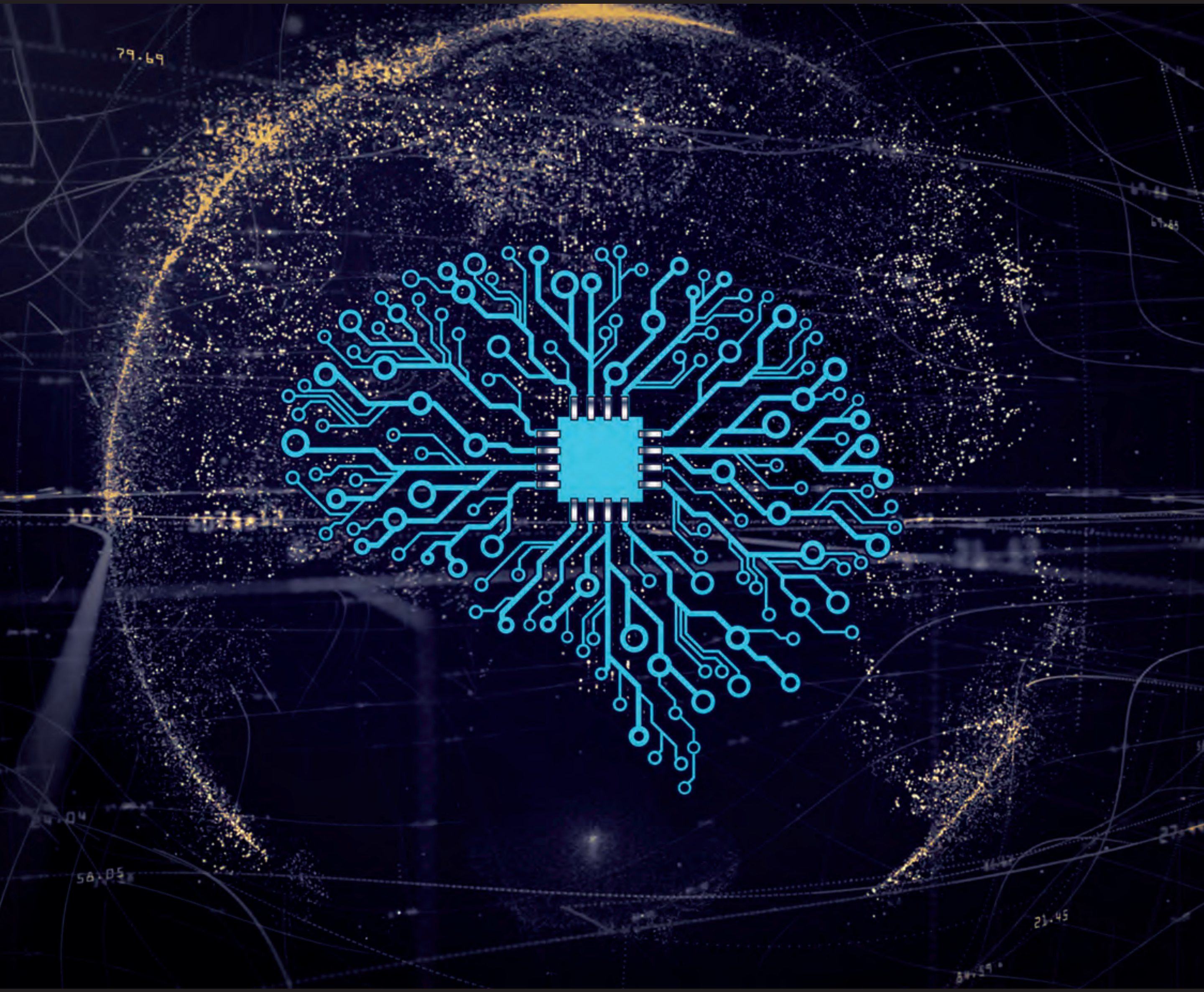


China is pursuing what its leaders call a "first-mover advantage" in artificial intelligence (AI), facilitated by a state-backed plan to achieve breakthroughs by modeling human cognition. (www.vpnsrus.com)

China's "New Generation" AI-Brain Project

By Wm. C. Hannas and Huey-Meei Chang

China is pursuing what its leaders call a "first-mover advantage" in artificial intelligence (AI), facilitated by a state-backed plan to achieve breakthroughs by modeling human cognition. While not unique to China, the research warrants concern since it raises the bar on AI safety, leverages ongoing U.S. research, and exposes U.S. deficiencies in tracking foreign technological threats.

The article begins with a review of the statutory basis for China's AI-brain program, examines related scholarship, and analyzes the supporting science. China's advantages are discussed along with the implications of this brain-inspired research. Recommendations to address our concerns are offered in conclusion. All claims are based on primary Chinese data.[1]

China's Plan to "Merge" Human and Artificial Intelligence

Analysts familiar with China's technical development programs understand that in China things happen by plan, and that China is not reticent about announcing these plans. On July 8, 2017 China's State Council released its "New Generation AI Development Plan"[2] to advance Chinese artificial intelligence in three stages, at the end of which, in 2030, China would lead the world in AI theory, technology, and applications.[3] The announcement piqued the interest of the world's techno-literati[4] in light of the plan's unabashed goal of world hegemony, its state backing, and a well-founded belief that China is already a major AI player.[5] Although China still lags in semi-conductor design and basic AI research, it is moving to address —or circumvent— these problems, lending credence to its long-term aspirations.

Buried in this plan, and absent entirely from the Western dialog on China AI, is what we see as that country's most interesting and potentially significant research, namely, a top-down program to effect a "merger" (混合) of human and artificial intelligence. These efforts to use neuroscience to inform AI, and vice-versa, date to at least 1999[6] and precede China's focus on AI as a standalone discipline. Whereas the earliest appearance of AI in a ministry notification was in July 2015,[7] China's "National Medium- and Long-term S&T Development Plan"[8] issued in 2006 had already identified brain science and cognition among its top research priorities. The 2016 "Notification on National S&T Innovation Programs for the 13th

William Hannas is Lead Analyst at Georgetown's Center for Security and Emerging Technology (CSET).
Huey-Meei Chang is a Research Analyst at Georgetown's Center for Security and Emerging Technology (CSET).

Five-Year Plan" mentioned AI but did not count it among its major projects.[9] What appeared instead was "brain science and brain-inspired research" defined as "brain-inspired computing" and "brain-computer intelligence."

