Processing Artificial Intelligence: Highlighting the Canadian Patent Landscape

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Canadian Intellectual Property Office

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Iu71-4/81-2020E-PDF
ISSN 978-0-660-35529-0

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TABLE OF CONTENTS

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The Canadian Intellectual Property Office (CIPO) would like to extend its gratitude to the United Kingdom Intellectual Property Office for its ongoing collaboration and support to arrive at a commonly accepted definition of Artificial Intelligence (AI) in addition to sharing its patent search strategy.

This report applies a comprehensive taxonomy developed by the World Intellectual Property Organization (WIPO) for its *Technology Trends 2019* report to categorize the AI patented invention data into groupings which facilitate a targeted analysis of specific technology areas. For this, CIPO is thankful to WIPO for publishing its methodology and its ongoing effort to push the boundaries of IP research.

We would also like to thank Statistics Canada for their analytical contribution to this report in the Canadian institution section, which presents descriptive statistics on institutions holding patented inventions. This contribution greatly enhances our understanding of the demographics of potential CIPO clients in the AI technology field and to benchmark against national statistics for all technology fields.

ABOUT CIPO

The Canadian Intellectual Property Office (CIPO), a Special Operating Agency of Innovation, Science and Economic Development Canada (ISED), is responsible for the administration and processing of Intellectual Property (IP) in Canada. CIPO contributes to Canada's innovation and economic success by providing greater certainty in the marketplace through high-quality and timely IP rights, fostering and supporting invention and creativity through knowledge sharing, raising awareness to encourage innovators to better exploit IP, helping institutions compete globally through international cooperation and the promotion of Canada's IP interests, and administering Canada's IP system and office efficiently and effectively.[1]

EXECUTIVE SUMMARY

Artificial Intelligence (AI) is a technology area that has garnered significant interest in recent years. As society becomes increasingly dependent on the latest technologies, the amount of data generated from the complimentary services linked to such products has increased at an exponential rate; so much so that alternative methods of parsing through all this data is essential to being able to extract additional value. Some have characterized data as a new resource, equivalent to “oil.”[2] With society in an era of big data, it is necessary to have the appropriate tools to leverage this abundance of information.

Measuring innovation pertaining to AI is a challenging task since the field involves a variety of different techniques that can be broadly applied across a wide array of industries. Even though patented inventions are not a universal indicator for measuring innovative activities, there is no measure that captures all of the elements that comprise the innovation process. For this reason, this report is based on the premise that patent activity is a good proxy for measuring innovation in a particular technology sector.

The primary focus of this report is to highlight Canadian innovation undertaken domestically and abroad in the field of AI. Combined, Canadian researchers and institutions accounted for 1.8%, or 1,516, of the 85,144 AI inventions patented worldwide between 1998 and 2017. The number of worldwide AI patented inventions has increased exponentially over the past 20 years. In 1998, fewer than 2,000 inventions were patented, while in 2017, that number increased to slightly less than 20,000. In 2017, Canada ranked sixth globally, both in terms of the number of patented inventions assigned to Canadian researchers and to Canadian institutions. Canada’s rankings fall behind notable countries that file prolifically, namely China and the United States. Canadian researchers are identified as being specialized in the following sub-categories of AI Applications: Natural Language Processing, Knowledge Representation and Reasoning, and Computer Vision. Furthermore, the Toronto, Ottawa–Gatineau and Vancouver Census Metropolitan Areas (CMA) have the highest concentration of inventive activity for Canadian researchers. Canadian institutions, on the other hand, are not only specialized in Life and Medical Sciences and Physical Sciences and Engineering, but also the Telecommunications AI Field. However, Canadian institutions are not as specialized as some of the other countries in the quickly growing Transportation field. The Toronto and Montréal CMAs have the most inventive activity for institutions, while the Ottawa–Gatineau and Vancouver CMAs are tied for third. In terms of the gender distribution among Canadian researchers in this field, there was one female researcher identified for every six male researchers, while internationally, the ratio is one female researcher for every three male researchers.

Considering that this report is based on information that is publicly available and leverages the valuable content included in such patent data, it begs the question: will reports such as this be one day generated through AI? Diving deeper into the patent data could assist in determining if such a technology that has the potential to generate such an analytical report, has already been developed.

INTRODUCTION

The rapid pace of innovation in Artificial Intelligence (AI) technologies, and the fact that it touches many industry sectors, makes this a topic that is top of mind to a wide range of stakeholders. Although the main advances in AI have been developed over the past seventy years, the discussion around the creation of an alternative intelligence dates back to the 1300s.[3] By 1943, the idea of "artificial neurons" spurs the interest in computer-based neural networks and then deep learning.[4] In 1950, Alan Turing proposes what is now fondly called the "Turing Test": an imitation game that tests a machine's intelligence by imitating the sentient behaviour of a human.[5] This sequence of events ultimately led to the term "Artificial Intelligence" first being coined in 1955 by John McCarthy, Marvin Minsky, Nathaniel Rochester and Claude Shannon in a research proposal that looked to explore the thinking capacity of machines.[6]

The significant progress made in the early days of AI was followed by what is now commonly known as "AI Winter": a period of time when ". . . commercial and scientific activities in AI declined dramatically".[7] The decline ended in the 1970s and greatly stalled any further progress in AI.[8] Despite this, there has been relentless progress in current years. The availability of data in combination with higher computing power has caused an explosion in the field.[9]

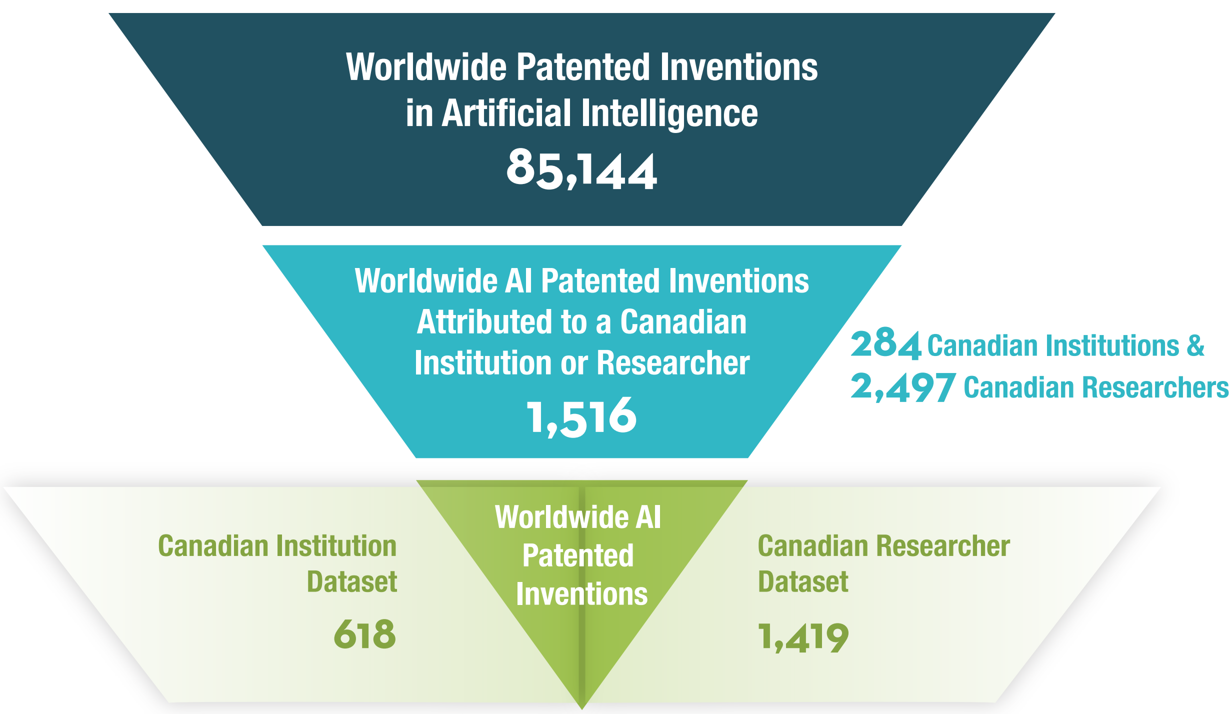
Establishing a universally accepted definition of AI from a patent perspective is a challenging feat. Due to the ever-evolving nature of AI, its patent definition needs to be continuously adjusted by incorporating the latest terminology to capture breakthroughs. The World Intellectual Property Organization (WIPO) was one of the first Intellectual Property (IP) institutions to provide a general overview of patenting in AI using a patent-based definition. Subsequently, the United Kingdom Intellectual Property Office (UKIPO) developed its own search strategy and released a report articulating the AI patenting landscape in the United Kingdom (U.K.). Building on the work of the UKIPO, CIPO has adopted the methodology used by our colleagues in this report and expanded it to present the patent landscape from the perspective of Canadian inventions filed in Canada and abroad rather than focusing on those only filed at CIPO (additional details in Annex A). The intent of this research is to highlight the areas where Canadian researchers and institutions are most innovative and identify where they may be relatively more specialized globally. Examining Canadian researchers and institutions separately provides a deeper understanding of the state of innovation in AI. Understanding Canada's technological strengths from the perspective of researchers and institutions is helpful to policymakers when developing targeted policies that can be designed to increase our strength in specific technology fields with the ultimate objective of advancing innovation.

Ultimately, this report is the culmination of a literature review, a compilation of organization-specific information, an extensive and targeted patent search strategy, and a close examination of the differences between the filing activity of Canadian institutions and those of Canadian researchers, regardless of their affiliations to institutions and the nationality of those entities. The next section of the report discusses the patent dataset used as an indicator for innovation in the AI field. The third section presents an overview of the international patent landscape based on the origin of the names assigned to the patented inventions, hereafter referred to as assignees. The fourth and fifth sections look at AI inventions patented by Canadian institutions and Canadian researchers, respectively. These two sections provide a detailed overview of filing activity looking at areas of specialization by AI sub-category, key players, geographical distribution across the country, and patent landscape maps. The details presented in these sections are useful to better understand the evolution and the current state of innovation in this technology field. The sixth section follows CIPO's collaboration with Statistics Canada and sheds light on the industry, size, and ownership characteristics of the Canadian institutions patenting in AI.

DATASET

The breakdown of the dataset used for this report, which covers the 1998-2017 period, is presented in Figure 1. The worldwide dataset is comprised of approximately 85,000 AI patented inventions. Combined Canadian researchers and institutions account for 1.8% of the international dataset, or more than 1,500 patented inventions. Our analysis divides this dataset into two subsets by separately examining the data from the perspective of filings by Canadian institutions and another focused on filings by researchers. The institutions dataset is comprised of 284 Canadian institutions, which, for the purpose of this analysis, includes academic institutions, companies and government departments. In total, these Canadian institutions patented more than 600 inventions. The researcher dataset consists of approximately 2,500 Canadian inventors that are associated with more than 1,400 patented inventions.

Figure 1: Breakdown of AI patented inventions by dataset analyzed in this report

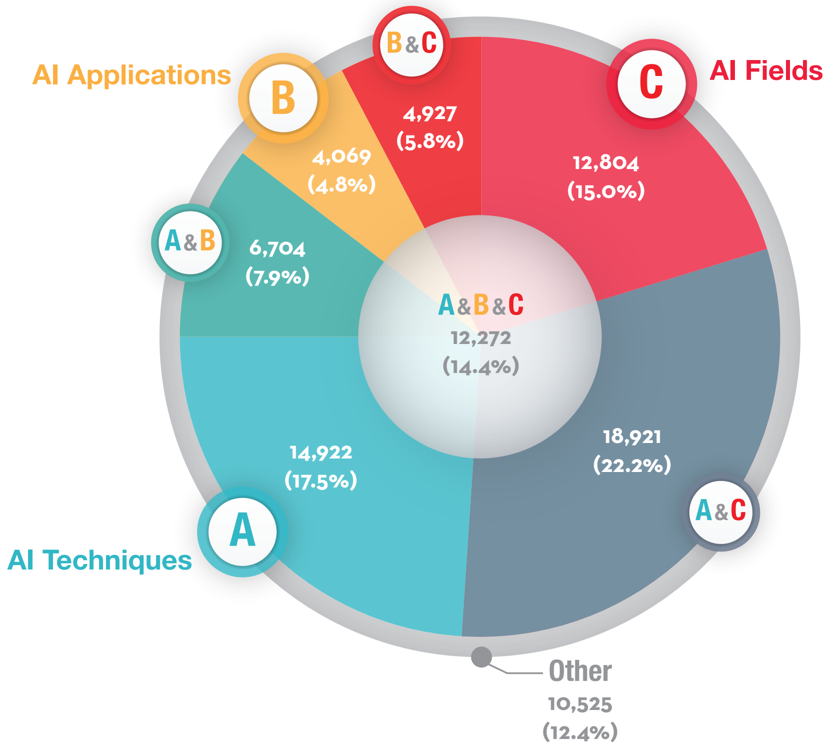


In order to gain a deeper understanding of where Canada's strengths lie in AI and how it fares in comparison with other nations, the international dataset is further broken down using the taxonomy presented by WIPO in the *Technology Trends 2019* report.[10] The taxonomy, which is based on the Association for Computing Machinery (ACM) Computing Classification System, involves grouping the data into three categories: AI Techniques, AI Applications and AI Fields. The AI Techniques category includes advanced forms of statistical models that facilitate the computation of tasks typically performed by humans; the AI Applications category includes functions that can be realized using one or more AI Techniques; and the AI Fields category includes the different fields, areas or disciplines where AI Techniques or AI Applications may be applied. Breaking down the AI patented inventions dataset into these three categories is effective from an analytical perspective, as each category represents developments in AI from different perspectives, moving from the fundamental technical aspects of AI, to applications of AI at the functional level or as used in specific industries. The distribution of this data across these three AI categories is presented in Figure 2. These AI categories are established based on the inclusion of a combination of International Patent Classification (IPC) codes, Cooperative Patent Classification (CPC) codes and a set of relevant keywords in each patented invention.[11] In assigning the patented inventions to each of these designated categories, we note that not all patented inventions are classified according to these specific groupings. An area of potential future work would be to analyze these patented inventions to determine whether they are representative of emerging fields of AI that have not yet been classified.

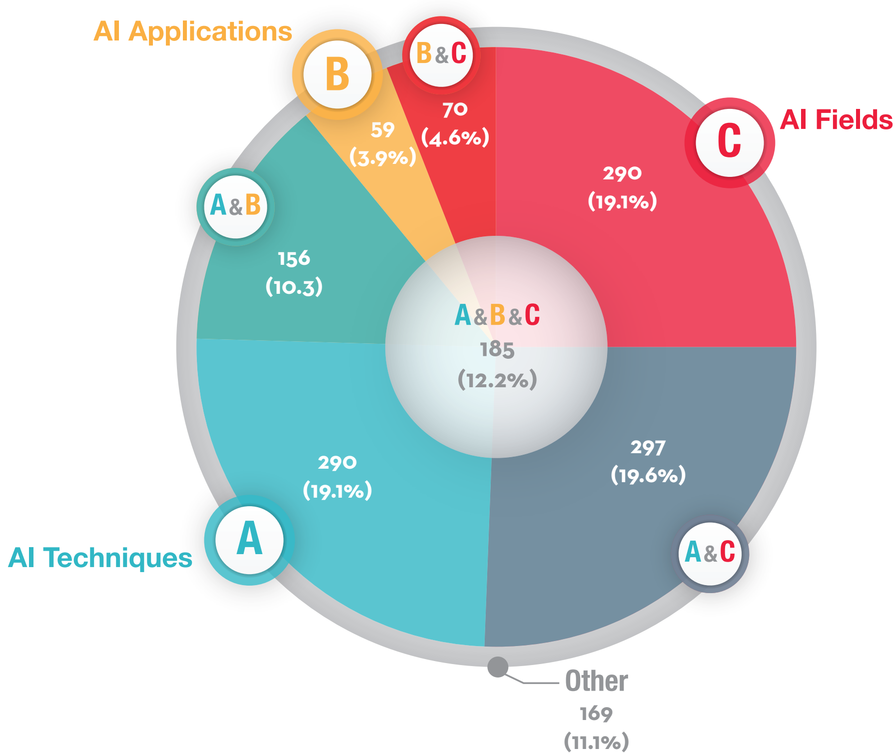
The Canadian dataset is categorized using the same approach as the international dataset. One of the most noticeable differences between the two datasets is that a larger proportion of Canadian inventions is categorized under AI Fields only, as opposed to both AI Fields and AI Techniques. On the other hand, a larger percentage of patented inventions in Canada are categorized to both AI Techniques and AI Applications rather than just AI Applications. The intersection of AI Applications and AI Fields is lower in the Canadian dataset compared to the international dataset. There are no significant differences for the intersection of all three categories, as shown by the inner circle of each diagram, or for the outer circle labelled as the "Other" category.

