Understanding China's AI Strategy:
Clues to Chinese Strategic Thinking on Artificial Intelligence and National Security

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INTRODUCTION

In the second half of 2018, I traveled to China on four separate trips to attend major diplomatic, military, and private-sector conferences focusing on Artificial Intelligence (AI). During these trips, I participated in a series of meetings with high-ranking Chinese officials in China's Ministry of Foreign Affairs, leaders of China's military AI research organizations, government think tank experts, and corporate executives at Chinese AI companies. From these discussions – as well as my ongoing work analyzing China's AI industry, policies, reports, and programs – I have arrived at a number of key judgments about Chinese leadership's views, strategies, and prospects for AI as it applies to China's economy and national security. Of course, China's leadership in this area is a large population with diversity in its views, and any effort to generalize is inherently presumptuous and essentially guaranteed to oversimplify. However, the distance is large between prevailing views in American commentary on China's AI efforts and what I have come to believe are the facts. I hope by stating my takeaways directly, this report will advance the assessment of this issue and be of benefit to the wider U.S. policymaking community.

CHINESE VIEWS ON THE IMPORTANCE OF AI

1. **China's leadership – including President Xi Jinping – believes that being at the forefront in AI technology is critical to the future of global military and economic power competition.**

   In July 2017, China's State Council issued the *New Generation Artificial Intelligence Development Plan* (AIDP).[1] This document – along with *Made in China 2025*,[2] released in May 2015 – form the core of China's AI strategy. Both documents, as well as the issue of AI more generally, have received significant and sustained attention from the highest levels of China's leadership, including Xi Jinping. Total Chinese national and local government spending on AI to implement these plans is not publicly disclosed, but it is clearly in the tens of billions of dollars. At least two[3] Chinese regional governments have each committed to investing 100 billion yuan (~$14.7 billion USD).[4] The opening paragraphs of the AIDP exemplify mainstream Chinese views regarding AI:

   > AI has become a new focus of international competition. AI is a strategic technology that will lead in the future; the world's major developed countries are taking the development of AI as a major strategy to enhance national competitiveness and protect national security.[5]

   The above quote also reflects how China's AI policy community[6] is paying close attention to the AI industries and policies of other countries, particularly the United States. Chinese government organizations routinely translate, disseminate, and analyze U.S. government and think tank reports about AI. In my conversations with Chinese officials and my reading of Chinese government AI reports, they demonstrated substantive and timely knowledge of AI developments in the United States and elsewhere. Chinese government AI reports frequently cite U.S. national

security think tank publications.[7] The U.S. policymaking community ought to make it a priority to be equally effective at translating, analyzing, and disseminating Chinese publications on AI for the insights they provide into Chinese thinking.[8]

2. **China's leadership – including Xi Jinping – believes that China should pursue global leadership in AI technology and reduce its vulnerable dependence on imports of international technology.**

In October 2018, Xi Jinping led a Politburo study session on AI. Such sessions are reserved for the high-priority policy issues where leaders need the benefit of outside expertise. Xi's publicly reported comments during and after the study session reiterated the main conclusions of both the *AIDP* and *Made in China 2025*, which were that China should "achieve world-leading levels"[9] in AI technology and reduce its vulnerable "external [foreign] dependence for key technologies and advanced equipment."[10]

In his speech during the study session, Xi said that China must "ensure that our country marches in the front ranks where it comes to theoretical research in this important area of AI, and occupies the high ground in critical and AI core technologies."[11] Xi further said that China must "pay firm attention to the structure of our shortcomings, ensure that critical and core AI technologies are firmly grasped in our own hands." Xi's speech demonstrates that China's leadership continues to subscribe to AIDP's and *Made in China 2025*'s two major conclusions that China should pursue both world leadership and self-reliance in AI technology. The Chinese AI sector's dependence on foreign technology is discussed further in point nine.

CHINESE VIEWS ON AI'S INTERNATIONAL SECURITY IMPLICATIONS

3. **Recently, Chinese officials and government reports have begun to express concern in multiple diplomatic forums about arms race dynamics associated with AI and the need for international cooperation on new norms and potentially arms control.**

In a keynote speech during China's largest international relations conference on July 15, 2018, Fu Ying,[12] the Vice-Chair of the Foreign Affairs Committee of the National People's Congress, said that Chinese technologists and policymakers agree regarding the "threat of the new [AI] technology to mankind." She further stated that "We believe that we should cooperate to preemptively prevent the threat of AI."

Madam Fu's depiction of AI as posing a shared threat to international security was echoed by many other Chinese diplomats and PLA think tank scholars in my private meetings with them. For instance, one official told me he was concerned that AI "will lower the threshold of military action," because states may be more willing to attack each other with AI military systems due to the lack of casualty risk. Chinese officials also expressed concern that increased used of AI systems would make misperceptions and unintentional conflict escalation more likely due to the lack of

well-defined norms regarding the use of such systems. Additionaly, Chinese officials displayed substantive knowledge of the cybersecurity risks associated with AI sytems, as well as their implications for Chinese and international security.

Madam Fu said that China was interested in playing a leading role in creating norms to mitigate these risks. At the World Peace Forum private roundtable on AI, one senior PLA think tank scholar privately expressed support for "mechanisms that are similar to arms control" for AI systems in cybersecurity and military robotics. However, he also said that AI-related arms control would be uniquely difficult since "AI is low-cost and can be disseminated easily and cannot be monitored easily."

Notably, the recent "Artificial Intelligence Security White Paper," published in September 2018 by the China Academy of Information and Communications Technology (CAICT), an influential Chinese government think tank, calls upon the Chinese government to "avoid Artificial Intelligence arms races among countries."[13] The AIDP does not address arms races but does state that China will "deepen international cooperation on AI laws and regulations, international rules and so on, and jointly cope with global challenges."

