SITC Bulletin Analysis
July 2013

The Tianhe-2 Supercomputer: Less than Meets the Eye?

Brian TSAY
Graduate Researcher
UC Institute on Global Conflict and Cooperation

The Chinese Tianhe-2 (TH-2; 天河二号) is now the fastest supercomputer in the world. Manufactured by China's National University of Defense Technology (NUDT) and the Chinese company Inspur (浪潮), its peak performance—and power consumption—are roughly double that of the next fastest supercomputer, the Cray XK7 Titan located at the Oak Ridge National Laboratory. Titan, the world's former number one supercomputer, has a peak performance of 17.59 petaflops; the TH-2 has a peak performance of 33.86 PFlops.[1] While the TH-2 represents a significant achievement for the Chinese in the race towards exascale computing and the second time a Chinese supercomputer has achieved top ranking, there appears to be less progress in the drive towards indigenous Chinese innovation. Like China's previous supercomputers, the TH-2 continues to rely on foreign sources for critical components—namely the processors—and the development of Chinese software applications for supercomputers continues to lag behind the notable advances in hardware, limiting the practical uses for supercomputers in China.

Supercomputers, often referred to as high-performance computers (HPC), offer far greater performance than typical mainstream computer systems and are used to tackle larger problems and to solve them in a shorter amount of time.[2] Usually, these problems are derived from complex mathematical models of the physical world, simulated from physical systems that are often too complex to analyze through observations or theory. Complex systems and models also tend to generate large amounts of data; supercomputers allow the end user to process these data much more rapidly than mainstream computers. In addition, supercomputer modeling can be used to replace experiments that would be infeasible or just impossible to run. Supercomputers are used in a broad array of scientific fields, including atmospheric sciences, astrophysics, chemical separations, and evolutionary biology, to name a few.[3]

Supercomputing applications can also have implications for national security. In the United States, simulations run on supercomputers are now used in lieu of actual nuclear weapons testing. Accurate supercomputer models are required to evaluate the potential performance of explosives used in nuclear weapons. They are also used to assess the state of America's nuclear stockpile and to predict the effect of aging on weapons components. The ability of

1 One petaflop is one quadrillion floating point operations per second. A floating-point operation is any mathematical operation or assignment that involves floating-point numbers, which have decimal points in them, as opposed to binary integer options. The TH-2 is therefore capable of performing roughly 34 quadrillion of these operations in one second. Performance data for the TH-2 from "Top500 List - June 2013," http://www.top500.org/list/2013/06/.

2 The terms "HPC" and "supercomputing" will be used interchangeably throughout this article.

3 Susan L. Graham, Marc Snir, and Cynthia A. Patterson, eds., *Getting Up to Speed: The Future of Supercomputing* (National Academies Press, 2004), http://www.nap.edu/openbook.php?record_id=11148; *The Potential Impact of High-End Capability Computing on Four Illustrative Fields of Science and Engineering* (National Academies Press, 2008), http://www.nap.edu/openbook.php?record_id=12451.

This material is based upon work supported by, or in part by, the U.S. Army Research Laboratory and the U.S. Army Research Office through the Minerva Initiative under grant #W911NF-09-1-0081. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors(s) and do not necessarily reflect the views of the U.S. Army Research Office.

supercomputers to handle large amounts of information and process it quickly also lends supercomputing to intelligence work requiring the aggregation and prompt analysis of large amounts of streaming, image, spectral, and text data.[4] Finally, the raw computing power of supercomputers allows them to have applications in the field of cryptography.[5]

According to various reports, the Tianhe-2 is expected to be used for climate modeling, medical research, computational fluid dynamics, seismic modeling, optimization problems in quantum mechanics, and larger computational chemistry projects.[6] The role of NUDT as the main manufacturer of the TH-2 suggests, however, that national security applications may figure prominently in its use. The Tianhe-1A, also manufactured by NUDT, is purportedly being used for military purposes and intelligence mining.[7] As the successor of the Tianhe-1A, the TH-2 is expected to be used for the modeling and design of aircraft, potentially including military aircraft.[8] Moreover, development programs for supercomputer software applications also suggest that the TH-2 could be used for military applications, including such dual uses as aircraft design, spacecraft design, complex electromagnetic field simulations, and the design of new materials.[9]

