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As satellites orbit Earth capturing images of farmland and collecting data on weather conditions, United States technology startup Descartes Labs conducts an analysis. By integrating the information from satellites with several data points, the company is able to recognize patterns and estimate crop yield in nearly real-time. Ultimately, Descartes contributes to more informed farming and agricultural decisions by sharing useful insight with stakeholders ranging from the farmers themselves to the United States government.

This example of the opportunity technology presents to improve society fascinates me. I enrolled as a student at the University of New Hampshire (UNH) as a mechanical engineering major with an interest in technology, but after taking a few classes in philosophy and business I found studying the social, political, and economic implications of technologies more intriguing. I am now pursuing a dual degree in economics and philosophy: two seemingly contrasting disciplines that complement each other nicely. Economics emphasizes quantitative and theoretical analysis, while philosophy encourages critical thinking and exploration of ideas.

The essence of economics—how scarce resources should be allocated by society—is increasingly seen as less of an issue about markets, state plans, and economic institutions, and more of a technical problem about the availability of data, development of effective algorithms, and access to technology (American Economic Association, 2017). During the summer of 2017, I explored the potential implications of applying artificial intelligence (AI) to resource management. I conducted this research at the Centre for the Study of Existential Risk (CSER) at the University of Cambridge in the United Kingdom, funded by a Summer Undergraduate Research Fellowship (SURF) Abroad. Essentially, I researched the benefits and drawbacks of using AI algorithms to help people make the best use of resources, such as water and farmland.

The author outside the CSER office in Cambridge.

Artificial intelligence (AI) can be applied to the problem of resource scarcity because it considers more information than

humans can, and can offer solutions that are not possible for humans to conceive. Hereby, AI could improve technical efficiency and progression toward a world of abundance that has seemed "just around the corner" for nearly a century (Keynes, 1930). I hoped that my summer research would allow me to identify and share with others ways to ensure the development of AI that is broadly beneficial, and that could lead to more efficient resource management.

Project Background

AI can be defined in many different ways. For the purposes of this project, AI refers to machine learning algorithms that develop over time without being explicitly programmed. An algorithm is a set of rules to be followed. In the case of machine learning, most software algorithms develop with data inputs and guidance from humans regarding desired outcomes. In the context of resource management, AI could be used to offer agricultural recommendations about which crops to grow and how best to grow them. AI could use inputs including weather conditions and predictions, market prices, and geographical location to provide insight to farmers. This would be especially useful to farmers in marginalized communities who currently rely upon a synthesis of historical data, empirical observations, tradition, and intuition. Better-informed farming could lead to higher crop yields and less water usage, as well as food and economic security of communities worldwide.

The Mathematical Bridge is a wooden bridge that connects two parts of Queens' College. It was very near the office where the author spent most of his time, and he thought the complexity of the bridge was fascinating.

Although the positive potential of AI is promising, the technology also is associated with several serious risks. AI as an agricultural tool has obvious potential benefits but it is not obvious who will actually benefit. While the technology may manage resources more efficiently, what the algorithms optimize for is not inherent. Developers design AI systems to optimize specifically for a certain variable, which might not be associated with a broadly beneficial result. To prevent exploitation and to ensure increased wealth and improved well-being for everyone, the advancement of AI for resource management must be carefully considered.

With this topic in mind, my UNH mentor, Professor Nick Smith, and other philosophy department faculty members connected me with Huw Price, professor of philosophy at the University of Cambridge, who co-founded the Center for the Study of Existential Risk (CSER). CSER is an interdisciplinary academic research institution dedicated to the study and mitigation of risks that could lead to human extinction or civilizational collapse, such as risks arising from climate change, synthetic biology, or artificial intelligence (Centre for the Study of Existential Risk [CSER], 2018). Alongside my mentor Dr. Simon Beard, a research associate at CSER, I sought to determine the most noteworthy risks and benefits associated with developing resource management AI that

could guide marginalized communities and offer insight into more efficient, effective, and equitable resource distribution.

