NSF Robotics Topics and Future Predictions

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Abstract

This research project consists of two types of data analysis, with one being a simple analysis of the overlying trends within robotics programs in the National Science Foundation (NSF), and the other being a Latent Dirichlet Allocation analysis (LDA) in order to find the trends of subtopics being utilized within these programs. The purpose of these analyses is to discover trends in robotics funding over the last decade and to predict the future of NSF robotics programs as a whole. Since grant funding proceeds publication of papers, this analysis would also uncover potential future trends in publication. Ultimately, the goal of this research is to assist future researchers in adjusting their programs to fit the trends of the future, pointing out major corresponding topics that are likely to secure funding. From the simple analysis, several trends were discovered within these programs over the last decade.

Introduction

According to NSF, "...many of the underpinnings of today's robots began in fundamental research in sensing, computer vision, artificial intelligence, mechanical engineering and many other areas that some might not immediately recognize as being related to robots."[1] Additionally the NSF itself acknowledges the importance of this field through its development of the National Robotics Initiative 3.0, which aims to support research that "promotes integration of robots to the benefit of humans including human safety and human independence". The NSF also highlights the importance of collaboration between academics, industry, non-profits, and other varying organizations to help better establish links between fundamental science and engineering and technology development, deployment, and use.[2] Because of the fact that these areas of study are not recognized as being related to robotics, it raises the question: What areas of research are being utilized in the broader robotics programs at NSF? Our group's hypothesis regarding this question is that many topics will coincide with robotics research, but the most prominent and promising will be Computer Science and Artificial Intelligence. By running the LDA analysis over the last 10 years of robotics funding data, we will be able to discover overlapping fields of research as well as the trends in their popularity. In doing so, we will be able to share our findings with researchers who will be pursuing robotics grants in the future and give them the upper hand on securing funding by understanding the future landscape of grants and robotics applications.

Introduction to the Robotics Data

A simple analysis was run throughout the data to familiarize ourselves with it. Multiple simple visualizations were created, as shown below, to help visually show the content that resides within. Each visualization was created using all of the grant data available within the last decade between the years of 2014 to 2023.

Figure 1

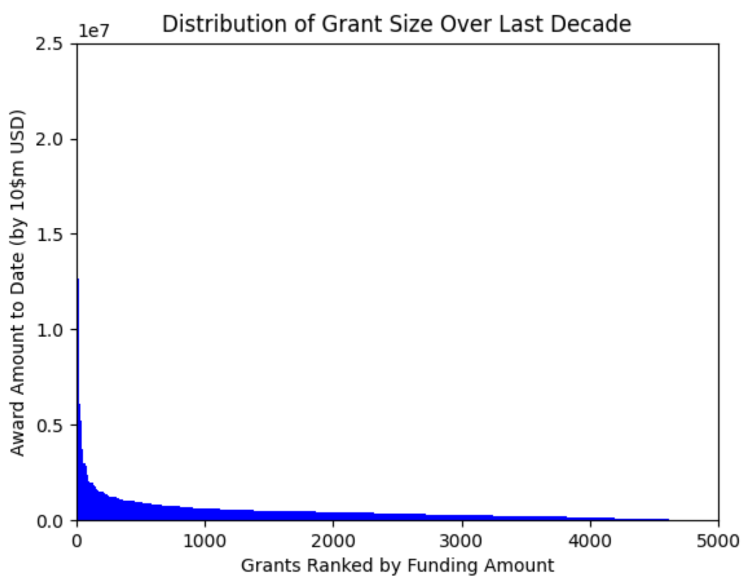


Figure 1 shows the outliers and the trends in the amount of money that is being awarded to robotics projects. It is evident that most robotics grant programs are awarded 5 million dollars or less, with few outliers being greater than this. About a tenth of all robotics programs are awarded more than one million dollars over the course of their work.

Figure 2

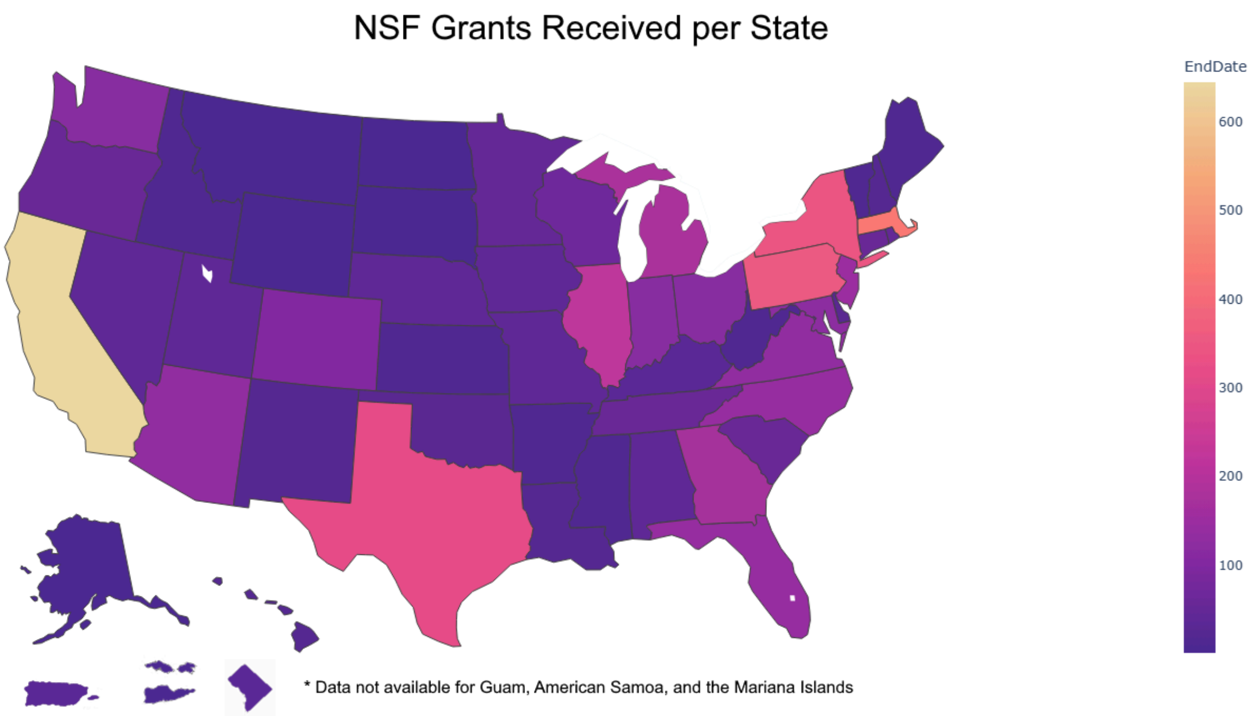


Figure 2 uses a heatmap to show the distribution of individual grants by state. By number, California is overwhelmingly the largest recipient of grants, with just over 600 awarded. This is not surprising given the population and number of technical universities and organizations located in California. It should be noted that all states, as well as Washington D.C., Puerto Rico, and the Virgin Islands, had at least one project that received funding. This shows that the field of robotics is not entirely dependent on location and has opportunities nationwide. Though Guam, the Northern Mariana Islands, and American Samoa are notably missing from this map, the NSF INCLUDES SEAS (Supporting Emerging Aquatic Scientists) program is designed to promote STEM programs in these territories as well as in free association countries like Palau and

Micronesia[3]. Thus, the potential for these regions to receive robotics funding in the future should not be discounted.