Figure 2: Distribution of patented inventions across AI categories for International and Canadian AI datasets

INTERNATIONAL AI DATASET



CANADIAN AI DATASET



INTERNATIONAL IMPORTANCE OF INTELLECTUAL PROPERTY IN ARTIFICIAL INTELLIGENCE

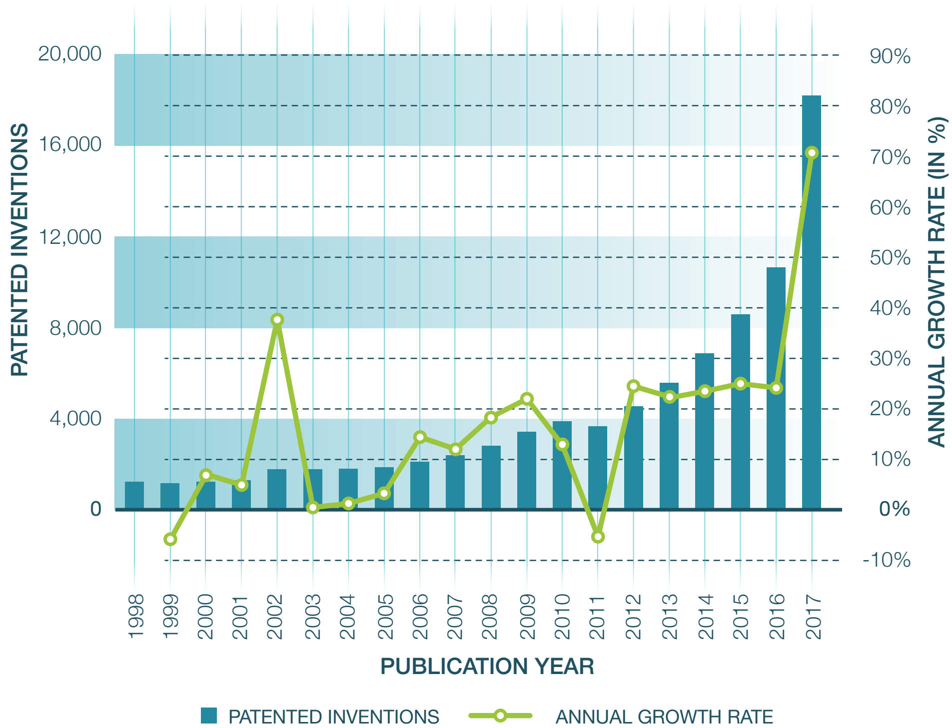
AI has started to pave the way for more innovative and futuristic approaches to daily tasks. From autonomous vehicles to smart toys, AI has become synonymous with being on the edge of leading innovation. To protect the new advancements, key players, such as universities, companies and public research organizations, have turned to IP rights to help protect their new technologies. The fast-paced environment of AI development has led to protecting inventions in two ways: (1) a patent, and (2) through scientific publication.[12]

Canada, the U.K., Australia and Germany are leaders in scientific publications in specific applications of AI.[13] Players may be strategically publishing in scientific journals to put the work into the public domain, thereby preventing others from patenting the invention.[14] For countries participating in the *European Patent Convention*, computer programs are not considered to be patentable subject matter. On the other hand, U.S. has no such restrictions.[15] For Canada, the *Canadian Patent Act* states that a patent can only be granted for the "physical embodiment of an idea" and hence computer programs are not considered to be patentable subject matter.[16] When interpreting the analysis in the following sections, it is important to keep in mind that the culture towards patenting for AI is evolving and is currently applied differently between countries which could have some influence on the overall patent activity as measured by patented invention counts.

Patent Filing Trend

As seen in Figure 3, worldwide patent filings in AI between 2011 and 2017 have grown considerably, increasing on average by 31% annually. More research should be undertaken to understand the factors responsible for this increase. Other than the fact that there are more researchers actively patenting their AI inventions, it would be useful to understand if this growth is a result of researchers increasingly recognizing the value of patent protection as it relates to AI inventions.

Figure 3: International patent activity in AI between 1998 and 2017



In Figure 4, we take a closer look at the trend in patented inventions published over time based on the country of origin of the assignee, which includes institutions and researchers who are assigned the rights to an invention. China has made considerable headway in patenting AI inventions and is responsible for most of the growth worldwide over the past decade. Canadian assignees rank sixth overall in terms of absolute counts of patented inventions, ranking behind assignees originating from Germany and ahead of those from the U.K. The surge in filings from assignees originating from the United States (U.S.) is likely a result of the U.S. government policies to promote innovation in this field.[17]

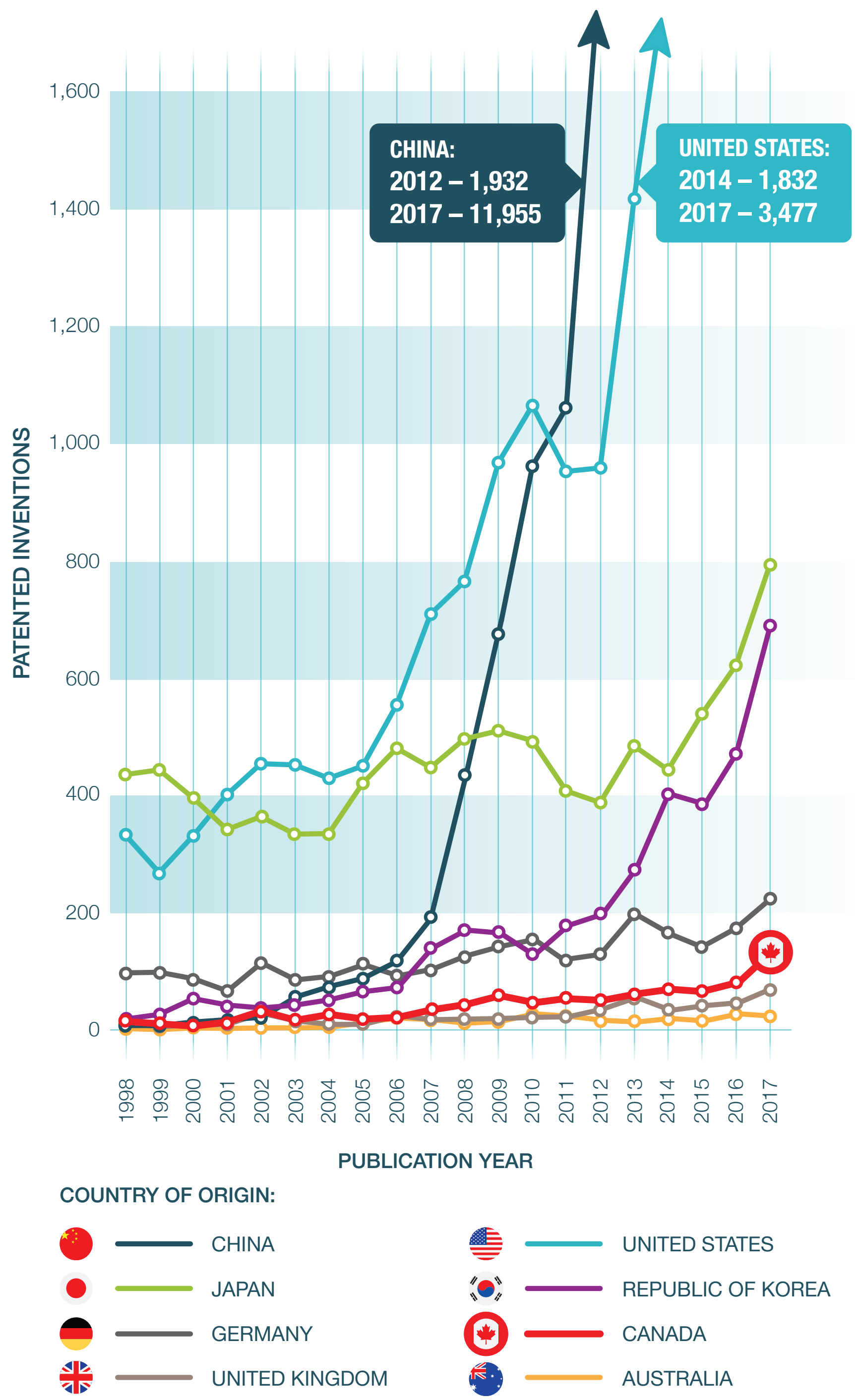
It should be noted that China's representation in the international dataset pertaining to domestic filings by applicants[i] is incomplete for the timeframe considered in this analysis.[ii] As a result, China will not be used to benchmark Canada's performance in this report. Inventions originating from Chinese applicants that are patented abroad are assumed to be accurately captured by the respective filing offices that administer the international filings.

[i] The term "applicants" includes both assignees and researchers of a patented invention.

[ii] In reviewing the dataset, it was noticed that data for the total inventions patented by Chinese applicants was incomplete in EPO-PATSTAT. Upon consulting a representative from EPO-PATSTAT, we were informed that this was due to the China National Intellectual Property Administration (CNIPA) gradually decreasing the applicant information provided. The following Tableau dashboard illustrates this fact:

https://public.tableau.com/profile/patstat.support#!/vizhome/CoverageofPATSTAT2019SpringEdition/CoveragePATSTATGlobal

Figure 4: Trend in AI patent activity by assignee's country of origin between 1998 and 2017



IP Concentration

In order to gauge the predominance of assignees from certain countries in patenting AI inventions over time, we have developed a metric called the Intellectual Property Concentration Index (IPCI). This index can be used to determine the competitiveness of an industry or technology field based on the distribution of patented inventions held by all the countries active in that industry or field (additional details in Annex C). Index values closer to 0 indicate a more competitive global environment consisting of a large number of less-active countries, whereas index values closer to 1 would indicate a more concentrated global environment consisting of a few dominant countries.

In Figure 5, we observe the change in the IPCI value over time at the international level. After the initial dip in the index value in the early 2000s, we notice a gradual increase in the value over the years, synonymous with an increase in the level of concentration of AI patented inventions by country of origin. Interestingly, the index value is approaching 0.5 in 2017, which can indicate a near duopoly: a situation where assignees from two countries file predominantly in AI. Based on the trend observed in Figure 4, we confidently establish that these two countries are China and the U.S., since they cumulatively account for 85% of the inventions patented globally in 2017.

Figure 5: Intellectual Property Concentration Index in AI between 1998 and 2017

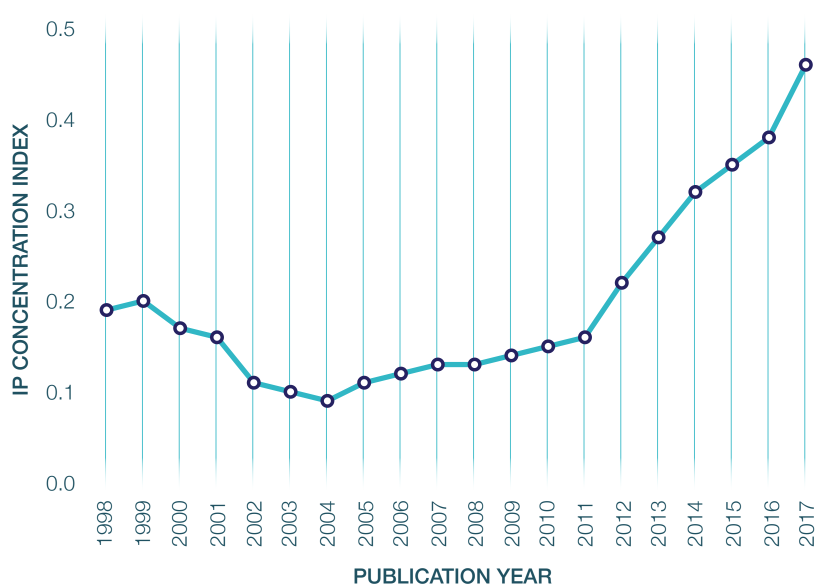
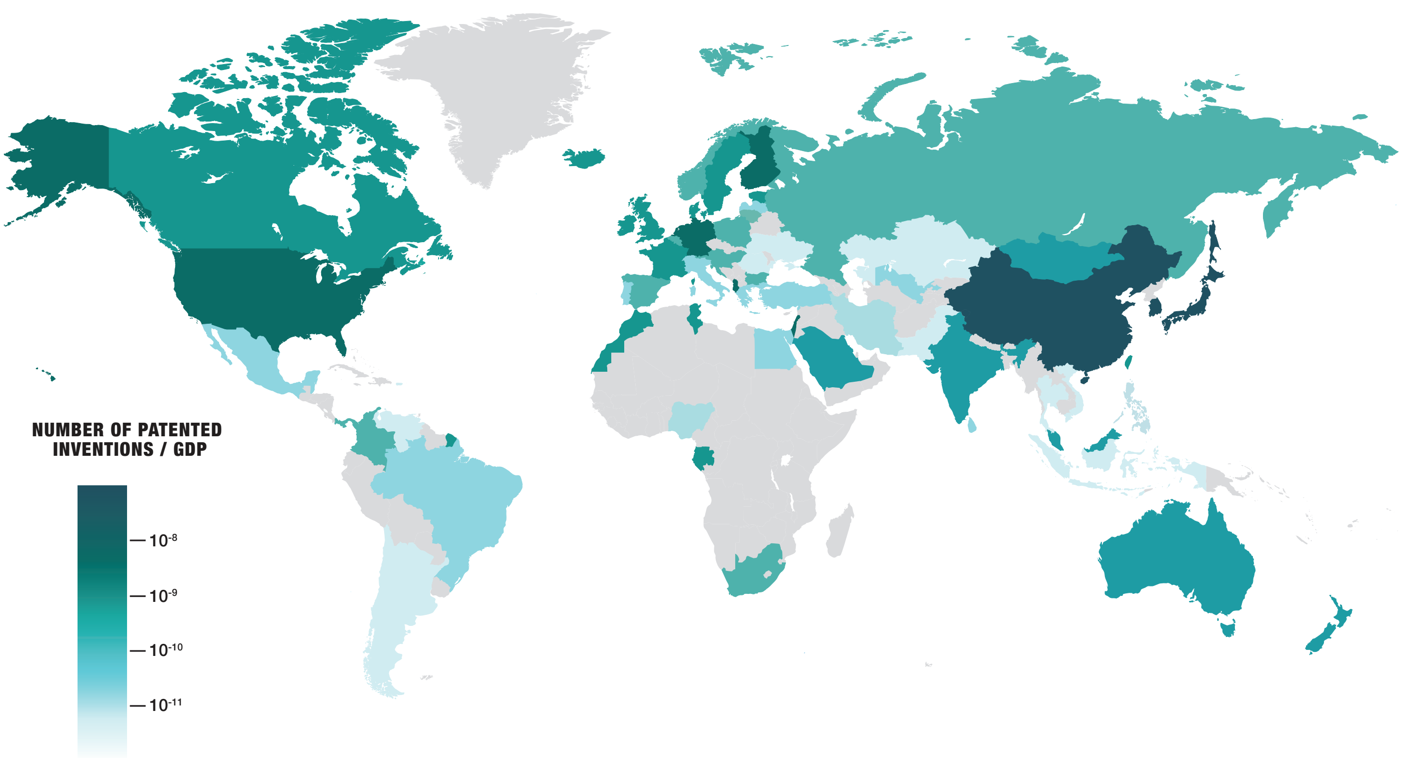


Figure 6 provides a representation of influential countries in AI. A fractional counting approach of assignees assigned to patented inventions is used to better represent the distribution of assignees across jurisdictions from which they originate. This approach avoids double counting assignees while accurately accounting for patented inventions involving multiple assignees, sometimes from different countries. For example, in the case where an invention is patented by an American researcher and two Canadian researchers, Canada would be assigned two-thirds of the patented invention count, whereas the U.S. would be assigned the remaining third. The counts are normalized by gross domestic product (GDP) in order to account for countries of different economic size. Even after accounting for this, China and the U.S. remain the leaders in this field, followed by Japan and Republic of Korea.

