Communities and Ancestors Associated with Egon Börger and ASM

Jonathan P. Bowen[1,2](✉)

[1] School of Engineering, London South Bank University, Borough Road, London SE1 1AA, UK
jonathan.bowen@lsbu.ac.uk
[2] Centre for Research and Innovation in Software Engineering (RISE), Faculty of Computer and Information Science, Southwest University, Chongqing 400715, China
http://www.jpbowen.com

Abstract. In this paper, we discuss the community associated with Abstract State Machines (ASM), especially in the context of a Community of Practice (CoP), a social science concept, considering the development of ASM by its community of researchers and practitioners over time. We also consider the long-term historical context of the advisor tree of Egon Börger, the main promulgator of the ASM approach, which can be considered as multiple interrelated CoPs, distributed over several centuries. This includes notable mathematicians and philosophers among its number with some interesting links between the people involved. Despite most being active well before the inception of computer science, a number have been influential on the field.

1 Background

> *There are two kinds of truths: those of reasoning and those of fact. The truths of reasoning are necessary and their opposite is impossible; the truths of fact are contingent and their opposites are possible.*
>
> – Gottfried Leibniz

This paper has been inspired by the work of the computer scientist Egon Börger [11,12] and is presented in celebration of his 75th birthday. The author has been involved in building and investigating communities [38], both in the area of formal methods, especially the Z notation [49], and also in museum-related [8,59] and arts-related [44,50] contexts. Börger has been central to building the community [10] around the Abstract State Machines (ASM) approach to modelling computer-based systems in a formal mathematical manner. This paper considers aspects of this community, especially with respect to Egon Börger's role, and also in the context of the Community of Practice (CoP) approach to considering the evolution of communities based around an area of developing knowledge [94,95].

A. Raschke et al. (Eds.): Börger Festschrift, LNCS 12750, pp. 96–120, 2021.
https://doi.org/10.1007/978-3-030-76020-5_6

1.1 Personal Appreciation

> *All our knowledge begins with the senses, proceeds then to the understanding, and ends with reason. There is nothing higher than reason.*
>
> – Immanuel Kant

I first met Egon Börger when he visited Tony Hoare [34] at the Oxford University Computing Laboratory's Programming Research Group (PRG) in September 1993, including a talk by him entitled *The methodology of evolving algebras for correctness proofs of compilation schemes: the case of OCCAM and TRANSPUTER* [12,19]. I was a Research Officer working on formal methods [68] and specifically the Z notation [33,67] at the time. I also became involved with the European ESPRIT **ProCoS** I and II projects on *Provably Correct Systems*, led by Tony Hoare at Oxford, Dines Bjørner at DTH in Denmark, and others in the early 1990s [9,31,47].

The subsequent **ProCoS-WG** Working Group of 25 partners around Europe existed to organize meetings and workshops in the late 1990s [32]. Egon Börger gave a talk to the group on *Proof of correctness of a scheme for compilation of Occam programs on the Transputer* at a January 1995 workshop in Oxford [12,19]. The **ProCoS-WG** final report in 1998 [48] included the following:

> Prof. Egon Börger of the University of Pisa, Italy, has participated at many **ProCoS-WG** meetings, largely at his own expense. He was an invited speaker at ZUM'97 [46] and organized, with Prof. Hans Langmaack of the University of Kiel, an important set of case studies formalizing a Steam Boiler problem in a variety of notations [1], including a number of contributions by **ProCoS-WG** members. He reports:
>
>> The **ProCoS** meetings have been for me a very useful occasion for fruitful exchange of ideas and methods related to the application of formal methods. In particular I appreciate the occasion I had to present my work on the correctness theorem for a general compilation scheme for compiling Occam programs to Transputer code. This work appeared in [23]. Furthermore I appreciated the chance to present the Abstract State Machine (ASM) method to **ProCoS-WG** members.

See Fig. 1 for a group photograph of participants at the final **ProCoS-WG** workshop held at the University of Reading in the UK during 1997, including Egon Börger and myself. Egon Börger was also an invited speaker [27] at the co-located ZUM'97 conference [46] that I co-chaired, introducing the Z community to ASM.

Much later, in 2006, we both contributed to a book on *Software Specification Methods* [64] based around a common case study, including use of the Z notation [37] and ASM [24]. In the same year, I also attended Egon's 60th birthday *Festkolloquium* at Schloss Dagstuhl, Germany [3], later contributing to the associated *Festschift* volume [45].

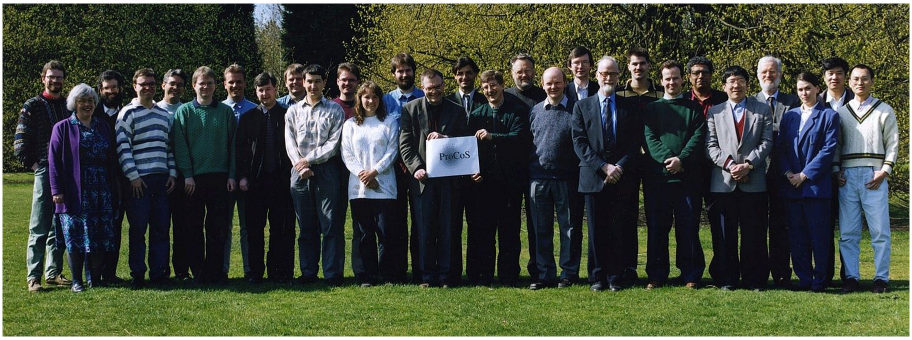

Fig. 1. ProCoS-WG meeting at the University of Reading, 1997. Egon Börger is 4th from the right; I am 10th from the right.

From the early 2000s, I was Chair of the UK BCS-FACS (Formal Aspects of Computing Science) Specialist Group. In December 2003, Egon presented on *Teaching ASMs to Practice-Oriented Students with Limited Mathematical Background* at the BCS-FACS Workshop *Teaching Formal Methods: Practice and Experience*, held at Oxford Brookes University. Subsequently, I invited Egon to speak to the group at the BCS London office in March 2007, and a chapter appeared in a book of selected talks [18].

In 2008, we were co-chairs of the newly formed *Abstract State Machines, B and Z: First International Conference, ABZ 2008* in London, UK, edited by Egon Börger (ASM), Michael Butler (B), myself (Z), and Paul Boca as a local organizer [21,22], including an ASM-based paper co-authored by Egon Börger [30]. This was an extension of the previous ZB conferences, that were a combination of previously separate B and Z conferences. In 2011, we collaborated on a special issue of selected and extended papers from the ABZ 2008 conference in the *Formal Aspects of Computing* journal, edited by Egon Börger, myself, Michael Butler, and Mike Poppleton [20]. Most recently, I reviewed his 2018 book on *Modeling Companion for Software Practitioners* using the ASM approach, co-authored with Alexander Raschke [42].

2 Communities of Practice

Reason is purposive activity. – Georg Hegel

A *Community of Practice* (CoP) [94] is a social science concept for modelling the collaborative activities of professional communities [10] with a common goal over time [95,96]. It can be used in various scenarios, for example, formal methods communities [39,41,49]. A CoP consists of:

1. A **domain** of knowledge and interest. In the case of ASM, this is the application of a mathematical approach to computer-based specification modelling and development.

2. A **community** around this domain. For ASM, this includes the ABZ conference organizers and programme committee members that are interested in ASM at its core, conference presenters and delegates, as well as other researchers and practitioners involved with ASM.
3. The **practice** undertaken by the community in this domain, developing its knowledge. The ASM community is encouraging the transfer of research ideas into practical use. The ASM approach has been used to model industrial-scale programming and specification languages, and a recent book has been produced to encourage use by software practitioners [28].

There are various stages in the development of a CoP:

1. **Potential:** There needs to be an existing network of people to initiate a CoP. In the case of ASM, researchers interested in theoretical computer science and formal methods were the starting point, especially the original progenitors, Yuri Gurevich and Egon Börger.
2. **Coalescing:** The community needs to establish a rhythm to ensure its continuation. In the case of ASM, a regular ASM workshop was established.
3. **Maturing:** The community must become more enduring. The ASM workshop combined with the ZB conference, already a conference for the Z notation and B-Method, to become the ABZ conference in 2008 [21].
4. **Stewardship:** The community needs to respond to its environment and develop appropriately. The ASM community has interacted with related organizations such as the Z User Group (ZUG), the B User Group (BUG), etc., and has fostered these relationships especially through the regular ABZ conference.
5. **Legacy:** All communities end eventually; if successful they morph into further communities. ASM continues as a community, although it has combined with other state-based approach communities such as those around B, VDM, Z, etc. Exactly how these related communities will continue is something that is worth considering and planning for at the appropriate time.

It remains to be seen precisely what legacy ASM leaves in the future. For the moment, the ASM community continues through the ABZ conference and other more informal and individual interactions.

3 The Development of ASM

The model should not dictate but reflect the problem.