Figure 3

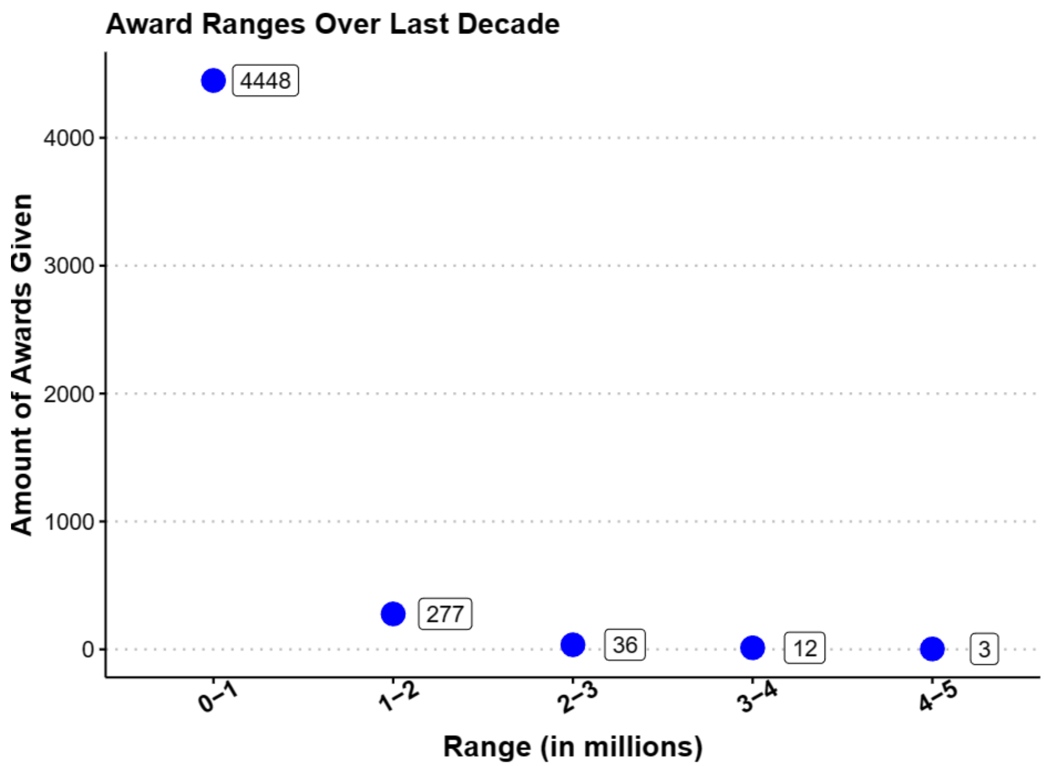


Figure 3 separates all grants that have been awarded into 5 groups by the amount of money allocated in millions. From this, we can conclude that a majority of grant programs were awarded 1 million dollars or below with very few qualifying for awards in higher ranges. Only three projects were allotted more than 4 million dollars and only twelve were awarded 3-4 million. Many programs did not receive more money, indicating that many programs are not deemed as important to the future of robotics compared to others.

Figure 4

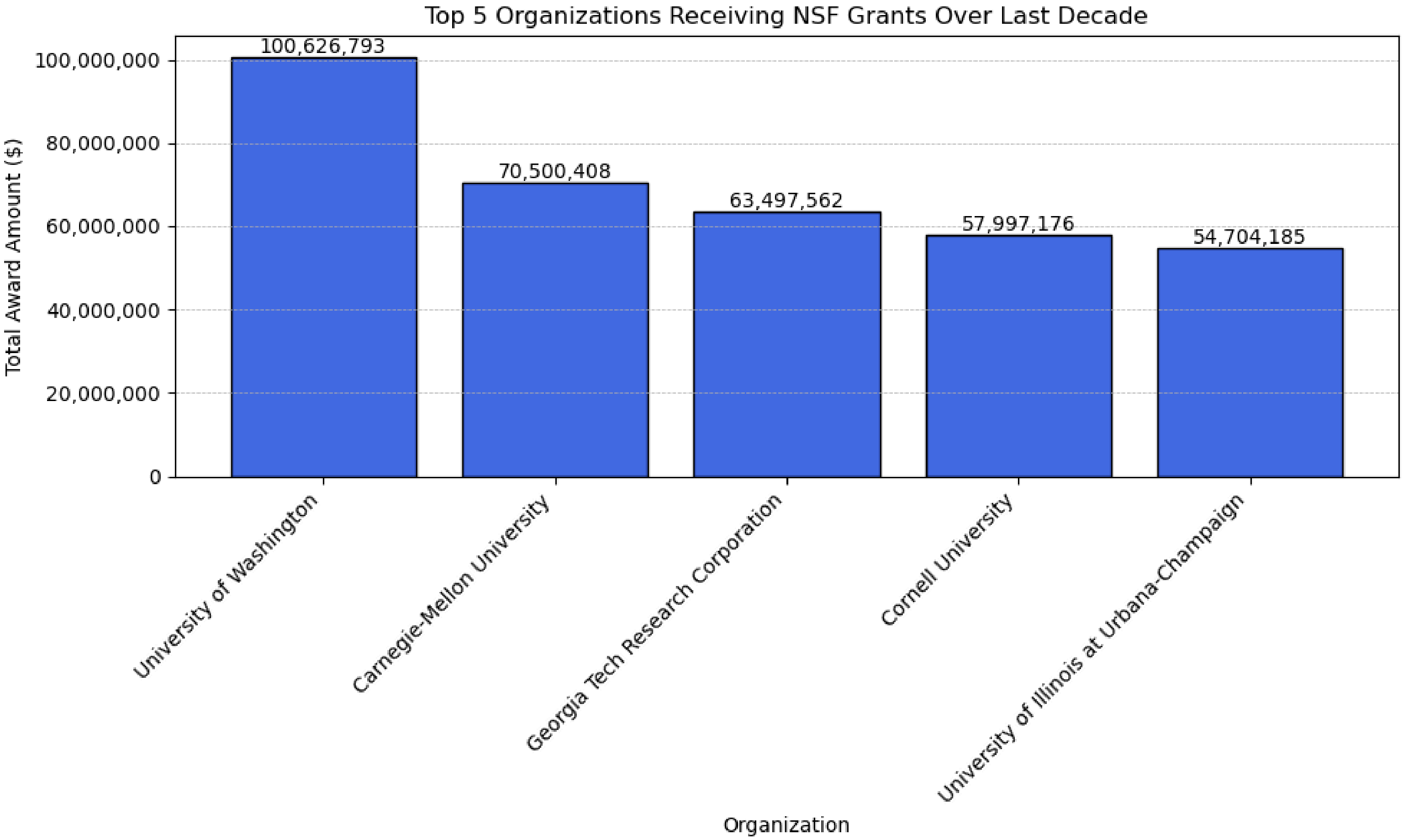


Figure 4 displays the top five organizations that received the most funding overall. With four out of the five top organizations being universities and the other being a non-profit related to a university, this determined that the NSF places high importance on the funding and relationship between universities and the NSF. This also shows that of the Ivy League programs, Cornell University is the most influential in the area of robotics. Furthermore, it illustrates that Ivy League schools do not have a strong correlation with high robotics funding as there are many stronger alternatives.

