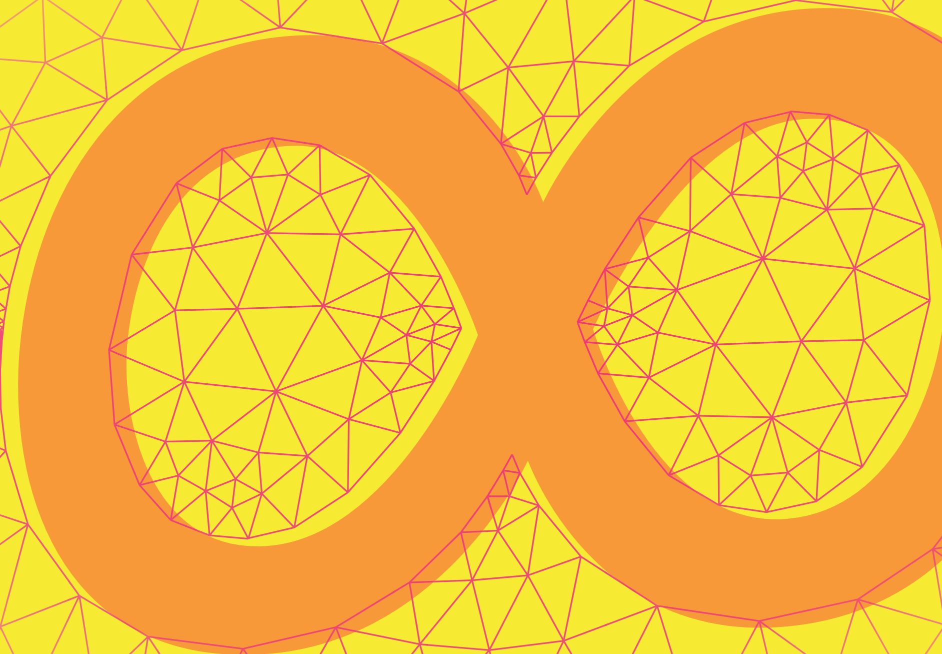
Theorist
Looking at the finite element method

Francken Vrij lustrum
A revision of the last five years of Francken Vrij

Life After
Mark's career after working at Shell

Francken Vrij

Finite

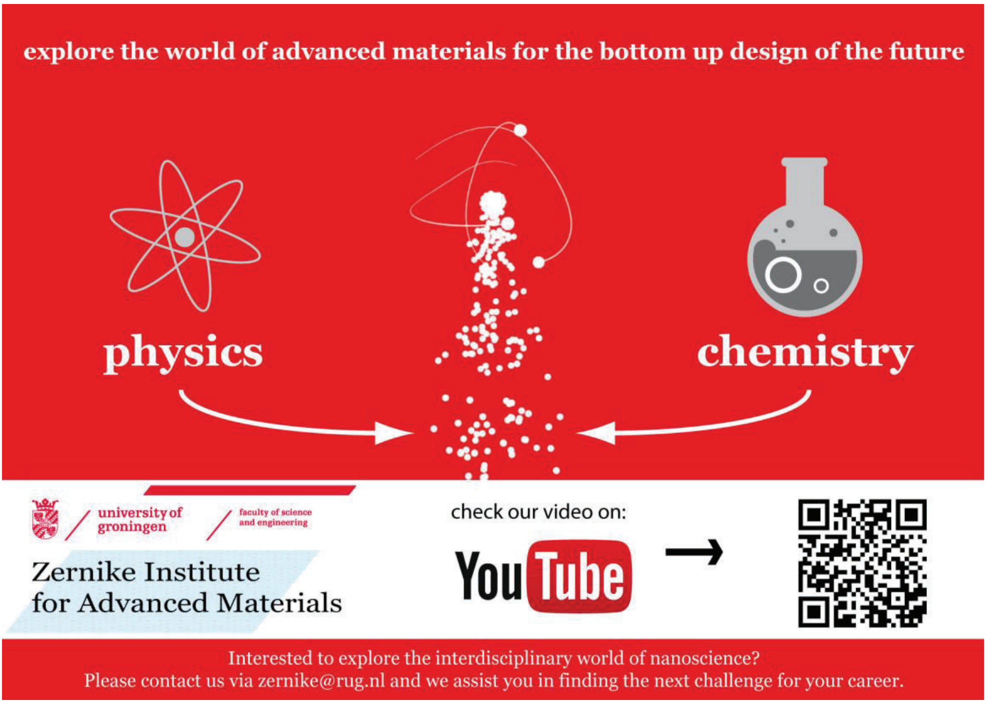


25.2 - Finite

Zernike Institute for Advanced Materials

You want to build the next generation of solar cells, starting from molecular building blocks? Or change the world of computing by crafting groundbreaking memory materials atom-by-atom? Maybe you want to use your talents and interests for learning how to develop materials preventing or curing disease? Then have a look at the Bachelor, Master and PhD programs related to and inspired by the Zernike Institute for Advanced Materials' research lines.

Our activities cover both **Bachelor** and **Master** levels in the field of *Physics and Chemistry.* It is our mission to *train a new generation of researchers in cross-disciplinary approaches to research and equip them with the diverse skills required by modern science*. For making our mission real, we have established programs breaking the traditional boundaries between disciplines. One example is our interdisciplinary Top Master program Nanoscience, which is rated as best Master program of the Netherlands several times by national study guides. We also offer the High Tech Systems and Materials Honours Master in collaboration with industry. In this program you can pursue real-life product development challenges in a really interdisciplinary setting.
Additionally to the Bachelor and Master education, the Zernike Institute is training approximately 150 PhD students to become independent, high level scientists. The main component of our training is 'hands-on experience', building and developing your skillset side-by-side with the research staff of the institute.



Are you interested in joining our team for a Bachelor-, Master-, or PhD-project? Check our website http://www.rug.nl/research/zernike/education/ on the different educational programs or directly approach us via zernike@rug.nl.

Colophon

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Lau Kerdijk
Leon Trustram
Tabitha Minett

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Editorial

There are only a finite number of weekends per year during which we can have layout sessions. At this point, thinking that the Francken Vrij will be on time is more a mistake of the reader than of the editorial board. Luckily the number of editions per year is also finite. If you're patient enough we'll have an amazing last edition to finish off this anniversary with you.

Then, as you might have noticed by know, the the theme for this edition is finite. Since almost anything in Applied Physics is finite, there's many ways to approach this topic. I hope you'll enjoy reading about it.

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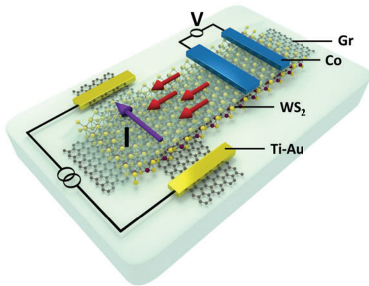
General:
Advertisers
Ziam$_2$, ICD$_{14}$, Schut$_{36}$
ISSN:
2213-4840 (print)
2213-4859 (online)
Edition and circulation:
May 2021, 1000

Special thanks to:
Jelle Bor MSc., Pelle Koeslag, Arjen Kramer, Melav Salih, Mark Schenkel, Bradley Spronk, and Dennis de Wal MSc.

