# UMBC REVIEW

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## Journal of Undergraduate Research

# UMBC Review

Journal of Undergraduate Research

**EDITORS**
Irina Sbornova
Clair Volkening

**JUNIOR EDITORS**
Oliver Santos
Madelyn Pollack

**DESIGNER**
Jordan Fisher

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# UMBC Review

## Journal of Undergraduate Research

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# Editors' Introduction

**Welcome to the 24th volume of the *UMBC Review: Journal of Undergraduate Research*!**

The *UMBC Review*, now into its third decade of publication, offers a priceless opportunity for undergraduate students to showcase the results of their academic journey. As the world recovers from the COVID-19 pandemic, each of our authors continues to relentlessly pursue their passion for knowledge and discovery. It is with great pleasure that we, the editors, present to you the following nine exemplary articles produced by our undergraduate researchers.

As an interdisciplinary journal, the *UMBC Review* is a collection of outstanding works of authors from any and all majors and, in this volume, you will find just that! We begin with **Simon Maxwell's** discussion of the current state of mathematics and machine learning. Continuing with this theme, **Edward Humes** shows us how computer science can be applied to engineering while **Nithya Navarathna** bridges the gap between computer science and cancer treatment. Extending the relationship between mathematics and biology, **Christina Dee**, **Meghan Kwon**, and **Julia Neylan** introduce a novel model of cell migration, whilst **Esther Olajide**, **Irina Sbornova**, and **Madi Kore** examine how breast cancer tumors affect surrounding tissues.

On the Humanities and Social Sciences side, **Joshua Gray** illustrates the importance of crisis communication during emergencies like the COVID-19 pandemic while **Will Murphy** presents a feminist critique of the 1976 film *Carrie*. Finally, **Alexa Smith** tackles the history of the Ku Klux Klan in small town Maryland and James Angle digs deep into how we stereotype sexuality. These authors offer new and insightful research that advance their respective fields and contribute to our understanding of the changing world around us.

While this publication is crafted entirely by undergraduate students, all articles are held to the same standard as other established research journals. Each paper underwent rigorous peer review from off-campus professionals and multiple rounds of revisions based on feedback from the editors. Being published in the *UMBC Review* is an honor only a few UMBC students will receive and we are pleased to be sharing their work with you. We invite you to join us in celebrating the curiosity and creativity embedded in each of these papers!

# Meet the Authors

**Science, Technology, Engineering, and Mathematics (STEM)**

**Simon Maxwell** reviews the invasion of pure mathematics and proof-writing by machine learning and how an inclination to default to computers in solving problems leads to a lack of generalizable and useful solutions to broad-reaching questions.

**Edward Humes** addresses the challenges of integrating deep neural networks into autonomous aerial devices in a cost- and energy-efficient manner by examining how different factors necessary for obstacle detection and avoidance can be manipulated to enhance performance.

**Nithya Navarathna** merges the disciplines of computer science and biology by investigating how machine learning and recurrent neural networks could be utilized to improve the efficacy and accuracy of the proton beam therapy for cancer treatment.

**Christina Dee**, **Meghan Kwon**, and **Julia Neylan** meld mathematics and biology to create a simulation of the movement of cell clusters within the egg chamber of the *Drosophila melanogaster*, also known as the fruit fly.

**Esther Olajide**, **Irina Sbornova**, and **Madi Kore** examine the ways in which triple-negative breast cancer alters the size of adipose cells in breast tissue using an *in vivo* mouse model.

**College of Arts, Humanities, and Social Sciences (CAHSS)**

**Joshua Gray** explores the University of Maryland, Baltimore County's (UMBC) response to the pandemic, highlighting where UMBC and other institutions succeeded in crisis communication and offering thoughts on improved strategies for future use.

**Will Murphy** dives into the relationship between the horror genre in film and the presentation of the female body as something to be feared, examining the 1976 film *Carrie* in a detailed case study.

**Alexa Smith** discusses the history of the Ku Klux Klan in the small town of Braddock Heights, Maryland, examining the Klan's various resurgences in the area during the 1970s and 1980s.

**James Angle** examines the way speech features are used to make judgements about the sexuality of Spanish-speaking men and the characteristics that are commonly ascribed to men assumed to be gay.

# Acknowledgments

Faculty advisors play an essential role in the process of creating ideas and publishing research at the *UMBC Review*. From assisting the student author in developing their research and writing their paper to working with the student editors to adapt the submission to the requirements of our journal, these advisors have been critically important in creating this publication.

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**Dr. Bradford Peercy** – Department of Mathematics and Statistics

**Dr. Nykia Walker** – Department of Biological Sciences

**Dr. Fan Yang** – Department of Media and Communication Studies

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**Dr. Herbert Levine**

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We believe that the research published in this twenty-fourth edition of the *UMBC Review* is emblematic not just of the brilliance of the UMBC community, but also of its determination and perseverance. At UMBC, we refer to these qualities collectively as "grit." It is the grit of the UMBC community that has enabled the *UMBC Review* to thrive as an interdisciplinary journal and publish 232 phenomenal articles by undergraduate students. During the 2022-2023 academic year, the UMBC community has had the privilege of welcoming Valerie Sheares Ashby as our new university president. Under her leadership, the UMBC community has continued to demonstrate its grit, rising to meet the challenges of a world that is vastly different from what it was a mere three years ago.

President Sheares Ashby joins the UMBC community at a pivotal time. Last year UMBC gained R1 status, the highest designation a research university can receive. Additionally, President Sheares Ashby steps into her role as leader of the UMBC community as the majority of classes and student organizations are returning to campus. Her grit and enthusiasm in the face of uncertainty have been an inspiration, and her commitment to education and research embodies the values we hold so dear at UMBC. With the support of President Sheares Ashby, the *UMBC Review* is ecstatic to continue its commitment to honoring exemplary undergraduate research conducted by members of the UMBC student body.


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**Simon Maxwell**

Mr. Steven McAlpine

**Individualized Study Program, Mathematics, Philosophy**

# An Inconvenient Proof: A Testimony to Math's Deductive Spirit

# Biography

**Simon Maxwell** is a J.D. candidate at George Washington University Law School and an IP Legal Intern at Jones Day. Simon graduated from UMBC with a dual degrees in mathematics and interdisciplinary studies and a minor in French. During his undergraduate career, he was a member of the Honors College and the Math Team, and worked as a Quality Specialist for a COVID-19 diagnostics startup. By synthesizing public health, biotechnological, and legal studies, Simon hopes to address emerging issues in intellectual property, FDA regulation, and other critical issues of public health concern.

Simon would like to thank his research mentor Mr. Steven McAlpine for his unwavering support and encouragement. Additionally, he thanks Dr. Manil Suri and Dr. Freeman Hrabowski for imparting their love of mathematics and history.

# Research Journey

Mathematician and educator Junaid Mubeen stated that *"No study of mathematics can be considered complete without attention to its history"*. Historical context has always been a prerequisite for genuine understanding; as humans, we intuitively explore patterns of cause and effect that render the present.

So, naturally, when mathematics is decoupled from its pedigree, it becomes foreign and unrelatable. Negative perceptions of math are largely attributable to a flawed educational system that mongers "drill-and-kill" pedagogies and anesthetizes students to the joys inherent in mathematical discovery. Our modern curriculum, in an attempt to simplify mathematics, reduces the subject to a list of rules, and thereby fails to either enhance a proper understanding of the underlying concepts or provide intellectual challenge. Many teachers struggle to escape this mindset and imbue their students with an appreciation of abstract concepts and problem-solving.

It is important to humanize mathematics and reaffirm the traits of hard-work and persistence in those who practice it. Mathematicians should revel in engaged exploration and adventure — dismissing simplistic dichotomies of failure and success. For example, rather than taking the Pythagorean Theorem as a given, educators could try humbling its beginnings to hazardous conjecture by ancient geometers. And only by work, frustration, disappointment, and epiphany was a definitive proof obtained hundreds of years after its introduction. Let us embrace the reality that *"the process of mathematical discovery is messy and uncertain, even if the end result appears clean"* (Mubeen).

# Abstract

The embrace of deductive reasoning during the Classical Era redefined epistemology, promoting our notion of mathematical truth from that of empirical science to a quasi-sacrosanct standard characterized by elegance, permanence, and logical consistency. Recently, the advent of high-speed computers has enabled software programs to perform lengthy, enumerative proofs-by-exhaustion, while expert systems that emulate human decision-making have demonstrated the capacity to form novel inferences. While artificial intelligence has immense potential to accelerate knowledge acquisition, casual embrace of automated theorem proving may jeopardize mathematics' intellectual foundations.

# The Evolution of Standards

Over the course of human history, experimentation and inductive reasoning have been the primary tools through which knowledge is acquired. These processes are instinctual manifestations of our biological capacity for inference: we form observations using our physical senses and conduct risk assessment by employing our intuitive grasp of probability. As useful patterns emerge, they are monitored, probed, and gradually accepted into a body of conventional wisdom that is transmitted to future generations. Prior to the modern conceptualization of mathematics by the Ancient Greeks – as a descriptive science linking abstract objects together through deduction – the discipline was treated empirically like any other. This resulted in a latent period of mathematical activity during the pre-Classical era, in which accountants and metrologists curated a patrimonial collection of practical (though largely unexamined) conjectures and numerical operations (Kline 23).

Whether due to a lack of tangibility or conventional testability, the pedagogical treatment of math was that of a practical aid which, outside of a narrow range of applications, amounted to little more than gee-whiz, esoteric geekery. The arithmetic, algebraic processes, and geometrical rules developed by Babylonian and Egyptian civilizations were the end result of physical evidence and trial and error, characterized by minimal explanation or synthesis. That the methods worked was sufficient justification for their continued use. The concept of proof, the notion of a logical structure based on principles warranting acceptance on one ground or another, and the consideration of questions such as under what conditions solutions to problems can exist, had not yet been established.

A paradigm shift was precipitated by the Greeks' fascination with philosophy and their eschewal of commercial preoccupations (thanks to a vast and supportive slave class). Plato's Theory of Forms coupled with the Socratic method unlocked a powerful frame of reference from which Greeks could derive new information from nothing but pure thought. Mathematics became in vogue as the potential for establishing abstract and solipsistic structures was realized. Driven by their new aesthetic, the Greeks sought to decouple math from its "crudely practical" origins and refined the discipline through a rigid style of emerging formalistic beliefs. Stripping formulae of all worldly context, Hellenistic ideology "removed mathematics from the carpenter's tool box, the farmer's shed, the surveyor's kit, and installed it as a system of thought in man's mind. Man's reason, not his senses, was to decide henceforth what was correct" (Kline 30).

While statistical inferences and heuristic techniques are fundamental and necessary for human intellectual expansion, the emergence of deductive reasoning completely redefined epistemology, promoting our notion of mathematical truth to a quasi-sacrosanct standard characterized

by elegance, permanence, and logical consistency. With the recent advent of high-speed computers, the achievement of a new paradigm in mathematics may be ascribed to the development of machine-assisted theorem-proving, in which computers are programmed to perform lengthy, enumerative proofs-by-exhaustion. Expert systems that emulate human decision-making are even capable of forming novel inferences.

These computational techniques admit quasi-empirical inductive methods into mathematical arguments by relying on probabilistic reasoning — prompting discussions about the intellectual viability of so-called "experimental" mathematics. Many post-humanist philosophers, who welcome a world of pattern recognition and big-data divination, dismiss what they consider to be a naïve and anachronistic commitment to traditional proof. While techno-cultural shifts make the adoption of computational tools by the mathematical community inevitable, a casual embrace of automated theorem proving may jeopardize its intellectual foundations. We cannot relax our standards to the point that we forfeit any appeal or due process against algorithmic decrees. Limits of use should be imposed to ensure that artificial intelligence is only used to subtend our own – not replace it.

# Silicon Mathematicians

For mathematicians, the advantage of operating in a deductive setting is that (provided sound logic is employed) the validity of a conclusion is guaranteed. This quality endows mathematics with a privileged level of certainty that is inaccessible to the natural science disciplines. While analytic theorems may occasionally be generalized or reclassified to bridge mathematical domains or adapted for a particular audience, their results have nonetheless remained intact since their inception, preserved by their proofs. This contrasts sharply with the empirical sciences: no matter how overwhelming and incontrovertible the evidence supporting a particular hypothesis, scientific theories are subject to constant scrutiny and revalidation, as obligated under an open-world assumption.

In the modern era, a recent quantum leap in computing efficiency has led to the proliferation of artificial neural networks (ANNs), which have become universally adopted by mainstream society and applied to every conceivably compatible intellectual task, including speech recognition, computer vision, systems analysis, medical diagnosis, art creation, and myriad other uses (Lynch 383). As ANNs' range of utility continues to expand, researchers speculate whether these unsupervised algorithms challenge our embedded assumptions about the nature of knowledge acquisition and mathematical certainty (Moller & Vuik 263). ANNs enable software to analyze data and derive solutions to problems in a parameter-free setting, whereby models are self-generated and optimized independent from human input.

Critically, the thought process employed by machine learners does not closely resemble that of its human counterpart. For example, AlphaGo, Google's dedicated Go-playing computer, is not guided by top-down, general principles of good play; rather, its "intelligence" originates bottom-up from a complex parallel processing system composed of layers of interconnected, artificial neurons (Bringsjord & Govindarajulu 185). Via a recursive training process that verifies the program's model against millions of data points, a feedback loop modifies the strength of each interneural connection in order to reduce the error between output and target vectors. Eventually, a pattern emerges through the median equalization of diverse tendencies: this amounts to the network achieving its designated objective (Lynch 384).

The justification for any computer-generated result, therefore, only exists as an incomprehensible contingency of interdependent synaptic weights that have been refined over countless generations of backpropagation. ANNs' approach to reasoning inverts human convention: rather than reducing a system's complexity so as to derive a simplistic (yet generalizable) set of axioms, computers are free to produce models as large and sophisticated as desired (Weinberger). The paradoxical result is a system so finely calibrated and circumscribed that it cannot be used to infer basic principles.

# A Sea of Data

As machine-learning becomes ubiquitous, the obfuscation of computerized knowledge becomes normalized. Information is increasingly transmitted exclusively as sets of signals that cannot be registered by human senses. Contemporary perception has become machinic to a large degree, while the spectrum of human vision now only covers a tiny, shrinking portion of it. It is important to emphasize that the "signal" extracted by assessing correlations and probabilities is not the same as an actual fact; rather, it is determined by the inputs the software uses to learn and the parameters for filtering, correlating, and identifying patterns (Pasquinelli 61). This introduces novel risk factors that are historically foreign to deductive systems but commonplace in the realm of artificial intelligence, where the old engineering mantra "crap in – crap out" is readily applicable (Steyerl 8).

*Apophenia* is a general term for the tendency to perceive meaningful patterns in random data or draw connections between unrelated things; some common examples include seeing a man in the moon or spotting images of Jesus Christ in toast. Computers are all too willing to construe arbitrary patterns from sheer noise, as Google's evocative experimentation in *inceptionism* demonstrates: neural networks trained to discern zoo animals from National Geographic magazines were repurposed to

analyze plates of spaghetti or pictures of deep space (i.e., completely random stimuli), followed by algorithmic enhancement of these input photos to match the program's ultimate "interpretation". The output recognition images revealed mangled knots of disembodied, lidless eyes; Moiré, caniform apparitions; and chromatic form-constants scrambled into a psychedelic rat king – all incessantly swirling and surveilling their audience in a surrealist visual display of conscious pattern overidentification.

These digital hallucinations suggest that *normativity* – the capacity to distinguish between correct and incorrect deductions by way of value judgment – ultimately remains vested in the human collective. No machine or algorithm can decide whether a formal specification captures how a system *should* behave, or whether an expression captures the mathematical theorem it is *intended* to. In the following excerpt, writer Donald MacKenzie captures a scenario highlighting the gap between a theoretical objective and its mechanized implementation:

> Randy Pollack reported two months of theorem proving in the λ-calculus based upon a set of definitions that contained an undetected typographical error. The theorems proved, while correct derivations, were not proofs about the intended object system. (331)

The occurrence (and accumulation) of these phenomena can be highly insidious and difficult to detect within computer models and is compounded by the fact that smooth algorithmic operation is predicated on the endless labor of providing or fixing messy data. Many methods used are opaque, partly biased, exclusive, and – as one expert points out – sometimes also "ridiculously optimistic" (Sontheimer). Empirical orthodoxy inculcates the myth that "real" proofs can be reduced to a strict, linear chain of formal logical inferences. But mathematical concepts are not given: they are fabricated and relative to the dynamics of an intersubjective, social intelligence.

# Machines and Trust

To partake in the success and ubiquity of machine learning models, scientists necessarily forfeit comprehension and risk endorsing the results of an approximation as conclusive (Moller & Vuik 263). While the natural sciences have always accepted a degree of experimental uncertainty, the introduction of quasi-empiricism to the field of mathematics is notably controversial. Since the Greeks' embrace of deductive principles, mathematical knowledge has been inextricably tied to its justification.

The first theorem to be proved using computer-assistance was the four-color theorem (4CT) in 1976. The theorem states that for every map on a plane, its regions can be colored with no more than four colors such that no two neighboring regions share a color. Contributing mathematicians Kenneth Appel and Wolfgang Haken used a computer program to verify select combinatorial steps in an otherwise sophisticated and utterly convincing proof by induction (Tymoczko 57). However, philosopher of mathematics Thomas Tymoczko contends that the 4CT cannot really be considered proven because no mathematician can conceivably view the proof in its entirety. Tymoczko posits, "What reason is there, then, to accept the 4CT as proved? All mathematicians know that it has a proof according to the most rigorous standards of formal proof – a computer told them!" (58).

Tymoczko argues that the 4CT's non-surveyability ultimately disqualifies its legitimacy. Surveyability is the essential feature that enables a proof to be "comprehended by the pure power of the intellect – surveyed by the mind's eye, as it were" (60). As guarantees of absolute mathematical knowledge, surveyability necessitates that proofs be fully accessible by mathematicians (59). They must assume the form of highly syntactic constructions that are self-contained, lucid, airtight, and ensure that upon meticulous scrutiny (Tymoczko's standard involves checking the proof by hand so as to mentally apprehend each component), a mathematician may come to *know* its conclusion.

Tymoczko also expresses doubts as to the formalizability of 4CT. For two thousand years, mathematical theorems have constituted a *priori* deductions from premises. The 4CT proof blurs the demarcation that separates empirical experimentation from mathematics by running a computer program to resolve residual uncertainty. Following code execution, the theorem was converted to a *posteriori* knowledge and made irrevocably conditional by the latent observational error in instrumentation (the computer and program, in this case) (77). The possibility of an unseen digital malfunction secretly wreaking havoc on the internal logic of a coded function clearly produces an existential crisis. Proofs cannot be established by proxy; knowledge cannot be removed from the realm of mental content and placed inside machines, where rules and operations may not be verifiable or enforceable.