Such concerns extend to the China's private sector. Jack Ma, the chairman of Alibaba, said explicitly in a speech at the 2019 Davos World Economic Forum that he was concerned that global competition over AI could lead to war. [14]

4. **Despite expressing concern on AI arms races, most of China's leadership sees increased military usage of AI as inevitable and is aggressively pursuing it. China already exports armed autonomous platforms and surveillance AI.**

At the Beijing Xiangshan Forum on October 24, 2018, Major General Ding Xiangrong, Deputy Director of the General Office of China's Central Military Commission, gave a major speech in which he defined China's military goals to "narrow the gap between the Chinese military and global advanced powers" by taking advantage of the "ongoing military revolution . . . centered on information technology and intelligent technology." Chinese military leaders increasingly refer to intelligent or "intelligentized" (智能化) military technology as their confident expectation for the future basis of warfare. Use of the term "intelligentized" is meant to signify a new stage of military technology beyond the current stage based on information technology.[15] China's AIDP strategy document states that China will "Promote all kinds of AI technology to become quickly embedded in the field of national defense innovation."

The next day at the Xiangshan Forum, Zeng Yi, a senior executive at China's third largest defense company,[16] gave a speech in which he described his company's (and China's) expectations for the future implementation of AI weapons: "In future battlegrounds, there will be no people fighting." Zeng predicted that by 2025 lethal autonomous weapons would be commonplace and said that his company believes

ever-increasing military use of AI is "inevitable […] We are sure about the direction and that this is the future."

Zeng's comments are consistent with ongoing Chinese autonomous military vehicle development programs and China's current approach to exports of military unmanned systems. China's government already is exporting many of its most advanced military aerial drones to Middle Eastern countries such as Saudi Arabia and the UAE. China's government has stated that it also will export its next generation stealth drones when those are available.[17] Though many current generation drones are primarily remotely operated, Chinese officials generally expect drones and military robotics to feature ever more extensive AI and autonomous capabilities in the future. Chinese weapons manufacturers already are selling armed drones with significant amounts of combat autonomy. Ziyan, a Chinese military drone manufacturer, has sold its Blowfish A2 model to the UAE and in November 2019 reportedly was in negotiations with Saudi Arabia and Pakistan for Blowfish A2 sales.[18] Ziyan's website states that the 38kg Blowfish A2 "autonomously performs more complex combat missions, including fixed-point timing detection, fixed-range reconnaissance, and targeted precision strikes."[19] Depending on customer preferences, Ziyan offers to equip Blowfish A2 with either missiles or machine guns.

Beyond using AI for autonomous military robotics, China is also interested in AI capabilities for military command decisionmaking. Zeng Yi expressed some remarkable opinions on this subject, stating that today "mechanized equipment is just like the hand of the human body. In future intelligent wars, AI systems will be just like the brain of the human body." Zeng also said that "Intelligence supremacy will be the core of future warfare" and that "AI may completely change the current command structure, which is dominated by humans" to one that is dominated by an "AI cluster." Zeng did not elaborate on his claims, but they are consistent with broader thinking in Chinese military circles. Several months after AlphaGo's momentous March 2016 victory over Lee Sedol, a publication by China's Central Military Commission Joint Operations Command Center argued that AlphaGo's victory "demonstrated the enormous potential of artificial intelligence in combat command, program deduction, and decisionmaking."[20]

China is currently making extensive use of AI in domestic surveillance applications. General Wang Ning of the Chinese People's Armed Police Force recently boasted about China's success in using AI in Xinjiang province:

> In Xinjiang, we use big data AI to fight terrorists. We have intercepted 1200 terror organizations when still planning an attack. We use technology to identify and locate activities of terrorists, including the smart city system. We have a face recognition system, and for all terrorists there is a database.[21]

Xinjiang is home to millions of China's Uighur ethnic minority, which has been subject to extraordinary persecution aided by AI surveillance technology.[22] China's SenseTime corporation, a national champion in computer vision AI, is a major

provider of surveillance technology to China's government, including for Xinjiang. SenseTime's security and surveillance products often are described using the "smart city" euphemism. However, SenseTime also has many non-security products, such as computer vision machine learning related to autonomous vehicles.

SenseTime is a major exporter of surveillance technology in government and commercial markets across Latin America, Africa, and Asia. China's government and leadership is enthusiastic about using AI for surveillance. One scholar at a Chinese think tank told me that he looks forward to a world in AI will make it "impossible" to "commit a crime without being caught," a sentiment that echoes the marketing materials put out by Chinese AI surveillance companies.

China's behavior of aggressively developing, utilizing, and exporting increasingly autonomous robotic weapons and surveillance AI technology runs counter to China's stated goals of avoiding an AI arms race. However, this by itself does not necessarily mean that Chinese officials are being insincere in their expressions of concern about such arms races. Lamenting arms race dynamics while aggressively participating in them is a common story in the history of international relations. The strongest behavioral indication that China might be insincere comes from China's April 2018 United Nations position paper,[23] in which China's government supported a worldwide ban on "lethal autonomous weapons" but used such a bizarrely narrow definition of lethal autonomous weapons that such a ban would appear to be both unnecessary and useless. This rhetorical gambit allowed China to reap positive media attention for their support of global restrictions while avoiding hypocrisy over Chinese development of more advanced military AI and autonomy.[24] More broadly there seems to be less grassroots concern of the issue among Chinese AI researchers than their counterparts in the West, though evidence on this point is limited.[25]

5. **China's Ministry of National Defense has established two major new research organizations focused on AI and unmanned systems under the National University of Defense Technology (NUDT).**

The National Innovation Institute of Defense Technology (NIIDT, an NUDT subsidiary), has established and is rapidly growing two Beijing-based research organizations focusing on the military use of AI and related tech. These are the Unmanned Systems Research Center (USRC), led by Yan Ye, and the Artificial Intelligence Research Center (AIRC), led by Dai Huadong.[26] Each organization was created in early 2018, and each now has a research staff of over 100 (more than 200 total), which makes it one of the largest and fastest growing government AI research organizations in the world. However, there are larger private sector AI research organizations in both China and the United States. SenseTime, for example, has roughly 600 full-time research staff. DeepMind – a Google subsidiary focused on AI research – has around 700 total staff and annual expenditures of over $400 million.[27] Salaries of Chinese AI PhD's educated in China are generally much lower than salaries of Western AI PhD's, or Western-educated Chinese, which makes estimating the AIRC's budget based on staff difficult. AIRC staff are engaged in basic research into

dual-use AI technology, including applying machine learning to robotics, swarm networking, wireless communications, and cybersecurity. The AIRC also likely does classified work for the Chinese Military and Intelligence Community.

