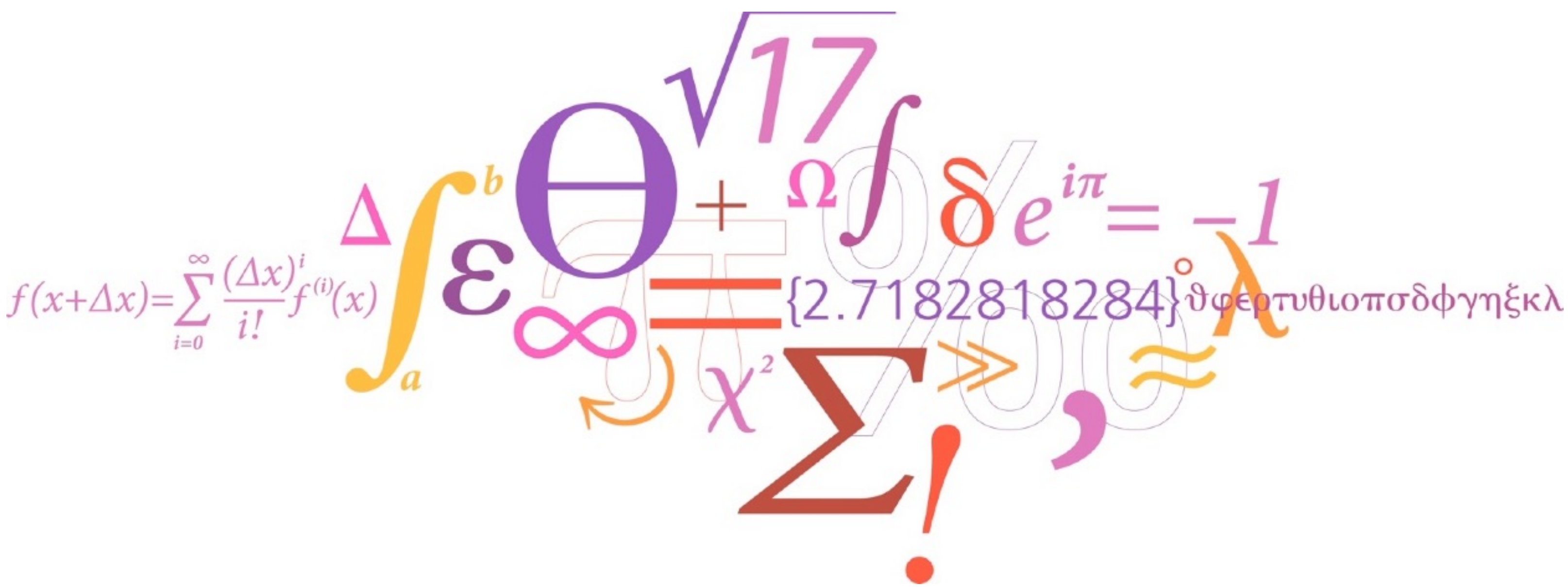
Collaborative Industrial Mathematics in Europe

a tale of many cities



Poul G. Hjorth,
Department of Applied Mathematics and Computer Science
Technical University of Denmark

DTU

"I had a feeling once, about Mathematics, that I saw it all — Depth beyond depth was revealed to me — the Byss, and the Abyss, I saw, as one might see the transit of Venus — or even the Lord Mayor's Show, a quantity passing through infinity and changing its sign from plus to minus.

I saw exactly how it happened and why it happened and how the tergiversation was inevitable and how one step involved all the others. It was like politics.

But it was after dinner, and I let it go."

Winston Churchill,
in *My Early Years, A Rowing Commission (1930)*

Abstract

Mathematics is not border-bound, and this is true in particular for industrial mathematics, as can be seen from the success of the **European Consortium for Mathematics in Industry** (ECMI).

I will briefly sketch the evolution of the so called European Study Groups with Industry (**ESGI**s) and a recent collaborative effort: MI-NET.

I will give examples of industrial maths problems I have encountered, being a small part of this adventure.

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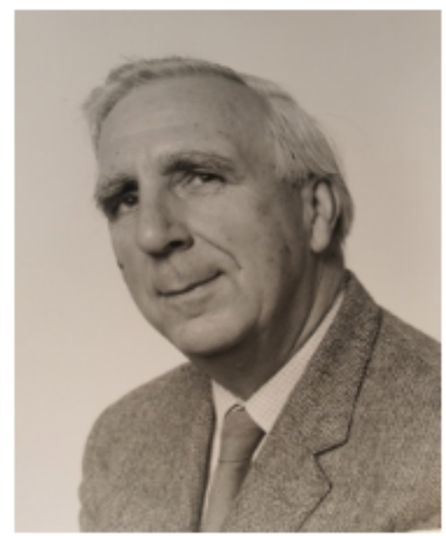
In the late 1960's, two Oxford applied mathematicians, **Alan Taylor** and **Leslie Fox**, began organising *Study Groups with Industry,* inviting industry contacts to challenge university mathematicians with problems of modelling or computation.

Alan Tayler



Leslie Fox

In the 1970's and 1980's these meetings began to be held at other UK universities.

After a 1985 meeting in Amsterdam: *European Symposium for Mathematics in Industry*, a group of applied mathematicians in **1987** founded the **European Consortium for Mathematics in Industry (ECMI).**

They saw a common European interest in **shared standards for education** in industrial mathematics, **shared experiences** with **industry cooperation**.

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ECMI

EUROPEAN CONSORTIUM FOR **MATHEMATICS** IN **INDUSTRY**

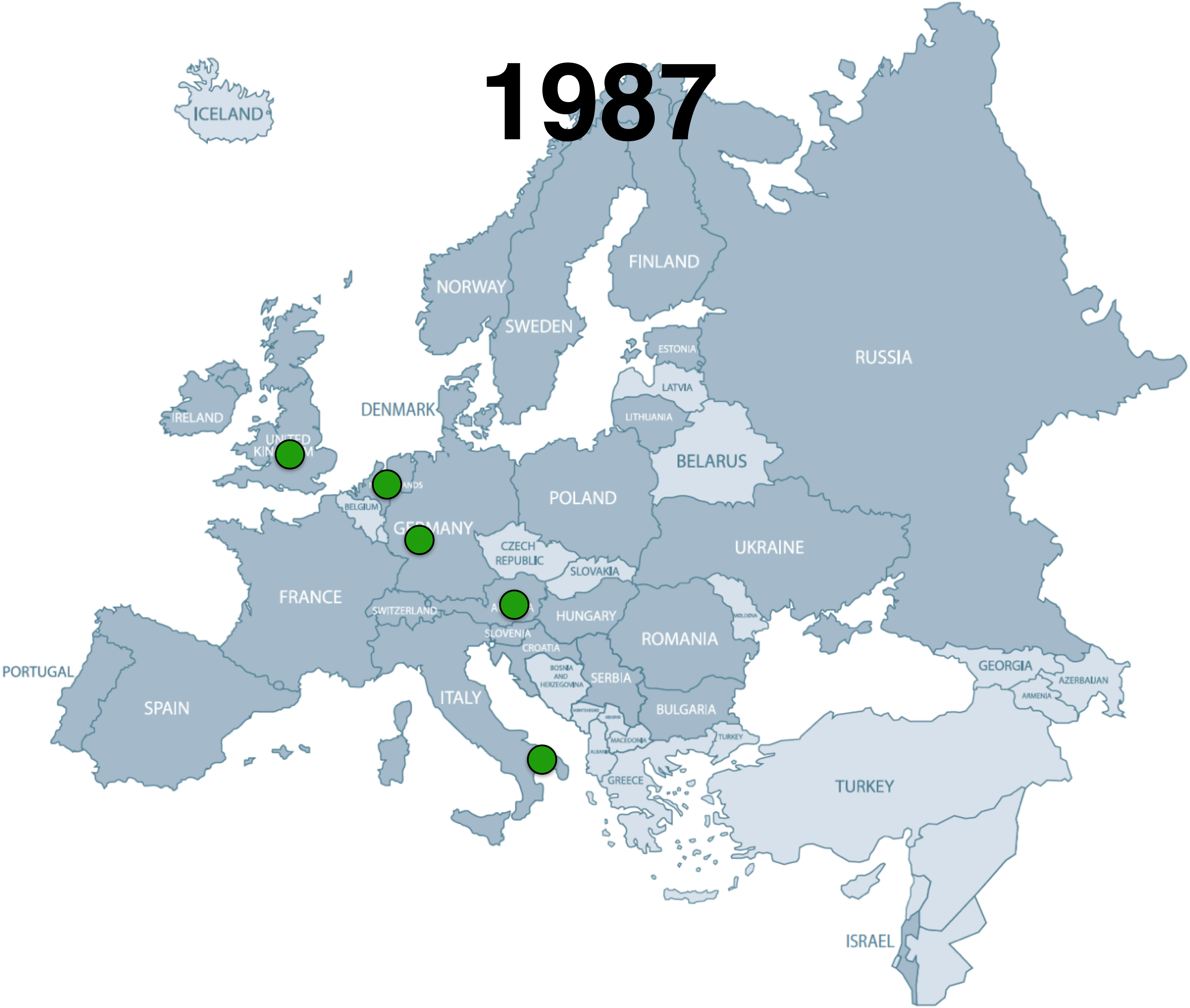
ECMI MISSION

- To **educate** *Industrial Mathematicians* to meet the growing demand for such experts

- To promote and **support** the use of **mathematical modelling**, **simulation**, and **optimization** (M-S-O) in any activity of social or economic importance.

