Francken Abroad
Cambridge and Oxford versus Groningen

Scribent
How Classical Mechanics is wrong

Puzzle
Wireless Friction

Francken Vrij

Friction

23.1 Friction

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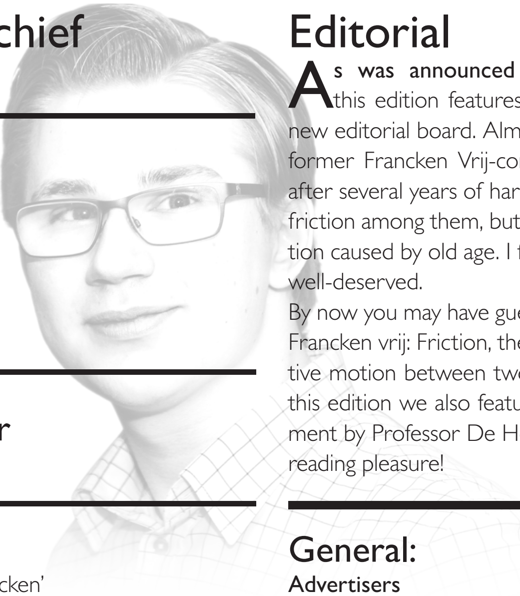

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Editorial

As was announced in the previous one, this edition features an almost completely new editorial board. Almost all members of the former Francken Vrij-committee have stopped after several years of hard work; not because of friction among them, but rather because of friction caused by old age. I feel that a 'thank you' is well-deserved.

By now you may have guessed the theme of this Francken vrij: Friction, the force that resists relative motion between two objects in contact. In this edition we also feature a special announcement by Professor De Hosson. I wish you much reading pleasure!

Address:
T.F.V. 'Professor Francken'
o/c Francken Vrij
Nijenborgh 4
9747 AG Groningen
The Netherlands
Telephone number: 050 363 4978
E-mail: franckenvrij@professorfrancken.nl

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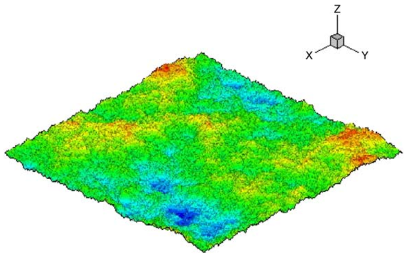

Chairman's Preface

By Joris Doting

By now it's November, and we've already made quite a start to the academic year. One entire block done, and a good 5 months since we became the new board of our beloved association. In this time, we've already gotten quite decent at handling the bunch of loose cannons that is Francken. A quick search about the origin of this term proves it quite adequate. It turns out a cannon not properly tied to the deck of a ship could be a life threatening hazard to its crew when things started to get rough, like they do every now and then with Francken. You just try to sail a ship with a two tonne cannon about to fly in your face. If only that deck would have more friction. Luckily the dangers (usually) aren't as physical as that and the roars of our members aren't produced by gunpowder, but by their dedication to shouting the Francken song as

loudly as possible. Like recently, at the Buixie Destination Announcement Borrel (BBBB). During this glorious evening at the Jut&Jul, the destination of this years' Buixie was announced: Copenhagen and Hamburg. It just so happens I am writing this piece from Copenhagen after driving through Hamburg earlier today (they should have asked me for Francken Abroad!). I can already assure you they have decent beer here, so another great Buixie is basically guaranteed this year!

News of the Association

By Chantal Kool

And suddenly it is my turn to bring back the memories of all the activities we organized this year at T.F.V. 'Professor Francken'! The past months have been very different from the ordinary studying life, but in a positive way, which made time fly like crazy. With the help of the members currently present in the Franckenroom I will eternalize the memories we have of all these activities below.

Free tostis

There is something peculiar about the word "free". Some people say this is a typically Dutch characteristic, but the enormous amount of (international) people showing up for the free tostis was just incredible. The Franckenroom was bursting at the seams and there were enormous rows outside the Franckenroom. The smell of grilled cheese, brie, ham, pesto and salami were present throughout building 13, a great success!

Cocktailborrel

The first activity organized by the borrelcie was traditionally the cocktailborrel. The committee (which expanded tremendously with all the new freshmen) made sure that no one left the building able to walk in a straight line. From pina colada to th's, many cocktails were present and the summer vibes from the holiday were definitely in the air for one more evening.

Applied Physics Quiz

Hosted by Bradley and Steven our knowledge on (applied) physics, music, history and random facts was tested. Of course, no one was surprised that teampje I won the quiz with walking music database Arjan as a member of this team. However, the real winner of the evening was one of our freshmen who thought that the board name of the 34th board was "borrelcie", perhaps due to our confusing Franckenlied.

Nedap borrel lecture

At this borrel lecture our member Jasper Compaijen shared his experiences ofworking at Nedap with us. With a beer in one hand and a bitterbal in the other, Jasper told us everything he could about the inventory management systems Nedap creates for shops and warehouses all over the world. The lecture was visited by a lot of people, including a lot of "ouwe lullen" who specifically came to the university for Jasper!

ASML case day

Together with the FMF we organized a case day where we tried to find a solution for a problem all the employees of ASML have not yet found a solution for. ASML creates machines which are used for creating chips for all the big technology companies in the world. The case was about finding a solution to one of the engineering problems concerning the positioning of the waivers, the material of the chips. The teams came up with an enormous array of different solutions, some more realistic than others, but all for sure very creative. For example, one of the solutions included using radioactive materials, a solution even ASML did not think of yet.

Dies Natalis VrijMiBo

This year, our birthday was celebrated on a Friday, which gave us the excellent opportunity to combine it with a VrijMiBo! We invited our very own Henry de Vries to give an amazing talk on his PhD research and Sjieuwe made a delicious white chocolate-coconut cake which gave everyone enough calories for the whole weekend. We thanked Henry and his supervisor professor Onck with our pride and joy: our home-brewed beer Gebouw 13.

Movienight

Just before the exam stress arrived, we hosted a movie night to let everyone relax while watching Mamma Mia and consuming unhealthy amounts of popcorn. After Mamma Mia, everyone moved to our good old Franckenroom where we watched the classic movie Sharknado. This was the first time we used our brand new shiny beamer setup with a screen and a stable beamer at the ceiling for ultimate Sharknado viewing experiences.

Life after Francken

By Sven van der Meer

You probably already knew (or expected) that as a graduated bèta student almost all companies are happy to welcome you. But why? And why did I choose to start my career at KPN in that case? These are questions I often get and I would like to answer in this blog.