Some mathematicians have objected to this so-called Platonist school of thought, citing repressive evidentiary criteria and selective bias towards Western ontology. Philosopher-mathematician Hilary Putnam advocated a dualist approach to mathematical inquiry: while he acknowledged empiricism as more conjectural than formal proof, Putnam underscored its capacity to inspire interdisciplinary exchange and spur breakthroughs (Ayer 317). A related argument by Gregory Chaitin compares the philosophy adopted by physicists favorably to that of mathematicians: whereas mathematicians assume axioms to be fixed

and self-evident, physicists remain open to exploring or appropriating new principals (21). However, Tymoczko's presentiments regarding the surveyability of machine-assisted proofs appear to be at least partially validated by ensuing collaborations among mathematicians and computer scientists to bolster the transparency of automated deduction systems. This has included developing programs that serve as "proof witnesses" while outputting detailed sequences of formal logic during proof verification processes (Borwein 22).

# Eden Defiled

Kurt Gödel's Incompleteness Theorem has frequently been wielded by cynical mathematicians, postmodern intellectuals, and even theologians as a weapon in the contemporary revolt against philosophical Platonism. From their perspective, the Incompleteness Theorem gleefully demonstrates that even in mathematics, the supreme bastion of reason, absolute truth is either beyond human achievement or merely the product of arbitrary consensus rather than objective fact. According to the theorem, we can vitiate the strongest of mathematical models at will by producing a carefully contrived, arithmetical statement such that it or its negation can be affixed interchangeably to the set, thus obtaining a paradoxical state of consistency among incompatible theories (Franzén 24). So, either reason is powerless in this context and, by extension, the universe as a whole (with real truth residing only with God) or there is no other truth than that which we more or less agree upon (just as in the physical sciences, according to this line of thought). Either way, after Gödel's theorem, mathematics flounders in a sea of undecidability. Therefore, as some theoretical computer scientists reason, why not double-down on this reality and embrace the coldly affirmative utopia enabled by proof-assistant software?

When we look at mathematical practice, however, we find that mathematicians, although well aware of the phenomenon of incompleteness, along with the theoretical possibility that a problem they are working on may be unsolvable in the current axiomatic framework of mathematics, are by no means floundering. This isolated uncertainty only reasserts what we already know: that we can't necessarily prove everything (Franzén 27).

Comparatively speaking, Appel and Haken's 4CT algorithm poses far less of a threat to the traditional acquisition and validation of mathematical knowledge than that of the black box technology of today's neural networks. If such insights are obtained through an illegitimate mode of acquisition, then perhaps we are obligated to forswear certain types of knowledge, emulating courtroom motions to strike evidence obtained without a warrant or the destruction of clinical data following

IRB disapproval. Conversely, technologist David Weinberger asserts that clinging to mathematics' traditional standard of decisive, incontrovertible argumentation amounts to perpetuating a naïve notion that the universe is tailor-fit to human mentality. He suggests that ineffably complex, computer-guided simulations should be embraced as a more accurate reflection of reality. Other mathematicians similarly predict a dramatic, computer-enabled expansion of experimental mathematics, and attribute any subsequent loss of certainty to the price of gaining a relativistic worldview (Horgan 103).

# Gestalt Realism

Does knowing the world require sacrificing our understanding of it? In *Journey Through Genius*, author William Dunham recounts a resolution to a debate waged by mathematicians in the mid-19th century over which of two analogous geometric systems was "correct":

> Of course, either the physical universe was Euclidean or it was not, but the resolution of this problem should be left to the physicists. It was an empirical matter, one to be addressed by experimentation and close observation. But it was irrelevant to the logical development of these competing systems. To a mathematician engrossed in the strange and beautiful theorems of non-Euclidean geometry, the beauty was enough. There was no need for the physicist to tell the mathematician which geometry was "real." In the realm of logic, both were. (246)

This statement captures the liberating aspects of a deductive system: mathematicians can explore topics free from corporeal entanglements. They may interact at will with the natural sciences or retreat to a noumenal plane of abstraction. Hellenistic traditions are honored as mathematicians strive to capture Platonic forms within elegant proofs and unifying theorems (McAllister 29). Empiricism should be embraced as a powerful investigative tool, but it cannot serve as the governing mode of knowledge acquisition in mathematics due to its conflicting values and relaxed standard of evidence.

Belief in a Platonistic world does not preclude us from adding new, complicated, computer-assisted axioms to mathematics for pragmatic reasons, in order to be able to better organize our mathematical worldview later on. However, the critical distinction from quasi-empiricism lies in the acknowledgement that such leveraged gains are not definitive, and it is our responsibility to remain vigilant of their surrogate status while

searching for more permanent solutions. Our goal should be to raise the level of general mathematical understanding to the level of complexity of the systems in which we are embedded.

Artificial intelligence may dwarf human capacity for pattern recognition and processing power, but reducing profound meditations to binary assertions of "Yes" or "No" by way of a technologically impressive, yet aesthetically bankrupt, procedure does not amount to a triumph of reason. More gigaflops and processing power fail to inoculate us from the risks posed by models embedded with flawed assumptions. If a problem is endemic to a system, then the exponential effects of Moore's law tend to amplify what's broken. Placebo techno-radicalism deprives mathematicians of logical completeness and torches any phenomenological gains. Rather than outsource investigations to an indifferent, alien intelligence, mathematicians should resume toying with conjecture while invoking a premise of knowability. We need not accept a paradigm in which truths are decided before they are established.

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**Edward Humes**

Dr. Tinoosh Mohsenin

**Department of Computer Science and Electrical Engineering**

# Optimizing Deep Neural Network Architectures for Low-Power Autonomous Tiny UAV Navigation

# Biography

**Edward Humes** is a computer science major in his senior year, graduating in Spring 2023. Long interested in the intersection between computer architecture and software, in October of 2021, he joined UMBC's Energy Efficient High Performance Computing lab (EEHPC), where he works with graduate students to deploy deep neural networks to computationally limited drones and interface multiple different hardware platforms. For this continuing work, he received an Undergraduate Research Award in his senior year, and plans to continue studying computer science in graduate school.

I would like to thank previous EEHPC lab members Griffin Bonner and Haoran Ren for initial setup of both the Crazyflie and GAP8. I would also like to thank Aidin Shiri for his guidance with initial experiments, and Mozhgan Navardi for her assistance in editing this article. I would also like to thank my mentor Prof. Tinoosh Mohsenin and thank the URA program for helping me conduct this research. This research project was sponsored by the U.S. Army Research Laboratory under Cooperative Agreement Number W911NF2120076.

# Research Journey

I have long been interested in unconventional computers; over the past few years, I have been involved in several hobbyist communities focused on 90s/2000s-era RISC-based UNIX workstations such as those made by Sun, SGI, and DEC. Despite this, my first time working with embedded systems and performing research did not arrive until I joined UMBC's EEHPC lab my junior year, where I was given broad leeway in implementing experiments designed by the graduate students into code and collecting data. While I was still unfamiliar with all the nuances of embedded systems, my prior experience with these workstations helped immensely as they taught me about relevant systems programming and debugging concepts. Concepts that were essential for the first major project I worked on in the lab: determining when to offload the computation of neural network inferences from an edge device to the cloud versus running it directly on the edge device. As part of this work, we found the model we were using for this research performed much worse than expected, leading us to research factors that affected performance.

# Abstract

Interest in deploying Deep Neural Networks (DNNs) on the lowest-end embedded systems has grown over the past several years as DNNs have advanced in capability. However, as embedded systems are often computationally limited to fit a specific price point, energy consumption, and size, deploying a deep neural network without modification risks facing poor performance and high energy consumption due to it taking advantage of hardware accelerators simply not present on embedded systems, or improperly making use of the limited hardware accelerators that are present on the embedded system that is being targeted. In this project, we address the challenges of DNN implementation on resource-constrained devices and analyze the effect of different DNNs on power consumption, memory, and processor usage. Moreover, we successfully deploy DNNs on an expansion board for the Crazyflie series of tiny drones for onboard autonomous drone navigation while avoiding obstacles. We conducted a series of benchmarks on an embedded microcontroller specifically designed for running DNNs, comparing neural network architectures that, apart from a series of minor tweaks, were otherwise the same to uncover design factors that impacted the performance of the model when run on the hardware. After we changed the model by incorporating changes that alleviated poor performance, we found that we were able to net significant performance gains and reduce the overall system's energy consumption.

# Introduction

The past decade has seen something of a Cambrian explosion in the number of edge devices - these are devices that are located at the edge of a network, often used to collect and transmit data from sensors or other types of input. Nowadays, it seems nearly everything, from smartwatches to CCTV cameras, has an embedded computer, a variety of sensors, and the ability to connect and share data with other devices. During this same time frame, the field of artificial intelligence has seen a dramatic rate of advancement, spurred on by what is colloquially known as the deep learning revolution. Naturally, there has long been an interest in combining these two developments; edge devices are increasingly being used to perform tasks that can benefit from artificial intelligence's ability to tackle complex unstructured problems such as voice recognition and person detection, problems on which traditional algorithms generally perform poorly [1], [2].

Despite the wide variety of uses that artificial intelligence presents on the edge, adoption has been slower than what one might expect thus far. This primarily comes down to one major factor. The hardware and software present on edge devices are often quite different from what one might see on the servers and workstations on which Neural Networks, the current most widely used type of machine learning model, are designed, trained, and validated. **Figure 1** shows an example of edge devices named Crazyflies that are generally computationally limited due to cost, energy efficiency, and size requirements, making it impossible to simply copy over a pre-trained neural network and run it the way one would on a standard desktop computer. It is possible to sidestep this and have the edge device send the data it collects off to a remote server for it to be processed by a neural network, then execute a specific action based on the response. Although this is good enough for particular uses, this is only sometimes feasible in other cases. Certain applications simply do not have any practical way of offloading computations of any sort to a remote server, whether it is having a poor connection to remote servers, dealing with hard real-time demands necessitating a response within a set deadline, facing the risk of catastrophic failure, or being limited by privacy concerns caused by uploading potentially sensitive data to the cloud. Thus, it is highly desirable to run neural networks on-device, allowing edge devices to generate inferences independently of any remote servers [3].

**Figure 1.** An example of an edge device. A Bitcraze Crazyflie UAV along with various sensor expansion boards.

There is previous work [1][2][3][4][10][11][12][13] on the deployment of neural networks to edge devices for autonomous unmanned aerial vehicles (UAVs). However, the challenges of deploying Deep Neural Networks (DNNs), a type of neural network with multiple layers between the input and output layer, for onboard processing and the effect of different DNN models on memory hierarchy access and core usage of the multicore processors are not addressed in detail. In this project, we addressed the implementation challenges of DNNs on resource-constrained devices and targeted a tiny UAV with Artificial Intelligence (AI) capabilities for deploying DNN models, followed by a discussion of the impacts various models have on memory hierarchy utilization, multicore utilization, and energy efficiency.

# Method

### Discussion on Challenges DNNs Pose for Edge Devices

As previously mentioned, it is not possible to directly copy over and run pre-trained neural networks designed and trained in industry-standard machine learning frameworks such as TensorFlow and PyTorch onto resource limited edge devices. Fortunately, in recent years, work has been conducted to partly resolve this issue, resulting in various solutions. TensorFlow Lite [20] is a framework allowing TensorFlow models — model referring to the neural network's structure and parameters — to be compressed into a single file and deployed on the web or within smartphone applications. On the even lower end, there is software such as the open-source TensorFlow Lite Micro [9] and ST's proprietary X-CUBE-AI [19] package. While these tools are quite well-optimized and are steadily improving, there is still one big issue, the neural network itself. As previously mentioned, these lower-end embedded devices are often very different, hardware and software-wise, from the servers and workstations on which the neural networks are designed and trained. This means that a design that performs well on powerful computers would not necessarily translate well, if at all, to embedded devices. Low-end embedded devices often only have a 32-bit native data size, feature at most a couple of megabytes of RAM, and lack many of the sophisticated Single Instruction, Multiple Data (SIMD) and vector accelerators present on modern high-end processors. The software situation is equally different, as embedded devices frequently run tiny Real-Time Operating Systems (RTOS), such as FreeRTOS rather than more conventional operating systems such as Windows or GNU/Linux.

As an example of a simple computational difference having dramatic consequences, most neural networks are designed and trained using what is known as floating point numbers, which is how computers represent the set of real numbers. Due to floating point numbers being ubiquitous in modern software, most desktop and server processors have been optimized for floating point arithmetic to the point that they can typically perform these operations at the same speed or faster than integer arithmetic operations. However, to save on cost, size, and power constraints, it is common for embedded processors to lack a floating point unit, instead only supporting integer arithmetic. Even if they do contain a floating point unit, these processors are typically still slower at performing floating point arithmetic than they are at performing integer arithmetic. Thus, to execute neural networks at any reasonable level of performance on embedded devices, one needs to convert these neural networks to use integers rather than floating point numbers in a process known as quantization. There are countless other seemingly minor differences that can easily make otherwise similar neural network architectures end up leagues apart in terms of runtime performance and memory usage. Thus,

we set out to empirically determine factors that affect the performance of neural networks on a specific resource-constrained embedded device and explore optimization methods, allowing us to deploy this finely tuned neural network to the device.

### DNN Deployment on the Crazyflie Edge Device

For this study, we were interested in implementing a deep neural network to detect and avoid obstacles on a Crazyflie UAV [1]. **Figure 2** depicts the Crazyflie UAV and the AI-deck we used in this project. The Crazyflie weighs only a few tens of grams, is centimeters in size, and has a measly 250mAh LiPo battery, making energy efficiency a top priority. Rather than targeting the STM32 ARMv7 microcontroller present aboard the Crazyflie, we targeted the GAP8 RISC-V microcontroller on the AI-deck, an expansion board for the Crazyflie UAV. We made this choice for a few reasons; first, our primary motivation for deploying DNNs was to enable autonomous UAV navigation. For this, we needed access to the camera onboard the AI-deck. This camera is only connected to the GAP8 processor, and the GAP8 processor itself is only capable of sharing data with the STM32 via UART, which, although it is a simple peripheral, is not known for being especially fast. A second reason is that unlike the STM32 on the Crazyflie, the GAP8 was specifically designed with the intention of being able to run deep neural networks, and so has a number of accelerators and compute cores, as well as an expansive memory hierarchy, enabling the GAP8 to run even relatively large DNNs. Finally, as part of the software suite GreenWaves maintains for the GAP8 processor, there is a cycle-accurate simulator named GVSOC [14], which models the entire GAP8 multicore processor. GVSOC also supports exporting traces of internal GAP8 peripherals in VCD format, allowing us to view the hardware utilization of the currently running neural network model.

**Figure 2.** Crazyflie and AI-deck, which includes a GAP8 processor. GAP8 is within the blue circle, penny for scale.

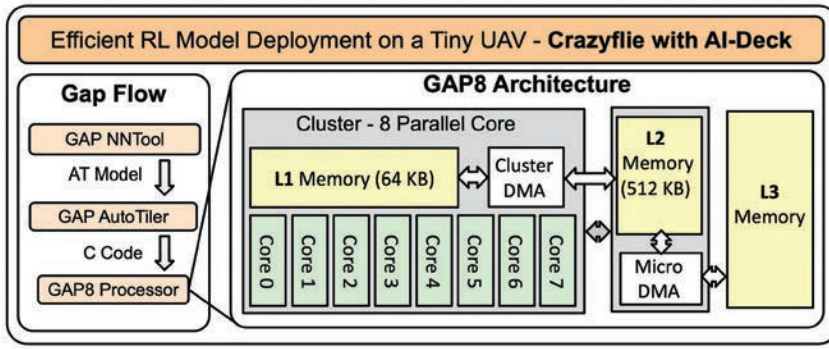


**Figure 3.** A high level overview of the GAP8's microarchitecture, displaying the 8 cluster cores and their relation to the memory hierarchy. The toolchain used for deploying deep neural networks is additionally shown, referred to as Gap Flow. [4][15][16]

**Figure 3** shows the GAP8 processor architecture and the Gap Flow for deploying DNN models on the GAP8 [4][15][16]. To maximize performance on machine learning and digital signal processing, the GAP8 processor, **Figure 3**, contains a variety of special hardware accelerators for linear algebra, bit manipulations, single instruction multiple data operations, and Direct Memory Access (DMA) operations. Similar to other microcontrollers, it has a software-managed memory hierarchy composed of three different layers, 80 KB of L1 memory, which can typically be accessed in a single cycle; 512 KB of L2 memory, which takes several cycles to access; and finally, a much slower, but also much larger, optional L3 memory, supporting many megabytes of memory. It should be noted that L3 memory is not directly memory mapped into the GAP8's address space; reads/writes require slow and energy-hungry DMA accesses to transfer L3 data in/out of L2 memory. As for general-purpose computations, the GAP8 has nine cores, one running at up to 250MHz and which serves as the primary core, also known as the Fabric Controller (FC), and then eight cluster cores running at up to 175 MHz, which run tasks assigned to them by the FC. The FC is also responsible for interacting with external peripherals attached to the GAP8 processor, and thus it maintains control over the Micro-DMA engine. Finally, there is also a specialized hardware accelerator known as the Hardware Convolution Engine (HWCE). Convolutions tend to be a frequent operation in DNNs, and these are rather computationally intensive as they require many multiply-accumulate sub-operations repeated over and over. The HWCE is dedicated exclusively to performing convolutions, and it can apply these operations directly to tensors in L1 memory. A significant limitation of the GAP8 processor is that it only supports integer arithmetic in hardware; all floating point arithmetic has to be done via software emulation, incurring a significant performance penalty. It should be noted however that the GAP8 processor does contain partial hardware support for

fixed-point arithmetic, which is an alternate method of representing and operating on a smaller subset of real numbers via integer operations. Although the GAP8 processor cannot compete with modern high-end desktop and server processors, it packs a punch compared to other embedded processors due to its cluster cores and the variety of hardware accelerators, which also have the side effect of increasing its overall energy efficiency.