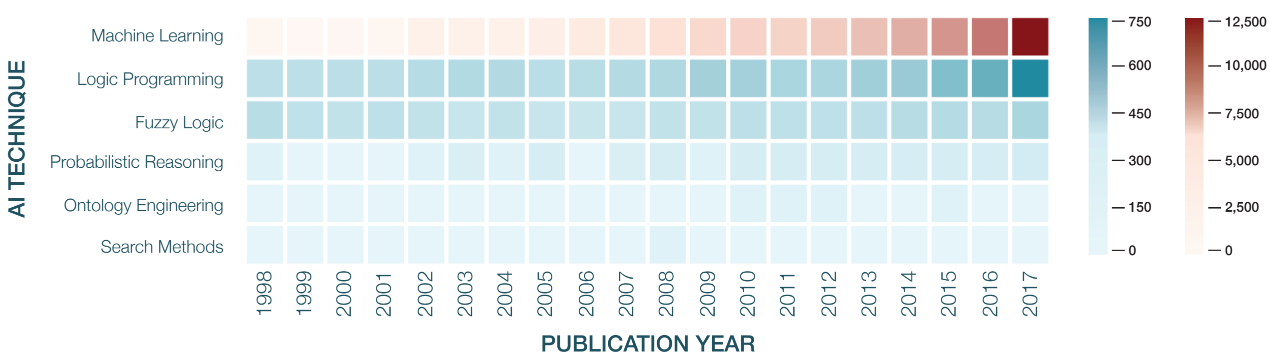
Figure 6: International patent activity by assignee's country of origin in AI between 1998 and 2017



AI Patent Classification

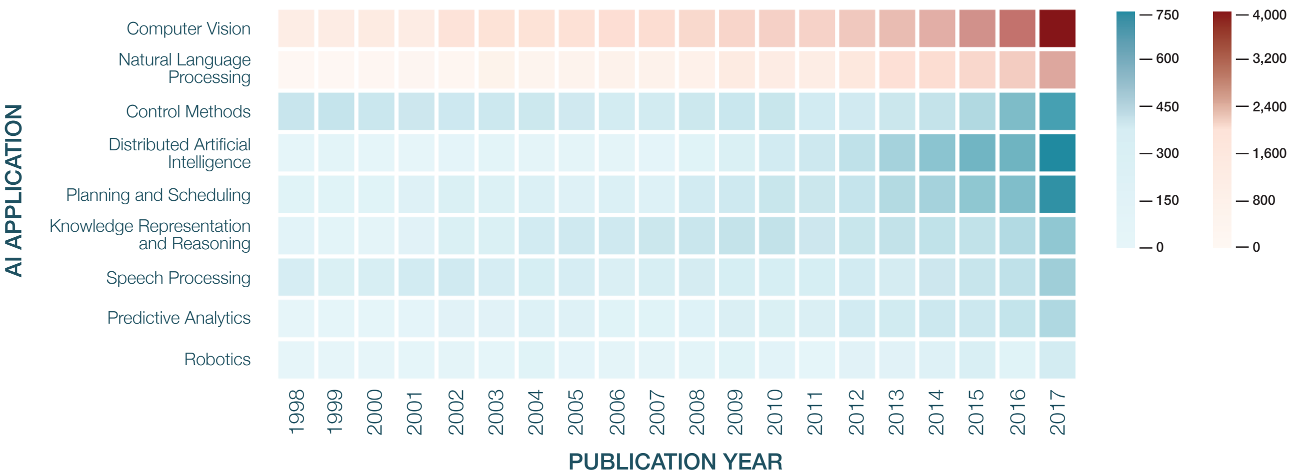
Taking a closer look at the international data, in Figure 7 we notice that 88% of patented inventions categorized to AI Techniques are related to Machine Learning (ML). Due to the significant difference in the magnitude of volumes of patented inventions between ML and the other AI Techniques sub-categories, a different legend, represented by different shades of orange, is used to depict the change in the volumes for this sub-category. ML inventions grew annually by 63% between 2011 and 2017. Even though China is responsible for most of the ML patented inventions, the same trend can be observed for the eight leading AI patenting countries presented in Figure 4. Of note, 37% of the patented inventions are not being categorized to the predefined sub-categories of AI Techniques. This undefined sub-grouping of the traditional AI Techniques categories experienced a growth rate of 23% between 2011 and 2017 in patented inventions. It will be interesting to monitor the growth in this category to see if new AI techniques emerge as this technology area evolves.

Figure 7: Growth in international AI patent activity by AI Techniques



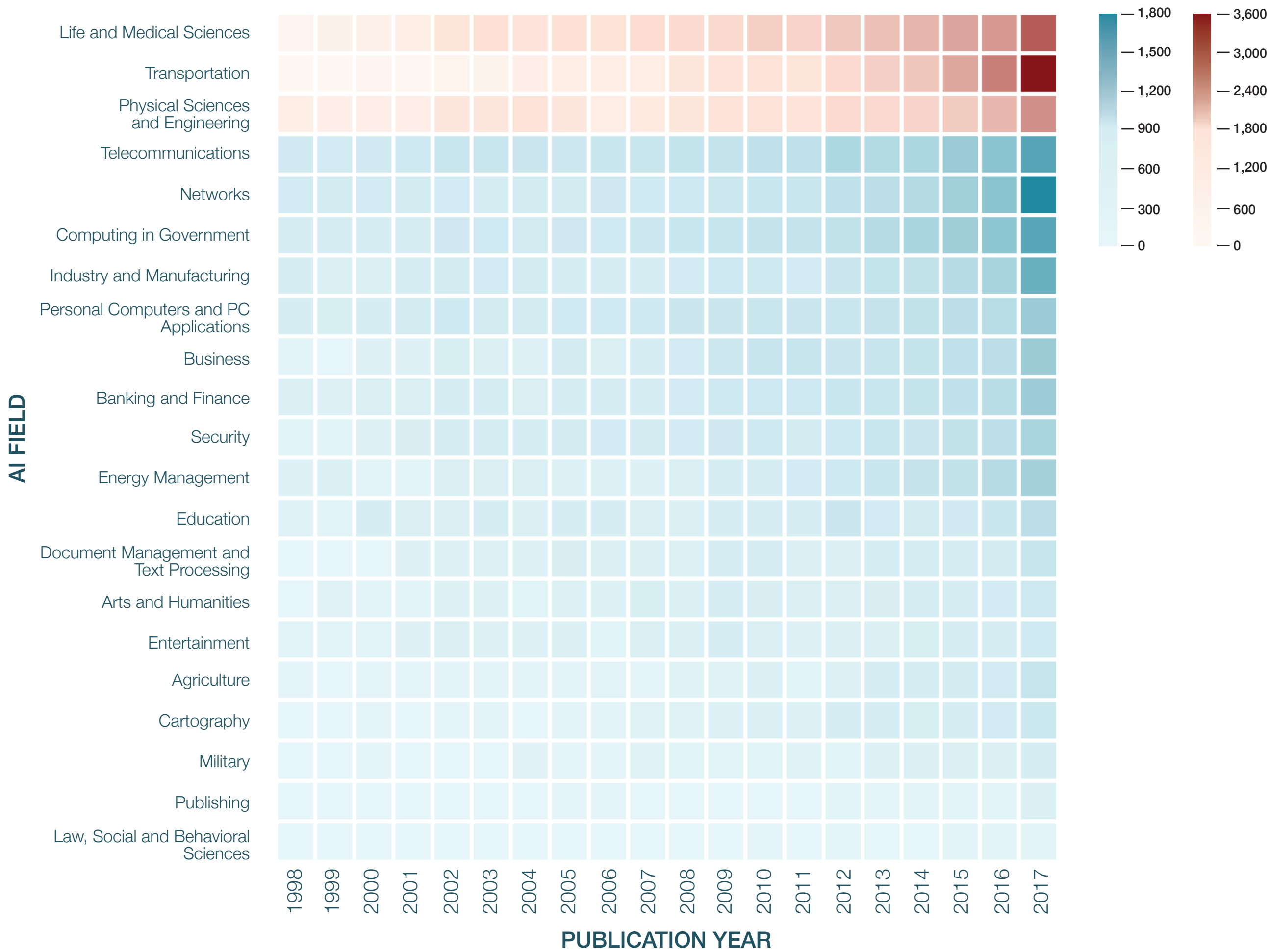
Turning to the applications of AI, it can be observed that AI was increasingly applied over the twenty-year period in patented inventions covering Computer Vision. It wasn't until 2006 that Natural Language Processing (NLP) started to emerge as a key area of AI innovation. It is also important to indicate that 66% of patented inventions are not being categorized to the designated sub-categories of AI Applications. This could imply that more work is needed to identify additional groupings for AI Applications or, alternatively, new applications of AI are being patented that are not yet defined. This is a challenge that presents itself when studying a technology area that is evolving very rapidly and that is difficult to accurately define.

Figure 8: Growth in international AI patent activity by AI Applications



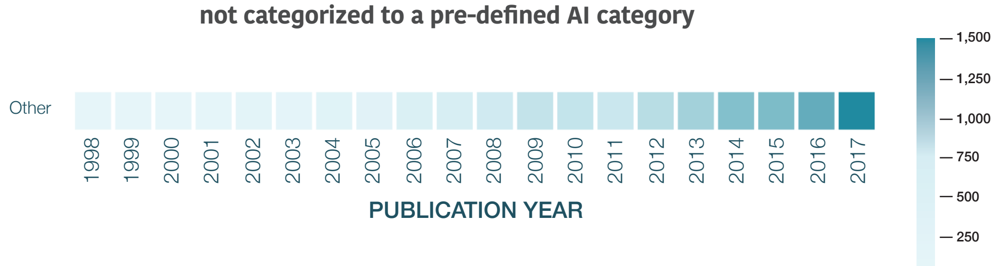
With respect to AI Fields over the 1998-2017 period, Life and Medical Sciences remains one of the main fields in terms of generating AI patented inventions. Physical Sciences and Engineering is another field where AI is being significantly patented. With the growing interest in autonomous vehicles, it is interesting to note the rise in AI patented inventions categorized to the Transportation field, especially over the past six years. In an economy where the transportation industry is responsible for a significant number of jobs, it will be important to keep pace in the creation and use of AI technologies for transportation.
As is the case with the two aforementioned groupings, we notice that 34% of the patented inventions are not being categorized to the pre-defined sub-categories of AI Fields.

Figure 9: Growth in international AI patent activity by AI Fields



Considering 12.4% of patented inventions do not fall into any of the designated AI categories, we decided that it was appropriate to look into this area more closely. Consistent with the growing trend in AI inventions being patented, the trend in inventions not being categorized is also growing, as seen in Figure 10. Deep diving into the data to identify the IPC and CPC codes, we notice that many of the patented inventions not being classified belong to the G06F, G06K, G06N, G06Q subclasses that are related to data processing and related systems, recognition of data, and computer systems based on specific computational models. Additional research into these patented inventions could be conducted to identify new emerging AI technologies that are not being captured according to the definition used in this report.

Figure 10: Growth in international AI patent activity for patented inventions not categorized to a pre-defined AI category



ANALYSIS FROM A CANADIAN PERSPECTIVE

This section provides a snapshot of Canadian involvement in AI based on researchers who patented inventions between 1998 and 2017. Canadian participation in this field is likely much larger based on those who use non-formal forms of IP, such as trade secrets, and involvement in scientific publications, among other activities. Based on the information extracted from the patent data, this report provides a partial indication of the overall activity level in AI using the detailed information that is captured from this source.

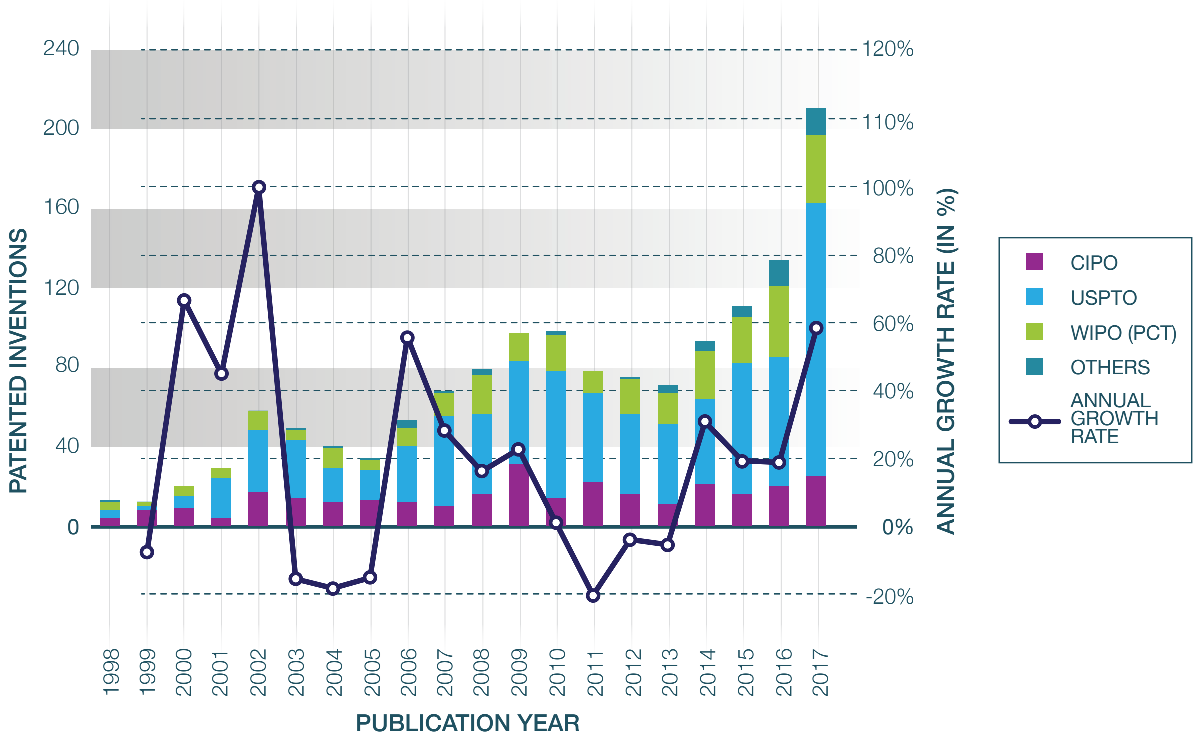
Canadian Researchers

As organizations turn their focus towards the ever-evolving world of AI, researchers, academics and experts are coming into higher demand. This has led to a greater push by academic institutions to fund AI-related disciplines, such as computer science, electrical and electronic engineering, mathematics and statistics, and neuroscience to name a few.[18] In turn, retaining those trained in a country while simultaneously attracting those trained in other countries has become an initiative many governments have taken on. In their annual *Global AI Talent Report*[19] , Element AI has found that, ". . . the AI talent pool is highly mobile, with about one-third of researchers working for an employer based in a country that was different from the country they received their PhD." Of this talent pool, Canada is one of the leaders in high-impact research. Element AI defines high-impact research as a country where a ". . . higher-than-average percentage of the local talent pool is making high-impact contributions to the field" of AI. This attributes to Canada's label as a platform country: a country which sees both an inflow and an outflow of talent. Our research in this section validates the aforementioned statement.

Patent Filing Trend

Patent filing activity by Canadian researchers in AI has experienced waves of increased activity over the past 20 years, with a significant increase over the past five years. The 31% average annual growth over this short period is similar to the growth rate experienced at the global level. As seen in Figure 11, inventions patented by Canadian researchers increased gradually between 1998 and 2001, before experiencing a significant surge in 2002. Canada experienced a slightly higher average annual growth rate of 24% between 2005 and 2010 compared to the global 20% growth rate observed during this timeframe.

