Mathematics and Engineering: A Fruitful Interaction

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Abstract Memories of a long life of scientific research offer an unusual point of view on the interactions between mathematics and engineering.

Keywords Mathematics and engineering · Borders and contacts · Automatic computation · Friuli's geography and history

The title could be understood as an encouragement to write an enormous book listing decisive events or, vice versa, declaim short but not interest-free invocations. But the present occasion is calling for felicities not for the boring preaching or the giving advice. And I could be considered, taking a long look, as an immigrant, though born in 'Gemona del Friuli' and so 'friulano' by birth. But Gemona is not far from the Italian state border and to its north there is a number of valleys of difficult access from the west but more easily accessed from the east. Topographically Friuli is a complex region escaping easy and general statements (just as the title topic of the present essay).

Besides all know how difficult it is to decide and declare without struggle and accept with serenity a border. In principle, on the meaning and consequences of the border of a body (possibly facing a variety of even foreign environments) both mathematicians and engineers must take a stand on the question if it makes sense to deem them as comparable with the consequences of internal contacts along an imagined internal frontier, an imaginary 'Euler cut'. Even, more specifically, if those consequences could be taken as depending only on strictly local geometric properties such as the existence of a tangent plane.

Ennio De Giorgi himself expressed embarrassment when we asked him about the possible ampler validity of his definition of 'reduced' frontier. Besides one may

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express doubts about the attribution of qualities naively and brusquely to a two-dimensional object as mathematicians suggest and wonder, rather, contrariwise, how one ‘sees’ the frontier from a near internal point, possibly with a perception declining steadily with the distance, as, possibly, an engineer would prefer to do. Finally, but not less importantly, there is the ambience within which the body is intended to be placed or even a container inside which the body may be constrained. An empty space (corpora et inane as a poet [and a mathematician, perhaps] would prefer considering, the choice as accessory, anyway) or whichever ambience a contract imposes to an engineer? A mathematician seems, sometimes, to arrogate the more convenient choice from a formal, functional stand. An engineer suffers, as nobody seems even to have started to classify ambiences and some, which the engineer is forced to confront, are the most diverse, sometimes unfortunate, even dangerous in the long run.

To pass on a larger view it is inevitable to recall that we all lived, from the beginnings of the past 50 years, in a period during which the political and military world circumstances have conditioned the choices (even the life) almost of every one of us. There was no alternative than to answer to the apocalyptic menaces and, in all great nations, a frenetic research activity relevant for our topic was launched: the interaction between mathematics and engineering was not only encouraged, it was even imposed, and financed generously also for the universities.

Even if one avoids mention of products of direct military interest, there is a sector (even that inevitably concerned, though) with revolutionary general consequences: automatic computers. They were also initially thought of to forecast exact trajectories of artillery shells but they invaded almost all activities, tacitly. There is no doubt that the whole spread of human geniality, from the most abstract logic for operating systems to the finest machining for output and printers, was involved.

An essential role was played by a strict collaboration between mathematicians and engineers. Personally, I traversed day by day that period of gestation even if at the margins and what I now mention is colored by my memories. That being premised, there is no doubt that the dominant personality in the field was a great genius, miscast then, Alan Turing. He had already described, in principle [1], a machine capable of self-control to carry out mathematical operations. But then, during the war, Turing worked hidden in the absolutely secret environment of military decryption. It was known later, much later, that, in parallel with the polish scientist Marian Rejewski, he had managed to decrypt the code ENIGMA used by the German Army. In that success a machine, called BOMBA, appropriately designed, had a decisive role. Soon after the end of the war, the superintendent of the mathematics division of the British National Physical Laboratory (NPL) offered Turing a job to design and, hopefully, build a large computer (denominated ACE, automatic computing engine), to match US projects. In a matter of months, Turing provided a document with detailed plan, times to specify details, time scales of activities required, costs to cover them. The project was approved, adding the need for an initial smaller version called DEUCE. Importantly, a member of the NPL Advisory Council was Sir (later Lord) George Nelson, president of a large conglomerate of companies English Electric Co Ltd. He intervened to provide the necessary staff not available at NPL (1949) so that

DEUCE was working within 2 years. ACE required still some years to exist (1958). But Turing was a homosexual, which was a crime in Britain then. Recognized as such in 1954, he could choose to be castrated or go to prison. He committed suicide during the chemical castration process.

As it happened, I was employed to work in the central research laboratories of the English Electric from 1956 and for 6 years, using for my researches one of the two DEUCE installed there. The conglomerate provided no end of problems, particularly of concrete mechanical engineering, which became my field of competence.

In the same years, other scientists, who were engaged into defense during the war, claimed the need of aligning investments in the civil Britain manufacture industry, after the war, to the level reached during the war itself. This was the so-called *white heat scientific revolution.* P. Blankett, a labour party adviser, was one of the most active promoters. Other successful persons contributed, as C. P. Snow, who was at that times in the English Electric board of directors. Several initiatives emerged; an important one was the creation of Nelson Research Laboratories, dedicated to fundamental research in the fields that industrial group was interested in.