- To promote **European collaboration** in industrial mathematics

1987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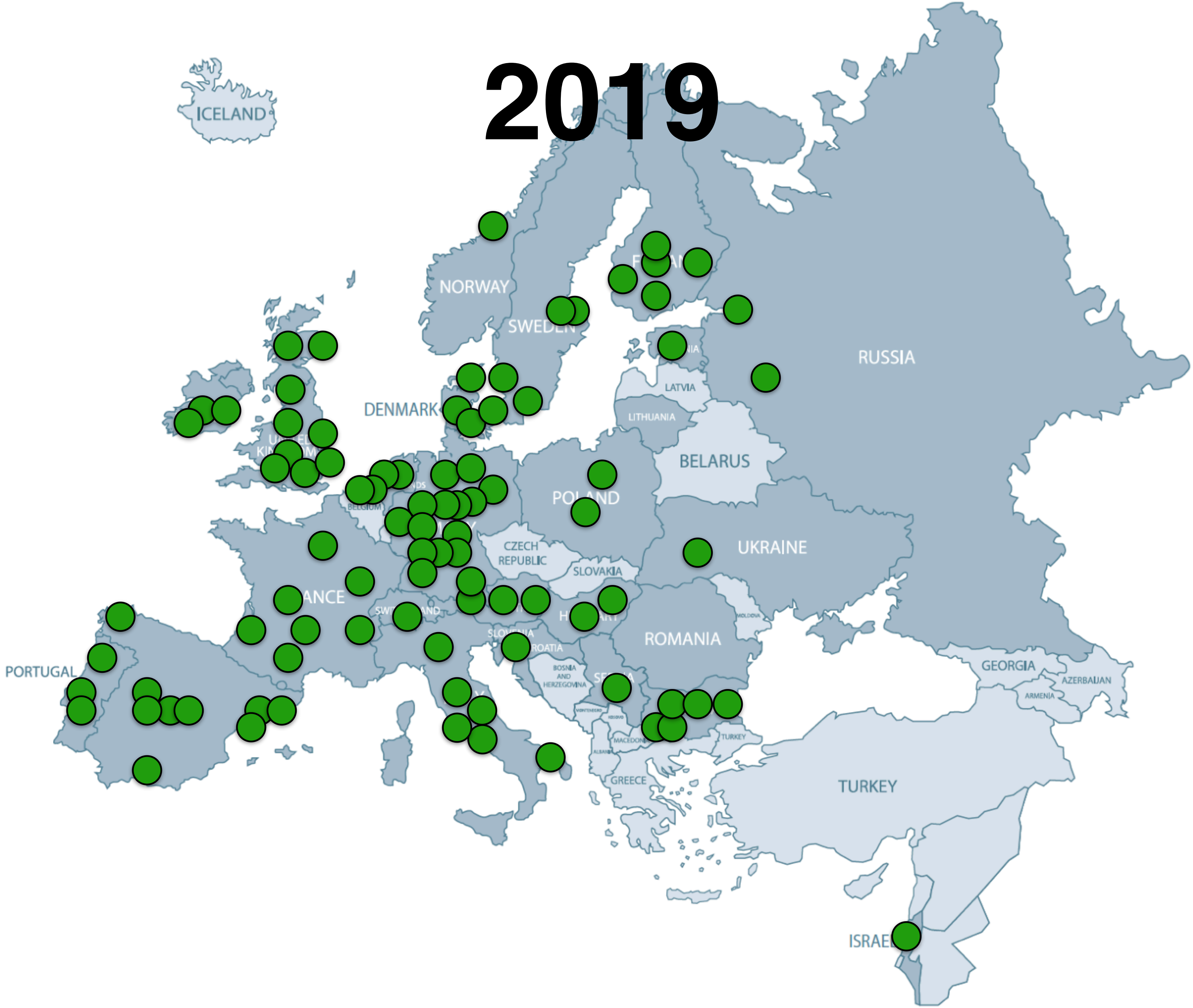
2019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In the present (and future) society

Technological Innovation

and

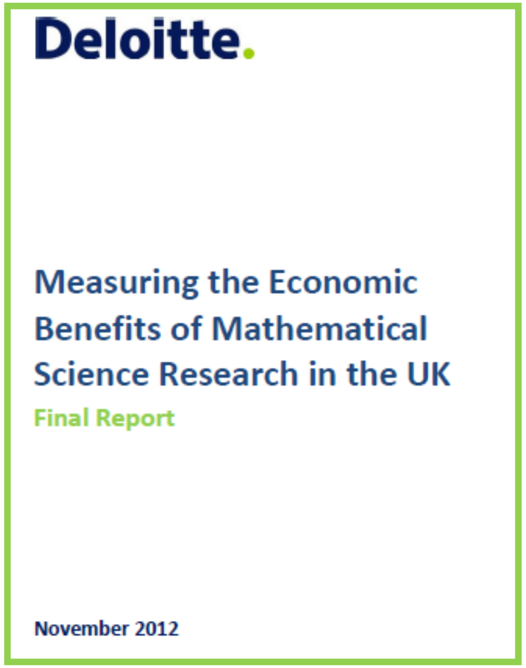
rapid data processing

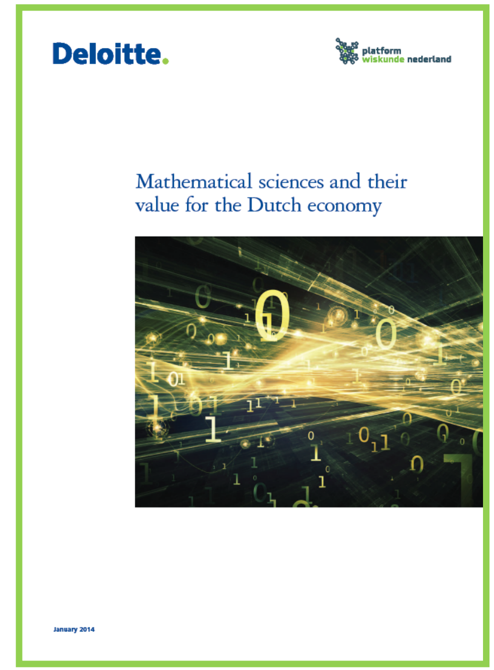
is crucially dependent

on strong and innovative

mathematical know-how.

In France, in the UK, in The Netherlands





reports about the **importance to society** of mathematics

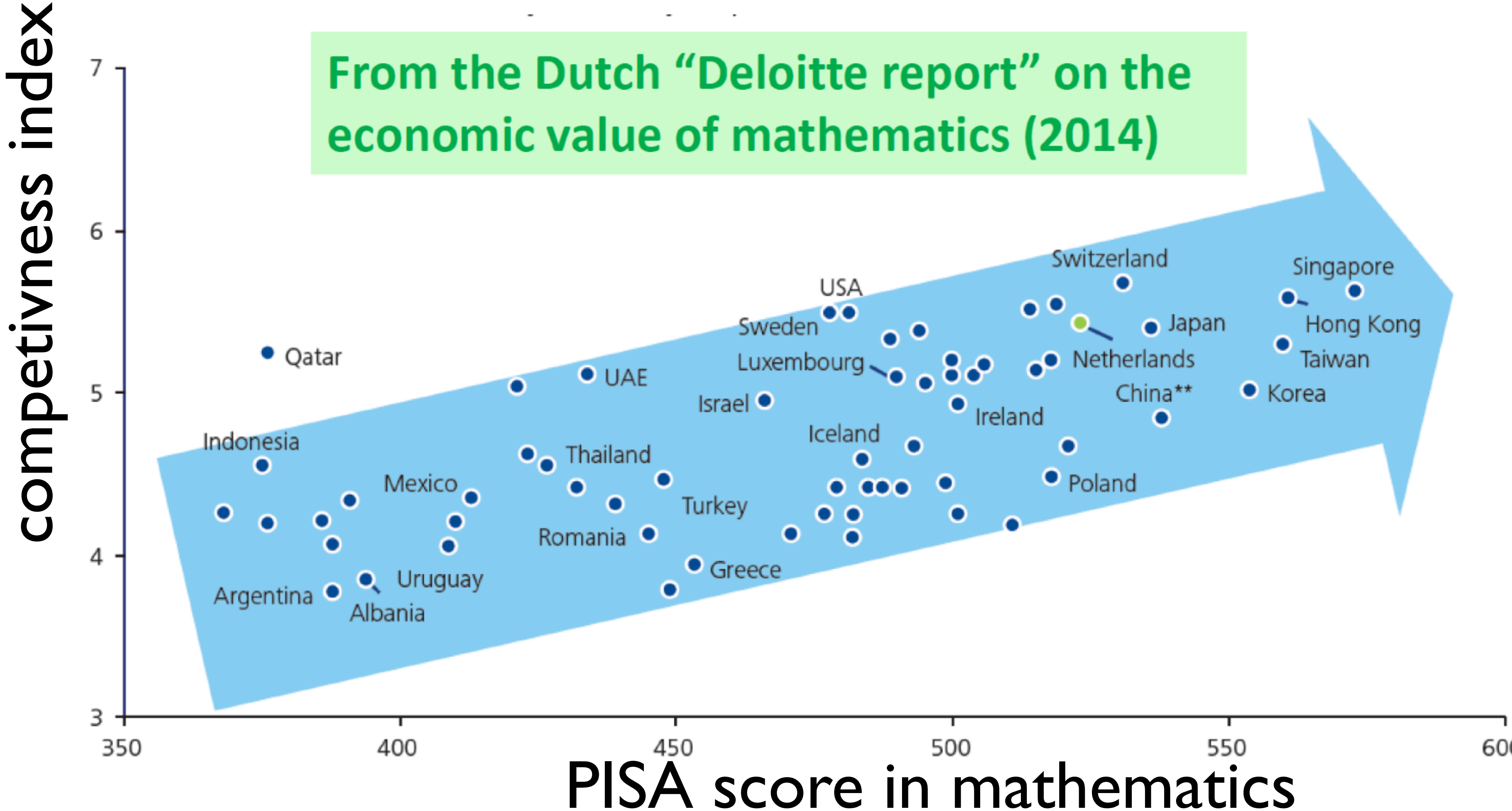
make **the same** conclusion:

Mathematics-related occupations contributes up to **25%** of jobs

Since these jobs earn relatively **high salaries** the contribution to the national economy is even higher

Maths-based research forms a **decisive basis** for success of the economy .
Better **math skills** correlates with a **competitive economy** and a higher standard of living.