– Egon Börger [28]

In the 1980s, the American computer scientist and mathematician Yuri Gurevich (originally from the Soviet Union) conceived of the idea of "evolving algebras" [62], based on the Church-Turing thesis, with algorithms being simulated by a suitable Turing machine [90]. He suggested the *ASM thesis*, that every algorithm, however abstract, can be emulated step-for-step with an appropriate ASM. In

2000, he axiomatized the notion of sequential algorithms, proving the ASM thesis for them [61]. Essentially, the axioms consist of state structures, state transitions on parts of the state, with everything invariant under isomorphisms of the structures. The structures can be considered as algebras; hence the original name of evolving algebras. However, later the term Abstract State Machine (ASM) was generally adopted and Yuri Gurevich's colleague Egon Börger became the leading figure in the ASM community. The axiomatization of sequential algorithms has subsequently been extended to interactive and parallel algorithms.

During the 1990s, a research community built up and an ASM method was developed, allowing ASMs to be used for the formal specification and development of computer-based software and hardware [14]. ASM models for widely used programming languages such as C, Java, and Prolog, as well as specification languages such as SDL, UML, and VHDL, were created. A more detailed historical presentation of ASM's early developments has been produced by Egon Börger in 2002 [15].

Subsequently, two ASM books have appears in 2003 [29] and 2018 [28], both with Egon Börger at the lead author. As we have seen, the original ASM workshops have been combined with the B-Method, Z notation, and other state-based formal approaches to form the ABZ conference, started in 2008 [21], and continuing to this day.

3.1 Publications

Some key evolving algebra and ASM publications are shown in Fig. 2. An ASM tutorial introduction as also available [17]. A 1996 Steam Boiler Control case study competition book for different formal methods [1,2] included an "Abstract Machine" specification and refinement [7]. An annotated ASM bibliography is available, covering 1988–1998 [26].

Some of the main author influences of Egon Börger can be seen in Fig. 3, both in terms of who has influenced him and who he has influenced. Figure 4 shows mentions of Egon Börger in the Google corpus of books, from the late 1960s onwards. It is interesting to note the peak of "Egon Boerger" with no umlaut in the mid-1990s and the peak of "Egon Börger" with an umlaut in the mid-2000s, perhaps illustrating improvements in computer typesetting around the end of the 20th century. Similarly, Fig. 5 shows mentions of Abstract State Machines in books from the 1980s onwards. This indicates a peak of interest in the early 2000s, although there may be a slight revival in the late 2010s, perhaps due in part to the 2018 book on the subject [28].

4 A Longterm Historical View

What is reasonable is real; that which is real is reasonable.

– Georg Hegel

1995: Yuri Gurevich, *Evolving Algebras 1993: Lipari Guide* [62].
1995: Yuri Gurevich and Egon Börger, *Evolving Algebras: Mini-Course* [63].
1995: Egon Börger, *Why use Evolving Algebras for Hardware and Software Engineering?* [14].
2000: Yuri Gurevich, *Sequential Abstract-State Machines capture Sequential Algorithms* [61].
2002: Egon Börger, *The Origins and Development of the ASM Method for High-Level System Design and Analysis* [15].
2002: Wolfgang Grieskamp, Yuri Gurevich, Wolfram Schulte & Margus Veanes, *Generating Finite State Machines from Abstract State Machines* [60].
2003: Egon Börger & Robert Stärk, *Abstract State Machines: A Method for High-Level System Design and Analysis* [29].
2003: Egon Börger, *The ASM Refinement Method* [16].
2008: Egon Börger, Michael Butler, Jonathan Bowen & Paul Boca, *Abstract State Machines, B and Z: First International Conference, ABZ 2008* [21,30].
2010: Egon Börger, *The Abstract State Machines Method for High-Level System Design and Analysis* [18].
2018: Egon Börger & Alexander Raschke, *Modeling Companion for Software Practitioners* [28,42].

Fig. 2. Some key ASM publications.

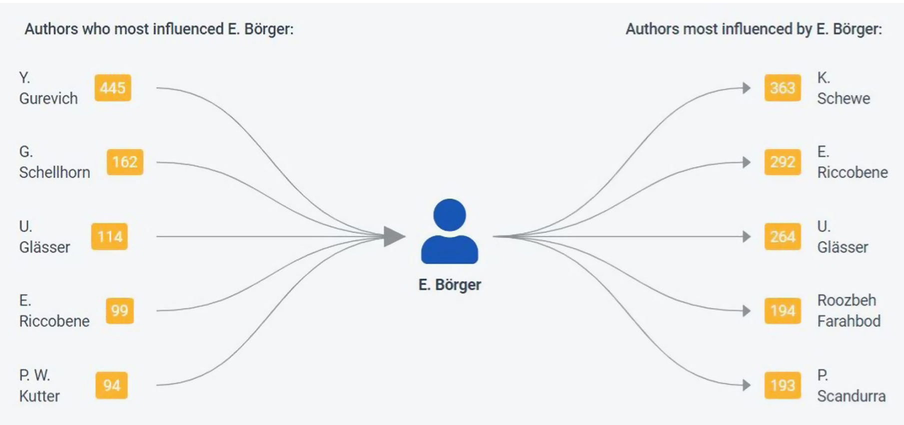

Fig. 3. Author influences of Egon Börger. (Semantic Scholar: http://www.semanticscholar.org.)

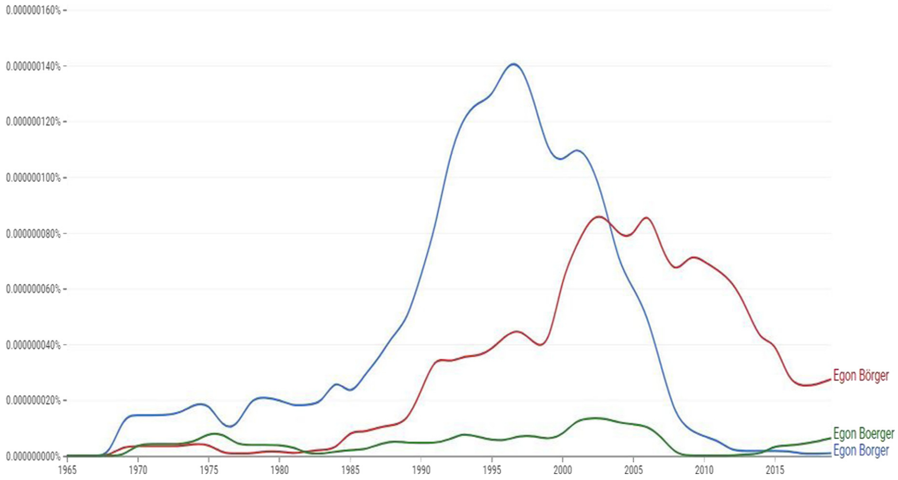

Fig. 4. Graph of mentions of Egon Börger in books. (Ngram Viewer, Google Books: http://books.google.com/ngrams.)

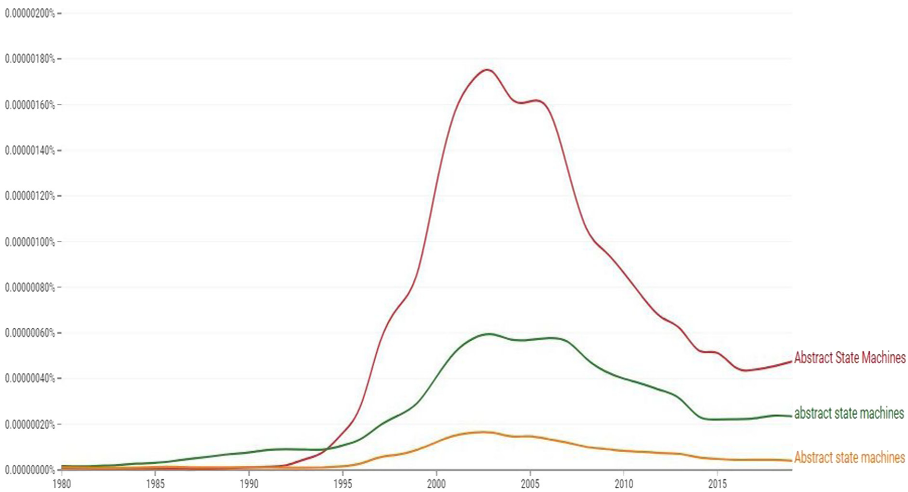

Fig. 5. Graph of mentions of Abstract State Machines in books. (Ngram Viewer, Google Books: http://books.google.com/ngrams.)

It is interesting to study the historical ancestry of ASM through the advisor tree of its leading promulgator, Egon Börger [97]. This itself forms a fascinating interrelated set of communities of related researchers through the centuries. Although Egon Börger has been based at the University of Pisa in Italy for much of his career, he was born in Germany and most of those in his advisor tree are of Germanic origin. This is assumed for those mentioned in the rest of this section, except where indicated otherwise.

We are lucky in the mathematical sciences such as computer science to have the excellent *Mathematics Genealogy Project* (MGP) resource available online (https://www.mathgenealogy.org), providing over a quarter of a million records of mathematicians (including many computer scientists), giving details of their degree, university, advisor(s), etc. This provides the foremost online resource for discovering degree and advisor information of people included in this database. In particular, records for advisors can be followed on the web through hyperlinks.