Figure 5

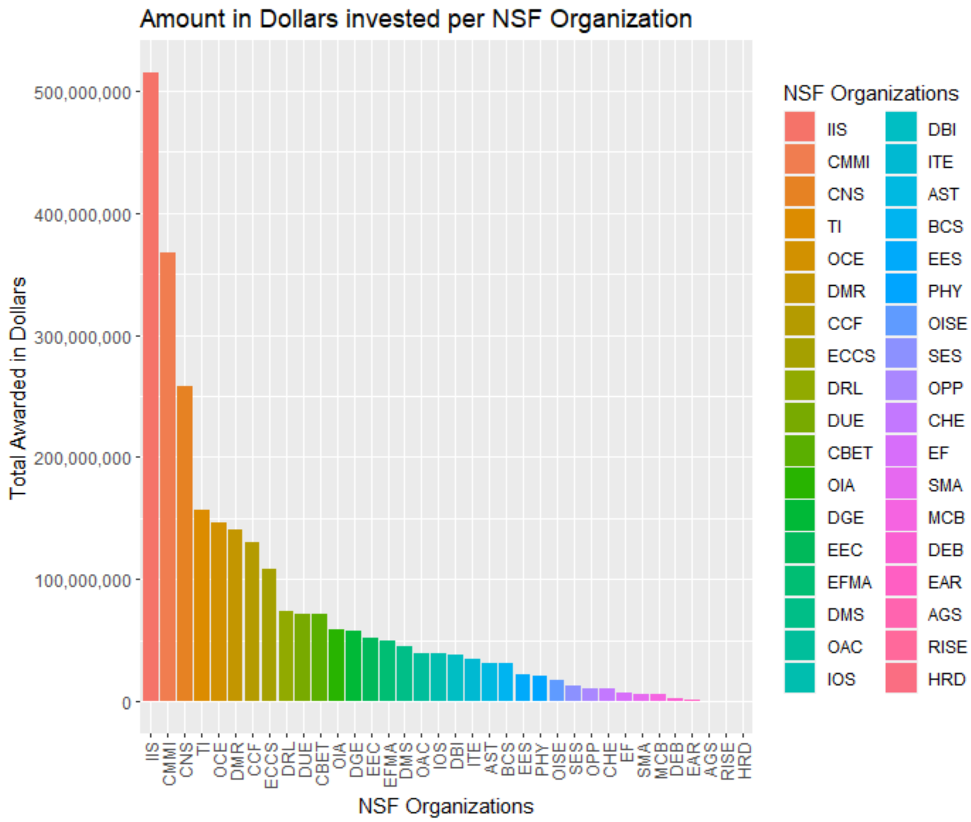


Figure 5 displays the spread of funds awarded to robotics programs by each subdivision of the NSF within the last decade. The Division of Information and Intelligent Systems (IIS) awards by far the most amount of dollars towards robotics research at over five-hundred million dollars. This supports our hypothesis that Artificial Intelligence and Computer Science are the most likely subtopics to receive funding, as the IIS focuses on these fields almost exclusively[4]. The IIS even provided more funding to robotics research than the Civil, Mechanical and Manufacturing Innovation (CMMI) branch of the NSF, which is dedicated to “systems for decision-making, robotics and controls”[5]. This goes to show that there has been a huge shift in the applications of robotics towards artificial intelligence and computing and away from manufacturing.

To view the translations of the program acronyms located within the legend, please view the full list of the NSF acronyms here.

Data Collection and Simple Analysis Methodology

Our dataset for robotics funding comes directly from the NSF's funding search. The NSF website (www.new.nsf.gov) allowed us to conduct an advanced grant search to view projects that have been funded under certain criteria. For our purposes, we chose to narrow our time range from January 1st, 2014 to December 31st, 2023 to get the last ten years of data and further applied a filter to match grants with the "Robotics" keyword while including expired grants as well. Compiling these year-by-year, we reached a combined 4,870 grants, which we downloaded as an Excel spreadsheet, and then converted to a CSV file. The most relevant values in this dataset were the amounts awarded, the program start dates, and the abstract of each project. It should be noted that other data such as the sub-organizations providing the funding as well as the programs of the researchers were also included. We utilized these to look for specific trends in location and industry as well, but those were secondary to our goal. Our team used Python and R to both organize and plot our data, which resulted in the graphs shown above.

By navigating to the NSF website, we were able to click on a link located within the homepage of the website that stated: "What we've funded". After clicking on this link, we clicked on "Advanced Search" in the bar at the top, which then opened a page where search criteria could be entered. From here, in the "Additional Information" section, the keyword "Robotics" was entered, as well as on the right side of that same section, we checked the box next to "Expired Awards" in order to include both expired and active awards. Lastly, due to the fact that we split up the last decade into two-year sets, one of our group members entered 01/01/2014 into the "From" box under "Original Award Date", then under "To", 12/31/2015 was entered. This process was repeated by different group members for the yearsets of 2016-2017, 2018-2019, 2020-2021 and 2022-2023. After executing the advanced search, the results showed, and we clicked on "Excel" above the results in order to export them as an Excel spreadsheet. From here, we copied and pasted the data into one spreadsheet that contained all of the data for the last decade. The reasoning behind searching for this data in segments is that the NSF advanced search allows up to 3,000 results per search, thus it was imperative that we divided these ten years up into groups. Finally, using this spreadsheet that contains all of the data for the last decade, we were able to conduct the simple analysis, as well as saving it as a text file to use for the LDA analysis.

LDA Methodology

The data from the abstracts required deeper analysis that was conducted and graphed in R, as the abstracts contained keywords that show links to other topics that robotics applies to. Our primary objective was to identify and find trends in these keywords to show which fields of research robotics overlaps with - and in turn, help us understand where the future of robotics and its funding will lie. To do so, using the data gathered from the advanced search and breaking this up into two-year segments, we ran a latent Dirichlet allocation analysis. Furthermore, by breaking down this data into two-year segments, the LDA analysis was able to be run on standard personal computers, rather than using a supercomputer, which would allow us to run all ten years of data in one instance.

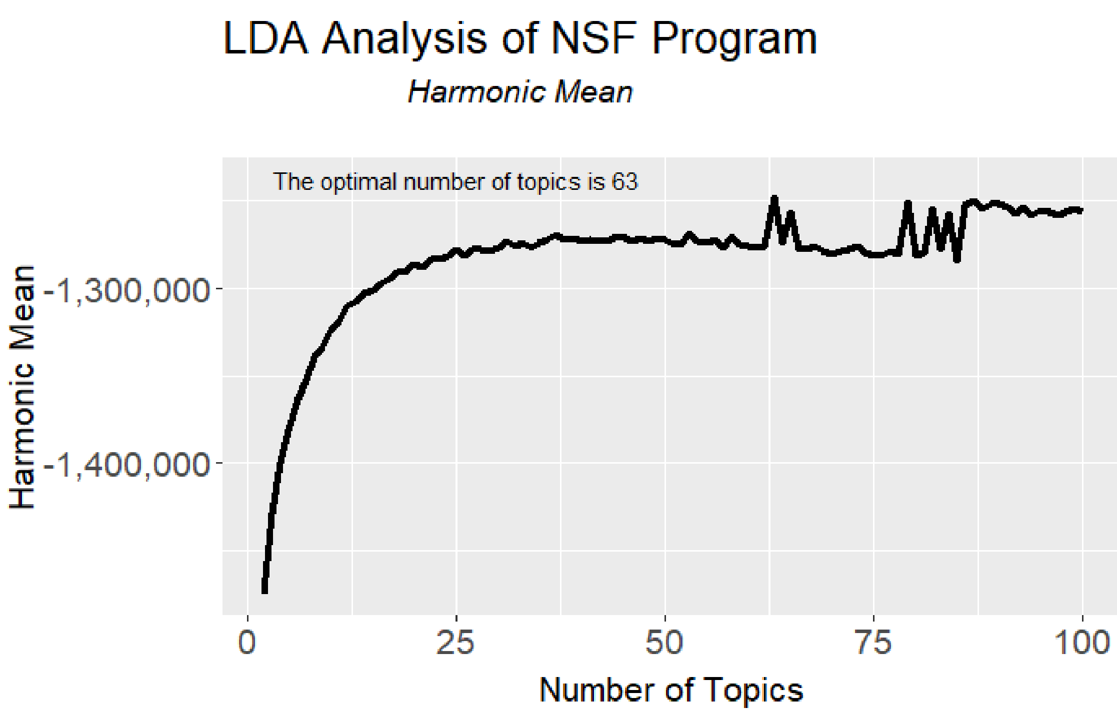
Prior to running the analysis, it was important to establish stop words, which are words that were not to be included in the final results. Examples of these words include enable, impact, and experience, which are words that do not identify any particular topic or process. After running an analysis, we would remove words that had no relation to any particular field of research, which was determined by personal judgment. This process was repeated several times until the results of the LDA analysis were populated by words that could be interpreted under a subtopic.

The stop words we used within the LDA analysis are: “system", "robot", "human", "control", "student", "network", "design", "learning", "algorithm", "material", "robotic", "datum", "research", "project", "model", "task", "object", "user", "technology", "hand", "physical", "environment", "science", "application", "power", "develop", "propose","sensor", "time", "manufacturing", "process", "study", "interaction", "sense", "performance", "stem", "planning", "team", "program", "manipulation", "train", "theory", "method", "motion", "social", "enable", "safety", "workshop", "behavior", "scale", "agent", "development", "approach", "career", "communication", "compute", "complex", "school", "industry", "increase", "activity", "impact", "dynamics", "property", "result", "action", "modeling", "pi", "structure", "costs", "program", "level", "provide", "field", "vehicle", "experience", "base", "real", "computational", "potential", "advance", "include", "community", "child", "challenge", "goal", "support", "multi", and "device”.