From the Dutch “Deloitte report” on the economic value of mathematics (2014)



* Mathematical ability as defined by OECD – PISA study among 15 year old

** PISA score of Macao

Source: World Economic Forum (2013), OECD-PISA (2013); Deloitte analysis

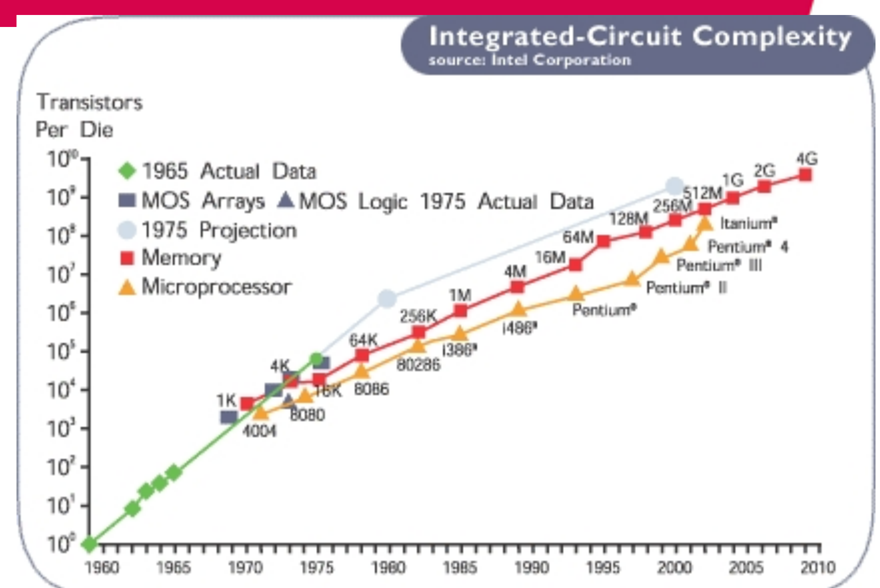
“Revolutions in computational science, big data, statistics and analytics are likely to substantially increase the importance of mathematical sciences”

Example:

The contribution of mathematics to computational power

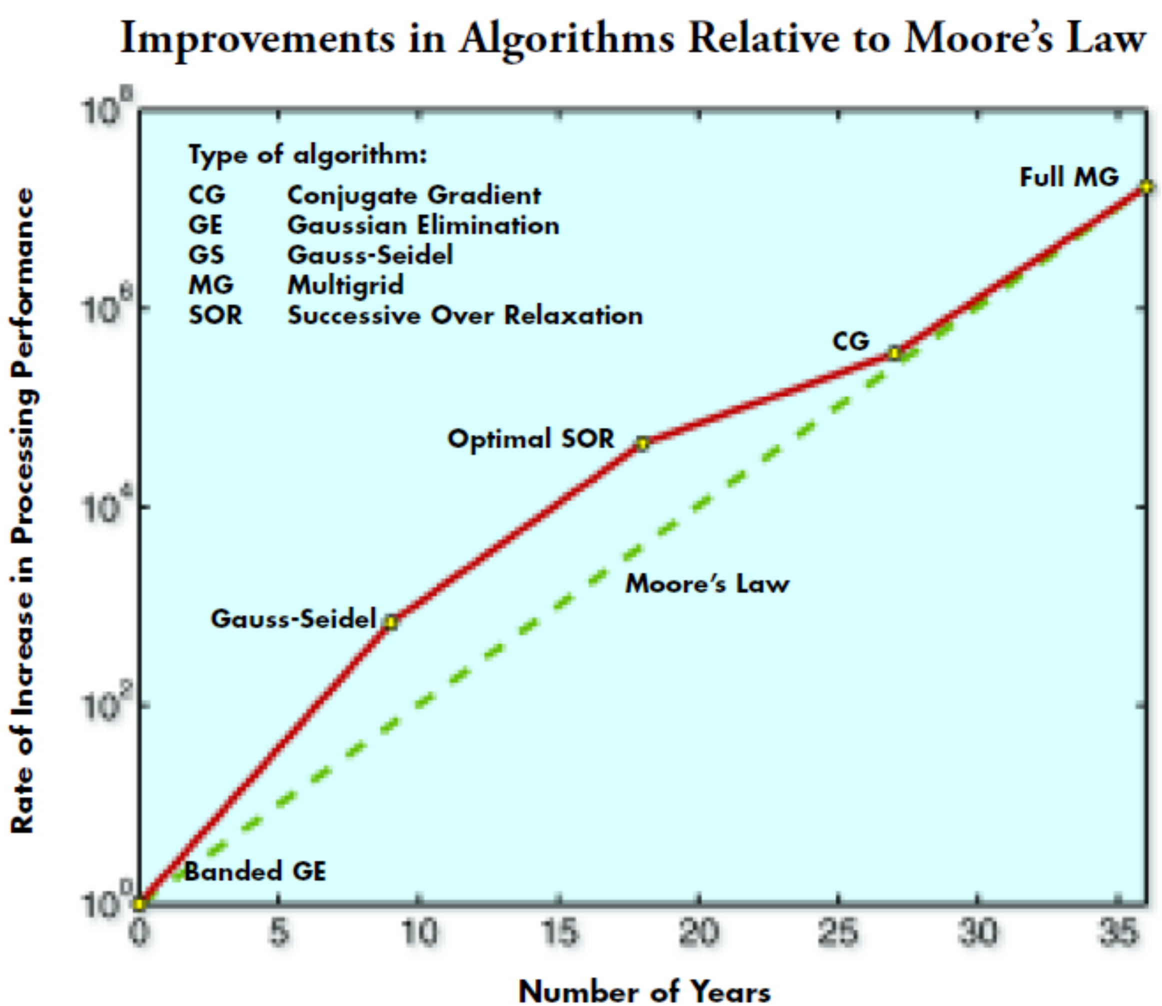
Law of (Gordon) Moore

The engine behind the chips industry is Moore's law: every 2 years the speed and density of transistors is doubled



However:

Moore's law also holds for mathematical techniques!
(but nobody knows.....)



These effects strengthen each other!

Challenging simulations can ONLY be carried out by virtue of the faster hardware AND faster mathematical algorithms

This holds also for developments in Linear and Mixed Integer Programming.....

Linear Programming

Progress in LP: 1988—2004

(Operations Research, Jan 2002, pp. 3—15, updated in 2004)

- Algorithms (*machine independent*):

  Primal *versus* best of Primal/Dual/Barrier 3,300x

- Machines (workstations →PCs): 1,600x
- NET: Algorithm × Machine 5,300,000x

  (2 months/5300000 ~= 1 second)

Mixed Integer Programming

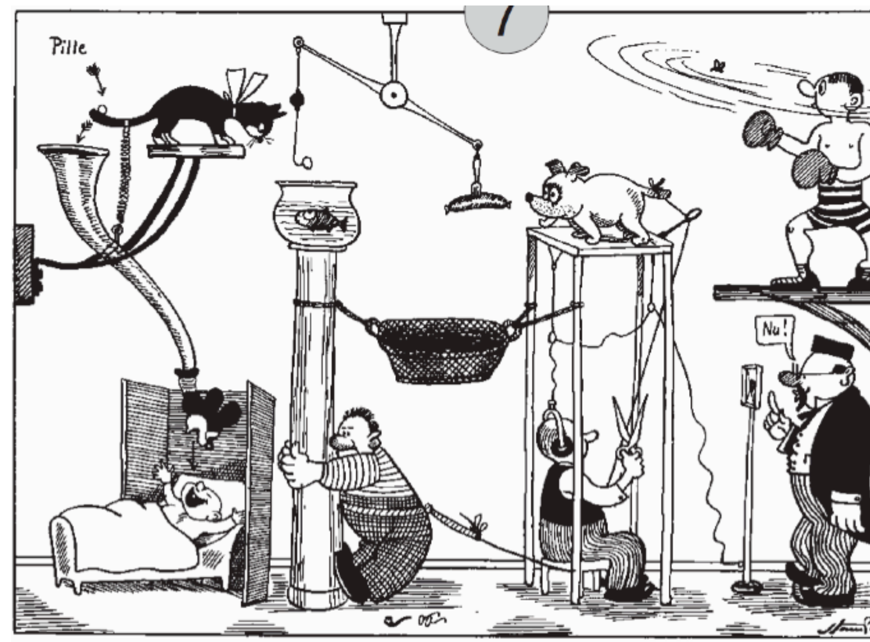
- Overall improvement: 1990 to 2014
  - Algorithms: 870,000x
  - Machines: 6,500x
  - NET: Algorithm x Machine 5,600,000,000x

  (180 years / 5.6B ~= 1 second)

Clearly, algorithm development outperforms machine development

WHAT'S GOING ON?

WHAT'S GOING ON?