Indeed, NUDT is a key base for scientific research on national defense technologies and advanced weaponry and equipment.[10] Founded in 1953, NUDT is a national key university and falls under the dual supervision of China's Ministry of Education and Ministry of National Defense.[11] NUDT has been responsible for many of China's HPC achievements. NUDT first broke into supercomputing with the 1983 Yinhe-1 (YH-1; 银河-1), or Galaxy-1, which was capable of achieving 100Mflops and was China's first ever supercomputer.[12] NUDT was also behind China's first supercomputers that were capable of performing one billion (YH-2), one trillion (another Galaxy variant), and one quadrillion (Tianhe-1) calculations per second. In terms of hardware and software components, NUDT has also designed its own line of microprocessors, FeiTeng (飞腾), and its own operating system, Kylin (麒麟); both are in use in the TH-2.[13]

Inspur, NUDT's partner on the TH-2, is a Chinese IT group that offers various cloud computing, HPC, server, data center, and software solutions. In addition to working on the TH-2, Inspur was involved in the construction of the Tianhe-1A, rated as the world's fastest supercomputer in 2010, and the Sunway Bluelight, currently China's fourth-fastest supercomputer. Inspur also manufactures its own line of supercomputers, known as Tiansuo (天梭).[14]

---

4 *Scientific Grand Challenges in National Security: The Role of Computing at the Extreme Scale* (Washington, DC: U.S. Department of Energy, Office of National Nuclear Security Administration, and the Office of Advanced Scientific Computing Research, 2009).

5 Graham, Snir, and Patterson, *Getting Up to Speed: The Future of Supercomputing.*

6 Nicole Hemsoth, "China Means Business with Supercomputing Push," HPCwire, June 20, 2013, http://www.hpcwire.com/hpcwire/2013-06-20/china_means_business_with_supercomputing_push.html; Jack Dongarra, "Visit to the National University for Defense Technology, Changsha, China," Oak Ridge National Laboratory, University of Tennessee, June 3, 2013, http://www.netlib.org/utk/people/JackDongarra/PAPERS/tianhe-2-dongarra-report.pdf.

7 "The Team Responsible for Building the 2010 #1 Top500 Supercomputer Tianhe-1A at China's Tianjin-based National Supercomputer Center," accessed July 18, 2013, http://www.hpcwire.com/specialfeatures/people_to_watch_2011/Tianhe-1A-114266824.html.

8 Hemsoth, "China Means Business with Supercomputing Push."

9 "Notice Regarding the Twelfth Five-Year Plan 863 Program 'High Productivity Computing and Application Service Environment' Major Project Call for Proposals [关于征集十二五863计划高效能计算机及应用服务环境重大项目课题建议的通知]," September 23, 2011, http://www.most.gov.cn/tztg/201109/t20110923_89811.htm#.

10 "National University of Defense Technology," June 26, 2007, http://english.chinamil.com.cn/site2/special-reports/2007-06/26/content_858557.htm.

11 "NUDT Profile," http://www.nudt.edu.cn/introduce.asp?classid=4.

12 Jin Zhong, "Recent Advances of Chinese Efforts in HPC," paper presented at the Meeting 6 of the International Exascale Software Project, San Francisco, CA, April 6, 2012, http://www.exascale.org/iesp/IESP:Documents.

13 Yutong Lu, "HPC Efforts in China & Next Gen of Tianhe," paper presented at the Europe-China HPC Conference on "Partnership for Supercomputing Applications," Sofia, Bulgaria, April 8, 2013, http://scc.acad.bg/ncsa/index.php/bg/2011-06-29-08-34-48?task=article&id=198.