This timeline establishes "AI-brain research" as a line of inquiry in China before AI became a household word and a focus of state interest. In March 2016, the "China Brain Project" (中国脑计划) was approved, a 15-year effort that "prioritized brain-inspired AI over other approaches."[10] In May of the same year, Chinese president Xi Jinping publicly endorsed one of its key pillars:

> "Connectomics is at the scientific forefront for understanding brain function and further exploring the nature of consciousness. Exploration in this area not only has important scientific significance, but also has a guiding role in the prevention and treatment of brain disease *and the development of intelligent technology*." (our emphasis)[11]

Taking these circumstances into account, it is not surprising that the 2017 New Generation AI Development Plan[12] uses the word "brain" 27 times and "brain-inspired/neuromorphic" (类脑) some 20 times. The plan's "strategic goals" include "major breakthroughs in brain-inspired intelligence, autonomous intelligence, mixed [human-artificial] intelligence, swarm intelligence, and other areas so as to have an important impact in the area of international AI research, and occupy the commanding heights of AI technology." The document goes on to explain:

> "Brain-like intelligent computing theory focuses on breakthroughs in brain-like information coding, processing, memory, learning, and reasoning theories; on forming brain-like complex systems, brain-like control, and other theories and methods; and on establishing new models of large-scale brain-like intelligent computing and brain-inspired cognitive computing models."

In terms of priorities, "AI-brain" occupies two of the plan's eight "basic theory" categories: "(3) hybrid enhanced intelligent theory" and "(7) brain intelligent computing theory," defined as:

> "Research on 'human-in-the-loop' hybrid enhanced intelligence, human-computer intelligence symbiosis behavior enhancement and brain-computer collaboration, machine intuitive reasoning and causal models, associative memory models and knowledge evolution methods, hybrid enhanced intelligent learning methods for complex data and tasks, cloud robot collaborative computing methods, situational understanding in real-world environments, and human-machine group collaboration."

and,

> "Research theories and methods of brain-like perception, brain-like learning, brain-like memory mechanisms and computational fusion, brain-like complex systems, and brain-like control."

In sum, China's New Generation AI plan aims to "build for China a *first-mover advantage* in artificial intelligence development," [13] which to us invokes the self-bootstrapping scenario—a mainstay of the AI safety literature—of a country with an early AI advantage leveraging its lead past the point where others are able to compete.

China's AI-Brain Academic Research

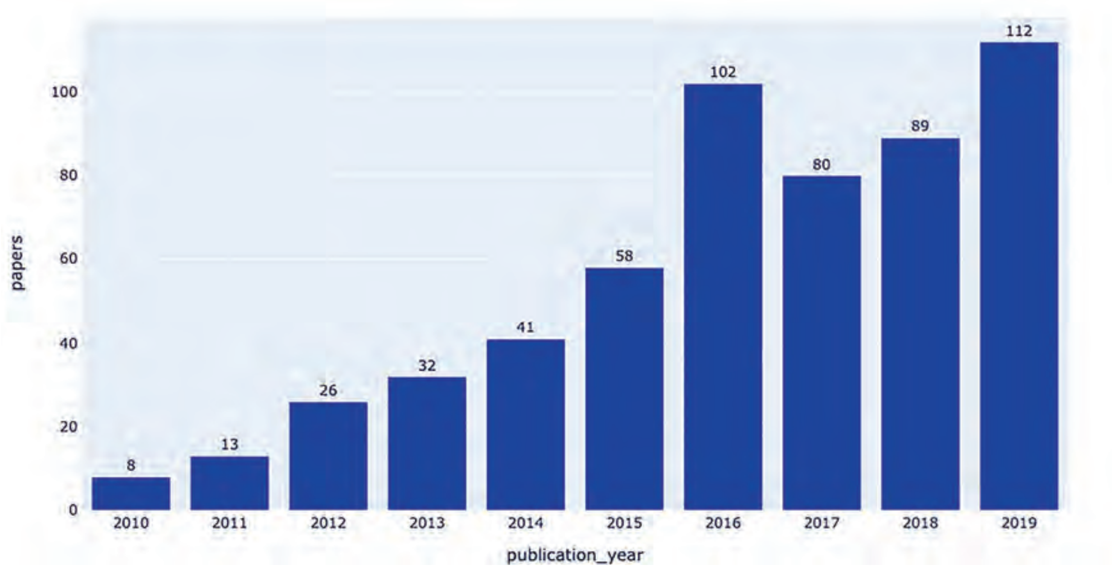
2016 was a watershed year in terms of China's AI-brain scholarship. We identified a core group of six papers published that year by leading Chinese researchers that define China's approach to this hybrid area and signal acceptance of the paradigm:

- "Retrospect and Outlook of Brain-inspired Intelligence Research" (类脑智能研究的回顾与展望).[14]
- "Brain Science and Brain-inspired Intelligence Technology-an Overview" (脑科学与类脑研究概述).[15]
- "Progress and Prospect on the Strategic Priority Research Program of 'Mapping Brain Functional Connections and Intelligence Technology'." ("脑功能联结图谱与类脑智能研究"先导专项研究进展和展望).[16]
- "The Human Brainnetome Atlas: A New Brain Atlas Based on Connectional Architecture."[17]
- "Neuroscience and Brain-inspired Artificial Intelligence: Challenges and Opportunities" (神经科学和类脑人工智能发展：机遇与挑战).[18]
- "China Brain Project: Basic Neuroscience, Brain Diseases, and Brain-inspired Computing" (全面解读中国脑计划：从基础神经科学到脑启发计算).[19]

The content of these and other key studies is described in our technical review of China's AI-brain program;[20] these samples give a sense of the topics and players. That same year—2016—saw the start of an upward trend in the number of papers by Chinese scientists on brain-inspired AI specifically, one of the discipline's three defining elements.[21]

Meanwhile, China's National Natural Science Foundation (NNSF), the main sponsor of state grants to individual scholars, in August 2017 solicited proposals for 25 AI projects, most of which are brain-related, within the following ten approved research areas:[22]

1. Multi-modal, efficient cross domain perception and augmented intelligence
2. Machine understanding of perception and behavior under uncertain conditions
3. New methods for complex task planning and reasoning
4. Machine learning theory and methods based on new mechanisms (deep reinforcement learning, adversarial learning, brain-like / natural learning)



Brain-inspired AI papers in China's CNKI database
(reprinted with permission from GU/CSET "China AI-brain Research")

5. New brain-inspired computing architectures and methods
6. New methods of human-machine hybrid intelligence
7. Chinese semantic computing and deep understanding (machine reading comprehension and Chinese text creation, human-computer dialogue, etc.)
8. New computing devices and chips for artificial intelligence
9. Heterogeneous multi-core parallel processing methods and intelligent computing platforms
10. Machine intelligence test models and evaluation methods

In January 2018, NNSF funding guidelines recognized AI for the first time as an independent category, but also listed *nine specific subcategories* for "cognitive and neuroscience-inspired AI." Here are the topics and their respective funding codes:[23]

China NNSF cognitive-neuroscience-inspired AI funding subcategories

F060701 computational modeling of cognitive mechanisms (基于认知机理的计算模型)

F060702 modeling attention, learning, and memory (脑认知的注意、学习 与记忆机制的建模)

F060703 audiovisual perception modeling (视听觉感知模型)

F060704 neural information encoding and decoding (神经信息编码与解码)

F060705 neural system modeling and analysis (神经系统建模与分析)

F060706 neuromorphic engineering (神经形态工程)

F060707 neuromorphic chips (类脑芯片)

F060708 brain-like computing (类脑计算)

F060709 BCI and neural engineering (脑机接口与神经工程)

Besides NNSF support, China's Ministry of Science and Technology, the Chinese Academy of Sciences (CAS), and local municipalities also announced grants for AI-brain research.[24] In terms of scholarship and support, it is clear that China has committed to this alternative paradigm.

