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Supercomputing and the emergence of digital federalism

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Abstract

Supercomputing has been an integral feature of science policy and programs since the late 20th century. As such, it has extended the capacity for calculation and enhanced the power of simulation. The enormous amount of money spent on high-performance computers implies that these machines are important because they are expensive – the priority given to them stimulates both conspicuous computing and demonstrative government spending. Providing a specialized scientific community with cutting-edge computational power benefits from centralized resources. Consequently, it seems natural that allocation of these budgets be left to the highest levels of government decision-making. Yet, perhaps surprisingly, this does not mean that federal political systems with many decision levels are automatically handicapped vis-à-vis the development of supercomputing. Our study focusing on the southern part of Germany shows that, historically, supercomputing also developed as an essential cornerstone of digital federalism, an emergent field of technoscientific practice.

Introduction

Supercomputers are the fastest and most powerful computing systems in the world. They offer much higher speed and performance than any other class of computers. Supercomputing also means the allocation of an extreme amount of resources in a single and very complex computing center. This leads to operating costs no market could possibly absorb. Hence, supercomputing has always been a playground for powerful, splendid governments and their technoscientific programs. Like military might, supercomputing came under the national purview and was the privileged realm of strong governments whose centralistic allocation of financial, human, and technological resources produced representational effects. Supercomputing was organized as a worldwide competition for processing power and a very earnest game of «conspicuous computing».[1]

Three decades ago, Donald MacKenzie asserted that the Los Alamos and Lawrence Livermore National Laboratories exclusively sponsored and shaped the development of supercomputing architecture. It was the labs' nuclear programs that set computing standards: they defined the main criterion for deployable computing capacity as the number of floating point operations per second (FLOPS).[2] In the 1980s, FLOPS became an early means of comparing the computing power of any calculating sovereign anywhere in the world. Only later, in 1993, did the Top500 list offer a slightly more sophisticated benchmark for state-of-the-art supercomputing by ranking all centers. Over the last quarter of a century, the Top500 list has closely tracked the field of high-performance computing (HPC) and reported where «computing at the limit of computability» is happening.[3]

Despite its association with politics, power, and sovereignty, almost no attention has been paid to supercomputing by science and technology studies. Whereas most scholars in the field did discuss the centralizing and decentralizing effects of computers in general, they typically claimed that «the» computer and «the» network dissolved the geographic, political, and legal boundaries of the nation-state. Moreover, they argued that this dissolution led to the formation of new global infrastructures and new spaces of a fragmented and heterogeneous, yet very powerful political authority.[4] However, any increase in autonomy at the periphery might simply have been illusory. According to conventional science and technology studies, hardware and software remain a source of central authority even at its remotest ends, since

1 Computing, not consumption was the demonstrative purpose of this game.

2 Donald MacKenzie, The Influence of the Los Alamos and Livermore National Laboratories on the Development of Supercomputing, in: IEEE Annnals of the History of Computing, 1991, 13(2): 179–201.

3 David Gugerli, Supercomputer – an der Grenze der Berechenbarkeit, in: Merkur. Deutsche Zeitschrift für europäisches Denken, 2019, 73(846): 53–59.

4 Jean-François Lyotard, La condition postmoderne. Rapport sur le savoir, Paris 1979; Saskia Sassen, Losing Control: Sovereignty in the Age of Globalization, University Seminars: Leonard Hastings Schoff Memorial Lectures, New York 2015; Keller Easterling, Extrastatecraft, London 2014.

they provide the sovereign with the silent language of digital codes, which are difficult to contradict.[5] Consequently, science and technology studies encouraged analysis of digital and mathematical games of language in the development of algorithms and simulations; they highlighted the importance of a political economy of hardware and software providers; and they considered the importance of computing centers as the focal points of data-driven knowledge production.[6] Obviously, there was no incentive to distinguish between supercomputers and computers in general. Insights into the (de)centralizing effects of the computer were necessarily as true for standard computing as for computing in extremis, i. e., for HPC.

In what follows, we argue that fully understanding the politics, power, and sovereignty of supercomputing requires introducing more distinctions to allow a more subtle analysis. First, we wish to reintroduce the distinction between «the computer» and «the supercomputer». Second, we wish to differentiate the technopolitical notions of center and periphery by discussing the configuration of three historical forms of digital federalism.[7] In order to demonstrate this empirically, we draw on our case study on the history of technology of supercomputing at the University of Stuttgart.[8] In this study, we very much had the impression that the history of HPC must take into consideration a wide array of stakeholders acting in what we call «digital fed-

5 Friedrich Kittler, Protected Mode, in: Norbert Bolz et al. (eds.), Computer als Medium, Munich 1994, pp. 209–220.

6 Lucas Introna, David Wood, Picturing Algorithmic Surveillance: The Politics of Facial Recognition Systems, in: Surveillance & Society, 2002, 2(2/3): 177–198; Tung-Hui Hu, A Prehistory of the Cloud, Cambridge 2015; Malte Ziewitz, Governing Algorithms: Myth, Mess, and Methods, in: Science, Technology, & Human Values, 2015, 41 (1): 3–16; Robert Seyfert, Jonathan Roberge (eds.), Algorithmuskulturen. Über die rechnerische Konstruktion der Wirklichkeit, Bielefeld 2017; Sven Opitz, Simulating the World: The Digital Enactment of Pandemics as a Mode of Global Self-Observation, in: European Journal of Social Theory, 2017, 20 (3): 392–416.

7 However, we will not distinguish between *supercomputing* and the more operational term *high-performance computing*, since both terms are similarly different from other forms of computing, e. g., computing supported by mainframe computers, data processing computers, file servers, or computers used exclusively for network maintenance.