Edition 25.2



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Chair's Preface

By Melav Salih

As **my board** year has crossed the halfway mark, it daunts me that my time to make a difference is approaching the limit. Many things have been different this year with the pandemic and the chain reaction that followed. However, we can almost see the light at the end of the tunnel with more vaccinations getting approved by health ministers around the world and millions of people getting vaccinated globally. It has already been announced that 11.3 million doses of the Janssen vaccine, which only requires one round of dosages to protect you from COVID-19, have been ordered by the Dutch goverment.

There have been many fine nights with Charm where we sit together and consider what we want to transfer to our candidate board to maintain our vision for Francken. The thing we always circle back to is making sure that we are included in all the fun that comes with doing a board year as a lot of it was missed this year. But we are also planning an epic end to our year! It is only fitting that we go out with a bang.

Personally, I have been keeping myself busy with the FSE radio as we are building a website and continue to send out invitations everyday. Besides that, many different projects are circulating the boards of the study associations in the Faculty of Science and Engineering as we prepare for the coming year. We, Charm, are not finished just yet and still have a lot in store for Francken. We hope to make the most out of our time away from members, but that's up to our candidate board and future members to decide!

News of the Association

By Tabitha Minett

I **find the** theme of this edition very fitting - we only have a finite number of photos of the events from the past few months. Although we mostly see each other as pixelated images, it's still been lovely to see you nevertheless. It's my pleasure to look back on some of the great activities since November.

Feesten Met Francken
Fortunately, the annual collaborative event between Francken and FMF was still able to go ahead this year! Instead of the usual mystery hunt, teams searched the city, digitally or physically, to find the location of the provided images. Since I was in a team with Mark, it was wisest to participate digitally. Despite not finding all the locations in the record time, everyone was a winner at this event and received a prize!

Limited Edition Online Francken Gameshow Deluxe XL
Fraccie's second online event certainly did not disappoint; after teasing us with an intriguing trailer, we gathered on Discord to see what they had in store for us. The board took numerous rietadtjes for bonus points, but despite that, Mare and Nieske came out on top! Unfortunately, those numerous rietadtjes may be the reason why all I can remember from the evening is the Ganzenbord round and the stunning adverts as interludes (now available on YouTube).

Francken Friday Lectures

Dennis de Wal was able to give December's Francken Friday Lecture from the members room - possibly the first time some of us had seen the room in many months. Dennis talked about how playing with 2 dimensional "nano-lego" makes the future. This was nicely followed by Marcos Guimaraes' talk about using 2 dimensional materials to manipulate magnets with electric currents for future memory devices.

Codenames

This online version of the Czech card game sees players work in teams to guess as many of their words with the fewest hints. It took me a shamefully long time to understand the game, which is possibly why I'm always an operative and not a spymaster, but it's a very entertaining and competitive game, one that we're sure to play in the future.

H-GMA

Another day, another online GMA. This GMA was particularly interesting as the hot topic of discussion was our beloved magazine. Many of you will be reading this on your phone or laptop because of the results of the GMA! Additionally, the board learned that they had poor audio and sitting on the floor for the duration of a GMA is not comfortable, but it does mean you don't have to wear bottoms.

Jackbox Games

Sjaarscie's first event was a collection of delightful games! Groups played Jackbox games, Cards Against Humanity, and Skribbl, games that the witty and creative excelled in. Skribbl allowed for customised words, which inspired some physics-related drawings. It was lovely to see some of the older members meet the sjaars!

Online Francken Friday lecture in front of a laptop

ZIAM Lab Tours

After the successful round of lab tours for the freshmen, third years looking towards their thesis had the opportunity to get a glimpse of the ZIAM labs. The event wasn't exclusive for Applied Physicists in order to attract more students to the field. Students were able to get a glimpse of research group's work, projects they have on offer, and ask all their questions.

International Pubquiz

This year, it was the Borrelcie's responsibility to host the infamous international pubquiz, and they rose to the occasion! With internationally-themed goodie bags delivered by the sjaars, participants were ready to have their knowledge put to the test. After six competitive rounds, the board of De Chemische Binding was crowned victorious. Regardless, it was a *charming* evening!

Comic

By Bradley Spronk

Francken Abroad

By Pelle Koeslag

Now that's a surprise, getting the request to write something for the Francken Vrij after all these years... and I'm happy to do so. It's been a while since I was found hanging out in the *Franckenkamer*, so maybe it's good that I start with a short introduction. I joined T.F.V. 'Professor Francken' in 2004 on my first day of studying in Groningen after walking into this legendary room and was offered a free coffee in my new association mug. I've spent a good deal of my studying life with my fellow Francken students and a fantastic year as treasurer of the '07/'08 board.

It says something about the relevance of the T.F.V. that, many years after they've been active in Francken, some of her older members (dating back to board members of '03/'04) still meet up once in a while to hang out. Now in corona times this happens on vierde-man.nl and I want to take this opportunity to thank everyone that was involved in the development of this really impressive work!

My story abroad starts back in my student days when I used the Erasmus program to study a semester in Uppsala, Sweden. I can strongly recommend any student (not yet) thinking about doing something similar to, once the immediate pandemic is over, do it. It made me experience a new degree of freedom, meet loads of new people with very different backgrounds and learn a lot about myself by reflecting on their ideas and foreign customs. Even though Groningen is arguably the greatest city for a student to live in, the fantastic time spent abroad did stick out. In my case there's an additional reason why this was an important time in my life as I met a beautiful German girl there, who is now my wife and, at the time you read this, mother of my two sons.

In 2011, after I got my degree, I turned my back on Groningen and started my working life. As a physics (post-)graduate you're well prepared to start a career in many different directions. Most obvious is a scientific career, but after some time most of my fellow students moved away from that and went into teaching, industry (scientific/technical), medical applications, business (consulting/financials) or in my case data.

The world of data, which as a student I wasn't aware of, is big, divers, and growing. On the more scientific side of the data spectrum you'll find the data scientists. As a data scientist you'll be creating methods, based on statistics & mathematics, to extract knowledge from data. Of course, the big tech companies spring to mind here, but the field is much bigger and today any big company has teams working on artificial/augmented intelligence applications that either increase effectivity or open new doors. With the potential to change many facets of life as we know it and most use-cases yet to be thought of, this is definitely an interesting field in the years to come.

A bit further away from the science you find jobs like data engineers/-architects/-warehouse specialists. I came to be one of these people.