It is time, however, that I come back to some personal issues.

31 years old—it was 1956—since some tentative of starting in Rome a serious academic career failed, I decided to move towards industry. Curious circumstances pushed me to apply for a research position in General Electrics. Nelson Research Laboratories offered me a contract (with an initially modest salary) for the mathematical section. There, the activity was essentially focused on DEUCE computers. At that times, the user was almost in direct contact with the inner hardware, in the absence—so to say—of an appropriate software. It was about to program numerical calculations able to furnish in acceptable time approximate solutions to rather complex problems. Learning several specific things was necessary. Eventually, I was able to collaborate with J. H. Wilkinson, who received the Turing Award in 1970 for his research in numerical analysis. On my background I had a mathematical-physics culture, which was essential in modeling engineering problems. I was in constant contact with the design offices in the group, the NPL at Reading, already quoted above, and also with the National Engineering Laboratory, opened near Glasgow, for data on new alloys, which were appropriate for high-temperature environments. I'll mention only some special cases for the pertinent prominence of unusual mathematical questions asked by engineers: (i) the shear in heating environment, which involves fractional derivatives, (ii) the whole rheology with the corresponding imaginative proposals, (iii) the effects of condensation drops on a supersonic turbine, (iv) thermal stresses on selenium discs, even those doped, for current rectified in electric locomotives. I'll dwell a bit more on a vibration problem concerning a rotating beam on lubricated bearings because it requires a mathematical formulations from which peculiar problems emerge: the boundary conditions for the beam involve per se evolution equations! As it moves, the beam floats over the lubricant and such a floating obeys to the balance equations describing the viscous fluid motion. The liquid film undergoes cavitation if the bearing clearance has no cylindrical symmetry. Consequently, the boundary conditions are themselves evolution equations: the pin can bounce within the bearing so that the breaking effects due to viscosity can or

cannot prevail on the rotational energy transfer with the consequence of exciting vibrations. The whole system sizing requires care to avoid disastrous consequences, which historically occurred in realized machines. In this case, engineers imposed to mathematicians a new class of problems, still open as far as I know.

I already quoted above the vastness of the interactions between engineers and mathematicians for military purposes, during XX Century's first half, dwelling on the first computers because they have eventually had a universal influence. At the same time there were other chapters that were temporarily very important and engaging, but their value was only specific (see, e.g., [2]).

In those years, the English Electric was involved in the construction of power plants based on fossil fuel or nuclear power. Its laboratories, specifically the Nelson Research Laboratories, were engaged in the analysis of pertinent problems and DEUCE was largely used. I must also mention another project imposed to Great Britain by the existing politic-military situation. The Soviet bombers Tupolev 22 could haul an atomic bomb through the North Sea to keep East England strategic installations down. And, therefore, the Great Britain needed to have in its possession a so high speed interceptor able to destroy the possible threat, after a sudden alarm, tackling it on the North Sea, before the bomber could reach the British airspace. English Electric was able to offer a solution with an extraordinary airplane able to reach Mach 2 and corresponding rate of climb to altitude, with the power of two jet engines fitted one over the other. In our laboratory we named it *P1*. The more appropriate official name was *Lightning* (see, also, [3]).

In 1962 I returned to Pisa, called back by Alessandro Faedo to assure continuity for the pioneering work carried out up to then by Marcello Conversi, who followed a suggestion by Enrico Fermi, to design and make servicing an electronic computer called CEP. I quote these personal events because they give me the chance to insist once again on how much fruitful the interactions between mathematicians and engineers can be. In Pisa I found two strongly involved actors: Alfonso Caracciolo di Forino and Giovanni Battista Gerace; the first interested and competent in logic and theory, even if always conscious of the needs of practicality, the other a disciplined engineer, with specific competence in the more advanced electronics. Two perfect examples of the interactions this essay is dedicated to.

Some years later I received an offer to become president of a new company, named Tecsiel and created within the financial corporation Finsiel by its president, Carlo Santacroce—a former student of the Scuola Normale Superiore and Faedo's friend—to manage what at that times was called an *intermediate software*. That company produced a heterogeneous net software, namely a net involving computers with different origins (on this there was in Pisa the leading expert, Luciano Lenzini, who was professor in the engineering faculty).