8 David Gugerli, Ricky Wichum, Simulation for All: The Politics of Supercomputing in Stuttgart, Zurich 2021.

eralism». Therefore, we focus on the distribution of authority among the many different layers of a federal political system and the many and highly differentiated public spheres.[9]

We will argue that HPC is not so much the effect of a centralistic government's decision gracefully offered to its scientific, military, and industrial subjects, but rather the result of permanent and complex negotiations in a dynamic, multileveled political context of technoscience.[10] We distinguish three successively dominant forms of digital federalism in Germany in the late 20th century. The first was a program oriented at federal distribution (mainly in the 1970s). The second – in evidence roughly from the mid-1980s to the mid-1990s – was a form of digital federalism that sought to allow supercomputing the power to grow from regional competitiveness. Finally, in the second half of the 1990s, a new digital federalism started to emerge. It materialized as a product of various special «trading zones». These trading zones primarily centered on organization, access to supercomputing, and even evaluation of architectural options. Some of them persisted only temporarily; others grew in importance and became quite stable. In terms of their institutional framing, most trading zones varied from one working group to the next, involving a variety of sponsors and many organizations, thus maintaining a growing network of both federal and regional actors. All produced traces of their deliberations – vast materials we were able to access in the Stuttgart University Archives, and the personal document collections of former and current employees at the High Performance Computing Center Stuttgart.

Distributing funds under digital federalism

In the 1970s, computing became a matter of course in German universities and research institutions. This computational normalcy was largely the result of a federal policy aimed at overcoming American supremacy in software

9 For a similar approach in the political sciences, see Jenna Bednar, The Political Science of Federalism, in: Annual Review of Law and Social Science, 2011, 7: 269–288.

10 Peter Galison, Trading Zone: Coordinating Action and Belief, in: Mario Biagioli (ed.), The Science Studies Reader, London 1999, pp. 137–160.

competence, equipment, and computing power.[11] «Germany» should catch up with «the US» (or «Siemens» with «IBM») by building up a strong computational infrastructure and genuine computing competence. The federal policy for technoscience operated through an established distribution network and intensive cooperation between the federal state and its member states.[12] Federal programs in technoscience were consensus oriented and essentially based on the principle of uniform funding. Two agencies of the federal state, the Ministry of Research and Technology and the German Research Foundation (DFG), defined the terms for allocating subsidies.[13] They carefully orchestrated interactions between the federal government and the member states. There were two different channels of technoscientific development: the University Construction Act (Hochschulbauförderungsgesetz, from 1972), which governed construction of new university buildings, and a trio of funding programs for «data processing» (1973–1981).[14]

These programs did not distinguish between different machines. For the programs as such, it was irrelevant whether the funds they provided went to support a mainframe computer, a programmable data processor, or a high-performance machine. The task was to provide science and research with the computing capacity they arguably needed. Institutions got the machine and

11 Hartmut Petzold, Moderne Rechenkünstler. Die Industrialisierung der Rechentechnik in Deutschland, Munich 1992; Johannes Bähr, Die «amerikanische Herausforderung». Anfänge der Technologiepolitik in der Bundesrepublik Deutschland, in: Archiv für Sozialgeschichte, 1995, 35: 115–130.

12 Fritz Wilhelm Scharpf et al., Politikverflechtung: Theorie und Empirie des kooperativen Föderalismus in der Bundesrepublik, Kronberg/Ts. 1976; Andreas Stucke, Staatliche Akteure in der Wissenschaftspolitik, in: Dagmar Simon et al. (eds.), Handbuch Wissenschaftspolitik, Wiesbaden 2016.

13 Ulf Hashagen, Computers for Science – Scientific Computing and Computer Science in the German Scientific System 1870–1970, in: Mark Walker et al. (eds.), The German Research Foundation 1920–1970: Funding Poised between Science and Politics, Stuttgart 2013, pp. 135–150.

14 Timo Leimbach, Die Softwarebranche in Deutschland. Entwicklung eines Innovationssystems zwischen Forschung, Markt, Anwendung und Politik von 1950 bis heute, Stuttgart 2011, p. 166; Bernd Reuse, Roland Vollmar (eds.), Informatikforschung in Deutschland, Berlin 2008.

the computing power whose acquisition they could justify in a funding application.[15]

The federal technoscientific programs certainly had an impact. The hardware used at German universities became faster and the available software more differentiated, while the number of users from different disciplines skyrocketed. The availability of additional computing capacity even led to new study programs for computer science and for applied computer science, in Stuttgart and elsewhere.[16] However, toward the end of the 1970s federal programs began to lose some of their coordinating power. It was difficult to maintain a coherent set of rules for future development. The programs and mechanisms for distributing funds ran into hurdles.[17]

In 1977, as previously planned, the University of Stuttgart applied for a new, powerful mainframe computer – a Cyber 175 – to be financed by the DFG.[18] The proposal failed miserably to convince the reviewers. While the importance of computing per se was beyond any doubt, there was no consensus among these experts on how a normal university was to keep up with increasing computational needs. The DFG did not believe in Stuttgart's long-term expansion course, nor did they buy the argument of a growing demand for centralized computing power.[19] Moreover, there were serious doubts

15 Joachim Mönkediek, Rückblick auf die Förderung der Informationstechnologie an Hochschulen durch Bund und Länder, in: Hannes Hartenstein (ed.), Informationstechnologie und ihr Management im Wissenschaftsbereich. Festschrift für Prof. Dr. Wilfried Juling, Karlsruhe 2009, pp. 23–28.

16 Leimbach, Softwarebranche, pp. 218–219; Christine Pieper, Das «Überregionale Forschungsprogramm Informatik» (ÜRF). Ein Beitrag zur Etablierung des Studienfachs Informatik an den Hochschulen der Bundesrepublik Deutschland (1970er und 1980er Jahre), in: Technikgeschichte, 2008, 75(1): 3–31; Bernd Reuse, Roland Vollmar (eds.), Informatikforschung in Deutschland, Berlin 2008. On the early connection between computer-based research and teaching, see Christoph Hoffmann, Eine Maschine und ihr Betrieb: Zur Gründung des Recheninstituts der Technischen Hochschule Stuttgart, 1956–1964, in: Barbara Büscher et al. (eds.), Ästhetik als Programm: Max Bense/Daten und Streuungen, Berlin 2004, pp. 118–129.

17 Leimbach, Softwarebranche, pp. 182 ff.

18 Stuttgart University Archives (UASt), Universität Stuttgart, Rechenschaftsbericht des Rektors 1975/76, p. 246; Ibid. 1976/77, p. 242.