After moving to Germany I learned that it wasn't as easy as I'd imagined to find a job. First and foremost, the difficulty lies in knowing what you want to do. In my case I knew I wanted to do something with IT as I enjoyed the way of thinking when programming for my master's research, but that's far from specific. An additional hurdle is the fact that I was looking for a job in a foreign country, where you don't know the companies, have some disadvantage due to language (many Germans prefer German over English), and are unfamiliar with the customs (more formal, use of Xing instead of LinkedIn and sending applications in form of a physical "Bewerbungsmappe" in particular). After a rather unsuccessful streak of applications I went to a job fair. While trying to talk to one company serendipity stroke and I was tapped on the shoulder by someone from the opposite booth and asked whether I was interested in data warehousing. It turns out that, after I learned what it meant, I was.

The goal of data warehousing/-engineering is to organize a business' data in such a way that people throughout the organization can safely access and insightfully analyse it. There's a phrase "data is the new oil", which is partially accurate as it both highlights the importance of processing and its empowering potential if you do so. It also shows that this is a key field with good prospects.

A typical career here would start with a position in an IT Consulting company and after some years of experience move to a company big enough that it produces enough data. If you have a click with IT and enjoy working on challenging puzzles in an environment that's relevant and changing fast, this might be something for you. Please note here that programming is something that you can learn and you don't have to be an expert when starting a career here.

For me, after living and working in several cities in Germany, 6 years ago we moved to Hamburg. Since then, the transformation from once a student to now a "burger" is all but complete as we are settling down in the outskirts of Hamburg. And as this is a beautiful city (with a direct bus connection from Groningen), I have my "Doppelkopf"-group (you'll enjoy it if you like Klaverjas) and my wonderful family here, I guess that's not the Wurst.

WHERE GREAT MINDS WORK

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We are a group of high-tech companies in the Northern Netherlands that work together on solutions for the major challenges of the future 'on the edge of technology'. We call this our 'big 5' of high-tech: 'the internet of things', big data, robotics, 3D printing and alternative energy. We do this by using state-of-the-art high-tech or, where necessary, developing it ourselves. This is possible thanks to the unique collaboration of our R&D departments, in which mutual competition has given way to strengthening each other. The result is more than 50 new products every year worldwide. Products that save people's lives, make the operation of complex systems child-friendly, tailor products to the individual wishes and needs of consumers and make data accessible to improve the quality of food. We are Innovationcluster Drachten: 'The heart of the smart factory region' of North-West Europe.

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Ring-ring

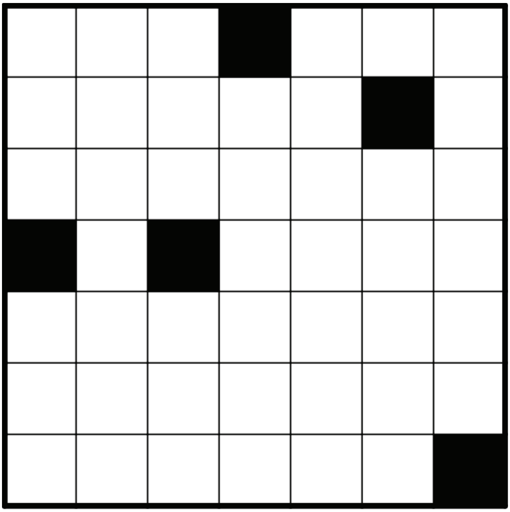
By Arjen Kramer

Can you make a puzzle with the theme 'finite' they asked me, to which I answered: "sure". But as I started thinking, it became clear to me that pretty much every puzzle is already finite. There is a grid of finite size, a finite number of items to place, a finite number of possibilities to try, and a finite number of solutions (one, for a good puzzle). So how to make a puzzle which is especially finite?

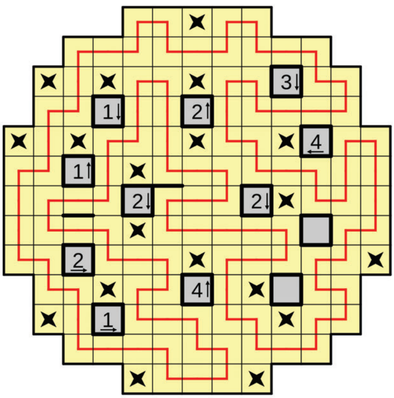
Well, when do you say something is finite? If you know that there is an actual finite number, but you don't know that number. Because if you knew you would just say the number. Therefore the puzzle needs a lot of unknown numbers, preferably an unknown number of unknown numbers. This led me to a puzzle type I discovered quite recently, called Ring-ring, which has the following rules:

- Draw an unknown number of rectangles in the empty cells of the grid.
- Rectangles consist of horizontal and vertical lines connecting the centers of cells.
- The height and width of rectangles may be any unknown integer.
- The sides of different rectangles may intersect, but not overlap.
- Rectangles can't touch otherwise; in particular, they can't touch by a corner.
- Every empty cell is part of at least one rectangle.

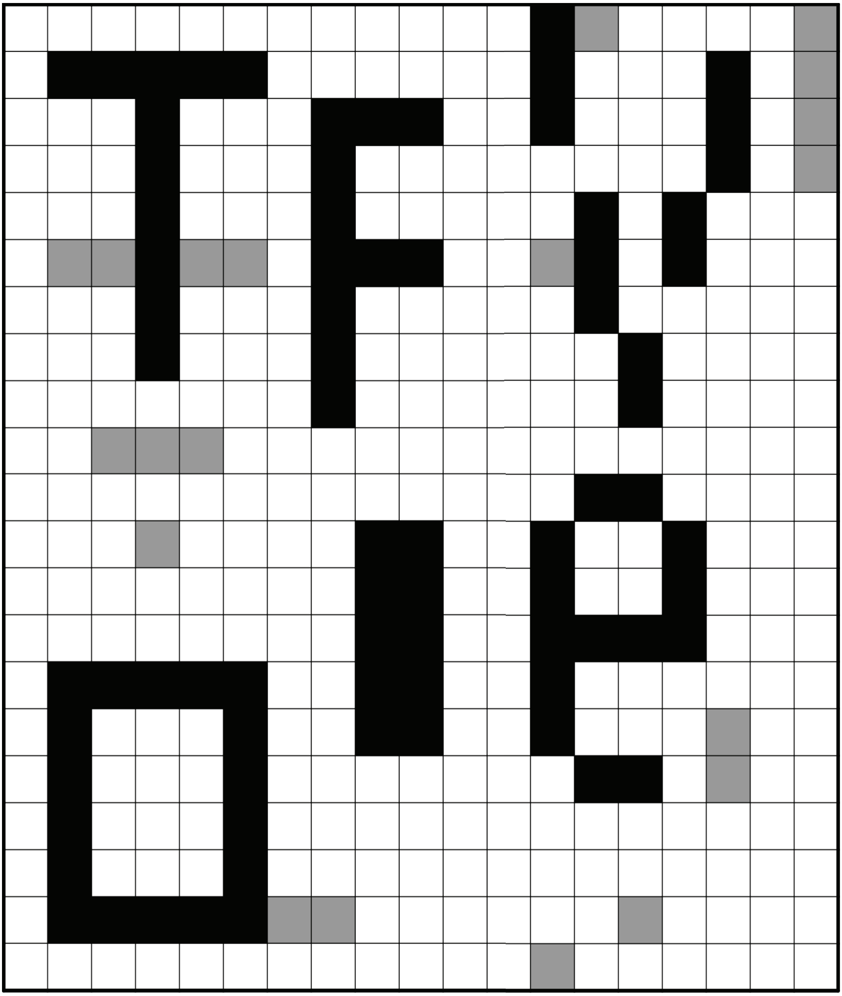
As a warm-up/try-out problem I've added a smaller puzzle which needs five rectangles to be completed, For the real puzzle, the solution is the number of rectangles you need to fill the whole grid following the Ring-ring rules.
The first to submit the correct answer will win an unknown, finite number of the famous Gebouw13 beers.