Looking back at these stop words, some of these words could possibly be reconsidered. Words such as ‘network’, ‘stem’, ‘vehicle’, ‘pi’, ‘science’, and more could represent overlaps in mathematics, autonomous vehicles, etc. These words may be included in the LDA analysis in future iterations of this analysis to get a more realistic topic result. In addition, we replaced any extended characters (e.g. letters with accent marks, symbols, and Unicode characters) to ensure that these will not accidentally create their own topics. Next, using TreeTagger, we collapsed words like “run”, “running” and “ran” into their base form - also known as the lemma - to count them as the same word. This reduced clutter and prevented words with the same meaning from breaking into distinct categories. These two steps were essential in preprocessing the abstracts prior to conducting the LDA analysis.

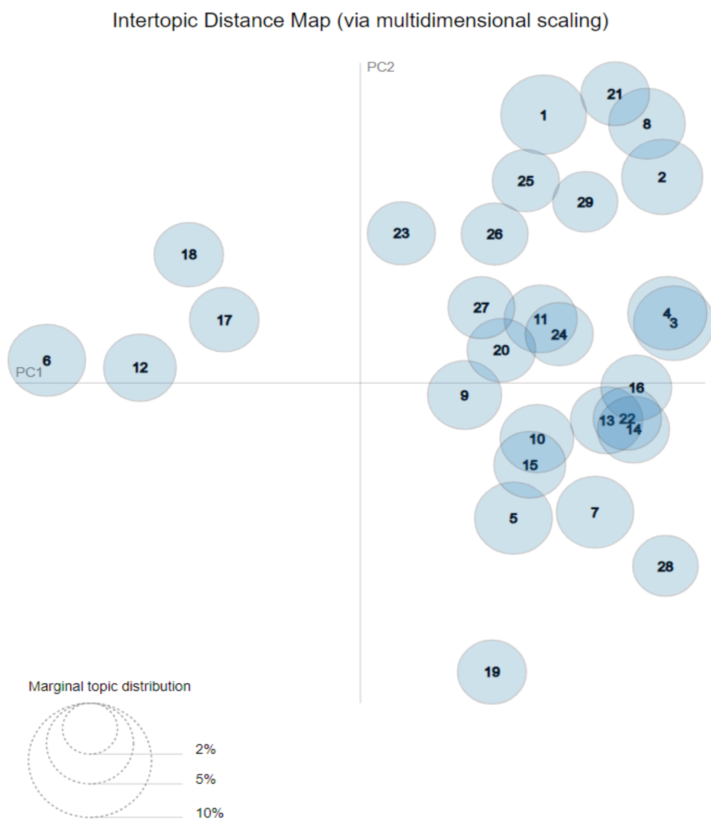
After cleaning the words that will be used in the LDA analysis, it is important to determine the number of topics that the grants will be dispersed into. By plotting the number of topics according to the harmonic mean, we were able to determine the number of topics we wanted to use by finding where the line plateaus in the graph. For example, Figure 6 (below) states that the optimal number of topics would be 63. However, the line plateaus when the number of topics reaches 25, indicating that this is the best possible number to disperse groups into. After this, we ran the LDA analysis.

Figure 6



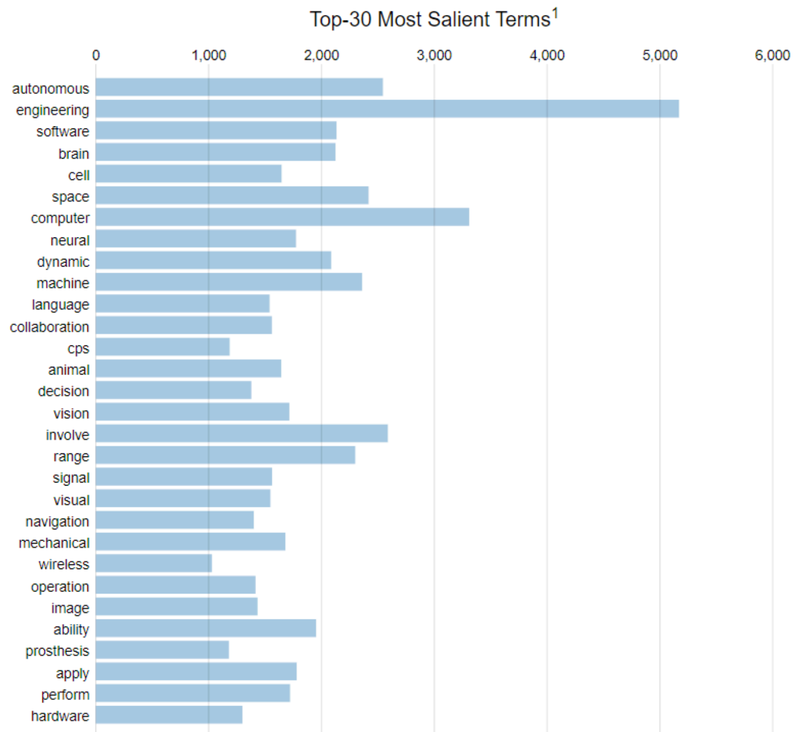
After running the LDA analysis, the different topics were displayed in a multidimensional scaling intertopic distance map. This map displays all topics, with the distance between topics representing how similar each topic is to one another. For example, in Figure 7 below, topic number 1 is very different from topic number 19, as the distance between them is large. In comparison, topic number 1 and topic number 21 are very similar, as they are closer in distance.

Figure 7



In addition to the intertopic distance map, a bar graph was created that displays the 30 most salient words within the abstracts of the programs, shown in Figure 8. We ran an LDA analysis over 5 sets of 2 years each. The differences between the salient words in each iteration allowed us to see the trends in topics at a more granular level.

Figure 8



From then on, the group went ahead and found the topics that were extremely similar based on the words that reside in the different topics in the different LDA analysis year sets. Those topics that have similar keywords to topics in different year sets are then considered the same topic. From that point on, the group filtered out different documents and decided to keep the documents that were within the top five gamma per topic. With this, we are able to calculate how much money is spent on each of these topics based on the amount spent on the programs associated with these documents and rank the topics based on that current amount.

After that, the group was able to compare how much money a given topic is awarded per year and track to see if the funds are increasing or decreasing per topic. With that given information, it is evident that the topics are either higher priority as more money is being invested, or lower priority if less money is being invested over time.

	document	topic	gamma	row	bigram1	bigram2	bigram3	bigram4	bigram5	title	amount	TopicWorthRank	WorthSum
1	2145278	1	0.44421	1	anchor dev	friendly ent	grain locali	fine grain	indoor spa	CAREER: Closing the	$249,634.00	20	17289257.71
2	2145936	1	0.464328	2	dense iot	range nfc	ultra dense	NA range	nfc tag	CAREER: Long-Rang	$276,326.00	20	17289257.71
3	2140650	1	0.488131	3	air jet	fly inside	inside tight	confined s	bat inspire	Collaborative Resea	$382,640.00	20	17289257.71
4	2334994	1	0.497239	4	tuskegee u	wing exten	morphing v	fix wing	rotorcraft r	Collaborative Resea	$335,526.00	20	17289257.71
5	2334995	1	0.511474	5	tuskegee u	wing exten	morphing v	fix wing	rotorcraft r	Collaborative Resea	$324,220.00	20	17289257.71
6	2152180	2	0.55433	1	actuation v	fluid NA	wave spee	excitable n	pacemake	Neuromechanical R	$103,532.00	8	20341358.17
7	2240770	2	0.585441	2	actuation v	fluid NA	wave spee	excitable n	pacemake	Neuromechanical R	$203,226.00	8	20341358.17
8	2317443	2	0.660617	3	free live	healing ca	mechanica	stentor coe	wind resilie	Collaborative Resea	$185,027.00	8	20341358.17
9	2317442	2	0.664376	4	free live	healing ca	mechanica	stentor coe	wind resilie	Collaborative Resea	$651,399.00	8	20341358.17
10	2317444	2	0.664376	5	free live	healing ca	mechanica	stentor coe	wind resilie	Collaborative Resea	$139,341.00	8	20341358.17
11	2301357	3	0.658184	1	increase c	device incl	knit textile	wearable c	NA touch	Collaborative Resea	$81,480.00	24	14921118.33
12	2301355	3	0.666918	2	increase c	device incl	knit textile	wearable c	NA touch	Collaborative Resea	$279,027.00	24	14921118.33
13	2312155	3	0.700481	3	haptic inte	touch perc	direct skin	skin conta	haptic devi	Collaborative Resea	$320,987.00	24	14921118.33
14	2312154	3	0.712109	4	haptic inte	touch perc	direct skin	skin conta	haptic devi	Collaborative Resea	$321,388.00	24	14921118.33
15	2312153	3	0.715985	5	haptic inte	touch perc	direct skin	skin conta	haptic devi	Collaborative Resea	$557,614.00	24	14921118.33
16	2322284	4	0.767116	1	NA lead	greenhous	ice cover	quantitativ	water qual	Collaborative Resea	$331,771.00	22	15770966.38

This table not only gives us the amount that each of these top five grants per topic are worth, but also the total sum of the topic as a whole and the topic rank based on the total worth of the topic. Placing them from the most and the least amount of money awarded.