4.1 Logicians

Information on Egon Börger's doctoral thesis in 1971 is available on MGP [74]. It was entitled *Reduktionstypen in Krom- und Hornformeln* (in English, "Reduction types in Krom and Horn formulas"), from Westfälische Wilhelms-Universität (now the University of Münster) in Germany and was supervised by Dieter Rödding [13]. Rödding (1937–1984) was a mathematical logician who made contributions to the classification of recursive functions and on recursive types in classical predicate logic. He was one of the first researchers to use a machine-oriented approach to complexity in his investigation of recursive functions and logical decision problems, before computer science had been established as an academic field.

Rödding's advisor, also at Münster, was Gisbert Hasenjaeger (1919–2006), another Germany mathematical logician. In 1949, Hasenjaeger developed a new proof for the completeness theorem of Kurt Gödel (1906–1978) for predicate logic. He worked as an assistant to the logician Heinrich Scholz (1884–1956) at the Cipher Department of the High Command of the Wehrmacht and was responsible for the security of the Enigma machine, used for encrypting German messages in World War II. The Enigma code was broken by Alan Turing (1912–1954) and his team at Bletchley Park in England [52]. Hasejaeger constructed a universal Turing machine (UTM) from telephone relays in 1963, now in the collection of the Heinz Nixdorf Museum in Paderborn. In the 1970s, Hasenjaeger learned about the breaking of the Enigma machine and he was impressed that Turing had worked successfully on this [81].

As well as working together, Heinrich Scholz was also Gisbert Hasenjaeger's doctoral advisor at Münster. Scholz was a philosopher and theologian, in addition to being a logician. Alan Turing mentioned him regarding the reception of his ground-breaking paper *On Computable Numbers, with an Application to the Entscheidungsproblem*, read in 1936 and published in 1937 [90]. Turing received a preprint request from Scholz and was impressed by the German interest in the paper. Perhaps the use of a German term in the title helped! The *Entscheidungsproblem* (German for "decision problem" [25]) was a challenge posed by the mathematicians David Hilbert (1862–1943) and Wilhelm Ackermann (1896–1962) in 1928. The origin of the *Entscheidungsproblem* goes back to Gottfried Leibniz (1646–1716) [83,84], of which more later. Scholz established the Institute of Mathematical Logic and Fundamental Research at Münster in 1936 and it was later led by Dieter Rödding.

Much later, during the early 21st century, Achim Clausing inspected Scholz's papers at Münster. He discovered two original preprints from Alan Turing, missing since 1945. The first paper *On Computable Numbers* [90] was with a postcard from Turing. In a letter from Turing to his mother while he was studying for his doctorate under the supervision of Alonzo Church (1903–1995) at Princeton University in the USA, there is indication that Scholz not only read Turing's paper, but also presented it in a seminar [51]. This could arguably have been the first theoretical computer science seminar. The second preprint found was Turing's foundational 1950 article on machine intelligence [91], foreseeing the subsequent development of artificial intelligence (AI). Turing noted by hand on the first page "This is probably my last copy" [51]!

Heinrich Scholz studied for two advanced degrees. The first was for a Licentiate theology degree at Humboldt-Universität zu Berlin (awarded in 1909) under the theologian Carl Gustav Adolf von Harnack (1851–1930) and Alois Adolf Riehl (1844–1924), an Austrian neo-Kantian philosopher. We shall hear more of Kant [5] later. The second was a Doctor of Philosophy degree at the Friedrich-Alexander-Universität Erlangen-Nürnberg (awarded in 1913) under Friedrich Otto Richard Falckenberg (1851–1920), entitled in Germany *Schleiermacher und Goethe; Ein Beitrag zur Geschichte des deutschen Geistes* (in ENglish, "Schleiermacher and Goethe; A contribution to the history of the German spirit"). This covered the theologian and philosopher Friedrich Schleiermacher (1768–1834), together with the renowned polymath Johann Wolfgang von Goethe (1749–1832).

Here we will follow each of these lines separately to an interesting denouement at the end. Those not interested in the history of mathematics [80] or philosophy [6,89] can safely skip to Sect. 4.4. The first line of advisors includes an eclectic mix of academics. The second line includes some of the leading philosophers and mathematicians of all time. Börger's advisor lineage as described in this section is illustrated in Fig. 6.

4.2 Polymaths: Astronomers, Geometrists, Mathematicians, Philosophers, Physicists, and Theologians

> *If others would but reflect on mathematical truths as deeply and continuously as I have, they would make my discoveries.*
>
> – Carl Gauss

Adolf von Harnack (sometimes known as just Adolf Harnack) was a Lutheran theologian and church historian. He gained his doctorate at the Universität Leipzig

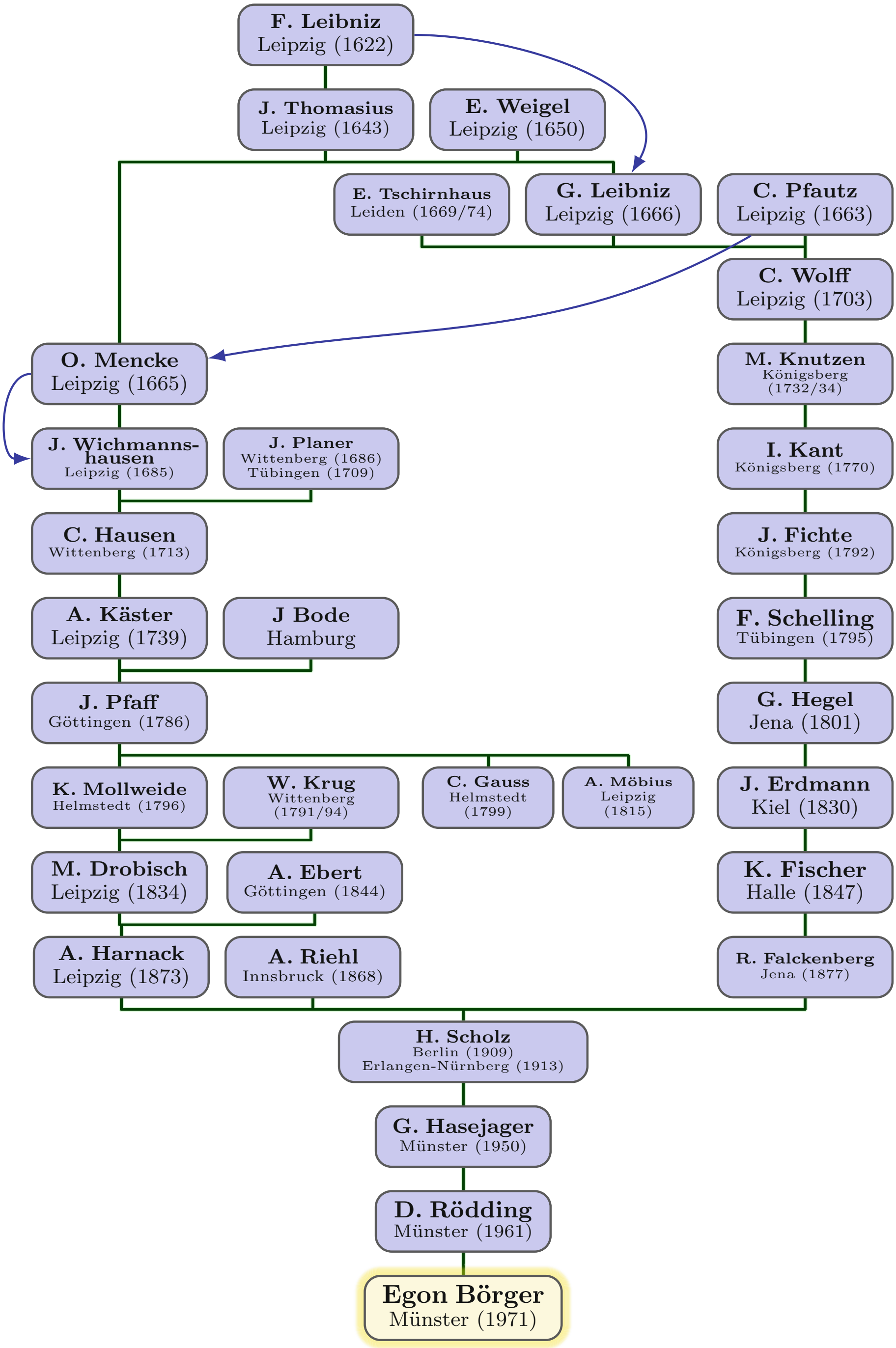

Fig. 6. Academic advisor tree for Egon Börger [74]. (Family relationships are indicated with additional curved arrow links, as discussed in the text.)

in 1873 under Moritz Wilhelm Drobisch (1802–1896) and Georg Karl Wilhelm Adolf Ebert (1820–1890), a philologist and literary historian. Drobisch was a mathematician, logician, psychologist, and philosopher. He was the brother of the composer Karl Ludwig Drobisch (1803–1854).