Research Process and Experience Abroad

I began the summer by discussing my project with individuals at CSER and at the Leverhulme Centre for the Future of Intelligence, which shared an office with CSER. I was also introduced by my mentor and others at CSER to academics and experts in the fields of AI, climate science, data analytics, economics, ethics, and robotics at institutions throughout the United Kingdom. CSER is very well-connected, and people with whom I worked were helpful in identifying individuals whose experience might benefit my project. I gained insight through interviews and discussions, as well as attending relevant events. Because both the use of AI in the context of agricultural resource management and research regarding the risks and benefits associated with AI in general are in their early stages, the work that I began with this project is ongoing and evolving.

During my summer in Cambridge, I had the opportunity to become involved in academia in a new way. It was incredibly interesting to work with postdocs who took me in as a colleague and to collaborate with them every day. I found the academic atmosphere of Cambridge very welcoming. Everyone I contacted was friendly and quite open to scheduling meetings. After I briefly described my project, many were interested in talking over lunch or tea, or even just on a Skype call. Discussing AI in the context of resource scarcity with people from such a variety of backgrounds was immensely beneficial; throughout the summer I recognized that many institutions emphasized interdisciplinary research, which I greatly appreciated.

From left, members of CSER Simon Beard, Jens Steffensen, Haydn Belfield, Julius Weitzdörfer, Andrew Ware, and Lalitha Sundaram. *(Photo by Imke van Heerden for the Centre for Research in the Arts, Social Sciences and Humanities (CRASSH) at the University of Cambridge.)*

I visited the Cambridge Computational and Biological Learning Lab to gain a greater understanding of machine learning, the Future of Humanity Institute at the University of Oxford to discuss the ethical implications of relying on AI for decision-making, and the Bristol Robotics Lab to see how humans and artificially-intelligent machines can collaborate. I also met with individuals from the Computer Laboratory at the University of Cambridge and the British Antarctic Survey to learn about algorithms and the innovative ways they are being developed for AI, and how these algorithms contribute to models that can be applied to climate research. It was great to incorporate their insight into my project.

Positive Potential of AI for Resource Allocation

By the end of the summer, I concluded that there are several significant positive outcomes that could result from applying AI to the problem of resource scarcity. The algorithms employed by AI could help determine which crops need water or nutrients, and when and to whom these resources should be distributed. The AI systems could identify patterns of production and consumption of agricultural resources that are too complex for humans to perceive. The systems could make precise recommendations for the management and distribution of resources with consideration of regional and cultural context, including traditions and social norms, specific climate and weather conditions, and people's expectations, to offer more efficient solutions.

AI's potential to improve the efficiency of agriculture and security of food systems (contributing to the minimization of scarcity) is best illustrated by an example of the current use of AI. As mentioned earlier, Descartes Labs uses satellite images of corn fields and other data to estimate crop yields. The images include spectral information that show chlorophyll levels, which reveal the health of a harvest, and indicate whether additional nutrients and inputs (such as water) should be provided to maximize yield. Other data inputs, including advanced weather predictions and historical information, contribute to the accuracy of corn yield estimates (United States National Aeronautics and Space Administration [NASA], 2017). Ultimately, Descartes Labs offers a great understanding of crop yield and the factors that maximize it to farmers and the agricultural industry. If farmers learn that a season is slightly drier than previous years and that the soil has a higher level of nitrogen, for example, they can decide to provide particular nutrients in order to maximize yield.

AI-generated crop health assessments can be provided to the government as well, which offers subsidies to farmers based on demand and yield. For example, if the United States Department of Agriculture (USDA) is made aware before the end of the harvest season that the yield for a particular crop will greatly differ from previous years, it may decide to reallocate subsidy funding in order to accommodate the change, while avoiding shocks to the market (offering a greater level of predictability to farmers' incomes). More informed crop prediction allows farmers to use time, water, and land more efficiently, and allows the USDA to determine subsidies more accurately.

Further, Descartes Labs has shown that gaining insight from data analysis does not require farmers to use new infrastructure or advanced technology, or to have higher levels of education; predictions are derived from information collected by satellites, and insights can be communicated to farmers, the government, and other stakeholders through existing channels, such as cell phone text messages, in a way that is easy to understand.