Similar to some existing approaches in [1], [3], [17], [18], [21], [24], [25], [26], we designed a variety of DNNs based partly on pre-existing architectures such as MobileNet [5][6][7] and ResNet [8] for deployment of DNN models on resource constrained devices. Once we designed and trained our networks in TensorFlow and Keras, we converted them to TensorFlow Lite models [9]. As the GAP8 processor does not have a floating point unit, we made sure to quantize the networks to only use 8-bit integers, also having the side effect of reducing the amount of RAM used at runtime. Finally, we began converting the model into code and data that could be run on the GAP8 processor. GreenWaves provides a complete toolchain for this entire process, consisting of a custom fork of the GNU Compiler Collection (GCC) that adds support for the custom instructions and instruction scheduling model used by the GAP8 processor, as well as two programs called Neural Network Tool (NNTool) and AutoTiler. NNTool is responsible for performing adjustments to the DNN architecture, such as replacing unsupported operations with equivalent supported operations and converting the overall DNN into a format AutoTiler can use. On the other hand, AutoTiler is responsible for algorithmically determining the best possible memory layout for the DNN to optimally lay the DNN out around the GAP8's memory hierarchy, and then generate an implementation of the DNN in C code according to the determined layout. While we were able to automate most of this process, certain DNNs will often require some manual adjustment to be converted correctly, for example, adjusting the maximum stack sizes for the FC and cluster cores, as some networks allocate more data on the stack than others. Similarly, the heap space will often need to be adjusted for a specific DNN; by default, AutoTiler will attempt to allocate the entire system's L1 and L2 memory for use in the DNN. However, this will inevitably result in heap overflows, corruptions, and an overwritten stack, as the stack for all the GAP8's cores is stored in L1 memory that would inevitably get overwritten by the heap. Additionally, the RTOS used by the GAP8 processor will frequently make its heap allocations before the deep neural network starts up, leaving less space than expected by the DNN.

# Experimental Setup

**Figure 4** shows the setup for measuring the power consumption of the GAP8 processor, which was similar to our previous work in [4][3][22][23]. For benchmarking purposes, we used the aforementioned AI-deck and the GVSOC simulator [14]. We conducted our performance measurements within this simulator and performed energy measurements using the physical hardware.

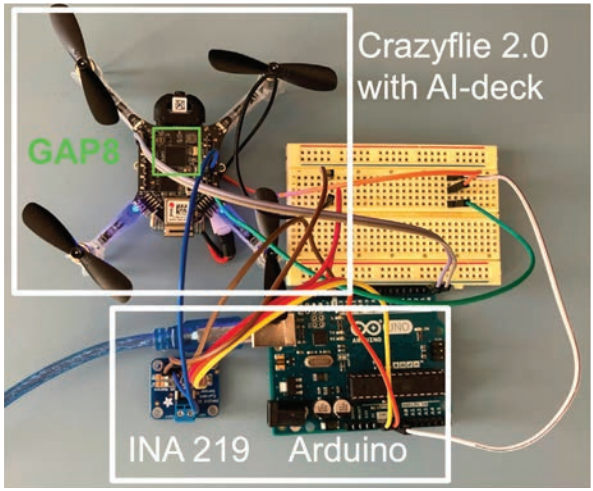


**Figure 4.** The Crazyflie, AI-deck, and the custom Arduino/INA219 setup used to measure power consumption during the runtime of the deep neural network similar to [4][3][22][23].

# Experimental Results

### Gap Autotiler Optimization

By default, GCC, the C compiler, compiles with all optimizations turned off. This means that GCC will more or less directly translate a given piece of C code into what becomes the final executable. This is useful for debugging as the actions taken in the assembly code will more closely resemble the operations specified in the original C code from which it was compiled. However, this also prevents the compiler from deploying a wide variety of optimizations, such as branch elimination, tail call elimination, alias analysis, and especially relevant for the GAP8 processor, vectorization. As shown in **Figure 5**, we found that compiling the auto-generated C code for the neural network architecture under the O3 optimization level significantly increased inference speed, resulting in greater than a 2x speedup over the same neural network when compiled using the O0 optimization level. However, it's possible that the speed increase could be even higher for other neural networks as the GAP8's memory hierarchy bottlenecked the neural network we tested.

**Milliseconds per Inference by GCC Optimization Level**

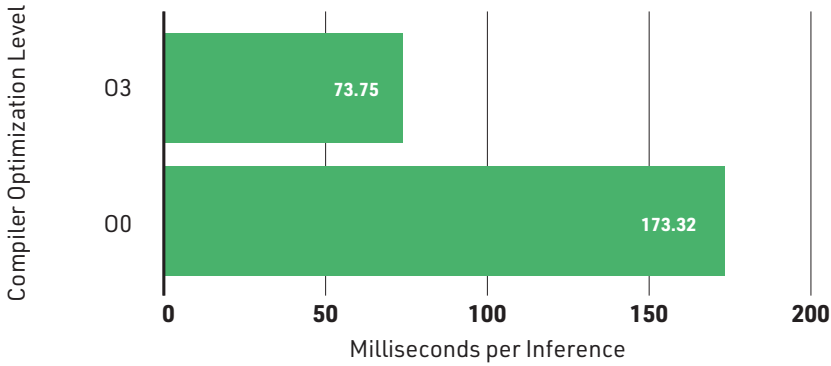


**Figure 5.** The impact of the GCC compiler's different optimization levels on the model's performance (Milliseconds per Inference). Compiling the AutoTiler's generated code with -O3 enables the use of the GAP8's hardware accelerators and custom instructions.

**Amount of RAM, Operations, and Cycles Taken By Two Different Neural Networks**

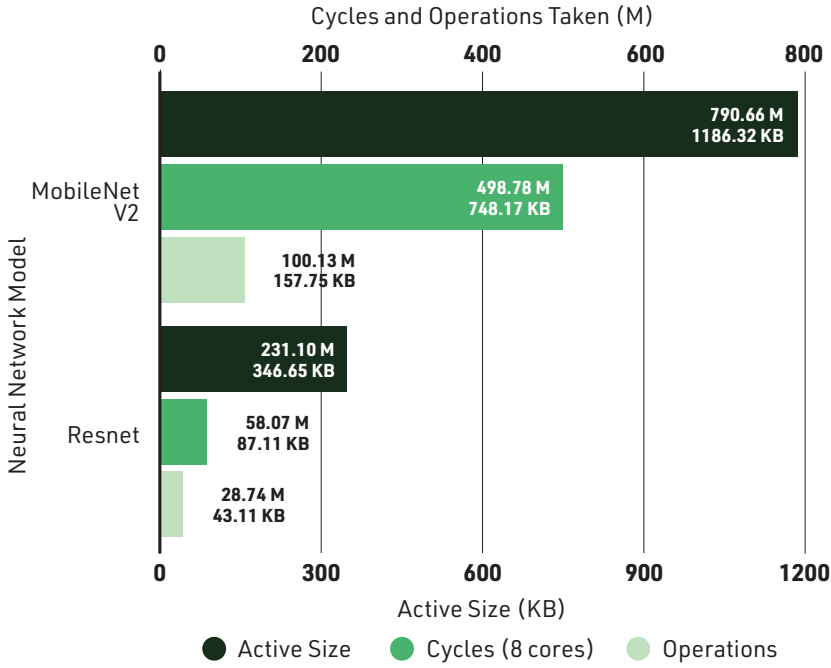


**Figure 6.** Amount of active memory in kilobytes (KB), as well as the number of operations and cycles in millions (M) taken by two different neural networks running on GAP8.

### Memory and Core Optimization

The memory hierarchy bottleneck was a consistent theme across the various neural networks we tested on the GAP8. It was an even more significant bottleneck than the number of CPU cores assigned to the neural network. We compared the memory usage of different neural networks via their "active size", this refers to the maximum amount of memory in use at any given time during the entire runtime of the given neural network, so if one layer uses 800 KB of memory, but all of the rest of the layers only use 300 KB, the active size would be 800 KB. As shown in **Figure 6**, a neural network using a given architecture generally followed the trend where the larger the active size, the slower the inference speed of the neural network. This primarily comes down to L3 memory access. As previously mentioned, L3 memory is not directly memory mapped into the GAP8's address space; as such, to read/write data to it, one must submit DMA commands to the GAP8's Micro-DMA engine.

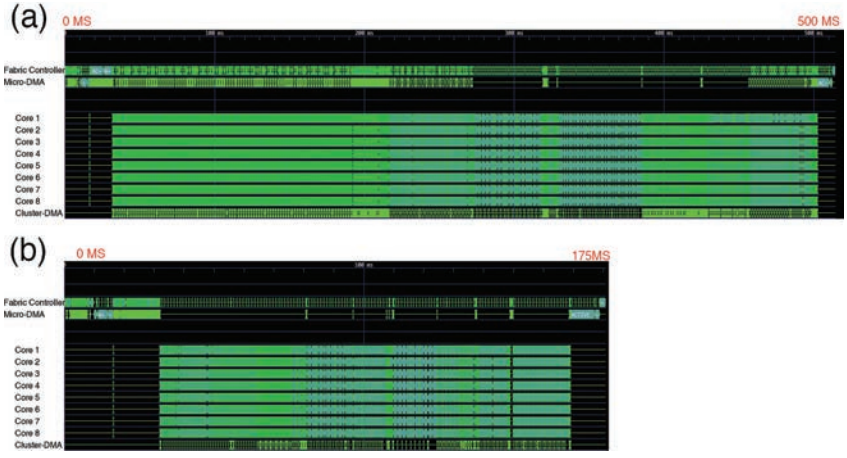


**Figure 7.** A neural network with a much larger active size of 369KB **(a)** requires the use of the GAP8's DMA engines for proportionally more time than a neural network with a smaller active size of 157KB **(b)**.

It is possible to run the Micro-DMA engine asynchronously of the GAP8's processor cores and thus avoid the latency incurred by transfers as long as the processor cores already have work to do. However, this strategy fails if the neural network being run on the GAP8 has layers that require more space than available in the GAP8's memory-mapped RAM. The neural network will be forced to stall as it waits on the completed data to be swapped to L3 memory, and a new working set of data to be retrieved from L3 memory. **Figure 7** shows a visualization of the DMA and GAP8 core utilization of two neural networks using the GVSOC emulator [14], both of which were nearly identical architecturally apart

from their active sizes. As can be seen in **Figure 7.b**, the neural network with the smaller active size only required the use of the Micro-DMA engine during its initialization process. At this time, the engine was used to transfer tensors from the slower L3 memory into the faster L2 memory. The following computations on those weights once loaded were extremely "dense" on the cluster cores, with them not needing to pause and wait for L3 memory transfers to complete. On the other hand, the neural network with the larger active size required frequent L3 accesses during its runtime since it kept having to swap tensors in and out of L1/L2 memory. Thus, one can observe the cluster cores were continually being power gated during the runtime of the network, as there was nothing for them to do while waiting for data.

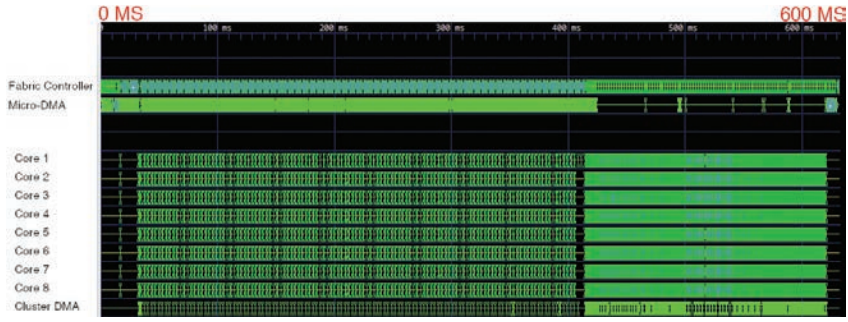


**Figure 8.** A trace of the network that accepts 250x225 images shows that the GAP8 processor's cluster cores are underutilized. The green line segments represent periods of activity, whereas the gray line segments and unshaded portions represent periods of inactivity.

While a larger active size generally correlates with a longer runtime and energy usage, this is not always the case. We discovered while benchmarking variations of the same model, with the only difference between them being the input image dimensions, that specific input image dimensions, and in particular, mixed even/odd dimensions performed significantly worse than other variants of the same model that contained larger active sizes. While we weren't able to discover every reason for this performance anomaly, we did find part of the reason why mixed even/odd image dimension networks perform so poorly. The GreenWaves implementations of neural network layer operations will try to farm out as many of the computations as possible to the GAP8's hardware accelerators, such as its vector units. However, these accelerators and specialized instruction sets present on the GAP8 processor require input data to be of a specific size, such as a vector of four bytes, making the handling of tensors with certain dimensions awkward, as they will require padding and other adjustments to be applied before and after each operation. In particular, we discovered that for mixed even and odd tensor sizes, the

GreenWaves implementations will often give up trying to use hardware acceleration and simply revert to a scalar version of the operation. This will cause the operation to underutilize the GAP8's potential capabilities. As shown in **Figure 8**, the cluster cores are frequently powered on and off in order to perform calculations that would normally be handled by the GAP8's hardware accelerators, with the undesirable side effect of lengthening the overall execution time.

### GAP8 Energy Consumption and Analysis

Other factors in neural network performance are the architectural choices made when designing the neural network itself. Each layer within the neural network means another set of computations that will need to be done during inference, and some layers are more computationally intensive than others. Additionally, even if a neural network can finish an inference within an acceptable amount of time, it may be worth switching network architectures for energy efficiency reasons. We tested both MobileNet and ResNet-based neural networks. Although both had acceptable levels of performance for our use case (obstacle detection and avoidance), as shown in **Figure 9**, we found that ResNet used less energy per inference than MobileNet does, making it more advantageous given the limited power envelope of the UAV we were deploying on.

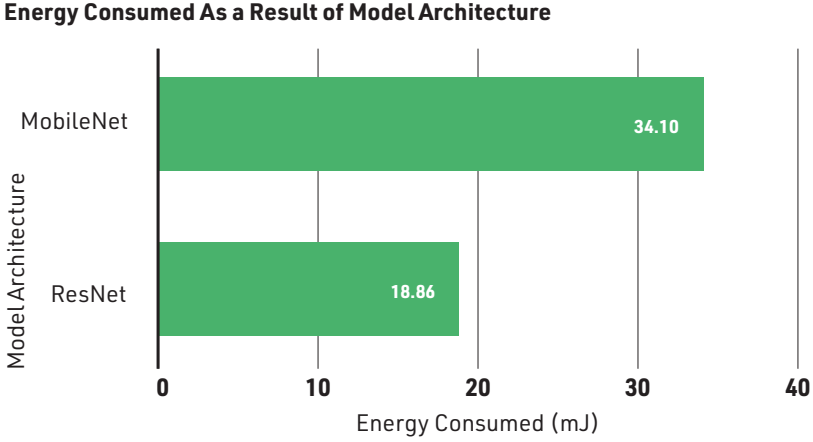


**Figure 9.** Average power consumption at any given time during the inference phase of neural networks with different image input sizes.

Generally speaking, we found that across the board, power consumption and model performance are strongly correlated. This is not entirely surprising, given that for each unit of time that the GAP8 processor is spending on inferences, additional portions of the GAP8 are powered up and consuming energy while waiting on the inference to finish. Even if the cluster cores are power gated while waiting for the Micro-DMA engine to complete, the Fabric Controller, Micro-DMA engine, HyperBus, and L3 memory are all likely still active and drawing power. A quick burst of energy where every part of the processor is actively doing useful work on inference is preferable to a longer, more drawn-out inference where the cluster cores are constantly having to switch on and off again from cold sleep.

After identifying factors influencing the poor performance of our original model, we were able to adjust our obstacle detection model based on our findings. The neural network implementation we started was only able to perform 4 inferences per second, while our latest revised model based on ResNet easily ran 25 inferences a second. Not only is this more than adequate for the drone's task of obstacle detection, but the ResNet-based network was completing inferences faster than the camera could even capture and transmit images to the GAP8.

# Conclusions

Given the performance results we saw, it is possible to empirically state that putting in the effort to understand the factors affecting neural network performance, then optimizing neural networks based on those collected data for inference speeds and power consumption can significantly improve their real-world usage. The difference in speeds between the various neural networks we benchmarked can mean the difference between successful task completion and a catastrophic failure due to poor inference time. Similarly, the increased energy efficiency brought about by a carefully optimized neural network means that a task can be performed for a longer time, increasing the edge device's usefulness. We were able to optimize a model to the point that the main source of latency became the drone's camera rather than the neural network itself. With these extra cycles to spare, we could potentially extend the neural network to perform even more tasks, such as categorizing the different obstacles it sees and responding differently to each, or even to react to voice commands. This is not limited to obstacle detection though, by taking into account factors that affect neural network performance and energy efficiency, engineers and other future researchers can specifically design or tweak more complex and computationally intensive neural networks for low-power UAVs.

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**Nithya Navarathna**

Dr. Matthias K. Gobbert

**Department of Computer Science and Electrical Engineering**

# The Power of GPUs in Machine Learning to Improve Proton Beam Therapy for Cancer Treatment

# Biography

**Nithya Navarathna** is an undergraduate senior at UMBC pursuing a dual degree in biological sciences and bioinformatics and computational biology, with a minor in computer science, and is on the pre-medicine track. She is a Meyerhoff Scholar, Louis Stokes Alliance for Minority Participation (LSAMP) Scholar, and also a member of UMBC's Grand Challenges Scholars Program. She is also a two-time Undergraduate Research Award (URA) recipient. In the future, Nithya hopes to become a physician-scientist by attending an MD/PhD program after her undergraduate studies.

Nithya would like to thank her research mentor, Dr. Matthias K. Gobbert, for his guidance and support throughout this research project. Additionally, she would like to thank her biology research mentor Dr. Achuth Padmanabhan, for their continued support and encouragement.

# Research Journey

When I first enrolled in UMBC, I had a strong desire to be involved in STEM research, which was further encouraged and supported by the Meyerhoff Scholars Program. Through participating in the Louis Stokes Alliance for Minority Participation (LSAMP) Research Program my freshman year, I joined The Padmanabhan Lab in the Biological Sciences Department as an undergraduate researcher. To further explore my research interests, I was seeking a summer internship that combined my interests in both biology and computer science for the summer after my junior year. My LSAMP advisor suggested that I apply to the National Science Foundation's Big Data REU 2022 at UMBC. The research project was a great fit because the project's applications were in cancer biology while the actual project was solely computational. Specifically, my project explores how the utilization of graphics processing units (GPUs) can be advantageous when used with machine learning models to improve proton beam therapy for cancer.