What Constitutes "AI-Brain" Science in China?

As confirmed by a survey of its practitioners, three areas of research contribute to China's AI-brain program: brain-inspired artificial intelligence (BI-AI, 类脑智能), connectomics ("brain mapping"人脑连接组), and brain-computer interfaces (BCI, 脑机接口).[25]

- BI-AI seeks mathematical descriptions of brain processes that contribute to behavior. This is understood literally, not as metaphor—the models match the actual "computation performed by biological wetware."[26]
- Connectomics involves empirical and computational efforts to replicate brain structure and functioning. The link with AI derives from a need to invoke AI to test simulations, and from AI's role in interpreting (aligning) images of brain sections.
- BCIs acquire electrical signals from the brain, interpret them, and optionally transform the signals into actions. Their link with AI is twofold: AI is used to process brain signals and, potentially, support direct access to computing resources.

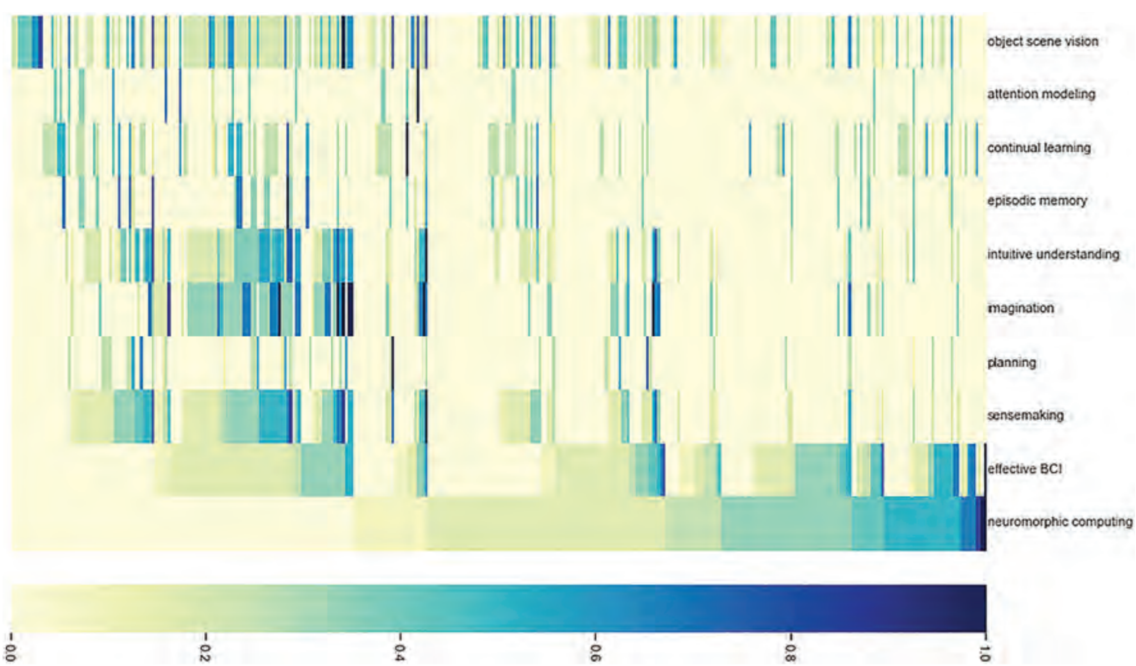
Although some goals of this research mirror mainstream AI, the difference is while the latter may seek to replicate brain behavior, the new approach emulates the actual neuronal functioning that gives rise to behavior. The motivation for BI-AI (and its companion discipline connectomics) is the empirical observation that the human brain, with minimal resources, effortlessly performs many high-order tasks beyond the reach of today's machine learning (ML).

A short list of these tasks, culled from standard references,[27] includes object/scene vision, attention modeling, continual learning, episodic memory, intuitive understanding, imagination, planning, and sensemaking. Two other goals are effective BCI (minimally invasive interfaces with useful throughput) and neuromorphic computing (hybrid digital-analog chips that mimic brain structure). In this context, we examined 561 Chinese papers and found 352 of them binning into one or more of the aforementioned categories, indicating that Chinese BI-AI research aligns with worldwide scientific aspirations.

Further testimony to China's commitment comes from the number of institutes, state and university affiliated, engaged in BI-AI, connectomics, or BCI as their primary research area. We identified 30 such institutes, including concentrations in Beijing and Shanghai, and in provincial locations such as Chengdu, Guangzhou, Hangzhou, Harbin, Hefei, Nanjing, Qingdao, Shenzhen, Suzhou, Tianjin, Wuhan, Xiamen, and Zhengzhou, exclusive of facilities working the disciplines peripherally.

We are struck by the caliber of personnel, collaborative networks, and research directions at three of these "outlying" institutes: the Fujian Key Laboratory for Brain-like Intelligent Systems (福建省仿脑智能系统重点实验) operating since 2009 in Xiamen;[28] the HUST-Suzhou Institute for Brainsmatics (华中科技大学苏州脑空间信息研究院) established 2016 at Wuhan's Huazhong University of S&T; and Hefei's National Engineering Laboratory for Brain-inspired Intelligence Technology and Application (NEL-BITA) (类脑智能技术及应用国家工程实验室), a government-sponsored lab set up in 2017 with China's major AI companies and Microsoft Research Asia.

NEL-BITA researches brain cognition and neural computing, brain-inspired multimodal sensing and information processing, brain-inspired



"Heat map" of 352 Chinese BI-AI technical journal articles. The color spectrum of each segment is the paper's category affinity. (reprinted with permission from "China AI-brain Research") chips and systems, "quantum artificial intelligence," and brain-inspired intelligent robots.[29] The HUST-Suzhou "Brainsmatics" facility, whose work has been praised by the Allen Institute's chief scientist,[30] has pioneered research in micro-optical sectioning tomography on its way to creating a high-resolution mammalian brain atlas.[31] Bear in mind that these are institutes *outside* the main research nexus.