A warm-up puzzle to get you started



The solution to 25.1's puzzle



The true puzzle of this edition.

Life After Francken

By Mark Schenkel

If there is one thing I'd like you to take away from this piece is that it is very rewarding to contribute something to the world, rather than only your company's shareholder value. I'll try to illustrate this by explaining the route I took following graduation as it shows the variety of things you can work on when it comes to the energy transition and climate change. But to do that, I can't really start without underlining the urgency of climate action.

Noticed how it's getting warmer? The five warmest years since we started measuring them in 1880 all occurred since 2015. In the 2020 summer, six out of the twenty largest wildfires in the history of California occurred – five of which burned simultaneously. At the same time, 2020 is poised to be one of the coolest years of the following decades; because it will only be getting warmer. And this warming trend is still accelerating.[1]

> *"I want you to act as if our house is on fire. Because it is"*
>
> Greta Thunberg

Mooie Gekken

Dear *Franckenleden*, you are needed. Rarely have I seen such a group of creative and brilliant individuals as on a random Friday afternoon borrel in the *Franckenkamer*. You combine utter madness with correcting the AIVD kerstpuzzel (or so I read). You win Almanac prizes, pursue PhDs in quantum mechanics, design highly

advanced Tour de Franckens and throw infamous constibos in Groningen yet do one of the most complex and time-consuming studies in this university-dominated city. Please, between your next hangover and your next drink, take some time to consider how you can use these admirable skills to stop our house from burning down.

Choices

With the realities of climate change getting clearer to me somewhere in the second half of the noughties and my studies, I realized I wanted to work in the energy transition. You know, fighting the good fight.

So I joined Shell. Bear with me.

I figured I needed to understand the intricacies of the energy system in order to *change it from within*. I still think this was the right decision at the time: I had a great time and learned a lot about the energy system and how industry and multinationals work and think. The company is moving in the right direction, albeit slowly in my view. But at that time there was so much misalignment between the companies' vision and my own, that after almost five years I decided I needed to leave the company and rethink my career path.

Consulting

After travelling for a while, I found a consulting firm that focused fully on the energy transition and climate action:

Ecofys, now called Guidehouse. They had such an impressive track record of impactful projects that were right up my alley that I decided to arrange a call with one of their consultants through a mutual friend – and ultimately landed a job.

At Guidehouse I worked on such a wide variety of projects it's hard to describe it all. Let me just highlight some random ones that I was involved in to give a taste of the variety of things they do:

- We supported the Platform Carbon Accounting Financials (PCAF)[2]. Don't be fooled by how boring that name is. PCAF devised a harmonized set of accounting rules to allow financials like banks and insurers to measure, steer and take ownership of the carbon emissions of their investments. The collaboration started in 2015 under the vision of ASN Bank and grew to be a global and growing group of financials that all commit to start measuring and disclosing their emissions this way. Still sounds boring? This means that each year, these institutions will report on how much climate damage they are indirectly responsible for. Publicly. And all partners agree measurement is a means to an end – meaning they will need to steer their investments down a path to 'Paris.' Globally, they represent over US$ 21 trillion in assets under management at the time of writing. That's huge!

- We supported a large Asian investment firm in understanding the Carbon Capture, Utilization, and Storage (CCUS) ecosystem so that they could start to engage with different startups and scaleups in that field. It really helps to be a physicist when you need to explain how the fundamentals of thermodynamics don't make it very easy nor cheap to take what is one of the most stable molecules, CO_2, break it up, only to rebuild hydrocarbons again. Then again, such *utilization* technologies may prove to be invaluable in decarbonizing aviation or fine chemicals for example. Understanding future market dynamics and low-carbon alternative pathways in various economic sectors is key to do market research like this.

- We helped large corporates set so-called *Science-Based Targets* on their greenhouse gas emissions. These are essentially climate targets demonstrably in line with 'Paris'; so a well below two degree global warming world. Some of the world's most valuable retail brands were our clients, but I unfortunately cannot disclose any of them. My colleagues published an article in Nature that explains the methodology behind this target setting.[3]

I could go on, but I won't. My point is that there is so much work cut out for us geeks to combat climate change! When I was rethinking my career prior to leaving Shell a couple of years ago this article from Bret

Victor was an inspiration: http://worry-dream.com/ClimateChange/.

Next step

Very recently I decided to take another turn. I am fascinated by the role energy infrastructure will need to play to help society, and specifically industry, decarbonize. I realized I wanted to dive deeper on these two highly interlinked topics: industrial decarbonization and energy system integration (think hydrogen from electrolysis, for example). I just started working in Gasunie's energy transition team to support industrial clusters in strategizing to meet the Dutch 2030 climate target. We look at the roles hydrogen, carbon capture, biogas and heat infrastructure can play to reach climate targets in an affordable way – from a societal perspective.

Through realizing this infrastructure early, industry can pivot to sustainable production processes sooner and is better capable of developing in a future, climate-proof manner. I hope I can support this development in my new role.

Disclaimer

Ok, ok, so reading back maybe I came off a bit strong. I'm not saying everybody needs to work in the energy transition specifically. I have close friends – a lot of which are proud Francken members – that work as a teacher (please be a teacher!) or as a medical physicist (please cure diseases!) or that work on biodiversity, for example. My point is this: if you're about to graduate, please look how you can contribute to the world with your amazing skills. A meaningful job is rewarding beyond a paycheck and definitely a lot of fun.

1. Source of claims: https://www.ncdc.noaa.gov/sotc/global/201913.
2. More info at carbonaccountingfinancials.com
3. Krabbe, O., Linthorst, G., Blok, K. et al. Aligning corporate greenhouse-gas emissions targets with climate goals. Nature Clim Change 5, 1057–1060 (2015).

