IMSA
Illinois Mathematics and Science Academy

2023-2024

Student Research Projects

AI & MULTI-AGENT SYSTEMS

Heterogeneous Multi-Agent Reinforcement Learning for Last-Mile Delivery Optimization

by Aaditya Shah '25
Mentor: Professor Ankit Agrawal, Saint Louis University Human Computation Lab

The last-mile delivery, or the final leg from distribution centers to customer doorsteps, poses significant logistical challenges. The implementation of autonomous delivery vehicles (ADVs) emerged as a possible solution, with Multi-Agent Reinforcement Learning (MARL) algorithms being used to optimize the delivery through coordination between multiple autonomous vehicles. These algorithms define a reward function and let agents learn through observation; however, their inability to account for diverse delivery vehicles hinders their effectiveness.

Existing algorithms often struggle with inherent heterogeneity, potentially leading to suboptimal delivery routes and delivery cost increase. In this project, we propose H-MARL, a novel MARL algorithm specifically designed to work with heterogeneous agents like cars and drones. H-MARL accounts for diverse delivery vehicles and enables coordination between them.

Through comprehensive computer simulations in a real-world urban city environment, we demonstrate that H-MARL enables significantly faster deliveries compared to traditional MARL approaches, minimizing delivery times while navigating obstructions and avoiding collisions. The proposed algorithm provides a promising solution to the logistical challenges of last-mile delivery. The results of this study have potential applications in the use of autonomous vehicles delivering goods in urban areas, reducing delivery times and increasing efficiency.

BEHAVIORAL SCIENCE

Exploring the Correlation Between Absence of Linguistically Aligned Mental Health Resources and Adverse Teen Outcomes in Chicago Neighborhoods

by Ashley Hernandez '24
Mentor: Dr. Riley Tucker, University of Chicago, Environmental Neuroscience Lab

Chicago southside neighborhoods serve as examples of systemic underfunding and enforcing an environment where youth risk not succeeding. The youth in these neighborhoods are both Latinx and Black and they face the reality of not having proper educational resources and the trauma that comes from gang violence within these neighborhoods. We have developed the research questions of understanding if Chicago neighborhoods have more negative teen outcomes when mental health resources aren't offered in the main language of the neighborhood. Negative teen outcomes are defined as undesirable circumstances, behaviors, or consequences that impact teenagers and hinder their well-being, development, and overall chances of success.

The quantity and quality of neighborhood resources provide insight into how youth are supported. A properly funded neighborhood offers individuals support that will set them up for success. As lower-income neighborhoods lack mental health resources among other inequities such as language barriers, this may lead to negative teen outcomes. In this study, participants ages 12 to 19 will be gathered for surveys aiming to attain information on language prevalence within their neighborhoods and their awareness of local mental health resources. The surveys will ask about the languages spoken in the community and the frequency of their usage. Additionally, publicly available data on current mental health resources will be analyzed, focusing on the languages offered. The anticipated results include insights into how language diversity influences a teen's access to services.

COMPUTER SCIENCE

Mixed Reality and Applications

by David Weng '25
Mentor: Elahé Soltanaghai, University of Illinois Urbana-Champaign

This study delves into the nuanced realm of mixed reality, often confused with virtual or augmented reality. Unlike the latter two, mixed reality seamlessly integrates virtual elements with the physical world, allowing each to influence the other. A notable application involves employing mixed reality headset-mounted cameras to detect diet-related activities in real time. The system, supported by the Internet of People (IoP) and user-centric applications, actively encourages informed nutritional decisions based on recorded camera data. Providing personalized dietary suggestions by integrating with other technologies, this example highlights how mixed reality's utility. Our exploration focuses on its practical applications and capitalizing on the technology's limitless potential.

Recently, many companies have begun to embrace mixed reality, with a notable example including Meta AI's release of headsets. Gaming companies have also taken an interest in mixed reality, as demonstrated in a project controlling robots with Raspberry Pi for enhanced artificial intelligence. The study was presented at the Iberian Conference of Information Systems and Technologies and showcased an interactive team-based game with projected maps, emphasizing human engagement and monitoring accessibility. Furthermore, web content has also started to have a physical impact, as web content is becoming streamlined with the implementation of Extended Reality Web Browsers.

In essence, mixed reality exhibits vast potential, extending beyond gaming to improve existing systems to improve society. Our research contributes to the scientific discourse by exploring the multifaceted applications of mixed reality, highlighting its capacity to enhance technologies and foster innovative solutions that positively impact society.

BIOCHEMISTRY

Determining the Effect of Retained Introns on Neuronal Cell Development

by Joshua Mu '25
Mentor: Dr. Jingyi Fei, University of Chicago, Fei Lab

In mammalian systems, mRNA transcripts comprise a combination of introns and exons. Within the nucleolus, splicing allows for the cutting and recombination of mRNA transcripts to generate multitudinous mRNA sequences composed only of exons. However, introns are sometimes retained in the final mRNA transcript, resulting in intron-mediated gene regulation that includes nonsense-mediated decay and translation failure.