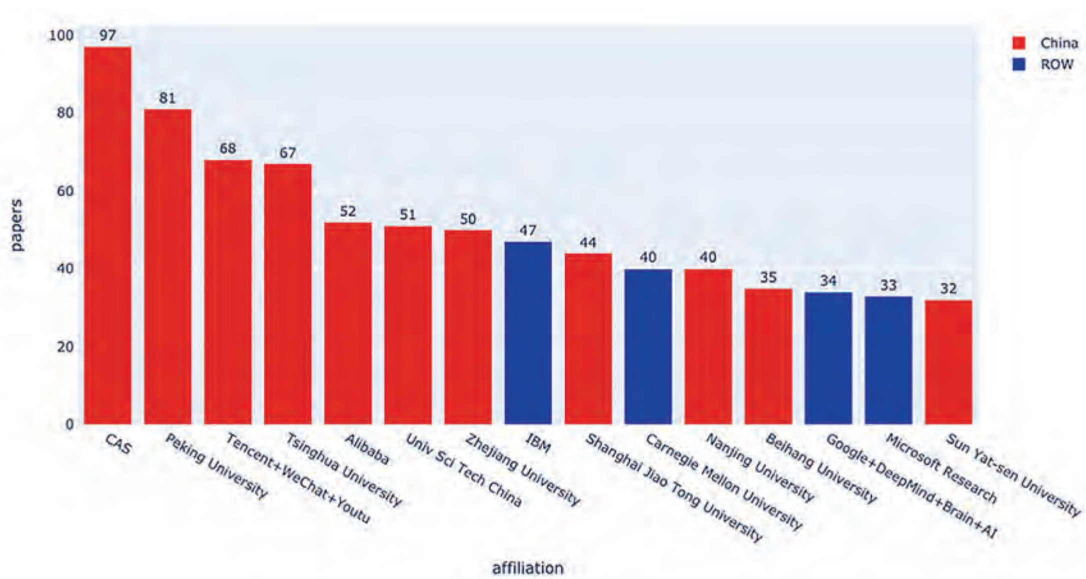
Meanwhile, Pu Muming's Center for Excellence in Brain Science and Intelligence Technology (中国科学院脑科学与智能技术卓越创新中心), one of three major complexes in Shanghai, is host to a "G60 Brain Intelligence Innovation Park" established in 2018 with a U.S. $1.5 billion budget for BI-AI research and $2.85 billion more promised in 2020.[32] The facility uses cloned monkeys.[33] A final example, from Beijing, is Tsinghua University's Center for Brain-inspired Computing Research (清华大学类脑计算研究中心), established in 2014 to study neural coding, ML algorithms, and chip architecture.[34]

The China-ROW Balance Sheet

China enjoys several advantages over other nations in AI-brain research. We lay this out for consideration without judgment on how these advantages may play out. Similar research is being conducted worldwide and we have no crystal ball to foretell what nation will prevail in the global AI competition (if "prevail" is the right way to frame the matter). For China, seven such factors come to mind, the first three being the usual staples about *China's more permissive experimental ethos, abundance of data, fewer privacy concerns on data collection and use*, and the fourth being *national commitment*, which we have been at pains to demonstrate. The other advantages require elaboration.

Fifth, and most obvious, is China's *AI talent*, as shown in a breakdown of papers accepted at the Association for the Advancement of Artificial Intelligence's (AAAI) 2020 conference, a central event for the world's AI community.[35]

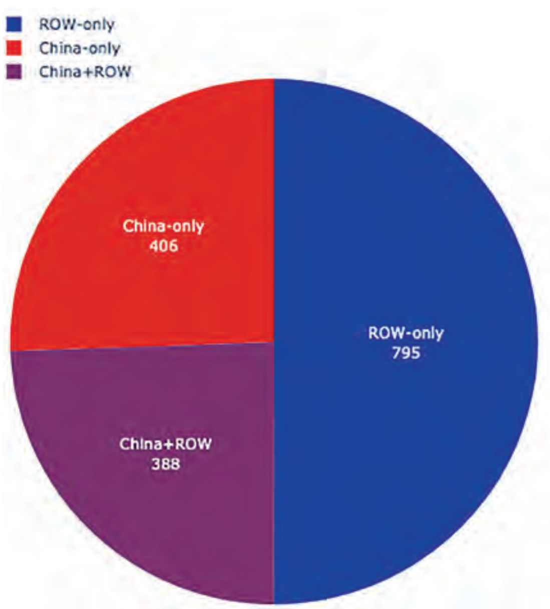
The key takeaway is that ownership of the event has slipped from U.S. institutions, which dominated previous years.[36] A China-ROW comparison of papers at the NeurIPS 2019 conference, a more focused gathering where China is a relative newcomer, had scholars from Tsinghua University placing 13th in number of accepted papers.[37] In



AAAI 2020 Accepted Papers - Top Affiliations

2020, Tsinghua papers ranked 7th behind AI giants Google, Stanford University, MIT, Microsoft, UC Berkeley, and Carnegie Mellon, all of which are targets of PRC "talent" co-option programs, if not actively cooperating with China already (see technology transfer discussion below).[38]

Both the AAAI and NeurIPS conferences had roughly the same paper acceptance rate (20.6 percent and 21.2 percent), so it is clear China is playing with the best. Chinese participation at these two key events would be skewed more in China's favor if we account for co-authorship and the national origins of authors with non-China affiliations. Here is another breakdown of the AAAI 2020 event that accommodates co-authorship:



AAAI 2020 Accepted Papers - China and ROW

Papers by authors with China-only affiliations are 26 percent of the total. Papers by authors with China affiliations collaborating with authors claiming other (rest-of-world) affiliations constitute another 24 percent. Together they account for half of the papers.[39] Statistics for the NeurIPS 2019 gathering show 42 percent of accepted papers having "Chinese authorship" (华人作者).[40] The importance of Chinese AI talent can also be measured by the stream of arguments from our own Georgetown center for measures to retain Chinese students and other diaspora talent to keep the U.S. competitive, a position we wholly support.[41]

A sixth advantage is China's *near monopoly on non-human primates* (NHP) regarded by most AI-brain researchers as essential.[42] By 2016, when China's AI-brain project had come into its own, high-tech primate facilities already existed in Guangzhou, Hangzhou, Shenzhen, Suzhou, and elsewhere in Guangxi, Hainan, and Yunnan. While other countries were scaling back NHP production, China was raising laboratory grade monkeys in volume at a fraction of the cost for export and as a lure to foreign scientists, inhibited by domestic restrictions, to conduct their research in China.[43]