LDA Results

Below are the results of the LDA analysis showing the most salient terms within the given year sets. These terms are represented as bar graphs illustrating which terms are prominent within the thousands of grants collected. Within these visualizations, we can see changes within the grants as they are catered towards different research. Following these grants, as a group, we are able to analyze the trends throughout the decade.

Figure 9: 2014-2015

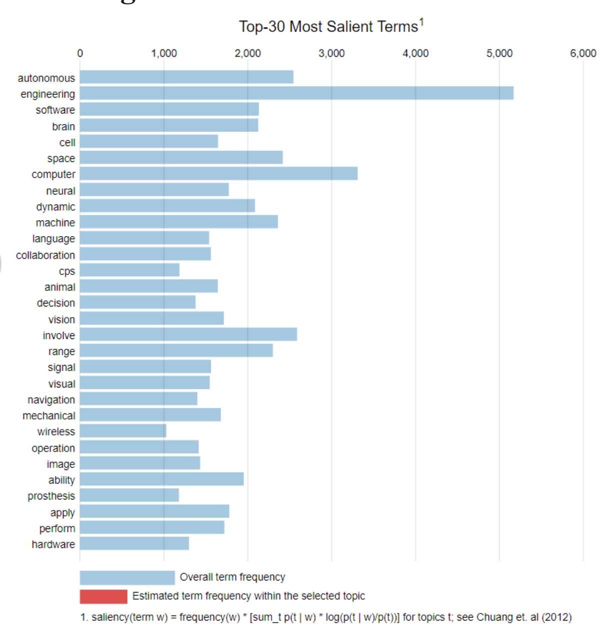


Figure 10: 2016-2017

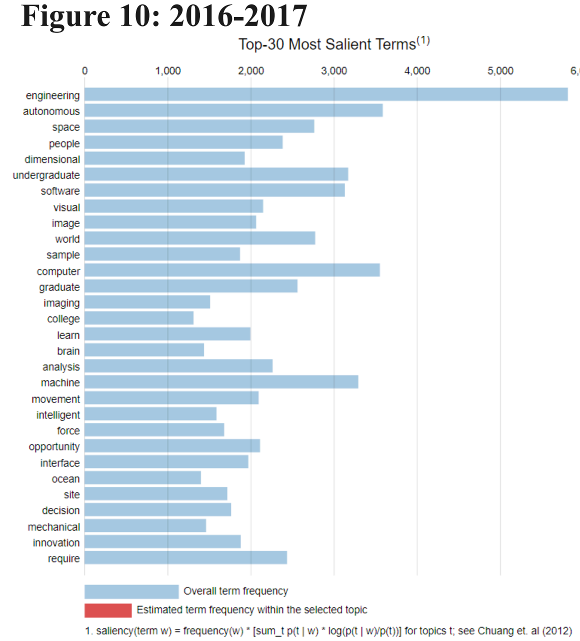


Figure 11: 2018-2019

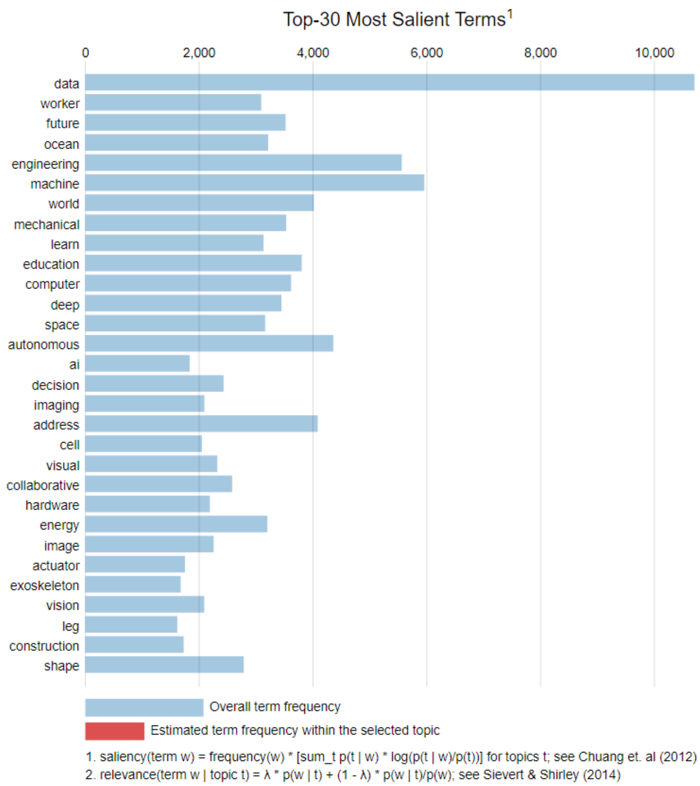


Figure 12: 2020-2021

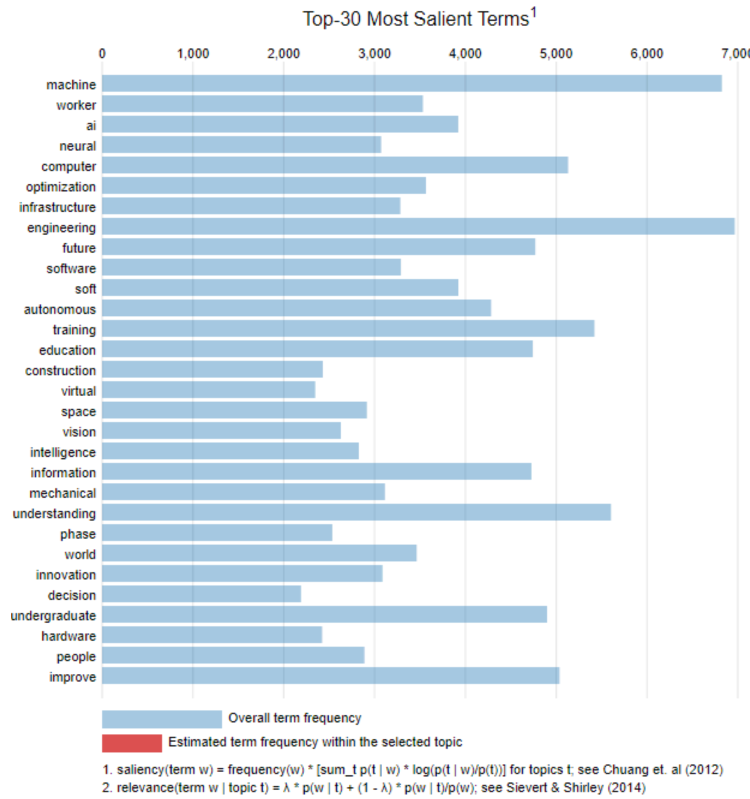
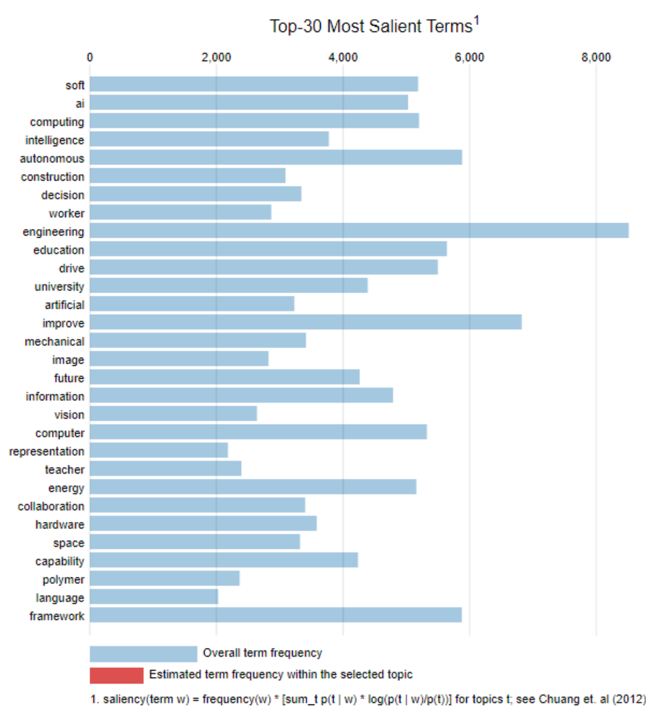