Francken Vrij
Een kijkje bij Samuel Hoekman vertelt ons over het leven als klinisch fysicus.
De theoreet Ook theorieën kunnen ziek zijn. Vooral als het om Lagrangianen gaat.
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Fifth lustrum of Francken Vrij

By Sibren Wobben & Leon Trustram

At Francken, we love celebrating anniversaries and lustra. After celebrating our general Francken lustrum in the previous academic year, this year it is our turn to celebrate our fifth lustrum of the Francken Vrij. In this piece we will reminisce about the previous 5 years of producing the Francken Vrij. We have thoroughly gone through the 15 Francken Vrij editions that make up our fifth lustrum.

What has changed content- and layout-wise? Which members have provided most columns during the fifth lustrum? What kind of remarkable events have been documented in these editions? What are our plans for the next 4-5 years to make the sixth lustrum of the Francken Vrij just as good as the fifth lustrum. These questions, and more, will be covered in this piece. Special thanks goes out to all the members, former members, and professors who have contributed many columns over the years.

It goes without saying that the Francken Vrij would not exist without these 'beautiful fools'. As some of you may have seen and heard at borrels before corona, we like to claim that the Francken Vrij is *in our heart and in our soul*. I like to think that the Francken Vrij committee is the heart, but the members providing the column contents are the soul of the Francken Vrij!
We hope you enjoy reminiscing about the previous lustrum with us.

History:
The start of this lustrum brought quite some changes to the way the Francken Vrij was made. In the first edition an attempt towards the current cover design was established, and the conventional usage of grey was changed to 'Francken blue' (#001841).

The second edition saw the Francken Vrij adapting to the internationalisation of the university of Groningen. For the first time all pieces were completely in English, although one ad for pwc was still in Dutch. This was also the first time we saw Jasper's pretty face at the start of the Colophon. Edition 20.3 had a special interview with the first editor in chief, Emiel Havinga.

In the 21st year we had a very special trilogy from Joran and Rob for the Francken Abroad. Jasper quit as editor in chief but stayed in the committee, while Evelien became editor in chief.

Between the 22nd and 23rd year a lot changed. After Esmeralda and Jasper had already left a year before, Evelien, Gerjan, Steven, Paul, and Kathinka also left the Francken Vrij, leaving a fresh faced Sibren Wobben as the sole remaining Francken Vrij committee member. After convincing some people the Francken Vrij was absolutely perfect for them, Sibren took over as editor in chief, supported by Emiel, Emma, Leon, and Laurens (and later Tabitha).

The 24th year of the Francken Vrij was the first time the theme's of the editions were connected via past-present-future

Columns:
25 years of Francken Vrij means that much of the present-day content differs a lot from the very beginning. Besides layouts

Emiel, Sibren, and Leon puting in extra hours working on the Francken Vrij during a borrel.

and language, many columns have changed over the years. In some editions in this lustrum we have added extra columns but overall we have had the following 'standard' columns in the past 5 years: Inside view, Life after Francken, Francken Abroad, Theorist, Puzzle, Comic. In this section we want to show you a nice overview of the amount of different columns and the people contributing to this.

Taking a look at our 6 recurring column pieces in the previous 15 editions that make up our fifth lustrum, we have had 13 Inside views, 11 Life Afters, 13 puzzles, 11 Comics, with the Theorist and Francken abroad topping it all with both columns being present 15 out of 15 times.

The Theorist:

This has been a recurring piece for many years. The theorist shines light on fields of normal physics (or math). An example for a unique topic was Jasper's theorist of edition 23.2, in which composed an equation showing we can't help it that we are always late:

$$FV = FV_{physical\mu} B^{\mu}_{\nu} FV^{\nu}_{non\_physical} = ((\prod_{n=1}^{9} P_b^{a_{1n}a_{2n}}) S_{a_{11}\ldots a_{19}} S_{a_{21}\ldots a_{29}} I^b)_{\mu} \ldots \ldots B^{\mu}_{\nu} (\prod_{n=1}^{>2p} M^{\nu}_{\rho i}) (\prod_{n=1}^{p} T^{\rho i})$$

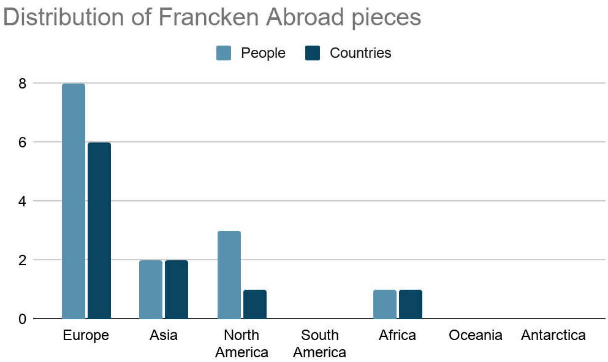
In the previous 5 years, only 3 different people have written this column: Remko Klein with 6, Jasper Pluijmers with 5 and Jelle Bor 4 (and counting).

Since the theorist is very special to us, there is a special font associated with this column (for those who've wondered which: KG Blank Space Sketch).

Francken Abroad:

Probably my personal favourite column to read and edit. Here you can read about the work and adventures your fellow Francken members have undergone in the (mostly) latter stages of their studies and can give you inspiration for your own potential study abroad adventure. 13 different people have provided these 15 column pieces. Out of these 15 pieces, these 13 people have been to a total of 10 different countries, spanning over 4 different continents, with the USA on top of the list with 3 different people providing 4 pieces, and most people staying within the European continent.

As you can see, none of the previous contributing members to the Francken Abroad column have done their studies/research/



Bar graph showing the distribution of Francken Abroads during the last lustrum

work on the Australian/Oceania, South American and Antarctica continents (also never in previous editions before this lustrum).

If you're reading this and have been there or you want to go there for your study abroad, let us know. To my surprise we haven't had any piece from the South American continent. To any potential fellow Astronomers reading this who might consider working abroad after their studies or for their PhD, I would highly recommend looking into the Paranal or La Silla observatories in Chile.
So to all those people aspiring to work or study abroad: think outside the box. Who knows, perhaps in several years time I will open a Francken Vrij and read about someone's work or internship at the IceCube neutrino observatory in Antarctica. Or perhaps you will be part of a group of scientists that work at some of the most remote places on the Earth in Oceania, helping countries like Kiribati survive from rising sea levels.

Lastly, we would like to take this opportunity to thank everyone who's contributed to the last five years of Francken Vrij! Without the contributions of these people we wouldn't have had a magazine in the first place.