# Abstract

Proton beam therapy utilizes proton beams to treat cancerous tumors while avoiding unnecessary radiation exposure to surrounding healthy tissues. Real-time imaging of proton beams while they travel through a patient's body can make this form of radiotherapy more precise and safer for the patient. The use of a Compton camera is one proposed method for real-time imaging of the prompt gamma rays that are emitted by proton beams. Unfortunately, some of the Compton camera data is flawed, and the image reconstruction algorithm yields noisy and insufficiently detailed images to evaluate proton delivery for the patient. Machine learning can be a powerful tool to clean up the Compton camera images. Previous work used a deep residual fully connected neural network, but the use of recurrent neural networks (RNNs) has been proposed since they use recurrence relationships to make potentially better predictions. In this work, RNN architectures using two different recurrent layers are tested, the LSTM and the GRU. Although the deep residual fully connected neural network achieves over 75% testing accuracy and our models achieve only over 73% testing accuracy, the simplicity of our RNN models containing only 6 hidden layers as opposed to 512 is a significant advantage. This greatly decreases the amount of time it takes to load the model from the disk, potentially enabling the use of Compton camera image reconstruction in real time during patient treatment. A graphics processing unit (GPU), known to perform complex mathematical calculations to display high-quality graphics, could enable the use of this approach in a clinical setting since they are small and affordable.

# 1. Introduction

Proton beam therapy has gained popularity as a cancer treatment due to its many advantages. With cancer being the second highest cause of death in the United States, radiation therapies have been widely used as a treatment [9]. Also known as radiotherapy, radiation therapy uses high-energy particles such as x-rays, gamma rays, or protons, to damage the DNA of target cancer cells. X-ray therapy can deliver dosage at the tumor site, and its radiation continues to travel through the body until it exits on the other side. This may potentially harm healthy surrounding tissues and organs that are unnecessarily exposed to radiation. In contrast, proton beams have a finite range that can be controlled, and deposit the majority of their energy just before they stop depositing energy. This sharp energy increase of the proton beam right before stopping is known as the Bragg peak. Since almost no radiation is delivered beyond the Bragg peak, healthy tissue can be spared from unnecessary radiation [9]. Thus, the Bragg peak allows proton therapy to be advantageous in delivering the radiation dosage directly at the tumor site without traveling further into the body.

To take full advantage of the properties of proton therapy, we must have an efficient technique to image the prompt gamma rays produced by the beam in real-time, as they travel through the patient's body. A Compton camera is one instrument that can be used to detect the prompt gamma rays emitted when the proton beam travels through the body. Moreover, an algorithm is available to reconstruct the beam's image from the prompt gamma data, which then provides an indirect image of the proton beam. Unfortunately, a lot of the raw data of the Compton camera is flawed, and the reconstruction algorithm yields noisy and insufficiently detailed images to evaluate the proton delivery for the patient [7, 8].

Machine learning can be used to clean the raw Compton camera data by identifying and removing false data before image reconstruction [7,8]. Research efforts to clean the Compton camera data have led to the use of neural networks. Shallow networks like the one in [7] use 1 to 2 hidden layers to perform simple classifications of simulated prompt gamma data under ideal conditions that do not represent the irradiation conditions encountered during clinical proton beam radiotherapy. This shallow network in [7] is a binary classification network that simply determines which event data are true events and should be used for reconstruction and which are false events that should not be used for reconstruction. This is improved upon in [8] by using the deep residual fully connected neural network described in [3] for triple event classification. This neural network consists of 64 residual blocks with 8 fully connected layers per block yielding a total of 512 hidden layers. Each layer had 256 neurons per layer, a 45% dropout rate, and used leaky ReLU activation. More detailed results and discussions about the impact of neural network

processing on the use and viability of Compton camera-based imaging in clinical proton radiotherapy are the focus of [8], while providing details on the network and its training are the focus of [3]. The full capabilities of the described neural network are specified in [2], where preprocessing the data, all classification capabilities, and postprocessing output data are described in detail. Other recent work [1, 10] focused on hyperparameter studies on the deep residual fully connected neural network from [3], varying batch sizes, neurons, and layers. The use of recurrent neural networks (RNNs) is proposed in [1] since they use recurrence relationships in sequence data sets to make potentially better predictions. The potential for RNNs to be an improvement over feedforward neural networks (FNNs) is shown in [6].

In this work, we test RNN architectures using two different recurrent layers because of their potential for classifying sequence data, the Long Short-term Memory (LSTM) (discussed in **Section 3.1**) and the Gated Recurrent Unit (GRU) (discussed in **Section 3.2**). The LSTM uses memory cells with gates and a carry track to encode and learn from sequence data. The GRU uses two gating units to encode and learn from sequence data. The goal of this change in the type of network architecture is to examine data as a sequence of interactions rather than one single event, but preliminary results do not show any benefit. We use models with 4 GRU layers and with 4 LSTM layers and achieve similar testing accuracy as the deep residual fully connected model from [3]. The model with 4 GRU layers outperforms the deep residual fully connected model in 3 classes but has a larger gap (within 10%) in accuracy in the other 10 classes. The model with 4 LSTM layers outperforms the previous deep residual fully connected model in only 2 classes but has a smaller gap (within 6%) in accuracy in the other 11 classes. Although the deep residual fully connected model achieves slightly higher accuracy in nearly every class, the simplicity of our RNN models containing only 6 hidden layers (4 recurrent and 2 fully connected) as opposed to 512 is an advantage. And importantly in a clinical setting, this advantage could enable the use of real-time Compton camera image reconstruction during patient treatment.

A graphics processing unit (GPU), known to perform complex mathematical calculations to display high-quality graphics, could enable the use of this approach in a clinical setting since they are small in size and affordable. With this motivation, we use the available GPU partitions in the UMBC High Performance Computing Facility (hpcf.umbc.edu) to test and compare their performance for this application problem. HPCF has several GPU partitions in the clusters taki and ada. The taki system has two GPU partitions 2013 and 2018. For 2018, This 1 GPU node has four NVIDIA Tesla V100 GPUs (5120 computational cores over 84 SMs, 16 GB onboard memory) connected by NVLink, two 18-core Intel Skylake CPUs, and 384 GB of memory (12 × 32 GB DDR4 at 2666

MT/s). The 2013 GPU node contains 18 hybrid CPU/GPU nodes, each with two NVIDIA K20 GPUs (2496 computational cores over 13 SMs, 4 GB onboard memory), two 8-core Intel E5-2650v2 Ivy Bridge CPUs (2.6 GHz clock speed, 20 MB L3 cache, 4 memory channels), and 64 GB of memory (8×8 GB DDR3). Networks built on Taki were built using Tensorflow v2.4.0 (www.tensorflow.org) with the bundled Keras module. We also used SciKit-learn v0.23.dev0 (https://scikit-learn.org/stable/) to preprocess and normalize the data. Moreover, pandas v1.1.0 (https://pandas.pydata.org/) and NumPy v1.18.1 (www.numpy.org) were also used to help preprocess the data. Finally, we used the Matplotlib v3.5.1 (www.matplotlib.org) library to graph our results.

The ada system has 3 distinct node types. Four nodes each with 8 Nvidia RTX 2080 Ti GPUs each with 11GB GPU memory. Seven nodes with 8 Nvidia Quadro RTX 6000 GPUs each with 24GB of GPU memory. Two nodes each with 8x Nvidia Quadro RTX 8000 GPUs each with 48GB memory. Each node has 384 GB of CPU memory (12×32 GB DDR4 at 2933 MT/s) except the two RTX 8000 nodes which have 768GB of CPU memory(12×64 GB DDR4 at 2933 MT/s). Networks built on ada were built with the software package Anaconda3 and Tensorflow v2.6.0 with the bundled Keras module.

The remainder of this report is organized as follows: **Section 2** provides the background on proton beam therapy to treat cancer and the Compton camera to image prompt gamma rays. **Section 3** details the basics of machine learning and recurrent neural networks, while also providing details on the LSTM and GRU. **Section 4** contains selected application-oriented results using our trained network, while **Section 5** presents the performance results using the GPUs described above.

# 2. Application Background

### 2.1 Proton Beam Therapy

Radiation therapy is a form of cancer treatment that uses high doses of radiation to kill cancer cells. X-ray therapy, a form of radiation therapy, is a common technique used for cancer treatment, where the majority of the radiation dosage is delivered upon entering the body. Because of this, the tumor does not receive as high of a concentrated dose as it should. In addition, X-rays will continue to travel posteriorly into the human body until it exits on the other side. This is not ideal as there is no need for extra radiation exposure within the body. Proton therapy on the other hand, which is another form of radiation therapy, is more efficient in this manner. Rather than depositing the majority of the dosage at the entry site, proton therapy works to deposit the majority of the dosage at the tumor site itself, thus making the process more effective. Proton therapy also has an advantage over X-ray therapy in the sense that the proton

beam travels no further posterior into the body than the site of the tumor, allowing for minimal exposure to surrounding tissue. To fully take advantage of all the benefits that proton therapy has to offer, we must have a sufficient technique to monitor the proton beam's path in real time as it travels through the patient's body.

When delivering a dosage to a tumor, the professional treating the patient will create a safety margin that enlarges the treatment area to ensure that all parts of the tumor are guaranteed to receive dosage. The safety margin is needed to account for slight movements in the patient during treatment as well as slightly different positioning of the patient from one treatment to the next, over several weeks. The availability of real-time information on the trajectory of the proton beam through the patient's body during treatment could enable us to make the safety margin smaller and use the optimal path. The use of Compton cameras is one proposed method for the real-time imaging of prompt gamma rays that are emitted by the proton beams as they travel through the body.

### 2.2 Compton Camera

The Compton camera is a multi-stage detector that produces data used to generate images of proton beams used in proton beam therapy [3]. As protons from the beam enter the body, they interact with cells in the body causing the emission of prompt gamma rays. Some of these gamma rays will collide with the Compton camera. An interaction is when a prompt gamma collides with a stage of the Compton camera. For each interaction, the camera records x-, y-, z-coordinates and the energy level of the scatter. The readout of interactions in a single period is called an event. The raw output data from the camera for each interaction is in the form $(e_i, x_i, y_i, z_i)$ where $i = 1, 2, 3$ for the three stages of the Compton camera, and $e_i$ is the energy level.

Image reconstruction algorithms exist that can recover the path of the proton beam from the Compton camera data. The Compton camera's capability to reconstruct full 3D images of the proton beam range could be used with the patient's CT scan to compare the planned treatment dose and make adjustments. Radiotherapy treatment requires conformity between the treatment plan and the treatment delivery, making sure that the patient's bone and soft tissue landmarks are aligned as they were at the time of treatment planning [9]. If a patient changes position, such as wiggling, scratching, looking the other way, or doing any other subtle movement, it could disrupt the treatment plan. By obtaining reliable information regarding the patient from the reconstructed images, clinicians have the opportunity to better ensure that the entire tumor receives the exact dose as planned while making sure surrounding healthy tissues are safe.

Although the Compton camera is able to detect interactions, prompt gammas are emitted close to the speed of light and, consequently, the camera is unable to detect the true ordering of interactions in an event. The false events that do not detect the true ordering of interactions cause noise in the image created, impacting the usefulness of the image [3]. There are three different types of scatters detected by the Compton camera:

a. **True Triples:** In the True Triples event, the Compton camera will detect the path of the prompt gamma. However, the true path may be some other ordering. There are a total of 6 total combinations of True Triple scatters: 123, 132, 213, 231, 312, 321 and, as the data stands, only the 123 ordering is usable.

b. **Double-to-Triples (DtoT):** In the DtoT event, the Compton camera will detect the path of a single prompt gamma as a true triple. However, in reality, two prompt gammas had varying paths. One prompt gamma could have been detected as the first and third interaction and the second prompt gamma could have been mistaken as the second interaction. Similar to true triples, there are a total of 6 misdetection orderings: 124, 134, 214, 234, 324, 314. The second prompt gamma interaction is classified as "4" in the misdetection orderings. In this case, without processing the data, all 6 orderings are unusable.

c. **False Triples:** In a false triples event, the Compton camera will detect a true triple whereas, in reality, there were three different prompt gammas. As a result, this entire event provides no insight into the path of a single prompt gamma and must be discarded.

### 2.3 The Need for Machine Learning

To make proton beam therapy more effective, real-time imaging is needed to verify the location and effectiveness of the proton beam, in particular the location of the Bragg peak. Machine learning is capable of classifying which type of scatter event occurred based on data provided by the Compton camera. These classifications lead to the removal of unusable data which will clean the resulting image. A clearer image allows for treatment verification. A sufficiently accurate machine learning model could produce an image that is clear enough to be used in proton beam therapy as a form of treatment verification. A machine learning algorithm will need approximately 90% testing accuracy to be useful for clinicians.

# 3. Machine Learning

Machine learning is a type of artificial intelligence where a machine is trained to identify specific trends and patterns to make predictions from data. In the case of Compton camera data, the machine learning algorithm will try to predict the appropriate class for a scatter event. The main benefit of machine learning is its efficiency in producing results that would take humans alone much longer to produce. There are four different ways that a machine can be taught: supervised, unsupervised, semi-supervised, and reinforcement. Supervised learning is a form of learning where the machine is provided a labeled data set that has regular input data as well as the desired output data. This allows the machine to produce a model that has been fitted appropriately. Unsupervised learning is used when one wants to identify hidden patterns within an unlabeled data set. This allows the machine to identify any trends it finds in the data without special instruction. Semi-supervised learning is a mixture of supervised and unsupervised where the model is provided some labeled data and a large amount of unlabeled data. Reinforcement learning is similar to the way humans learn where the machine will interact with the data and there will be either a positive or negative reward depending on whether the machine does something the programmer wants or not. The method used in this study is supervised learning because the data set contains both the data from the scatter event and the corresponding label of which event scatter took place.

Recurrent neural networks (RNNs) are efficient neural networks used for time series tasks. They work similarly to a coupling process in biology. They rely on information from the previous system or "loop" to move forward with the next. In this type of neural network, the sequence or order of the network is very important. The system can be read and executed differently if the elements of both series are in different orders. In the case of RNNs, elements include an input layer, hidden layers, and an output layer. RNNs use back-propagation through time to illustrate gradients. The difference between RNN backpropagation and other methods such as in a feed-forward network is that sum errors are necessary at each time step because of the shared parameters throughout the network. Several types of RNNs are distinguished by the pathways between inputs and outputs. RNNs may also contain activation functions that allow a neuron to translate the input into a specific output. Finally, there are a few RNN structures that vary depending on the desired use. There are bidirectional recurrent neural networks, long short-term memory, and gated recurrent units. Bidirectional recurrent networks rely on future data to generate predictions.

RNNs are a viable option for Compton camera data because of their ability to encode information about previous events. Shaping an event in the Compton camera as a sequence of three interactions each with five

features, we have transformed the data produced by the Compton camera into a sequence. Using the sequence of interactions, the RNN will be able to predict the ordering of interactions, i.e., the appropriate scatter.

### 3.1 Long Short-Term Memory

A Long Short-Term Memory (LSTM) neural network is a type of RNN that is traditionally used for natural language processing and time series forecasting. The unique aspect of LSTM is that it contains a memory cell. This memory cell is used to store certain pieces of information that may be needed later in the training process, called a state. The memory cell has three gates to determine the state: forget gate, input gate, and output gate. The forget gate controls what stored information can be forgotten. The input gate controls what information should be used to change the state of the memory cell, and the output gate controls which part of that information is needed at a given time. As stated previously, RNNs use the output of one step and carry it over into the next step in addition to the new data input. The memory cell was added to combat the main issue with RNNs which is long-term dependency whereas more and more information is fed into the RNN, it becomes less effective in learning because the network cannot remember everything.

### 3.2 Gated Recurrent Unit

A Gated Recurrent Unit (GRU) is essentially a streamlined version of the LSTM in **Section 3.1**. The GRU has gating units that modulate the flow of information inside the unit. The GRU factors in the previous short-term dependency with a reset gate by using a linear interpolation between the previous activation function value and the current one. The GRU also factors in previous long-term dependencies with an update gate by taking a linear sum between the existing state and the newly computed state. Unlike the LSTM the GRU does not have separate memory cells.

# 4. Machine Learning for Compton Camera Imaging

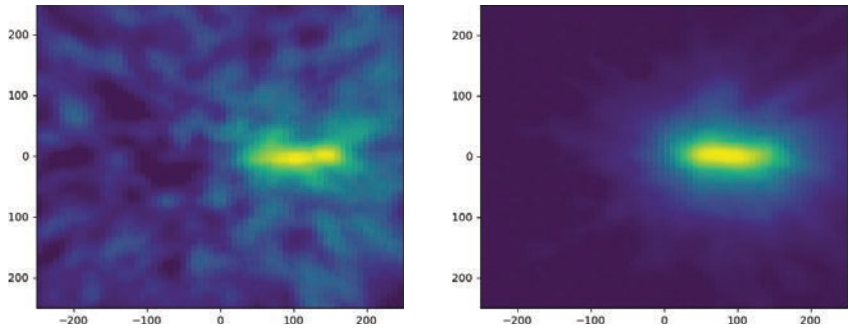
For our studies, we trained the neural network on a data set that was generated using a Monte Carlo simulation and that consisted of 1,443,993 records and 15 features. These features represent each interaction's spatial coordinates, Euclidean distance, and energy deposition. An interaction is a grouping of three spatial coordinates and an energy level. Each row is either a triple, double-to-triple or a false triple and consists of three interactions each. Our training data set only consisted of True Triples, Double-to-Triple scatter, and False events. Furthermore, when

testing the neural network, we used datasets that used 150MeV (Mega electron Volt) beams with three different dosage rates: 20kMU (kilo Monitor Unit), 100kMU, and 180kMU. The larger kMU values correspond to more intense dosage rates. Both the training and testing datasets were reshaped to be sequentially read. Therefore, each record of 15 features was reshaped to 3 interactions of 5 features each: three spatial coordinates, Euclidean distance, and energy deposition. Each record is fed into the neural network as a sequence of 3 interactions. The testing data contains 37,151 testing data points for 20kMU/min, 17,425 for 100kMU/min, and 12,254 for 180kMU/min from MCDE model test 1 150MeV. More details on these studies and results are available in [4, 5].

| Model | Accuracy | Load Time |
|---|---|---|
| DRFCN (512 FCL) | 75.8% | 47s |
| 1 LSTM, 256 FCL | 74.6% | 24s |
| 4 LSTM w/ more neurons | 74.4% | 15s |
| 2 LSTM, 128 FCL | 74.2% | 13s |
| 4 LSTM, 64 FC | 70.0% | 11s |
| 4 GRU | 73.4% | 10s |
| 4 LSTM | 73.2% | 7s |

**Table 1:** Comparison of top-performing models with the deep residual fully connected network (DRFCN) from [3].

The key results of our work are summarized in **Table 1** and are detailed in [5]. The Model column refers to the architecture of the model used. The first row shows the results of the deep residual fully connected network (DRFCN) in [2]; this model has 512 fully connected layers (FCL). All of the following rows correspond to the various models tested in [5] while 4 GRU represents the model with 4 GRU layers and 2 dense layers of 128 and 64 neurons. 4 LSTM represents the model with 4 LSTM layers and 2 dense layers of 128 and 64 neurons. The Accuracy column represents the overall testing accuracy of the model at the dosage rate of 100kMU/min. The Load Time column represents the observed wall clock time in seconds to load the model from its saved state to an active state, i.e., from disk to GPU memory.