6. **China's government sees AI as a promising military "leapfrog development" opportunity, meaning that it offers military advantages over the US and will be easier to implement in China than the United States.**

The term "leapfrog development" describes a technology for which laggard countries can skip a development stage, or one for which being behind on the current generation of technology actually offers an advantage in adopting the next generation. A commonly cited example is the rapid and widespread adoption of cellular phone technology in countries that had only minimal landline phone adoption. Kai-Fu Lee, one of the leading venture capitalists in China's AI sector, argues that the absence of many developed-economy capabilities, such as easy credit checks, have led to a flood of Chinese entrepreneurs making innovative use of AI capabilities to fill those gaps.[28] Plastic credit cards are nearly nonexistent in China, but mobile phone payments secured by facial recognition are ubiquitous.

China's emphasis on AI as a leapfrog technology enabler extends to national security applications. China's 2017 National AI Development Plan identifies AI as a "historic opportunity" for national security leapfrog technologies.[29] Chinese Defense executive Zeng Yi echoed that claim, saying that AI will "bring about a leapfrog development" in military technology and presents a critical opportunity for China.

If China is correct that AI presents a leapfrog opportunity, it would mean that China is better positioned to adopt military AI than the United States. In this theory, the United States' current advantages in stealth aircraft, aircraft carriers, and precision munitions actually would be long-term disadvantages because the entrenched business and political interests that support military dominance today will hamper the United States in transitioning to an AI-enabled military technology paradigm in the future.[30] As one Chinese think tank scholar explained to me, China believes that the United States is likely to spend too much to maintain and upgrade mature systems and underinvest in disruptive new systems that make America's existing sources of advantage vulnerable and obsolete. China's military also faces perverse incentives to protect legacy systems, but to a far lesser extent: Military spending tripled over the 2007–2017 period,[31] modernization is a top priority, and there is a general understanding that many of its current platforms and approaches are obsolete and must be replaced regardless.

Just one of many examples of China's AI leapfrog strategy is its prioritized investment[32] and technology espionage[33] for low-cost, long-range, autonomous, and unmanned submarines. China believes these systems will be a cheap and effective means of threatening U.S. aircraft carrier battlegroups and an alternative path to projecting Chinese power at range. In general, China sees military AI R&D as a cheaper

and easier path to threatening America's sources of military power than developing Chinese equivalents of American systems.

CHINESE VIEWS ON THE STRENGTHS OF CHINA'S AI ECOSYSTEM

7. **China's government and industry believe that they have largely closed the gap with the United States in both AI R&D and commercial AI products. China now sees AI as "a race of two giants," between itself and the United States.**

China's July 2017 national AI strategy set a 2020 goal for China's "AI industry's competitiveness [to] have entered the first echelon internationally." In truth, China's leadership already assesses China as having achieved this objective as of mid-2018. At the World Peace Forum, Tsinghua University's Xue Lan delivered a briefing on Tsinghua University's major report on the state of the AI sector in China.[34] This study found that "China has secured a leading position in the top [AI] echelon in both technology development and market applications and is in a race of 'two giants' with the U.S." It also finds that China is:

- #1 in both total AI research papers and highly cited AI papers worldwide
- #1 in AI patents
- #1 in AI venture capital investment
- #2 in the number of AI companies
- #2 in the largest AI talent pool.

China's assessment of being in the first echelon is correct, though there are important caveats that will be discussed more below. Not only is China advancing the state of the art in AI research, its companies are very successfully developing genuinely innovative and market-competitive products and services around AI applications. SenseTime, for example, is undisputedly one of the world leaders in computer vision AI and claims to have achieved annual revenue growth of 400 percent for three consecutive years. DJI offers another example. DJI leads the world in consumer drones with 74 percent market share.[35] DJI has innovatively incorporated machine learning technology into its most recent products.

In many cases the products and underlying technologies between commercial AI and military/security AI products are identical or nearly so. DJI recently was selected as the sole drone provider to the New York Police Department, which will use DJI's consumer model drones. Similarly, SenseTime's consumer facial recognition systems share infrastructure and technology with its security systems, used by both Chinese law enforcement and intelligence organizations.

8. **China's strong current position in AI R&D and commercial applications has been enabled by access to international markets, technology, and research collaboration.**

China's success has been enabled by its access to global technology research and markets. Many seemingly "Chinese" AI achievements are actually achievements of multinational research teams and companies, and such international collaboration has been critical to China's research progress.[36] According to the Tsinghua University study of China's AI ecosystem, "More than half of China's AI papers were international joint publications," meaning that Chinese AI researchers – the top tier of whom often received their degrees abroad – were coauthoring with non-Chinese individuals. Even purely Chinese successes often build upon open source technologies developed most often by international groups.

Partly as a result of this, leading Chinese technology companies have significant and under-reported dependencies on the United States. For example, DJI, the Shenzhen-headquartered, world-leading drone manufacturer, is vertically integrated with nearly all design, manufacturing, and marketing done in-house. However, all of DJI's drone flight software development is performed at DJI's American office in Palo Alto, which predominantly employs U.S. citizens as staff. Additionally, nearly 35 percent of the bill of materials in each of DJI's products are from the United States, mostly reflecting semiconductor content.

CHINESE VIEWS ON THE WEAKNESSES OF CHINA'S AI ECOSYSTEM

9. **Despite China's strength in AI R&D and commercial applications, China's leadership perceives major weaknesses relative to the United States in top talent, technical standards, software platforms, and semiconductors.**

Though most in China's leadership agree that China is one of two "giants" in AI, there is a similarly widespread understanding that China is not strong in all areas. China's January 2018 "White Paper on Artificial Intelligence Standardization" points out that the China's AI ecosystem lags in several key areas:

> Although China has a good foundation in the field of AI, even as core technologies such as speech recognition, visual recognition, and Chinese-language information processing have achieved breakthroughs and possess huge market environments for applications, the overall level of development still lags behind that of developed countries.[37]

Similarly, the Tsinghua University China AI Development report finds:

> China's strengths are mainly shown in AI applications and it is still weak on the front of core technologies of AI, such as hardware and algorithm development, China's AI development lacks top-tier talent and has a significant gap with developed countries, especially the U.S., in this regard.[38]

There are additional comparative weaknesses in China's AI ecosystem worth discussing, but I will focus on the four that most often came up in my meetings in China: top talent, technical standards, software platforms, and semiconductors.