In essence, an AI tool that provides agricultural insight could improve access to resources by considering more data, recognizing patterns, and increasing efficiency. Better-informed farming would meaningfully affect the agricultural industry and could help minimize scarcity worldwide.

Risks and Recommendations

Risks emerge from industrialization and advancements in technology. For example, as technology advances and as humans increasingly rely upon algorithms to make decisions, serious safety and security risks become apparent. Although AI systems could improve resource management, they could also make the problem of scarcity worse (International Telecommunication Union [ITU], 2017). The technology could be used to manipulate rather than beneficially manage resources. Through my research, I found that the development of AI for resource management must therefore be carefully considered.

Bias in data and algorithms is an important issue in the development of AI. Most algorithms use historical data, so outputs reflect past injustices and do not necessarily offer guidance that is meaningfully better than human ability (Dunietz, 2016). Criminal risk assessment tools illustrate the issue of prejudice perpetuated by machine learning algorithms. Throughout the United States, software is used to predict whether a criminal might reoffend. Findings influence sentencing decisions in courtrooms by identifying which defendants could be safely released on bail while awaiting trial. The intention is to minimize overcrowding in jails, but the algorithms have been found to correlate race with criminal history and incorrectly predict that black defendants would reoffend nearly twice as often as white defendants (Angwin, Larson, Mattu & Kirchner, 2016). In the end, the system is discriminatory because it amplifies prejudices present in the historical data used in its development. Ultimately, while there is the potential for AI systems to lead to ideal outcomes, there is also the risk that systems will benefit the interests of the wealthy and powerful, rather than improve the conditions of those who are worst off, either intentionally or by design.

I have discovered that collaboration and cooperation throughout the development of AI is important in minimizing bias. The perspectives of farmers must be involved from the earliest stages of development, as well as guidance from non-governmental organizations (NGOs), support from world banks, and expertise of data scientists, machine learning researchers, AI experts, and policy and lawmakers. It is also crucial that mechanisms are in place for AI systems to be modified in the future to reflect changing social and economic structures, values, and cultural practices. Local stakeholders must not follow guidance blindly, but rather offer criticism and reject poor suggestions in order to influence algorithms to better align with current conditions.

I have discovered, too, that the trustworthiness of these systems is important, and critical to the acceptance of using AI for resource management. It is challenging for people to accept guidance if it is not shown to be derived legitimately and credibly, so suggestions offered by a system regarding resource management and distribution will likely not be adopted if humans cannot understand how and why the AI reached its conclusions (Cash et al., 2003). For example, neural networks (the foundation of many AI systems) function in a way that is implicit and opaque, without clear reason offered that explains outputs (Knight, 2017). Further, without local stakeholders' awareness of how the output of systems is reached, historic exploitation of people and land similar to the Age of Imperialism might continue. Developers of such technology could use data and machine algorithms to justify land use in a particular region that is not broadly beneficial. For example, a system might indicate that an 'optimal' distribution could be achieved by growing economically lucrative crops such

King's College Chapel is one of the most recognizable landmarks of Cambridge. It was about three minutes from the office where the author spent most days researching. He often went there to eat lunch, and the photo is a view from where he sat to eat.

as sugar cane, rather than growing sustainable, nutritious foods. The result would not be the mitigation of hunger; instead, AI could be used to increase inequality and consolidate power.

To increase the trustworthiness of systems, it is important that AI used to manage resources be meaningfully transparent and comprehensible (Association for Computing Machinery, United States Policy Council [USACM], 2017). Developers must determine and articulate what is important for people to know. Guidance about resource management and distribution must be explained clearly. People using the systems must understand how suggestions are reached in addition to knowing how to use the systems (O'Neill, 2015).

Ultimately, AI has enormous positive potential to address the problem of resource scarcity, but we cannot be led by utopianism. Transparency is necessary to the successful advancement of trustworthy AI systems, and an honest and thoughtful consideration of benefits alongside risks is required to foster trust among all stakeholders throughout development. With a foundation of trust, built with a collaborative effort among all stakeholders, it will be possible to ensure that the technology contributes to a better future.