Moritz Drobisch studied under Karl Brandan Mollweide (1774–1825) and Wilhelm Traugott Krug (1770–1842), gaining his doctorate at the Universität Leipzig in 1824, with a dissertation entitled in Latin *Theoriae analyseos geometricae prolusio* on theories for analysis in geometry. Wilhelm Krug was a philosopher and writer who followed the Kantian school of logic.

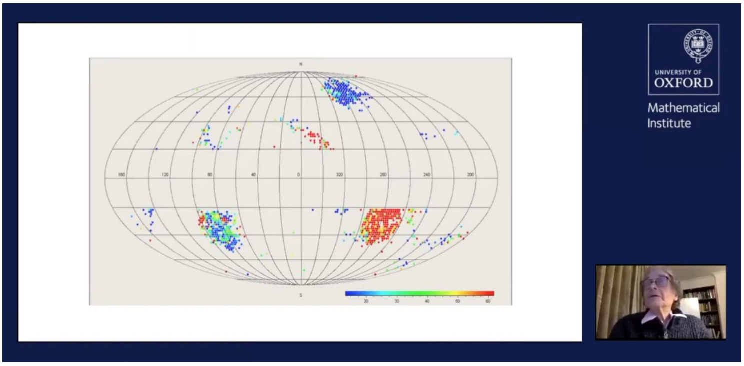

Fig. 7. A cosmological Mollweide projection, used in an online 2021 talk by the Oxford mathematical physicist Roger Penrose, in celebration of his 2020 Nobel Prize. (YouTube: http://www.youtube.com/watch?v=1zXC51o3EfI.)

Karl Mollweide was a mathematician and astronomer. He invented the *Mollweide projection* for maps, giving equal areas for different parts of a map of a curved surface like the spherical world. This is useful for wide-area global and cosmic maps, giving a projection in the form of a flat ellipse. This projection is used to the present day, as illustrated in Fig. 7. Mollweide also discovered what is now known as *Mollweide's formula* in trigonometry, useful in finding solutions relating to triangles:

$$\frac{a+b}{c} = \frac{cos(\frac{\alpha-\beta}{3})}{sin(\frac{\gamma}{2})} \qquad \frac{a-b}{c} = \frac{sin(\frac{\alpha-\beta}{3})}{cos(\frac{\gamma}{2})}$$

where a, b, c are the lengths of sides of a triangle and α, β, γ are the opposite angles. These pleasingly symmetrically matching equations both include all the important constituent parts (side lengths and angles) of a triangle.

Mollweide studied under the mathematician Johann Friedrich Pfaff (1765–1825) at the Universität Helmstedt, attaining his award in 1796. Pfaff was the advisor for two other famous mathematicians, Carl Friedrich Gauss (1777–1855), also a physicist, and August Ferdinand Möbius (1790–1888), also a theoretical astronomer [56]. Gauss has many mathematical and scientific concepts named after him as the leading scientist of his generation. Möbius has a number of mathematical, especially geometrical, ideas named after him too, the most well-known of which is the *Möbius strip*, a surface in three-dimensions with only one side, which he discovered in 1858.

Johann Pfaff achieved his doctorate in 1786 at the Georg-August-Universität Göttingen under Abraham Gotthelf Kästner (1719–1800) and the astronomer Johann Elert Bode (1747–1826), known for the Titus-Bode law for predicting the space between planets in a solar system. Kästner was a mathematician and also an epigrammatist. He wrote mathematical textbooks, compiled encyclopaedias, translated scientific proceedings, and even wrote poetry in an epigrammatic style. In 1789, he was elected a Fellow of the Royal Society, the leading scientific society based in London, England. The moon crater *Kästner*, 49 km in diameter, is named after him.

Abraham Kästner studied under the mathematician Christian August Hausen (1693–1743) Universität Leipzig, achieving his doctorate in 1739, with a dissertation entitled in Latin *Theoria radicum in aequationibus* (in English, "The theory of the roots of equations"). Hausen is also known for his research on electricity, using a *triboelectric* generator. The triboelectric effect is a type of electricity where some materials become electrostatically charged after being separated from another material that they were touching previously. Rubbing the two materials can increase their surface contact, and thus increase the triboelectric effect. Combing hair with a plastic comb is a common way of creating triboelectricity.

Christian Hausen gained his doctorate in 1713 at the Universität Wittenberg (now merged with Halle to later become the Martin-Luther-Universität Halle-Wittenberg), under the guidance of the philologist Johann Christoph Wichmannshausen (1663–1727) and the mathematician Johannes Andreas Planer (1665–1714). Wichmannshausen studied under the direction of his father-in-law, the philosopher and scientist Otto Mencke (1644–1707), gaining his doctorate at the Universität Leipzig in 1685, on issues concerning the ethical nature of divorces.

Otto Mencke also studied at Leipzig and his doctorate was awarded in 1665. His advisor was the philosopher and jurist Jakob Thomasius (1622–1684), and his dissertation was on theology. In 1682, he founded the first German scientific journal in Germany, entitled *Acta Eruditorum*. He was a professor of moral philosophy at Leipzig.

Jakob Thomasius conducted his studies at Leipzig as well, under Friedrich Leibniz (aka Leibnütz, 1597–1652), gaining his degree in 1643. He was an important foundational scholar in the history of philosophy [88]. Friedrich Leibniz was a Lutheran lawyer, a notary, registrar, and professor of moral philosophy at Leipzig. He was the father of the notable mathematician and polymath Gottfried Wilhelm (von) Leibniz (1646–1716), to whom we shall return [84].

4.3 Philosophers and Mathematicians

To comprehend what *is, is the task of philosophy: and what* is *is Reason.*
– Georg Hegel

We now return to the advisor for Heinrich Scholz's second dissertation in 1913, under Richard Falckenberg (1851–1920) at the Friedrich-Alexander-Universität Erlangen-Nürnberg, at the bottom of the right-hand lineage in Fig. 6. Fackenberg was a historian of philosophy. He wrote the book *History of Modern Philosophy*, originally published in 1886, and still available in English translation through *Project Gutenberg* online as an open-access resource [55], scanned from the original editions [54]. Falckenberg received his doctorate from the Friedrich-Schiller-Universität Jena in 1877, having studied under the philosopher Ernst Kuno Berthold Fischer (1824–1907). His dissertation was entitled in German *Über den intelligiblen Charakter. Zur Kritik der Kantischen Freiheitslehre* (in English, "About the intelligent character. On the criticism of the Kantian doctrine of freedom").

Kuno Fischer was also a historian of philosophy and a critic, known for his lecturing skills. One of Fischer's philosophical contributions was to categorize philosophers into followers of empiricism and rationalism, including Gottfried Leibniz as a rationalist. He was a follower of Hegelianism and interpreted the works of Kant. He published a six-volume set of monographs entitled *Geschichte der neuern Philosophie* (in English, "History of modern philosophy") [57], which influenced the philosopher Friedrich Wilhelm Nietzsche (1844–1900). Fischer also taught the philosopher, logician, and mathematician Friedrich Ludwig Gottlob Frege (1848–1925) at Jena and, more unusually, the English playwright, novelist, and short-story writer William Somerset Maugham (1874–1965) at Heidelberg. Fischer's 80th birthday in 1904 was celebrated with a Festschrift, published three years later [73]. Fischer studied at the Universität Halle (now merged with Wittenberg to be the Martin-Luther-Universität Halle-Wittenberg) under Johann Eduard Erdmann (1805–1892). He was awarded a doctorate in 1847 for a dissertation on the ancient Athenian philosopher Plato.

Johann Erdmann was a pastor, historian of philosophy, and philosopher of religion. He wrote a three-volume set of books entitled *A History of Philosophy*, available in an English translation [53]. Erdmann studied for his doctorate under the leading philosopher Georg Wilhelm Friedrich Hegel (1770–1831) [76] at Christian-Albrechts-Universität zu Kiel. He received his doctoral degree in 1830 with a dissertation entitled in Latin *Quid intersit inter Philosophiam et Theologiam* (in English, "What is the difference between Philosophy and Theology").

Hegel was a leading figure in German idealism [85], developed from Kant's ideas [87], linked with Romanticism and the Enlightenment, where reality is seen depending on human perception or understanding. Hegel's ideas continue to be highly influential on contemporary Western philosophical issues, in areas relating to aesthetics, ontology, politics, both in analytic philosophy (mainly in English-speaking countries) and continental philosophy (largely in mainland Europe).

Hegel's philosophical ideas are now termed *Hegelianism*, summarized in the title of the preface in *Elements of the Philosophy of Right* as "What is rational is real; And what is real is rational" [66].

Hegel's *Science of Logic* [65] presented his idea of logic as a system of dialectics, later dubbed *Hegelian dialectic*. This is normally presented in a three-stage developmental style, as provided by Heinrich Moritz Chalybäus (1796–1862): 1) a thesis or problem; 2) an antithesis or reaction, contradicting this thesis; and 3) their resolution through a synthesis or solution. Although named after Hegel, this is a different formulation to his. Hegel was influenced in these ideas by Kant, with Johann Gottlieb Fichte (1762–1814, see later) elaborating and popularizing the approach. As well as science, Hegel has also been influential in artistic circles with respect to aesthetics to this day [77].