19 Ibid. 1977/1978, p. 303.

about the preferred hardware provider.[20] Thus, it became difficult to defend the well-established mainframe solution for a data processing factory at the center and a growing number of terminal stations at the periphery. The existing installation of a CD 6600 coupled with a Cyber 174 certainly integrated many different applications. However, there was nothing spectacular about the infrastructure and the planned applications; there were no technological thrills and barely any scientific challenges.

The DFG simply declined to fund the planned expansion of the computing center at the University of Stuttgart. Instead, it started to support programmable data processors and other smaller machines in the university's most active research institutes.[21] Small machines became so beautiful that one could no longer successfully argue with the economies of scale of centrally supplied computing power.[22] Even such strong defenders of computing centers as the editors of the journal *Rechenzentrum* publicly mentioned the imminent possibility of a sudden «death of the computing center». In the context of the midi-computer hype and the appeal of distributed computing, directors of existing computing centers had to face the vaporization of their budgets. A fair amount of conceptual homework must have featured on their to-do-lists.[23]

If the computing center was still to play a key role in the future development of academic computing, it would have to be emancipated from its data factory model. In order to not succumb to a distributed processing scheme, the center had to defend its centrality with the help of a new, but genuinely

20 See UASt, Deutsche Forschungsgemeinschaft, 12. Mai 1978, Stellungnahme der Kommission für Rechenanlagen zur Anfrage des Landes Baden-Württemberg vom 26. Juli 1977 bezüglich Erweiterung des Regionalen Rechenzentrums Stuttgart im Programm zur Errichtung Regionaler Rechenzentren (Az.: 375224/2/77), 12 May 1978.

21 Karl-Gottfried Reinsch, Strukturveränderungen des Rechenzentrums und seiner Benutzer, in: Das Rechenzentrum, 1982, 31: 171–175, on p. 171.

22 Karl-Gottfried Reinsch, Regionale Großrechenzentren zur Versorgung japanischer Universitäten. Praxis der Informationsverarbeitung und Kommunikation, in: Das Rechenzentrum, 1980, 3(2): 73–79, on p. 79.

23 Cf. Das Rechenzentrum, 1978, 2, pp. 59 and 60.

central service. HPC was definitely one such possibility that many scientists could not ignore.[24]

The idea was simple, but the implementation a wearisome endeavor. It also entailed learning the hard way, since supercomputing implied reshaping the hitherto well-established relations between all stakeholders – on campus, in industry, and in the federal and local governments. Buying a supercomputer could mean all sorts of things. Some people at the center even floated the extravagant idea of buying a supercomputer and eventually using it as a substitute for the old CD 6600 mainframe.[25]

The most difficult problem for the University of Stuttgart was posed by its regional competitor, the Technical University of Karlsruhe, after the DFG flatly rejected proposals from both universities in 1980. A supercomputer is a very expensive, very exclusive tool that was at the limit of the agency's budget. The DFG played hardball, refusing to decide which university in Baden-Württemberg should get a supercomputer.[26] Instead, the agency stipulated that the universities would have to develop a means of coordinating and distributing their services. By restructuring its approach to distributing funds, it sought to obtain a long-term strategic advantage over its clients. If Karlsruhe or Stuttgart was the question, the choice between them was not a matter of concern. But the question was an important one for the state of Baden-Württemberg, which had to choose an institution within the state; they could not blame the federal government for a wrong decision. All the while, each of the universities was going to great lengths to justify its burning need for a supercomputer. That is how the DFG succeeded in developing new spaces of negotiation for distributing federal subsidies and found a way to insert these trading zones into the technoscientific landscape of the member state in question. The qualitative improvement in terms of legitimacy of federal

24 See UASt, Reinsch, Strukturveränderungen. Universität Stuttgart, Wissenschaftlicher Grösstrechner für das Land Baden-Württemberg. Antrag zur Realisierung am Regionalen Rechenzentrum der Universität Stuttgart, Stuttgart 15/3/1980.

25 UASt, Rechenschaftsbericht des Rektors 1978–1980, p. 171.

26 Peter Sandner, ALWR-BW. Arbeitskreis der Leiter der Universitätsrechenzentren in Baden-Württemberg, in: PIK, 2008, 31(3): 193–198, on p. 193.

sponsorship was considerable. Moreover, it strengthened the distinction that supercomputing brought to the winning team.[27]

Negotiations are no substitute for decisions. Stuttgart and Karlsruhe were surely each bound to lose their wager if they failed to reduce the estimated costs for their future supercomputers. Obviously, neither the University of Karlsruhe nor the University of Stuttgart could be arm-twisted into backing down. Instead, both universities reduced the federal part of their budget by half and sought to compensate the remaining half through contracts with future external users. For the subsidizing DFG, this was a win-win-win situation. It gained two supercomputers at two different places for the price of one, doubling its subsidizing effect and enhancing the legitimacy of its policy. Science policy had positive effects not only for public universities but also for industrial enterprises. The industrial partners finally began to invest in supercomputing, the universities guaranteed its operation, and the computing centers maintained all necessary network connections.[28]

The simultaneous acquisition of a supercomputer in Karlsruhe and in Stuttgart produced a trading zone in Baden-Württemberg that achieved consensus on seemingly contradictory or mutually excluding interests. First, the new digital federalism created a new arena of decision-making on a regional level. The university rectors and the regional ministry of science and arts, together with the heads of the computing centers, negotiated the procurement and organization of supercomputing in Baden-Württemberg. Second, digital federalism increased the autonomy of both the state and the federal government. While the federal government placed supercomputing within its distribution program and thus legitimized and consolidated the program as a whole, the federal state and its universities also gained new formative power. By no means did these developments herald a spectacular ushering in of a

27 The rectors' conference (Landesrektorenkonferenz) in Baden-Württemberg had to establish a working group to mediate the conflict over scarce resources, keep it at a controllable level, and work out an acceptable consensus that could then be submitted again «to the federal government». Ibid. The working group was the nucleus for the «Arbeitskreis der Leiter der Universitätsrechenzentren in Baden-Württemberg», founded in 1981, whose members concluded the «Peace Treaty of the Lake of Constance» at their first meeting.