Looking to the Future

I had the opportunity to explore my own interests regarding an incredibly relevant and complex issue with my summer research and cultural experience in the United Kingdom. I found it inspiring that the people I worked with loved their research. I also found it striking how seriously everyone took their work. Everyone's passion and dedication to research caused me to recognize the significance of the work we were doing. In fact, shortly after my arrival in Cambridge, the U.K. parliament appointed a committee "to consider the economic, ethical, and social implications of advances in artificial intelligence," demonstrating a noteworthy reliance on academics and other individuals with relevant education and experience in shaping public policy (2017). I contributed to a paper submitted by my mentor, Simon Beard, to the committee's public inquiry seeking, "to understand what opportunities exist for society in the development and use of artificial intelligence, as well as what risks there might be" (United Kingdom Lords Select Committee on Artificial Intelligence, 2017). My time in Cambridge was a fascinating glimpse into the realm of international academia and public policy, and offered me great confidence in my decision to attend law school. I plan to pursue a career in contributing to the development of laws, policies, and regulations that influence technology's impact.

I am immensely appreciative of the support I received in completing my Summer Undergraduate Research Fellowship (SURF) project from Mr. Dana Hamel, the Rogers Family Undergraduate Research Fund, the Grand Challenges for the Liberal Arts Initiative, and Dr. Heidi Bostic, Dean of the College of Liberal Arts. I would also like to thank the staff of the Hamel Center for Undergraduate Research—in particular, I am grateful for the hard work of Georgeann Murphy and Peter Akerman. Finally, thank you to my mentors Nick Smith and Simon Beard, and the many others at the University of New Hampshire and University of Cambridge who offered their encouragement and expertise, contributing greatly to the success of project and my experience abroad.

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Author and Mentor Bios

Andrew Ware, from Manasquan, New Jersey, will graduate from the University of New Hampshire (UNH) in December 2018, with a bachelor of arts in philosophy and a bachelor of science in economics. He is also in the University Honors Program. Ware completed his research on artificial intelligence with a Summer Undergraduate Research Fellowship (SURF) Abroad grant. "I am fascinated by the cultural changes associated with technology," Ware says. He was offered a glimpse into the world of academia at Cambridge and in the United Kingdom, where work is being done to ensure that technology is developed thoughtfully. He realized that it is important to consider feedback from as many people as possible. "Everyone brings a unique perspective to the research," he says. Ware heard about *Inquiry* from his advisors at UNH. He decided to submit to the journal to invite a broader audience to view his research. This way, other students could gain insight into the research process. Ware plans to attend law school and to continue to explore the connection between philosophy, economics, and technology as he pursues a career in technology policy and regulation.

Nick Smith is professor and chairperson of the University of New Hampshire (UNH) Department of Philosophy. He has been at UNH for sixteen years. Before coming to UNH, Smith, who holds a J.D. and Ph.D., worked as a litigator for a private law firm and as a judicial clerk for the Honorable R. L. Nygaard of the United States Court of Appeals for the Third Circuit. He has published two books on his studies on the meaning and role of apologies in justice and contributes regularly to interviews in national media outlets. Smith has mentored many undergraduate researchers at UNH and considers it "one of the genuine highlights of teaching at UNH." Dr. Smith first met Andrew in an introductory philosophy course in Andrew's first semester at UNH. "I knew from first working with him that he really could write his ticket to whatever he wanted to do after UNH," said Smith. Working with Andrew has pushed Smith to dig deeper into areas that he is interested in. Smith believes learning to write for *Inquiry* is useful for students in philosophy because it allows them to communicate complex ideas to a broader public in concise and compelling ways.

Simon Beard is a research associate at the Centre for the Study of Existential Risk (CSER), located at the University of Cambridge in the United Kingdom. Dr. Beard was excited to serve as Andrew's mentor because their areas of research aligned well. He helped Andrew formulate his research question and methodology and discussed his findings with him. He facilitated meetings between Andrew and a range of academics at Cambridge and other U.K. institutions and extended invitations to relevant conferences and events. Dr. Beard was very pleased with Andrew's ability to produce high-quality work as a researcher. He says that Andrew's research was directly relevant to CSER's work, reflected in the fact that it informed CSER's response to the U.K. parliamentary enquiry on artificial intelligence.