Nikos Logothesis, director of the Max Planck Institute for Biological Cybernetics, one of several brain scientists who migrated some or all of their research to China, announced plans to co-direct with Shanghai neuroscientist Pu Muming (Mu-ming Poo) an International Center for Primate Brain Research[44] built at a cost of U.S. $106 million.[45] Pu's success in cloning monkeys, which speeds breeding and eliminates genetic variation, is another draw.[46]

Finally, we consider *foreign technology transfer*, generally seen as a sign of weakness but which we regard—from China's perspective—as a stunning advantage. For more than six decades China has operated a comprehensive program of foreign technology appropriation to remedy shortcomings in indigenous science and technology without the cost, risk, and political challenges incurred by the world's liberal democracies. The phenomenon has been documented in scholarly and government studies both in general[47] and for AI.[48] It has been briefed to U.S. and allied elected and counterintelligence officials, who are well-informed on the matter, and is a mainstay of media reporting, so that the discussion turns

Neural Net Accelerator Board for China's Artificial Brain (brewbooks, licensed with CC BY-SA 2.0.)

not on whether these illegal and extralegal transactions take place but rather on what to do about it.

We raise the matter to emphasize that whatever else one thinks of it, China's hybrid system of indigenous innovation and foreign "borrowing" has been extraordinarily effective. China through its outreach efforts, talent programs, diaspora exploitation, cooperative ventures, open source tracking, overseas support guilds, indigenization enclaves, "two-bases" and "short-term return" schemas, and other hidden or barely disguised practices has mastered the skill of adapting useful technologies created abroad into its own (under-rated) indigenous enterprises.[49]

If these are China's advantages, what are its disadvantages? Two deficits are commonly cited: chip design and fabrication, and foundational research. We defer judgment on the former, which is outside our fields of expertise. As for the latter, China is seen as weak in basic research, specifically in AI theory, by the country's top practitioners. Sinovation founder and best-selling AI author Kai-Fu Lee argues that China's forte is its ability to create practical AI products, not revolutionize the field.[50] His point is supported by top Chinese scientists. Here is a sample:[51]

- Sun Maosong (孙茂松), Tsinghua University professor of computer science, argues that China lacks leaders in world-class scientific research and falls behind other countries in training "top talent in the basic sciences."[52]
- Tan Tieniu (谭铁牛), deputy director of CAS (see below), claims "At present, China is still in the 'follow-up' position in terms of frontier theoretical innovation of artificial intelligence. Most of the innovations are focused on technology applications."[53]

- Xu Kuangdi (徐匡迪) former head of the Chinese Academy of Engineering (CAE) said, "The cornerstone of artificial intelligence is mathematics, and the key element is algorithms. But China's investment in this field is far behind the United States."[54]
- Yau Shing-Tung (丘成桐), Harvard professor and Fields Medal winner, concludes that China "is still some distance from the United States and Britain in terms of basic theory and algorithm innovation."[55]
- Zheng Nanning (郑南宁), another CAE academician, believes it will take China another 5 to 10 years to reach world levels in basic theoretical and algorithmic research. Hardware design is also an issue.[56]

We regard these complaints as valid but vacuous: theory cannot be embargoed and there is no will to do so either by governments or by scientists,[57] who embrace collaboration as part of their enterprise. Accordingly, to the extent this is a problem at all, China is addressing it as it always has, by a robust program of foreign interaction, cooperation, co-option, licit and illicit transfers, and—like everyone else—by monitoring publicly available information.[58]

The Chimera of AGI

China's decision to focus on AI-brain research leads to speculation that the effort may be aimed at the "holy grail" of artificial general (human level) intelligence (AGI), or will end up there as an unintended consequence of this brain-centric pursuit. Indeed, as will be shown, that view is held by many Chinese researchers. The issue in a nutshell is this: in contrast to AI, which focuses on narrow problems of "creating programs that demonstrate intelligence in one or another specialized area,"[59] AGI aims at,

> "the construction of a software program that can solve a variety of complex problems in a variety of different domains, and that controls itself autonomously, with its own thoughts, worries, feelings, strengths, weaknesses and predispositions."[60]

In other words, the elements of human cognition—with instant access to the sum of the world's knowledge and ability to process that information at lightning speed. Since BI-AI models brain function to enhance AI programs, there is a tendency among scientists working in brain-inspired AI to equate their research with this outcome. A survey of China's AI scientists revealed 74 percent believe BI-AI will lead to general AI. The number rises to 83 percent among China's BI specialists.[61] These figures are buttressed by statements from BI-AI principals of standing:

Xu Bo (徐波), director of the CAS Institute of Automation—host to Beijing's Research Center for Brain-inspired Intelligence (home of the "Brainnetome" connectomics project), Associate Director of Shanghai's Center for Excellence in Brain Science and Intelligence Technology (中国科学院脑科学与智能技术卓越创新中心, CEBSIT), and chair of the "Next Generation Artificial Intelligence Strategic Advisory Committee" is cited in the Ministry of Science and Technology's official newspaper *S&T Daily*:

> "As General Secretary Xi Jinping pointed out in the collective study of the Politburo, artificial intelligence research must explore 'unmanned areas.' In the areas of swarm intelligence, human-machine hybrid intelligence and autonomous intelligence, there are large unmanned areas to be explored… We believe that autonomous evolution is a bridge from weak artificial intelligence to general artificial intelligence."[62]

Shi Luping (施路平), director of the Center for Brain-inspired Computing Research, Tsinghua University and leader of the research group that created the Tianjic neuromorphic chip, has a novel epistemological take on the emergence of AGI:

> "Our human intelligence is built on carbon, and we have built the current digital universe on silicon. The structure of carbon and silicon is very similar, so we believe what can be realized on carbon, must be possible on silicon… Moreover, nanodevices have enabled us to develop electronic devices such as neurons and synapses at the level of human brain energy consumption, so now is the best time to develop artificial general intelligence."[63]

Tan Tieniu (谭铁牛), deputy director of the Chinese Academy of Sciences, deputy chief of the PRC's liaison office in Hong Kong, and a leading AI figure, explained in *Qiushi*, the Communist Party's main theoretical journal:

> "How to make the leap from narrow artificial intelligence to general artificial intelligence is the inevitable trend in the development of the next generation of artificial intelligence. It is also a major challenge in the field of research and application."[64]

Zeng Yi (曾毅), deputy director of CAS's Research Center for Brain-inspired Intelligence, 2019 member of the New Generation Artificial Intelligence Governance Expert Committee, and keynote speaker at "AGI-19," the 12th annual international conference on AGI:

> "Whether to develop general artificial intelligence, or limit it to specific AI is a major point of divergence among many proposals for artificial intelligence guidelines… In fact, the development of dedicated [专用, 'narrow'] AI does not completely avoid risk, because the system is likely to encounter unexpected scenarios in its application. Having a certain general ability may improve the robustness and adaptiveness of an intelligent system."[65]