As an applied physics student I noticed quite quickly that I liked the program, not because of the content but because of the way of thinking that is needed. I started to use this way of thinking, analytic thinking, outside the walls of the FSE. Committees, an entrepreneurial program and a year as a board member of Gyas. During these activities I found out that I did not only like it more than physics research, it was also useful to introduce this way of thinking in other areas. In these cases a reasonably well-known career path is to apply for Strategy Consultancy after your master's. Just like everyone who wants to do 'something


Race of classic KPN

with people' in high school decides to study medicine (no offense, I was such a person myself).

In order to increase the odds, I decided to sign up for a 3-day business course of 1 of the 3 major strategy consultants. Because I knew that these are tough courses, I decided to 'practice' with the business course of KPN. I assumed that I did not really have anything to lose there as I was not interested in KPN. However, after having done both business courses I was greatly impressed how much better KPN understood me and how much more they do than just internet, phone and TV. KPN connects the Netherlands in the broadest sense of the word to the capillaries of society. That's why I decided, after many coffees and visits to smaller and bigger companies, to sign up for KPN's Young Talent program.

Figure 1: Sailing with KPN

This program means that, for 2 years, you do several assignments of 6 to 12 months. For the first assignment you have a few options to choose from, because it is impossible for you to oversee the entire company and KPN can reasonably estimate what you can and want. After that you get the freedom to create your new assignments yourself. This means that you can, for example, specialise in a specific area or, as I have done, take a tour through the whole company. I worked in a very technical team, in a sales team, worked on big data platforms, created propositions for 1 product, and now I am part of the team that is implementing the new strategy for the whole company together with the board.

Working for KPN is great with all the opportunities they offer. In addition, you get the freedom to spend time on your own projects that you think are important. For example, I am currently working with a group of trainees to make KPN even more sustainable than we already are (#1 sustainable telecom provider in the world). Last but not least, I have a huge group of new friends to go on weekend trips, gala's, sailing trips to England, skiing holidays and not to mention the many VrijMiBo's. At this moment the counter of Francken members in the traineeship is at 3. Camiel van Hooff, Bauke Steensma and myself. Who will be number 4?

Friction? A matter contact

By Prof. dr. ir. Erik Van der Giessen

Contact and frictional sliding between two solids governs a range of technologically important mechanical behaviours and failure mechanisms. Frictional dissipation significantly contributes to the energy needed for material processing and to that used by rotating machinery, with an estimated cost in modern industrialised countries of a few percents of the gross national product. Friction is a longstanding issue that has fuelled technology, in the form of for example roller bearings and high-tech lubricants, but it has not been fully resolved scientifically. The issue has gained renewed attention in recent years because of the overarching role that friction can play in miniature devices, such as MEMS, with a high area-to-volume ratio.

Scientific (and not-so-scientific) studies of friction go back a long time. A sketch from one of his notebooks suggests that Leonardo da Vinci (1452--1519) was among the first to perform systematic experiments (see Fig. 1). Yet, a mathematical description of friction was not formulated until the 17th and 18th centuries. The Coulomb, or rather Amontons, law of friction states that a block pressed against a surface with normal force *N* will not slide for tangential forces smaller in magnitude than

$$F = \mu N. \qquad (1)$$

The proportionality constant μ is the coefficient of friction for the particular combination of the two surfaces.

The linear dependence of the friction force on the normal force according to (1) is, at

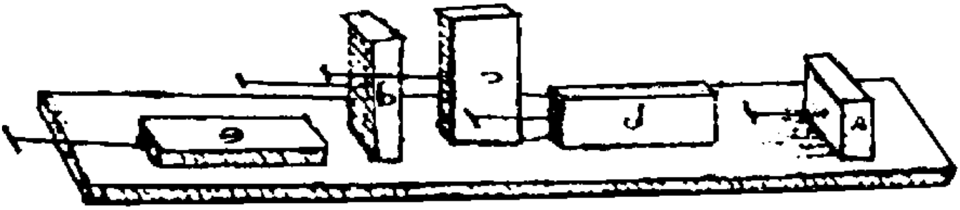

Figure 1: Sketch by Leonardo da Vinci of his experiments of friction[1]

least, remarkable when one takes a more microscopic view on the origin of friction. Surfaces are never flat, but contain a distribution of asperities, as illustrated in Fig. 2. When the two surfaces are pressed together, contact only takes place at asperities. When the normal load is gradually increased, asperities deform and neighbouring asperities come into contact. The two bodies interact under application of a tangential force through these contacting asperities. Relative tangential motion requires slip or plastic deformation of asperities. So, taking into account that the material response does not depend on force but on stress (force / area) and noting that the actual (or true) area in contact is smaller than the nominal area, why would tangential and normal force be proportional to each other?

Bowden and Tabor[2] argued that this surprising observation can be resolved if the normal force dependence arises from its effect on the number of asperities in contact, such that the contact force N is at every instant proportional to the true contact area A. This is far from being trivial: for instance, the well-known Hertzian elastic contact model implies that the contact area between a sphere and a flat surface scales as $N^{2/3}$. But here the stochastic nature

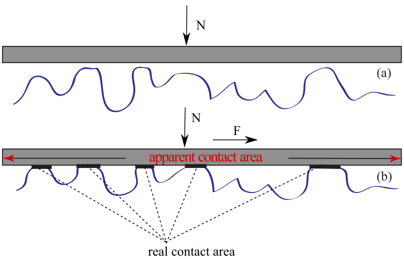

Figure 2: 2D sketch of friction process: contact (flattening) of rough surface by a rigid flat followed by horizontal shearing. The apparent contact area is the length of the rigid flat and the true contact area is the sum of the contact patches indicated by black bars in (b). From [3]

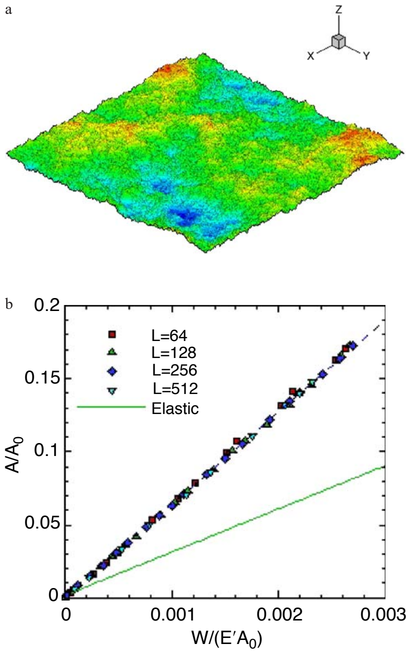

Figure 3: (a) A self-affine fractal surface on a 256x 256 grid, with heights magnified by a factor 10 to make the roughness visible. The color varies from dark (blue) to light(red) with increasing height. (b) True-to-nominal contract Area A/A_0 versus normalised applied load W for surfaces of the type shown in (a) for different sizes.[6]

of the surface roughness comes to rescue: asperities have different heights and when the highest summits have been deformed other asperities come into contact. Greenwood and Williamson[4] were the first to develop a theory for nominally flat yet rough surfaces, based on the simplifying assumption that all peaks are spherical asperities with the same radius. Assuming that the asperities behaved as a linear elastic material, indeed their statistical analysis yielded a near-linear relation between normal force and true contact.