After that experience I came back to the Department of Mathematics in the University of Pisa still doing research on materials with (say) active microstructure, along a view unifying different specific models. Later I started to study the possibility of constructing continuum mechanics avoiding the axiom, rarely rendered explicit, of the exclusive and perennial existence of each material element. That axiom is even too convenient for a mathematician because it allows one-to-one correspondence between reference and current macroscopic shapes of a continuous body. Already Galileo Galilei mentioned it referring, for a concrete example, to the bending of beams made by carpenters in the Venetian arsenal. At times that axiom is nefarious for an engineer; for example, if rearrangements of matter due to temperature variations are non negligible. From thoughts about that problem, the invention of a new conceptual scheme, the one of so-called *ephemeral materials*, emerged, with a new line of studies (see [4], and references therein).

So, in my professional life, I floated on the perilous sea which links and divides the shore of engineering from that of mathematics. Perilous, I wrote, and, appropriately, not long ago, I was elected member of the Accademia dei Pericolanti of Messina. The, now, colleagues, who voted me in, have long meditated on whether the stretch of sea, they are used to admire, be more perilous to cross for a mathematician who pretends to act as an engineer or for an engineer who wants to argue as a mathematician.

Perhaps this peculiarity was among the factors which led me to the presidency of AIMETA (Italian Association of Theoretical and Applied Mechanics) from 1998 to 2001. In that period, beyond standard duties, I essentially worked to protect *Meccanica*, the AIMETA journal, from influences that could have potentially reduced its character of a true research journal.

My memory jumps and comes back, for the moment, to Friuli, mentioned in beginning this text, and to the topography of its northern border, which is determined by ‘Alpi Carniche’ and ‘Alpi Giulie’. As an old man, I adopt here names that have stayed in my mind from my childhood, when I wandered in those places. I know that nowadays, officially, we need to use those names selected by southern Slav, who came after Istrians and Romans. That Alps (as the branch that separates Styria from Slovenia) are permeable because the pertinent heights and asperities are modest. Consequently, various populations were able to overcome them easily, above all descending along the valley traced by the river ‘Isonzo’. Then, as a name, ‘Forum Iulii’ moved west and named the region: Friuli, precisely. The city, a border city, referred to itself briefly as ‘civitas’, i.e., ‘Cividale’.

Barbarians of various tribes overcame long ago that Alps, not only Huns led by Attila, to escape whom, some Venetians went on the islands scattered in front of the Adriatic coast. The first Slavic invaders arrived from the far north of, say, Slavonia from the surroundings in the bay that St. Petersburg now overlooks. They probably followed the amber route that extended from the Baltic coasts and, much appreciated by the Romans, was the first imperial market in Friuli and among the Venetians.

Those proto-Slavs camped in the widening of the Isonzo valley which now has Saga as its center around A.D. 500. Then, around 700 the cruel Longobards, to whom the genocide of those found there was no stranger, came. Some proto-Slavs, among those I have already mentioned, were able to escape climbing through an extremely inaccessible valley, which then opens to the west, arriving at what is now called the ‘Tanamea pass’. A small river, active only when the snow melts, now called Mea, flows from there towards the west to the sources of a stream—named nowadays in Italian as ‘Torre’, in Friulian ‘Tor’, in their language ‘Ter’—flowing south, at a certain point crossing a second precipitous and impassable narrow passage now called ‘Crosis’. Shortly after the source of ‘Torre’, the valley widens and offers the possibility of growing something edible, so that they built a village still called ‘Ter’ (nowadays ‘Pradielis’, in both Friulian and Italian). They have managed to survive hardship for a thousand years and speak their language, studied in 1800 by a Polish scholar, only a few now (see [5] for further details).

At the end of 1600, one of them managed to climb a pass between the mountain ranges of ‘Musi’ and ‘Quarnan’, up to descend to ‘Gemona’. He said his name was Crapiz; he married a Gemonese. An error, perhaps, in the parish register moved the letter *r* as early as 1700. Currently, the closed valley is called by them ‘Terski Dolina’ (‘Alta Valle del Torre’ in Italian). There is still a family in Pradielis called Crapiz.

I went into details, partly irrelevant, also to justify being still alive at 96: I derive, at least in half, from a people who have survived a thousand years of hardship.

On closing this essay I must add a remark on the tool used by both communities (those of mathematicians and engineers) to diffuse the theorems they proved or the structures they planned and made real: the scientific journals. Great is the courage needed to propose a new one and the fatigue required to keep one alive which is already on the shelves, waiting to be read.

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References

1. Turing, A.: On computable numbers, with an application to the Entscheidungsproblem. Proc. London Math. Soc. **s2-42**, 230–265 (1937)
2. Edgerton, D.: The Rise and Fall of the British Nation: A Twentieth-Century History. Allen Lane, London (2018)
3. Lavington, S.H.: Early British Computers. Manchester University Press, Manchester (1980)
4. Capriz, G., Mariano, P.M.: Interactions in a multi-scale representation of sparse media: from mechanics to thermodynamics. J. Elast. **135**, 91–115 (2019)
5. Melis, G.C.: Storia del Friuli, 10th edn. Soc. Filologica Friulana, Udine (2002)