Huang Tiejun (黄铁军), chair of Peking University's Department of Computer Science, dean of the Beijing Academy of Artificial Intelligence, and also a 2019 member of the New Generation Artificial Intelligence Governance Expert Committee:

> "My point is different from that of the other colleagues. Absolutely we should [build superintelligence]. Our human race is only at one stage. Why stop? Humans evolve too slowly. It's impossible for humans to compare to machine-based superintelligence. It will happen sooner or later, so why wait? Even from the perspective of human centrism or human exceptionalism, superintelligence is needed to face big challenges that we can't figure out. That's why I support the idea." (Future of Life conference)[66]

Other such prognostications are commonplace.[67] As part of the trajectory, China's Ministry of Science and Technology and the Beijing city government in 2020 stood up a "Beijing Institute for General Artificial Intelligence" (北京通用人工智能研究院, BIGAI)[68] headed by returned UCLA professor and renowned AI scientist Zhu Songchun (朱松纯),[69] in concert with Peking University's Institute for Artificial Intelligence and Tsinghua University's own (planned) AGI institute.[70] The facility is in Beijing's Haidian districts and will be staffed by some 1,000 researchers drawn from China and, as usual, "all over the world."[71]

The move will lead to clones, first in Shanghai then the other major cities and provinces. Our concerns are two-fold. Firstly, AI hype tends to outpace its accomplishments, and the former should not become the basis for fear and countermeasures. In our view, a *move toward* AGI is a natural feature of AI research, in China or anywhere, as AIs become more capable. While the research warrants scrutiny, we believe AGI, understood literally, is not imminent (five years out) but possible in some form by the end of the decade.

Beijing Institute of General Artificial Intelligence

Inviting talents from all over the world

Secondly—and more ominously—AGI may not be the best way to envision the result of brain-inspired or other lines of AI research. One need not subscribe to an AGI scenario to appreciate that *all AI research* entails risks. Nor is AGI a necessary condition for "superintelligence." Here is one scenario, for example, which is plausible over a shorter term and comes directly from a credible Chinese source:

> "Speaking of the brain-computer interaction of tomorrow, we will move from intelligence [of one type] to intelligence [of another] (从智能而来，到智能而去). The future is not about replacing human beings with artificial intelligence, but making AI a part of human beings through interconnection and interoperability. A blend of human and computer without barriers is the inevitable end of the future."[72]

This potential outcome, a way station on the path to AGI, portends fundamental changes in the human condition, indeed, in the nature of humanity and is cause for concern by itself.

Policy recommendations

The authors are daunted by the expectation that we propose policies addressing the issues we write about—something not encouraged in our former lives. Here are three, offered in good faith.

1. Pay greater attention to AI safety

We assess the likelihood of China achieving artificial general intelligence (AGI) through BI-AI within the next five years as improbable. Chinese scientists agree. The project is in its infancy and there is nothing in the open literature to suggest China has made breakthroughs in key areas. We are less confident other troublesome aspects of this research will not emerge sooner rather than later. We encourage the U.S. government, allied nations, and scientists worldwide to draw China and its AI cadre into a strong safeguards regime to manage these common dangers.

2. Mitigate greyzone technology transfers

China's appetite for foreign technology, obtained with or without permission, is insatiable and we see no indication that China's status as an emerging S&T power will impact this behavior. Absent a concerted effort to control technology transfers, the rest of the world is disadvantaged as it invests resources in technologies that China acquires gratis. We propose the creation of dedicated centers, nationally and internationally, to monitor "informal" technology transfers and refer them to cognizant authorities. The framework should also encompass legal transfers of sensitive technology where national security is at risk.[73]

3. Build a "National S&T Analysis Center"

China's AI-brain project blossomed in 2016, yet there has been no significant reporting about it outside China. As we describe elsewhere,[74] U.S. intelligence agencies, unlike China's, are ill-equipped to detect emerging technologies because their secrets-based platforms, a Cold War relic, are not tuned to capture worldwide scientific trends. Open source intelligence, by contrast, is well poised to provide the "indications and warnings" to reduce technology surprise. Realizing its full value will happen under the auspices of an organization established *outside the IC* to provide assessments and forecasts of S&T developments without institutional biases. **PRISM**

Notes

[1] This study expands on research done at Georgetown University, reported in the authors' "China AI-Brain Research: brain-inspired AI, connectomics, brain-computer interfaces."https://cset.georgetown.edu/research/china-ai-brain-research/. We thank CSET's Lynne Weil for connecting us with PRISM, Daniel Chou for data and graphics support, and Founding Director Jason Matheny for his counsel on AI policy.

[2] 国务院关于印发新一代人工智能发展规划的通知. State Council (35).

[3] Hannas and Chang, "China's 'artificial' intelligence," in Wm. C. Hannas and Didi Kirsten Tatlow, eds. *China's Quest for Foreign Technology: Beyond Espionage*, Routledge, 2021.

[4] Roberts, H., Cowls, J., Morley, J. *et al*. "The Chinese approach to artificial intelligence: an analysis of policy, ethics, and regulation," *AI & Soc* (2020). https://doi.org/10.1007/s00146-020-00992-2. Sarah O'Meara, "Will China lead the world in AI by 2030?," *Nature*, August 21, 2019. https://www.nature.com/articles/d41586-019-02360-7.

[5] Kai-Fu Lee, *AI Superpowers: China, Silicon Valley, and the New World Order*, 2018.

[6] Pu Muming' Shanghai-based "International Mesoscopic Connectome Project," a part of the Chinese Academy of Sciences' Institute of Neuroscience, was founded in November 1999. A "Beijing Key Laboratory of Human-Computer Interaction" was stood up the same year.

[7] PRC State Council, "国务院关于积极推进 "互联网 +" 行动的指导意见 (State Council Guiding Opinions on Positively Promoting 'Internet +' Activity)," No. 40, July 1, 2015. The notification promoted "AI and other technologies" as catalysts for commercial products, not as a self-contained discipline.

[8] PRC State Council, "国家中长期科学和技术发展规划纲要(2006-2020年) (National Medium- and Long-term S&T Development Plan (2006-2020))," February 9, 2006.

[9] PRC State Council, "国务院关于印发 "十三五" 国家科技创新规划的通知 (State Council Notification on National Science and Technology Innovation Programs for the 13th Five-Year Plan)," No. 43, July 28, 2016.

[10] Mu-ming Poo (Pu Muming), "Towards brain-inspired artificial intelligence," in *National Science Review* 5: 785 (October 25, 2018).