14 Dong Zhang, "Inspur and HPC," paper presented at the Europe-China HPC Conference on "Partnership for Supercomputing Applications," Sofia, Bulgaria, April 8, 2013, http://scc.acad.bg/ncsa/index.php/bg/2011-06-29-08-34-48?task=article&id=198.

While NUDT and Inspur were responsible for the manufacture of the TH-2, the project also received much financial support from the Chinese government. Supercomputing in China falls under the purview of multiple government programs at the national level, including the Twelfth Five-Year Plan for Science and Technology (科学技术”十二五”发展规划), the Medium- and Long-Term Plan for the Development of Science and Technology (MLP; 国家中长期科学和技术发展规划), the National High-Tech R&D Program (863; 国家高技术研究发展计划), the National Natural Science Foundation of China (NSFC; 国家自然科学基金委员会), and the National Basic Research Program (973; 国家重点基础研究发展计划). The Twelfth Five-Year Plan runs from 2011 to 2015 and gives a broad overview of China's overall science and technology goals, calling for the development of the next generation of supercomputers and an indigenous Chinese cloud computing platform.[15] Reportedly, a total of 4 billion RMB (~$650 million USD) will be allocated to HPC between 2011 and 2015, with 60 percent of the funding coming from MOST and 40 percent coming from local governments.[16]

The 863 Program, which is updated in tandem with China's Five-Year Plans, is likely the most significant in Chinese HPC. The 863 Program is a major Ministry of Science and Technology program that provides much of the funding for China's major supercomputing projects, including the TH-2. Supercomputing currently falls under the 863 major project "High Productivity Computers and the Application Service Environment" (高效能计算机及应用服务环境重大项目). The stated purpose of the program is to provide supercomputing resources for China's industrial and strategic sectors.[17] According to one source, the 863 Program under the Twelfth Five-Year Plan allocates 1.2 billion RMB (~$190.3 million USD) and an additional 600 million RMB for software.[18]

In addition to building hardware, an additional goal of the 863 Program is to design domestic software suitable for petaflop computing. Ideally, software would be designed to be scalable up to 300,000 cores—the Tianhe-2 has 3.12 million cores—and achieve a parallelization efficiency of no lower than 30 percent, meaning that software is designed in such a manner that the performance gain for every core added, up to 300,000, is no lower than 30 percent. The project has also identified eight main application areas for supercomputing software: fusion and fission simulation, aircraft design, spacecraft design, new drug research and development and protein folding modeling, animation rendering, structural analysis of large-scale engineering projects, complex electromagnetic field simulations, and the design of new materials and performance analysis. Each application area will be allocated 10 million RMB (~$1.63 million USD). There will also be 20 million RMB (~$3.26 million USD) allocated for the research and development of structural mesh, non-structural mesh, non-mesh geometry, and finite element methods. These would be scalable up to 900,000 cores and achieve a parallel efficiency of no lower than 30 percent.[19]

While the software goals appear quite clear, sources differ over China's HPC hardware goals. According to Zhong Jin of the Chinese Academy of Sciences' Supercomputing Center the goal of the current Five-Year Plan is to have multiple petascale supercomputers and to have at least one supercomputer that achieves 50–100 PFlops performance.[20] However, David Kahaner of the Asian Technology Information Program states that the goal is to have two 100 PFlop systems, with one being installed in Guangzhou—ostensibly this is the Tianhe-2—and the other

15 "The Twelfth Five-Year Plan for Science and Technology Development [国家'十二五'科学和技术发展规划]," July 4, 2011, http://www.most.gov.cn/mostinfo/xinxifenlei/gjkjgh/201107/t20110713_88230.htm.