ECMI activities

https://ecmiindmath.org

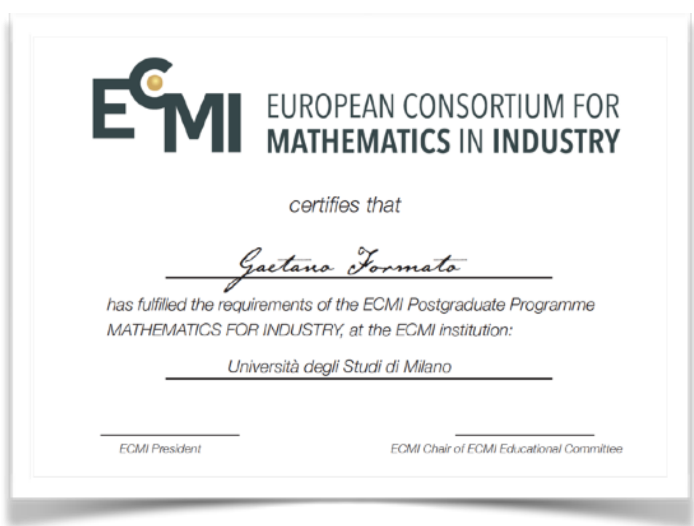
ECMI Activities

EDUCATION

ECMI Model Curriculum in Industrial Mathematics

ECMI Teaching Centres in Industrial Mathematics

ECMI Master Certificate in Industrial Mathematics


ECMI EUROPEAN CONSORTIUM FOR MATHEMATICS IN INDUSTRY

certifies that

Gaetano Formato

has fulfilled the requirements of the ECMI Postgraduate Programme MATHEMATICS FOR INDUSTRY, at the ECMI institution:

Università degli Studi di Milano

ECMI President

ECMI Chair of ECMI Educational Committee

ECMI Activities

MODELLING CAMPS

Students come from all over Europe to spend a week working in small multinational groups on projects which are based on real life problems.

Each group is led by an ECMI instructor who introduces the problem – usually formulated in non-mathematical terms – on the first day and then helps to guide the students to a solution during the week.

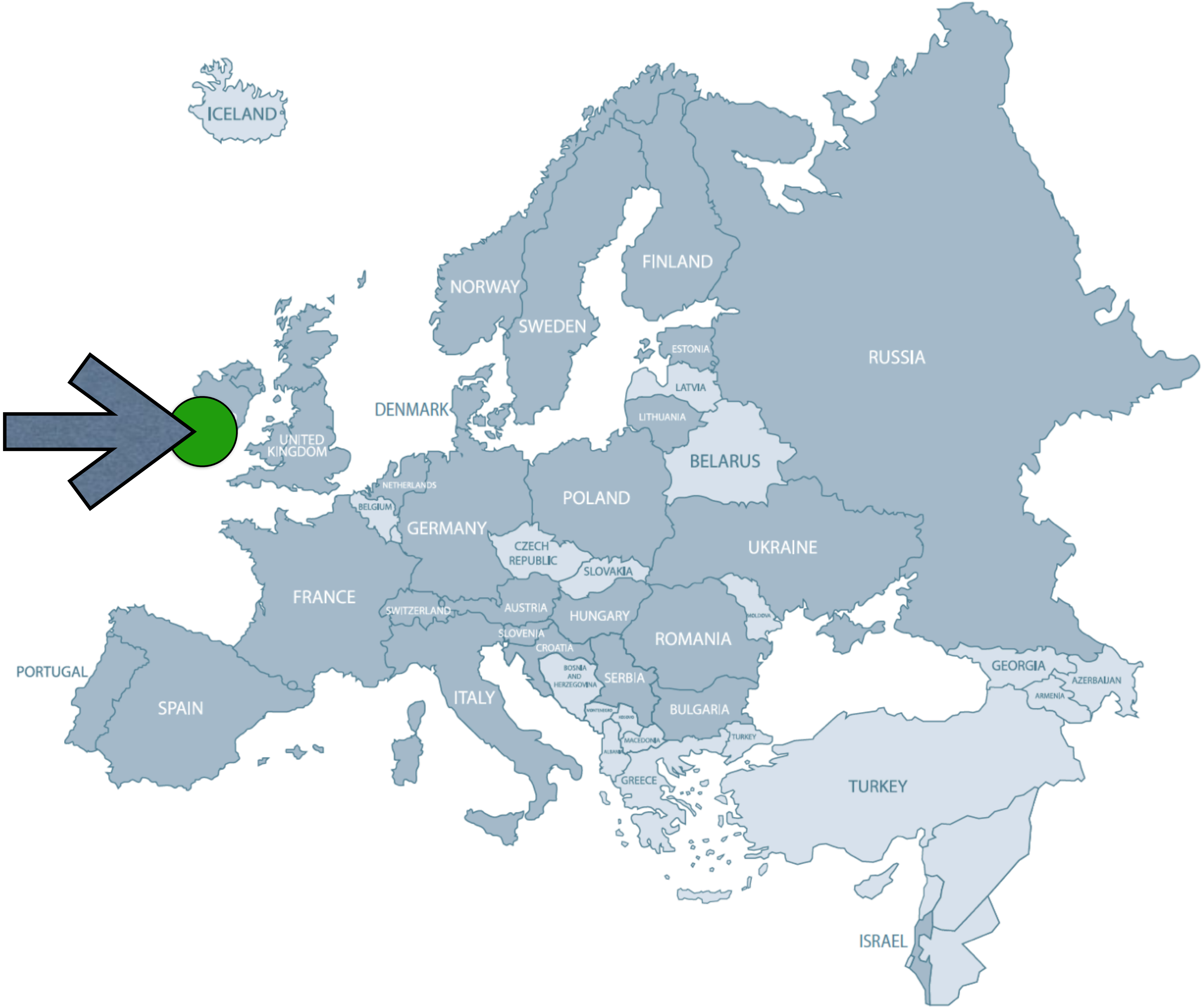
ECMI Activities

SCIENTIFIC CONFERENCES

The bi-annual

ECMI Conference

2018: Budapest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ECMI EUROPEAN CONSORTIUM FOR MATHEMATICS IN INDUSTRY

Limerick 2020

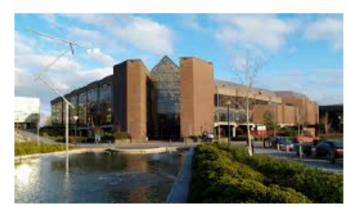
ECMI
EUROPEAN CONSORTIUM FOR MATHEMATICS IN INDUSTRY

2020 conference

ECMI Conference on Industrial and Applied Mathematics

22-26 June 2020, University of Limerick, Ireland

https://ulsites.ul.ie/macsi/ecmi2020



MACSI
Mathematics Applications Consortium for Science & Industry

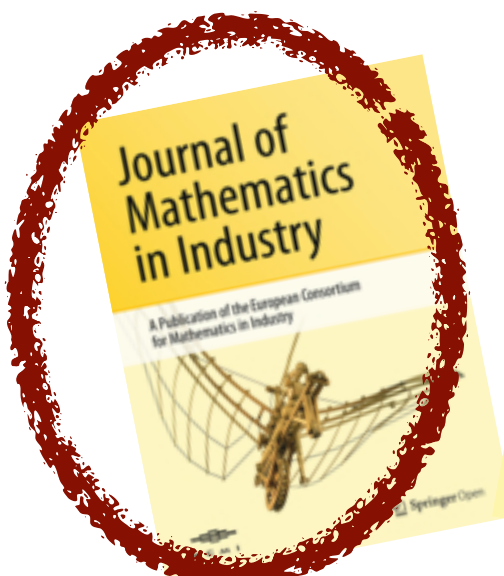
UNIVERSITY of LIMERICK
OLLSCOIL LUIMNIGH

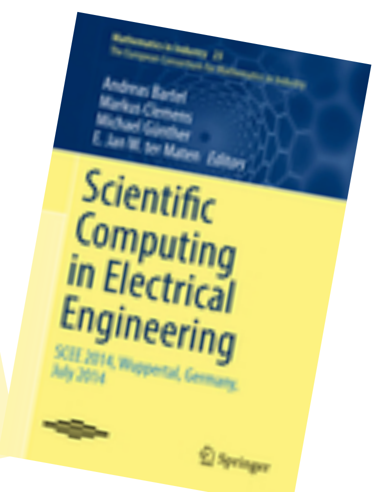
Science Foundation Ireland sfi For what's next