[11] Xi Jinping, "Striving to Build a World S&T Superpower," May 2016. http://www.xinhuanet.com/politics/2016-05/31/c_1118965169.htm.

[12] PRC State Council, "New Generation AI Development Plan." Translation by the Foundation for Law and International Affairs, verified by the present authors.

[13] Ibid.

[14] Zeng Yi (曾毅), Liu Chenglin (刘成林), Tan Tieniu (谭铁牛) in *Chinese Journal of Computers* (计算机学报), 39(1), January 2016, 212-222.

[15] Pu Muming (蒲慕明), Xu Bo (徐波), Tan Tieniu (谭铁牛) in *Bulletin of Chinese Academy of Sciences* (中国科学院院刊), 31(7), July 2016, 725-736.

[16] Zhang Xu (张旭), Liu Li (刘力), Guo Aike (郭爱克) in *Bulletin of Chinese Academy of Sciences* (中国科学院院刊), 31(7), July 2016, 737-746.

[17] Fan Lingzhong (樊令仲) and 13 others, primarily with Chinese institutional affiliations, in *Cerebral Cortex*, 26 (8), August 2016.

[18] Han Xue (韩雪), Ruan Meihua (阮梅花), Wang Huiyuan (王慧媛), Yuan Tianwei (袁天蔚), Wang Chaonan (王超男), Fu Lu (傅璐), Chen Jing (陈静), Wang Xiaoli (王小理), Xiong Yan (熊燕), Zhang Xu (张旭) in *Chinese Bulletin of Life Sciences* (生命科学), 28.11, November 2016, 1295-1307.

[19] Pu Muming (蒲慕明), Du Jiulin (杜久林), Nancy Y. Ip (叶玉如), Xiong Zhiqi (熊志奇), Xu Bo (徐波), Tan Tieniu (谭铁牛) in *Neuron* 92.3, November 2016. The Chinese version of the paper, issued separately, omits "Brain Diseases" from the title. It reads literally: "Comprehensive interpretation of the China Brain Project: from basic neuroscience to brain-inspired computing." The content of the two versions is comparable.

[20] Hannas and Chang, "China AI-Brain Research: Brain-inspired AI, Connectomics, Brain-computer Interfaces," Georgetown University / CSET, September 2020.

[21] The authors retrieved some 22,000 documents (2010-2019) from the China National Knowledge Infrastructure (CNKI) database of Chinese academic journals that responded to an abbreviated list of keywords on AI-brain topics. The chart is based on a hand-curated subset of papers that address the BI-AI topic specifically. The survey did not include papers in English or those whose primary authors are diaspora (overseas) Chinese.

[22] http://www.nsfc.gov.cn/publish/portal0/tab452/info69927.htm.

[23] http://www.research.pku.edu.cn/docs/2018-07/20180702201045167492.pdf.

[24] https://www.sciping.com/21237.html; http://www.cebsit.ac.cn/xwdt/202007/t20200722_5639392.html; http://news.sciencenet.cn/htmlnews/2021/1/452104.shtm; https://www.yicai.com/news/100028706.html.

[25] Some Chinese scholars add a fourth pillar: neuromorphic computing and chips. See Hannas and Chang, "China AI-Brain Research: Brain-inspired AI, Connectomics, Brain-computer Interfaces," Georgetown University / CSET, September 2020.

[26] IARPA, "IARPA Seeks Partners in Brain-Inspired AI Initiative," January 22, 2015, www.iarpa.gov/index.php/research-programs/microns.

[27] Olaf Sporns, *Discovering the Human Connectome*. The MIT Press, 2012. Nikola Kasabov. *Time-Space, Spiking Neural Networks and Brain-Inspired Artificial Intelligence*, Springer 2019. Also, Intelligence Advanced Research Projects Activity, "Machine Intelligence from Cortical Networks (MICrONS)" project, "Proposers' Day Briefings" (https://www.iarpa.gov/index.php/research-programs/microns/microns-baa).

[28] Xiamen, not a backwater by any means but not the first place one goes for cutting edge technology, has a history of AI research. Hugo de Garis, an AI pioneer and early AGI prophet, taught until 2010 at Xiamen University, where he built China's first "artificial brain." (https://en.wikipedia.org/wiki/Hugo_de_Garis). Ruting Lian, spouse of AGI's foremost proponent Ben Goertzel, did her doctoral work at Xiamen University's Fujian Key Lab for Brain-like Intelligent Systems (https://www.sciencedirect.com/science/article/abs/pii/S0925231210003498#!).

[29] https://braindata.bitahub.com/.

[30] Dr. Christof Koch, personal communication, August 2020.

[31] http://en.jitri.org/yanjiuyuan72.html.

[32] https://www.cingta.com/detail/17634.

[33] Zhou Wenting, "Insights to Come from New Brain Research Base," *China Daily*, July 19, 2018, http://www.chinadaily.com.cn/cndy/2018-07/19/content_36603871.htm.

[34] https://www.cbicr.tsinghua.edu.cn.

[35] Our thanks to DARPA contractor Dr. Jennifer Wang and CSET data scientist Daniel Chou for analysis and graphics. Affiliation names were normalized. If multiple authors identify with ABC in a given paper, then ABC's output tally increased by only 1. "Microsoft Research" (33) is different from "Microsoft Research Asia (MSRA)" (18) and the rest of "Microsoft" (25).

[36] Based on Microsoft Academic "AAAI Conference Analytics, January 2019. https://www.microsoft.com/en-us/research/project/academic/articles/aaai-conference-analytics/.

[37] https://zhuanlan.zhihu.com/p/81781547.

[38] https://www.baai.ac.cn/news_article?content_id=43&type=news. Interestingly, the three top-ranked Chinese institutes for accepted papers at the 2020 NeurIPS event are all located in Beijing—Tsinghua, Peking University, and Beijing Academy of Artificial Intelligence (北京智源人工智能研究院, BAAI). A Shanghai-based institute ranks only 8th after iFlytek, Alibaba, Huawei, and the University of Hong Kong.

[39] Some 7,077 affiliation instances were extracted from 1,589 AAAI 2020 accepted papers. Each affiliation in a given paper was labeled as China or non-China according to a hand-curated list of 616 affiliation name variants. https://aaai.org/Conferences/AAAI-20/wp-content/uploads/2020/01/AAAI-20-Accepted-Paper-List.pdf.

[40] https://zhuanlan.zhihu.com/p/81781547.

[41] See for example Remco Zwetsloot, "Keeping Top AI Talent in the United States," Center for Security and Emerging Technology, December 2019, https://cset.georgetown.edu/research/keeping-top-ai-talent-in-the-united-states/.

[42] There is a counter-argument that access to NHP's derails research from human-based studies and should be seen as a disadvantage, since discoveries about the one do not necessarily transfer to the other.