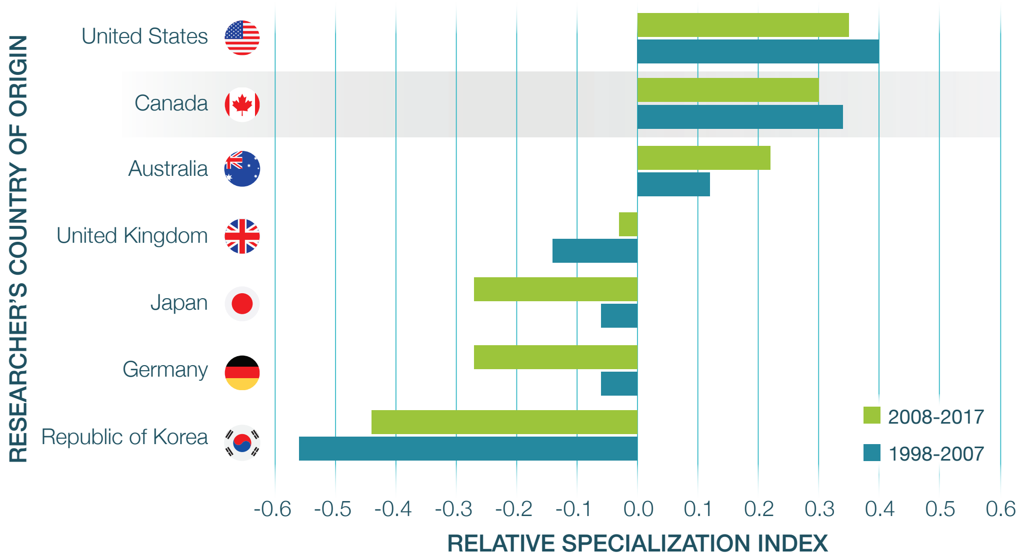
Figure 11: Patent activity by Canadian researchers in AI between 1998 and 2017



Relative Specialization of Canadian Researchers

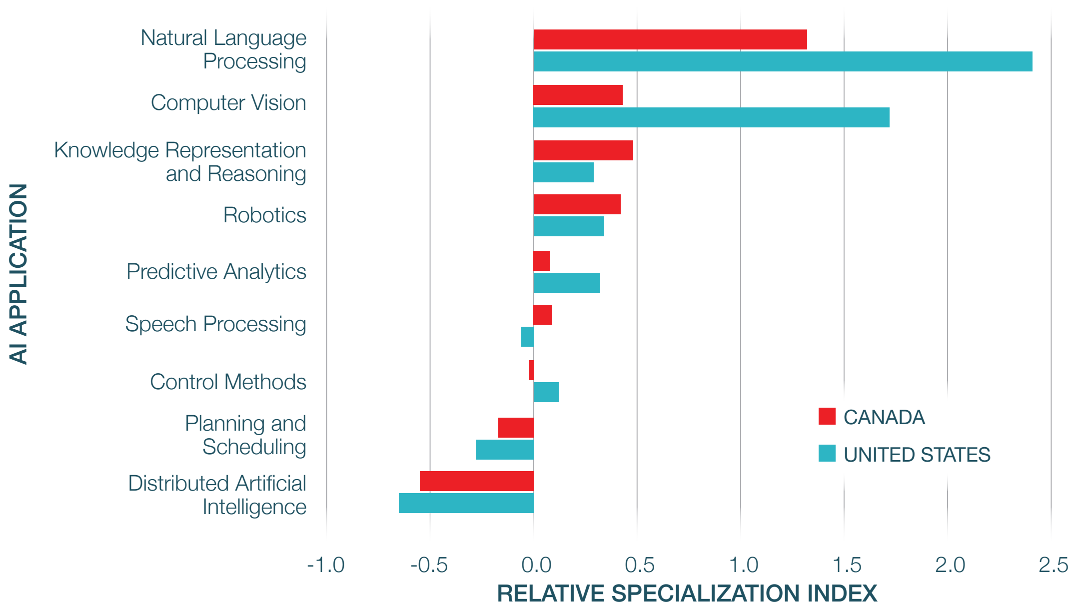
In order to gain a better understanding of a country's performance in terms of AI patent activity, we use the Relative Specialization Index (RSI) (additional details in Annex D). This measure uses patenting intensity to allow for technology sectors to be compared between countries of different sizes. The index provides a measure of each country's share of patented inventions within the AI field as a share of the country's total patented inventions produced within a given timeframe. For countries where the value is greater than zero, they are seen as being relatively specialized compared to the rest of the world. Conversely, countries with an RSI value of less than zero are deemed to not have a specialization.
In Figure 12, we incorporate a time dimension to present the change in degree of specialization by spliting the dataset in two 10-year periods. It is interesting to see that the index scores for Canada, along with Germany, Japan, and the U.S., have decreased over the index scores for the first decade.

Figure 12: Relative Specialization Index by researcher's country of origin in AI



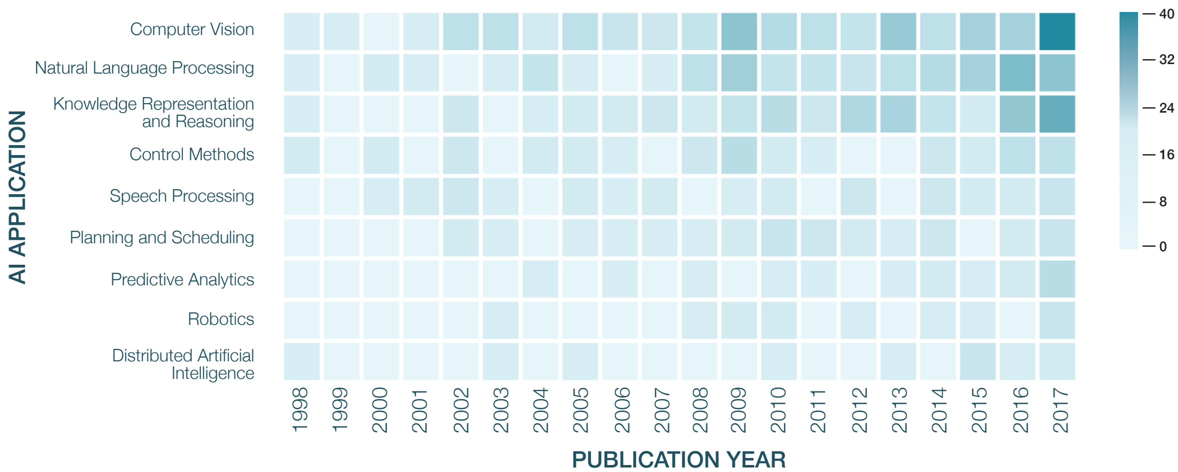
The index can be further broken down at an AI Applications grouping level to determine areas in which Canadian researchers are specialized. As observed in Figure 13, Canadian researchers are highly specialized in Knowledge Representation and Reasoning, and NLP. It is interesting to compare RSI values between Canada and the U.S., as Canada appears to hold its own against a country that is a world leader in terms of patent activity in AI more broadly. The question then arises: how can Canadian researchers' talent be leveraged to advance innovation in this field so as to allow this specialization to increase further?

Figure 13: Relative Specialization Indices by AI Applications for American and Canadian researchers



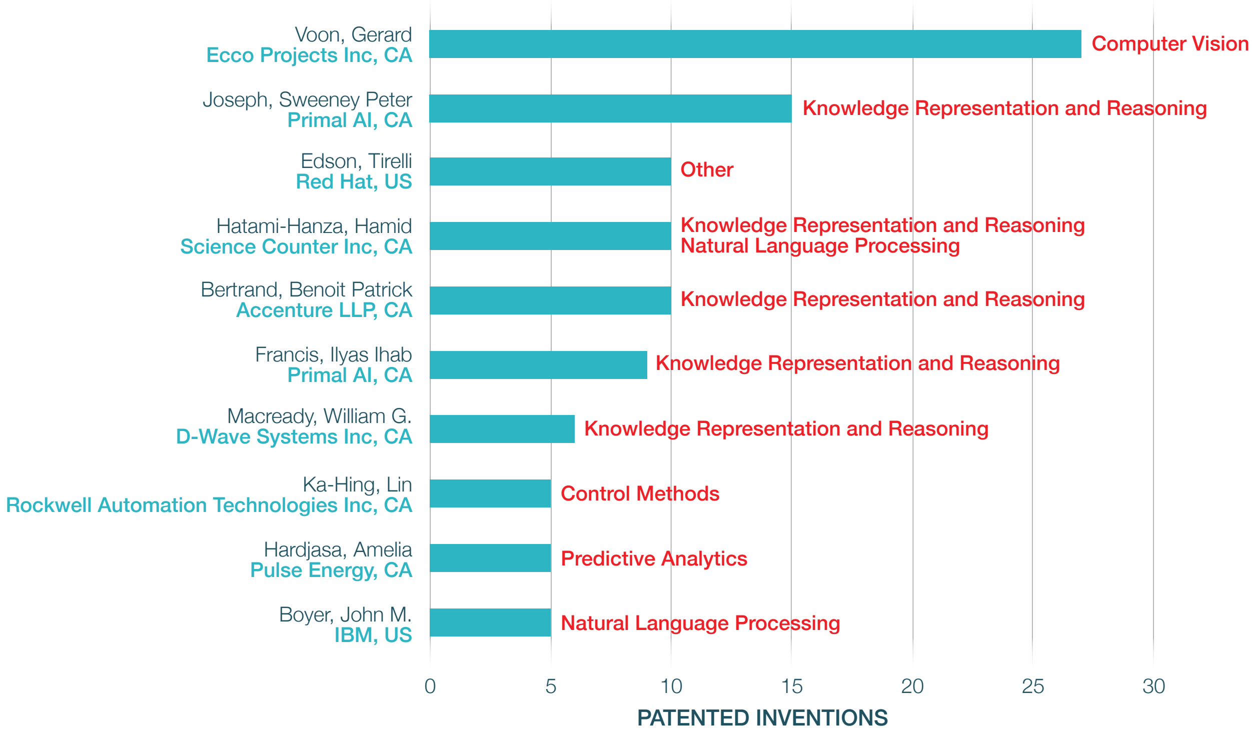
From the perspective of absolute patented invention counts, it is reassuring to observe that Canadian researchers are prolific filers in areas in which they are deemed specialized. This is not always the case, as seen with Robotics, where Canadian researchers do not hold many patented inventions but are considered specialized relative to researchers from other countries who file a proportionately lower number of patented inventions.

Figure 14: Growth in patent activity for Canadian researchers in various AI Applications



The leading Canadian researchers patenting in AI are presented in Figure 15 below. The institution associated with a particular researcher and the researcher's primary area of expertize are shown in blue and red respectively in the figure below. Interestingly, 93% of Canadian institutions include at least one Canadian researcher on patented inventions included in this dataset. However, only 51% of Canadian researchers in the AI field are associated with Canadian institutions or a Canadian subsidiary of a multi-national company. Focusing on the top ten researchers, only two are associated with international institutions. Canada's top patenting researchers have a significant presence in Canada, working for established companies, such as Primal AI and D-Wave Systems Inc.

Figure 15: Top Canadian researchers along with their associated institutions (in blue) and their main area of expertise (in red)



Beyond using patented invention data to identify trends and top filers, it is useful to further explore the types of technologies being created. A patent landscape map is presented in Figure 16, which was generated using an algorithm that relies on the keywords from patent documentation to cluster patented inventions according to shared language. The patented inventions are organized based on common themes and grouped as “contours” on the map to identify areas of high and low patent activity. The white peaks represent the highest concentrations of patented inventions, and each peak is labelled with key terms that tie the common themes together. The distance between keywords helps to illustrate the relationship between peaks, where shorter distances indicate that the patented inventions they represent share more commonalities relative to those that are further apart. Words located close together may be part of similar systems or technologies, whereas keywords that are further apart likely have less of a relationship.

Superimposing the names of the leading Canadian researchers is a useful way to highlight who is working in what space. For example, we see that Peter Joseph Sweeney and Ihab Francis Ilyas—both associated with Primal AI and patenting in the Knowledge Representation and Reasoning application field—are both captured in the middle-right side of the map and are associated with patented invention characterised by keywords such as “Atomic knowledge representation model”, “Complex knowledge representation”, “Concept”, “Structure” and “Program”. Perhaps as expected, we see that Amelia Hardjasa, who is the only leading researcher patenting in the Predictive Analytics application field, has patented inventions on the map that are located at the bottom centre on an island separated from the mainland on the map. This type of landscape map can also be useful to institutions in order to target talent. For example, in the case where a researcher’s patented invention portfolio overlaps with that of another researcher, it can indicate that the two are patenting in similar areas, as in the case of Gerard Voon and Patrick Benoit Bernard in the upper right quadrant of the map.

Figure 16: Landscape Map of Canadian researcher's patent activity highlighting top filers

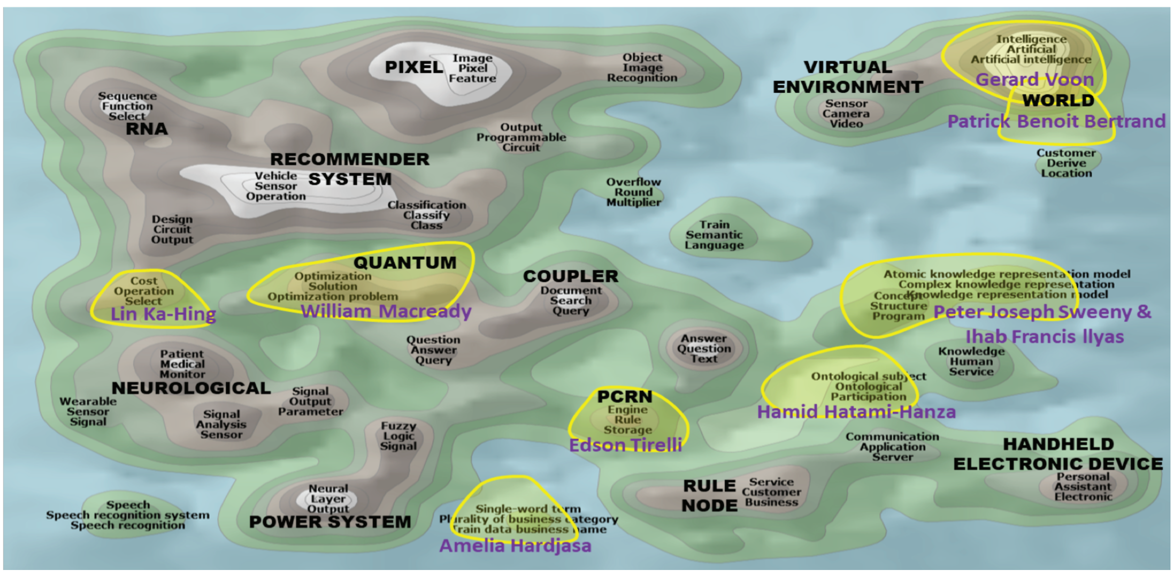
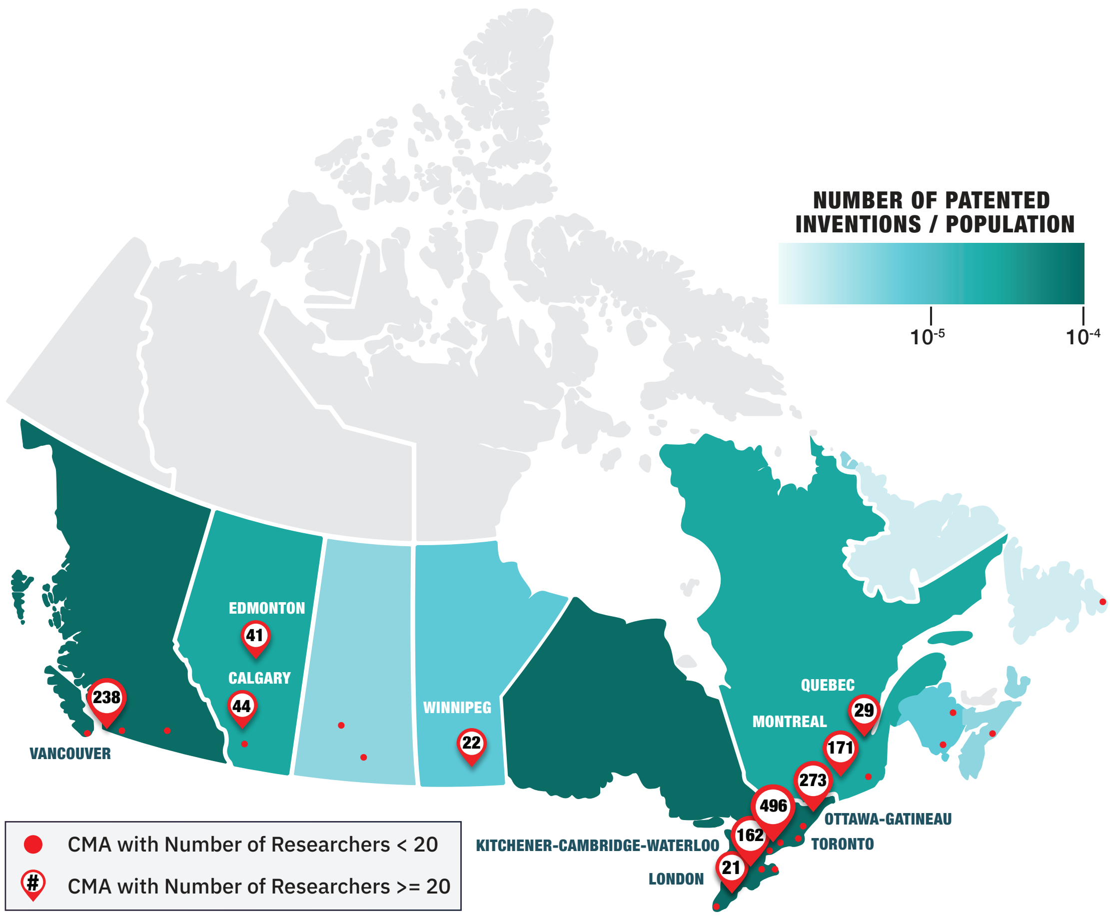


Figure 17 shows the distribution of the patent activity by Canadian researchers by province across the country. Each province is shaded in blue, with darker shades representing a higher number of patented inventions. The number of researchers residing in prominent Census Metropolitan Areas (CMA) with prolific patenting populations is highlighted on the map using red location pointers. It should be noted that patented invention volumes were calculated using the fractional counting approach and have been normalized by population size in this figure. The provinces that have a higher number of patented inventions, such as Ontario, British Columbia and Quebec, remain the leading provinces after being adjusted. The provinces with more patent activity tend to be associated with clusters of researchers around large cities.