Weaknesses in Top Talent

The Tsinghua University China AI report did a remarkable study of the global AI talent distribution, concluding that by the end of 2017, the international AI talent pool comprised 204,575 individuals, with the United States having 28,536 such individuals and China in second place with 18,232. However, China's ranks eighth in the world in terms of Top AI talent, with only 977 individuals compared to the United States' 5,518. Though acknowledging the disparity, venture capitalist Kai-Fu Lee argues that this is not a major barrier because "the current age of implementation [AI application commercialization] appears well-suited to China's strengths in research: large quantities of highly skilled, though not necessarily best-of-best, AI researchers and practitioners."[39] Some researchers at leading Western AI research insitutions have told me they agree with this conclusion, noting that AI breakthroughs by leading institutions are quickly replicated by other institutions worldwide.

Lee is influential among China's technology industry, but not everyone agrees with his theory. Many that I spoke with said that China's shortage of top talent will be a handicap in the future development of China's AI sector, and China's government is taking aggressive action to improve the size and quality of China's AI talent pool.[40] In April 2018, China's Ministry of Education (MOE) launched its *AI Innovation Action Plan for Colleges and Universities*. Among other elements, the plan:

- Will create "50 world-class teaching materials for undergraduate and graduate studies" related to AI applications for specific industries

- Will create "50 national-level high-quality online open courses"

- Will establish "50 artificial intelligence faculties, research institutions, or interdisciplinary research centers."[41]

In a separate initiative, the MOE also plans to launch a new five-year AI talent training program to train 500 more AI instructors and 5,000 more top students at top Chinese universities.[42]

Weaknesses in Technical Standards

The determination and common adoption of international technical standards is a key enabler of technology interoperability and market growth. Common adoption of Wi-Fi standard, for example, is what allowed such a wide diversity of modems, routers, mobile phones, and computers to all effectively connect to each other over Wi-Fi networks. Companies that create intellectual property related to such standards often reap significant rewards, especially when their patents, such as the design of a specific semiconductor chip, are declared essential to effective operation of any device using

the standard.[43] For example, Qualcomm's intellectual property was critical to development of the Code-Division Multiple Access (CDMA) cellular standard. It is essentially impossible for a device to access CDMA cellular networks unless the device uses Qualcomm semiconductor patents, hence why they are an example of so-called "Standard Essential Patents" (SEPs). Historically, Chinese companies and government organizations produced very few SEPs, but China has made rapid progress on this front. Huawei, ZTE, and the China Academy of Telecommunications Technology have produced hundreds of SEPs related to fifth generation (5G) cellular standards.[44]

AI technical standards are far less mature than those in cellular networking, but China's government strategy for pursuing leadership in AI technical standards is informed by its experience in the cellular networking. China's government and Chinese corporations want to ensure that their intellectual property and products are critical features of the future of AI. Because of China's experience with ZTE export restrictions, Chinese leadership perceives its success in technical standards as critical to both economic growth and national security.

Weaknesses in Software Frameworks & Platforms

Developers of AI systems rarely start from scratch. More often, they leverage pre-written programs developed by others and shared into code libraries. This allows developers to focus on the unique specifics of their application usage requirements, rather than solving generic problems faced by all AI developers. Some organizations have combined machine learning code libraries with other AI software development tools into mature machine learning software frameworks, many of which are open source. Popular machine learning frameworks include, but are not limited to, TensorFlow (Google), Spark (Apache), CNTK (Microsoft), and PyTorch (Facebook).

Notably, none of the most popular machine learning software frameworks have been developed in China. The importance of leadership in software frameworks is debated even among America's leading technology companies. Companies that do prioritize framework development claim that it offers opportunities to attract top talent, influence technical standards, and guide the overall ecosystem toward increased usage of their products and services. The absence of Chinese AI companies among the major AI framework developers and open source AI software communities was identified as a noteworthy weakness of China's AI ecosystem in several of my conversations with executives in China's technology industry. Additionally, China's CAICT AI and Security White Paper lamented the fact that "At present, the research and development of domestic artificial intelligence products and applications is mainly based on Google and Microsoft."[45] SenseTime has devoted extensive resources its own machine learning framework, Parrots, which is intended to be superior for computer vision AI applications. So far, the company appears to have had limited success in promoting adoption: No Chinese computer scientists I met with outside of SenseTime had even heard of Parrots, even though it was announced more than two years ago.

Weaknesses in Semiconductors

Most of the world's consumer electronics products bear a "Made in China" label. Sixty-five percent of the world's personal computers, notebooks, and tablets as well as nearly 85 percent of the world's mobile phones reportedly are made in China.[46] However, many of these products are assembled with high-value semiconductor chips that are designed in the United States, manufactured in Taiwan or Korea, and running software developed by American firms such as Google, Microsoft, and Apple. The iPhone, for example, bears a "Made in China" label, but only low-skill assembly and commodity component production takes place in China. A study found that Chinese contributions account for less than 2 percent of the overall cost of the iPhone, even though 100 percent of the cost of the device is counted in the United States' trade deficit with China.[47]

Even in the consumer drones market, where the leading Chinese company (DJI) enjoys 74 percent global market share, 35 percent of the bill of materials in each drone is actually U.S. content, primarily semiconductors. China brings extraordinary scale, skills, and infrastructure to bear in electronics manufacturing, which accounts for its central role in the global electronics supply chain. However, recent developments suggest that this centrality may be less irreplaceable than is often claimed. In the face of increasing Chinese wages and U.S. tariffs, many international electronics manufacturers, such as Samsung,[48] Apple, and Foxconn,[49] are relocating ever more of their Chinese operations to lower-cost countries such as Vietnam and India. China's 85 percent share of global mobile phone manufacturing in 2017 is actually down from 90 percent in 2016.[50] In other words, electronics is following other rapidly relocating industries such as textiles.[51] China is attempting to forestall these movements by massively increasing its use of robotics and automation in manufacturing,[52] with unclear prospects.