Hegel's dissertation was defended at Friedrich-Schiller-Universität Jena while with the philosopher Friedrich Wilhelm Joseph von Schelling (1775–1812) [86]. Hegel and Schelling shared a room at university. Schelling was an "Extraordinary Professor" (a professor without a chair in Germany) at Jena and encouraged his friend Hegel to come to Jena in 1801. Hegel became a *Privatdozent* (unsalaried lecturer) at Jena. His inaugural dissertation that year, in Latin, was entitled *De orbitis planetarum* (in English "The orbits of the planets"), interestingly in the field of astronomy, which then was considered as natural philosophy [4]. The dissertation is inscribed in Latin *Socio Assumto Carolo Schelling* (in English "an assumed ally Karl Schelling") and Schelling was present at Hegel's defence on 27 August 1801, Hegel's 31st birthday. At the time, Schelling was still only 26, several years younger than Hegel.

Karl Schelling was part of the German idealism philosophical movement. He and Hegel were early friends, but later became rivals, and Schelling became rather eclipsed by Hegel. Schelling undertook his doctorate at the Eberhard-Karls-Universität Tübingen, completing his dissertation in 1795, and working with the philosopher Johann Gottlieb Fichte (1762–1814) [86].

Johann Fichte's ideas were criticized by both Schelling and Hegel [92]. He studied for his doctorate with the well-known philosopher Immanuel Kant (1724–1804) [5] at the Universität Königsberg. His dissertation, produced in 1792, was entitled in German *Versuch einer Kritik aller Offenbarungen* (in English, "Attempt to criticize all revelations").

Immanuel Kant was an important thinker in the Age of Enlightenment (aka the Age of Reason). He produced works covering aesthetics, epistemology, ethics, and metaphysics. Subsequently, his ideas have made him one of the most influential historical figures within modern Western philosophy. He founded transcendental idealism, as expounded in his *Critique of Pure Reason* [70].

Kant enrolled at the University of Königsberg (now Kaliningrad) in 1740, at the age of 16, and remained there for his entire career. He studied the philosophy of Gottfried Leibniz and Christian Freiherr von Wolff (1679–1754) under the direction of Martin Knutzen (1713–1751), the Extraordinary Professor of Logic and Metaphysics there until his early death, aged 37. Knutzen was a rationalist who had an interest in British philosophy, especially empiricism, and science. He introduced Kant to the then relatively recent mathematical physics of Isaac Newton (1642–1727). Knutzen discouraged Kant from following Leibniz's theory of pre-established harmony [88], where substances only affect themselves despite apparent interactions, and idealism, the concept that reality is mental, which many 18th-century philosophers regarded negatively.

In 1755, Kant received a license to lecture at Königsberg, and produced a master's thesis in that year under the Prussian physicist and philosopher Johann Gottfried Teske (1704–1772). His doctoral dissertation was produced in 1770, entitled in Latin *De mundi sensibilis atque intelligibilis forma et principiis* (in English, "The form and principles of the sensible and the intelligible world").

Martin Knutzen studied mathematics, philosophy, and physics, at Königsberg, producing his inaugural dissertation in 1732, his Master of Arts dissertation in 1733, and his doctoral dissertation in 1734, resulting in him becoming a professor at the early age of 21 shortly after. Knutzen was a follower of Christian von Wolff at Königsberg and the rationalist school of thinkers. He also had an interest in natural sciences, teaching astronomy, mathematics, and physics, as well as philosophy. His interest in Newton's ideas led to him question the theory of pre-established harmony, as espoused by Leibniz and Wolff. He defended the idea of mechanical causality in moving physical objects and his lessons at Königsgberg influenced Kant, especially in his work on the *Critique of Judgement*, which attempted reconcile spiritual autonomy with respect to mechanical reality [71].

Christian von Wolff enrolled at Jena but moved to Leipzig in 1702, producing a *Habilitationsschrift* dissertation in 1703, written in Latin and entitled *Philosophia practica universalis, methodo mathematica conscripta* (in English, "On Universal Practical Philosophy, composed according to the Mathematical Method"). Wolff's main advisor was Ehrenfried Walther von Tschirnhaus (1651–1708). Otto Mencke, whom we have met early on the other branch of Egon Börger's advisor tree, served as an examiner for Wolff's dissertation. Mencke was impressed enough to send Wolff's dissertation to Gottfried Leibniz. Wolff and Leibniz remained in correspondence together until Leibniz died in 1716. The astronomer, geographer, librarian, and mathematician Christoph Pfautz (1645–1711) was also an advisor. Wolff was a mathematician, philosopher, and scientist during the German Enlightenment and is regarded by many to be the most influential and important German philosopher between Leibniz and Kant, two giants in the field.

Pfautz helped to co-found the first German scientific journal *Acta Eruditorum* (as mentioned earlier) with his brother-in-law Otto Mencke in 1682, in Egon Börger's other advisor line. To raise the journal's profile and encourage submissions, Pfautz took Otto Mencke to Holland and England in 1680, via Amsterdam, Antwerp, Delft, Leiden, Utrecht, London, and Oxford. Pfautz met leading scientists, including Isaac Newton, whose views he introduced to Germany scholars in the journal. Pfautz was a regular correspondent with Gottfried Leibniz from 1679 and was one of the early Enlightenment proponents at Leipzig.

Ehrenfried von Tschirnhaus was a mathematician, physician, physicist, and philosopher who originally studied at Leiden University in Holland. He developed the *Tschirnhaus transformation* to remove intermediate terms from an algebraic equation, published in the *Acta Eruditorum* journal in 1683. He is also considered by some to have invented European porcelain.

Gottfried Leibniz was a leading polymath of his age and one of the most important logicians, mathematicians, and philosophers during the Enlightenment. He followed the 17th-century philosophical tradition of rationalism. His most important mathematical contribution was the development of differential and integral calculus, at the same time that Isaac Newton developed these ideas independently too in England. They used different notations and Leibniz's more general notation is the one that has endured. Indeed, Newton's notation held back subsequent mathematical advances in England compared to continental Europe for centuries.

Leibniz introduced heuristic ideas of the law of continuity, allowing finite reasoning to be generalized to the infinite case (e.g., when considering a circle as being an infinite-sided polygon), and the transcendental law of homogeneity, allowing terms tending to the infinitesimal to be ignored (e.g., $a + dx = a$). Much later in the 1960s, these ideas became important in non-standard analysis, reformulating calculus using a logically rigorous notion of infinitesimal numbers, illustrating how long it can take for mathematical ideas to have a useful application.

Leibniz was also inventive in the development of mechanical calculators. While considering the inclusion of automatic multiplication and division in Pascal's calculator of the French mathematician Blaise Pascal (1623–1662), he originated a pinwheel calculator in 1685 with adjustable numbers of teeth (normally 0 to 9 in the decimal system). He also invented what became known as the Leibniz wheel, a cylindrical drum with stepped teeth, as used in the *arithmometer*, the first mechanical calculator to be mass-produced, introduced in 1820. This interest in mechanical reasoning can be seen as a precursor to later consideration of the nature of computation in a logical framework, including issues concerning the *Entscheidungsproblem* ("decision problem"), as previously mentioned [83].

Gottfried Leibniz studied for his doctorate under Jakob Thomasius (whose student Otto Mencke is also on Egon Börger's other line of advisors on the left-hand side of Fig. 6) and the astronomer, mathematician, and philosopher, Erhard Weigel (1625–1699) at the Universität Leipzig, producing his dissertation in Latin entitled *Disputatio arithmetica de complexionibus* on arithmetic in 1666.

Leibniz also studied with the legal scholar Bartholomäus Leonhard von Schwendendörffer (1631–1705) at the Universitẗ Altdorf and later with his mentor, the Dutch astronomer, inventor, mathematician, and physicist, Christiaan Huygens (1629–1695) through the French Académie Royale des Sciences (Royal Academy of Sciences) in Paris, after visiting the city from 1672. Hugygens was a major figure in the European Scientific Revolution that marked the emergence of modern science and was influential in the Age of Enlightenment. He invented the Huygens eyepiece with two lenses for telescopes.

As we saw earlier, the father and son Friedrich and Gottfried Leibniz are also related via Jakob Thomasius academically. Both are part of Egon Böger's academic lineage, Friedrich Leinbiz via both his major lines, as illustrated in Fig. 6.

4.4 The Origins of Binary Computing

> *There are 10 types of people: those that can count in binary and those that can't.* – Anon.

Gottfried Leibniz, 13 generations back in Egon Börger's academic genealogical tree (see Fig. 6), studied the binary numbering system in 1679, later published in an 1703 French article *Explication de l'Arithmétique Binaire* (in English, "Explanation of Binary Arithmetic", see Fig. 8) [72]. In 1854, the English mathematician George Boole (1815–1864), based at Queen's College (now University College), Cork, in southern Ireland, published a foundational book, *The Laws of Thought*, detailing an algebraic system of binary logic, later dubbed Boolean algebra, important in the design of digital electronics.