Figure 17: Geographical clusters of inventive activity by Canadian researchers



Gender Analysis: Female participation in AI patent activity

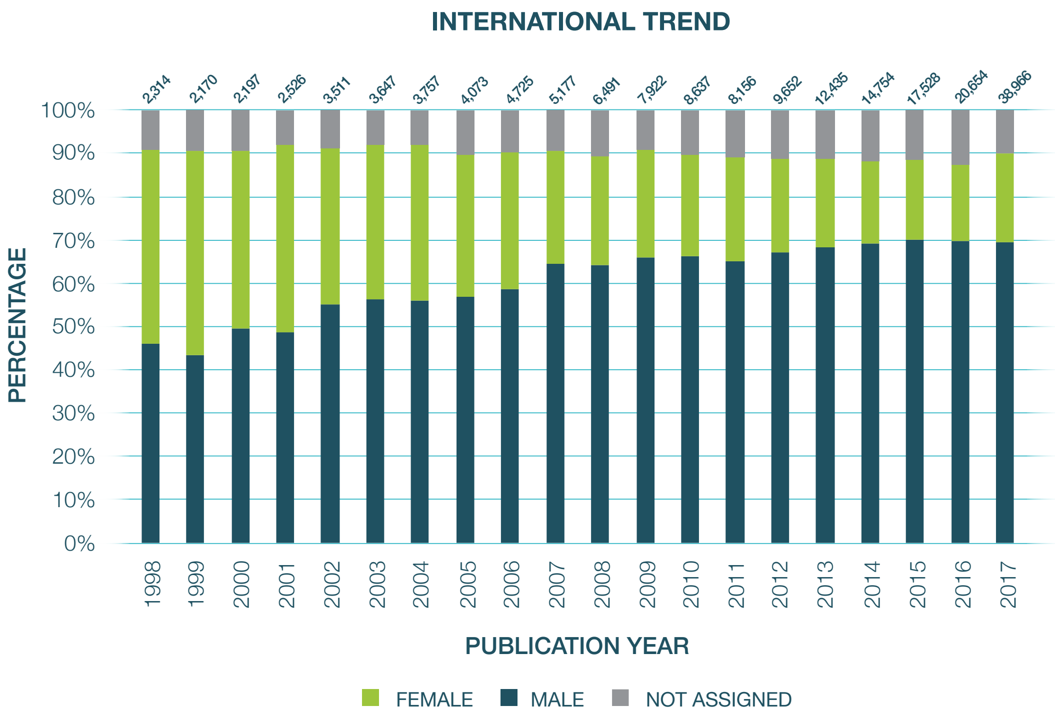
In 2014, 59% of graduates aged 25 to 34 in Canadian science and technology programs were female. However, only 23% of engineering graduates of that same age group were female.[20] Understanding that female representation in science, technology, engineering, and mathematics (STEM) fields is lower than desired, this observation is expected to also be reflected in female participation in patenting. To measure female participation in AI, we leverage WIPO's comprehensive name dictionary to assign genders to the names of researchers listed on patented inventions.[21]

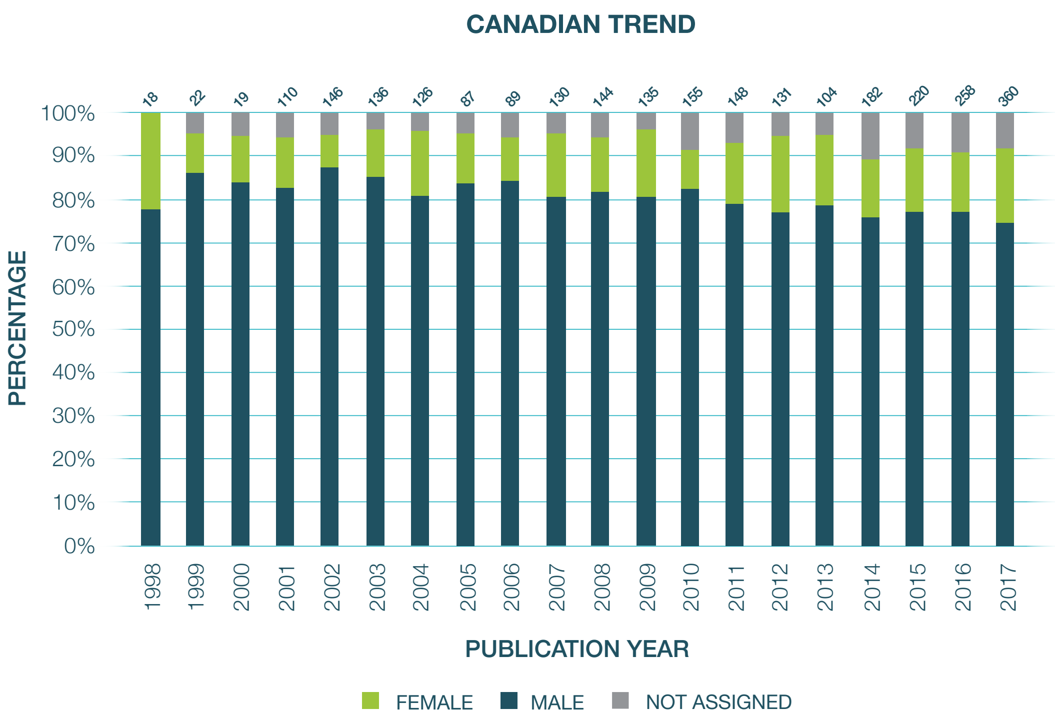
At the international scale, there was one female identified for every three males involved in AI patenting. By comparison, for patented inventions containing at least one Canadian researcher, that ratio decreases to one female for every six male researchers.

Figure 18: Gender representation in AI, both globally (left) and in Canada (right)

To better understand female participation in this technology field, Figure 19 effectively shows the evolution of females involved in AI over the twenty-year period. The following figure shows new researchers by gender entering the field based on their involvement as captured by the first patent application published. Unlike the trend observed for women in Canada, which is relatively steady over the twenty-year period, the international trend is much different, with female representation as a share of the total number of researchers decreasing over time.

Figure 19: Trend in gender distribution by new entrants in AI, both globally (top) and in Canada (bottom)





Non-traditional sectors, such as mining, forestry, electricity and the skilled trades among others, tend to experience a drop in women's participation five to ten years after graduation.[22] This lack of retention could possibly be due to the systemic barriers faced by women who already work in the field, a theory more closely examined in a report CIPO had published titled "*Women's Participation in Patenting: An Analysis of PCT Applications Originating in Canada*".[iii] Increasing this retention rate is one of the values set forth by the Department for Women and Gender Equality. A result of this would be an expected increase in women's representation in patented inventions across STEM fields, which would include AI. In 2012, Germany's Institute of Labour Economics published an article that looked into the causes for the lack of participation by women in patenting, and the results coincide with the observations made for Canada.[23]

To continue growing in AI, Canada must work to retain our best talent and also attract new talent into the country. In Element AI's 2019 *Global AI Talent Report*, Canada cements itself as a platform country.[24] Interestingly, the U.S., Germany and China are anchored countries: able to retain more talent but unable to attract talent into the country. Australia, however, finds itself as an inviting country; meaning it is able to draw in a large portion of international talent without losing much of its domestic talent. Canada is among the top countries in the world consisting of high-impact researchers, joined by the U.S., China, the U.K. and Australia.

[iii] https://www.ic.gc.ca/eic/site/cipointernet-internetopic.nsf/eng/h_wr04331.html

After gaining a better understanding of the AI patent landscape from the perspective of Canadian researchers, this section examines AI from the perspective of Canadian institutions. A Canadian institution for the purpose of this report includes a corporate firm, an academic institution, or a government establishment.

Canadian Institutions

Overall, corporate firms were responsible for 82% of the patented inventions in this section, whereas academic institutions and government departments accounted for the remaining 15% and 3% of the patent activity, respectively. To better understand innovation in the field by Canadian institutions and where their specialization lies, this section examines the associated patent activity in Canada and abroad. To limit the overall data cleaning effort in order to capture patented inventions by institutions, CIPO only focused its attention to cleaning the institution data for select countries that were used to benchmark against Canada. These countries include Australia, Germany, the U.K., Japan, Republic of Korea, and the U.S., and were selected based on the fact that they are among the leaders in terms of rankings by the WIPO Technology Trends report and their inclusion in the UKIPO's AI report.

The *Innovation Superclusters Initiative*, introduced in 2017, is an investment of $950 million, matched dollar for dollar by the private sector, to support "superclusters" across Canada, which bring together "small, medium-sized and large companies, academic institutions and not-for-profit organizations" to "transform regional innovation ecosystems".[25] While the Scale.AI supercluster is largely focussed on AI, each of the superclusters plan to support projects that will promote the use of AI in their respective industries. The superclusters include the Digital Technology Supercluster, the Protein Industries Supercluster, the Next Generation Manufacturing Supercluster, SCALE.AI Supercluster, and the Ocean Supercluster.[26] The funding is allocated to the superclusters to help support advances in each sector and to help build and support emerging start-ups.[27]

The second investment is a joint venture between Canada and the U.K. known as the *Canada-UK AI Initiative*. This is a funding opportunity that requires interdisciplinary research between three major domains: social sciences and humanities, health and biomedical sciences, and natural sciences and engineering. The initiative looks to support the responsible development of AI while creating partnerships between researchers in Canada and the U.K.[28]

Finally, in 2017, the Government of Canada appointed the Canadian Institute for Advanced Research (CIFAR) to develop and lead the *Pan-Canadian Artificial Intelligence Strategy*.[29] This strategy is a $125 million initiative in partnership with the Alberta Machine Intelligence Institute (Amii), the Montréal Institute for Learning Algorithms (Mila) and the Vector Institute.[30] This funding initiative looks to do several things:

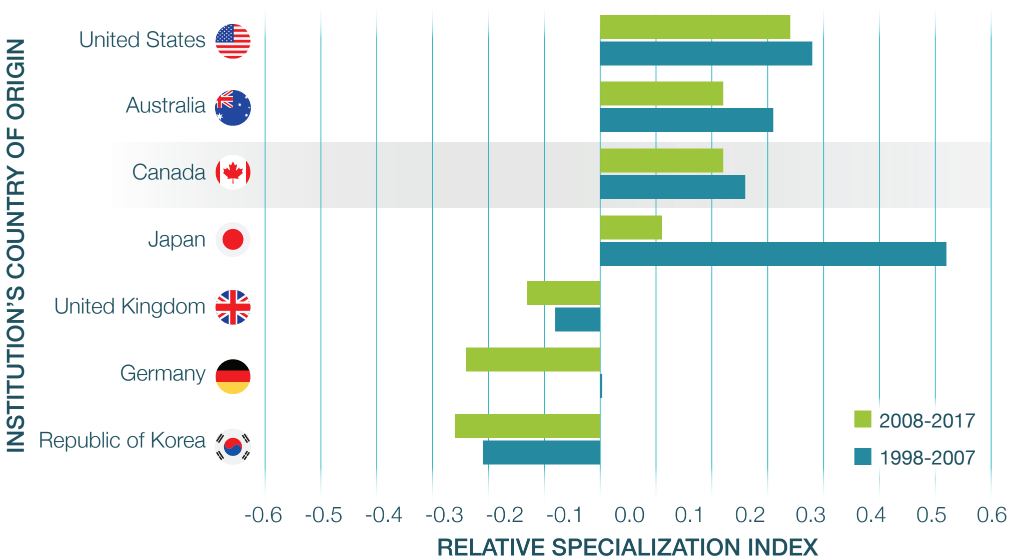
1. Increase the number of AI researchers and skilled graduates in Canada
2. Connect three of the major centres for AI in Canada
3. Invite conversation surrounding economic, ethical, policy and legal implications of advances in AI
4. Support the national research community

These initiatives work to further AI development in Canada ethically and fairly. Many of these initiatives focus on improving the lives of Canadians by funding and supporting researchers and developers as they explore the world of AI.

Relative Specialization of Canadian Institutions

Prior to exploring the AI Canadian institution data more closely, it is useful to begin by establishing where Canadian institutions rank in terms of relative specialization. In comparison to the six other countries presented in Figure 20, Canada is seen to be specialized because it holds a positive index score. When breaking down the institution dataset over the two decades covered, it is interesting to observe that the specialization for all seven countries under consideration has decreased during the second decade. Later in this section, we will explore the AI fields in which Canadian institutions are predominantly patenting and their respective RSIs.

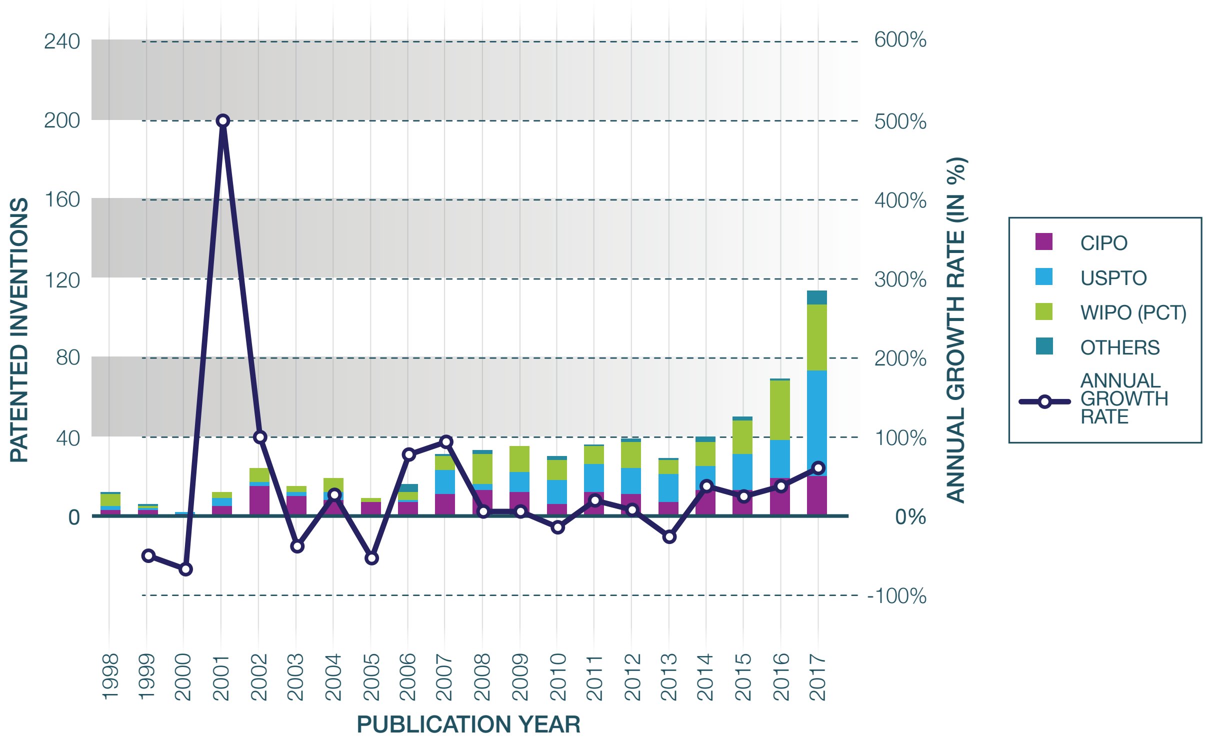
Figure 20: Relative Specialization Index by institution's country of origin in AI



Patent Filing Trend

Figure 21 shows the general trend in AI patent filing activity by Canadian institutions. The annual growth rate of 8% between 1998 and 2010 for Canadian institutions is similar to the growth rate experienced at the global level during this timeframe. Although the 21% growth rate observed in patent activity by Canadian institutions over the 2011 and 2017 period is significantly higher, this rate is lower than the 31% growth rate observed at the international scale. Even though Canada has assumed a leadership role in defining a policy framework for AI,[31] their overall influence is limited considering Canadian institutions account for less than 1% of the total number of inventions patented by institutions globally.