By contrast, U.S. and international products and services are sometimes irreplaceable, such as when Chinese electronics manufacturer ZTE faced a quick turn from profitability to imminent bankruptcy in the wake of U.S. export restrictions on critical input products such as semiconductors.[53]

WHY CHINA'S TECH SECTOR IS UNLIKELY TO FACE SOVIET-STYLE STAGNATION

Like the Soviet Union during the Cold War, China today is engaged in an extensive campaign to harvest technological and scientific information from the rest of the world, using both legal and illegal means. Unlike the Soviet Union, China's efforts have prioritized using such access to build industries that are competitive in global markets and research institutions that lead the world in strategic fields. For example, the Soviet Union gave an overwhelming priority to the military application of illegally imported semiconductor manufacturing equipment well into the 1980s, which essentially guaranteed that the Soviet Union's industry would remain dependent on Western technology and never reach internationally competitive economies of scale.[54]

By contrast, China's strategy for making effective use of foreign technology is to use it to support domestic commercial industry. When a state-owned Chinese company recently sought to steal U.S. memory chip semiconductor manufacturing technology, the primary motive was to raise the technological competitiveness of China's domestic semiconductor industry in global markets.[55] China's leadership has concluded that possessing commercially competitive industries often is of greater long-term benefit to China's national security sector than short-term military utilization of any stolen technology. For example, China's approach for AI, as outlined in its national AIDP strategy document, is to:

> Follow the rules of the market . . . accelerate the commercialization of AI technology and results, and create a competitive advantage. Grasp well the division of labor between government and the market.[56]

The Soviet Union had a large community of brilliant scientists and technologists, but this community spent a disproportionate amount of its creative and intellectual potential on compensating for the shortcomings of the Soviet system. On top of perverse institutional incentives divorced from economic reality, the Soviet economy was deliberately self-isolated from global trade.[57] Compared with the Soviet Union's non-market communist economy, China's policies promoting market-oriented entrepreneurship have made them far superior consumers of international and especially U.S. technology, whether gathered by legal or illegal means. Despite sensational successes in the Space Race and some key military technologies, overall, the Soviet Union fell further and further behind each year that the Cold War dragged on. China, by contrast, has gone from a scientific backwater to a leading player in a long list of scientific fields and technology industries in just two decades.

CHINA'S NEAR-TERM GOAL: MAINTAIN ACCESS TO FOREIGN TECHNOLOGY BUT REDUCE DEPENDENCE

10. **China's leaders seek to preserve access to foreign technology in the short term but believe that they must promote domestic independence in the longterm. This has long been China's goal, but it has taken on new urgency.**

In November 2018, Dr. Tan Tieniu, Deputy Secretary-General of the Chinese Academy of Sciences, gave a wide-ranging speech before many of China's most senior leadership at the 13th National People's Congress Standing Committee. In the speech, he argued that China's lagging status in technical standards, software frameworks, and semiconductors left China vulnerable and in dire need of domestic alternatives. Due to the frankness and insightfulness of Dr. Tan's comments, they are worth quoting at length:

> [China should] construct an independent and controllable innovation ecosystem. American companies such as Google, IBM, Microsoft, and Facebook have actively built innovation ecosystems, seized the innovative high ground, and already in the international AI industry hold the upper hand in AI chips, servers, operating systems, open source algorithms, cloud services, and autonomous driving, among others. China's AI open source community and technological innovation ecosystem are comparatively lagging, the strength of technology platform construction needs to be reinforced, and [China's] international influence remains to be improved.

> The U.S. ban on ZTE fully demonstrates the importance of independent, controllable core-, high-, and foundational technologies. In order to avoid repeating this disaster, China should learn its lesson about importing core electronic components, high-end general-purpose chips, and foundational software.[58]

Though expressed in a more urgent tone, Tan's comments are in line with China's preexisting technology policy. The Tsinghua University AI Report conducted a comprehensive quantitative analysis of Chinese technology policy documents and found that Made in China 2025 is the single most important policy underpinning Chinese regional governments' development of AI policies.[59] The regional governments bear primary responsibility for implementing the strategic objectives laid out by the central government. Made in China 2025 notably outlines policies across various industries for China to reduce dependency on foreign technology, either by developing it indigenously or acquiring it from foreign sources, and thereafter capture global market share.

Tan Tieniu also argued that China can leverage its existing strength in AI applications to improve its position in other parts of the AI value chain, such as international standards. "As China is at the global forefront of AI technology applications, it should seize its right to speak in the formulation of international AI standards," he said.

11. **China's pursuit of reducing foreign dependence is bearing fruit, as shown by increasing value capture share by Chinese suppliers in the global smartphone market supply chain and China's success in advanced semiconductor design.**

A 2011 study[60] of which countries capture what share of revenue from each sale of the iPhone found that the factories assembling the iPhone in China captured less than 2 percent of the value[61] of each iPhone sold and that there were no Chinese suppliers to the iPhone other than assembly laborers.[62] By contrast, nearly half of the value of each device was captured by Chinese companies in the case of Huawei's 2017 flagship P9 smartphone, a direct iPhone competitor.[63] For Huawei, these value capture share gains are not limited to low-skill tasks. Huawei's HiSilicon subsidiary designed the main semiconductor processor of the P9, including its AI deep learning accelerator element, in-house.[64] Indeed, the study arguably understates China's value capture in smartphones because it undercounts China's software gains. Though Chinese firms are not major competitors in the smartphone operating system market, Tencent's WeChat app fulfills many of the functions of an operating system and is ubiquitous among Chinese smartphone owners.

There are three major segments of the semiconductor value chain: design, manufacturing, and assembly.[65] China historically has only been a major player in assembly, which is relatively low skill. Recently, Chinese companies have demonstrated remarkably high quality and competitive semiconductor design, exemplified by Huawei's Kirin 980. The Kirin 980 is one of only two smartphone processors in the world to use 7 nanometer (nm) process technology, the other being the Apple-designed A12 Bionic. Both Apple and Huawei rely upon Taiwan's TSMC for outsourced 7nm manufacturing. Even the most advanced Chinese semiconductor manufacturers are only in 2019 introducing 14nm technology, which international firms such as Intel and Samsung achieved in 2014. SMIC, China's most advanced semiconductor manufacturer, hopes to reach 7nm manufacturing in the early 2020s,[66] which would still be significanty behind the most advanced global competitors, though possibly by a smaller margin.[67]

THE IMPORTANCE OF SEMICONDUCTORS TO FUTURE AI COMPETITION

12. **Other than military AI applications, the future focus of strategic national AI competition is likely to be the semiconductor industry,[68] because the cutting edge of AI technology increasingly depends on custom computer chips.**

Historically, AI companies have been able to build competitive advantages based on possessing more and higher quality data to use for training purposes. Data quality, diversity, and especially quantity all remain key sources of competitive advantage for many AI applications, but there are two caveats to this. First, much of the training data for machine learning is application-specific. This means, for example, that having a large quantity of health care data does nothing if one's goal is to develop a driverless car. Second, some applications of AI can use so-called "synthetic data,"[69] created

through computational simulation or self-play, to reduce or eliminate the performance advantage from very large quantities of real-world data.