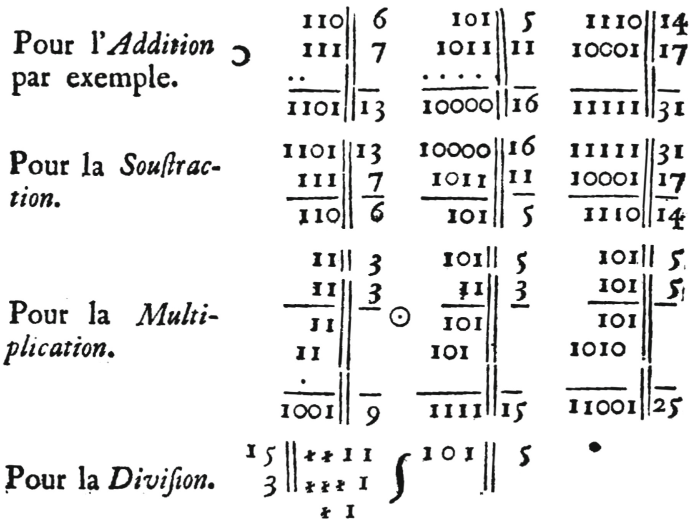

Fig. 8. Leibniz's examples of binary arithmetic, published in 1703 [72].

In 1937, the American engineer and mathematician Claude Shannon (1916–2001) [58] worked on his novel master's thesis (issued later in 1940) at the Massachusetts Institute of Technology (MIT) that implemented Boolean algebra and binary arithmetic using electronic relays and switches, entitled *A Symbolic Analysis of Relay and Switching Circuits* [82], foundational in digital circuit design.

Also in 1937, George Stibitz (1904–1995), while working at Bell Labs in the USA, created a relay-based computer called the *Model K* (for "Kitchen", where it was assembled!), which implemented binary addition [35]. In the same year, Alan Turing's foundational paper based on what became known as a *Turing machine*, a mathematical model for a digital computational device, appeared [90].

In 1945, the Hungarian-American mathematician and polymath John von Neumann (1903–1957) produced a draft report on the EDVAC binary computer design, that became dubbed *von Neumann architecture*, a standard style of digital computer design [93]. Thus, with all these subsequent developments, Leibniz's ideas on the binary number system were foundational for modern digital computer design. The discipline of computer science has developed especially from the second half of the 20th century [40], with the first academic computer science departments opening in the 1960s [36]. Without all these developments, there would be no need for formal methods in general and ASM in particular.

4.5 Further Academic Advisor Relationships

We have seen (as illustrated in Fig. 6) that Egon Börger's academic lineage goes back to the leading mathematician Gottfried Leibniz and his father. His immediate "ancestors" are logicians. Then there is a split into two major lineages with Heinrich Scholz through his two separate degrees in 1909 and 1913. The first line (on the left in Fig. 6) includes an eclectic mix of scientists and philosophers, including a relationship with Gauss and Möbius, leading to Gottfried Leibniz's father Friedrich Leibniz (also his "grandfather" in the academic tree of advisors via Jakob Thomasius). The second line (on the right in Fig. 6) of mainly philosophers includes two of the most important philosophers of all time, Hegel and Kant, as well as Gottfried Leibniz himself, and then links to the first line via Jakob Thomasius. These can be seen as a historical community of academics, each passing on their knowledge to the next generation, eventually to Egon Börger.

Egon Börger is a distant academic "relative" of the 19th/20th century mathematician David Hilbert, via Johann Pfaff and his student Gauss. Hilbert was influential on theoretical computer science through the likes of Kurt Gödel and then Alan Turing. Börger is also related to Turing, who's academic advisor line goes back to Gottfried Leibniz as well, via another follower of Leibniz in Paris, the rationalist philosopher Nicolas Malebranche (1638–1715) [43]. Even Yuri Gurevich and Egon Börger are distantly related by advisor. Following Gurevich's advisor tree back in time on the Mathematics Genealogy Project [75], we find the important Russian mathematician Pafnuty Lvovich Chebyshev (1821–1894) several generations back, eventually leading to Johann Pfaff in Börger's advisor tree via another of Pfaff's students, the mathematician Johann Martin Christian Bartelsi (1789–1836), who also tutored Gauss.

5 Conclusion

There is nothing without reason. – Gottfried Leibniz

The Abstract State Machines (ASM) approach is one of a number of competing state-based formal methods for modelling computer-based systems. It has been used in this role for industrial-strength computer-based languages such as programming languages and specification notations. The community associated with ASM has developed since the 1980s and continues in tandem with other state-based approaches such as the Z notation, the B-Method, and Event-B. Each has their own advantages and disadvantages, which are beyond the scope of this paper. Each have their own community of adherents, that have now somewhat merged with the establishment of the ABZ conference in 2008 [21].

The 2003 book on ASM [29] is a general introduction to ASM. The subsequent 2018 ASM book [28] is entitled *Modeling Companion for Software Practitioners*. It can be used for self-study, as a reference book, and for teaching, but its title indicates the intention of being a practical book for potential industrial use. A third book with industrial case studies in due course could complete these books as a trilogy [42].

The ASM community is an example of a Community in Practice (CoP) in action. Other related CoPs are based around state-based specification and development approaches such as the Z notation, B-Method/Event-B, etc. CoPs can potentially merge and create new CoPs. For example, the B-Method and then Event-B were developed after the Z notation largely by the same progenitor, Jean-Raymond Abrial, and with some in the Z community becoming part of the B community.

A Community of Practice depends on people with different skills for success, be it for ideas, vision, organization, etc. Yuri Guevich and Egon Börger were both key for the success of ASM, just as Steve Wozniak and Steve Jobs [69] were both crucial for the initial launch of Apple. I will leave it for the reader to decide who has taken on which roles.

We have also considered Egon Börger's advisor tree historically, which started mainly in the fields of mathematics and philosophy, and more recently has included several logicians. All this knowledge has helped to lead to the development of the ASM approach. Members of the advisor tree have themselves participated in CoPs, such as the rationalist movement, German idealism, etc. Some have been eminent enough to be leaders of CoPs, like Kant and Hegel. They have inspired their own eponymous schools of thought, such as Kantian ethics and Hegelism.

Predicting the future is always difficult, but the community around ASM has been successful enough to leave its mark on the formal methods community as a whole. What is clear is that without Egon Börger, it is unlikely that the ASM community would have developed to the extent that it has.

6 Postscript

Genius is the ability to independently arrive at and understand concepts that would normally have to be taught by another person.

– Immanuel Kant

What it means to be a genius and how long it takes to become a genius are matters for debate [78]. However, Kant's definition above is perhaps a good one. Egon Börger completed his doctoral thesis in 1971 [13] and his first two decades of papers were mainly on logic and decision problems [11]. Subsequently his research centred increasingly around Abstract State Machines [15]. As the main leader of the ASM community, he has to this day produced papers developing ideas around ASM, advancing its use. He has been the teacher of ASM and co-author the two main books on the subject [28,29]. Thus, by Kant's definition above, Egon Börger is a genius.

Acknowledgments. The author is grateful to Egon Börger, for inspiration and collaboration over the years, and to Museophile Limited for financial support. Tim Denvir, Cliff Jones, and an anonymous reviewer provided helpful comments on earlier drafts of this paper.

References

1. Abrial, J.-R., Börger, E., Langmaack, H. (eds.): Formal Methods for Industrial Applications. LNCS, vol. 1165. Springer, Heidelberg (1996). https://doi.org/10.1007/BFb0027227
2. Abrial, J.-R., Börger, E., Langmaack, H.: The steam boiler case study: competition of formal program specification and development methods. In: Abrial, J.-R., Börger, E., Langmaack, H. (eds.) Formal Methods for Industrial Applications. LNCS, vol. 1165, pp. 1–12. Springer, Heidelberg (1996). https://doi.org/10.1007/BFb0027228
3. Abrial, J.R., Glässer, U. (eds.): 06191 Summary – Rigorous Methods for Software Construction and Analysis. No. 06191 in Dagstuhl Seminar Proceedings, Internationales Begegnungs- und Forschungszentrum für Informatik (IBFI), Schloss Dagstuhl, Germany, May 2006. http://drops.dagstuhl.de/opus/volltexte/2006/665
4. Adler, P., Hegel, G.W.F.: Philosophical dissertation on the orbits of the planets (1801). Graduate Faculty Philos. J. **12**(1&2), 269–309 (1987). Translated with Foreword and Notes
5. Ameriks, K.: Kant, Immanuel. In: Audi [6], pp. 398–404
6. Audi, R. (ed.): The Cambridge Dictionary of Philosophy. Cambridge University Press, Cambridge (1995)
7. Beierle, C., Börger, E., Đurđanović, I., Glässer, U., Riccobene, E.: Refining abstract machine specifications of the steam boiler control to well documented executable code. In: Abrial, J.-R., Börger, E., Langmaack, H. (eds.) Formal Methods for Industrial Applications. LNCS, vol. 1165, pp. 52–78. Springer, Heidelberg (1996). https://doi.org/10.1007/BFb0027231