28 Ibid.

new supercomputing era in Baden-Württemberg. However, the University of Stuttgart had managed – at least formally – to join the club, to handle the new negotiation culture imposed by the federal funding agency, and to maintain the centrality of its computing center with the help of a relatively cheap Cray-1.[29]

Regional competition in digital federalism

In fall 1983, the new Stuttgart supercomputer found its place of operation in the former main kitchen on the Vaihingen campus, directly wired to the existing computing center. Although the Cray-1 no longer represented the cutting edge of supercomputing, Stuttgart's formal participation in the supercomputing game greatly altered perspectives and expectations. The university's computing center forgot the good old times of mainframe computing. Even more important was finding out that the scientific and economic coordination provided by the federal funding agencies was probably not the sole source of orientation for local strategies and developments. The complex acquisition process of the Cray-1 made clear the importance of a whole array of alternative allies. Consequently, in the mid-1980s, the University of Stuttgart developed a close cooperation with the state of Baden-Württemberg's government and its restless minister president, Lothar Späth. The university discovered the benefits of setting an independent agenda for its future development in supercomputing.[30] The field was about to play an important political role as an argumentative resource in the context of an increasingly dynamic and competitive German federalism.[31] Späth announced

29 The Cray-1 made computer history when it was launched in 1976 with its unprecedented computing capacity. The first computing center in Germany to operate a Cray-1 was the Max Planck Institute for Plasma Physics in Garching (1979). Friedel Hoßfeld, Vektorrechner, in: Phys. Bl, 1984, 40(8): 280–281.

30 Franz Effenberger, Lothar Späths Forschungsförderung und Technologiepolitik am Beispiel der Universität Stuttgart, Ubstadt-Weiher 2020.

31 In a programmatic statement of the Science Council in 1985: «Wettbewerb setzt zunächst ein gewisses Maß an Handlungsfreiheit für die am Wettbewerb Beteiligten voraus. Wer sich im Wettbewerb bewähren soII, muß das Recht und die Möglichkeit haben,

his «pivot to the future», insisted on the potential for shaping conditions, and strongly advocated a combined science and economic policy.[32]

In June 1985, Späth traveled to the US, where he visited Cray Inc. in Minneapolis. This was an excellent opportunity to demonstrate what the pivot to the future implied. Späth audaciously decided to buy a cutting-edge Cray-2, with no concern for the complicated federal coordination mechanisms that applied in acquiring a supercomputer in Germany. The contract with Cray was a demonstrative act of governmental decision-making. The provider even assured that he would not deliver another machine to any other German university for a year. Competition apparently went hand in hand with new forms of market protection. Europe's first Cray-2 was built out in Stuttgart and was to be exclusively operated by the Stuttgart computing center. However, buying the machine proved much easier than operating it. The old Cray-1 was well established and handled calculations for most of Stuttgart's supercomputing projects. It was not easy to find new clients whose computing needs required access to the Cray-2, and it was simply impossible at the price the University of Stuttgart and the government of Baden-Württemberg settled on to justify their lonely decision. The free-market economy

nach eigener Entscheidung individuelle Leistungen zu erbringen und dabei auf die Signale des Wettbewerbsmechanismus zu reagieren» («Competition presupposes a certain degree of freedom of action for those involved in the competition. To be competitive, they must have the right and the opportunity to decide whether to provide individual services and to respond to the demand for resources»). Wissenschaftsrat, Wettbewerbsempfehlung des WR. Empfehlungen zum Wettbewerb im deutschen Hochschulsystem, Cologne 1985, p. 7.

32 Lothar Späth, Wende in die Zukunft. Die Bundesrepublik auf dem Weg in die Informationsgesellschaft, Spiegel-Buch, Reinbek bei Hamburg 1985. On the reorganization of the rules of science policy in the DFG around the middle of the 1980s, cf. Alexander Gall, «Bundesliga-Spielregeln in der Wissenschaftspolitik». Föderalismus und Forschungspolitik zur Mikroelektronik, in: Johannes Abele et al. (eds.), Innovationskulturen und Fortschrittserwartungen im geteilten Deutschland, Cologne 2001, pp. 147–164. On the discovery of the shapability of society, see Adalbert Evers and Helga Nowotny, Über den Umgang mit Unsicherheit. Die Entdeckung der Gestaltbarkeit von Gesellschaft, Frankfurt am Main 1987.

makes for an exhilarating topic of conversation until the market declines to pay the bill.[33]

For the Stuttgart computing center, the Cray-2 adventure entailed considerable work at the conceptual and communicative level. The old regime of cooperative allocation of federal funds was increasingly being replaced by intensive regional networking and an increased need to publicly explain the role, advantages, and operative principles of supercomputing. This was Roland Rühle's task. The new scientific director of the computing center was keen to present HPC in Stuttgart as the university's central platform for simulation to meet the intellectual and operational needs of the city's research institutes and industrial enterprises. This constituted a broad range of clients with one common denominator: a strong interest in evidence and demonstration. Hence, the coupling of simulation and visualization techniques, which around 1990 represented a novel approach in supercomputing.[34] Visual demonstrations began determining the semantics even of a supercomputer's number-crunching operations. Stuttgart went so far as to claim that its Cray-2 opened «a completely new dimension of technoscientific simulation».[35] Instead of staring at «endless, barely understandable rows and columns of numbers», users were provided with «visualizations of technological processes and scientific models».[36] The pictorial evidence of any kind of supercomputer-based simulations found its way into countless project descriptions, conference slides, and published papers. Images, not tables, produced the insights into an artificial world created by the supercomputer.

Pictorial competence was good news and was welcomed by sponsors and users. Images were a helpful means of reducing cognitive complexity, and they propelled the development of theoretical models in engineering. Wherever interdisciplinary cooperation of specialists was as critical as it was

33 UASt, Karl-Gottfried Reinsch, Bericht Betriebszeitraum CRAY-2 vom November 1986 – Oktober 1987, p. 9.

34 See, for example, Ulrich Lang and Roland Rühle, Visualisierung von Supercomputerberechnungen am netzintegrierten Ingenieursarbeitsplatz, in: Hans-Werner Meuer (ed.), Heterogene Netze und Supercomputer, Berlin 1992, pp. 121–133, on p. 125.