The type of roughness presumed by Greenwood and Williamson has been criticised, especially in light of the discovery that the roughness of real surfaces is fractal over several orders of magnitude. Much more recently, Persson[5] published a scaling approach for such surfaces, and, again, true contact area was found to be nearly linear with the normal load.

One limitation of the contact theories cited above is that the contact pressure at some asperities exceeded the yield strength of any real material. Pei et al.[6] studied the role of plastic deformation in the asperities of a self-affine fractal surface flattened by a rigid flat. They found that plasticity gives rise to qualitative changes in the organisation of contact patches and distributions of local pressures in the contacts, yet the contact area *A* was found to increase linearly with applied load, see Fig. 3.

Length scale issues

The findings mentioned so far look good, in the sense that these "microscopic" views

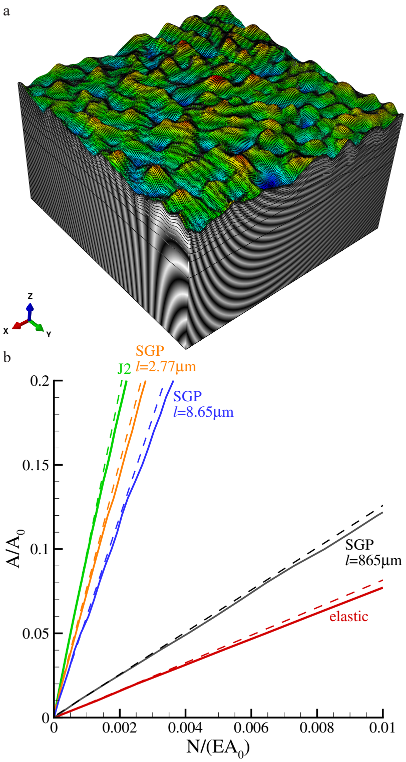

Figure 4: (a) 3D deformable solid of 10x10 µm^2 with a representative random rough surface on top (rms = 0.16µm, l_s = 0.4µm) of a . Color coding-blue : valley, red : peak. (b) True-to-nominal contact area A/A_0 versus normalised applied load N for the surface shown in (a). The green durve labeled 'J2' is for a similar size-dependent plasticity model with various values of the material length scale l. The dashed lines are the linear fits to the behaviour at small areas.[9]

on fractal rough surfaces support the Bowden--Tabor interpretation of Amontons' friction law (1). However, the very fractal nature of rough surfaces also raises a potential new problem: plastic deformation below dimensions of tens of micrometers is size dependent, yet this was not incorporated in the computations in[6]! The flattening of an asperity is somewhere in between the compression of a pillar and indentation, and both of these phenomena exhibit size-dependent plastic behaviour.[7,8]

PhD student Hengxu Song in the Micromechanics of Materials group, together with former postdoc Xiaoming Liu (currently with the Chinese Academy of Sciences), was the first to study the role of size dependence in rough surface contact. For this purpose, Song et al.[9] adopted a phenomenological theory for size-dependent plasticity that was developed for, and fit to, indentation experiments[8]. The numerical computation was carried out in 3D for a random surface (see Fig. 4a) with similar roughness properties as that in Fig. 3a.

The important result in Fig.4 is that $\mathbf{N} \propto \mathbf{A}$ even when size effects are taken into account. The value of the material length scale *l* just determines the mean contact stiffness *N/A*, varying between 'soft' for nearly size-independent behaviour (small *l*) and 'hard' for a material where size effects suppress plasticity in the asperities (large *l*).

Concluding remarks

The evidence presented in this essay is in full support of the linearity between *N* in Amontons' friction law (1) - excellent news, I'd say! Of course one can debate the accuracy of the models used in the computations. For instance, the size-dependent plasticity model used to obtain Fig. 4 is highly phenomenogical; like all continuum theories of plasticity, it assumes that dislocations -the carriers of plasticity- are available whenever and wherever they are needed. This assumptions breaks down at sufficiently small length scales. The Discrete Dislocation Plasticity method developed in our group in the mid 1990's does take generation and annihilation of dislocations into account, but is too demanding in terms of computing power to be used for fractal surfaces. Song[3] developed a statistical workaround, but a major methodological improvement was recently developed by former PhD student Lucia Nicola (now professor at Deft University of Technology and the University of Padova). Using Green's functions instead of the finite element method, she has been able to study contacting fractal surfaces using Discrete Dislocation Plasticity[10]. And, even then $\mathbf{N} \propto \mathbf{A}$! So, my bet is that we can be pretty sure it is correct.

The next step is to study friction, in the Bowden- Tabor form $\mathbf{F} = \tau_{fr}\mathbf{A}$, and find the answer to the question what it is that determines the friction stress τ_{fr}. I am not ready to place any bet on this yet, accept that it will keep scientists busy for a while.

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Program overview Symposium Jeff 40+

Prof. dr. Jeff Th. M. De Hosson
40+ years Professorship in Applied Physics
University of Groningen

March 29th 2019
Academiegebouw
Senate Room and Grand Auditorium (Aula)
Broerstraat 5, 9712CP Groningen

The autumn of the year 2017 marked the 40th anniversary of the appointment by the Crown (H. M. Juliana, October 6th 1977 RD 101) of Professor Jeff Th. M. De Hosson at the University of Groningen.

The Applied Physics-Materials Science (MK) group would like to celebrate this occasion with all friends of MK, paying tribute through a commemorating symposium Jeff40+.

The program centers on important cornerstones in the last four decades of the applied physics-materials science research activities of Professor De Hosson focusing on structure-property relations of materials through in-situ electron microscopy and also on the significance of engineering physics for the education program of the Faculty of Science and Engineering (in the old days Faculty of Mathematics and Natural Sciences).