8. Beler, A., Borda, A., Bowen, J.P., Filippini-Fantoni, S.: The building of online communities: an approach for learning organizations, with a particular focus on the museum sector. In: Hemsley, J., Cappellini, V., Stanke, G. (eds.) EVA 2004 London Conference Proceedings, EVA Conferences International, University College London, UK, pp. 2.1–2.15 (2004). https://arxiv.org/abs/cs/0409055
9. Bjørner, D., et al.: A ProCoS project description: ESPRIT BRA 3104. Bull. Eur. Assoc. Theoret. Comput. Sci. **39**, 60–73 (1989). http://researchgate.net/publication/256643262
10. Borda, A., Bowen, J.P.: Virtual collaboration and community. In: Information Resources Management Association Virtual Communities: Concepts, Methodologies, Tools and Applications, chap. 8.9, pp. 2600–2611. IGI Global (2011)
11. Börger, E.: Egon Boerger. Google Scholar. https://scholar.google.com/citations?user=j2lxsK0AAAAJ
12. Börger, E.: Prof. Dr. Egon Börger. Dipartimento di Informatica, Università di Pisa, Italy. http://pages.di.unipi.it/boerger/
13. Börger, E.: Reduktionstypen in Krom- und Hornformeln. Ph.D. thesis, Westfälische Wilhelms-Universität Münster, Germany (1971). Translation: "Reduction types in Krom and Horn formulas"
14. Börger, E.: Why use evolving algebras for hardware and software engineering? In: Bartosek, M., Staudek, J., Wiedermann, J. (eds.) SOFSEM 1995. LNCS, vol. 1012, pp. 236–271. Springer, Heidelberg (1995). https://doi.org/10.1007/3-540-60609-2_12
15. Börger, E.: The origins and development of the ASM method for high-level system design and analysis. J. Univ. Comput. Sci. **8**(1), 2–74 (2002). https://doi.org/10.3217/jucs-008-01-0002
16. Börger, E.: The ASM refinement method. Formal Aspects Comput. **15**, 237–257 (2003). https://doi.org/10.1007/s00165-003-0012-7
17. Börger, E.: The ASM method for system design and analysis. a tutorial introduction. In: Gramlich, B. (ed.) FroCoS 2005. LNCS (LNAI), vol. 3717, pp. 264–283. Springer, Heidelberg (2005). https://doi.org/10.1007/11559306_15
18. Börger, E.: The Abstract State Machines method for high-level system design and analysis. In: Boca, P.P., Bowen, J.P., Siddiqi, J.I. (eds.) Formal Methods: State of the Art and New Directions, chap. 3, pp. 79–116. Springer, Heidelberg (2010). https://doi.org/10.1007/978-1-84882-736-3_3
19. Börger, E.: Private communication, March 2021
20. Börger, E., Bowen, J.P., Butler, M.J., Poppleton, M.: Editorial. Formal Aspects Comput. **23**(1), 1–2 (2011). https://doi.org/10.1007/s00165-010-0168-x
21. Börger, E., Butler, M., Bowen, J.P., Boca, P. (eds.): ABZ 2008. LNCS, vol. 5238. Springer, Heidelberg (2008). https://doi.org/10.1007/978-3-540-87603-8
22. Börger, E., Butler, M.J., Bowen, J.P., Boca, P.P. (eds.): ABZ 2008 Conference: Short papers. BCS, London, UK (2008)
23. Börger, E., Durdanovic, I.: Correctness of compiling Occam to transputer code. Comput. J. **39**(1), 52–92 (1996)
24. Börger, E., Gargantini, A., Riccobene, E.: ASM. In: Habrias and Frappier [64], chap. 6, pp. 103–119. https://doi.org/10.1002/9780470612514
25. Börger, E., Grädel, E., Gurevich, Y.: The Classical Decision Problem. Springer, Heidelberg (1997/2001)
26. Börger, E., Huggins, J.K.: Abstract state machines 1988–1998: commented ASM bibliography. Bull. EATCS **64**, 105–127 (1998). https://arxiv.org/pdf/cs/9811014

27. Börger, E., Mazzanti, S.: A practical method for rigorously controllable hardware design. In: Bowen, J.P., Hinchey, M.G., Till, D. (eds.) ZUM 1997. LNCS, vol. 1212, pp. 149–187. Springer, Heidelberg (1997). https://doi.org/10.1007/BFb0027289
28. Börger, E., Raschke, R.: Modeling Companion for Software Practitioners (2018). https://doi.org/10.1007/978-3-662-56641-1
29. Börger, E., Stärk, R.: Abstract State Machines: A Method for High-Level System Design and Analysis. Springer, Heidelberg (2003). https://doi.org/10.1007/978-3-642-18216-7
30. Börger, E., Thalheim, B.: Modeling workflows, interaction patterns, web services and business processes: the ASM-based approach. In: Börger, E., Butler, M., Bowen, J.P., Boca, P. (eds.) ABZ 2008. LNCS, vol. 5238, pp. 24–38. Springer, Heidelberg (2008). https://doi.org/10.1007/978-3-540-87603-8_3
31. Bowen, J.P.: A ProCoS II project description: ESPRIT Basic Research project 7071. Bull. Eur. Assoc. Theoret. Comput. Sci. **50**, 128–137 (1993). http://researchgate.net/publication/2521581
32. Bowen, J.P.: A ProCoS-WG Working Group description: ESPRIT Basic Research 8694. Bull. Euro. Assoc. Theoret. Comput. Sci. **53**, 136–145 (1994)
33. Bowen, J.P.: Formal Specification and Documentation Using Z: A Case Study Approach. International Thomson Computer Press (1996). http://researchgate.net/publication/2480325
34. Bowen, J.P., Hoare, C., Antony R.: Rojas [79], pp. 368–370
35. Bowen, J.P.: Stibitz, George. In: Rojas [79], pp. 732–734
36. Bowen, J.P.: Computer science. In: Heilbron, J.L. (ed.) The Oxford Companion to the History of Modern Science, pp. 171–174. Oxford University Press (2003). https://doi.org/10.1093/acref/9780195112290.001.0001
37. Bowen, J.P.: Z. In: Habrias and Frappier [64], chap. 1, pp. 3–20. https://doi.org/10.1002/9780470612514, http://researchgate.net/publication/319019328
38. Bowen, J.P.: Online communities: visualization and formalization. In: Blackwell, C. (ed.) Cyberpatterns 2013: Second International Workshop on Cyberpatterns - Unifying Design Patterns with Security, Attack and Forensic Patterns, pp. 53–61. Oxford Brookes University, Abingdon (2013). http://arxiv.org/abs/1307.6145
39. Bowen, J.P.: A relational approach to an algebraic community: from Paul Erdős to He Jifeng. In: Liu, Z., Woodcock, J., Zhu, H. (eds.) Theories of Programming and Formal Methods. LNCS, vol. 8051, pp. 54–66. Springer, Heidelberg (2013). https://doi.org/10.1007/978-3-642-39698-4_4
40. Bowen, J.P.: It began with Babbage: the genesis of computer science, by Subrata Dasgupta: Oxford University Press, 2014, 334 p. £22.99 (hardback), 263–265, ISBN 978-0-19-930941-2. BSHM Bulletin: Journal of the British Society for the History of Mathematics 30(3) (2015). https://doi.org/10.1080/17498430.2015.1036336
41. Bowen, J.P.: Provably correct systems: community, connections, and citations. In: Hinchey, M.G., Bowen, J.P., Olderog, E.-R. (eds.) Provably Correct Systems. NMSSE, pp. 313–328. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-48628-4_13
42. Bowen, J.P., Börger, E., Raschke, A.: Modeling companion for software practitioners. Formal Aspects Comput. **30**(6), 761–762 (2018). https://doi.org/10.1007/s00165-018-0472-4
43. Bowen, J.P.: The impact of Alan Turing: formal methods and beyond. In: Bowen, J.P., Liu, Z., Zhang, Z. (eds.) SETSS 2018. LNCS, vol. 11430, pp. 202–235. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-17601-3_5