Training machine learning algorithms on large data sets is very computationally intensive. Running simulations to generate synthetic data is, for many applications, even more computationally intensive. For the large and growing set of AI applications where massive data sets are needed or where synthetic data is viable, AI performance is often limited by computing power.[70] This is especially true for the state-of-the-art AI research.[71] As a result, leading technology companies and AI research institutions are investing vast sums of money in acquiring high performance computing systems.

Chinese companies and government laboratories are strong in high performance computing and specifically on efficient high performance AI computing. China's SenseTime, for example, revealed in December 2018 that its aggregate computing power is more than 160 petaflops, more than the world's top-ranked supercomputer at Oak Ridge National Laboratory.[72] SenseTime's computing infrastructure includes more than 54,000,000 Graphical Processing Unit (GPU) cores across 15,000 GPUs within 12 GPU clusters. Such numbers indicate that SenseTime has spent hundreds of millions of $USD on computing infrastructure. SenseTime's computer network spans multiple countries but is not connected to the Internet, using a so-called "under the top" setup. At the JP Morgan Asia TMT conference on November 14, 2018, where SenseTime was presenting to potential investors, cofounder Bing Xu said that SenseTime's willingness to invest in supercomputing infrastructure was critical to its overall ability to generate IP and sustainable competitive advantages. He further said that "30–40 percent" of SenseTime's research team is devoted to improving SenseTime's internal machine learning framework, Parrots, and improving SenseTime's computing infrastructure. Several Chinese researchers told me that they consider China's expertise in designing and integrating high-performance computing systems to be one of China's strongest advantages in AI.

Most of the world's GPUs are designed by NVIDIA in the United States and manufactured by TSMC in Taiwan. At the moment, China does not have a major manufacturer or designer of advanced GPUs. However, the GPU's current position as the most commonly used AI computing accelerator chip is under increased competition from chips custom-designed to run AI applications.[73] Many traditionally software-focused U.S. technology companies, such as Google and Amazon, have created and acquired semiconductor design divisions specifically to work on AI accelerator chips. These chips can offer dramatically superior performance over GPUs for AI applications even when manufactured using older processes and equipment. The first generation of Google's primary AI chip, called a Tensor Processing Unit (TPU), for example, is manufactured using 28 nanometer process technology, which is already widely available in China. Google claimed in 2017 that its first generation TPU was 15–30 times faster and 30–80 times more power efficient for AI workloads than contemporary GPUs.[74]

Chinese firms Baidu (in partnership with Intel),[75] Alibaba (via a new subsidiary, Pingtouge),[76] and Huawei (via its HiSilicon subsidiary) have all established semiconductor design divisions focused on developing AI accelerator chips. Chinese AI chip startups Horizon Robotics and Cambricon have raised hundreds of millions of $USD in venture capital funding at multibillion-dollar valuations.[77]

CHINA'S PROSPECTS FOR AI AND SEMICONDUCTORS

13. **China's prospects in the AI chip semiconductor market are strong, likely stronger than they are in the overall semiconductor industry.**

China's goal as outlined in Made in China 2025 is to increase domestic semiconductor manufacturing as a share of domestic consumption to 80 percent by 2030 and to reduce all external dependences, including reliance on Taiwanese firms such as TSMC. According to China's Semiconductor Industry Association (CSIA), Chinese producers are on track to increase their share of domestic consumption from 29 percent in 2014 (the year before Made in China 2025 was announced) to 49 percent by the end of 2019.[78] However, most of these gains have been in product segments that do not require the most advanced semiconductors, which remain a large share of the market.[79] In its Q4 2018 financial disclosures, TSMC (which has roughly half of the global semiconductor foundry market share)[80] revealed that nearly 17 percent of its revenue came from eight-year old 28nm processes, and that 37 percent came from even older processes.[81] Chinese manufacturers plan to prioritize those market segments where older processes can be competitive.

AI chips offer Chinese manufacturers a uniquely attractive opening for their older process technology. As mentioned above, AI chips can offer potentially superior performance and cost than state-of-the-art GPUs even while using less advanced manufacturing processes.[82] The rise of AI chips therefore offers China the chance to combine its highly advanced semiconductor design and AI software sectors to expand market share and competitiveness in the broader semiconductor industry. Though flagship mobile phones likely will always demand the most advanced generation of semiconductor manufacturing processes, many applications can be addressed with older technology nodes. With low-cost AI chips, this could be a uniquely attractive, diverse, and rapidly growing set of applications. One Chinese industry observer has openly promoted this exact strategy.[83] Understanding of the importance of AI chips appears to be increasingly widespread in China. The recent Tsinghua University "White Paper on AI Chip Technologies" demonstrates a deep understanding of all the relevant technology and market dynamics. That report strongly emphasizes the strategic importance of AI chips:

> Whether it is the realization of algorithms, the acquisition and a massive database, or the computing capability, the secret behind the rapid development of the AI industry lies in the one and only physical basis, that is, the chips. Therefore, it is no exaggeration to say "No chip, no AI" given the

irreplaceable role of AI chip as the cornerstone for AI development and its strategic significance.[84]

At the same time, China hopes to use success in AI chips to build an enduring competitive advantage in the overall AI industry, underpinned by superior computing capacity, larger datasets, and a more favorable regulatory environment. This is a high priority area for China's AI companies and government. Yu Kai, the CEO of Chinese AI Chip startup Horizon Robotics, is an influential member of China's Ministry of Science and Technology (MOST)[85] AI Strategic Advisory Committee.[86]

14. **Where China is behind in AI and semiconductors, present trends suggest that the gap will narrow. This is a key government priority, receiving enormous attention and investment.**

In both AI and semiconductors, China has dramatically shrunk the gap between its domestic firms and leading international ones. Absent some kind of major change in U.S. policy to increase competitiveness, or a major Chinese economic crisis, China's policies likely will be sufficient to ensure that over the next 5 years China secures a defensible competitive advantage across many AI application markets and at least narrows the gap between Chinese and non-Chinese firms in many semiconductor market segments.