Dept. of Applied Physics
Zernike Institute for Advanced Materials
Materials Science group
University of Groningen

Prof.dr. Jeff Th. M. De Hosson
Chair Applied Physics-Materials Science
Nijenborgh 4, 9747 AG Groningen, the Netherlands
phone:31(0)503634898; fax: 31(0)503634881
e-mail: j.t.m.de.hosson@rug.nl

Program overview:

12.30 - 13.00h: walk-in (Bruinzaal, floor#0)

Senate Room (Senaatskamer, floor #1)

13.00-13.05h: Welcome by Prof. Dr. Frans Zwarts, former Rector Magnificus, Symposium chair
13.05-13.35h: Prof. dr. ir. René de Borst, U. of Sheffield, UK, Spinoza Laureate, 'Computational mechanics of materials: multiple scales, diffusion phenomena and discontinuities'
13.35-14.05h: Prof. dr. ir. Eric Detsi, U. of Pennsylvania, USA, 'Nanoporous Materials for Next-Generation Electrochemical Energy Storage and Conversion Systems'
14.05-14.20h: Short break (mineral water, soft drinks, Bruinszaal, floor # 0)
14.20-14.50h: Prof. dr. ir. Albert van den Berg, U. Twente, The Netherlands,Spinoza Laureate, 'Labs on a Chip for medical and sustainable applications'
14.50-15.20h: Dr. ir. Daan Hein Alsem, Hummingbird Scientific, Lacey, WA, USA, 'In- situ electron microscopy: recent advances'
15.20-15.40h: Short break (mineral water, soft drinks, Bruinszaal, floor # 0)
15.40-16.10h: Prof. dr. ir. Wim van Saarloos, President Royal Netherlands Academy of Arts and Sciences, KNAW, University of Leiden, The Netherlands), 'The Dutch polder model of science and research'
16.10-16.30h: Coffee, tea, cake (Bruinszaal, floor # 0)

Grand Auditorium (Aula, floor #1)

16.30-17.05h: Prof. dr. Jeff Th. M. De Hosson (U. of Groningen), *'Put the Pedal to the Metal'*
17.05-17.30h: --------------- responses -------- Thanks and adjourn
Prof. dr. ir. Caspar van der Wal (U. of Groningen); Prof. dr. Rob Boom (TUDelft);
Dr. ir. Wouter Soer (Lumileds, San Jose, USA) and Joris Doting (President TFV 'Professor Francken', U. of Groningen)
17.30h -19.30h: Reception in Academiegebouw (Spiegelzaal, floor #0)

You have register trough the mk website:

materials-science.phys.rug.nl or drop a mail to j.t.m.de.hosson@rug.nl
Prof. Dr. Jeff Th. M. De Hosson, 40+ years Professorship in Applied Physics

Francken Abroad

By Serte Donderwinkel

In **October 2017,** two of your favourite mooie gekken decided to swap their Franckensweater for a gown, 0.33 mL bottles for pints and their tiny student town in the Netherlands for a tiny student town in the UK. Rob and I moved to Cambridge. At the time of writing I have left this elitist bubble and settled in the next, namely Oxford. Therefore, I would like to present you, our comparative analysis of 'Oxbridge' vs. Groningen, both as a PhD student and as a master student.

First of all, what are we doing here? Rob is doing a PhD in the Material Science department. He is working on perovskite solar cells, and yes, there are SEMs in his lab. Although Cambridge and Oxford are in general known for their ancient architecture (everything is a castle!), Groningen manages to have a Physics faculty that is more outdated and has higher rate of asbestos deaths than the ones here.

Last year, I did a master's in 'Mathematics and Theoretical Physics' in Cambridge. I do not know the difference between a proton and a neutron, so I have to say I mostly ignored the physics bit in the course title. This program is so big (~300 students and over 60 courses to choose from) that you can cherry pick amongst the courses to completely design your own mathematics or physics master. I focused on probability theory and analysis. After finishing that, I moved to Oxford to start a PhD (or DPhil as it is called here) in the probability group in the Department of Statistics, although I know about as much about p-values as about protons and have no idea what I

March to the graduation ceremony

am doing in this department. I study scaling limits of random graphs. A scaling limit is basically zooming out from a discrete structure (like a very big pixely image) to obtain a continuous structure (a 'smooth' image in which you cannot count the pixels anymore). I do this with random graphs. Hence, I generate (in theory of course, do not want to get my hands dirty with anything else than chalk) humongous random graphs, scale them down, and see what continuous random structure this yields. This does indeed involve many epsilons and deltas, so I will not bore you engineers with more details.

We both think that the difference between 'student life' in the Netherlands and Oxbridge is a lot bigger for undergraduate and master students than for PhDs. This is because 'taught' programs, i.e. programs with mostly courses, tend to be very competitive. The courses are graded comparatively, and in practice this means that students drive each other crazy with their work ethos. If your course mates start working harder, you'd better do the same, because otherwise your grade will plummet. Also, everyone knows that they are in Oxford or Cambridge, so they are expecting to work hard, which in this way becomes a self-fulfilling prophecy. Furthermore, Oxford and Cambridge do not use ECTS or another credit system. This has as the effect that you either pass your year or you are kicked out of university, so passing a course on to next term because you were too hungover to sit the exam or because you had to fill the Franckenfridge to not upset your Borrelciechairman does not happen. Consequently, all libraries are open 24 hours a day and are used from the first to the last week.

Speaking of weeks, the weeks in Cambridge last from Thursday to Wednesday. That's because it has always been this way, and that is a perfectly good reason to continue a completely unnecessary and strange phenomenon here. Moreover, the year consists of only three terms of 8 weeks, of which the last one is only intended for studying and sitting exams. This also means that all exams of the year are in June. Because 16 weeks of lectures is not a lot for an entire master, they decided to solve this problem by offering lectures on Saturdays. This is indeed not the most sensible way to design a year of studying, but as often, tradition is valued more highly than logic here.

Moreover, there are also some differences between doing a PhD in Oxford and Cambridge, and in the Netherlands. In the Netherlands, your official status as a PhD candidate is an employee of the university. You earn a salary, build a pension, get a Christmas present (!) and are in general expected to work during office hours. In the UK, you are a student. This means that being offered a PhD position is not the same as being offered an income. You first have to find a scholarship to get your living expenses covered, and otherwise you even have to pay tuition fees! Both Rob and I have a scholarship, but there are people around that are paying to do their PhD! Also, because of this different status, you in general have a lot of freedom. This has advantages, such as being able to work from Ibiza for a month if you feel like it, but also disadvantages, because you need to be quite disciplined to actually get work done if you could also be on a tropical island.