With new advances in sequencing techniques, mammalian systems have become a key focus in the study of retained introns. Recent analyses have indicated intron retention as a key component of gene expression in response to stress and disease, regulating expression via intron-mediated protein production, RNA stability, and translation efficiency. In mouse embryonic cells, retained intron regulatory schemes switch between cell development stages, indicating the role of retained introns on the cell development cycle. This form of gene expression can be mediated by the nuclear speckles, organelles enriched in snRNPs and other non-snRNP splicing factors that play an important role in gene expression.

This investigation aims to determine how nuclear speckles influence gene expression in neuronal cells via retained introns, influencing their development. Nuclear speckle reads obtained from neuronal and progenitor cells via Illumina next-generation sequencing were pre-processed using Cutadapt and STAR. The next step in this investigation will be to determine the specific retained introns and experimentally verify them.

ENGINEERING

Water Filtration with Ionic Silver Treated Proteins

by Joshua Solone '24
Mentor: Dr. Mark Carlson, IMSA

Clean, drinkable water is a necessity that the developing world does not always have. As of 2021, up to 2 billion people are at risk for disease and death due to waterborne bacteria according to the World Health Organization. Current water purification systems are too expensive, not reliable, or intended only for emergencies.

This investigation aims to develop a water purification system that reduces the bacterial load by 90%, provides 40 L per day, and costs less than $20 per year. Ionic silver was chosen due to its modest cost, killing efficacy, and relative safety for consumption. Biological proteins containing disulfide linkages provide a means to harbor silver ion which can interact with passing bacteria without being washed away by the effluent water. Bone marrow and egg albumin have been investigated with the latter showing greater promise to create a semipermeable plug at the end of a plastic pipe.

To quantify the performance, a solution of weakened E. coli is loaded into the pipe and percolates through via gravity. Colony counts on agar plates are done with the effluent water and compared to those of the initial solution. bacterial solution will be treated by the filter, and then plated and cultured. Currently, silver nitrate concentration and albumin heating conditions are being optimized to achieve best performance while maintaining structural integrity.

ENVIRONMENTAL SCIENCE

Effects of Sunscreen Chemicals on Freshwater Algae

by Gwendolyn Olney '24 and Eliana Nungaray '24
Mentor: Dr. Jessica Amacher - IMSA Staff,
Ms. Sarah O'Leary-Driscoll - IMSA Staff,
Dr. Melissa Lenczewski - Northern Illinois University Staff

In areas with high tourism, the negative impacts of sunscreen on aquatic life are heightened. One area in particular that our group is focused on is the cenotes in the Yucatan region of Mexico, a water source for the cities surrounding the region. A cenote is a sinkhole that is created naturally due to limestone collapsing and exposing the groundwater below. This is an area in which large amounts of tourists regularly swim and distribute their sunscreen by default. The sunscreen's chemicals are distributed in the water after just one person comes in, as well as the runoff from the sand areas. The water being exposed to the harmful chemicals within the sunscreen can negatively affect aquatic life in these areas. In places without adequate water filtration, these chemicals could potentially spread to water used by citizens.

We are researching the specific chemicals in reef-safe as well as traditional sunscreens in order to gain a better understanding of the human impact on ocean chemistry and its effect on biological systems. Since the research regarding the effects of sunscreen on the coral reefs has been expanding, it is crucial that our research mainly focuses on the impact of the harmful sunscreen chemicals on freshwater ecosystems. In this case, the focus is on algae, which currently holds a lesser amount of scientific research.

MEDICINE

Promoting Contact Inhibition: Role of Desmosomal Protein Upregulation in TNBC Cells

by Jaden Blankenship '25
Mentor: Dr. Richard D. Minshall, University of Illinois at Chicago

The primary objective of cancer therapy is the prevention of metastasis, a complex process involving the dissemination of cancer cells to distant organs. In late-stage breast cancer metastasis, a crucial regulatory determinant is Caveolin-1 (Cav-1), functioning as a structural membrane and scaffolding protein. Recent studies demonstrate that the dephosphorylation of Cav-1 results in its dissociation from β-catenin, causing β-catenin to accumulate at the plasma membrane where it can interact with integral membrane proteins.

In this context, β-catenin plays a crucial role in fostering the assembly of cell-cell and cell-matrix adhesion complexes by interacting with desmosomal, adherens junction, and focal adhesion proteins. In the current study, we show that the dephosphorylation of Cav-1 upon activation of the potassium channel Kv11.1, which is expressed in MDA-MB-231 triple-negative breast cancer cells (TNBCs), promotes contact inhibition through the upregulation of desmoglein and other desmosomal proteins. The increased concentration of the desmosomal proteins contributed to an increase in cell-cell and cell-matrix adhesions and promotes contact inhibition, as the cell has a higher concentration of proteins that control the growth rate of a cell.