Special thanks to:
Nikki Arendse, Prof. dr.T.Banerjee, Jasper van den Berg, Sjoerd Bielleman, Joran Böhmer, Jelle Bor, Jasper Bosch, Jasper Compaijen, Hilbert Dijkstra, Serte Donderwinkel, Joris Doting, Maaike van Egmond, dr. ir. Gert Eising, Kathinka Frieswijk, prof. dr. ir. Erik van der Giessen, Emma Giovinazzo, Steven Groen, Emiel Havinga, Ir. Joop Hendriks, prof. dr. R.M. Hildner, Samuel Hoekman, dr. ir. Hedde van Hoorn, prof. dr. Jeff Th. M. de Hosson, Ir. Thijs Huijskes, Marten Hutten, Peter Jacobse, Rob Jagt, Anton Jansen, Max Kamperman, Anna Kenbeek, Lau Kerdijk, Remko Klein, prof. dr. ir. B.J. Kooi, Chantal Kool, Marten Koopmans, dr. L.J.A. Koster, Arjen Kramer, Christiaan van der Kwaak, Christiaan Leutenantsmeyer, prof. dr. M.A. Loi, Hilbert van Loo, Sven van der Meer, Tabitha Minett, Willeke Mulder, prof. dr.B. Noheda, Carla Olsthoorn, prof. dr. ir. P.R. Onck, Arjen van der Pal, prof. dr. G. Palasantzas, Jasper Pluijmers, Gertjan Pomstra, Chantal Rikse, prof. dr. W.H. Roos, Melav Salih, drs. T. Sherkar, Bradley Spronk, Kristel Staal, Bauke Steensma, Reeuwerd Straatman, Leon Trustram, Anne in 't Veld, Bas Vlaming, Gerjan Wielink, Ir. Paul Wijnbergen, Esmeralda Willemsen, Emiel de Wit, Sibren Wobben, Friso Wobben, Xu Yang, Prof. dr. J. Ye, Jeanne van Zuilen, and last but certainly not least Evelien Zwanenburg.

Elements need to be Finite

Jelle Bor, MSc.

Life is finite, and that's a good thing in my opinion. I'm not aiming at the fact that everybody is going to die at some point, but about the fact that everything has an end: the earth, fossil fuels, Donald Trump's presidency, your student life, the growth of the cryptomarket, or even a joyful night with fellow students (probably you have been drinking again around the clock due to corona curfew). But are these exemples really finite? Maybe we move to a new planet, we find another fuel to move our vehicles, Trump does get re-elected in 2024 (hopefully not), you choose a new study after you finish, you did invest in Bitcoin before 2017, or you have planned a party for next weekend which is going to be awesome. I suppose we are not sure, but we can figure that elements of life are approximately finite to our understanding.

Let's look at it in another way. As physicists among each other we can agree that everything around us is physics, or in other words, (partial) differential equations. If possible we like to solve them analytically, but this is not always the case as things become rather complex in our daily life. We can approximate the result by using small finite elements, i.e. we split up an object into small elements each having physical values. Whereby it is natural that by reducing the size of these elements we approximate better the exact solution (if our equation is right in the first place). However, there is a value at which results converge and further mesh refinement does not increase accuracy. The finite element method is used mostly numerically to solve very complicated problems of engineers in strength calculations,

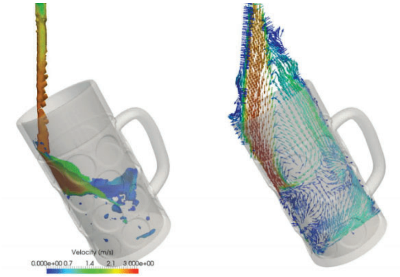


Figure 1: Simulation of beer poured into a maas

electromagnetism, heat flow, fluid dynamics and many other disciplines. Each element is assigned properties on the basis of the drawn geometry. In a thermal calculation, thermal properties must of course be assigned such as energy, heat, velocity, etc. When performing a dynamic calculation it is also necessary to assign mass-damping properties (like the classical mechanical oscillator), in case of forced vibrations. In general, 2D models offer great advantages due to the short calculation time (for similar reasons more coarse elements reduce computation time), but then geometry and boundary conditions must be two-dimensional as well.

The finite element method shoud not be confused with the more simple finite-difference method. This method approximates various derivatives in terms of the finite differences (just like you learned in your calculus course) of a function evaluated upon a fixed grid. The finite element method, on the other hand, breaks space up into multiple geometric opbjects, determines an approximate form for the solution appropriate to each element, and then matches the solutions up at the elements' edges. The latter method is shown to be much more efficient and powerful than the finite-differences method, however a lot more work is required to derive such an algorithm. In practice it is rare to derive a finite element method for a particular problem, because many finite element appliciations are available which use highly developed packages that are customized for an individual problem. Therefore, we only go into the schematics here.

Firstly, the domain in which the partial differential equation is solved is split into finite elements, and a trial solution to the partial differential equation in each element is hypothesised. Then the parameters of the trial solution are adjusted to obtain a best fit to the exact solution. Essentially, this approach converts a given partial differential equation into an integral equation known as weak or variational form. Note that weak means that there is no longer the requirement that the second derivative of the solution exists. A trial solution on each element is then postulated, and this leads to numerically intensive work of finding the best values for the parameters in the trial solution, and matching up the various trial solutions from the different elements.

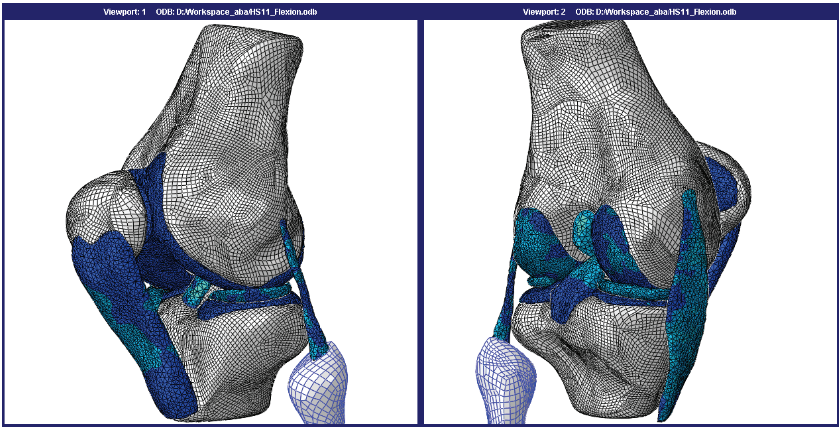


Figure 2: Finite element method of a human knee joint.

A variety of specializations under the umbrella of the mechanical engineering discipline commonly use the finite element method in the design and development of their products. In a structural simulations it helps tremendously in producing stiffness and strength visualizations and also in minimizing weight, materials, and costs. It also allows detailed visualization of where structures bend or twist, and indicates the distribution of stresses and displacements. Finite element software provides a wide range of simulation options for controlling the complexity of both modeling and analysis of a system. Similarly, the desired level of accuracy required and associated-computational time requirements can be managed simultaneously to address the engineers' needs. It allows entire designs to be constructed, refined, and optimized before the design is manufactured. This powerful design tool has significantly improved both the standard of engineering designs and the methodology of the design process in many industrial applications. The introduction of the finite element method in the industry (from the 1970s on) has substantially decreased the time to take products from concept to the production line. In summary, benefits of the finite element method include increased accuracy, enhanced design and better insight into critical design parameters, virtual prototyping, fewer hardware prototypes, a faster and less expensive design cycle, increased-productivity, and increased revenue, which all in all is fully in line with our current Western society. We should be happy that life gave us the ability to approximate things to consist of finite elements!