Figure 13: 2022-2023



From these figures, one of the largest increases in salient terms was artificial intelligence as we can see that artificial intelligence is not among the top salient terms within the years of 2014-2017. Artificial intelligence first popped up in the terms in 2018. Artificial intelligence was only referenced around 2,000 times while in the later years of 2023, it was increased to around 5,000 times collectively throughout all of the grants under robotics. Following this trend, we can see that Artificial Intelligence has not slowed down. With that in mind, we can expect it to continue to increase throughout the upcoming years. The fascinating part is that Artificial Intelligence had first popped up in robotics grants in 2018 while the first mainstream artificial intelligence first hit the commercial market on November 30, 2022, in the likes of ChatGPT. In a statement from May of 2018, the director of NSF states, "As we look even further into the future, NSF is supporting fundamental research to bring AI technologies to maturity, thereby enhancing the lives of all Americans." [6] This further illustrates the NSF's focus on increasing artificial intelligence research which coincides with the fast uptick in artificial intelligence being referenced within 2018 robotic grants. From then on, with the success of OpenAI and ChatGPT, others can be persuaded to focus more on artificial intelligence research as it already has proven success with how underdeveloped it is in its current state.

On the other hand, one of the words that had the largest decrease among the salient terms was the term 'brain'. The term brain was only among the top thirty salient terms in the years 2014 through 2017. In our first iteration of the salient terms graph, we can see that 'brain' was mentioned around 2,100 times while in the year set 2016-2017, 'brain' was only used around 1,500 times. From that point on, 'brain' was not included in the top thirty salient terms in the next six years. Brain is undeniably still mentioned within robotic grants in the latter years. However, as topics rise in research popularity, topics can slowly be left behind. Some new words that have appeared since 2018 are ‘future’, ‘ai’, ‘data’, ‘world’, ‘innovation’, and many more. With these added words being a focus on research throughout the years, brain research seems to have slowed down and taken a backseat to other research topics that have become more of a priority.

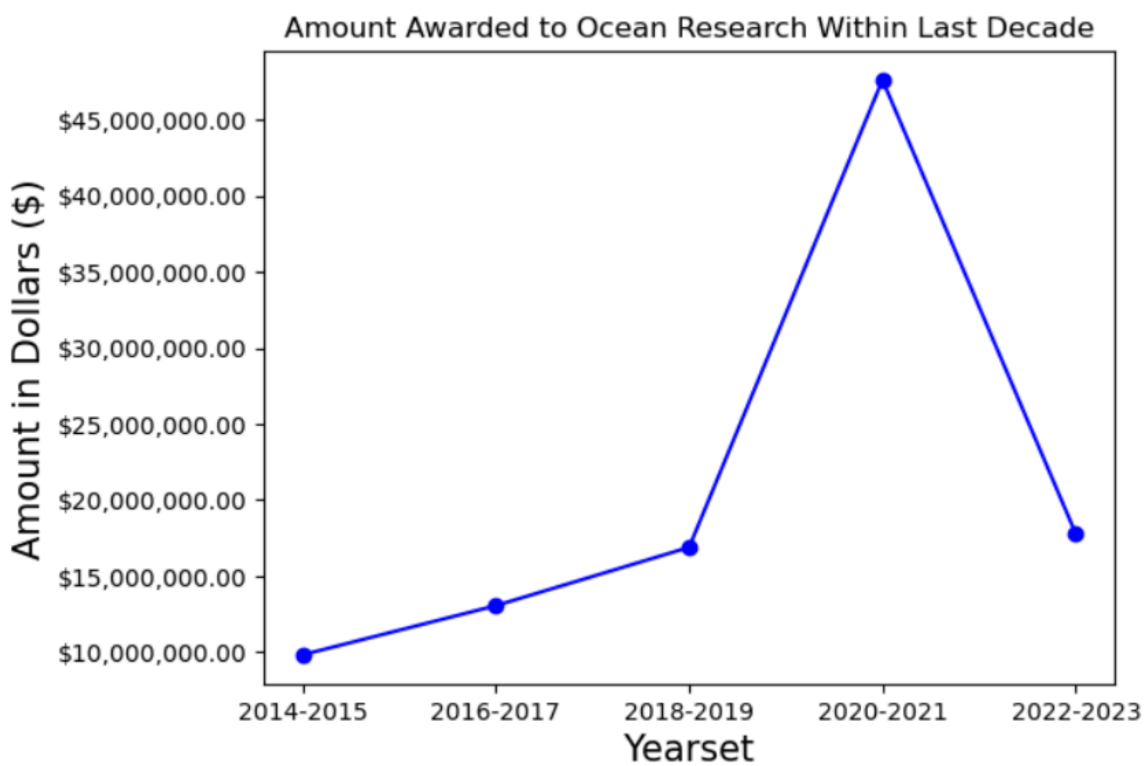
The biggest surprise within the salient terms is the term ‘data’ in the year set of 2018-2019. With the word being used the most, by far, out of any term in any year set, it could just be an outlier. Looking at abstracts, it would make very little sense for ‘data’ to be used over ten thousand times while having a quick drop-off in the later and prior years. With this in mind, as a group, it’s decided to ignore data completely as it doesn’t give us any information on current topics and what research was primarily focused on in that yearset.

As a group, we decided to investigate five topics and their awarded dollar amounts trends throughout the year sets in terms of the total money funded. These topics included: Ocean Research, Biological Human Research, Polymer Research, Artificial Intelligence, and Brain Research. In order to determine what the topics were, we searched through all of the topics in the year sets of 2020-2021 and 2022-2023 and wrote down the top words in terms of salience for each topic. From here, we determined which topics contained the most similar keywords and associated them together as the same topic. Then, we searched the topics of the remaining year sets in order to determine which topics in those years were the most similar to each other.

By plotting the total amount of money funded to each topic across these years, we were able to get a better sense of the trends and future of the relationships between them and the Robotics programs at NSF.

It is important to note that in the ‘COVID year’ in 2020, funding increased astronomically at NSF, this explains why the amount of money funded in these topics had dramatic spikes during 2020 and 2021. Observing the NSF-provided trendlines for their fiscal years, we see a sharp increase in newly funded awards with the 2018-2019 fiscal years only holding 22,967 when compared to the 2020-2021 fiscal years of 23,518 newly funded awards[7]. With this in mind, our group considered the COVID year as an anomaly, so we try to focus mainly on the increase/decrease from the years prior and after 2020-2021.

Figure 14



The figure above shows the amount funded towards Ocean Research in Robotics programs at the NSF across the last decade. The keywords for deciding this topic were: ocean, marine, plant, water, oxygen, and coral. From this, we can see that Ocean Research gained funding steadily from 2014 to 2019, with these increases being around 2.5 million dollars a year. Then, during the COVID-19 year set, funding spiked dramatically, which was expected, then dropped down to around where it was before COVID-19 if not a little more. This illustrates that over the last decade, Ocean Research has gained ground in being associated with Robotics programs at the NSF.