In 2014, China's government established a national integrated circuit industry investment fund[87] to reduce China's dependence on foreign semiconductors. The first fund ultimately invested 138.7 billion RMB ($20.5 billion) and was followed in 2018 by a second government fund that will reportedly invest 300 billion RMB ($44.5 billion). Recent moves by the United States – including the Obama administration's April 2015 decision to restrict semiconductor exports to Chinese supercomputing centers and the Trump administration's previously mentioned semiconductor export restrictions on ZTE – have strengthened the conclusion of China's leadership that increasing "self-reliance" is more important than ever. Dr. Tan Tieniu stated this explicitly in his November Party Congress speech before China's leadership, and Alibaba cofounder Jack Ma publicly announced similar conclusions in April 2018: "the market for chips is controlled by Americans," Ma said. "And suddenly if they stop selling – what that means, you understand. And that's why China, Japan, and any country, you need core technologies."[88]

As demonstrated by Huawei, the top tier of China's semiconductor design segment is already competitive at the global state of the art. Chinese design firms benefit from access to world-leading Taiwanese semiconductor foundry companies that manufacture semiconductors but do not design them.

The primary barriers to additional Chinese semiconductor manufacturing progress are access to the most advanced semiconductor manufacturing equipment and access to skilled workers with the knowledge of and training in how to effectively implement the most advanced manufacturing processes. China is making significant progress on

both points, but the gap in the number of skilled workers is notably large given the scale of China's semiconductor industry growth ambitions.[89]

While it does not possess any of the world's most advanced equipment manufacturing companies, China has strong negotiating leverage with foreign companies due to the size and growth of its domestic market. Semiconductor manufacturing equipment sales in China represented 11.8 percent ($6.5B) of the global market in 2017 but are expected to grow in 2019 to 25.6 percent ($17.3B).[90] Recently, semiconductor equipment manufacturers in Europe have signed deals with Chinese companies to export critical 7nm manufacturing equipment.[91] China also has successfully recruited many workers and executives from leading Taiwanese semiconductor companies,[92] including SMIC's new co-CEO, who has a documented history of stealing intellectual property.[93] When I toured a Samsung semiconductor lab, they noted that all of the printer paper in the building was laced with a metallic thread to set off the exit door metal detectors, a potent illustration of Samsung's view that intellectual property theft is a significant threat.

15. **Adverse macroeconomic factors and a potential financial bubble could slow China's AI sector growth.**

China's venture capital and technology entrepreneurial ecosystem is one of the country's major strengths. Chinese AI startups increased their share of global AI equity investment to 48 percent in 2017, while U.S. startups attracted 38 percent.[94] However, China's investment is concentrated on far fewer firms, most of which have extraordinarily high valuations relative to their current profitability. Several leading Chinese investors have hypothesized that this represents a financial bubble in China's technology sector, where growth is fueled primarily by the sector's easy access to investment capital rather than prospects for profitable revenue growth.[95] If true, such a bubble would not call into question the existence of China's strong AI sector but rather its financial sustainability. Additionally, in the second half of 2018, China's tech sector saw reports of sufficiently widespread layoffs that office real estate prices fell in the major technology districts of Beijing.[96] The broader macroeconomic climate in China also worsened in 2018, partly as a result of China's trade dispute with the United States. It is difficult to determine what extent this reflects a tech sector slowdown, a change in the financial environment, or merely the tech sector's share of macroeconomic headwinds. However, a major technology sector downturn or economic recession would make it difficult for China's government and companies to afford the R&D investments necessary to improve competitiveness.

THE IMPORTANCE OF COMMERCIAL AI SUCCESS TO CHINESE POWER

16. **China's success in commercial AI and semiconductor markets has direct relevance to China's geopolitical power as well as its military and espionage AI capabilities.**

China's commercial market success has direct relevance to China's national security, both because it reduces the ability of the United States government to put diplomatic and economic pressure on China and because it increases the technological capabilities available to China's military and intelligence community. Regarding the latter, essentially all major technology firms in China cooperate extensively with China's military and state security services and are legally required to do so. Article 7 of China's National Intelligence Law gives the government legal authority to compel such assistance, though the government also has powerful non-coercive tools to incentivize cooperation.[97] "Military-Civil Integration" is one of the cornerstones of China's national AI strategy. Several Chinese executives that I spoke with reported that they are feeling significantly more oversight and pressure from China's central government, a finding consistent with recent media reports.[98]

In 2018, China's government took the remarkable step of announcing that Baidu, Alibaba, Tencent, iFlytek, and SenseTime were officially the country's "AI Champions." SenseTime executives told me that this position gave the companies privileged positions for national technical standards setting and also was intended to give the companies confidence that they would not be threatened with competition from state-owned enterprises. In December, SenseTime cofounder Bing Xu said, "We are very lucky to be a private company working at a technology that will be critical for the next two decades. Historically, governments would dominate nuclear, rocket, and comparable technologies and not trust private companies." In explicitly comparing AI to nuclear and rocket technology, Xu appears to be referencing the critical role of AI to the future of national security. The price of SenseTime and the other AI Champions being allowed to dominate these technologies is the Champions' extensive cooperation with China's national security community. Even beyond direct cooperation, China's success in commercial AI and semiconductor markets brings funding, talent, and economies of scale that both reduce China's vulnerability from losing access to international markets and offer useful technology for the development of weaponry and espionage capabilities.

CONCLUSION

In my interactions with Chinese government officials, they demonstrated remarkably keen understanding of the issues surrounding AI and international security. It is clear that China's government views AI as a high strategic priority and is devoting the required resources to cultivate AI expertise and strategic thinking among its national security community. This includes knowledge of U.S. AI policy discussions. I believe it is vital that the U.S. policymaking community similarly prioritize cultivating expertise and understanding of AI developments in China. I hope this report has helped contribute to that objective.

Still, no amount of information on China's AI strategy will be sufficient by itself to meet the competitive challenge posed by China. If the United States wants to lead the world in AI, it will require funding, focus, and a willingness among U.S. policymakers to drive large-scale necessary change. U.S. leaders have more powerful tools to influence the technological and economic competitiveness of the United States than they have tools to influence China's competitiveness. They should prioritize accordingly.