44. Bowen, J.P.: A personal view of EVA London: past, present, future. In: Weinel, J., Bowen, J.P., Diprose, G., Lambert, N. (eds.) EVA London 2020: Electronic Visualisation and the Arts, Electronic Workshops in Computing (eWiC), BCS, London, UK, pp. 8–15 (2020). https://doi.org/10.14236/ewic/EVA2020.2
45. Bowen, J.P., Hinchey, M.G.: Ten commandments ten years on: lessons for ASM, B, Z and VSR-Net. In: Abrial, J.-R., Glässer, U. (eds.) Rigorous Methods for Software Construction and Analysis. LNCS, vol. 5115, pp. 219–233. Springer, Heidelberg (2009). https://doi.org/10.1007/978-3-642-11447-2_14
46. Bowen, J.P., Hinchey, M.G., Till, D. (eds.): ZUM 1997. LNCS, vol. 1212. Springer, Heidelberg (1997). https://doi.org/10.1007/BFb0027279
47. Bowen, J.P., Hoare, C.A.R., Langmaack, H., Olderog, E.R., Ravn, A.P.: A ProCoS II project final report: ESPRIT Basic Research project 7071. Bull. Euro. Assoc. Theoret. Comput. Sci. **59**, 76–99 (1996). http://researchgate.net/publication/2255515
48. Bowen, J.P., Hoare, C.A.R., Langmaack, H., Olderog, E.R., Ravn, A.P.: A ProCoS-WG Working Group final report: ESPRIT Working Group 8694. Bull. Euro. Assoc. Theoret. Comput. Sci. **64**, 63–72 (1998). http://researchgate.net/publication/2527052
49. Bowen, J.P., Reeves, S.: From a community of practice to a body of knowledge: a case study of the formal methods community. In: Butler, M., Schulte, W. (eds.) FM 2011. LNCS, vol. 6664, pp. 308–322. Springer, Heidelberg (2011). https://doi.org/10.1007/978-3-642-21437-0_24
50. Bowen, J.P., Wilson, R.J.: Visualising virtual communities: from Erdős to the arts. In: Dunn, S., Bowen, J.P., Ng, K.C. (eds.) EVA London 2012: Electronic Visualisation and the Arts, Electronic Workshops in Computing (eWiC), BCS, pp. 238–244 (2012). http://arxiv.org/abs/1207.3420
51. Clausing, A.: Prof. Dr. Achim Clausing. University of Münster, Germany. https://ivv5hpp.uni-muenster.de/u/cl/
52. Copeland, B.J., Bowen, J.P., Sprevak, M., Wilson, R.J. (eds.): The Turing Guide. Oxford University Press, Oxford (2017)
53. Erdmann, J.E.: A History of Philosophy. Swan Sonnenschein & Co., London (1890). English translation by W. S. Hough
54. Falckenberg, R.: History of Modern Philosophy: From Nicolas of Cusa to the Present Time. H. Holt (1893). https://www.google.co.uk/books/edition/_/BZwvAAAAYAAJ
55. Falckenberg, R.: History of Modern Philosophy: From Nicolas of Cusa to the Present Time. Project Guttenberg (2004). http://www.gutenberg.org/ebooks/11100
56. Fauvel, J., Flood, R., Wilson, R. (eds.): Möbius and his Band: Mathematics and Astronomy in Nineteenth-century Germany. Oxford University Press, Oxford (1993)
57. Fischer, K.: Geschichte der neuern Philosophie. Stuttgart-Mannheim-Heidelberg (1854–77), New edn, Heidelberg (1897–1901)
58. Giannini, T., Bowen, J.P.: Life in code and digits: when Shannon met Turing. In: Bowen, J.P., Diprose, G., Lambert, N. (eds.) EVA London 2017: Electronic Visualisation and the Arts, Electronic Workshops in Computing (eWiC), BCS, pp. 51–58 (2017). https://doi.org/10.14236/ewic/EVA2017.9
59. Giannini, T., Bowen, J.P. (eds.): Museums and Digital Culture. SSCC. Springer, Cham (2019). https://doi.org/10.1007/978-3-319-97457-6
60. Grieskamp, W., Gurevich, Y., Schulte, W., Veanes, M.: Generating finite state machines from abstract state machines. ACM SIGSOFT Softw. Eng. Notes **27**(4), 112–122 (2002). https://doi.org/10.1145/566171.566190

61. Gurevich, Y.: Sequential abstract-state machines capture sequential algorithms. ACM Trans. Comput. Logic **1**(1), 77–111 (2000). https://doi.org/10.1145/343369.343384
62. Gurevich, Y., Börger, E.: Evolving algebras 1993: Lipari guide. In: Börger, E. (ed.) Specification and Validation Methods, pp. 231–243. Oxford University Press (1995). https://arxiv.org/abs/1808.06255
63. Gurevich, Y., Börger, E.: Evolving algebras: mini-course, Notes Series, vol. NS-95-4. BRICS: Basic Resarch in Computer Science, July 1995. https://www.researchgate.net/publication/221329427
64. Habrias, H., Frappier, M. (eds.): Software Specification Methods. ISTE (2006). https://doi.org/10.1002/9780470612514
65. Hegel, G.W.F.: Wissenschaft der Logik. Johann Leonhard Schrag, Rürnberg (1812–16). http://www.gutenberg.org/ebooks/55108
66. Hegel, G.W.F.: Grundlinien der Philosophie des Rechts. Nicolaischen Buchhandlung, Berlin (1821)
67. Henson, M.C., Reeves, S., Bowen, J.P.: Z logic and its consequences. Comput. Inf. **22**(3–4), 381–415 (2003). https://doi.org/10289/1571
68. Hinchey, M.G., Bowen, J.P., Rouff, C.: Introduction to formal methods. In: Hinchey, M.G., Rash, J., Truszkowski, W., Gordon-Spears, D.F. (eds.) Agent Technology from a Formal Perspective, pp. 25–64. Springer, Cham (2006). https://doi.org/10.1007/1-84628-271-3_2
69. Isaacson, I.: Steve Jobs. Little, Brown, London (2011)
70. Kant, I.: Kritik der reinen Vernunft. Johann Friedrich Hartknoch, Riga, 2nd edn. (1781). https://www.gutenberg.org/ebooks/4280
71. Kant, I.: Kritik der Urteilskraft. Lagarde & Friedrich, Berlin & Libau (1790). http://www.gutenberg.org/ebooks/48433
72. Leibniz, G.W.: Explication de l'arithmétique binaire. Mémoires de Mathématique et de Physique de l'Académie Royale des Sciences, pp. 85–89 (1703). https://hal.archives-ouvertes.fr/ads-00104781
73. Liebmann, O., Wundt, W., Lipps, T., et al.: Die Philosophie im Beginn des 20. Jahrhunderts. Festschrift für Kuno Fischer, Heidelberg (1907)
74. MGP: Egon Börger. Mathematics Genealogy Project. https://www.mathgenealogy.org/id.php?id=155832
75. MGP: Yuri Gurevich. Mathematics Genealogy Project. https://www.mathgenealogy.org/id.php?id=7906
76. Pippin, R.B.: Hegel, Georg Wilhelm Friedrich. In: Audi [6], pp. 311–317
77. Polmeer, G.: Historical questions on being and digital culture. In: Giannini and Bowen [59], chap. 3, pp. 49–62. https://doi.org/10.1007/978-3-319-97457-6_3
78. Robinson, A.: Sudden Genius?. Oxford University Press, Oxford (2010)
79. Rojas, R. (ed.): Encyclopedia of Computers and Computer History. Fitzroy Dearborn Publishers, Chicago (2001)
80. Rooney, D. (ed.): Mathematics: How It Shaped Our World. Science Museum, London (2016)
81. Schmeh, K.: Enigma-schwachstellen auf der spur. Telepolis, Heise Online, Germany, August 2005. https://www.heise.de/tp/features/Enigma-Schwachstellen-auf-der-Spur-3402290.html. (in German)
82. Shannon, C.E.: A symbolic analysis of relay and switching circuits. Master of science, Massachusetts Institute of Technology, USA (1940). https://doi.org/1721.1/11173

83. Siekmann, J., Davis, M., Gabbay, D.M., et al.: Computational logic. In: Gabbay, D.M., Siekmann, J., Woods, J. (eds.) Handbook of the History of Logic, vol. 9. North Holland (2014)
84. Sleigh, R.C.: Liebniz, Gottfried Wilhelm. In: Audi [6], pp. 425–429
85. Smart, N.: Hegel, the giant of nineteenth-century German philosophy. In: Smart [89], pp. 243–244
86. Smart, N.: Idealism: Fichte and Schelling on the road to Hegel. In: Smart [89], pp. 241–243
87. Smart, N.: Immanuel Kant and the critical philosophy. In: Smart [89], pp. 238–241
88. Smart, N.: Leibniz and the idea of universal harmony. In: Smart [89], pp. 231–233
89. Smart, N.: World Philosophies. Routledge, London (1999)
90. Turing, A.M.: On computable numbers, with an application to the Entscheidungsproblem. In: Proceedings of the London Mathematical Society s2–42, pp. 230–265 (1937). https://doi.org/10.1112/plms/s2-42.1.230
91. Turing, A.M.: Computing machinery and intelligence. Mind **LIX**, 433–460 (1950). https://doi.org/10.1093/mind/LIX.236.433
92. Vater, M.G., Wood, D.W. (eds.): The philosophical rupture between Fichte and Schelling: selected texts and correspondence (1800–1802). Suny Press, Albany (2012)
93. von Neumann, J.: First draft of a report on the EDVAC. Moore School of Electrical Engineering, University of Pennsylvania, June 1945. http://web.mit.edu/STS.035/www/PDFs/edvac.pdf
94. Wenger, E.: Communities of Practice: Learning, Meaning, and Identity. Cambridge University Press, Cambridge (1998)
95. Wenger, E., McDermott, R.A., Snyder, W.: Cultivating Communities of Practice: A Guide to Managing Knowledge. Harvard Business School Press, Brighton (2002)
96. Wenger-Trayner, E., Wenger-Trayner, B.: Introduction to communities of practice: a brief overview of the concept and its uses (2015). https://wenger-trayner.com/introduction-to-communities-of-practice/
97. Wikipedia: Egon Börger: The Free Encyclopedia. https://en.wikipedia.org/wiki/Egon_Borger