeneous society would become more homogeneous, and where the different elements would "melt together" into a harmonious whole with a common culture.

In hindsight one can argue that the USA has not become this melting pot, but could rather be compared with a salad bowl with different ingredients all with its own distinct flavors. Of course this segregation within society is not something which is special to the USA. However if you want to understand the segregation of society within Europe, America is a good place to start.

Hypocrisy in the USA

I believe that president Trump disqualified himself at numerous points in the campaign. However, there is now this idea that anyone who voted for him has to be defined by the worst of its rhetoric. Not everyone who voted for him are necessarily bigots, racists or xenophobes. People are also afraid of the rise of their insurance premiums, the loss of manufacturing jobs and the impact of globalization and automatization. Just as Muslims are looked upon as a monolith, so are voters for Trump. That hypocrisy is also real.

The Sky is the limit

But what is now the biggest difference between California and the Netherlands? For me this boils down to how success is

View from my back garden

perceived and judged by your surroundings. We have a nice saying in the Netherlands which (badly translated) goes like: "Don't stick your head to much above the mowing field". This is totally different in the US. Where in the Netherlands you have to be very humble about your success, here it is totally okay to show that you are doing well. You are in charge of your own success and if you do well that is something you are praised for. On the contrary if you mess up, then this is your own fault and there is very little social security on which you can rely. A city like San Francisco for instance has a lot of homeless people, even though the city itself is very rich.

What makes America Great?
This is one of the things that differentiates America from for instance Europe, both in a positive and a negative manner. The positive mentality makes people very entrepreneurial, which is exemplified by the success of Silicon Valley, but also by the dominance at the Olympic sports, space programs and research. The top 25 of the best universities around the world are heavily dominated by American universities. On multiple levels there is always the strive to be the best. This is in high contrast with the Netherlands where we are much more interested in improving on average.
The price the American society pays for their dominance on the global stage at different levels is that not necessarily everything is that great. The difference in quality of education at different universities is enormous. Also the price tag itself is enormous. With staggering tuition fees

> Yes, there exists such a thing as drive-through ATM's.

of $45.846 and $48.452 for Caltech and MIT the average cost of a year of studies is close to $68.000 dollars. You can now imagine that student debt is a huge problem in the USA. This system also adds to the large division between poor and rich, since you have to be rich to be able to study. The impact this has on accessibility of education is depicted in table 1.

My prejudice about US madness
When I came to America I had a lot of ideas and prejudices. Al this was based on what you see in a South Park episode, American talk shows and reading articles. To my surprise a lot of the prejudices have been confirmed rather than rejected. Yes, gas here is insanely cheap. Yes, people do everything by car. Yes, people do fight during ice hockey games. Yes there is a lot of fast food. Yes, there exists such a thing as drive-through ATM's and I could continue this list for a while.
One specific example which I found interesting is that everyone pays for stuff with

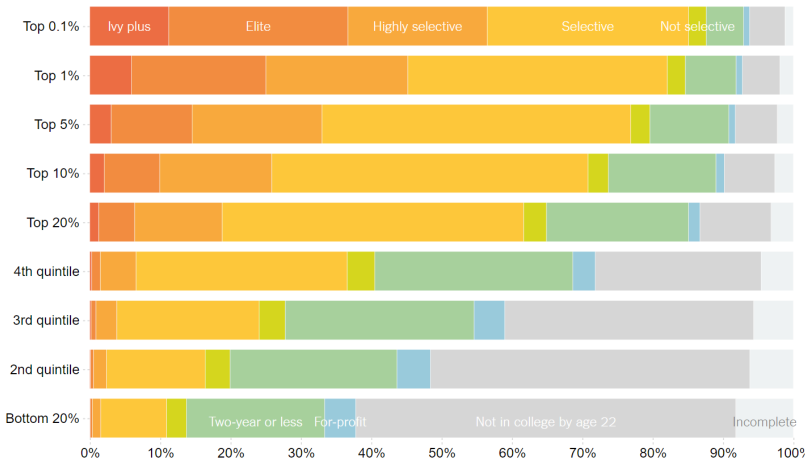


Table 1. Distribution of university level attendees for different income groups.

credit cards. You actually get paid to use your credit card. If for instance I use my credit card to buy gas I get 3% back in cash from my bank. So people are motivated to spend money on credit (and pay for everything with debt). People even buy mattresses on credit, something unbelievable in the Netherlands. It is easily imaginable how this type of spending has led to the housing bubble in 2008.

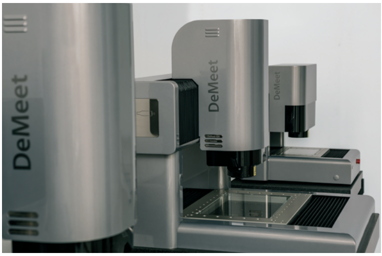
Lastly, people here have the strange belief that something can only be good if you have to stand in line for it. So if you have to wait in line for a club, bar or even for a coffee place, it is considered to be a good thing. Because if people are willing to wait in line for it, it probably must be good.

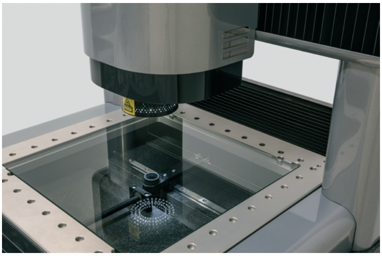
What did I like the most?

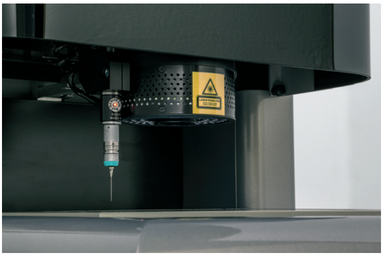
Next to the awesome research environment what I like the most and surprised me the most in a positive way is the beautiful nature. According to the editorial board people enjoy watching pictures much more than reading stories, so I'll just let the pictures speak for themselves! In the next and last episode I'll (hopefully) will tell about the results of my project! Cheers!

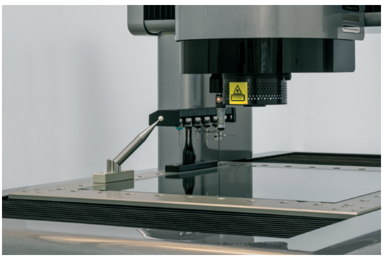

Death valley


Antelope Canyon









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Aangezien we onze activiteiten uitbreiden, zijn we continu op zoek naar enthousiaste medewerkers om ons team te versterken. Als jij wilt werken in een bedrijf dat mensen met ideeën en initiatief waardeert, dan is Schut Geometrische Meettechniek de plaats. De bedrijfsstructuur is overzichtelijk en de sfeer is informeel met een “no nonsense” karakter.

Op onze afdelingen voor de technische verkoop, software support en ontwikkeling van onze 3D meetmachines werken mensen met een academische achtergrond. Hierbij gaat het om functies zoals ***Sales Engineer***, ***Software Support Engineer***, ***Software Developer (C++)***, ***Electronics Developer*** en ***Mechanical Engineer***.

Je bent bij ons van harte welkom voor een oriënterend gesprek of een open sollicitatiegesprek of overleg over de mogelijkheden van een **stage-** of **afstudeerproject**. Wij raken graag in contact met gemotiveerde en talentvolle studenten.

Voor meer informatie kijk op **www.Schut.com** en **Vacatures.Schut.com**, of stuur een e-mail naar **Sollicitatie@Schut.com**.

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