Another very important difference between Oxbridge and the University of Groningen, is the collegiate system we have here. All students and most academics are part of a college. This is a bit like a house in Harry Potter. Before you arrive, the sorting hat decides which of the approximately 30 colleges you are going to be a part of, and after that the college basically organizes your life for you. What college you are in does not have anything to do with your degree, so in fact the university has a matrix structure, with everyone being part of both a department and a college. The college has housing for most of their students, has a dining hall where you can eat three meals a day (none of them consisting of just a vlamtosti and a Bounty, and you get to eat sausage for breakfast, *kneits!*), and organizes social activities and has money for

BBQ at Serte's former house

scholarships. The colleges also organize the tutorials for undergraduate students. The care the college takes of you is very convenient, because literally all you need to do yourself is studying, but it can also be a bit patronizing. For instance, my Cambridge college has the rule that undergraduates are not allowed to use frying pans, because this is too risky, they organize puppy cuddling sessions for stress relief, and they have employees that empty the students' bins every day and clean their rooms.

Although student life involves a lot less binge drinking than in the Netherlands, also in Oxbridge students have found ways to entertain themselves. For example, May balls are organized after exams, in, yes indeed, June. These are a bit like Francken-gala's, but then with artists, food, activities and decoration that only distract you from drinking. Another very typical social event here is a formal dinner. The students dress up in formal wear (including their gown!) and sit down for a *n*-course fancy dinner with $n \geq 3$ in one of the Hogwarts style dining halls. Grace is said in Latin, phones are not allowed, professors eat at the high table separated from the students and drinking games are strictly forbidden. However, there is the tradition that if for some reason a penny ends up in your drink, you have to down it. This has given rise to the phenomenon of 'engineer's pennies', which are coins that are bent in such a way that they fit through the opening of a wine bottle. Engineers will be engineers…

There are some other strange traditions that do not involve cramming your money into a wine bottle. For instance, in Oxford, students need to wear 'sub fusc' to their exams. This consists of a gown, tuxedo, bow tie, and mortarboard (this is the funny hat with a chopping board on top that US graduates wear in movies), and a fresh rose


Master result presentation, Senate House

of which the colour represents the exam your sitting (white for the first one, red for the last, pink for anything in between). I have heard stories of girls that were unable to sit their exam, because 'too much flesh was showing around the ankles'. Also, the graduation ceremony in Cambridge was quite memorable. Because of the rules of the university, you have to hold the hand of an important person during a part of the graduation ceremony. However, since the student numbers have gone up considerably and important people are too busy to hold the hands of students, they have changed this ritual a bit. Of course changing the rule would be too absurd, so now four students each hold one finger of this person at the same time. Not that it could possibly make the ceremony more incomprehensible, because it is completely conducted in Latin…

Overall, it is very special to be able to study in a place with so many ridiculous traditions, where your life is organised for you by your college and where world-famous scientists walk (or ride, in the case of Stephen Hawkings) past while the students would be studying themselves into a burnout if it were not for the puppy cuddling. I dare to say that Oxford and Cambridge are places with a massive impact on the world, although they also seem to be quite detached from it. We will be here doing our research for the coming years, so if anyone is around and is in for a cup of tea and a biscuit, send us an owl with a message!

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It's in our nature

By Jasper Pluijmers

The subject friction made me very happy, but not because of the reasons you can think of (and no Steven, not because you can very easily make the word fiction out of it by putting the r in parentheses). No, it makes me happy because I can do with it what all theorists like to do with friction, I can ignore it and pretend it does not exist. This could make the article a worse article or at least make it a more incomplete model of reality, but who is to judge that? It is hard to quantify what makes one thing good and the other objectively worse. People try it with articles, but some people also try it with physical models.

In the first place a physical model should describe reality in the most complete way possible. Usually a model without friction is less complete than a model with friction. Some situations come close like superconductivity, Bose-Einstein condensates or motion through deep space but in the end the boundary conditions will harbor the need for some friction to exist. But what if your model does describe reality perfectly? Could one model be better than another model on other grounds?

A lot of physicists like aesthetically pleasing theories, for example the Maxwell equations are a beautiful collection of mathematics that perfectly describe electrodynamics. There is this, sometimes unconscious, idea that the form of equations should 'make sense' and the simpler your model is the better. Of course scientists would like to make these feelings quantifiable and do so by describing the naturalness or finetuning of a theory. These terms have all to do with the parameters in a theory and why they have the values they do.

There are two ideas on which to validate a theory to be natural:

- A theory could be called natural if the dimensionless parameters are of order 1.
- A theory could be called natural if deviations of the parameter do not change the theory by a large amount.

The first statement basically states that it is strange if a parameter in a theory is disconnected from the others by being much larger or much smaller. It could be a sign that the theory does not describe the 'real' physics but there is more underlying physics hiding in it. There are several hierarchy problems in physics which have no apparent reason like the huge strength difference between the forces.

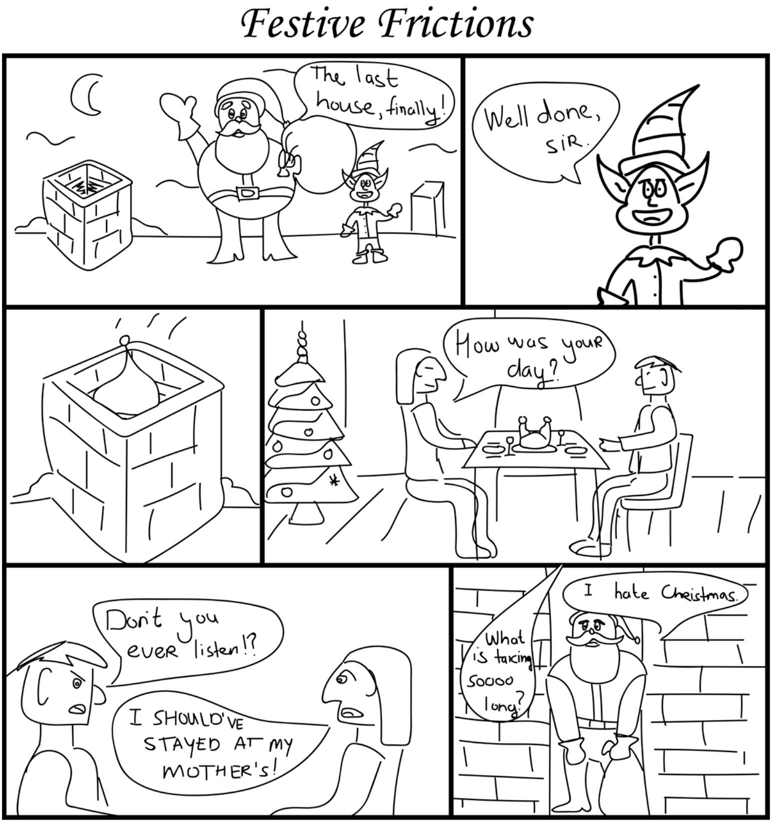
The second statement basically says, a theory is more natural if in parameter space the partial derivative of this parameter is small. It worries about certain constant parameters not being exactly constant. If varying the parameter changes your theory by a lot it seems to be strange for our region of the universe to be in the exact value needed to sustain this theory. Because we do not know if these constants are the same in other, unobserved, regions of our universe.