**a.** 20kMU/min Uncleaned **b.** 20kMU/min Uncleaned

**Figure 1:** Image **(a)** uses testing data without the NN classification for data correction, called "uncleaned" data. Image **(b)** uses testing data with NN classification for data correction, called the "cleaned" data with the 4-layer LSTM model. Testing data used comes from MCDE model test1 150MeV. Results for additional treatment regimes are included in [4].

The DRFCN model has the highest accuracy of 75.8% with a load time of 47s. The models in the last two rows of the table have accuracies of 73.4% and 73.2% respectively while loading in 10s and 7s. These 4 GRU and 4 LSTM models are much simpler with only 6 hidden layers instead of 512. In particular, they have a factor of 85 fewer layers while being only 2% less accurate. These two recurrent models are also 4 times faster to disk an advantage when treating the patient.

To illustrate the effect that network event classification can have on the PG images produced from the camera data, reconstructed PG images are shown in **Figure 1**. The image in the left column is the PG image reconstructed with raw data before neural network classification, called the "uncleaned" data. The image in the right column is the PG image reconstructed with data after it has been corrected based on the neural network classifications, called the "cleaned" data. Since each PG image is from data collected during delivery of the same 150MeV proton beam, they will have the same position and range even though they are reconstructed from data collected at different dose rates. We observed an improved visual appearance of the beam in which the start point and end point are now easily distinguishable at all three dose rates. The method used to reconstruct these images is described in [3].

# 5. GPU Performance Tests on Taki and Ada Partitions

The tests in **Table 2** were performed to compare the performances of the 2013 taki partition with the 2018 taki partition, along with the three GPUs of ada- RTX 2080 Ti, RTX 6000, and RTX 8000. All studies in the performance comparison study were run using a deep fully connected neural network whose architecture is similar to the model in [3] with residual blocks and some hyperparameter changes. The hyperparameters used for these tests include 128 layers with 256 neurons, a batch size of 8192, a learning rate of 1e-3, and varying epochs from 64 to 1024 epochs. **Table 2** record the performance times for each partition based on the number of epochs. The taki 2018 partition performs the fastest completing the job in 4 hours, 13 minutes, and 42 seconds for 1024 epochs. The slowest performance is that of the taki 2013 partition, which takes 15 hours, 49 minutes, and 31 seconds for the same number of epochs. All three ada partitions perform similarly and are slightly slower than the taki 2018 partition. The taki 2018 partition is at least three times faster when compared to the taki 2013 partition and is the most efficient partition to use for future studies.

In **Table 2**, the taki 2018 GPU cluster was shown to have the fastest GPU node. The performance of the GPU nodes on ada is very similar to those on the taki 2018 GPU, but ada has many more available GPUs. There are 56 RTX 6000 GPUs available and only 4 GPUs available on taki 2018. The taki 2013 GPUs are too slow for the studies in this research. The number of high-performance GPUs on ada is a huge advantage for performing numerous simulations simultaneously.

The Load Time measurements from **Table 1** report observations on a reference computer, a basic laptop with an 11th Gen Intel Core i7–1165G7 CPU at 2.80 GHz with 16 GB of memory. The laptop has Intel Optane Memory H10 with 512 GB Intel QLC 3D NAND solid state drive connected by PCIe 3.0 x4 with NVMe interface. The GPU on the laptop is an Intel Iris Xe Graphics card. On a large cluster like taki or ada, described at the end of **Section 1**, these times would be slower, since the central rotating disk storage is much larger and connected only via network cables to the compute nodes. Even with high-performance fiber-optic cables, this is slower than a direct connection from solid-state storage inside a laptop. However, such direct connection and the use of solid-state storage are more realistic for the type of computer used in a clinical setting in a treatment room. The use of a GPU in the treatment laboratory can significantly decrease the load times, and it is a realistic possibility since GPUs are small, affordable, and can easily fit in the treatment room. More details on these studies and results are available in [4].

**a.** Performances with 64 epochs

| Cluster | Partition | Total Time (hh:mm:ss) |
|---|---|---|
| taki | 2013 | 00:59:49 |
| taki | 2018 | 00:16:01 |
| ada | RTX 2080 | 00:19:17 |
| ada | RTX 6000 | 00:20:32 |
| ada | RTX 8000 | 00:21:08 |

**b.** Performances with 128 epochs

| Cluster | Partition | Total Time (hh:mm:ss) |
|---|---|---|
| taki | 2013 | 01:59:06 |
| taki | 2018 | 00:31:48 |
| ada | RTX 2080 | 00:39:16 |
| ada | RTX 6000 | 00:40:05 |
| ada | RTX 8000 | 00:41:06 |

**c.** Performances with 256 epochs

| Cluster | Partition | Total Time (hh:mm:ss) |
|---|---|---|
| taki | 2013 | 04:57:11 |
| taki | 2018 | 01:03:21 |
| ada | RTX 2080 | 01:18:38 |
| ada | RTX 6000 | 01:20:04 |
| ada | RTX 8000 | 01:20:17 |

**d.** Performances with 512 epochs

| Cluster | Partition | Total Time (hh:mm:ss) |
|---|---|---|
| taki | 2013 | 10:30:07 |
| taki | 2018 | 02:06:39 |
| ada | RTX 2080 | 02:38:19 |
| ada | RTX 6000 | 02:40:09 |
| ada | RTX 8000 | 02:41:34 |

**e.** Performances with 1024 epochs

| Cluster | Partition | Total Time (hh:mm:ss) |
|---|---|---|
| taki | 2013 | 15:49:31 |
| taki | 2018 | 04:13:42 |
| ada | RTX 2080 | 05:09:07 |
| ada | RTX 6000 | 05:18:45 |
| ada | RTX 8000 | 05:25:41 |

**Table 2:** Table of taki and ada performances with varying epochs.

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**Christina Dee**
**Meghan Kwon**
**Julia Neylan**

Dr. Bradford Peercy

**Department of Mathematics and Statistics**

# Clustered Cell Migration: Modeling Boundary Forces

# Biographies

**Christina Dee** graduated from UMBC magna cum laude in May 2022 with a B.S. in mathematics and an Honors College Certificate. Christina attended UMBC with support from a merit scholarship, the CNMS Scholars Program, and the Smart Local 100 scholarship fund. During her study at UMBC, Christina completed research under Dr. Bradford Peercy, through support, in part, by an NSF grant (#1953423) and both attended and presented at several research conferences. In May 2022, she was inducted into Phi Beta Kappa and Pi Mu Epsilon. She would like to thank her mentor, Dr. Bradford Peercy, for his exceptional help and guidance throughout this process. Christina would also like to thank Dr. Michelle Starz-Gaiano for her guidance and advancements in cell migration research. Currently, Christina is working in industry at Westat as a statistician. In the future, she will continue her career in mathematics through graduate school.

**Meghan Kwon** is a junior at UMBC pursuing a double major in biological sciences and mathematics. Meghan is working as an undergraduate research assistant for the mathematics department at UMBC under Dr. Bradford Peercy. Meghan is attending UMBC with support from a merit scholarship and is also funded, in part, by Dr. Peercy's NSF grant (#1953423). After completing an undergraduate degree, Meghan plans to further her education and attend graduate school for computational biology or applied mathematics and plans to pursue a career as a researcher.

**Julia Neylan** is a junior at UMBC seeking a B.S. in mathematics and a minor in computer science. Julia is attending UMBC with support from a merit scholarship. Currently, Julia is completing research in the mathematics department at UMBC under Dr. Bradford Peercy. She is also funded, in part by Dr. Peercy's NSF grant (#1953423). After completing an undergraduate degree, Julia plans to pursue an industry career.

# Research Journey

In 2017, my mother was diagnosed with breast cancer. It was one of the scariest moments of my life. Luckily for me, she was diagnosed early, and it was treatable. However, that is a moment I will always remember. A few years later, in my junior year of college, I had the opportunity to work with Dr. Peercy on mathematically modeling clustered cell migration. This was particularly exciting for me because discoveries in clustered cell migration can lead to advancements and further knowledge on cancer metastasis and wound healing. I wanted to be a part of research that was contributing to this cause, both on an academic and personal level. In the past year and a half, we created a mathematical model that utilizes complex boundaries and force balances to simulate cell migration in the *Drosophila melanogaster* egg chamber. Over this time, I have presented locally at URCAD and SURF and nationally at SIAM Life Science, mentored students, developed a detailed senior thesis, and attended seminars and conferences. In May 2022, I graduated from UMBC, and two new students, Meghan and Julia, took over the model. During this time, they added another force to the model and found new results.

**— Christina Dee**

# Abstract

We present a mathematical model of cell migration using complex boundaries and force balance methods. Our goal is to answer how one represents membrane tension interactions in a mathematical model for individual cells with complex boundaries. We seek to determine how we can realistically combine and create different forces to affect cell migration in a complex mathematical model for clustered border cells and what parameters are needed to correctly simulate this. We extend a previous model with different forces of adhesion, repulsion, and migration using functions to measure the amount of overlap between boundary points of cells. Furthermore, we create volume, spring, and curvature forces to control the size and shape of cells and the distance between boundary points. We adjust force balances, parameters, equations, and code accordingly to realistically simulate migration and interpret the progression of cell displacement over time. From this, we develop a more efficient model and create a partial simulation of cell migration in a new complex model. Furthermore, we find a more ideal force balance and move closer to a full simulation. From our work and collaborations with Dr. Starz-Gaiano's lab, we suggest that extracellular geometry can have a significant impact on cluster migration [8].

# 1. Introduction

Cell migration via chemotaxis is defined as the movement of unicellular or multicellular units responding to chemical gradients acting as signals [12]. Cell migration is an essential process to many complex organisms and is needed in a variety of biological processes, such as wound healing, embryonic development, and immune response. It is integral to daily functions such as development and healing. Consequently, errors in the migratory process can result in devastating repercussions, such as tumor formation, cancer metastasis, vascular disease, and intellectual disability [12] [3]. Our research examined activity in the egg chamber of the *Drosophila melanogaster*, otherwise known as the fruit fly. This organism has a well-studied history and has many human genetic homologs—meaning the genome for fruit flies and humans has considerable overlap. This research centers on the simulation of a migratory cell cluster moving among nurse cells toward the oocyte in the *Drosophila melanogaster* egg chamber. We capture heterogeneous cells of the *Drosophila* egg chamber, including nurse, epithelial, and migratory border cells. Border cells are the cells that cluster and migrate, nurse cells are the large cells that make up the tortuous boundary of the migratory pathway, and epithelial cells make up the egg chamber boundary. We specifically focus on the cell cluster, which is the group of six to eight border cells that, having emerged from the egg-chamber-encompassing epithelium, surround two non-migratory polar cells. This cluster migrates through the 15 nurse cells, which provide supportive nutrients while making up the migratory pathway to the developing oocyte. Previous research focused on a replication of a similar egg chamber with 15 nurse cells and an active migratory cluster without complex boundaries [11]. We aim to simulate migration in a complex boundary model. We seek to understand how one represents membrane tension interactions in a mathematical model for individual cells with complex boundaries. Through the present study, we will better determine how we can combine these membrane forces with forces of migration and volume to affect cell migration in a realistic and complex mathematical model for clustered border cells and what parameters are needed to correctly simulate this.

# 2. Methods

### 2.1 Complex Boundaries

The mathematical model for cell migration was organized through matrices to represent complex boundaries for membranes developed around cell centers. These boundaries represent the cell membrane or the border between the intracellular and extracellular spaces of the cell. In migration, cells attach to one another via their membranes.

With defined boundaries, we can simulate the membrane rather than a singular center. As the cells move, each individual boundary point will represent points along the membrane or the surface of the cell and will feel forces representative of surface tension. The cell centers were structured as a matrix of two $(x, y)$ coordinate vectors. We created a node at each boundary point, which then generated a set of coordinates at each respective point. This extrapolated boundary points around the cell centers by using defined radii and trigonometric functions to utilize polar coordinates for the approximation of points around cell centers. These radii differed by cell type.

Using polar coordinates and the cell center vector, we created a matrix, $B_{new}$, containing the boundary points. The number of rows correlated with the number of boundary points. The model originally had 100 boundary points for each cell. However, this left too much space between points which allowed other cells to slip between the boundary points. To combat this, we increased our number of boundary points to $n = 200$. $B_{new}$ was a $n$ x $m$ matrix, as depicted below.

$$B_{new} = \begin{bmatrix} x_{1,1} & y_{1,1} & \cdots & x_{m,1} & y_{m,1} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ x_{1,n}, & y_{1,n} & \cdots & x_{m,n} & y_{m,n} \end{bmatrix}$$

**Figure 1:** Matrix of complex boundaries along the cell membrane.

We also created complex boundaries for our epithelial cells to make an egg chamber boundary. We treated each epithelial cell as its own boundary point. Since the egg chamber was an ellipsoid shape, we utilized a polarized surface area formula for an ellipse to approximate the egg chamber boundary. This formula relied on a defined major axis ($a$), minor axis ($b$), radius ($r_h$), number of boundary points ($n_b$), eccentricity ($e$), and a hard boundary factor ($h_{bf}$). We used $h_{bf}$ to determine the range of angles, written as:

$$s = 0 : \frac{\pi}{h_{bf} n} : 2\pi - \frac{\pi}{h_{bf} n}.$$

With this defined range and the formulas below, we formulated the ellipsoidal shape, where $a$ equaled twelve microns, $b$ equaled ten microns, and $s$ indexed our $n_b$ points over polar coordinates. The eccentricity, or the elongation of the ellipse, was denoted as:

$$e = \sqrt{\frac{1 - b^2}{a^2}}.$$

The hard boundary radius was defined as:

$$r_h = b\left(\sqrt{1 - (e\cos(s))^2}\right)^{-1}. \quad \textbf{(1)}$$

There was a trade-off between the number of boundary points and the speed of simulating the model. If we increased the number, we prevented large gaps between the boundary points; however, the model ran slower due to the increased number of calculations. The model originally had 600 boundary points for the hard boundary of the egg chamber, measured by $n \cdot h_{bf}$ where $n = 200$ was the number of boundary points per cell and three was the hard boundary factor. While the code ran efficiently with 600 points, gaps allowed cells to break through neighboring cells. Thus, we decided to increase the boundary points for the egg chamber to reduce cell excursions. This implementation utilized 1200 hard boundary points, with a hard boundary factor of six. With about 60 epithelial cells around the egg chamber edge (in a medial slice), this was about 20 boundary points per epithelial cell interior surface against the nurse cells.

## 2.2 Force Equations

The complex boundaries were used to represent interactions along cell membranes from arising forces. The displacement of the boundary points for each cell was directly proportional to the summation of the forces as seen in **Equation** (2) [11]. We utilized an ordinary differential equation to represent the relationship between the position over time and arising forces. The derivative of position over time, $\frac{dB_i}{dt}$, had a direct relationship with the summation of the forces:

$$\mu\frac{dB_i}{dt} = \sum_{j\in A_i}(F^a_{i,j} + F^r_{i,j}) + \sum_{j\in M_i}(F^m_{i,j}) + \sum_{j\in D_i}(F^p_{i,j} + F^v_{i,j}). \quad \textbf{(2)}$$

In **Equation** (2), the forces are enacted from the $i^{th}$ cell to the $j^{th}$ cell. This relationship included the adhesive, repulsive, migratory, volume, and spring forces. The adhesive and repulsive forces, denoted by $F^a_{i,j}$ and $F^r_{i,j}$ , are in the $A_i$ neighborhood. $A_i$ represents points within a certain

$d + \epsilon$ distance of each other. The migratory force, represented by $F^m_{i,j}$, is in the $M_i$ neighborhood. This neighborhood is embedded in the $A_i$ neighborhood between migratory and non-migratory cells. Finally, the spring and volume forces, denoted by $F^p_{i,j}$ and $F^v_{i,j}$ are in the $D_i$ neighborhood, which represents the nearest neighbors. The adhesive, repulsive, and migratory forces were already constructed in previous work in the lab [11]. However, we developed the volume and spring forces in order to realistically include complex boundaries in the model. These forces will be explained and developed in more detail in the following pages.

The adhesive and repulsive forces refer to the forces of attraction and repulsion. These forces are necessary for attaching between cells without unrealistic intersections. They were dependent on several parameters, including the force scaling factor and radius of interaction constant, $D$, the overlap constraint, $\epsilon$, and the force constants. The adhesive and repulsive forces were also dependent on the direction vector and the distance between cells. In **Equations** (**3**) and (**4**), $\rho$ was the overlap, $H$ was the Heaviside function, and $d_{ij}$ was the direction vector. The distance was measured by taking the normalization of the boundary points' locations individually. The direction vector then took the difference between these boundary points and divided by the norm. $\rho$ had two distinct identities depending on its correlation with the repulsive or adhesive force. $\rho^{\epsilon}_{i,j}$ was equal to $D(1 + \epsilon) - dist$ where $\epsilon = .5$, and $dist$ was the norm of the distance, $||d_{ij}||$. $\rho^0_{i,j}$ on the other hand was simply $D - dist$. These variables were measured using functions of two points and were considered for all points in the model, including the fixed egg chamber boundary. If cells were not within a certain $\epsilon$ distance in $\rho$, the lack of proximity caused the forces to be zero. This zeroing out factor was due to the Heaviside function. The adhesive and repulsive equations, denoted $F^a$ and $F^r$, made use of this and were written as:

$$F^a_{i,j} = C^a_{i,j}\rho^{\epsilon}_{i,j}H(\rho^{\epsilon}_{i,j})d_{ij}. \tag{3}$$

and

$$F^r_{i,j} = C^r_{i,j}(\rho^0_{i,j})^3H(\rho^0_{i,j})(-d_{i,j}). \tag{4}$$

To keep the boundary points elastically separated from each other, we formulated a spring force [13]. This force formula ensured that the boundary points stayed near their respective cell boundary neighbors so that the model was geometrically representative [13]. In **Equation** (**5**), $B_i$ was the location of a boundary point for a given cell, $B_{i+1}$ and $B_{i-1}$ were $B_i$'s neighboring points within the cell, and $H_s$ was the baseline spacing between boundary points [13]. The baseline distance was measured by taking the norm of two points in the model prior to

starting the simulation. This force was dependent on the distance between the nearest neighbors of points, and was defined as:

$$F_i^p = C_p\Big(||B_{i+1} - B_i|| - H_s\Big)\frac{(B_{i+1} - B_i)}{||B_{i+1} - B_i||} - C_p\Big(||B_i - B_{i-1}|| - H_s\Big)\frac{(B_i - B_{i-1})}{||B_i - B_{i-1}||} \quad \textbf{(5)}$$

Each cell's points $B_i$, $B_{i-1}$, and $B_{i+1}$ evolved and aimed for equal separation. The baseline distance was also included to emphasize the connection between the previous distance and the current displacement of points. While creating this force, we conducted a literature search for a known spring constant—this being 140 pN/nm [5]. We picked this constant because we wanted an estimate for a bilipid layer with units of pN/nm. Within the range of values in the paper, we selected the options available for area compression expansion modules, since they applied to bilipid layers and had the preferred units. Since the previous constants were nondimensionalized, we nondimensionalized the spring constant. From **Equation** (**2**) we have:

$$\mu\frac{dB}{dt} = \sum_{i=1}^{N} F_i.$$

Using the identities $v = D_p * U$, and $t = \tau * T$, we obtained

$$\mu\frac{dB}{dt} = \mu\frac{1}{D_pT}\frac{dv}{d\tau} = \sum F_i.$$

Since all the other forces were dimensionless, we only focused on the spring force. Using the relationship above and the spring force equation from **Equation** (**5**), we obtained:

$$\frac{dB}{dt} = \frac{D_pT}{\mu}C_p((||B_{i+1} - B_i|| - H_s) - (||B_{i-1} - B_i|| - H_s)).$$

The norm and $H_s$ had no units, so the only significant factor was $C_p$. From this we found

$$\frac{D_pT}{\mu}C_p = 25.17.$$

Since we scaled by one hour, we were able to take away the dimensions of the spring constant. Then, after substituting in $\mu = 10^{-6}$ g/s, we found our dimensionless spring constant, $C_{pnew}$, which we will rename $C_p$, to be 25.17. By looking at the original equation, we made substitutions and isolated the spring force and derivative, generating the new spring constant $C_{pnew} = \frac{1}{\mu}C_p$, where $\mu$ represented the

dynamic viscosity, and $C_p$ represented the previous spring constant. We found a value for $\mu$ by searching through Search BioNumbers and selecting a commonly used dynamic viscosity that applied to membranes, surface shear viscosity, and *in vivo* cytoplasm values. After plugging in this value, we concluded that the spring constant was 25.147 [6].