35 UASt, Universität Stuttgart, Antrag der Universität Stuttgart auf Beschaffung eines Höchstleistungsrechnersystems als Nachfolgerechner für die Cray-2 1992, p. 5.

36 Ibid.

in the context of a computing center, calculation, representation, supercomputing, and visualization became amalgamated into a coherent analytical tool.[37]

This methodological shift changed the role of the computing center. It became known for its centralized resources and strict rules of engagement. Moreover, it was run as an ensemble, if not a confederation, of machines, procedures, applications, and analytical tools. The center's personnel learned to expect and to exploit the heterogeneity of its resources. The center was building bridges between these diverse resources and coming to grips with the thematic and disciplinary differences of its users. In fact, the computing center remained a center precisely because it was able to integrate the diversity of its machines, networks, applications, and users. The Cray-2 was a prominent and privileged component in this game. Its privileging effects, however, stemmed from many other machines that protected the supercomputer from tasks other computers could handle just as well.[38] In Stuttgart, the Cray-2 «produced calculations» exclusively. «All other services, such as file servers, backup servers, dialog servers, graphic servers, printer servers, and network servers ran on pre-processing machines».[39] The research institutes connected their midi-computers, workstations, and desktops to the computing center through local area networks (e.g., DECnet). The computing center in turn also coordinated all connections to the European academic re-

37 Ibid., p. 312, and UASt, Universität Stuttgart, Forschungsbericht 1995/96, p. 348.

38 The principle of relieving the load on particularly powerful computers was applied as early as the mid-1960s at NASA's control center in Houston. At Mission Control Center, there were input computers, backup computers, systems for graphic evaluation, and around 2000 employees who reduced the amount of central computing and provided additional analytical loops or electromechanical and optical substitutes for the main computers. Cf. David Gugerli, Wie die Welt in den Computer kam. Zur Entstehung digitaler Wirklichkeit, Frankfurt am Main 2018, pp. 88–105.

39 UASt, Rechenzentrum Universität Stuttgart [Das Rechenzentrum der Universität Stuttgart 1986. Broschüre aus Anlass der bevorstehenden Auslieferung einer Cray-2 im September 1986], Stuttgart 1986.

search network, the German research network, and an experimental ISDN network developed by the federal post office (*Bundespost*).[40]

Increasing user diversity was yet another strategy for the Stuttgart computing center that helped improve the load of its Cray-2. The center managed to incorporate new regional user groups outside the university. One of the most prominent cases was the automotive industry. Porsche's research and development department simulated crash tests for sports cars.[41] Moreover, regional midsize manufacturers became members of Stuttgart's user community.[42] The state of Baden-Württemberg, the city and University of Freiburg, the Chamber of Industry and Commerce Southern Upper Rhine, and the Regio-Gesellschaft in Freiburg, a regional organization, founded High Tech Computerdienste Oberrhein GmbH, a services company.[43]

The increased diversity of services laid bare two principal problems of digital federalism: users (researchers, companies) and the public (government, citizens, and the media). By the end of the 1980s, the center had to find a means of keeping users at secure distance from the machine. The center tried to develop a protected mode of operation and offered users a uniform view on the center's infrastructure. Services were not available until a user accepted centrally defined procedures. At the same time, the center's representatives were well aware that Lothar Späth's trip to Minneapolis

40 A brochure published by the center in August 1987 stresses the diversity of network access: «Die Anlagen des Rechenzentrums sind mit Hilfe verschiedener Technologien (IBM-, DECnet-, TCP/IP-, OSI-Protokolle) über lokale und überregionale Netze (Ethernet, HYPERchannel, DATEX-P/DFN, EARN) erreichbar» («The facilities of the computer center can be accessed using various technologies (IBM, DECnet, TCP/IP, OSI protocols) via local and national networks (Ethernet, HYPERchannel, DATEX-P/DFN, EARN)»)., UASt.

41 Sauer Papers, Stürme aus dem Rechner, in: hightech 5/89, p. 5, HLRS.

42 Sauer Papers, Breisgaumetropole schließt sich Stuttgarter Superrechner an, in: Badisches Tagblatt, 20/9/1988, HLRS.

43 The establishment of this regional distribution company corresponded to the demand of Stuttgart University's chancellor Blum in the expert seminar for new organizational models for distributing the computing capacity of the Cray-1. Cf. UASt, Jürgen Blum, Vorwort, in: Jürgen Blum (ed.), Höchstleistungsrechner. Anwendung. Finanzierung. Organisation, Stuttgart 1985, pp. 2–3.

transformed the well-equipped computing center in Stuttgart into a concern for a wider public. *Computer Zeitung* magazine was a critical observer of the computing center's performance. In the spring of 1987, it published a biting article under the title: «The computing center of the University of Stuttgart acquired a Cray-2. Then the trouble started».[44] It was clear that science policy desperately needed to pay more attention to public relations. Operating a publicly funded supercomputer entailed communicative requirements far beyond the proposal, justification, and reporting scheme of a standard project in the academic world.

Trading zones of a new digital federalism

Much to everyone's surprise, the Cray-1 in Stuttgart remained in operation even after the installation of the Cray-2. When the old machine was finally retired in summer 1987, the new machine still ran with a very modest workload of barely 30 percent. It took half a year to increase its workload to «almost» 70 percent.[45] Nevertheless, there was no serious doubt that acquisition of a next-generation Cray-3 was inevitable. For one thing, the future of supercomputing was promising. The computing community strongly believed that there was a growing and almost unlimited demand for future computing applications in science and industry. Hence, it was still necessary to acquire supercomputers with greater processing power.[46] Baden-Württemberg promptly secured a contract that made sure the first Cray-3 in Europe would

44 Computer Zeitung, 4 March 1987.

45 Cf. UASt, Karl-Gottfried Reinsch, Bericht Betriebszeitraum CRAY-2 vom November 1986 – Oktober 1987, p. 9. This also led to a conflict with the building authorities, as the additional power requirement due to the double operation could only be covered thanks to the provisional installation of a transformer that was needed elsewhere, leading to either uncertainties in the building planning or additional investment costs. UASt, Universitätsbauamt an Rechenzentrum der Universität Stuttgart, 13. Oktober 1986.