Figure 21: Patent activity by Canadian institutions in AI between 1998 and 2017



Understanding in which countries Canadian institutions are seeking protection for their inventions internationally provides an indication of which markets they are strategically targeting. Not surprisingly, Canadian institutions, apart from filing at CIPO, file predominantly in the U.S. because of its large market size, and have priority filings in that country for each year over the 20 year timespan. The USPTO and CIPO administered 64% of all inventions patented by Canadian institutions. Inventions patented via the Patent Cooperation Treaty (PCT) system account for 32% of the filings. Other IPOs targeted by Canadian institutions, but to a significantly lower degree, include the IP Australia (IPA), China National Intellectual Property Administration (CNIPA), EPO, Japan Patent Office (JPO) and the French National Institute of Industrial Property (INPI).

Distribution of Patented Inventions

Since the early 1990s, IP has emerged as an important asset class to the corporate sector, be it in terms of protecting the value of its inventions resulting from significant investments in R&D or, alternatively, if there is interest in acquiring a targeted firm, or even simply if institutions are looking to exit the market and reap the benefits of their efforts.[32] Large acquisitions, resulting in significant transfers of IP, can create a monopoly-like condition by realizing economies of scale and driving out smaller players from the market. In this section, the IPCI is used to understand the distribution of patented inventions held by Canadian institutions actively patenting in AI and benchmark it against institutions from other leading countries. An index value closer to 0 in this section would indicate a country having a higher number of less-active institutions patenting in AI, whereas an index value closer to 1 would indicate a country has a few dominant players which patent extensively in AI. In reference to Figure 22, Canada has one of the lowest index values, thereby indicating that Canadian institutions operate in a highly competitive patenting AI environment.

Figure 22: IP Concentration Index for institutions from leading countries in AI

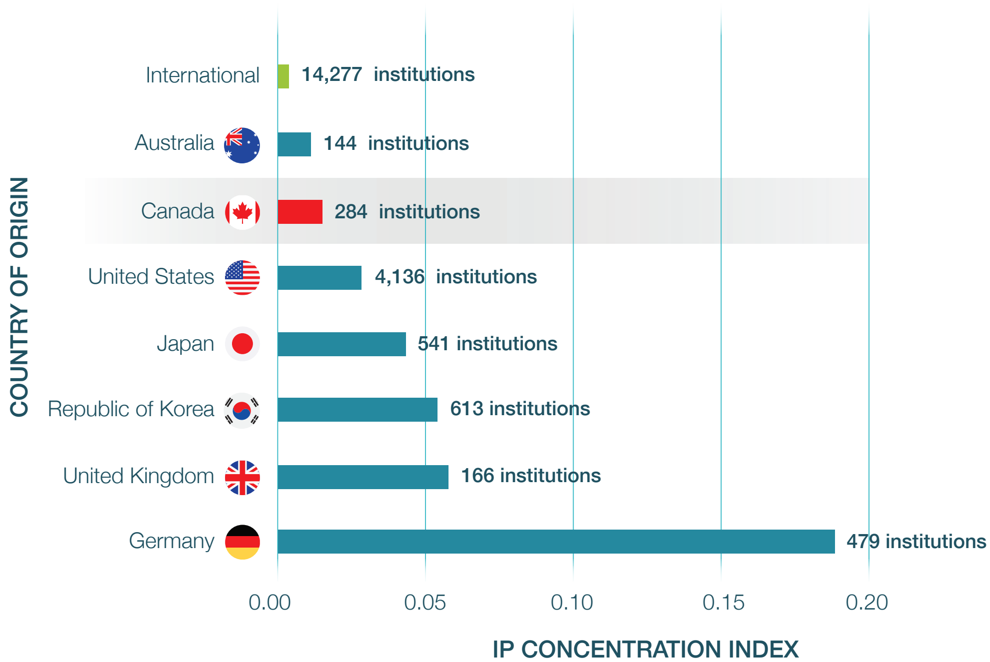


Figure 23 shows the distribution of inventions patented by Canadian institutions and their overall representation in the Canadian AI institution dataset. The size of each pie depicts the proportion of Canadian institutions responsible for the inventions in each of the five groups, whereas the angle prescribed by each pie in the figure represents the proportion of patented inventions in each group. As expected, a vast majority of the Canadian institutions hold between one and four patented inventions. On the other hand, institutions holding five or more patented inventions account for 43% of the Canadian institution AI dataset. Nevertheless, simply holding more patented inventions does not reflect the importance of such inventions.

Figure 23: Distribution of Canadian institutions by patented inventions and their overall representation

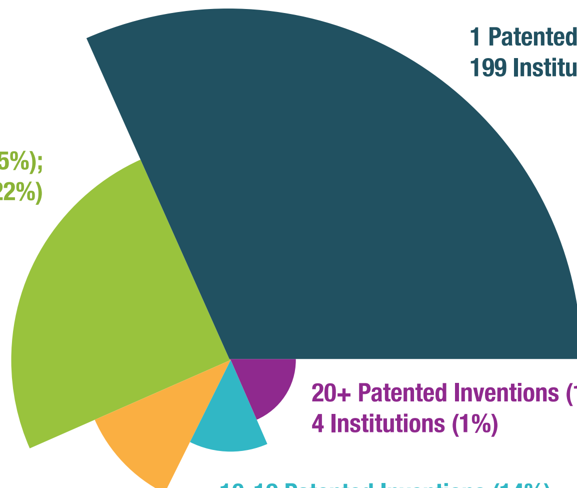
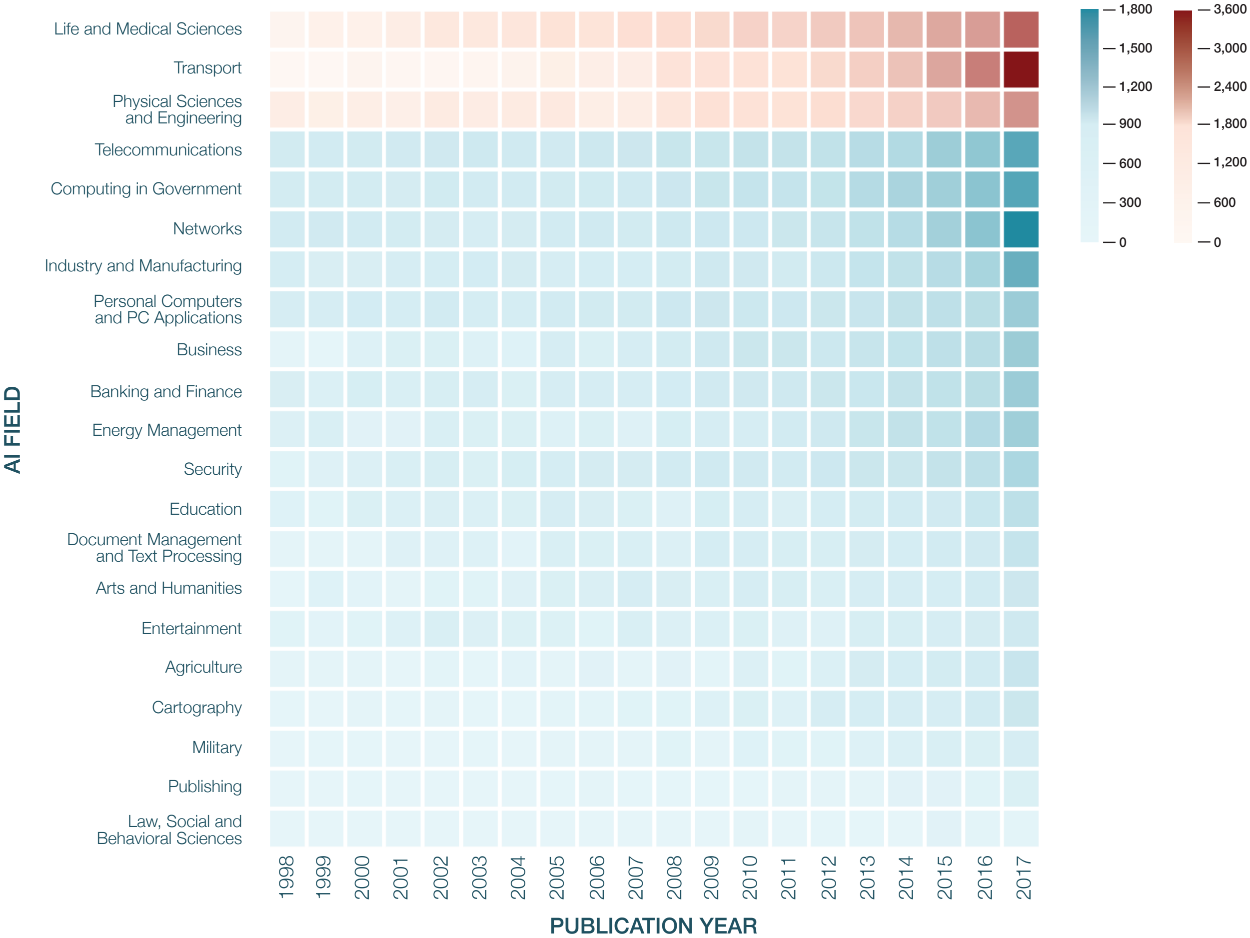
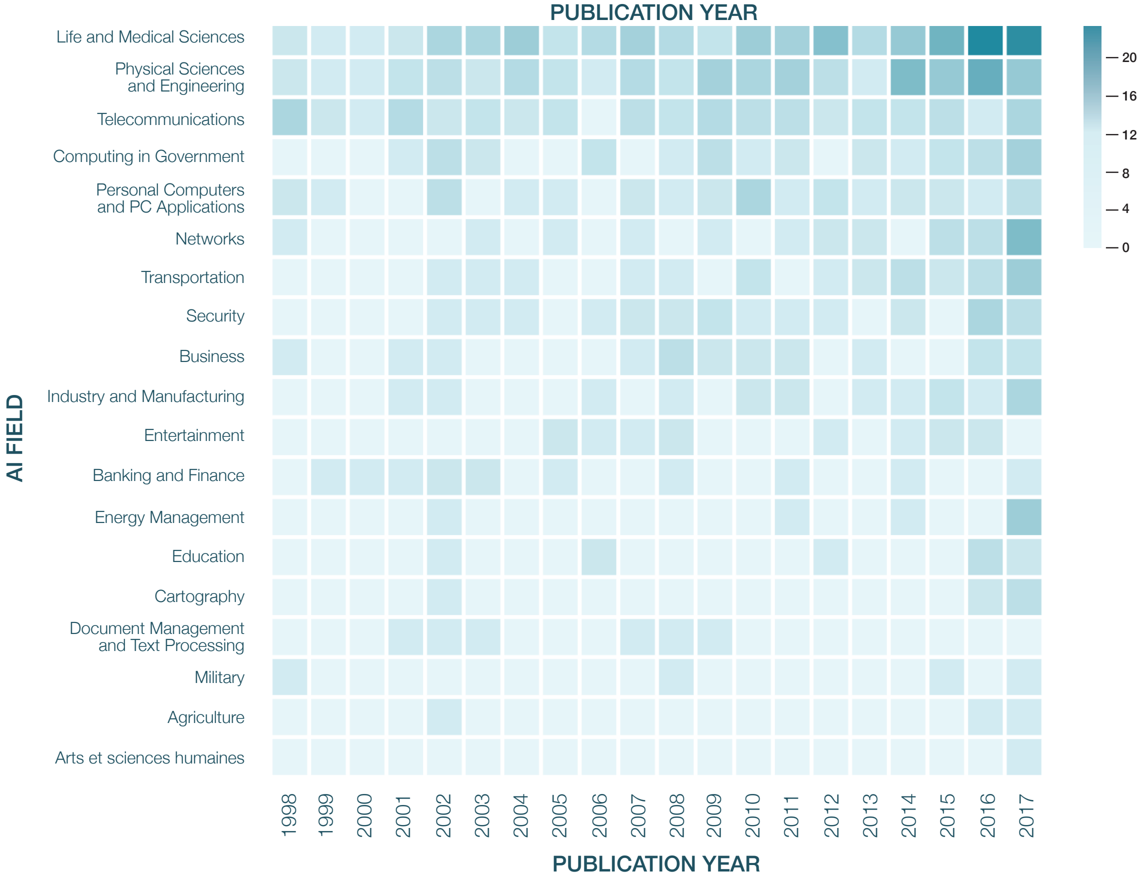


Figure 24 shows the breakdown of the data by application fields in order to gauge the industrial applications of AI inventions patented by international and Canadian institutions, respectively. As observed in Figure 24, institutions globally have been consistently filing for patented inventions pertaining to Life and Medical Sciences, and Physical Sciences and Engineering between 1998 and 2017, whereas patented inventions pertaining to Transportation gained prominence post 2011. On the other hand, Canadian institutions seem to specialize in the field of Telecommunications, apart from Life and Medical Sciences, and Physical Sciences and Engineering. However, there is a need for Canadian institutions to be more specialized in the field of Transportation. This fact is corroborated by Figure 25, in which Canadian institutions seem to have a low specialization index in this field.