Thus, this study unveils an innovative pharmacological mechanism that promotes contact inhibition via Cav-1 dephosphorylation, which holds great promise in curtailing metastatic processes and promoting contact inhibition. These findings provide compelling prospects for the development of targeted therapies against late-stage breast cancer metastasis, with a specific focus on Kv11.1 activation and its influence on cell-cell and cell-matrix adhesion complexes.

MEDICINE

5-hydroxymethylcytosine and TET Enzymes in Neuroblastoma

by EmmaLi Isham '25
Mentor: Dr. Mark Applebaum, The University of Chicago

Neuroblastoma is the most common extracranial solid tumor in pediatric cancer. The most malignant of these tumors have an amplification of the MYCN oncogene which correlates with poor prognosis and metastasis. When a hydroxymethyl group is added to a cytosine, 5-hydroxylmethylcytosine (5-hmC) is generated. 5-hmC promotes an "open" or active state of the chromatin. The addition of this hydroxyl group is facilitated by Ten-Eleven Translocation (TET) proteins. 5-hmC and H3K27me3, the catalytic product of PRC2, directly co-localize in MYCN-amplified neuroblastoma.

Although 5-hmC is traditionally associated with open chromatin, its presence alongside H3K27me3 presents the transcriptional repression of both genes. The inhibition of 5-hmC deposition leads to a loss of the repressive H3K27me3 mark. In neuroblastoma clinical cohorts, the low expression of these co-localized genes was revealed to have a strong negative effect on patient prognosis in MYCN-amplified neuroblastoma. We identified that upon activation, 5-hmC aberrantly recruited PRC2 and these cooperative mechanisms resulted in the repression of gene expression. Understanding these mechanisms would allow us to target pathways that promote aggressive neuroblastoma. We began knocking out the TET proteins, beginning with TET 1 and TET 3 as they are the most expressed.

However, the change of 5-hmC expression did not prove statistically significant, and it is hypothesized that TET 2 may be compensating for the loss of TET 1 and 3. As a result, our next step is to perform a triple TET1/2/3 knockout using a CRISPR/Cas9 system.

MEDICINE

Monobenzone and its Potential as a Treatment for Melanoma

by Jongwoo Kim '25

Mentor: Dr. Caroline Le Poole, Le Poole Labs, Feinberg School of Medicine at Northwestern University

MBEH has been proven as a treatment for Vitiligo, an autoimmune disorder that causes patches of skin to lose pigment or color. This is caused by the lack of a pigment called melanin in the skin. Melanin is produced by skin cells called melanocytes, in vitiligo, there are not enough working melanocytes to produce enough melanin in the body. This causes white patches to develop on the skin or hair. In one form of treatment for this disorder, MBEH was successful in killing off other melanocytes in the body to bring the skin to a unified pigment.

The successful implementation of MBEH begs the question "Will MBEH be effective in stopping Melanoma cells?" Melanoma is a type of skin cancer that develops when melanocytes grow too fast for the body to control. As MBEH has proven to be effective in killing melanocytes before, there is definite room for research and inquiry into whether it can be used to kill cancerous melanocytes.

This project involves the testing of MBEH and its derivatives which will be packaged in nanoparticles for enhanced trafficking to tumor cells to test for cytotoxicity to melanoma cells in vitro and in vivo. The project will also use cytotoxicity assays using the Inucyte platform, a measure of uptake of fluorescent particles by FACS, and tumor challenge and growth measurements. Overall, the research to test the cytotoxicity of MBEH and its derivatives will provide substantial research in the ongoing search for a treatment for Melanoma.

MEDICINE

Drug Discovery: IMSA

by Kosi Okeke '24

Mentor: Dr. John Thurmond, IMSA

Leishmaniasis is a disease caused by parasites of the Leishmania genus. The disease is prevalent in tropical and subtropical regions, such as parts of Asia, Africa, the Middle East, and Latin America. Leishmaniasis is caused by the bite of infected sandflies, which transmit the parasites during their blood-feeding process.

It starts out with an infected sandfly biting a mammalian host, introducing the Leishmania parasites into the bloodstream. Once in the host's bloodstream, the parasites invade and replicate within macrophages, the immune system cells. When another sandfly bites an infected host, it ingests the parasites along with the blood, becoming infected. The infected sandfly then transmits the parasites to a new host during its next blood meal, continuing the cycle. Leishmaniasis is not directly transmitted from person to person, and human-to-human transmission is rare. The risk of contracting the disease is influenced by factors such as environmental conditions, the presence of reservoir hosts, and the density of sandfly populations in specific regions.

The purpose of our study is to understand the biology of the Leishmania parasites and identify specific proteins or pathways essential for their survival and replication within the host. We also synthesize new compounds in search of a cure for Leishmaniasis by combining an amine and an acid to develop new compounds that had not been tested before. After developing a variety of compounds by combining acids with amine, we tested them to see how much of a pharmaceutical benefit they can have in battling Leishmaniasis.