Computing along the finite frontiers of thickness

By Dennis de Wal, MSc.

Industrial advances are driven by the human urge to go further, delve deeper or fly higher. Yet regardless of what triggers us, whether it is profit, curiosity or necessity, we always eventually end up at a point where one simply cannot go further. A point where we meet our limitations. Whether we like it or not, we have to face the fact that our world is finite.

An old, yet very relevant, example of nature's finiteness is found in the electronics industry. In its race to the bottom, the semiconductor industry has come up with many inventive ways to grow smaller transistors. In fact, since the early start of integrated electronics we are accustomed to a doubling of computer speed every 2 years. It was Gordon Moore who predicted the number of transistors on a chip would double every two years [1]. To his own surprise, this law still holds today, however, it has become very fragile. Moore foresaw several potential obstacles for miniaturisation, running into limitations in physics such as the speed of light and atomic nature of materials. Also, with every step smaller in size the production costs of the chips rise exponentially.

In a nutshell, with a top-down approach a Central Processing Unit (CPU) performs basic arithmetic operations. A CPU consists of one or multiple microprocessors which are single circuits with a number of integrated transistors. Nowadays such microprocessors contains billions of transistors. An Xbox One, for example, has 5 billion transistors in its processor. For comparison, the first Intel microprocessor,

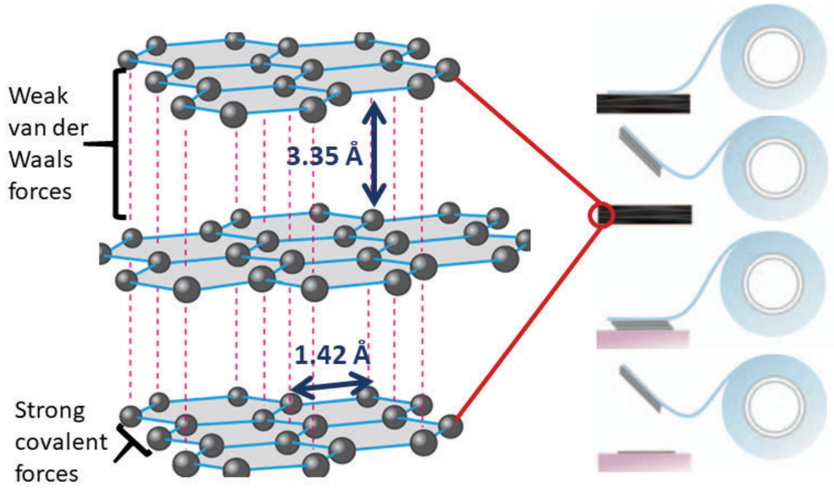


Figure 1: On the left: The layered structure of graphite. Top right: Using ordinary scotch tape to exfoliate (peel off) a number layers of graphene from a bulk crystal. Bottom right: Depositing one or a few layers of graphene onto a silicon wafer, when retracting the tape these few layers s stick tick to the wafer. [4]

the Intel 4004, had only 2300 transistors each 10 µm in size, slightly smaller than the thickness of a human hair, whereas nowadays a single transistor has the average size of 14nm and the sizes are still decreasing! In 2019, both Samsung and TSMC (a very large semiconductor foundry in Taiwan) announced to start production of 5 nm transistors. Today, Apple is using these extremely small transistors which brings the transistor density in the processor of the iPhone 12 to 134 million transistors per mm^2 [2]. For reference, the 32 kg Apollo Guidance Computer in the Apollo 11 had only a few ten thousands transistors in total [3].

So far, transistor sizes have been halved every two years and the speed of CPU has been roughly doubled. Nevertheless, the maximum operating speed of these microprocessors is finite. Nature's limit on speed, i.e. the speed of light, is finite and constant. Hence, passing information cannot be faster than light. In transistors where information in bits is carried by electrons, the speed is limited by the maximum speed of electrons in matter. Moreover, electronic circuits consisting of wires and transistors show electrical resistance and capacitance (capacity to store charge/electrons). As the sizes decrease the resistance goes up and the capacitance goes down.

Which means more dissipation of electrical energy and loss of stored charge, i.e. loss and data. This problem is already apparent in the computer memory speeds, where processors still increase in speed and memory already reached its maximum operating speed about 10 year ago.

So did we almost reach the bottom? Will computers stop becoming more powerful every year? Will we be able to use our phone until it literally falls apart, because a new phone is not any better than your old one? I do not believe so. If you cannot go in one direction, then go in another. It is true that we have to face the fact that continuing miniaturisation would eventually leave us with nothing more than a few or even one single atom which will bring miniaturisation to a halt. However, all conventional electronics is based on silicon but we can change the material. In electronics information is carried by electron charge but we can also use the electrons spin.

Materials that are only a few atoms thick are practically two-dimensional (2D). Some materials have the property that they consists of 2D sheets stacked on top of each other by van der Waals forces. These sheets are atomically thin (one to a few atoms thick) and in crystals they have the most interesting property that the individual sheets can be peeled off with nothing more than a piece of scotch tape! A method called exfoliation. An extremely straightforward method that is at the basis of isolation of 2D carbon sheets, graphene, that was awarded with 2010's Noble Prize [4].

The isolation of these thin layers of material also allows different van der Waals materials to be stacked in any arbitrary order and with different thicknesses of layers. These layers form a heterostructure where the van der Waals forces in between the layers will keep them together (like in a bulk crystal). You could see this as building a lego house with different type of lego pieces, tailoring it the way you like.

Besides being utterly thin and stackable, these materials also exhibit remarkable and widely ranging properties. Some of them are outstanding electrical conductors, whereas others are very robust insulators (meaning they do not break down when relatively high voltages are applied to them). Many of them are semiconductors, ready to replace silicon and some of them are even magnetic.

The reduction of the dimensionality from 3 dimensions to only 2 drastically changes the surface to volume ratio. In simple words, as there is much more surface than volume, physics in these systems is mostly dominated by the surfaces. Stacking combines different surfaces and creates new interfaces between the layers. You could see this as designing a material yourself where you can tune the properties to your

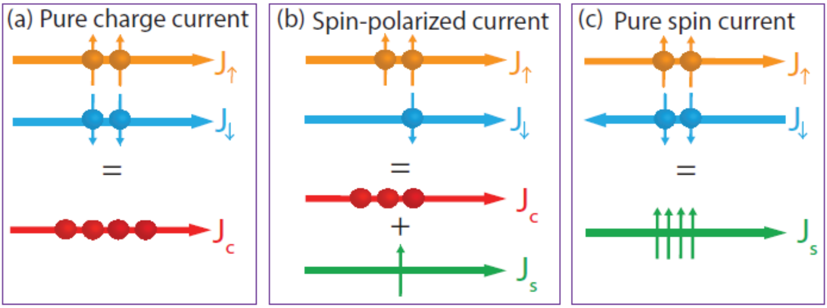


Figure 2: Left: pure charge current, balance between two spin species. Center: spin polarized current imbalance between two spin species creates both a charge and a spin current. Right: Pure spin current the two spin species are equivalent but flow in opposite directions creating only a spin current.[5]

liking. While the thickness of 2D materials is finite, their applicability seems almost infinite. Graphene, for example, happens to be an excellent electron spin transporter. Spin is a quantum mechanical properties of the electron, an intrinsic magnetic moment. This can be used to store and transfer information. In simple terms, the electron's spin can be either up or down.