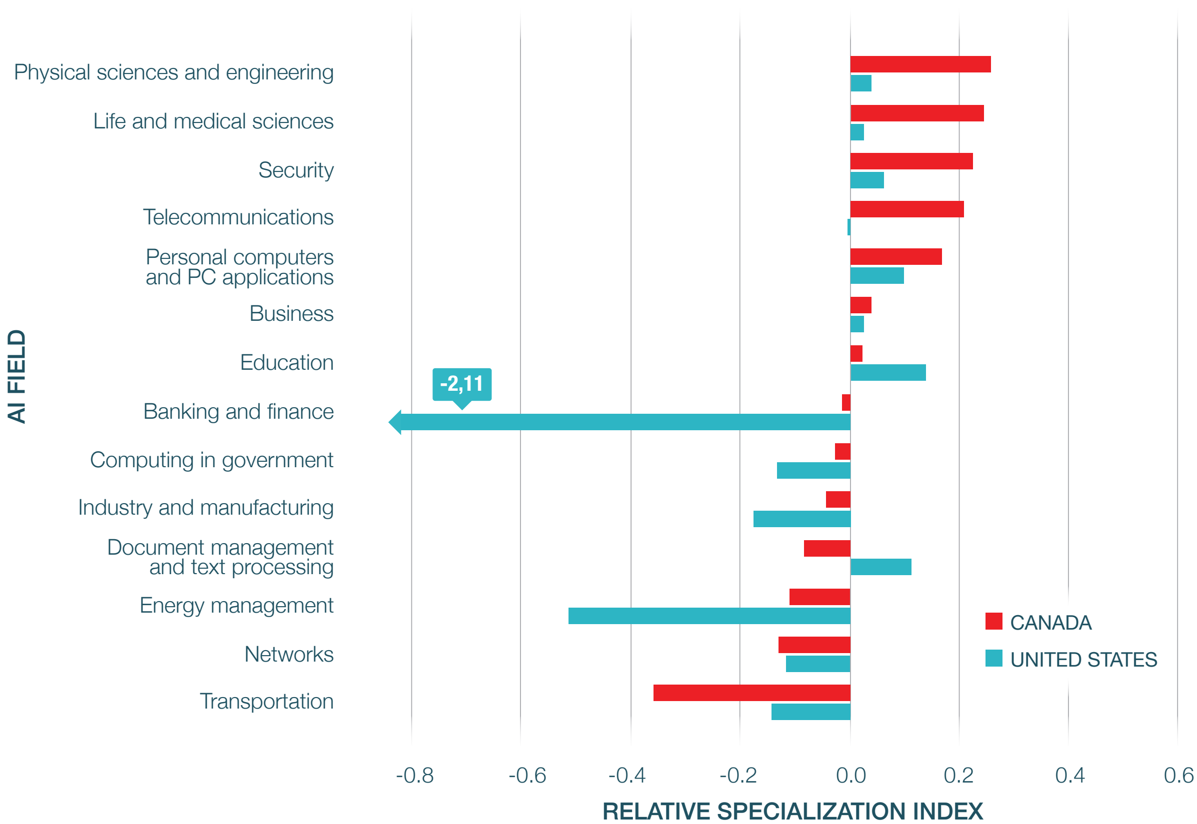
Figure 24: Growth in patent activity for international (top) and Canadian (bottom) institutions in various AI Fields





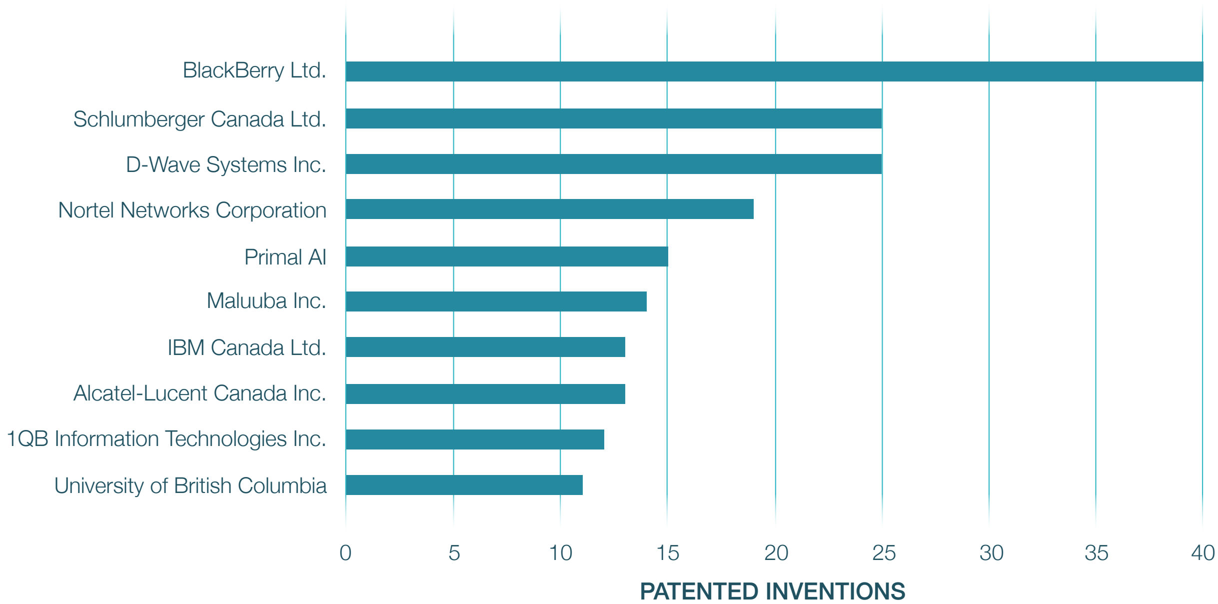
In reference to Figure 25, it is important to note that there are certain AI Fields, such as Banking and Finance, Military, Law, social and behavioural sciences, etc., that have not been included in the figure because they have not attracted considerable amounts of patent activity globally. As a result, the specialization indices for such AI fields may be biased.

Figure 25: Relative Specialization Index by AI Fields for American and Canadian institutions



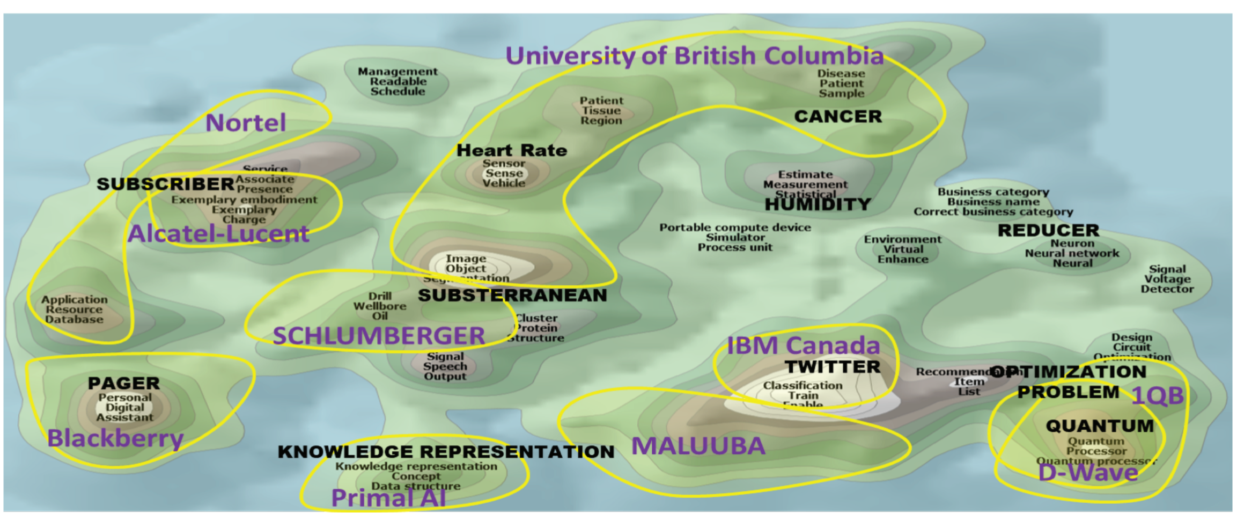
Canada's leading institutions patenting in the AI field over the 1998 to 2017 period are presented in Figure 26. Many of the institutions listed are prominent patenting entities that patent in a variety of technology fields while others, such as D-Wave Systems Inc. and Primal AI, specialize in this field. It is also interesting to note that Nortel Networks, a now defunct business entity, is among the leading filers. The fact that owners of patented inventions are not required to update the information held in the patent database reflects a challenge when using patented invention data to identify owners of such rights.

Figure 26: Top Canadian institutions and their associated patented invention counts



Presenting the patent landscape map for Canadian institutions is another way to visualize patented invention data. In Figure 27, we superimpose the names of the top ten leading Canadian institutions to highlight who is working in which space. Unlike the landscape map for Canadian researchers, there is not much overlap in areas where multiple institutions are patenting, the exception being D-Wave Systems Inc. and 1QB Information Technologies Inc., which are both operating in the quantum computing technology field. One thing that is striking is that Primal AI's patented inventions are captured in a peak on a peninsula secluded from the rest in the bottom-centre of the map. This peak is characterized by keywords such as "Knowledge Representation", "Concept", and "Data Structure". This placement on the map may suggest the company is operating in a niche area, far different than technologies related to those captured in the larger AI technology space.

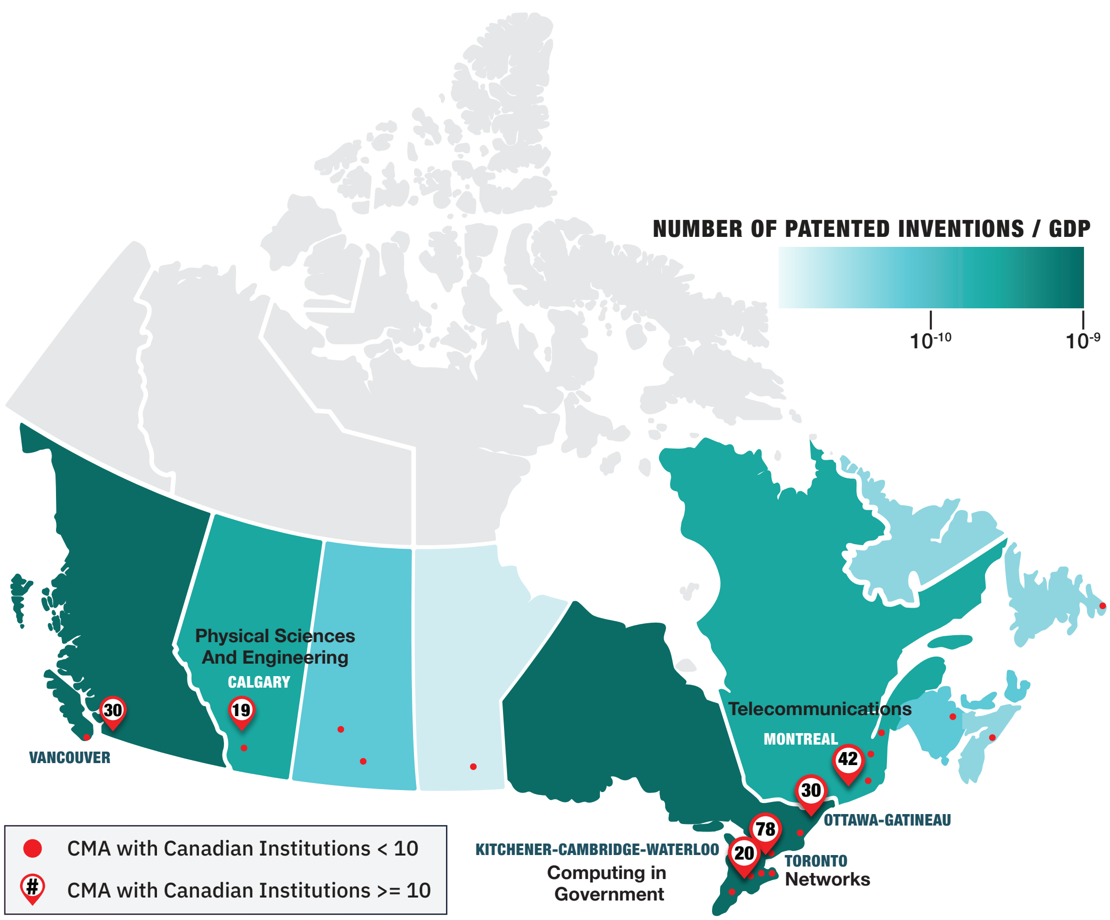
Figure 27: Landscape map of Canadian institutions' patent activity highlighting top filers



Geographical Clusters

In Figure 28, Canada's CMAs associated with more than 10 patented inventions by AI institutions are presented in a geographic map. It should be noted that patented invention volumes were calculated using the fractional counting approach and have been normalized by GDP in this figure. In 2018, 650 start ups were created "across all cluster cities". Many of these start-ups found support in local investors who helped give credibility to the ecosystem, leading to interest from international investors. The attention received by foreign investors has raised AI related deals by 41% and acquisition rates by 50% each year on average.[33] There are many benefits for institutions to cluster together, including increased productivity, faster innovation through collaborative research, and the creation of small institutions to cater to the niche needs of the industry.

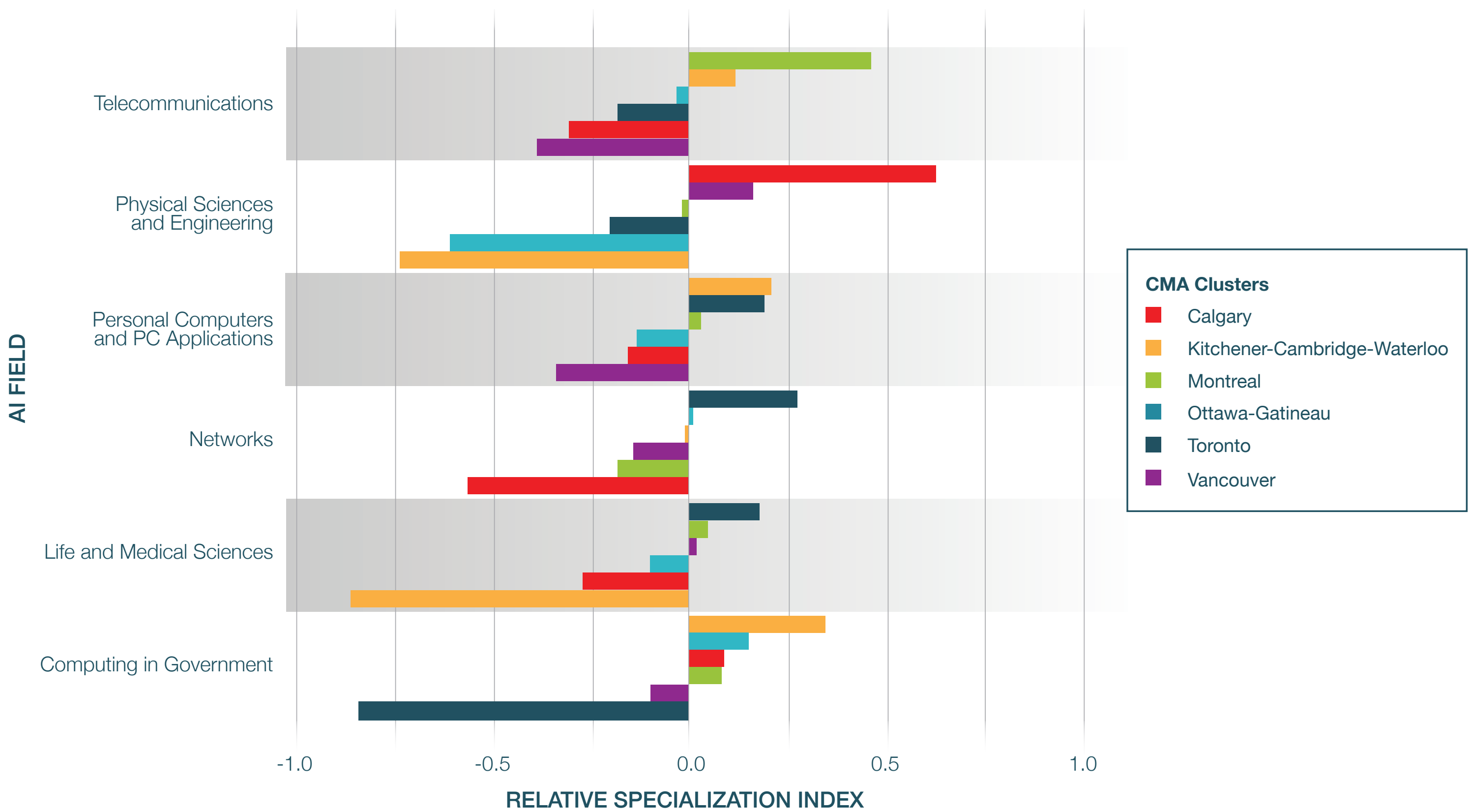
Figure 28: Geographical clusters of inventive activity by Canadian institutions



There are six institution clusters, each comprised of ten or more institutions, that emerge as key areas leading innovation in the Canadian AI sector. Patenting from these clusters accounts for 83% of AI patented inventions nationwide. Similar to the geographic map in the Canadian Researchers section, the provinces are shaded in blue and normalized by their GDP. Most of the institutions that have inventions patented in AI are located in Ontario, which holds three main CMA clusters: Toronto, Ottawa–Gatineau, and Kitchener–Cambridge–Waterloo. The largest is the CMA of Toronto, which boasts 78 patenting AI institutions. Other CMAs with large clusters include Montréal (42 institutions), Vancouver (30 institutions) and Calgary (19 institutions).

Figure 29 takes a closer look at the relative specializations for each of the CMAs by AI Field. It is interesting to note that most of the prominent CMAs are specialized in a different AI. The Toronto CMA specializes in Networks, and Life and Medical Sciences, whereas the Kitchener–Cambridge–Waterloo CMA specializes in Computing in Government, and Personal Computers and PC Applications. Toronto has become an integral part of the national ecosystem, partly owing to the Vector Institute, a "not-for-profit corporation" that works with start-ups, the marketplace, incubators and accelerators to help drive AI research.[34] Toronto has attracted a lot of attention from foreign investors because of its reputation as Canada's financial capital.[35] The city has also teamed up with Waterloo to gain the title of Silicon Valley of the North.[36]

Figure 29: Relative specialization of census metropolitan areas by AI Fields



Montréal was identified as a cluster specializing in Telecommunications. Relying on Mila, Montréal has a research focus on a wide range of topics, including deep learning, recurrent neural networks and generative models.[37] In addition to Mila, Montréal has another institution called IVADO, which focuses more on industrial research.[38] This combination has made them a target for international investors, leading to a wide range of deals and generous research funding. Last but not the least, Calgary was found to be specialized in Physical Sciences and Engineering.