46 Hans-Werner Meuer, Parallelrechner – bringen die 90er Jahre den Durchbruch? (erschienen in PIK 1/1990), in: Hans-Werner Meuer (ed.), Supercomputer 1986–1990. Anwendungen, Architekturen, Trends, Munich 1992, pp. 387–393, on p. 388.

come to Stuttgart.[47] Most of the experts in the supercomputing field were convinced that this machine – like its predecessor – would dramatically shift the «limit of computability».[48]

The Cray-3 changed the conditions of digital federalism, even though Cray Inc. ultimately abandoned the project and never built the machine. Supercomputing became a demonstration object for the power of digital federalism beyond its actual materialization. Supercomputers were powerful instruments when operated in computing centers, but also on paper in cutting-edge research projects and in government strategies. The demonstrative effects on paper extended into published records. This was the case in June 1993 when the Mannheim Supercomputer Seminar published the first Top500 ranking. The list gave the supercomputer a paper-based source of demonstrative power. Just as *Forbes* published a list of the 400 wealthiest people in the US, the Top500 aimed at ranking the most powerful computers in the world.[49] This ranking gained influence by ignoring many things. For example, the supercomputer list did not track computer costs, it took no notice of the importance of providers, nor was it keen to report on the special architectonic advantages of a given supercomputer. Henceforth, supercomputers would be exclusively distinguished according to their computing power as determined by the LINPACK Benchmark.[50] If the benchmark defined the power of a machine, then the institutional site, the knowledge of the crew, and the government sponsoring its computing center were of secondary significance. From 1993 onward, it was not the organizational context that defined a supercomputer, but rather the supercomputer that defined its context.

47 UASt, Correspondence, John Rollwagen (Cray) an den Ministerpräsidenten des Landes Baden-Württemberg Herrn Lothar Späth, undated (probably 1985).

48 Robert Übelmesser, Die neuen Supercomputer von Cray, in: Hans-Werner Meuer (ed.), Supercomputer ’89. Anwendungen, Architekturen, Trends, Berlin 1989, pp. 31–42, on p. 36.

49 See Harald Lux 1997: «Hans-Werner Meuer ist Herr über die Hitpararade der schnellsten Rechner der Welt», Die Zeit, 13 June 1997.

50 Jack J. Dongarra, James R. Bunch, et al., LINPACK Users’ Guide, Philadelphia 1979, pp. 803–820.

The Top500 list also showed that it was possible to tear down existing structures and mechanisms of established controls, replacing both with more complex, yet flexible rules. Naturally, machines that were on the Top500 list, and certainly the ones occupying the first ranks, belonged to a supercomputer elite that participated in a competition at the limit of computability. However, these positions could be lost within a few months. Because the ranking came out twice a year – announced in June at the International Supercomputing Conference in Mannheim (the successor to the Mannheim Supercomputer Seminar) and in November by the IEEE Supercomputer Conference in the US – there was no long-term guarantee for a ranking position.[51]

Under a regime of such visible dynamism in HPC, neither the rules of distribution of funds in the 1970s nor the courageous claims of regional sovereignty that later carried the day for a relatively short period could ultimately prevail. Subsequently, a new form of digital federalism emerged – a regime in which a broad variety of actors and programs participated. There was no predefined model and no organizational standard for supercomputing in Germany during this period. Each supercomputer installation represented a careful reconfiguration that met local requirements and somehow fulfilled the federal requirements of participation, competition, and distribution of opportunities in a unique technopolitical cluster of interests. No local *spiritus rector*, no powerful federal institution, no malicious lobbyist, and certainly no powerful hardware provider could have invented such a scenario. The rather unlikely configurations that materialized over time had to be constructed in three different trading zones, involving substantial experimental risk and a considerable amount of organizational creativity.

The first trading zone had to deal with organizational questions of HPC in the budgetary context of a university. Typically, universities monitored their annual budgets exclusively on the basis of expenditure. Long-term investments were difficult to represent in their accounting systems; and income made everyone nervous if it stemmed from any source other than governmental budget allocations or tuition fees. A university was an institution that knew how to spend public money, not an enterprise geared to in-

51 Jack J. Dongarra, Piotr Luszczek, Top500, in: David Padua (ed.), Encyclopedia of Parallel Computing, Boston 2011, pp. 2055–2057, on p. 2056.

come, not to mention profit. However, buying and operating a supercomputer did indeed mean a huge investment, and the University of Stuttgart was thus forced to contemplate selling a share of the computing time on its Cray-2 system. University administrators had to learn what kind of «business» a supercomputer represented. How should the university finance an investment ahead of demand? Was there a reasonable amortization rate for conspicuous computing? How could operating costs be justified independent of actual demand? Was it possible to develop differentiated tariffs for different users, and what did that mean for the university's own users or scattered potential users from other universities in Baden-Württemberg? What did it mean for a power user from another member state, or even from a private enterprise? The answers to such questions had a major impact on the financial governance of the university. An appropriate estimation of costs was a condition *sine qua non*, and this estimation had a deluge of consequences for the existing system of subsidies.[52]

During the early 1990s, after many rounds of intensive discussions and difficult negotiations, the University of Stuttgart found quite an inventive (and complicated) solution. Investment and service (as measured in computing time) should evolve in separate organizations. Founded in 1995, hww (Höchstleistungsrechnen für Wissenschaft und Wirtschaft) GmbH was a specialized company for HPC for science and business that assumed the task of financing future supercomputing investments. The company was set up according to a shareholder model in which Baden-Württemberg, the University of Stuttgart, debis Systemhouse (an IT service provider owned by Daimler), and Porsche participated with different shares.[53] One year later, in 1996,