Afterwards, we included a volume force to control the cell area in a 2D context and included heterogeneously and realistically sized cells. Force induced movement can deform the current area $A$; thus, we needed a restoring force, $F^v$. This force ensured that the area remained roughly constant and the egg chamber and cells did not expand unless given that direction. It is important to note that egg chamber growth has not been included at this point. The volume force was calculated by taking the difference between the areas measured during the initial run and the most current time step and applying that scaled difference to a force vector applied to each boundary point from the center point. This force can be written as:

$$F_i^v = \frac{C_v(A_{old} - A)(B_i - U_i)}{||B_i - U_i||}, \tag{6}$$

where $A_{old}$ is the initial area, $A$ is the current area, $B_i$ is the current boundary point, and $U_i$ is the cell center. The model measured the area using the boundary command in MATLAB. In the context of our model, we used the area constraint to realistically shape the cells and maintain heterogeneous sizing. With this in mind, nurse cells had an area around $\pi(50\mu m)^2$ and border cells had an area around $\pi(7\mu m)^2$. We started from initial positions and then inflated the cells until they properly filled the space. After reaching this, we utilized the volume force to keep the areas consistent and resistant to force induced reduction.

After initialization, we enacted the migratory force, which incited the cells to migrate. This migratory force stemmed from chemical gradient signaling, such as PVF1 signals [7] [9]. The migration force was only enacted when migratory cells interacted with non-migratory cells. Otherwise, the force between a migratory cell and a migratory cell, or a non-migratory cell and a non-migratory cell, balanced to net zero. This force depended on the direction vector and the projection of the chemical gradient onto the vector orthogonal to the direction vector to the direction vector. Due to this projection, the points would set off a migratory force in the perpendicular direction via the axis of interaction in response to the chemical gradient [11]. This projection is described in more detail in the appendix of *A Mathematical Model of Collective Cell Migration in a Three-Dimensional, Heterogeneous Environment* [11]. The chemical gradient was simply [0, 1], which was the direction of the anterior-posterior axis. This force essentially sent signals to the border cells to migrate or climb

through the migratory pathway and can be written as:

$$F_{i,j}^{m} = C^{m}\sigma_{i,j}Proj_{d_{ij}^{\perp}}\nabla f. \tag{7}$$

### 2.3 Force Balance

A free body diagram of the forces can be seen in **Figure 2**. This figure indicates the relationships between two cells $i$ and $j$, their respective boundary points, and the forces that arise from them. It features two zoom-ins, one that focuses on intercellular relationships and one that focuses on intracellular relationships. The lower left zoom-in elucidates the adhesive, repulsive, and migratory forces applied on boundary points from two distinct cells. The right zoom-in displays the spring and volume forces interacting on boundary points within the same cell.

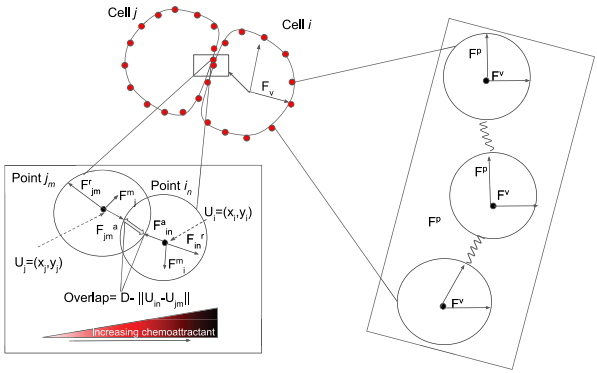



**Figure 2:** Free body diagram of the forces on two cells and their boundary points. $F^a$ represents the adhesion, $F^r$ the repulsion, and $F^m$ the migratory force. $j_m$ is the $m^{th}$ point on the $j^{th}$ cell. While $i_n$ is the $n^{th}$ point on the $i^{th}$ cell. Cell $i$ is migratory and cell $j$ is nonmigratory. $F^v$ represents the volume force and $F^s$ the spring force.

Each of these forces have constants/parameters associated with them. To realistically model migration, the forces must be balanced so that realistic motion and responses are achieved. We used adhesive, repulsive, and migratory force constants from previous research, which were defined as 1.872, 15.6, and 1.568 respectively [11]. Given this information, we only needed to quantify the spring and volume force constants. We found the spring force constant through external resources, and then non-dimensionalized it as seen in **Section 2.2** [13]. Then, we derived the area constant through experimental adjustments. The current model runs at a time step of $h = 0.00001$ with the parameters shown in **Figure 3**.

| Parameter | Value |
|---|---|
| $\frac{\alpha}{D\mu}C_i^p$ | $25.41 \cdot 10^3$ |
| $\frac{\alpha}{D\mu}C_{ij}^a$ | $1.872 \cdot 10$ |
| $\frac{\alpha}{D\mu}C_{ij}^r$ | $15.6 \cdot 10^3$ |
| $\frac{\alpha}{D\mu}C_i^v$ | $10^2$ |
| $\frac{\alpha}{D\mu}C_i^v$ | $10^2$ |
| $\frac{\alpha}{D\mu}C_{ij}^m$ | $1.568 \cdot 10^3$ |

**Figure 3:** Table of the force constants. $i$ and $j$ represent two cells, $\mu$ was dynamic viscosity, $D$ was cell diameter, and $\alpha$ was the time scale.

### 2.4 Euler's Step

We updated the boundary points using Euler's method. This was executed by:

$$B_{new}(t+h) = B_{new}(t) + hF_{new}. \tag{8}$$

Using Euler's formula, we updated the position according to the forces for each boundary point. Then we updated the time step $t$, refreshed the force matrix, $F_{new}$, and started again. There was a delicate relationship between the forces and the time step. If we used too large of a time step, the points inappropriately crossed boundaries. When this time step was too large, the forces were too strong which caused extreme cell displacement. Consequently, when forces were too large, we required a smaller time step to realistically simulate migration. The current model runs at a time step of $h = 0.00001$.

### 2.5 Time Reduction and Neighborhoods

To reduce simulation time, we defined a neighborhood of points for each point where interactions might occur. These neighborhoods were made up of nearby points that fit a set criteria. If points were within a certain distance of a boundary point, they were added to that point's cell array by their row and column location. We did this by creating a separate function and plugging in the respective matrices. This produced two cell arrays, one between the hard boundary and the cells, and one between individual cells. The two cell arrays were made up of individual arrays for each point that held that point's neighbors. Then, instead of running

through all of the points in the model for the intercellular forces, we instead just ran through each boundary point's neighborhood. This was done by running through the length of the neighborhood, selecting the neighboring point's location, and plugging it into the force calculation. Since the migratory force also relied on distance and included the Heaviside function, we used the pre-established neighborhoods to determine when points were close enough together. If they met certain conditions, we enacted the migratory force.

These neighborhoods were used for the intercellular forces, the adhesive, repulsive, and migratory forces. The distance for the neighborhoods was determined by picking a radius slightly larger than the radius of interaction for the adhesive, repulsive and migratory forces. This radius allowed for flexibility if the cells moved but was still fairly realistic. This saved running time considerably, however, there was a tradeoff between updating neighborhoods and the simulation running time. If we updated the neighborhoods too often, the running time greatly increased. However, if we neglected neighborhood changes, we would miss interactions. The neighborhoods needed to be updated at an efficient pace when the cells moved. In order to update the cells without slowing down the code extensively, we used the mod function to update the neighborhoods every 100 seconds. This significantly reduced the simulation time by eliminating unnecessary calculations. We updated this neighborhood often enough not to lose accuracy with interacting points. An example of an initial state with a specific boundary point labeled (cyan) and neighborhood points (black) is shown in **Figure 4**.

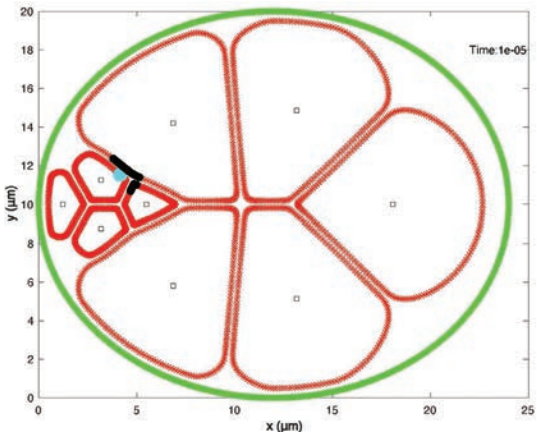



**Figure 4:** Neighborhood example. The boundary point is marked in cyan and its neighboring points on other cells are denoted in black. Green points denote the epithelial cells and red denotes the border and nurse cells.

## 2.6 Initial Migration Simulation

Initially, we ran the model simplistically and examined force balances by starting from one cell and gradually increasing to a more complete egg chamber. We then started applying more realistic cell junctions and sizing. There were some initial challenges getting the correct migration forces. We ran tests with parameters, individual forces, force balances, and the egg chamber set up to determine what was causing unusual patterns like spiraling and flattening. After making modifications, we determined that part of the root cause was the lack of a curvature force.

## 2.7 Plotting Individual Force Vectors

To confirm the accuracy of our implementation of the forces, we decided to plot the individual force vectors for each boundary point of the border cell. With this method, we observed the directions and relative magnitudes of the force vectors to predict the movement of a border cell. When plotting the individual force vectors, we decided to simplify the egg chamber to only include one border cell and two nurse cells. The border cell's location and shape were determined by the force vectors. When investigating the individual force vectors, we observed the volume and adhesive forces had directions pointing away from the center of the border cell. Furthermore, the spring and repulsive forces had directions pointing towards the center of the border cell, as expected. It is important to note that for each of the force vectors, in order to conveniently capture the magnitudes and directions within reason, we scaled the forces down by varied factors. This plotting technique was used to compare the individual force vectors' magnitudes with those of the boundary points within the same cell. Unless sharing the same scalar factor, we did not compare the magnitudes between plots of different forces. This technique was a helpful tool to compare relative directions between the adhesive and repulsive forces, and between the spring and volume forces.

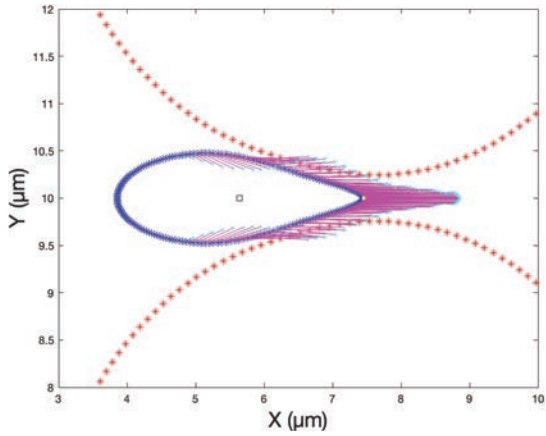



**Figure 5:** Migratory Force Vectors. Dark blue points represent the boundary points of the border (migrating) cell. Red points represent the boundary of the two nurse cells. Pink lines represent the force vectors and their directions. Cyan represents the tips of the force vectors. Plotting the appropriate migratory force vector for all of the boundary points when applied to the leading border cell. Captured at 3.167 minutes into the simulation.

We discovered that the border cell had an incorrect preference towards movement downwards. After plotting the individual force vectors, we observed that the migratory force was responsible for this inaccurate direction of movement. In the *Drosophila melanogaster*, the border cell cluster typically moves across the egg chamber to the oocyte (for our simulation, this was a horizontal movement). The migration force vector should have been perpendicular to the adhesive force vector to be consistent with the movement *in vivo*. Instead, we observed the migratory force vector had no directional relationship to the adhesive vector and the migratory force vector was exclusively in the downwards direction. Once we resolved the implementation for the calculation of the migratory force, we observed the correct movement of the border cell, as seen in **Figure 5**. This modification allowed for faster migration of the border cell and fixed the issue of favoritism towards downward movement.

### 2.8 Curvature

During the simulation, we initially observed an overabundance of flattening of border cells when moving through nurse cells. While some compression was to be expected, complete flattening at the leading tip of a migrating cell was unrealistic behavior. To avoid extreme angles, we decided to impose a curvature force.

Initially, cell shapes were primarily maintained by the volume force. However, this volume force only maintained a consistent area rather than a consistent shape. Consequently, the volume force did not enforce curvature. The cells could completely flatten and expand outwards with a consistent area. To preserve the circular cell shape and curvature between boundary points, the model needed a curvature force that measured the angle between boundary points.

This curvature force ensured that cells remained circular in shape and relied on arc length, the distance function, the direction vectors, and the angle, $\theta$, between boundary points. It measured the radius of an experimental circle and confirmed if the radius was proportional to the curvature. As the radius decreased, the curvature approached infinity. This curvature force also relied on the vectors between points. We needed to find the angle between direction vectors for each pair of neighboring boundary points. This made use of cosine, normal vectors, and unit tangent vectors. The image in **Figure 6** elucidates the potential direction vectors and the angle, $\theta$, used on boundary points 1, 2, and 3.

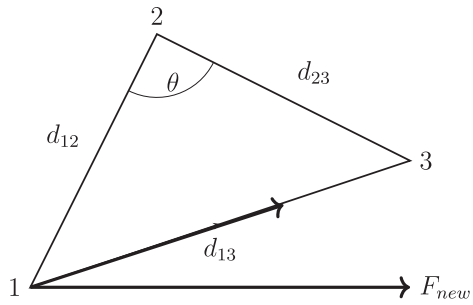



**Figure 6:** Curvature Force Diagram. This depicts the relationship between the direction vectors and the angle. Points 1, 2, 3 represent neighboring boundary points within the same cell. The vectors $d_{13}, d_{12}, d_{23}$ are the direction vectors between point 1 and 3, point 1 and 2, and point 2 and 3, respectively. $F_{new}$ is the net force matrix.

The angle was determined through its relationships to the direction vectors, which was written as:

$$\cos\theta = \left\langle \frac{d_{12}}{|d_{12}|}, \frac{d_{23}}{|d_{23}|} \right\rangle. \tag{9}$$

We used this angle to determine which boundary points needed the curvature force. If the angle between boundary points was too extreme, the curvature force activated. With an angle restriction, the points 1 and 3 pushed apart, which reduced the curvature. The most logical way to do this was through the vector $d_{13}$. Through this method, we pushed the points apart in the $d_{13}$ direction. Then, we subtracted this direction from the net force matrix, $F_{new}$. We derived this under the claim that the curvature force was the projection of $F_{new}$ on $d_{13}$ [1]. The relationship between the net force and the $d_{13}$ direction vector was shown in **Figure 6**. From this claim, we can gather that:

$$F_{new} = \alpha d_{13} + \beta d_{13}^{\perp}, \tag{10}$$

whereas

$$F^{c} = \alpha d_{13}. \tag{11}$$

From this equation $\alpha$ can be determined using dot products [1]. If one took the dot product of **Equation (10)**, they could determine that:

$$\alpha = \frac{\langle F_{new}, d_{13} \rangle}{\langle d_{13}, d_{13} \rangle}. \tag{12}$$

Using these terms, we assembled the curvature force. This force relied on the angles between boundary points. If that angle did not meet a certain criterion, the curvature force used the direction vector to restrict the curvature. We then added the curvature force to the net force equation, **Equation** (**2**), to maintain the circular shape of the cells:

$$\mu\frac{dB_i}{dt} = \sum_{j\in A_i}(F^a_{i,j} + F^r_{i,j}) + \sum_{j\in M_i}(F^m_{i,j}) + \sum_{j\in D_i}(F^p_{i,j} + F^v_{i,j} + F^c_{i,j}). \quad \textbf{(13)}$$

We decided to impose the curvature force on the border cells, as these cells were the only ones with observed unrealistic flattening. We determined the need for a curvature constraint by calculating the angle between neighboring boundary points within the same cell. To calculate the angle of any boundary point, we first found the vectors between neighboring points. In **Figure 6**, we found the vectors between points 1 and 2, and points 2 and 3. As defined by **Equation** (**9**), the angle calculation relied on the vectors, their magnitudes, and the dot product. Through this assessment, we determined that an appropriate critical angle would be $110^\circ$. Furthermore, any angle less than the critical angle received a curvature constraint. If the calculated angle at boundary point 2 was less than $110^\circ$, and all other conditions were met, then the curvature force was applied.