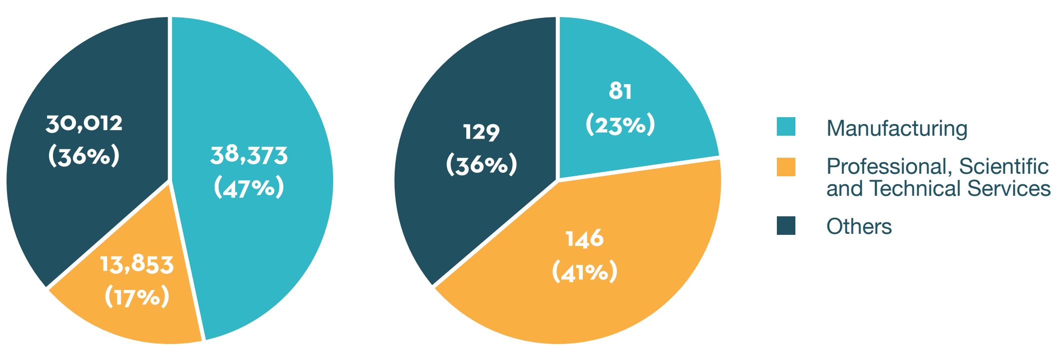
Profile of Canadian Institutions Patenting in the Field of Artificial Intelligence

While analysis of the patent data itself already yields substantial information on innovation in the area of AI by Canadian institutions and researchers, a more complete picture of the environment can be obtained when this data is linked to other data sources. With the support of Global Affairs Canada and CIPO, Statistics Canada linked the patented inventions for Canadian institutions from the EPO-PATSTAT database to data on the characteristics of institutions held at Statistics Canada. This linked data source sheds lights on the industry, size, and ownership characteristics of Canadian institutions patenting in AI.

Industry

A large percentage of patented inventions in the field of AI by Canadian institutions come from the Professional, Scientific, and Technical Services industry. Over the entire 2001 to 2016 period, 41% of AI patented inventions came from this industry. This is far higher than the 23% accounted for by the next largest source, the Manufacturing industry. When patenting across all fields is considered, the situation is reversed. The Manufacturing industry accounts for 47% of the patented inventions in all fields, while Professional, Scientific, and Technical Services industry accounts for 17%.

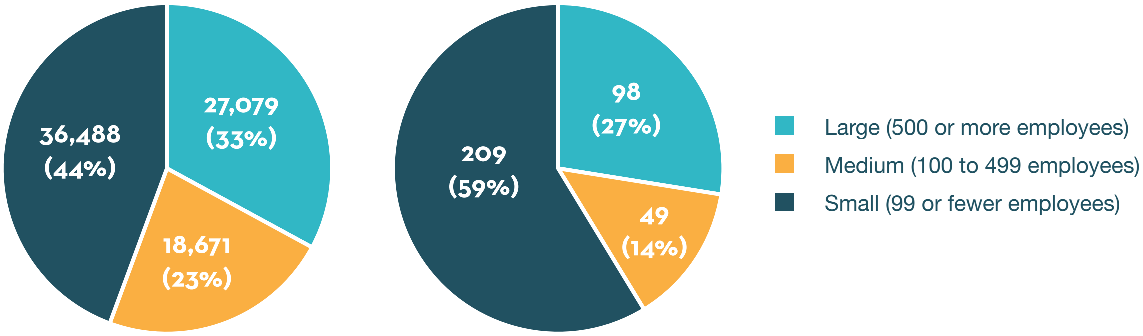
Figure 30: Breakdown of patent activity by industry sector across all sectors (left) and in AI (right)



Institution Size

Innovation occurs in institutions of all sizes. While innovation is often associated with younger, smaller institutions, larger institutions have more specialized resources and finances to sustain development efforts. The data on patent activity in AI is broadly consistent with this. Although 59% of the patented inventions in AI were made by institutions with less than 100 employees over the 2001 to 2016 period, the share of AI patented inventions accounted for by large institutions with 500 or more employees was also substantial at 27%. Compared with patenting in all fields, where 44% of patented inventions come from small institutions and 33% come from large institutions, patenting in AI is more concentrated in smaller institutions.

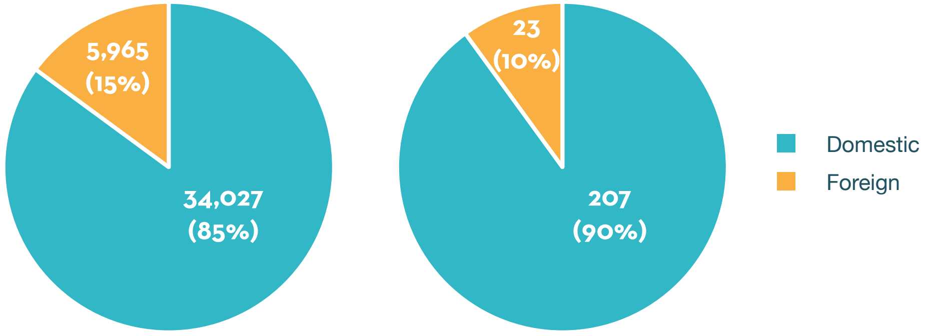
Figure 31: Breakdown of patent activity by institution size across all sectors (left) and in AI (right)



Ownership

The share of patented inventions in AI by Canadian institutions that are foreign controlled is lower than for overall patented inventions. Over the 2009 to 2016 period, 10% of the patented inventions in AI were made by foreign-controlled Canadian institutions. This is compared to 15% for patented inventions overall.

Figure 32: Breakdown of patent activity by ownership across all sectors (left) and in AI (right)



AI In Health

Canada is hailed as one of the leaders in healthcare AI. One initiative that is being heavily leveraged by Canada is the *Equitable AI Initiative*. This initiative focuses on using AI to provide opportunities in the area of public health not only to analyze complex data but also to design and provide impactful solutions that draw on a wider range of insights. This is done through the initiative's goals to fund, train and promote knowledge transfer across platforms.[39] At the University of Alberta, scientists are researching and creating prototypes of a bionic arm that can learn and anticipate the movement of its wearer to allow for better and smoother use of the prosthetic.[40] At Humber River Hospital, affectionately dubbed the first all-digital hospital, resides a command centre that tracks the flow of patients from their intake to their discharge, analyzes the data and reports back where there are slowdowns in the process.[41] This allows those working in the hospital to know where and why delays are caused and allows them to fix the problem before it arises. Humber River has taken it a step further and moved from electronic health records to a fully automated hospital.[42] From robots sorting medicine to machines delivering blood samples from patients to the lab, Humber River has made use of AI in almost all areas of the hospital.[43]

Opportunities and Challenges for Integrating AI at Intellectual Property Offices

AI and IP Policy

The world of IP is changing at an incredible pace. This change is driven by a number of factors, including rising value of intangibles, emergence of new countries as IP powerhouses, convergence of science and technology, increasing volumes of IP filing, increasing complexity of applications, interdisciplinary nature of innovation, and changing nature of work as a result of the integration of new technology.

CIPO is committed to ensuring that our IP system supports transformative technologies, such as AI. As we consider the implications of AI for the Canadian IP regime, Canada is adopting a whole-of-government approach to ensure that the Canadian IP system is well equipped to support the emergence of transformative technologies. Although we are still in the early stages of considering the implications of AI for the Canadian IP regime, CIPO is working with leading thinkers, policy makers, academics, practitioners and international partners to analyze the implications of AI for IP policy and law. In particular, we are engaged in discussion on

- the policy questions being raised for IP, creation and innovation, such as authorship and inventorship;
- the copyright considerations in using copyright protected work to train AI algorithms and data; and
- the best practices to address the implementation of AI in a manner compatible with core administrative law principles, such as transparency, accountability, legality, and procedural fairness.

AI Operations

Transformative technologies have the potential to benefit the administration of the IP system. CIPO is looking to use AI technologies to gain efficiencies both in the delivery of timely and quality IP rights and the provision of a modern service experience. Toward this end, CIPO is launching and managing multiple AI projects.

CONCLUSION

Since the 1950s, AI has been at the forefront of computer science and has been a topic of interest, especially in terms of patenting. This report captures 85,144 AI inventions patented worldwide between 1998 and 2017, of which approximately 2% or 1,516 patented AI inventions are associated with Canadian researchers and institutions. Breaking down this Canadian subset further, we find 618 AI inventions involved at least one Canadian institution and 1,419 inventions involved at least one Canadian researcher. Overall, Canada ranks sixth in terms of raw patented invention volumes, from either the perspective of researchers or institutions.

On an international level, China and the U.S. lead the AI race. In 2011, a spike in AI patented inventions transformed the landscape, much of this activity originating in China. Computer Vision and NLP are the AI Applications responsible for most of the activity, while Life and Medical Sciences and Transportation are the most patented AI Fields. ML overshadows all other techniques both domestically and internationally as it pertains to AI Techniques.

In Canada, there are several hubs of activity in this field. Each of the superclusters provides nurturing environments for emerging talent, focused on the industries local to those particular geographic areas. This creates activity hubs, with each having their own specialization, as is apparent from the CMA cluster map presented in the Canadian institution section. Other initiatives that have been put in place in Canada include the *Equitable AI Initiative* and the *Canada-UK Initiative*, each focusing on separate goals to advance international and domestic collaboration, ethics, and policy concerning AI. In addition, Canada created the *Pan-Canadian Artificial Intelligence Strategy*, a $125M initiative connecting the key players in the field to ensure collaboration, equity and economic advancement.

In terms of AI Fields, Canada has a high specialization in Physical Sciences and Engineering as well as Life and Medical Sciences, two of the most patented AI Fields. However, one area where Canadian innovation could stand to gain is Transportation, where its relative specialization falls far behind the rest of the world. In terms of AI Applications, Canada is more diversified than the U.S., where the latter excels in NLP and Computer Vision relative to the other AI Applications subcategories.

The gender ratio worldwide, as it relates to the distribution of researchers involved in AI patented inventions, is one female for every three males. In Canada, this ratio is one female for every six males. This gap cannot be explained simply by the ratio of engineering or science graduates, and rather hints at alternate reasons. The Canadian Department for Women and Gender Equality has put forward a number of initiatives to further influence young women to pursue as well as feel comfortable remaining in these positions and ascending the ranks of these institutions. IP awareness would be a welcomed addition to these initiatives.

Since the AI technology field is continuously growing and evolving, it is important to make note of the challenges facing AI in Canada, particularly the retention of talent and institutions. The first come, first serve nature of the AI market makes it incredibly competitive when looking for funding from investors. The findings also confirm the intensity of competition of the AI market in Canada, as validated by the IPCI results. Canadian funding patterns engage more with established companies than with companies on their first round of funding, in contrast with the U.S.[44] This difference in funding strategies reflects to the high acquisition rate of Canadian institutions by American companies. Looking forward, it will be interesting to see how Canada adapts to the quickly evolving nature of AI and how institutions are able to leverage their IP to support business decisions and growth. Nevertheless, as AI becomes better defined and understood, it can be expected that it will increasingly be regulated domestically and abroad, but at the present time, many opportunities exist for players to set the standards and influence the speed at which such a technology is implemented in our everyday lives.

ANNEX A - METHODOLOGY

The term "patented inventions" in our report refers to patent families. A patent family is a collection of similar patent applications filed across multiple jurisdictions. Even though there are multiple patent family indices developed by various organizations, the one considered in our report is the DOCDB patent family index. The earliest patent filed in every patent family is known as the priority patent application. For the purpose of this analysis, priority applications that were filed between 1998 and 2017 were considered.

As briefly mentioned in the introductory section of the report, defining AI from a patent perspective is challenging because of its constantly evolving nature. WIPO was the first to step forward and attempt to define AI in terms of international patent activity. Outlined in its *Technology Trends 2019* report, WIPO takes a generalized approach to defining AI patent activity. WIPO uses a combination of International Patent Classification (IPC) codes, Cooperative Patent Classification (CPC) codes, and File Index and File Forming Terms (FI/F-terms) classes and AI-specific keywords to define AI. In conjunction with WIPO's efforts, the Organisation for Economic Co-operation and Development (OECD) created a working group to establish a commonly accepted definition of AI. The working group involved representatives from IP Australia, the Canadian Intellectual Property Office (CIPO), the European Patent Office (EPO), the Israel Patent Office (ILPO), the Italian Patent and Trademark Office (UIBM), the National Institute for Industrial Property of Chile (INAPI), the United Kingdom Intellectual Property Office (UKIPO) and the United States Patent and Trademark Office (USPTO).

Inspired by the work carried out by WIPO and the findings from OECD working group discussion, the UKIPO subsequently published a report titled *Artificial Intelligence - a worldwide overview of AI patents*,[iv] which focused on the patenting trends in the U.K. for AI. In order to reduce the number of records being incorrectly captured by the patent search strategy, the UKIPO adopted a narrow definition of AI and considered a time span of 20 years (1998–2017). The complete search strategy can be found in Appendix 1 of its report, and the list of patent applications identified through this search strategy can be found on the UKIPO's website.[v] The underlying raw dataset for our report is the same as the one used by the UKIPO to conduct their analysis. However, owing to differences in the approaches adopted to clean the data, there may be instances where there is a discrepancy in the statistics reported between the two reports.

[iv] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/817610/Artificial_Intelligence_-_A_worldwide_overview_of_AI_patents.pdf

[v] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/808699/AI-raw-data.csv/preview

ANNEX B - DATA CLEANING

In order to account for the inconsistencies and spelling errors that are commonly found in any IP dataset, CIPO devotes a significant amount of time to ensure the underlying dataset on which the analysis is conducted has minimum inconsistencies. Previously, this issue was dealt with entirely by manually grouping the same names together with a software known as VantagePoint. This process was a highly inefficient process and took around 10 business days to accomplish.

Thus, in order to reduce this manual intervention, a Python script leveraging Machine Learning (ML) techniques to clean researcher information was developed. One of the attributes fed into the ML model includes a string comparison metric known as the Jaro–Winkler score, which compares the last name and first name of the two researchers under consideration. Another attribute considered is the difference between the application dates of the two researchers being compared. The ML model also takes into consideration the number of shared assignees between the two researchers.

Using this script, the record having the most information will replace records having similar information. For illustration, the first two records in the following example will be replaced by the third record:

- John Smith
- John Smith, CA
- John Smith, Ottawa, ON, CA

We are in the process of further improving the performance of the script with short names and are also trying to leverage the geographical information of researchers as an additional attribute for the ML model.

ANNEX C - INTELLECTUAL PROPERTY CONCENTRATION INDEX

The IPCI introduced in this report follows a long history of concentration indices applied in many disciplines, such as the Herfindahl-Hirschman Index, Simpson index, Shannon diversity index, and the effective number of parties index. The formula used to calculate the Intellectual Property Concentration Index (IPCI) is as follows:

$$IPCI = s_1^2 + s_2^2 + s_3^2 + \ldots\ldots + s_n^2$$

where s_n is the share of patented inventions held by participant *n*, in fraction. Note that a fractional counting approach was used to calculate patented invention totals for each participant.

The value of the index ranges between 1/n and 1. Index values closer to 0 would indicate an industry or technology field has an environment that is more competitive, consisting of a large number of less-active participants, whereas index values closer to 1 would indicate an industry or technology field has an environment that is more concentrated consisting of a few dominant players.

ANNEX D - RELATIVE SPECIALIZATION INDEX

In order to better understand a country's strengths in AI, the Relative Specialization Index (RSI) was used. The formula used to calculate the RSI for a particular country is as follows:

$$RSI_{Country} = log_{10}\left[\left(\sum_{1998}^{2017} P_{Country,AI} \Big/ \sum_{1998}^{2017} P_{World,AI}\right) \Big/ \left(\sum_{1998}^{2017} P_{Country} \Big/ \sum_{1998}^{2017} P_{World}\right)\right]$$

where P represents patented inventions.

Numerator

The sum total of patented inventions assigned to a particular country's applicants in AI is divided by the sum total of patented inventions identified globally in AI.

Denominator

The sum total of patented inventions assigned to a particular country's applicants is divided by the sum total of patented inventions identified globally across all technology sectors. The data pertaining to the denominator was obtained from EPO-PATSTAT.

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