Of course one could argue that because we were allowed to evolve into this (part of the) universe the parameters had to be in a way to support us, it is inevitable. One could even argue that for a universe to exist it has to harbor conditions in which some being could observe it, otherwise what would be the meaning of existing?

In principle there should be nothing stopping the universe from being the way it is, just because it is that way. For me personally it would be somewhat disappointing if in the end it turns out that a lot of numbers are what they are without any reason, currently the standard model contains quite a lot of them. But for the answer we will have to wait, maybe until the end of this universe and beyond. For now please do contact me if you have any ideas about the need for naturalness in our lives, other universes or the meaning of existence. For now, please contact me if you have any ideas about the need for naturalness in our lives, other universes or existing and let's hope all fundamental constants stay constant for a while, at least in our neigbourhoud.

Comic

By Bradley Spronk



Friction

A simple textbook question revisited

By prof. dr. Jeff Th.M. De Hosson (MK)

Many laws in classical physics are based on the concept that a constant driving force will lead to a response which is stable in time. In fact, the entire framework of solid mechanics, founded by Isaac Newton himself, is based on this principle. In the field of materials science, this concept was believed to be true as well. For example, according to Newtonian mechanics, a constant load exerted onto a material will lead to a particular deformation response everywhere and at any time in the material; a constant driving force will lead to a certain velocity at each point of an interface during recrystallization; a constant frictional load will generate a constant sliding velocity for two surfaces in contact, et cetera. Nevertheless, in recent times it has been demonstrated convincingly that in many situations such a concept does not apply. Typical examples are the jerky motion of dislocations when deforming a metal[1]; the jerky motion of interfaces during phase transformations as shown in an excellent recent publication by MK PhD student Gerrit Zijlstra[2]; or the jerky (stick-slip) motion of surfaces and friction between two surfaces in relative motion[3] which are all topics of research in MK.

Since the time of Leonardo da Vinci, who was arguably the very first 'universal' engineer to scrutinize friction in detail (we might induct him 'posthumous honorary member' of Engineering Physics Study Association 'T.F.V. Professor Francken'; what do you think ?) , friction and stick-slip phenomena at interacting surfaces have become an important branch of modern materials science. Please recall that friction

is a ‘system property’, i.e. it is not a ‘material property’ as it depends on the interacting system between (different) materials.
From a physics point of view, friction is determined by *short as well as long- range interactions* between the surfaces making it quite an interesting subject of study. Nevertheless, the underpinning mechanism of friction and the upscaling from atomic phenomena to microscopic effects are still not understood, a fact which, more than five centuries after da Vinci, is a big surprise in itself.

A textbook problem

The classical friction laws were discovered by Leonardo da Vinci and Guillaume Amontons, and were summarized much later by Charles Augustin Coulomb, who also contributed the so-called third friction law. The three laws of friction describe that the friction to resist sliding at an interface is

i. proportional to the normal force between the surfaces,
ii. independent of the apparent contact area, and
iii. independent of the sliding velocity.

A popular problem in textbooks of classical mechanics (1st year physics) is a block sliding on an inclined plane over a distance with friction (with friction coefficient), see Fig. 1. Students - at least in my time - were asked to calculate *‘the total work done by the frictional force’* or to calculate the

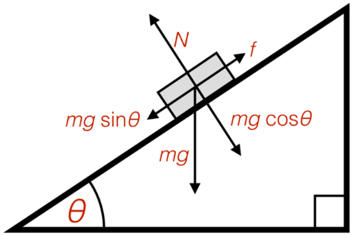


Figure 1: A classical mechanics textbook problem[4]

acceleration (in case the block is not dragged by friction at constant velocity). It looks like a rather trivial problem since according to Newton’s 2nd law, focusing on the net force, with the gravitational force $|\mathbf{F}_g| = \mathbf{mg}$, the work done can be written as:

$$\text{work done} = |\mathbf{F}_g|(\sin\alpha - \mu\cos\alpha)d = \partial E_{kin} \quad (1)$$

This all seems to be very correct: the total work done is the change in kinetic energy. At constant velocity, i.e. when the acceleration is zero, the total work done must be equal to zero! Eq.(1) can be found in each and every text book dealing with classical mechanics.

Nevertheless, here the eye-opener is that Eq.(1) is incorrect! There is a ‘snake’ sneaking in when posing the burning question: Where in Eq.(1), for goodness’ sake, is the increase of the thermal energy, i.e. heat production and heat conduction ? It is commonly known that the system may heat up due to friction. Clearly, some essentials are missing in the energy balance considerations and as a consequence Eq.(1) must be wrong: bye-bye Newton. The key solution to this paradox is that Eq.(1) is a center-of-mass equation, related rather to momentum (integration of Newton's 2nd law) than to 'energy' and therefore it does not contain vibrational/phonon/rotational/thermal energy forms of (internal) energy of the system. We may say, Eq.(1) represents the change in what I call 'spooky-energy', and does not consider modifications in the internal structure of the system. So there we have it: watch out for Newton. Eq.(1) is incomplete since it describes the 'kinematics' of a center-of-mass point and in fact tacitly ignores the laws of thermodynamics for the entire system!

At a microscopic scale local processes of the interactions among asperities of both the block and the base material play a crucial role (Mother Nature does not like infinitely flat atomic planes at T above 0 K, see Fig.2).

Heat may be dissipated due to plastic deformation in metallic asperities during sliding and obviously the occurrence of these interactions depends on the correlation distance between those asperities, say λ_{eff}. λ_{eff} lies in the same range as the height-height correlation distance but is not necessarily identical to it. The precise localization of heat (i.e. local warming up in time during service) will also depend on the thermo-physical properties such as the thermal conductivity and in particular on the difference in thermo-physical properties when we are dealing with dissimilar materials of block and base. Heat may flow either away or towards the block, depending on the local thermo-mechanical performance (e.g. plasticity, fracture, mechanical welding et cetera as a function of temperature and time).