16 Zhong, "Recent Advances of Chinese Efforts in HPC."

17 "Information Technology Under the National Science and Technology R&D Program (863 Program): Guidelines for Applying to the 2009 'High Productivity Computing and Network Service Environment' Major Project [国家高技术研究发展计划（863计划）信息技术领域'高效能计算机及网格服务环境'重大项目2009年度课题申请指南]," April 30, 2009, http://www.most.gov.cn/tztg/200904/t20090430_68951.htm.

18 David Kahaner, "Asia HPC Overview," paper presented at Meeting 8 of 2011 International Exascale Software Project, Kobe, Japan, April 12, 2012, http://www.exascale.org/iesp/IESP:Documents.

19 "Notice Regarding the Twelfth Five-Year Plan 863 Program 'High Productivity Computing and Application Service Environment' Major Project Call for Proposals [关于征集十二五863计划高效能计算机及应用服务环境重大项目课题建议的通知]."

20 Zhong, "Recent Advances of Chinese Efforts in HPC."

being installed in Chongqing. For both, local governments match funding from the 863 Program.[21] The TH-2 has a theoretical peak performance of 54.9 PFlops. If the first source is accurate, then the Tianhe-2 has achieved China's current hardware goals. If the second source is accurate, which is implied by an interview with the chief scientist of HPC applications at Inspur, then the TH-2 has fallen short of the original goal.[22] It is possible that the Tianhe-2 will be later upgraded into a 100 PFlops system, similar to how the Tianhe-1 was upgraded to the Tianhe-1A. Going beyond the current Five-Year Plan, the goal of the Thirteenth Five-Year Plan will be to build an exascale (1000 PFlops) system by the year 2020.[23]

Unlike U.S. supercomputer manufacturers, which use domestic components, China has so far used a combination of foreign and domestic components to achieve its goals. For example, the Tianhe-2's TH-2 interconnect system, Kylin operating system, and FT-1500 processors used in the front-end system are all domestically made.[24] However, much of the improved performance of the Tianhe-2 comes from its use of Intel-designed processors. As a result, the lack of domestic processors in any of the compute nodes indicates that Chinese-designed processors are not yet powerful enough to propel an HPC system into the ranks of the world's fastest supercomputers. While reports had suggested that the NUDT-designed FT-1500 processors would be used to power the entire TH-2 system, these domestic processors are only used in the front-end system that allows the user to send computational tasks to the compute node. They do not add to the TH-2's computing power.[25]

Of the three components that are of domestic origin in the Tianhe-2, the design of the interconnect is the most impressive and the most innovative. Interconnects are used in HPC systems to connect the different nodes of the system and are required for data to be transmitted throughout the entire supercomputer. The world's fastest supercomputers generally use a proprietary interconnect designed by the HPC vendor that built the supercomputer. The fact that a Chinese vendor is capable of designing its own interconnect is a notable feat, although the Tianhe-1A also employs a Chinese-designed interconnect system. Nevertheless, the TH-2 Express interconnect system is an upgrade over the interconnect system used in the Tianhe-1A.

In terms of theoretical performance, the TH-2 marks a significant improvement in Chinese supercomputing. However, the 33.86 PFlops number for the TH-2 is derived from the running of an artificial benchmark; achieving this same performance with real-world scientific applications would be tremendously more challenging. HPC experts at the San Diego Supercomputing Center (SDSC) also note that building a supercomputer that can achieve the same performance achieved by the TH-2 is largely a matter of money: U.S. HPC vendors could build a supercomputer of equal performance if they were given adequate funding. To provide a rough comparison, the Cray XK7 Titan at Oak Ridge unveiled last year reportedly cost $100 million to build, while the TH-2 is purported to have cost 2.4 billion RMB (~$390 million USD).[26]

Despite advances in hardware, it is an open question as to whether China has the software applications to take advantage of the TH-2's upgraded capabilities. Indeed, HPC experts at SDSC stress that the key to supercomputing lies in the applications. On the software application side, China has been weak in terms of designing software that takes advantage of their impressive HPC hardware assets, leading some to question whether China's supercomputers are