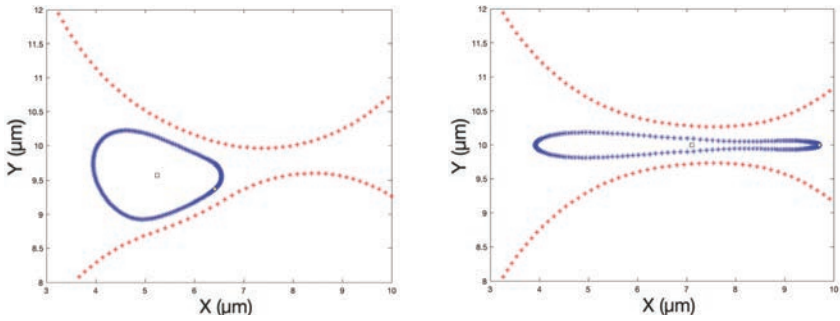
Once we determined the critical angle, we applied the curvature force to a boundary point's neighbors only if the force reduced their angle. We determined this through the sign of alpha in **Equation** (**12**). Thus, indicating whether the vector between the neighbors of the boundary point, relative to the force vector, followed the same direction. If alpha was positive, then we applied the curvature force to the force vector of the respective point; otherwise, the curvature constraint was not applied. Essentially, we only applied the curvature force when the point's direction vector followed the same direction as the direction vector between the point and its boundary point. If alpha was negative, we applied the curvature force to the force vector of the corresponding boundary point.

We first implemented the curvature force in a simplified model. We observed that when the curvature force was needed, it was either applied to both neighboring points or neither. In addition, the magnitude of the curvature force applied to the neighboring boundary points was equal. This behavior was expected since our egg chamber was completely symmetrical.

# 3. Results

### 3.1 New Force Implementations

Once we included a more realistic migratory force and curvature force, we found different simulation results. Below are figures that capture the border cell in the middle of the simulation, demonstrating the importance of appropriate implementation of direction for the migratory force. In each figure, all conditions are the same, except for the implementation of the migration force. Initially, in **Figure 7a**, the border cell had a preference towards the downward direction. This movement was asymmetrical and did not capture the appropriate or expected behavior. After we corrected this, the border cell migrated symmetrically, and moved from one side of the egg chamber to the other, as shown in **Figure 7b**.




**a.** **b.**

**Figure 7:** Comparison of the migratory force implementations. Simplified egg chamber with 2 nurse cells (red boundary points) and 1 border cell (blue boundary points). Captured at $t = 0.6944$ minutes into the simulation. **(a)** Past implementation of the migration force (undesirable behavior of border cell moving in the downwards direction). **(b)** Fixed/current implementation of the migration force. Border cell is moving from the anterior to posterior area of the oocyte (as desired).

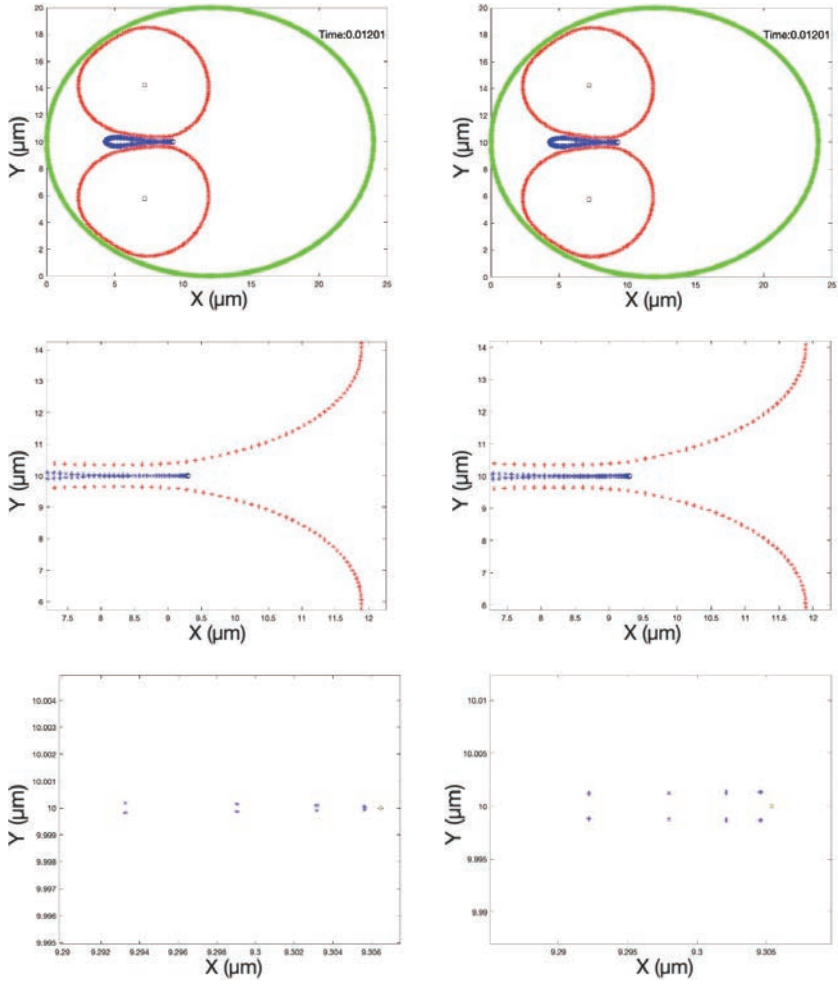



**Figure 8:** Egg chamber without and with the curvature force applied. **8a** depicts the chamber without curvature, captured at $t = 0.3336$ minutes into the simulation. **8b**, captured at $t = 0.3336$ minutes into the simulation, depicts the chamber with curvature.

Furthermore, with the new implementation of a curvature constraint, we were able to achieve more realistic cell migration behaviors. Previously during the simulation, the border cells would flatten completely when moving through the extracellular space between nurse cells, as seen in **Figure 8a**. Specifically, the leading boundary point of the migrating cell would approach an extreme angle of 0°. With the new implementation, in **Figure 8b** we still observed compression of the border cell, which was somewhat expected, but it never completely flattened.

### 3.2 Full Egg Chamber Simulation

Once we modified the migratory force and implemented the curvature force, we were able to run a simulation of the full egg chamber. This egg chamber contained a cluster of four border cells, six nurse cells, and an oocyte depicted at the far right of the chamber. In the initial stage, the border cells sat at the entrance to the migratory pathway. Then, the first border cell migrated through the junctions between the nurse cells. As it did this, the border cell flattened and stretched out to fit through the junction and move through the chamber. However, this flattening was much less extreme than earlier results. As the cell moved through the chamber, it still preserved curvature. Additionally, the leading border cell pulled the cluster along with it as it migrated, particularly the second and third border cells. Through this simulation, we obtained a partial migration through the chamber. These results can be seen in **Figure 9**. After this point in the simulation, the lead cells continued to flatten, though they still satisfied the curvature constraint. The top and bottom border cells pushed backward, which was likely because of the lack of space filled by the nurse cells.

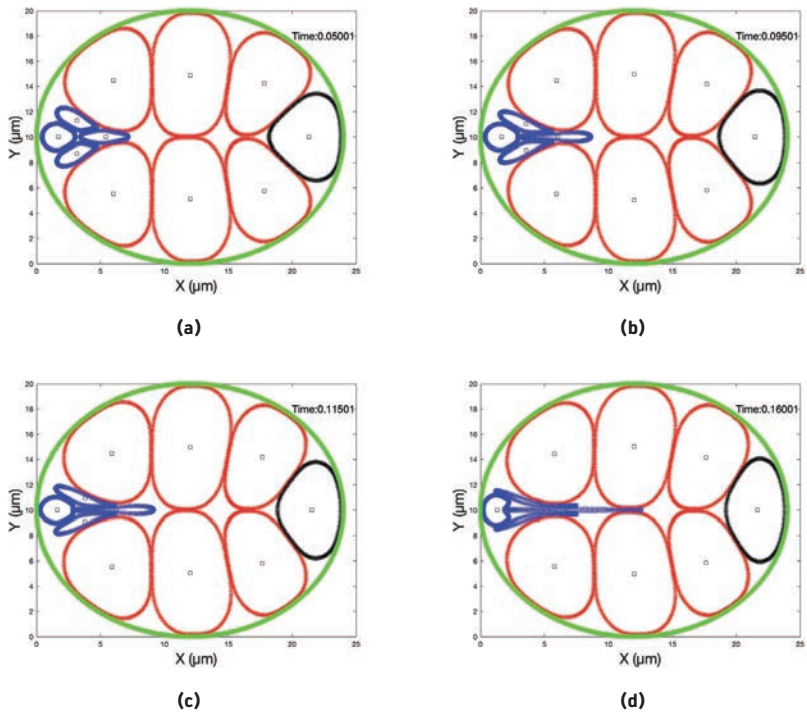



**Figure 9:** Progression of the cluster of border cells through the full egg chamber (6 nurse cells, 4 border cells, and the oocyte). **(a)** Captured at 1.3892 minutes. **(b)** Captured at 2.6392 minutes. **(c)** Captured at 3.1947 minutes. **(d)** Captured at 4.4447 minutes into the simulation, depicts the chamber with curvature.

We were able to simulate complex boundaries as cell membranes. After using area constraints to expand the areas to specific targets for border and nurse cells, we maintained a constant area. The spring forces accounted for boundary forces and negated clustering. Moreover, the adhesive and repulsive forces established close contact between neighboring cells while the migratory force incited cells to migrate. As the cell migrated, the curvature force prevented extensive flattening. While time progressed, the cells moved in respect to each other, area constraints, and the chemical gradient. This behavior is derived from globally valid force balance equations. The progression of clustered border cells through surrounding nurse cells through gaps is not due to local polarization signals but as a local response of global forces due to geometric spacing between guiding cells. The importance of extracellular geometry on clustered cell migration has typically been considered less important than other aspects of the system. However, our group's work with collaborators in Dr. Starz-Gaiano's lab has suggested that such geometry, including gaps between nurse cells, can have significant impact on cluster migration including timing of migration completion if completed at all [8]. With these implications, further research can be done on the geometrical impact of the egg chamber on cell migration.

# 4. Discussion

### 4.1 Key Findings

Initially, we ran into issues with clustering, spiraling, and flattening along point junctions for the border cells. We determined that the issue arose from faulty parameters and the egg chamber's setup. An eight-cell egg chamber had substantial vacant space that left room for the cells to grow and spiral. In nature, the *Drosophila melanogaster* egg chamber does not have considerable empty space. To combat this, we added two more nurse cells and an oocyte. Adding in these extra constraints removed the extra space from the model and prevented the cells from expanding unrealistically.

However, with a more compact chamber, we ran into issues with cell deflation and the direction of movement. The sensitivity and significance of spatial orientation in our model indicated that the geometry of the chamber could have a greater impact on the migratory process. To simulate migration amid these constraints, we further manipulated our forces. Since the volume force only regulated size and not shape, we needed to include a curvature force. We also ran tests on the individual forces to determine the directions of their magnitudes. After running these experiments, modifying the migration force accordingly, and including the curvature force, we were able to depict migration more accurately on a small scale. This new initial junction and force

balance allowed us to mostly simulate realistic migration of one border cell through the chamber. This border cell migrated towards the oocyte and partially dragged its neighboring border cells. As these cells moved, they flattened while satisfying the curvature constraint, and pushed the top and bottom border cell backward.

Our findings were consistent with those found in scientific literature. The papers *Two Rac1 pools integrate the direction and coordination of collective cell migration* and *Quantitative 3D analysis of complex single border cell behaviors in coordinated collective cell migration* suggest that a detailed representation of the boundary between clustered cells and between clustered cells and surrounding nurse cells (including potential gaps between them) is important and influential to the migratory process [3] [14]. These are more motivational in nature and suggest that the different physical variations could imply overall patterns within cluster and binding strength [3] [14]. In the future, we hope to compare an extended 3D version of our boundary point model with these data (or other data such as those from the Starz-Gaiano lab).

### 4.2 Interpretations

Our results were significant to the development of our model. Prior to this, the simulation extensively ran through pre-migratory stages. With the development of neighborhoods and time analysis, the model ran efficiently and quickly. Furthermore, through parameter manipulations, junction manipulations, and the development of new forces, we largely simulated the migration of one border cell. The migrating border cell pulled its neighboring border cells along with it, which was realistic considering migration *in vivo*. As these cells moved, they maintained curvature while flattening somewhat to fit through the chamber. We were successful in more realistically balancing flattening and curvature. Another promising part of the simulation was the pause before migration. After the pre-migratory stage, the border cells paused before moving across the gap: they moved slowly at first, speeding up when they slipped between the nurse cells. However, the displacement of the rear border cells was questionable. The top and bottom of the cluster appeared to move backwards as the simulation progressed. This could be realistic if chemoattractant was higher in the back, however, net movement would still likely be forward or stalled. Regardless, for the current gradient the rear cells should not have backward displacement. This is likely due to the lack of space filled by the nurse cells. This displacement could also arise from the pushing of neighboring border cells, but we would expect the rear cell to be pulled. Another potential cause could be the lack of force balance in initial stages, which could have also affected the ending stages of migration.

Additionally, the border cell did not fully make it to the oocyte. After extensive simulation time, the first border cell intersected with the

rear of the cluster. This is presumably due to the lack of space filled by nurse cells. A lack of proper force balance in initial stages could have also affected ending stages of migration. Or this may be an issue regarding density of boundary points. Since the cells flatten to migrate through the chamber, the volume force causes the cells to expand horizontally, thus increasing the distance from the cell center. This in turn affects the spring force and can cause clustering, leading to unrealistic trends in the simulation, such as cell intersections. We will continue to adjust parameters to avoid these non-physical results.

Although the border cells did not fully make it through the chamber and deflated to fit through junctions, the deflation was much less extensive than those from previous simulations, and the phenomena exhibited more realistic physical behaviors. We saw the migratory force move in the horizontal direction and saw the border cells migrate and pull each other along as they did so, without extensive clustering, spiraling, or flattening. Finally, this was all done at a more efficient pace with neighborhoods.

### 4.3 Implications

From our present results, we can deduce that the simulation setup is pivotal to successfully modeling migration. Through the simulation, we found an efficient force balance between the volume, spring, migration, adhesive, repulsive, and curvature forces. This allowed for a partially successful migration process. Since we measured this force balance from experimental adjustments, it should be applicable to varied models, regardless of cell count. We also determined that the geometrical setup impacted results. Chambers with too much empty space caused cell spiraling and chambers without enough space caused cell clustering. This could impact the view that the geometry of the chamber has little impact on migration and could lead to further research in this area.

Furthermore, we conclude that the simulation speed may need to be sacrificed for the necessary force balance without clustering and spiraling along junctions. Although, with time analysis efforts, we ran the simulation at a faster rate than before and witnessed new interactions within the egg chamber. The complex boundary mathematical model required changes and constraints to run efficiently. Through these experiments, we came closer to finding the right parameters and force constants that would allow the border cells to realistically migrate.

This will aid future scholars in their understanding of cell migration. Through modeling, the scientific community can learn more about migration and the biological processes it affects. This may affect further studies on cancer metastasis, wound healing, and development.

However, the model requires further constraints to realistically model cell migration. We hypothesize that further development of the curvature force, further parameter testing, and the inclusion of a more realistic egg chamber will aid in simulation efforts.

# 5. Conclusion

Through this research, we were able to partially simulate cell migration in a full egg chamber with complex boundaries. We extended a previous model to a more complicated and realistic chamber with defined boundaries that represented cell membranes. We developed spring and volume forces unique to a complex boundary model and determined that neighborhoods reduce unnecessary interactions and can increase the speed of the simulation. Furthermore, we found that unrealistic phenomena arose from faulty parameters and the setup of the chamber. The force balance was very delicate, and deviations within this balance caused problematic trends. We determined that the balance must be consistent throughout the simulation process. We also located errors within the migratory force implementation and included a curvature force to have a more realistic model. We developed methods for including the correct magnitudes, directions, and applications of various forces within the chamber. Experimental adjustments and tests have continuously aided us in better simulating a realistic model of cell migration and doing it in a timely and efficient manner.

As a result of this study, we learned the importance of avoiding clustering in initial stages, keeping the forces balanced so that the model was accurate, and avoiding unnecessary empty space. Changes in the migratory process indicated that there was a stronger local response of global forces due to geometric spacing between guiding cells. This suggested that extracellular geometry has a larger impact on clustered cell migration than previously believed. Through these developments and conclusions, we were able to largely simulate realistic migration of one border cell through the chamber. This border cell migrated towards the oocyte and partially dragged its neighboring border cells. As these cells moved, they flattened while satisfying the curvature constraint, and pushed the top and bottom border cell backward. This simulation also included the pause before migration, which is realistic in our model. We found that the inclusion of a curvature force, modification of the migratory force, and changes of the parameters and set up allowed us to more successfully and efficiently simulate cell migration within the *Drosophila melanogaster* egg chamber. As a result of the developments in the model, we simulated more realistic migration without inappropriate flattening or clustering at an efficient pace. Considering this, we can ascertain the correct methods to develop further models and more complex simulations in the future. Furthermore, considering our results regarding extracellular geometry, further research can be done to understand its impact in the biological system.

This progress is significant because further development of the model more accurately depicts real life observations and helps us gain understanding of the migratory process. Furthermore, this work aids in the

collaborative work with Dr. Starz-Gaiano's Lab. As we learn more about simulating cell migration, we gain a new perspective about cell migration and its collaborative work. This will allow future studies to more realistically model and understand migration in new and more complex ways, ultimately enabling scholars to learn more about the biological processes it affects, such as cancer metastasis, wound healing, and development. As the model is developed, further understanding will be obtained on the process of cell migration and its many analogs. There has been considerable progress in the simulation, and further adaptations will only more successfully enable the full simulation of the migratory process.

# 6. Future Directions and Limitations

In the future we would like to fully simulate migration through the egg chamber in 2D and 3D. We aim to see the entire migratory cluster migrate to the oocyte. During this process, we hope to see the initial border cell pull the cluster behind it as it migrates. To avoid non-physical results, such as backward movement, we will continue to adjust parameters. We would also like to find the ideal force balance that most realistically simulates migration.

We hope to continue reviewing the curvature force for optimization. Even with the curvature force, the cells still flatten to some degree, which may or may not be realistic in our model. Ideally, the border cells would push through the nurse cells and compress the migratory pathway some, rather than compress themselves. The eventual flattening occurs when the other forces within the egg chamber "overpower" the curvature force. We plan to run a series of tests to find the most optimized and constant set of parameters. We plan to work with the High-Performance Computing Facility at UMBC to do so.

We may also consider other aspects of the curvature force. This force was only enacted when specific criteria were met according to the sign and angle. Consequently, the cell was given more ability to deflate before the curvature force was enacted. Additionally, in certain conditions, the curvature constraint only seemed to postpone, rather than prevent flattening. In the future, we may experiment with this angle to better control the cell structure. We may decide to calculate a critical angle that is relative to the other boundary point angles within the same cell. Initially, we hypothesize that the points would start out with 180° angles, and they would decrease in size as the simulation runs. We claim that few points would be less than 90°. The initial angle of 110° meets a substantial amount of points criterion and updates forces efficiently. This, however, may require adjustments.