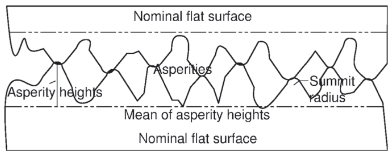


Figure 2: Figure 2: Local asperities on a real surface causing friction and wear[5]

To keep it simple, Eq.(1) is rewritten now (for the block) as:

$$\text{work done} = |\mathbf{F}_g|(d \sin \alpha - \mu\lambda_{eff} \cos \alpha) - \partial Q_t = \partial E_{kin} + \partial E_{thermal} \quad (2)$$

with a net heat transfer   to the base. The difference with Newton's Eq.(1) lies in $\mu|\mathbf{F}_g|(d - \lambda_{eff})$. Since $d - \lambda_{eff} >> 0$, the heat produced is positive as expected and confirming what we experience in practice.
Obviously surface or interface roughness, i.e. height-height correlations of asperities may have a crucial influence. This topic was studied initially by Fuller and Tabor[6], and it was shown that a relatively small surface

roughness could diminish or even remove asperities. In their model a Gaussian distribution of asperity heights was considered with all asperities having the same radius of curvature. The contact force was obtained by applying the contact theory of Johnson et al.[7] to each individual asperity. However, this approach considers surface roughness over just one single lateral length scale. On the other hand, randomly rough surfaces, which are commonly encountered for solid surfaces, possess roughness over many different length scales rather than a single one. This case was considered for random self-affine rough surfaces which we have studied in the MK group as well[8,9,10]. Therefore the first two friction laws (i) and (ii) should be critically considered in real systems, i.e. what is the real contact area and what is the correct energy balance?

Size effects: breakdown of friction laws

So far, the size of the block (Fig.1) and the times scales/length scales do not play any role in the revised Eq.(2). Is this correct or do we have a critical size/critical time below of which Eq.(2) breaks down? In the following I'll confine myself to effects in frictional behavior of nano-sized objects, ignoring thermal dissipation for the moment due to plasticity in metallic systems (which occur at a much larger length scale than nano's). In my microscopic view friction can be regarded as a conversion of translation motion of the two interacting solids of Fig.1 , with respect to each other, into vibrational/phonon energy leading to a warming-up of the system. It is important to recall that, for infinite systems, the phonon spectrum consists of a continuum of vibrational modes and phonon damping can be easily realized because, due to anharmonicity, energy can be easily transferred from one mode to the other. So, friction will always occur between infinite and bulky systems. As a matter of course, this is not the case in a finite system in which all the modes are discrete and only a certain combination of modes can carry the phonon damping. What is the particular critical length scale below of which classical friction will break down?

A translational motion may interact with (vibrational) phonons via scattering accompanying momentum transfer. Phonons are scattered by anharmonicities due to the strain fields of all kinds of defects, including point, line (dislocations), planar (grain-boundaries), volumetric defects (voids, clusters). Here, we assume that the time the system needs to travel a distance of the order of the phonon mean free path is still large compared to the phonon relaxation time, i.e. the phonon distribution is then, on average, always equal to the distribution in thermal equilibrium. We are not disturbing the phonon system in an experiment at time scales less than 10^{-13}s! Further, the phonon relaxation time, τ can be readily estimated from the phonon mean free path given by the thermal conductivity (see your

BaSc class on condensed matter physics).

Within this framework, we may conclude that *friction is only possible* if the inverse of the phonon lifetime is larger than the spacing of the vibrational modes. The latter depends on the size and increases with decreasing size. In a zero-order (harmonic) approximation, the spacing of the vibrational modes is determined by the spring constant κ and the mass *m* and we arrive at the hypothesis that friction will occur if the inverse of the phonon lifetime is larger than a certain vibrational spacing, namely:

$$\frac{1}{\tau_{ph}} \geq \frac{\pi}{N}\sqrt{\frac{\kappa}{m}} \quad (3)$$

where N represents the number of vibrational units involved. In other words *frictionless systems* become likely if:

$$N \leq \pi \tau_{ph} \sqrt{\frac{\kappa}{m}} \quad (4)$$

The spring constant of materials used in tribology are about 500 N/m in diamond like carbon (DLC) leading to the prediction that for N smaller than 50 units (order of 10nm), the friction becomes negligibly small. Therefore: nanos really help!

In the MK group we make nanostructured composite materials based on DLC, i.e. hydrogenated *nc*-TiC/*a*-C:H coatings are deposited by a magnetron sputtering in an argon/acetylene atmosphere[10]. A nanocomposite coating can be designed of homogeneously distributed TiC nanocrystallites (see Fig. 3a). Figure 3b shows graphs of the coefficient of friction (CoF) versus laps for coatings tested at different sliding velocities. The CoF of the *nc*-TiC/*a*-C:H drops quickly from an initial high value of about 0.2 at the beginning of sliding to a very low value of CoF (<0.05) at the steady state. In particular, a strong dependence of the steady state CoF *on the sliding velocity* is observed such that the faster the sliding velocity, the smaller the CoF. The steady state CoF at sliding velocities of 10, 30 and 50 cm/s is 0.047, 0.030 and 0.013, respectively. It is clear that the Coulomb friction law (see law # (iii) aforementioned) is no longer valid. It turned out that multilayered nanocomposite DLC coatings exhibit considerable enhancement in fracture toughness and even lower coefficient of friction, i.e. as low as 0.008 which is a very fine record.

Conclusions

In conclusion we may state that all three friction laws (see above # i,ii and iii) should be critically considered in real materials systems: '*what is the precise contact area and what are size/time scaling effects doing ?*' represent crucial questions. Second, MK was able to make nanostructured coatings with ultralow friction coefficients as low as 0.008, a record (as a point of reference, a metal-metal contact has a coefficient of friction close to 1). Third, we conclude for 'frictionless' interactions that nanos really help!

Finally, suppose in your classical mechanics written exam the abovementioned textbook problem appears: 'calculate the total work done by the frictional force of a block on an inclined plane'; then you may answer, like this:

"Dear professor, excuse me! This question is more like squaring the circle since the work done by the frictional force cannot be calculated as the value of λ_{eff} is unknown. Next question please!"

You will definitely be regarded as an excellent and bright scholar (I hope). Tons of success!