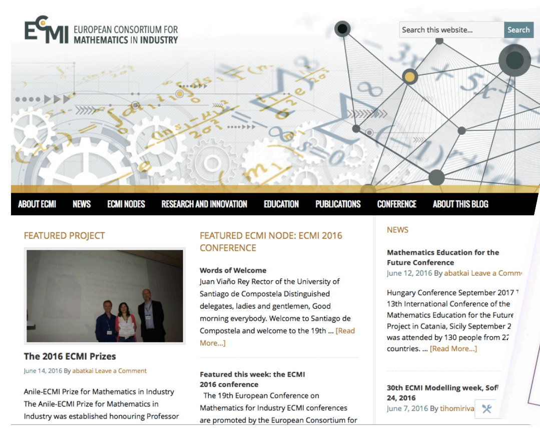
ECMI Activities

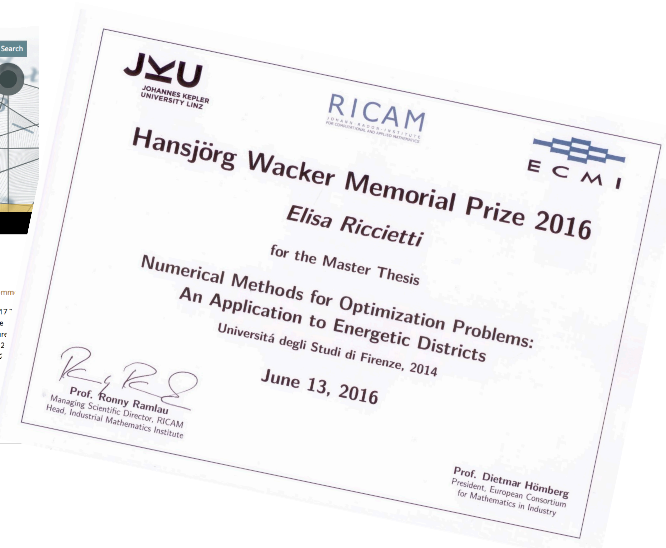
DISSEMINATION

Books, Blogs, Prizes



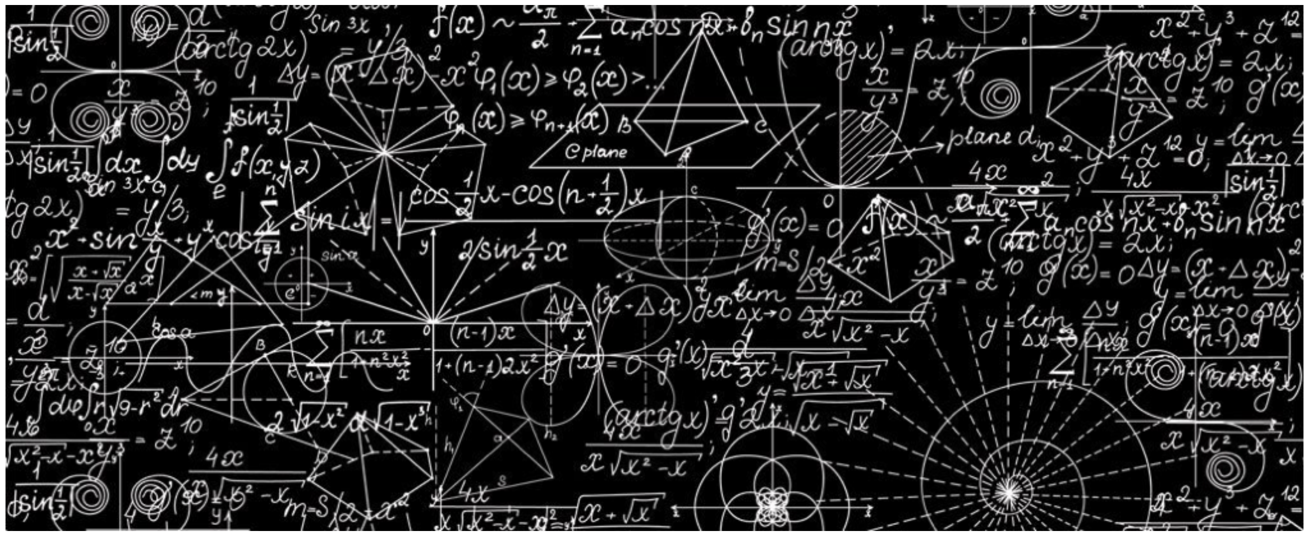






ECMI Activities

SPECIAL INTEREST GROUPS

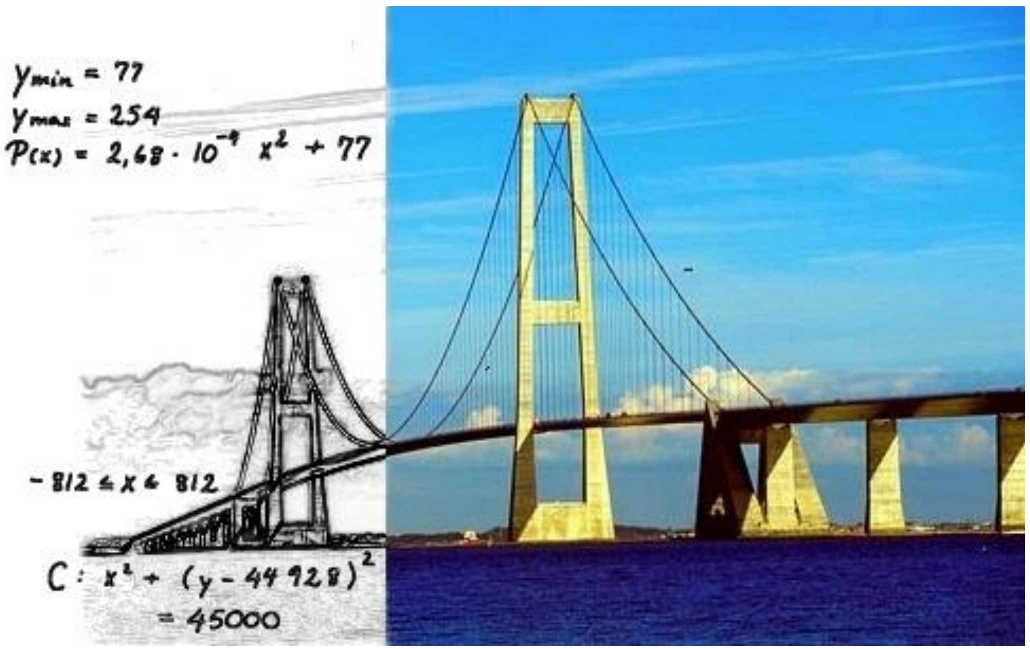


Special Interest Groups (SIGs) exist **to promote collaborative research on specific topics** in Mathematics for Industry within Europe.

A particular aim is to enable researchers (from both academia and industry) with similar interests to get together and **submit proposals for funding to the European Union** or to other funding bodies.

ECMI Activities

EUROPEAN STUDY GROUPS WITH INDUSTRY



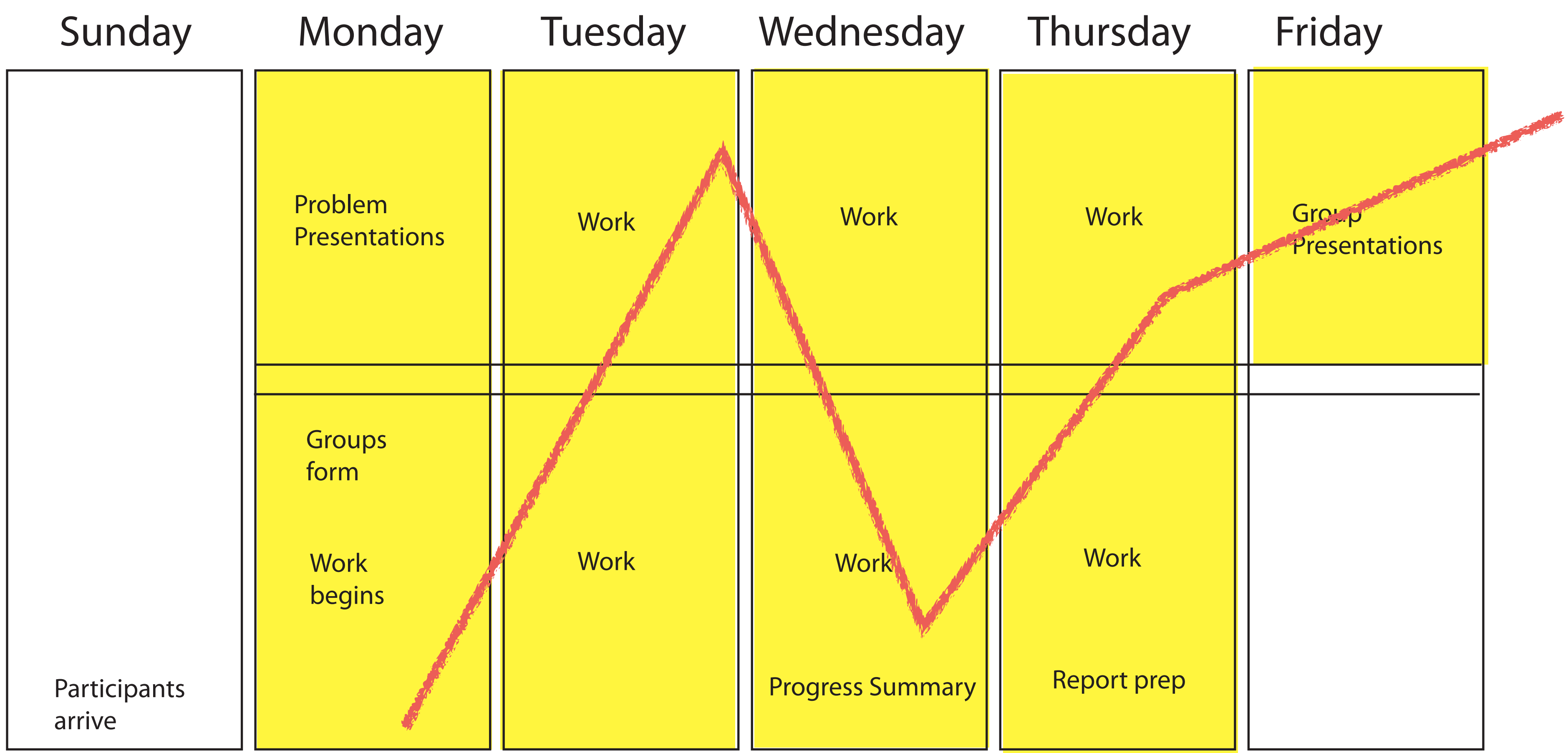
Week-long workshops

where mathematicians work

directly with industry

on mathematical challenges

Format of a typical ESGI week:



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ECMI Activities

EUROPEAN STUDY GROUPS WITH INDUSTRY

Upcoming European Study Groups with Industry

1. ESGI 144, Warsaw, 17 – 22 March 2019
2. ESGI 145, Cambridge, Apr. 8-12 2019
3. ESGI 147 Spain, Apr. 8-12 2019
4. ESGI 152, Palanga, Lithuania, 10-14 June 2019

6. ESGI 155, Polytechnic Institute of Leiria, Portugal, 1-5 July 2019.
7. ESGI 154, U. Southern Denmark, 19-23 August 2019
8. ESGI 150, Basque Centre for Applied Mathematics, 21-25 October 2019

Past European Study Groups with Industry

2019

1. ESGI 148/SWI 2019 Netherlands, Wageningen, 28 Jan. – 1 Feb., 2019
2. ESGI 151 Estonia, Tartu 4-8 Feb. 2019
3. ESGI 149 Innsbruck, March 4-8, 2019

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MI-NET

cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

https://mi-network.org

Success in numbers

21 Industrial Workshops

2000 participants from 46 countries

MI-NET

51 Short Term Scientific Missions

100 companies and non-academic institutions involved

12 Modelling Weeks

24 Industry Days

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MI-NET

Mathematics for Industry Network

About

Publications

ESGI Handbook

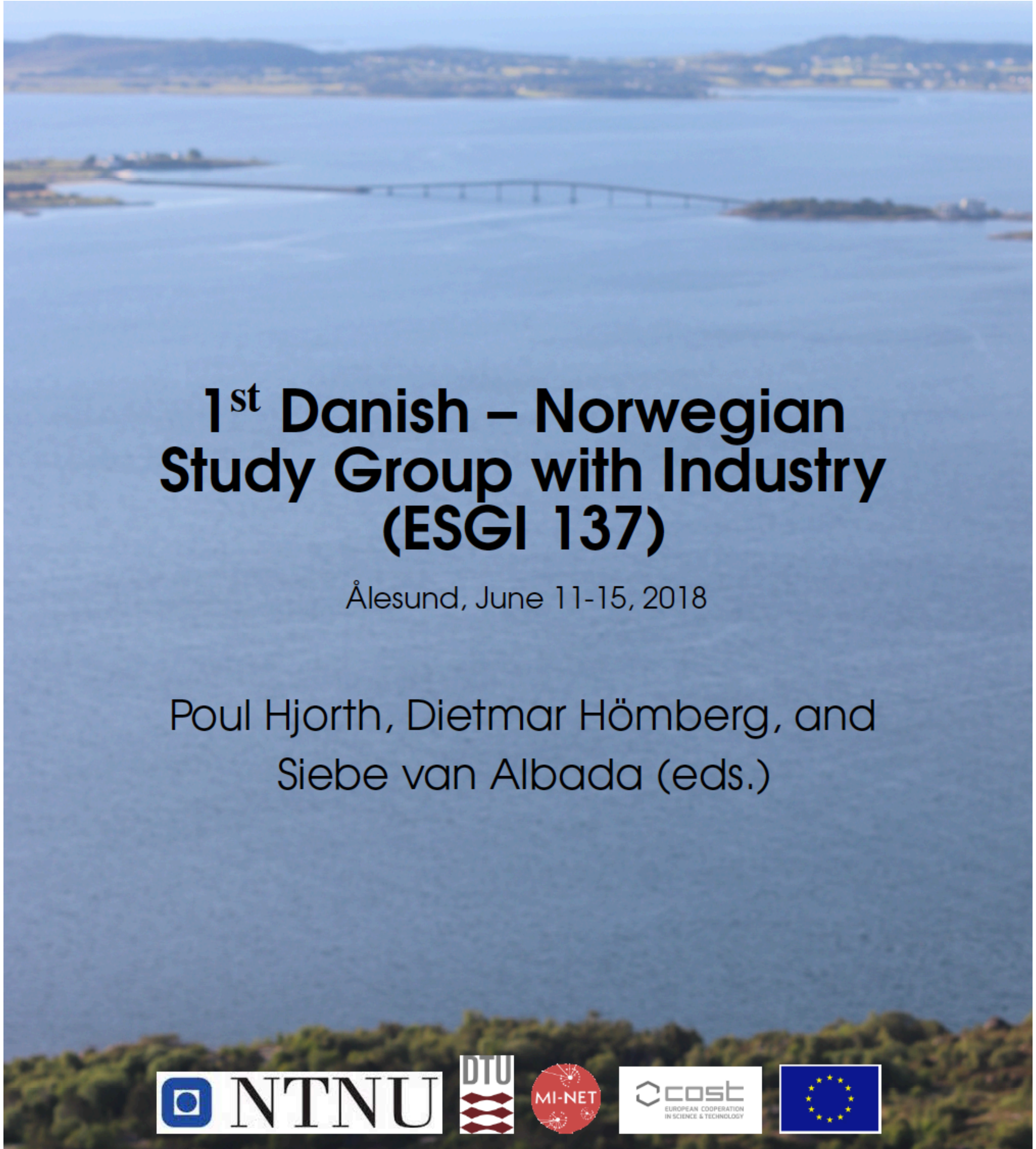
The '**Handbook for running a sustainable European Study Group with Industry'** aims to compile the knowledge and experience acquired to date throughout Europe.

The European Study Group with Industry (ESGI) format is an internationally recognised problem-solving forum for knowledge exchange between mathematical scientists and industrialists.

Download electronic version (PDF)

Request hardcopy by contacting us.

*Supplementary information:*templates for Academic Feedback Form, budget, Delegate packs, event checklists, Industry feedback form and Template attendance list. Sample flyer and letters promoting ESGI to Academicsand Companies.


1st Danish – Norwegian
Study Group with Industry
(ESGI 137)
Ålesund, June 11-15, 2018
Poul Hjorth, Dietmar Hömberg, and
Siebe van Albada (eds.)
NTNU
DTU
MI-NET
cost
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

sample ESGI problems:

Too Hard:

LEGO:
how to build with LEGO Bricks

LEGO asked for algorithms to output optimal building instructions for arbitrary 3D design shapes.

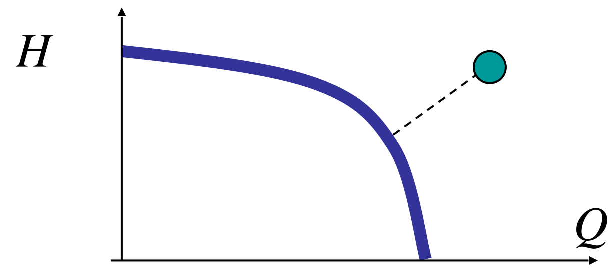
The Study Group provided:

Optimal Building algorithms for simple shapes: boxes, sheets, and beams.

Arguments why the general optimal problem is extrymely difficult (possibly np).

Too easy:

COMPLEXICON: Relation to Reference Curve

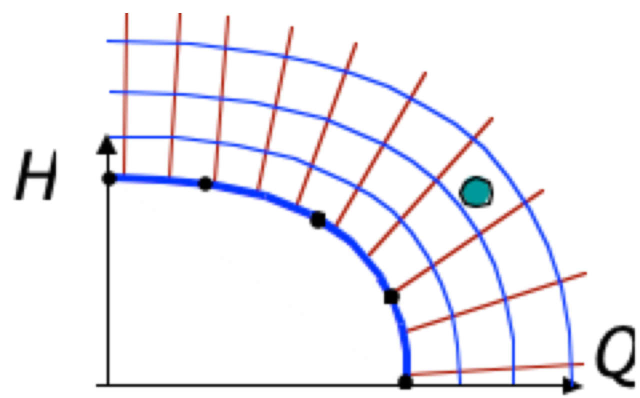


* Find the (orthogonal) distance from a measurement point to the reference curve H = H(Q) which is a segment of polynomial of degree n > 2.

Too easy:

"Schwarz-Christoffel"

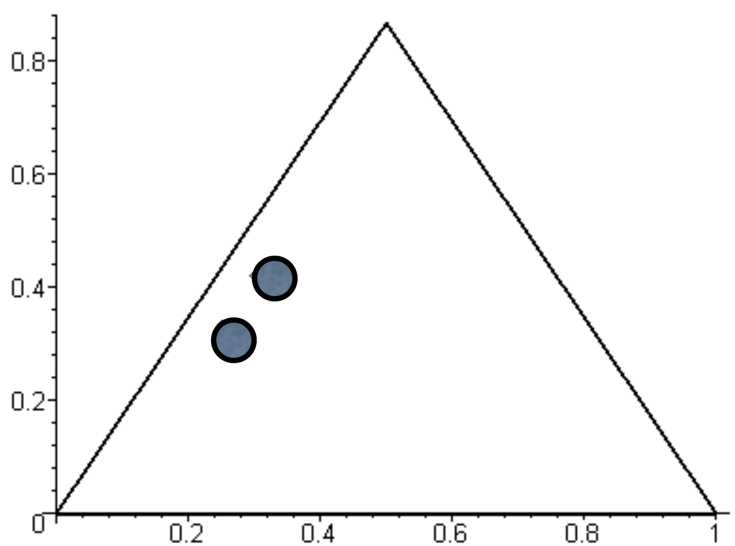
- 15 base points define a conformal map
- measure distance along curvilinear coords