[43] David Cyranoski, "China is positioning itself as a world leader in primate research," *Nature*, April 20, 2016, https://www.nature.com/news/monkey-kingdom-1.19762#auth-1.

[44] Gretchen Vogel, "Animal rights conflict prompts leading researcher to leave Germany for China," *Science*, January 27, 2020, https://www.sciencemag.org/news/2020/01/animal-rights-conflict-prompts-leading-researcher-leave-germany-china.

[45] https://www.nature.com/articles/d41586-019-00292-w.

[46] Sarah Zhang, "China is Genetically Engineering Monkeys with Brain Disorders," *The Atlantic,* June 8, 2018, https://www.theatlantic.com/science/archive/2018/06/china-is-genetically-engineering-monkeys-with-brain-disorders/561866/.

[47] The IP Commission Report, *The Theft of American Intellectual Property: Reassessments of the Challenge and United States Policy*, February 2019; Wm. C. Hannas, James Mulvenon, and Anna B. Puglisi, *Chinese Industrial Espionage* (London and New York: Routledge, 2013); Michael Brown and Pavneet Singh, "China's Technology Transfer Strategy" (Washington, DC: Defense Innovation Unit Experimental, February 2017); Office of the United States Trade Representative, "Section 301 Report into China's Acts, Policies, and Practices Related to Technology Transfer, Intellectual Property, and Innovation," March 27, 2018; U.S.-China Economic and Security Review Commission, "2019 Annual Report to Congress," November 2019; Hannas and Tatlow, eds., *China's Quest for Foreign Technology: Beyond Espionage*, Routledge, 2020; and Anastasya Lloyd-Damnjanovic and Alexander Bowe, "Overseas Chinese Students and Scholars in China's Drive for Innovation," U.S.-China Economic and Security Review Commission, October 7, 2020.

[48] Hannas and Chang, "China's Access to Foreign AI Technology—an Assessment," Georgetown University, Center for Security and Emerging Technology, September 2019; Hannas and Chang, "China's 'Artificial' Intelligence," in Hannas and Tatlow, eds. *China's Quest for Foreign Technology: Beyond Espionage*, Routledge, 2020; Hannas and Chang, "China AI-Brain Research," Center for Security and Emerging Technology, September 2020.

[49] We point out to analysts mired in the budget-as-progress paradigm that in China things work differently. Unless one factors in the operating costs of a multi-tiered transfer apparatus with over 100,000 operatives, hundreds of subsidized commercialization centers, and adds a constant for unearned advantages gained by tapping proprietary technology, China's visible R&D budgets have little meaning in cross-country comparisons.

[50] https://www.voachinese.com/a/kai-fu-lee-on-ai-development-2018116/4662278.html.

[51] Adapted from Hannas and Chang, "China's 'Artificial' Intelligence," in Hannas and Tatlow, eds. *China's Quest for Foreign Technology: Beyond Espionage*, Routledge, 2020, pp. 199-200.

[52] https://mp.weixin.qq.com/s/YtXW8HlWlRGGxQn5aOeabA.

[53] Qiushi (求是), April 2019. https:// www.kunlunce.com/llyj/fl11111/2019-02-28/131480.html.

[54] http://www.caeshc.com.cn/news_view.php?id=7997.

[55] http://news.stcn.com/2019/1017/15436849.shtml.

[56] https://www.nature.com/articles/d41586-019-02360-7.

[57] We dodge the question of whether foundational research should be subject to export control. This hot-button issue is currently a matter of debate among USG policymakers.

[58] Hannas and Chang, "China's STI Operations," Center for Security and Emerging Technology, January 2021.

[59] Cassio Pennachin and Ben Goertzel, "Contemporary Approaches to Artificial General Intelligence," in Goertzel and Pennachin, eds., Artificial General Intelligence, Springer, 2007, p. 1.

[60] Ibid.

[61] Hannas and Chang, "China AI-Brain Research: Brain-inspired AI, Connectomics, Brain-computer Interfaces," Georgetown University / CSET, September 2020. China's AI generalists were split on whether AGI could be achieved in 5-10 years or 10+ years. BI-AI specialists, facing real laboratory problems, opted for the latter prognosis.

[62] *S&T Daily*, June 20, 2019 (http://www.stdaily.com/qykj/qianyan/2019-06/20/content_773207.shtml).

[63] *Tencent Net* (腾讯网), October 31, 2019 (https://new.qq.com/omn/20191104/20191104A0BD9U00.html).

[64] *Qiushi* (求是), April 2019. http://www.qstheory.cn/dukan/qs/2019-02/16/c_1124114625.htm.

[65] *Guangming Daily* (光明日报), January 24, 2019. http:// www.cas.cn/zjs/201901/t20190124_4678012.shtml.

[66] Synthesized from Huang's address to the Future of Life conference on "Beneficial AGI," Puerto Rico, January 5, 2019, session 2 "Should we build superintelligence?" (https://www.youtube.com/watch?v=xLYE11yW-hQ&t=17s). Huang's Beijing academy announced its 2020 research would focus on the "cognitive neural basis of artificial intelligence" aimed in part at "building a functional brain-like intelligent system with performance that exceeds a brain" (构建功能类脑、性能超脑的智能系统) http://www.bj.chinanews.com/news/2020/0825/78660.html.

[67] A review of CNKI Chinese language academic journals shows a slight upward progression of papers mentioning "AGI" from 2014 through 2016, spiking sharply in 2017, the year after BI-AI took root, and rising thereafter.

[68] https://bigai.ai/index.html. "通用人工智能" ("GAI") is the Chinese term for AGI. Chinese reverses the English word order, hence the institute's name "Beijing Institute of General Artificial Intelligence" or "BIGAI."

[69] http://news.pku.edu.cn/xwzh/cc4e714d8d-ef4d1db071a43771c2bb41.htm, and https://www.sohu.com/a/420639562_260616.

[70] https://www.163.com/dy/article/G3C518KF0511DPVD.html.

[71] Ibid.

[72] Ming Dong, "Decipherer of 'Brain Language Code'." https://m.chinanews.com/wap/detail/zw/gn/2019/12-25/9042386.shtml. Ming is Dean of Tianjin University's Academy of Medical Engineering and Translational Medicine and Director of the Tianjin Key Laboratory of Brain Science and Neuroengineering.

[73] Specific proposals for a China-oriented technology transfer management regime are outlined in Hannas and Tatlow, eds., *China's Quest for Foreign Technology: Beyond Espionage*, Routledge, 2020, pp. 329-332. Interdiction practices are also reviewed in chapter 18, "Mitigation Efforts to Date" by James Mulvenon, et al.

[74] Hannas and Chang, "China's STI Operations," Center for Security and Emerging Technology, January 2021.