1 The China State Council's AIDP is available in English at Graham Webster, Rogier Creemers, Paul Triolo, and Elsa Kania (translators), "Full Translation: China's 'New Generation Artificial Intelligence Development Plan,'" *New America*, August 1, 2017. https://www.newamerica.org/cybersecurity-initiative/digichina/blog/full-translation-chinas-new-generation-artificial-intelligence-development-plan-2017/.

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3 Xinhua, "Shanghai to Set up Multi-billion-dollar Fund to Develop AI," China Daily, September 18, 2018, http://www.chinadaily.com.cn/a/201809/18/WS5ba0ade9a31033b4f4656be2.html.

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5 Webster et al. (transl.), "Full Translation: China's 'New Generation Artificial Intelligence Development Plan.'"

6 The AIDP was officially released by the Chinese State Council, but the advisory committees and authoring individuals included representation from China's national security, diplomatic, academic, and private sectors.

7 For example, the recent "Artificial Intelligence Security White Paper," published in September 2018 by the China Academy of Information and Communications Technology, includes a section summarizing my own report. Greg Allen and Taniel Chan, "Artificial Intelligence and National Security," Harvard Belfer Center for Science and International Affairs, July 2017, https://www.belfercenter.org/publication/artificial-intelligence-and-national-security.

8 See the acknowledgments section for a list of some of those engaged in this critical work.

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11 Xi, Jinping's speech is available at Elsa Kaniia and Rogier Creemers (translators), "Xi Jinping Calls for 'Healthy Development' of AI (Translation)," New America. November 5, 2018, https://www.newamerica.org/cybersecurity-initiative/digichina/blog/xi-jinping-calls-for-healthy-development-of-ai-translation/.

[12] A former Vice Minister of Foreign Affairs and UK ambassador, Fu Ying plays an important role in advancing Chinese interests before American think tank audiences. See Larry Diamond, and Orville Schell, "Chinese Influence & American Interests: Promoting Constructive Vigilance" (Hoover Institution, 2018), 64. https://www.hoover.org/sites/default/files/research/docs/00_diamond-schell_fullreport_2ndprinting_web-compressed.pdf

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[14] Ma stated: "The First World War was because of the first technology revolution. The second technology revolution caused the Second World War. This is the third technology revolution – we're coming." See Ryan Browne, "Alibaba's Jack Ma Suggests Technology Could Result in a New World War," CNBC, January 25, 2019, https://www.cnbc.com/2019/01/23/alibaba-jack-ma-suggests-technology-could-result-in-a-new-world-war.html.

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[20] Central Military Commission Joint Staff, "Accelerate the Construction of a Joint Operations Command System with Our Nation's Characteristics CMC Joint Operations Command Center," Seeking Truth, August 15, 2016, http://www.qstheory.cn/dukan/qs/2016-08/15/c_1119374690.htm.

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26 Dr. Dai is also a professor of computer science at the NUDT College of Computer Science.

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[59] Specifically, the report claimed, "Made in China 2025 is at the center of the China AI policy citation network and has served as a programmatic document for local governments' AI policymaking as they respond to the national AI development strategy."

[60] Kenneth Kraemer, Greg Linden, and Jason Dedrick, "Capturing Value in Global Networks: Apple's iPad and iPhone," ResearchGate, July 2011, www.researchgate.net/publication/265187229_Capturing_Value_in_Global_Networks_Apple's_iPad_and_iPhone.

[61] Value capture is defined in the report as follows: "Within a value chain, each producer purchases inputs and then adds value, which then becomes part of the cost of the next stage of production. The sum of the value added by everyone in the chain equals the final product price."

[62] As of 2017, 9 percent of Apple's iPhone suppliers were Chinese companies. Debby Wu and Cheng Ting-Fang, "How the IPhone Reshaped Asian Tech," *Nikkei Asian Review*, December 20, 2017, https://asia.nikkei.com/Spotlight/Cover-Story/How-the-iPhone-reshaped-Asian-tech2.However, these companies and Chinese laborers at international companies still only captured 3 percent of the value of each iPhone. See Jason Dedrick and Kenneth L. Kraemer, "Intangible assets and value capture in global value chains: the smartphone industry," World Intellectual Property Organization Working Paper, November 2017, https://www.wipo.int/edocs/pubdocs/en/wipo_pub_econstat_wp_41.pdf.

[63] Ibid.

[64] Though HiSilicon led the design effort, it licensed important intellectual property from international companies such as ARM. Additionally, Chinese AI chip startup Cambricon reportedly helped with the design of the deep learning accelerator element.

[65] The production of semiconductor manufacturing equipment and semiconductor design software are two other critical areas.

[66] Edward White, "China's Ability to Make Computer Chips Still 'Years Behind' Industry Leaders," *Financial Times*, January 22, 2019, https://www.ft.com/content/a002a9e4-1a42-11e9-b93e-f4351a53f1c3.

[67] China has no companies capable of producing the equipment required to manufacture at 7nm and other advanced process nodes. The top global equipment manufacturers are all based in the United States, Japan, South Korea, and Europe.

[68] To my knowledge, Tim Hwang, Director, Harvard-MIT Ethics and Governance of AI Initiative and a member of the CNAS AI Task Force, is the first person to make this claim in publication.Tim Hwang, "Computational Power and the Social Impact of Artificial Intelligence," March 24, 2018, updated January 2019, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3147971.

[69] The difference between 2015's AlphaGo – which was trained in part upon a data corpus of historical human vs. human go matches – and 2017's vastly superior AlphaGo Zero – which was trained entirely upon synthetic data generated from matches in which the AI played against itself – illustrates this issue. Synthetic data is not viable for all AI applications, since not all simulators are a perfect proxy for the real world they attempt to model. Nevertheless, synthetic data has proven to be increasingly important in cutting edge AI research and marketable AI applications. For example, U.S. self-driving car company Waymo (formerly Google) announced that in one year cars had driven 2.5 billion miles in virtual simulators compared with only 3 million miles of real-world roads. In 2017, one of the company's executives said that "The vast majority of work done – new feature work – is motivated by stuff seen in simulation." Alexis C. Madrigal, "Waymo Built a Secret World for Self-Driving Cars," *The Atlantic*, August 23, 2017, https://www.theatlantic.com/technology/archive/2017/08/inside-waymos-secret-testing-and-simulation-facilities/537648/.

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