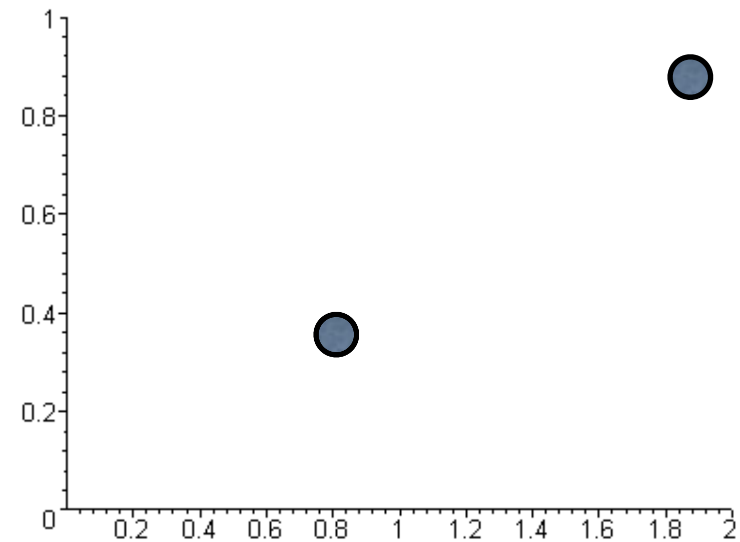


- "distance" depends on base points!
- COMPLEXICON algorithm not SC but has same defect

Too easy:

Schwarz-Christoffel





same distance
in original space

different distance
in image space

Too easy:

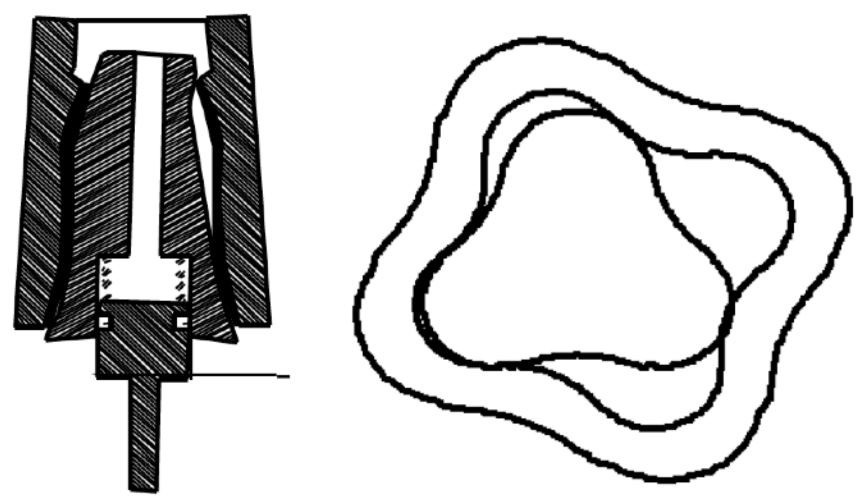
1. Discretization
2. Golden ratio search
3. Brent's method
4. Polynomial method

- these work for piecewise polynomials too

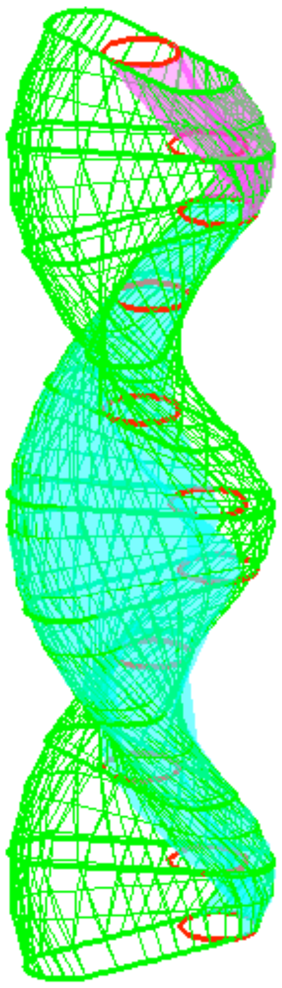
:: Tuesday optimism => report writing

Just right:

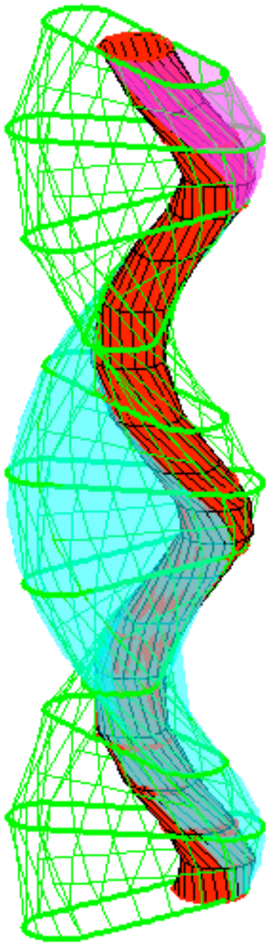
GRUNDFOS: Moineau pumps



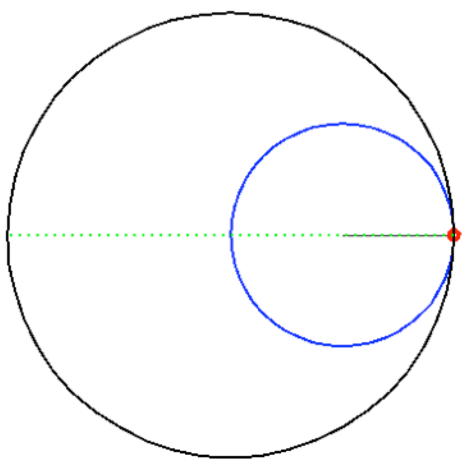
- For n-teeth running inside n+1 teeth: make an expression for as well internal as well as external element with different eccentricities.
- If the pump were conical in z-direction what would be the expression for the elements if the cross section of the cavities and thread height thread height should be constant for a linear increasing eccentricity in the z direction.
- Expression describing the flow for the pump above (Length L, Speed v (Hz))
- The pump making a pressure P: What would be the axial force on inner or external element as a function of the turning angle?
- What would be the radial forces as a function on turning angle?

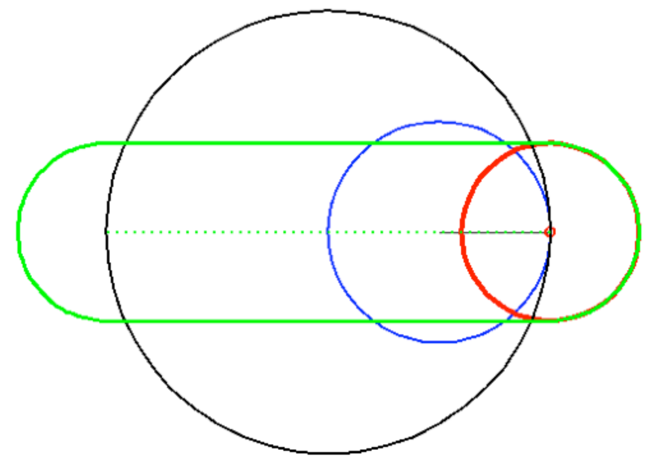


A series of chambers of constant volume are pushed up (or down) the pump chamber by the continous motion of the excentrically moving pump shaft.

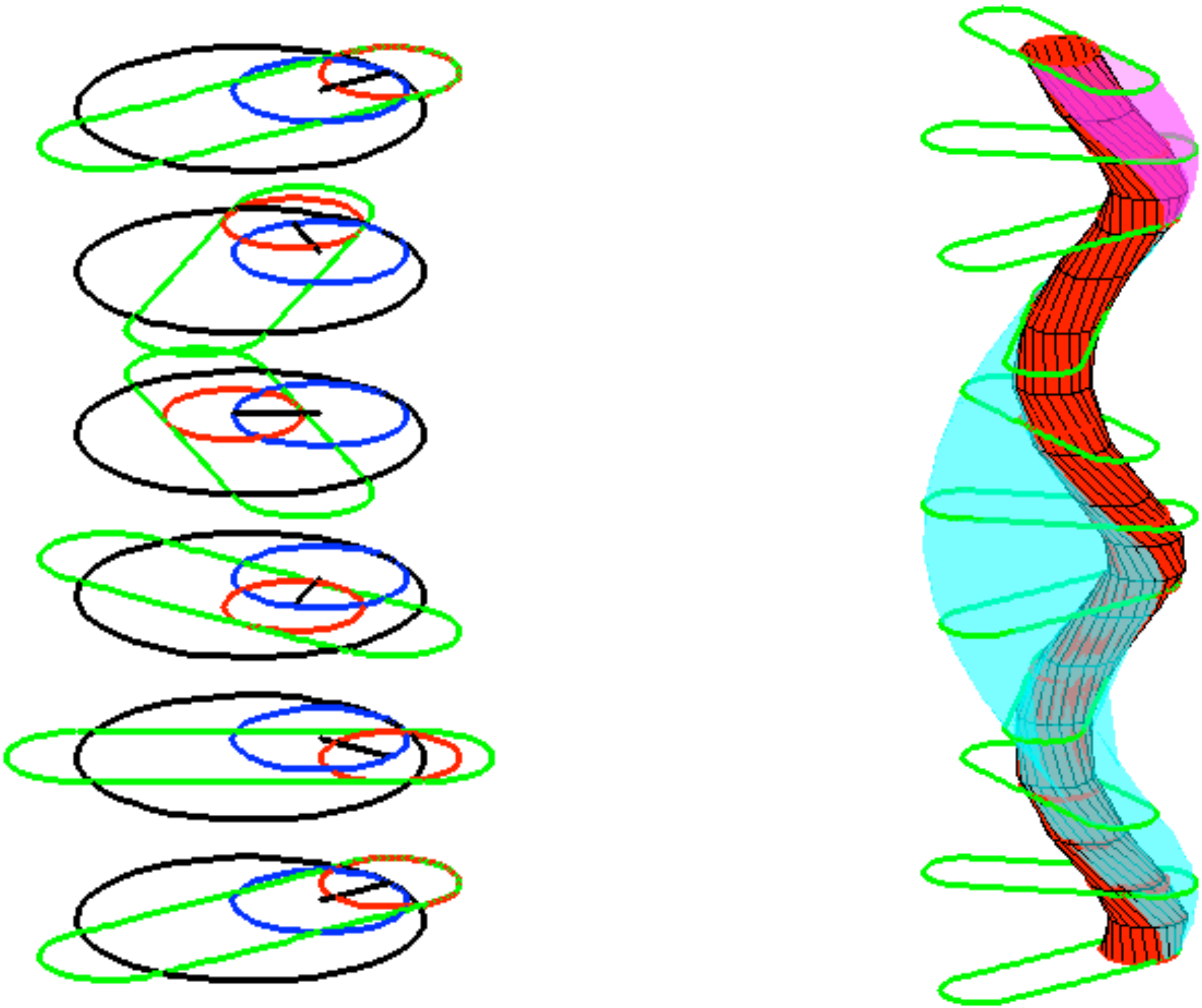


Rolling a circle of radius one on the inside of a circle of radius two will make a point fixed on the inner circle trace out a diameter of the outer circle