Electronics with operations based on spin is called spintronics. It turns out that in many of the 2D materials spin and charge interact, and in some spin can travel long distances without relaxing (scattering causes differences between the different spin species, up and down, to balance out). In a charge current, electrons flow from one place to another, transporting the electron's charge. In such a current the contribution of both spin species is equal, hence, there is no net transport of spin. In a spin (polarised) current there is an imbalance between the two spin species which creates a net transport of both spin and charge. This can be arranged in such a way that electrons of opposite spin flow in opposite directions. The result is that there is no net transport of charge, but there is transport of spin.

Using spin to transport information, rather than charge solves our problems of high power losses due to high electrical resistances and loss of information due to low capacitance. The two spin species serve as one bit of information. However, while graphene is a very good spin transporter, it does not allow for manipulation or detection (read out of information) of spin. In order to detect spin you can use (ferro)magnets and manipulation can be done using magnetic fields. However, while the first one is feasible for industrial application, the latter is not. Can you imagine putting a huge electromagnet around your computer or even around your phone!?

In order to manipulate and create the spin in graphene, electrons need to interact with the atomic nuclei. This spin orbit coupling is very weak in graphene as it consist only out of light weight carbon atoms. This gives graphene its excellent transport properties but makes it hard to manipulate the spin. Atoms with heavier nuclei have larger spin orbit coupling. A type of 2D materials known as transition metal dichalcogenides (TMDs) show strong spin orbit coupling and can be placed on top of graphene to form a heterostructure. The interesting physics that then occurs is that the spin orbit coupling is imprinted into the graphene without it losing its spin transport properties.

Now, by sending a charge current through the graphene, a spin current is generated, and vice versa. Additionally, the efficiency of this conversion can be controlled by

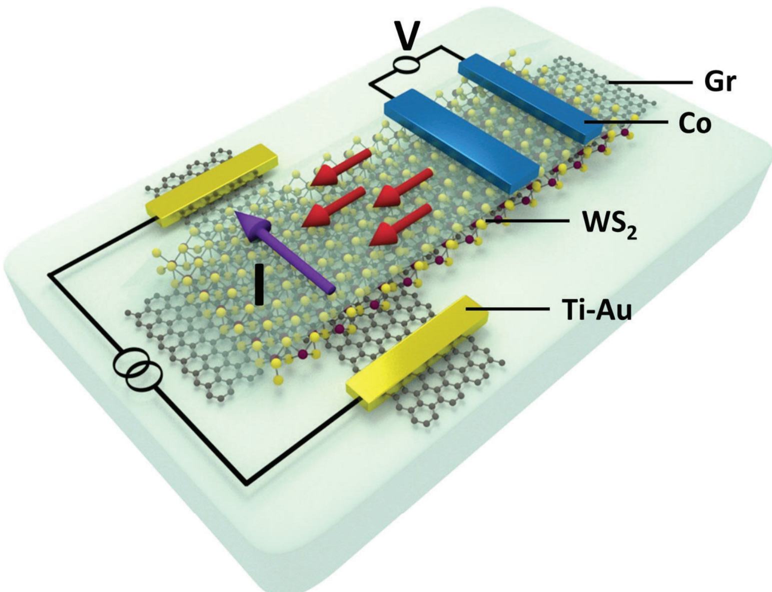


Figure 3: Heterostructured device constructed out of monolayer graphene, monolayer WS and a monolayer of hexagonal boron nitride (insulator). The proximity of the WS 2 imprints spin orbit coupling into the graphene that can then be used to convert spin to charge and vice versa. For illustration, the purple arrow indicates a charge current and the red arrows indicate the spins. [6]

an electric field (like the gate in an conventional transistor). This way the spin current can be switched on and off, basically ending up with a spin transistor. There is some nice earlier work from our group if you are interested: [6].

But the applications of spintronics go much further. In addition to using spin to transport information, bits are automatically stored in the spin being either up or down. Already used in hard disk drives (HHD) and magnetic random access memory (MRAM), both used to store data in your computer, spintronics can be used in combination with 2D materials, to build ultimately thin, very rapid and fully spin based microchips.

In the group of Physics of Nanodevices we are working together with many other research groups and industrial partners around Europe, in the EU Graphene Flagship program. We study the 2D van der Waals materials for all kind of applications. We focus on the (opto)spintronic applications and fabricate heterostructured devices out to the 2D materials. These type of devices give us deeper insight into the fundamental physics in both the 2D regime and in spintronics. For example, the spin to charge conversion mechanisms that are relevant for industrial application. Likewise, apart from giving us fundamental insights, they do pave the way for application with all-electrical (without the use of ferromagnets) 2D spin transistors. The significance of the 2D materials as the future `silicon' is such that the EU invested 1 billion euros [7] in the period of 2010-2020 on research and the program is being continued.

Altogether, in the information technology we run into nature's limitations on the finiteness of matter. However, though we cannot go smaller, we can walk along the frontiers of finiteness and look for new opportunities. 2D van der Waals materials in combination with spintronics can help us out. But we still have many question left and still many new phenomena are to be discovered in this 2D world. Will 2D spintronics come to our rescue? Nobody can say for sure. Yet, in my opinion it is quite worth the effort to delve deeper and feed our infinite curiosity.

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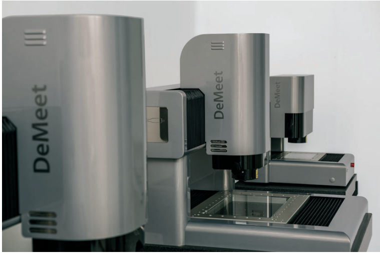

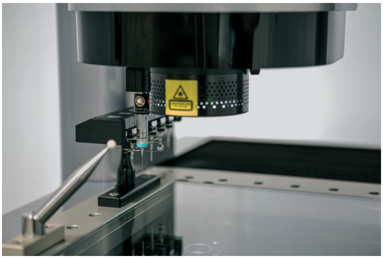

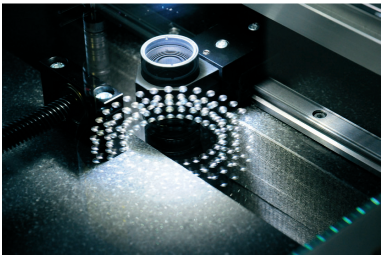

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