Figure 15

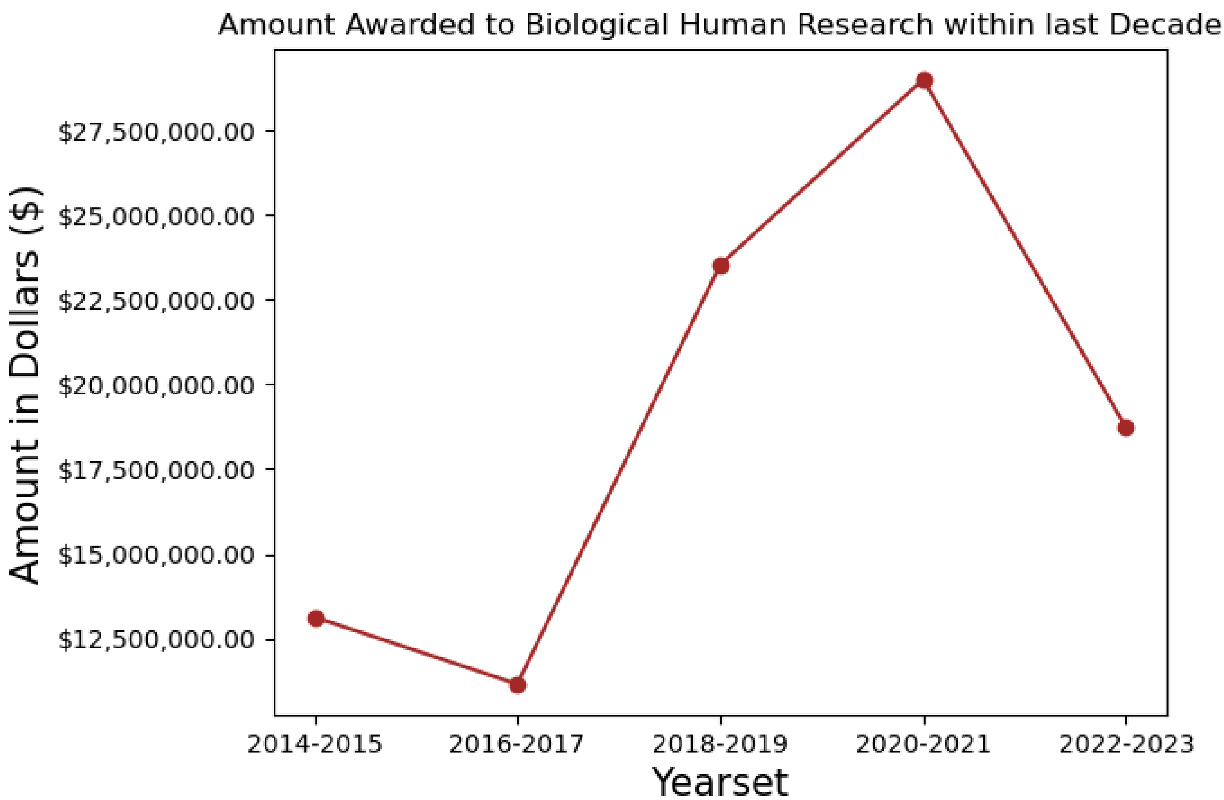
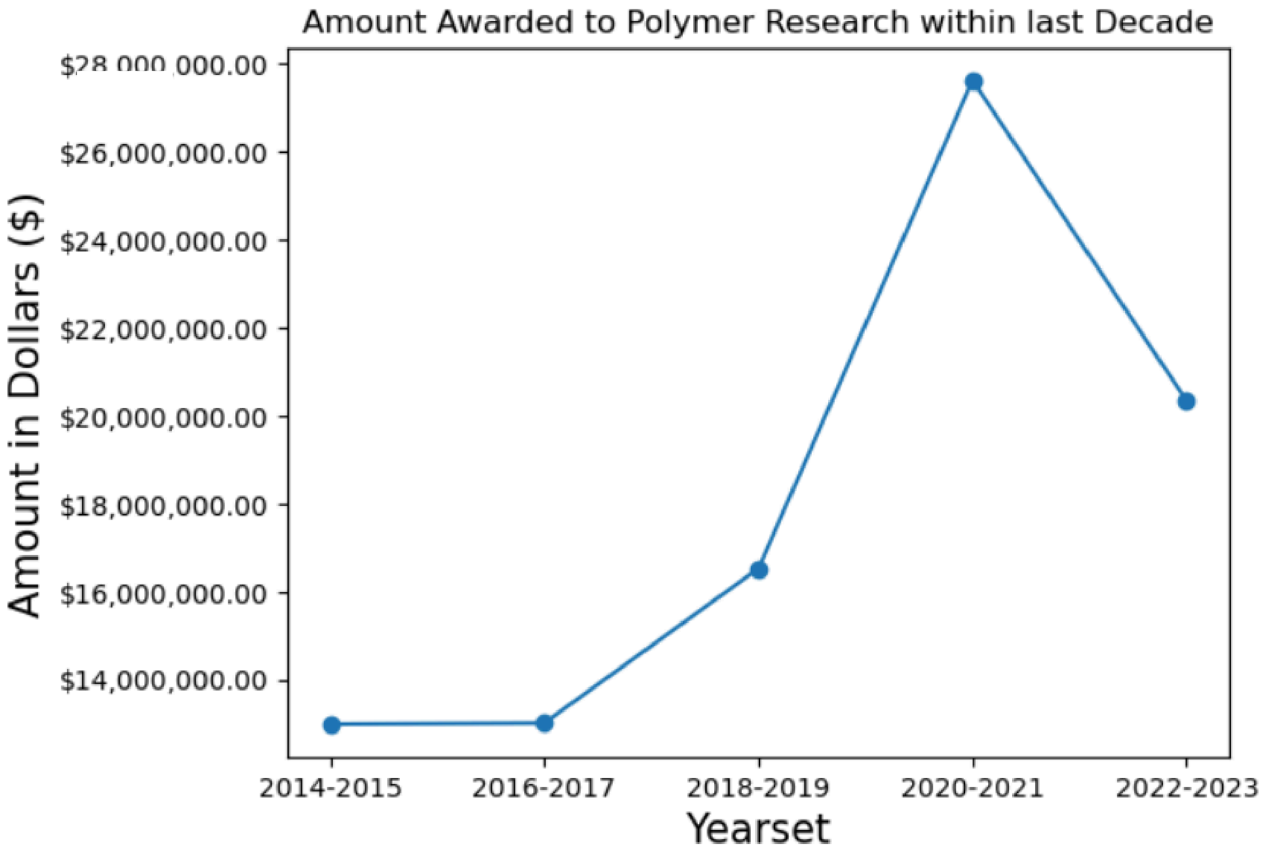


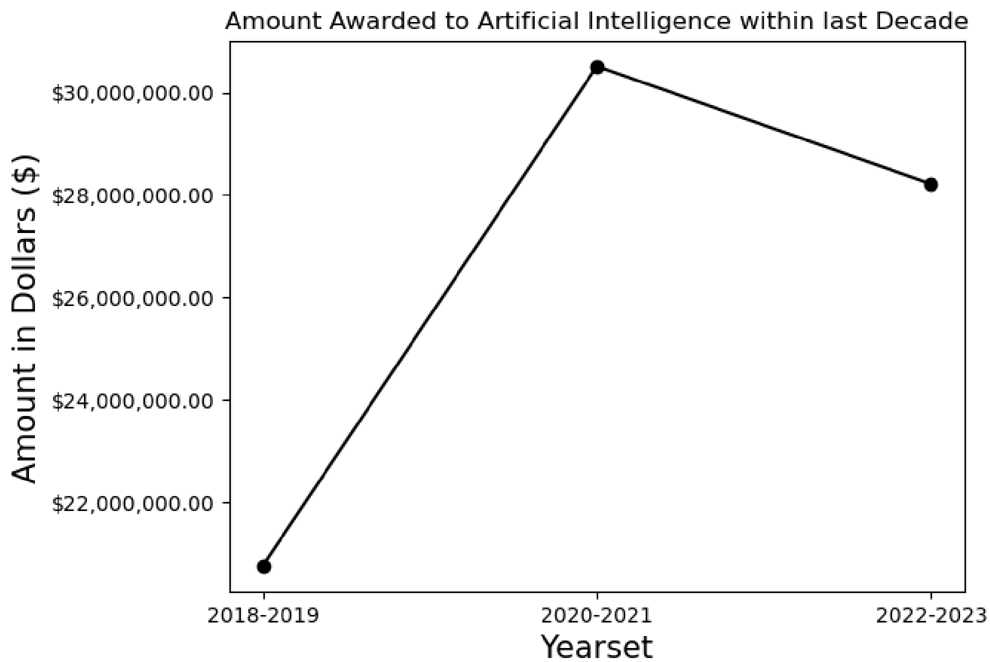
Figure 15 shows the amount funded towards Biological Human Research across the last decade. In terms of Biological Human Research, key terms are: exoskeleton, muscle, joint, limb, rehabilitation, ankle, prosthesis, and fatigue. Thus, according to the plot above, it is evident that from 2014 to 2016, this topic had reduced funding in Robotics programs. Then, in the next two years, funding increased by around 11 million dollars, which shows an increased usage of robotics in this area of research. But after the “COVID spike”, the funding of Biological Human Research decreased by about 5 million dollars, which may lead us to conclude that after 2023, funding for this topic may decrease in Robotics programs.