21 Kahaner, "Asia HPC Overview."
22 Hemsoth, "China Means Business with Supercomputing Push."
23 Zhong, "Recent Advances of Chinese Efforts in HPC."
24 Dongarra, Visit to the National University for Defense Technology Changsha, China.
25 Zifa Sun, "中国将建全自主国产千万亿次计算机'天河二号' [China to Build a Completely Domestic Petaflop Computer, the 'Tianhe-2']," People's Daily Online, March 3, 2010, http://ccnews.people.com.cn/GB/11061260.html.
26 Michael Feldman, "GPUs Will Morph ORNL's Jaguar Into 20-Petaflop Titan," HPCwire, October 11, 2011, http://www.hpcwire.com/hpcwire/2011-10-11/gpus_will_morph_ornl_s_jaguar_into_20-petaflop_titan.html; "10 Petaflop Computing: Unpacking the World's Fastest Supercomputer [萬萬億次計算 揭秘全世界最強超級計算機]," Xinhua, May 28, 2013, http://big5.xinhuanet.com/gate/big5/news.xinhuanet.com/info/2013-05/28/c_132412965.htm.

being effectively utilized.[27] The difficulty lies in the fact that applications must be tailored for implementation on supercomputers; it is not easy to write code that can actually utilize all the computing power that an HPC system has to offer. The result is that supercomputers can be left idle for long periods of time, raising the question of whether China even needs greater computing capacity.[28] For example, in response to the notion that the TH-2 will be used to improve China's automobile industry, a professor at Tsinghua University's department of automobile engineering commented, "I have never heard of Toyota or Daimler or any major carmaker using a supercomputer to design their cars […] It is like running after a chicken with an axe. It is quite unnecessary."[29] Despite this, funding for hardware continues to outstrip funding for software in China. As of 2012, the software budget for HPC is about one-third of the hardware budget in the United States, while in China, less than 10 percent of HPC funding goes towards software applications.[30]

Regardless, the Tianhe-2 will be moved to China's National Supercomputing Center in Guangzhou by the end of the year. It remains to be seen whether China can develop the software and the expertise to take advantage of the substantial performance increase that it offers. While the Tianhe-2 is a notable accomplishment on the hardware side, it does not seem to represent a significant advancement in China's indigenous innovation capabilities beyond the design of interconnect systems. China continues to rely on foreign sources for the "brains" of its supercomputers—the processors—and even with its fast supercomputers, China does not appear to have the software capabilities to match its advancements in the hardware arena.

---

27 Depei Qian, "HPC and e-Infrastructure Development in China," paper presented at the 2011 Fall Creek Falls Conference, Gatlinburg, TN, September 15, 2011, http://computing.ornl.gov/workshops/FallCreek11/presentations/d_qian.pdf; Bob Davis, "China's Not-So-Super Computers," *Wall Street Journal,* March 23, 2012, sec. Business Technology, http://online.wsj.com/article/SB10001424052702303812904577298062429510918.html; Stephen Chen, "World's Fastest Computer, Tianhe-2, Might Get Very Little Use," South China Morning Post, June 20, 2013, http://www.scmp.com/news/china/article/1264529/worlds-fastest-computer-tianhe-2-might-get-very-little-use; Richard Stone and Hao Xin, "Supercomputer Leaves Competition—And Users—in the Dust," Science 330, no. 6005 (November 5, 2010): 746–747, doi:10.1126/science.330.6005.746-a.

28 Chen, "World's Fastest Computer, Tianhe-2, Might Get Very Little Use."

29 Yutong Lu, "Overview of Tianhe-2 (MilkyWay-2) Supercomputer," paper presented at the International Supercomputing Conference, Leipzig, June 17, 2013, http://www.asc-events.org/13en/To%20web/!!!TH2-ISC13-Inspur-LYT.pdf; Chen, "World's Fastest Computer, Tianhe-2, Might Get Very Little Use."

30 Davis, "China's Not-So-Super Computers."