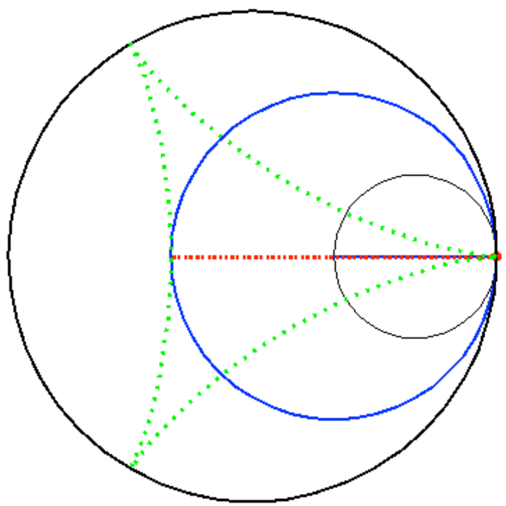




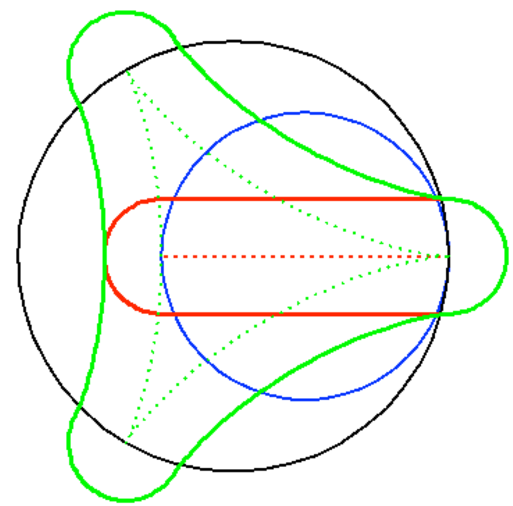
Expanding the point to a disk we get the disk moving in an excentric motion in a fixed `canal’ around the diameter.



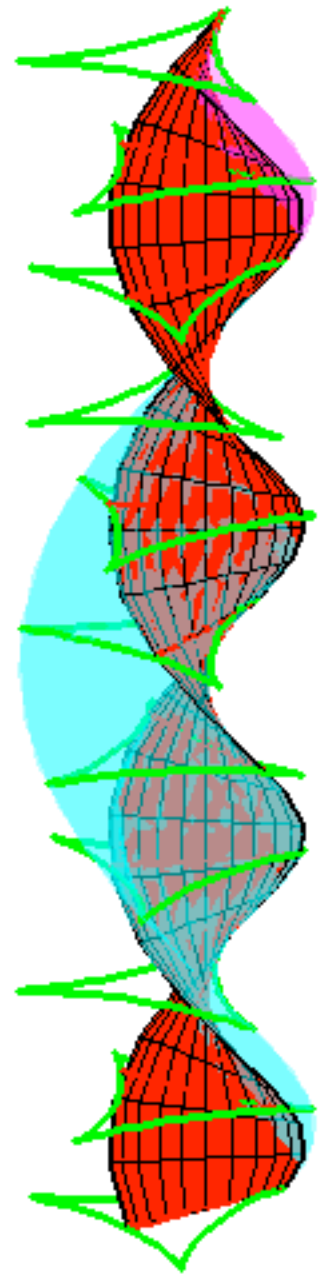
Hypo-Cycloid 3:2 construction

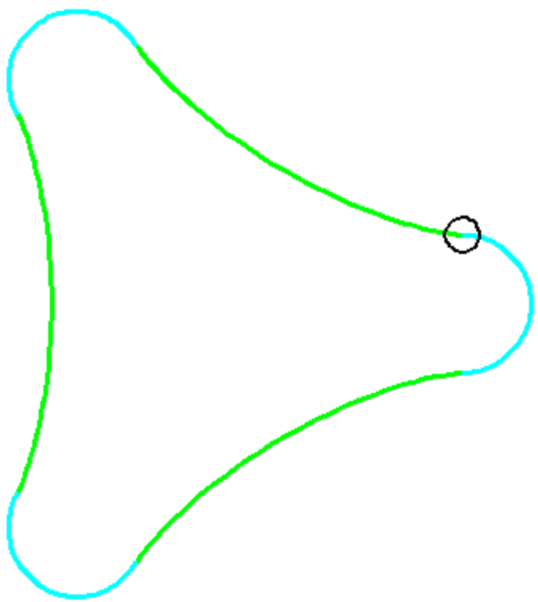


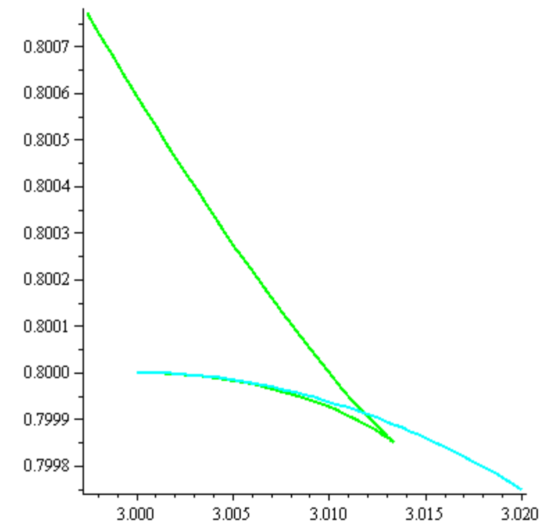
If we roll the previous construction inside a circle of radius 3, the point fixed on the smallest circle will trace out a hypocycloid.



‘fattening’ the diameter of the radius 2 circle gives us the pump chamber shape



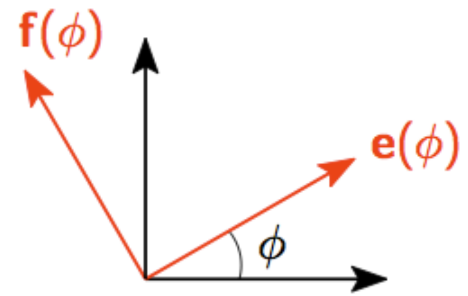




But there is a problem. The hypercycloid shape has infinite curvature at the cusps, -- and this problem remains present in the `fat' pump chamber shape.

$$\mathbf{e}(\phi) = \mathbf{R}(\phi)\begin{bmatrix}1\\0\end{bmatrix} = \begin{bmatrix}\cos\phi\\ \sin\phi\end{bmatrix}$$

$$\mathbf{f}(\phi) = \mathbf{R}(\phi)\begin{bmatrix}0\\1\end{bmatrix} = \begin{bmatrix}-\sin\phi\\ \cos\phi\end{bmatrix}$$



$(\mathbf{e}(\phi), \mathbf{f}(\phi))$ is a rotating frame.

$$\mathbf{x}(\phi) = h(\phi)\,\mathbf{e}(\phi) + h'(\phi)\mathbf{f}(\phi),$$

$$\mathbf{x}'(\phi) = (h(\phi) + h''(\phi))\mathbf{f}(\phi) = \frac{\mathrm{d}s}{\mathrm{d}\phi}\mathbf{t}.$$

So $\mathbf{f}$ is the tangent, $\mathbf{e}$ is the normal, $h = \mathbf{x}\cdot\mathbf{e}$ is the support,

$$\kappa = \frac{\mathrm{d}\phi}{\mathrm{d}s} = \frac{1}{h(\phi) + h''(\phi)} \qquad \text{is the curvature, and}$$

$$\rho = \frac{\mathrm{d}s}{\mathrm{d}\phi} = h(\phi) + h''(\phi) \qquad \text{is the radius of curvature.}$$

If $h + h'' \neq 0$ then the curve is regular.

Any planar curve without inflexion points can be given by its support function.

GRUNDFOS asked for a mathematical description of the Moineau pump, allowing for design experimentation and a possible avoidance of singularities.

The study group provided a complete description in terms of the support function h(ϕ).

The study group proved that the singular curvature problem is unavoidable for all Moineau constructions.

The support function description also permitted the design of an optimal construction, now in use by GRUNDFOS.

Summary

From humble beginings, the concept of collaborative mathematical interactions with industry has spread from England to almost every other country in Europe (and indeed beyond), and has given rise to international collaborations and an international community of industrial mathematicians.

Thanks to

Dietmar Hömberg

Adérito Arújo

Wil Schilders

Hilary Ockendon

John Ockendon

Thank You