52 See UASt, Jürgen Blum, Vorwort, in: Blum, Höchstleistungsrechner, pp. 2–3.

53 The University of Stuttgart held 25 percent of the share capital, the State of Baden-Württemberg also 25 percent, debis Systemhaus GmbH 40 percent, and Porsche the remaining 10 percent. Cf. UASt, Rechenschaftsbericht des Rektors Prof. Dr. Heide Ziegler, 1. Okt. 1994 – 30. Sept. 1995, p. 9. Two conditions were attached to the cooperation model. First, participation should be open to other universities – the University of Karlsruhe was treated carefully in this respect by the Baden-Württemberg government. Second, parity between industry and science should always be maintained in the participation model; each side should have a maximum of 50 percent of the share capital. The chairmen of the shareholders' advisory board, appointed by the state of Baden-Württemberg,

the university founded the Höchstleistungsrechenzentrum der Universität Stuttgart (High Performance Computing Center Stuttgart, HLRS). This organizational entity took care of allocating computing time to German universities, specialized research institutes, and industrial users. It is worth noting that the HLRS allocated computing time based on a federal scheme of subsidies.[54] Its 12-member controlling board regulated the allocation of time by approving or dismissing applications for supercomputing services. The board also recommended the acquisition of additional hardware and software. Half of the board members were appointed by the DFG, and the rector's conference of Baden-Württemberg sent in the others.[55] This model finally provided enough federal flexibility for the prevailing legal and accounting rules (venturing to «the edge of legality», as Stuttgart's university chancellor had urged back in 1986); and it furnished a new mode of cooperation between science and the global industrial players situated in and around Stuttgart.

A second trading zone emerged around the problem of providing Germany's research landscape with supercomputing power through a network

were responsible for monitoring this rule. Cf. Ministerium für Wissenschaft und Forschung Baden-Württemberg, Informations- und Kommunikationstechnik in den Hochschulen des Landes Baden-Württemberg, Ausstattungsplan für den Zeitraum 1995 bis zum Jahr 2000 (EDV-Gesamtplan IV), Stuttgart 1995, p. 102.

54 Harms and Meuer provide a concise overview of the model: «The idea is to think big: the state has firmly committed its share of 15 million marks and another 20 million marks for a second tranche. The federal government will contribute supplementary funds of 15 million marks. The Science Council has already endorsed the federal funding of 20 million marks. Industry will contribute appropriate computers and computer use worth more than 40 million marks, as well as associated know-how, to the cooperative effort, i.e., 70 million marks and a total of 110 million marks in the final stage for the ‹super center› in Stuttgart.» Uwe Harms, Hans-Werner Meuer, Höchstleistungsrechnen in Deutschland – ein Rückblick, in: PIK, 1995, 18(2): 100–107, on p. 106.

55 Höchstleistungsrechenzentrum Stuttgart (HLRS), Richtlinien für die Organisation, die Nutzung und den Betrieb, 14/6/1996, Stuttgart 1996. Just under 50 percent of the total capacity was to be reserved for users from the Federal Republic of Germany, about 30 percent for the universities in Baden-Württemberg, and about 20 percent for local demand at the University of Stuttgart. Only 8 percent of the total capacity was to be made available to industry. For industry, debis Systemhaus was to organize the distribution of the capacity, while Porsche wanted to use the computers exclusively for its own needs.

of high-speed data connections. The German Council of Science and Humanities started the discussions and published two reports in 1995.[56] These reports were an institutional answer to the Top500 ranking. The Top500 ranking was a convenient instrument for judging Germany's national supercomputing competitiveness, especially for administrators who lacked expertise in the technical and operational details of the field. Reading the Top500 list in search of a prominent German supercomputing center, however, returned a devastating result. Germany not only ranked way behind Japan and the US, but also behind France, Great Britain, Italy, Switzerland, Canada, and Korea. It was, so to speak, not on the map of global supercomputing.[57] Buying a single new machine could reverse the devastation and restore «Germany» to the ranks of the top players in the field. This was the reason the Science Council wished only to deal with future centers at the highest level of supercomputing.[58]

It was clear from the Top500 list that such a center did not actually exist in 1995. However, the Science Council had no intention of developing a new funding scheme. Rather, it called for «competition among the supercomputing centers».[59] The competition would result in a few exclusive centers providing the necessary supercomputer capacity for science and research.[60] In order to avoid the creation of regional principalities – the Science Council vividly remembered Lothar Späth's act of regional independence (or disobedience) – the council formulated yet another condition for the future development: from then onward, supercomputers would serve all universities in Germany and would be financed by one or various member states.[61]

For the German HPC community, the Science Council overshot the mark – its approach involved too much politics and at the same time too

56 Wissenschaftsrat, Empfehlungen zur Bereitstellung leistungsfähiger Kommunikationsnetze für die Wissenschaft, Saarbrücken 1995; Wissenschaftsrat, Empfehlung zur Versorgung von Wissenschaft und Forschung mit Höchstleistungsrechenkapazität, Kiel 1995.

57 Wissenschaftsrat, Empfehlung, p. 9.

58 Ibid., p. 17.

59 Ibid., p. 24.

60 Ibid., p. 17.

61 Ibid.

much focus on hardware performance. Nonetheless, the HPC community knew that it had to become active in politics if it wanted to shape the development in a politically subtle and somehow more science-oriented way. The community found an interesting and interested ally in the recently restructured Federal Ministry for Education and Research. In October 1997, the directors of Germany's most powerful supercomputing centers came up with a feasibility study for developing national supercomputing. In contrast to the Science Council's visions of competition, the directors proposed a cooperative mechanism. In their eyes, cooperation was the key to propelling Germany to an internationally competitive level. Instead of a destructive arms race in hardware acquisition, the feasibility study suggested focusing on networks and answering the question of how German universities might get access to the future national centers. The possibility of an organizational network of centers of excellence as well as of networking the universities was the response to the Science Council's strategy of competition. In this trading zone, too, new types of areas of negotiation emerged between the federal government, the federal states, and the universities and their supercomputing.