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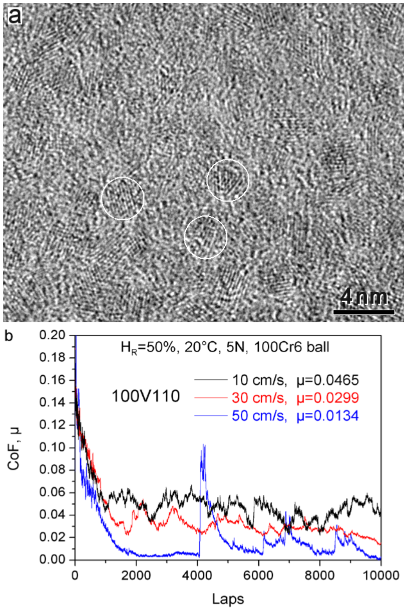


Figure 3: HR-XTRM micrographs showing (a) homogeneously distributed TiC nanocrystallites in TiC/a C:H nanocomposite coating (b) influence of sliding velocity on the coefficient of friction – break down of Coulomb friction law[10].

Puzzle

By Arjen Kramer

Sometimes the cause of a lot of friction in student houses is a bad internet connection. To remove this friction, the students in this house have decided to design the optimal setup of Wi-Fi routers, PC's and laptops. For this they need to follow a few steps:

1: Determine the layout of the house, they only know the shape of the rooms and that the hallway touches all of them.

2: Place the routers, for optimal coverage there need to be exactly 2 in every room, row and column. Also the routers can't touch each other, not even diagonally.

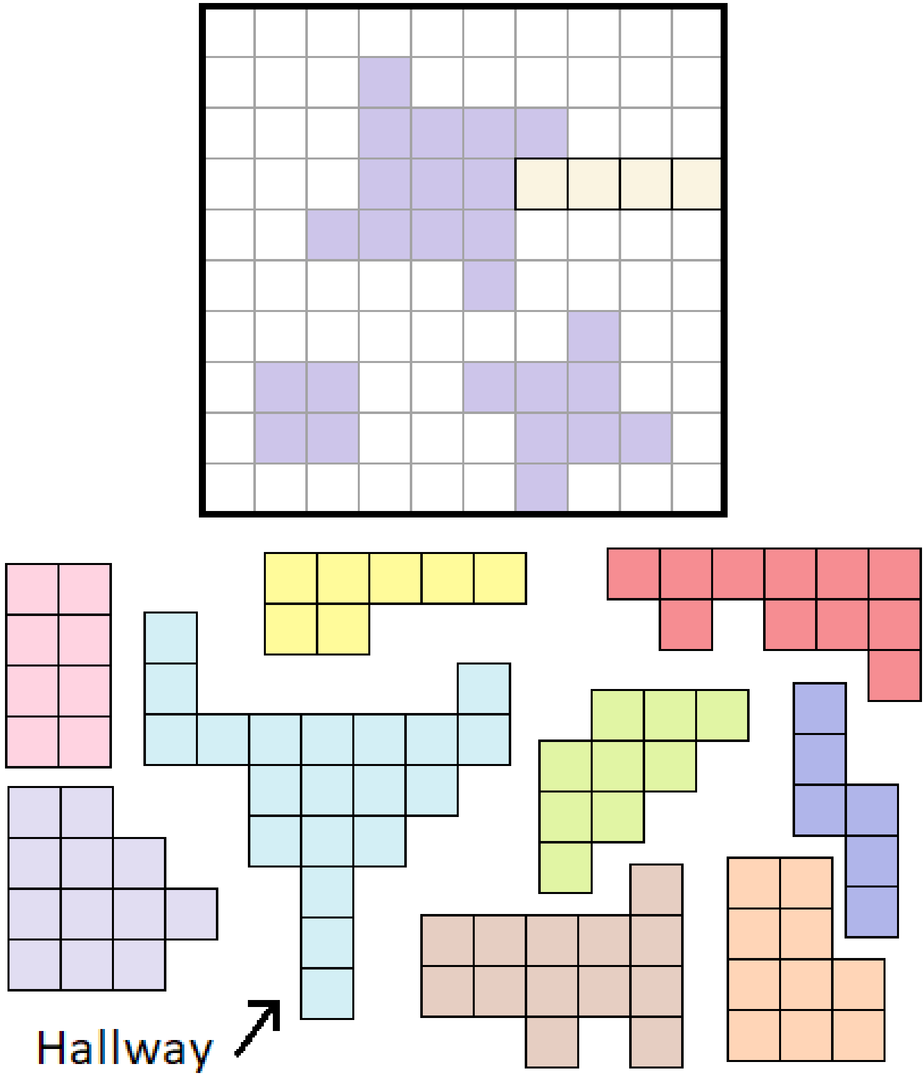
3: Place the PC's, there has to be exactly 1 in every room, row and column and they also can't touch other PC's, not even diagonally. Also also, each PC has to be directly adjacent to a router in the same room, for the best internet access.

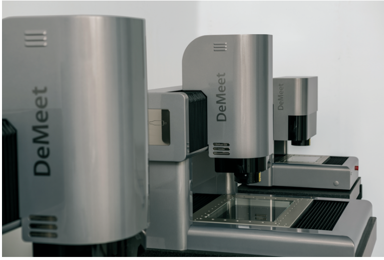
4: Place the laptops, again there needs to be exactly 1 in every room, row and column. Also, because of forced puzzle logic, uuh, I mean Wi-Fi interference, the laptops cant be placed in the interference zones, marked by the grey areas. Laptops are however allowed to touch other laptops diagonally.

Yes, the hallway also counts as a room and it needs 2 routers, a PC and a laptop. No, routers and laptops can't be in the same square.

I suggest working in pencil, as marking the squares where the items can not be is an important strategy and which squares that are changes with each step.

Want to know if you have found the right solution? You can send your solution to franckenvrij@gmail.com. And perhaps you might win a free hug!


Hallway



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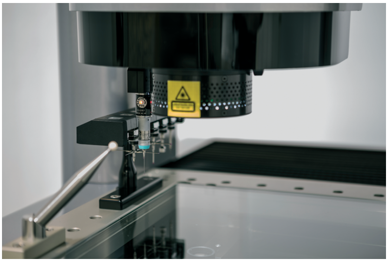

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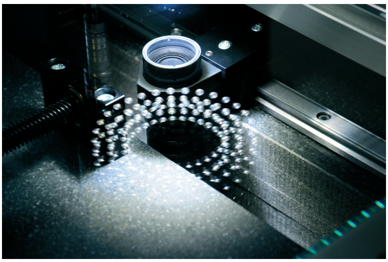

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