Figure 16



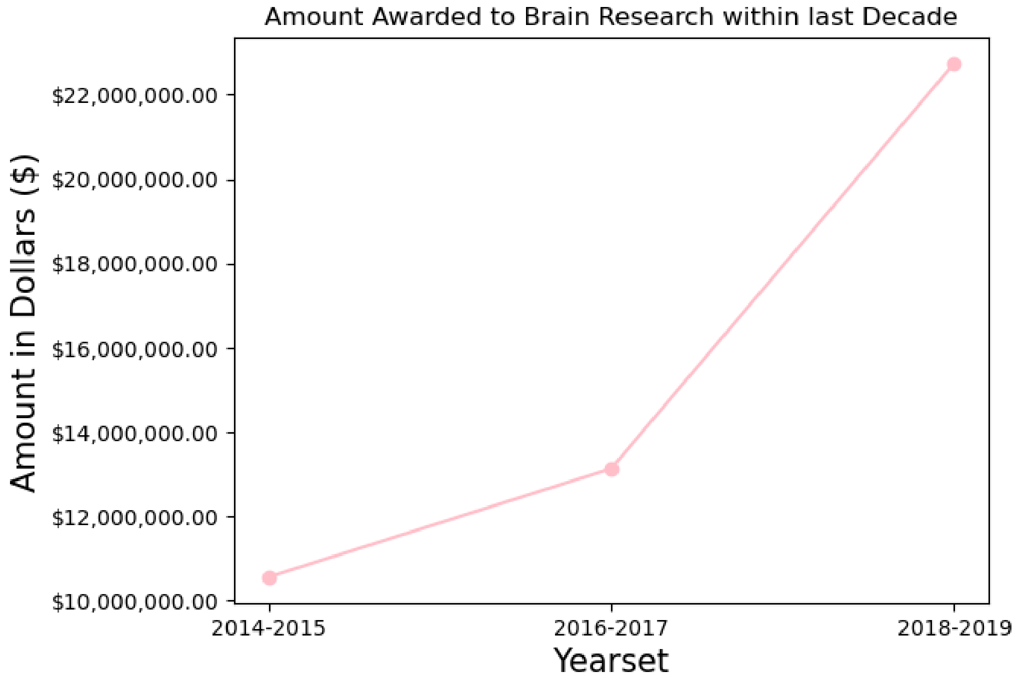
In Figure 16, the last decade of funding at NSF for Polymer Research in Robotics Programs is shown. In terms of this topic, the keywords are: polymer, experimental, additive, chemistry, synthesis, molecular, and energy. From 2014 to 2016, funding stayed at around 13 million dollars, then increased to around 17 million dollars in 2018 and 2019, showing a 4 million dollar increase. After the "COVID spike", funding decreased to around 20 million, which would be 3 million dollars more than it was before covid. This illustrates that funding for Polymer Research in Robotics programs may continue to increase, which can be helpful for researchers in the future.

Figure 17



Above in Figure 17, the amount of money funded for Artificial Intelligence in robotics programs is shown for the year sets from 2018 to 2023. For this topic, key words were: intelligence, computer, infrastructure, artificial, and ai. It is important to note that there was no Artificial Intelligence topic prior to 2018, as it may not have been a common topic being researched using Robotics at NSF. This coincides with our research above, as the NSF started to focus on funding more Artificial Intelligence projects in 2018, and major developments have taken place in this field in much more recent years. It is hard to deny that Artificial Intelligence will be slowing down in funding at NSF, which is especially shown in Figure 17. Funding for this topic was nearly 20 million dollars in the years 2018 and 2019, and after the "COVID spike", it remained quite high at around 28 million dollars. This massive increase in funding from before the spike then after illustrates that Artificial Intelligence may continue to be funded in increasing amounts in the years to come.

Figure 18



For the topic of Brain Research, the keywords are: brain, neuron, neuroscience, neural, signal, stimulus, and cortex. Similar to how Artificial Intelligence was not common enough prior to 2018 to be considered its own topic, the same is evident for Brain Research, prior to 2019. As shown in Figure 18, funding from the NSF for Brain Research was at around 10.5 million dollars in 2014 and 2015 and increased by around 1.5 million dollars in 2016 and 2017. Yet, after the "COVID spike", this topic did not exist anymore, which could be due to one or two things. For one, it may be that the increased funding during the COVID spike did not end in successful results, which may lead to the NSF decreasing the funding in this area altogether. On the other hand, Brain Research may have been maneuvered to other programs at NSF, such as Biology or Chemistry. Either way, it is evident this topic was not of importance anymore after 2019. When looking at grants past the 2019 years, the word 'brain' has only popped up in our topic analysis under ‘chip’, or ‘AI’ which allows us to speculate that the research is catered towards the popular ‘brain chip’ trend.

Thus in conclusion, through analysis, we can predict that Polymer research, Ocean research, and Artificial Intelligence will continue to be funded in Robotics Programs at the NSF. On the other hand, Brain Research and Biological Human Research may experience decreased, or no funding in the future years, especially in Robotics. These are important trends that future researchers must take into consideration when planning their research.

Limitations

Throughout the process of this analysis, limitations arose that hindered the team’s ability to work efficiently, such as the limit in computing power that we possessed. During the stage of the latent Dirichlet allocation analysis (LDA) is a Bayesian network for modeling automatically extracted topics in textual corpora. The LDA analysis code was run in RStudio, and within this code existed a line that contained a rounding function which had taken several hours to run. Because of this, and due to the limited time the group possessed to complete the analysis, there was not much time to experiment with the code. This is because the computing power the team possessed was minimal compared to a supercomputer, which would have run the code much faster. In addition, another limitation the group encountered was time itself. Since there were only a few months to run this analysis, the group was unable to extend this research past the LDA analysis. Finally, the LDA analysis relies on single words being pulled from the abstract, which may hinder how the program finds overlapping topics. The analysis is not capable of pulling out phrases like ‘neural network’ which would correspond to the topic of Artificial Intelligence. Single words may be considered too vague as well, as words like ‘network’ can appear in phrases like ‘neural network’, ‘social network’, and ‘network engineer’, all of which would indicate separate fields of research. This caused words like ‘network’ to be excluded for their ambiguity.

Conclusion

As this research is the first of its kind we believe that there are many possibilities in the future to expand upon our existing findings. Future research can expand upon our findings specifically in regards to robotics, but we are confident that these steps outlined above can be replicated for other grant topics such as Artificial Intelligence. Deeper analysis can be conducted on our data as well, such as finding the distribution of grants and funds per capita to get a better understanding of which states are most successful. Following the steps outlined and expanding upon them can enrich other research groups in predicting the future, while also displaying trends within accepted grants. We are aware of possible improvements to the research and overall process of configuring the data, the most apparent being the utilization of a Discriminant Correspondence Analysis instead of the LDA analysis if required since the research being conducted focuses on categorical variables but in the future tests could need to utilize nominal data. Changes in the bank of stop words may also be made to make the results more realistic. In addition, the determination of topics worked for this instance but due to lack of time, it was rather subjective. Thus, in order to have a more indepth determination of topics in further research, a correlation analysis could be done. This analysis is done by placing the topic numbers of all the topics in one yearset on the left side and placing the topic numbers of all topics in another yearset on the top. From here, the number of similar words in each topic would be written down, making the intersection of two topics a representation of how similar they are to one another. Thus, the topics with the highest number of similar words will be the same topics. Lastly, if our group had the opportunity, we would like to do a more in-depth financial analysis.

We view this paper and experiment to be successful in highlighting rising topics within the field of robotics. We believe this will allow organizations and future researchers to distinguish emerging topics and trends that will make them more confident in their search for funding.

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