Finally, a third trading zone dealt with promising supercomputing architecture. The concept of massively parallel computing was not new. Initial attempts date back to the 1970s and the famous Illiac IV developed at the University of Illinois.[62] However, it was only in the late 1980s that parallel computing became a useful alternative for Cray's vector-based supercomputing. Massively parallel systems came with many relatively cheap interconnected microprocessors and a distributed memory concept. The promise was an improved price-performance ratio; the problem was coming up with adequate programming techniques.[63] Neither the promise nor the problem was easy to assess. Some people familiar with the field maintained that workstation clusters might soon form a third way. Was this perhaps the end of conventional vector architecture for the entire, and in fact very heterogeneous, user community of supercomputers? Or was parallel computing just a spe-

62 R. Michael Hord, The Illiac IV: The First Supercomputer, Berlin 1982.

63 Richard A. Jenkins, Supercomputers of Today and Tomorrow: The Parallel Processing Revolution, Blueridge Summit, PA 1986.

cialized architecture for computational fluid dynamics in engineering and meteorology? Would further theoretical work eventually show that applied mathematics or theoretical chemistry and particle physics might also benefit from the new «weapon of mass computation»?[64]

The architecture trading zone became even more active when Stuttgart began coupling a brand-new vector computer (NEC SX4) and a powerful massively parallel system (Cray 3TE). Both machines made it into the Top500 list.[65] Now was the time to develop software tools that enabled communication between heterogeneous local systems.[66] The concept of connecting a national supercomputer offering the highest performance, as laid out in the 1997 feasibility study, transformed the architecture problem into a connection problem. Moreover, it served as an indicator that the local, national, and (most likely soon) international diversity of different systems was something to be expected and exploited. This development was the main reason behind Stuttgart's participation in a spectacular metacomputing experiment (with Pittsburgh and Sandia, in Albuquerque, New Mexico) and its efforts to expand supercomputing beyond the dominant institutional and political limits. Participants remember these experiments as «heroic, but unsuccessful». For the Supercomputing '97 conference, Stuttgart and its partners in the US constructed a virtual computer with 1024 processors connected through an extremely heterogeneous network. From the supercomputing center in Pittsburgh, this connection led through the «very high-speed Backbone Network Service (vBNS)» and STAR TAP, both NSF-run projects, to the Canada-based CANARIE and Teleglobe networks right into the network of Deutsche

64 In 1984, the journal *Parallel Computing* started to appear. For the German discussion, see Hans-Werner Meuer (ed.), Parallelisierung komplexer Probleme. Einsatz von Parallelrechnern in Forschung und Industrie, Berlin 1991; Robert Ahlrichs, Parallelrechner versus Workstation Cluster. Positionspapier, in: Hans-Werner Meuer (ed.), Supercomputer '93. Anwendungen, Architekturen, Trends. Mannheim 24.–26. Juni 1993. Proceedings, Berlin 1990, pp. 179–180, on p. 179.

65 In June 1996, the NEC SX-4/32 was number ten in the Top 500 list. In June 1997, Stuttgart's T3E Cray HPE was number ten, while the NEC SX-4/32 had already descended to rank 38.

66 UASt, Michael Resch et al., PACX-MPI, in: Informationen für Nutzer des Rechenzentrums (Heft 11/12) 1997, pp. 13–14.

Telekom AG, and from there to Stuttgart. Obviously, data also found its way back to Pittsburgh.[67] While the experiment could not overcome latency problems, Stuttgart acquired in Sandia a partner highly skilled in both wide area network technologies and computer-based methods for visualization. At the same time, Stuttgart was clearly the go-to location for any questions regarding grid computing in Germany.[68]

Conclusion

For scholars in public law it is no surprise that a developing federalism implies many corresponding differentiations for local and regional entities.[69] When the hotspots of political responsibility moved to federal actors, local actors had to develop matching structures – and vice versa. This holds true for digital federalism as well. When member states started to play a more competitive game in supercomputing (as they did in the mid-1980s), the federal system of technoscientific policies had to adjust its funding programs for the enhancement of computing, its policies for the development of universities, and its support for specialized research institutes. Supercomputing is such an expensive endeavor that no political entity, program, enterprise, or university is capable of acting alone. Some of Germany's cutting-edge facilities in supercomputing had to learn that lesson toward the end of the 1990s. It became clear that building and running a supercomputing center necessarily means cooperating selectively and excluding efficiently at the highest level of performance. In other words, success in supercomputing is extremely unlikely and requires the simultaneous development of rules of configuration

67 Pittsburgh and Stuttgart Inaugurate High-Speed Transatlantic Metacomputing, Pittsburgh Supercomputing Center, Press Release, 24 June 1997.

68 Thomas J. Pratt et al., Sandia's Network for SC '97: Supporting Visualization, Distributed Cluster Computing, and Production Data Networking with a Wide Area High Performance Parallel Asynchronous Transfer Mode (ATM) Network, in: Sandia National Laboratories (ed.), Sandia Report SAND98–1154, Albuquerque 1998.

69 Dietrich Schindler, Schweizerischer und europäischer Föderalismus, in: Schweizerisches Zentralblatt für Staats- und Verwaltungsrecht, 1992, 93(5): 193–223.

for machines, programs, users, and sponsors.[70] Hence, supercomputing requires strong alliances, carefully designed forms of autonomy, and selective interrupts for the control of desired and disruptive interdependence. Supercomputing's configuration is very much akin to a confederation. No wonder the multiple trading zones of supercomputing have formed the primary playing ground for emerging digital federalism since the late 20th century.

This conclusion is by no means valid only for supercomputing and its trading zones. The transfer of administrative work (both official and private) into the personal computer, and the concomitant use of local and wide area networks by interacting bureaucracies have played an equally important role in the development of digital federalism. However, arriving at this insight implies at least three analytical preconditions. First, having the courage to distinguish between different types of computing machines, notwithstanding claims of universality. Second, overcoming the pseudo-critical difference between the center and the periphery, and instead recognizing the entanglement of sociotechnical circumstances. Finally, abandoning the search for a hidden masterplan conceived by a *spiritus rector*, a powerful interest group, the *Zeitgeist*, the counterculture, or any other conspiracy to explain the messy, yet powerful situation in which digital federalism finds itself at the end of four decades.

70 On the age of configuration, see David Gugerli and Magaly Tornay, Das Zeitalter der Konfigurationen 1980 bis 2010. Ein Beitrag zur zeithistorischen Debatte, in: Historische Anthropologie, 2018, 26(2): 224–244.