A potential limitation for the curvature force is that the measurements are very local. A potential solution could involve looking at average angles between points within cells and comparing them. If an angle is small relative to its neighbors, then the curvature is high. Using this angle measurement, we could implement a restriction on the curvature globally. Another potential limitation is that the model still runs fairly slowly. The simulation and coding time is extensive. While the neighborhoods do help in reducing time, we cannot constrain them too much without neglecting important interactions. Since there is a substantial amount of points examined in the model, there is only so much we can do to speed up the simulation process. In the future, we may investigate more high-speed processes.

# Acknowledgements

Special acknowledgments to NSF-NIGMS (#1953423) for the three-year grant and funding. We would also like to acknowledge the work of Dr. Bradford Peercy and Dr. Starz-Gaiano for their guidance and their advancements in the field of cell migration research. We thank the members of Dr. Starz-Gaino's lab for their assistance and their work in migration. We also would like to thank the Department of Mathematics and Statistics and the Department of Biological Sciences at the University of Maryland, Baltimore County for making this opportunity for research possible. Finally, we thank URISE, Meyerhoff, HHMI for their support and resources.

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**Esther Olajide**
**Irina Sbornova**
**Madi Kore**

Dr. Nykia Walker

**Department of Biological Sciences**

# Breast Cancer-Induced Changes in Adipose Tissue Morphology

# Biographies

**Esther Olajide** is a senior studying biochemistry and molecular biology. She is a member of the NIH Undergraduate Research Training Initiative for Student Enhancement (U-RISE) and the Meyerhoff Scholars Program at the University of Maryland, Baltimore County. She expects to graduate in the spring of 2023. Upon graduation, Esther will attend a postbaccalaureate-research program to further her understanding of cancer biology and metastasis. She then plans to pursue a dual MD/Ph.D. degree with a research focus in cancer biology and metastasis. Esther joined Dr. Nykia Walker's lab in the fall of 2021 and has the opportunity to conduct sustained research under Dr. Walker's mentorship. She would like to give special thanks to Dr. Walker for being an outstanding mentor who gave immersive support in becoming a co-author of a manuscript for the *UMBC Review*. Her excellent mentorship has helped shape Esther into a stronger future physician-scientist.

**Irina Sbornova** is a senior, pursuing a dual degree in biological sciences and psychology. She is a member of the Phi Beta Kappa Honors Society and is affiliated with the Honors College Program at UMBC. Upon graduating in the spring of 2023, she intends to dedicate her future graduate studies to neuroscience, focusing on the biochemical mechanisms of emotional regulation. During the start of her undergraduate career, Irina had the opportunity to conduct research in Dr. Nykia Walker's lab, looking at adipose tissue morphology in breast cancer. That work has allowed Irina the opportunity to present at URCAD and co-author a paper for the

*UMBC Review*. Irina would like to recognize Dr. Walker's continued support and immense contribution to this project, as well as to her own scientific journey. Dr. Walker, as Irina's first research mentor, has helped her greatly in discovering her passion for biology and scientific research.

**Madi Kore** is currently a college junior with a biological sciences major B.S. with a minor in psychology. She is a member of the Meyerhoff Scholars Program. She expects to graduate from UMBC in the fall of 2024. After she completes her undergraduate education at UMBC, she plans to pursue her dual MD/PhD degree, focusing her studies on cancer biology. She is interested in cancer research as a career because of the work she conducted in a breast cancer research lab run by Dr. Nykia Walker. Dr. Walker's lab works with TNBC, a rare form of breast cancer. With the help of Dr. Walker as a phenomenal mentor, Madi has been able to present her research project at SURF and URCAD, as well as become a published co-author for the *UMBC Review*. Madi would like to acknowledge Dr. Walker for her unwavering support throughout her undergraduate research experience.

# Research Journey

Cancer biology is an ever-growing field constantly evolving our understanding of the cell machinery and mechanisms. As a child, I always loved the sciences and wanted to initially become a physician to complete my desires. During the summer of 2021, I had the opportunity of partaking in the UT at Austin, Dell Medical School Livestrong Cancer Institute (LCI-SURF) summer research program where I helped conclude the project "Characterization of Left versus Right-Sided Colorectal Tumor Sidedness" under the mentorship of Dr. Stephen Yi. We studied how different factors contribute to a worse prognosis seen in patients and identified genes that contribute the most to either left or right sided cancer. I had the chance to collaborate and interact with scientists and learn the impact of research and its translation into the clinic. I decided to continue my spark for research in Dr. Nykia Walker's lab where we study triple-negative breast cancer (TNBC) and the role of adipose tissue in breast cancer progression. Being in the lab helped solidify my yearning to becoming a physician-scientist with a focus in cancer biology. By studying the changes in mammary fat cells, we can potentially create preventative measures against breast cancer and save lives.

**– Esther Olajide**

# Abstract

Adipocytes in breast cancer (BC) produce growth factors that contribute to cell proliferation, tumorigenesis, and metastasis. Adipose cells adjacent to BC cells are called cancer-associated adipocytes (CAA) and help BC survivorship. Tumors next to normal mammary fat cells change the surrounding tissue, prompting CAAs to appear smaller and irregularly shaped. We hypothesized that adipocytes in tumor tissue (control) will appear smaller than in untreated healthy tissue (vehicle). Specifically, the control group might have similar morphology to CAA compared to vehicle. To investigate, hematoxylin and eosin-stained (H&E) tissue were imaged at 20x magnification and analyzed using GIMP software. Over 30,000 cells were examined, and 54 images were captured from nine mice across three different treatment groups. Our results showed that extra-small cells are abundant across all treatment conditions. Additionally, adipose tumor samples exhibited a greater number of cells similar in size to CAAs compared to normal tissue. Lastly, we observed that the mammary fat pad tissue far from the tumor had similar morphology to CAAs. These results can potentially have clinical implications such as developing a diagnostic tool to screen for breast cancer by examining the adipose tissue morphological differences in patients.

# Introduction

Breast cancer (BC) is the most common cancer among women, globally. In 2022, it is predicted that 287,850 invasive breast cancer cases will be diagnosed in US women alone.[1] The aggressive nature of breast cancer is attributed to its highly invasive, metastatic characteristic and rate of recurrence compared to other cancers, such as brain and lung cancers.[2]

Triple-negative breast cancer (TNBC) is an aggressive variant of breast cancer with an especially poor prognosis.[10] Unlike other types of BC, breast tissue in TNBC does not express specific key proteins, such as human epidermal growth factor receptor 2 (HER2), estrogen, and progesterone (ER/PR) receptors. These proteins are used as biomarkers in other types of BC and are the targets of many BC treatments. For example, HER2+ BC is commonly treated with Herceptin (trastuzumab) and ER+ BC is treated with tamoxifen. Herceptin is a humanized mouse mAB that targets HER2 by disrupting its ability to dimerize, therefore stopping the proliferation and growth of cancerous cells.[7] Tamoxifen, a selective estrogen receptor modulator (SERM), competitively binds to ER which prevents the recruitment of coactivator proteins, ultimately stopping the growth and proliferation of BC cells.[8] Since TNBC lacks growth hormone receptors, the growth of TNBC is believed to occur through a signaling pathway involving the pro-inflammatory cytokines IL-6 and IL-8. Inhibition of these cytokines inhibited TNBC growth *in vitro*, indicating that TNBC growth and tumorigenicity depend on the expression and signaling of these inflammatory cytokines. Although inhibition of IL-6 and IL-8 could be a potential novel treatment for TNBC, further research is needed to prove the effectiveness of this treatment.[9] Even though TNBC accounts for 10-15% of all breast cancers, only limited treatments are currently available for this fatal disease due to the lack of receptors.[10] TNBC is different from other types of BC because TNBC cells metastasize faster and are more invasive.[4]

Due to TNBC cells lacking the growth of hormonal receptors, this type of BC does not respond to hormonal therapeutics and drugs such as tamoxifen and Herceptin. The current standard treatment option is chemotherapy complementary to surgery. These treatment options are based on the stage grading system of breast cancer. The different stages of breast cancer range from stage I-IV, and as the stages increase, the cancer is more aggressive and harder to treat. During the earliest form of TNBC, the tumor may be small enough to be removed by surgery that either conserves the breast or a mastectomy is performed. Although surgery performed in the earlier stages of cancer is effective, many complications can arise from this invasive technique. Possible issues include higher risks of infections post-surgery, fat necrosis, the tissue death, and post-surgical pain.[11] Outside of complications created directly from the surgery, other issues adjacent include the recovery process which involves a reduction

in quality of life and activity.[11] Oftentimes, chemotherapy is used in conjunction with surgery prior to or after the removal of the cancerous cells. Chemotherapy, the use of cytotoxic drugs to kill fast-growing cells, is most commonly used during the later stages when the cancer is more belligerent and has metastasized to other parts of the body. The common drugs that are used include anthracyclines, taxanes, and gemcitabine and these drugs can be administered alone or in combination. Further, in the case of an individual with Breast Cancer Gene 1 (BRAC1) and those whose breast cancer no longer responds to treatment, other platinum chemotherapy drugs are used such as cisplatin or targeted drugs including PARP inhibitors such as olaparib. The short-term side effects include hair loss, fatigue, skin and nail changes, and nerve damage. In addition, the long-term effects are infertility, bone thinning, and other cancers such as leukemia, a cancer of blood cells.[12]

Certain populations are at a higher risk of developing TNBC. Studies have found that TNBC is three times more likely to occur in young women of African American descent. It has also been found that African Americans with late-stage TNBC had the worst prognosis and the poorest survival rates compared to other groups.[12] Another major risk factor for developing BC is obesity.[3] In obesity, the structure and metabolism of adipose tissue are greatly disturbed. As described in the article, white adipose tissue (WAT) is the largest endocrine organ that releases adipokines and cytokines. Further, adipokines are associated with physiological and metabolic signaling cascades and aid in insulin signaling, glucose uptake, and fatty oxidation.[14] Likewise, cytokines aid in inflammation regulation and adaptive angiogenesis. Upon weight gain and obesity, the environment changes from white adipose tissue to observed inflamed and dysfunctional adipocytes with immune cell invasions and stromal vascular fractions. Specifically, obesity changes the adipose tissue into a pro-inflammatory environment.

A fully differentiated breast consists of two compartments: the epithelial compartment and the connective tissue compartment. The epithelial compartment contains glands with branched ducts and tubuloalveolar components. However, the connective tissue compartment, also referred to as the breast fat pad, is composed primarily of adipose tissue. Adipose tissue is vital because it comprises most of the breast tissue and mammary gland to help maintain correct breast form and energy balance.[2] Under normal physiological conditions, natural epithelial and fat cells are limited in interaction due to separation by the basement membrane. Under abnormal circumstances, BC will break through the basement membrane and then interact with the healthy tissue, inducing changes in the breast microenvironment.

During its growth, a tumor induces certain changes within the surrounding tissue. These changes tend to be favorable for tumor survival, promoting its growth. Collectively, the "cells, molecules, and blood

vessels that surround and feed a tumor cell" are referred to as the tumor microenvironment (TME).[15] Recent studies have improved our understanding of the TME in invasive BC, especially the mechanisms by which cytokines within the TME promote tumor growth and metastasis.[2] In TNBC, adipocytes are one of the main components of the TME. Tumor-surrounding adipose tissue is largely composed of cancer-associated adipocytes (CAAs). CAAs are known to be involved in BC survivorship and have been confirmed in human samples as a hallmark of BC.[2] Cancerous cells will contact matured adipocytes which leads to the morphological change of normal cells into CAAs.

Recent findings have shown that CAA-BC interacts by releasing hormonal factors which promote BC progression and contribute to reshaping tumor characteristics.[2] CAAs exhibit altered biological characteristics such as having a smaller size, irregular morphology, sporadic dispersion of lipid content, and the overexpression of cytokines that promote the metastasis of breast cancer.[5] Specifically, the loss of lipid content is linked to a decrease in late adipocyte differentiation markers.

The female breast has a high content of adipose tissue. The main function of adipose tissue in the breast is to store energy and release it when it is needed in the body. Although adipocytes were thought to only function as energy storage, new studies have shown that adipocytes function as endocrine cells by producing hormones, growth factors, cytokines, and other molecules known as adipokines.[2] Several studies have shown that there is an upregulation of growth factors secreted by CAAs. These CAA-derived growth factors aid in the progression of breast cancer.[5]

Although adipose tissue is a major component of breast tissue, its role in the development of TNBC has not been heavily studied. A recent study analyzed markers involved in the progression of ductal carcinoma *in situ* (DCIS) into ipsilateral invasive breast cancer (iIBC).[16] They hypothesized that breast adipocyte hypertrophy in DCIS, which is the increase in the size of adipocytes indicative of dysfunctional adipose tissue, is associated with a risk of development of iIBC. Their results suggest that large breast adipocytes in DCIS are in fact associated with a risk of subsequent iIBC. Although the tumor-surrounding CAAs in our study displayed smaller than normal phenotypes, the differences in these results may be due to differences in a breast cancer type. These findings indicate that breast adipocyte size is a promising prognostic tool for DCIS as well as other types of breast cancer.

As discussed, adipose tissue plays a significant role in the development of breast cancer. The morphological changes seen in normal tissue as compared to cancerous tissue could serve as potential diagnostic markers for breast cancer and other related diseases such as cachexia, which is the loss of skeletal muscle and fat common in patients with advanced cancer.[2] In addition, adipose tissue-derived growth factors could

be important as a target or marker of breast cancer. A recent study explored the effects of a secretory protein in CAA's, FUCA2, on TNBC cell behavior. They found that FUCA2 exposure enhanced tumorigenesis and metastasis of TNBC.[17]

Our research focuses on evaluating changes in morphology and size of the tumor-bearing mammary fat pad adipocytes (control) compared to healthy tissue (vehicle). We hypothesized that adipocytes in tumor tissue will be smaller and less consistent in size compared to the untreated, healthy cells in mice. In our study, we examine over 30,000 cells across 54 images by nine mice capturing the morphological changes induced by BC cells through hematoxylin and eosin (H&E) stromal tissue and GIMP 2.10.30 software for analysis.

Our goal is to find potential biomarkers to use clinically as a measure to diagnose patients with breast cancer. Breast cancer types are subdivided according to the expression of specific molecular markers. Identification of molecular markers for TNBC allows for predicting patient outcomes and response to therapy. Specifically, 60-70% of breast cancers overexpress ER while 15-20% overexpress HER2. ER-positive tumors are treated via hormonal therapies while HER-2-positive cancers respond to HER-2-specific antibodies and inhibitors.[18] Since growth-like receptors are absent in TNBC, targeted therapy is not available. Thus, it is critical to identify biomarkers for TNBC to aid in the clinical prognosis of the disease.

# Materials and Methodology

This project utilized a mouse model of TNBC. Breast tissue slides were previously obtained and stained with hematoxylin and eosin. We looked at three treatment groups: control tumor (where mice were injected with human BC tumors), vehicle adjacent, and vehicle distal. Mice in both of the vehicle groups received saline injections. In control tumor and vehicle adjacent groups, tissue samples were obtained near the site of the injection, while vehicle distal samples were taken from a non-injected mammary pad. Both vehicle groups served as our negative control and were used to represent healthy tissue. Vehicle distal, in particular, was used to control for fat pad changes from mere trauma at the injection site.

A comparative analysis was conducted between healthy mice (vehicle distal and vehicle adjacent) and tumor-bearing mice (control tumor). A total of nine female nod/SCID mice were used in this experiment ($n$ = 3 per group) and a total of 54 20X magnification light microscopy images ($n$ = 6 per mouse) were obtained, totaling 18 images per group. The image areas were randomly selected from a tissue slide.

**Figure 1: Cell Counting and Color Assignment Schematic**

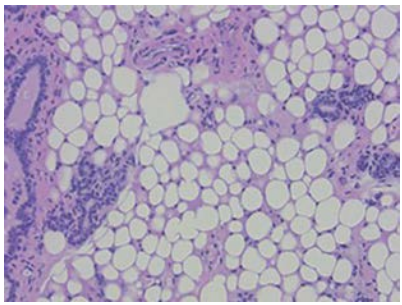


**Figure 1A:** 20X image snapshot of adipose tissue staining by a light microscope. Areas of interest were assigned at random and captured to be edited using the GIMP software.

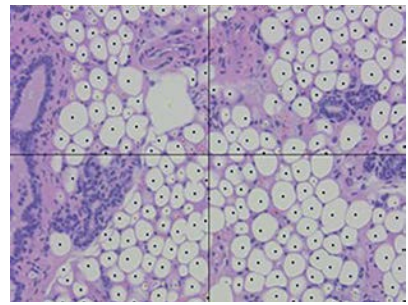


**Figure 1B:** A schematic view of the color-size counting scheme utilized to assign adipose cells into specific size categories.

To analyze the morphological changes in adipocyte sizes, the following protocol was employed: For each image, the resulting resolution is 2560 by 1920 pixels and was used to determine the uniform quadrant length and width in the image-editing software, GIMP 2.10.30. The purpose of the quadrant function is to provide a barrier and reference during cell counting. Each quadrant was then analyzed one at a time. The sizes were measured using a color-coded relative size scale of XS-XL (**Figure 1B**). For later comparisons, the sizes were also assigned a numerical value with a range from 1 (XS) to 5 (XL). Cell counting was performed using the GIMP software as well. Only visibly well-defined cells were accounted for. Cells that spanned more than one quadrant were only accounted for once. Since this study analyzed the relative sizes of cells, there is a reasonable chance of personal bias or inconsistencies during data collection. To minimize this effect, sizes were compared between images to reach homogeneity in size allocation. Sizes were compared within a mouse and among all mice.

The color-to-size designation for all the cells remained consistent between all images. Such that XS corresponded to red, S to green, M to blue, L to black, and XL to orange (**Figure 1B**). After designating the corresponding color assignments, the number of cells based on the varying sizes was counted and recorded. The cells were assigned to a number (1 through 5) corresponding to sizes XS through XL and the total size-specific cell count, mean, and proportions were generated following graphical analysis. All graphs and statistics were generated using Excel. An example of the counting procedure is depicted in (**Table 1**).

**Table 1: Statistical Analysis of Cancerous and Non-cancerous Mouse Pad Tissue**

| Total Cell Counts | Vehicle Distal | Control Tumor | Vehicle Adjacent |
|---|---|---|---|
| # XS | 4161 | 12811 | 6070 |
| # S | 1042 | 3140 | 1167 |
| # M | 1448 | 1062 | 790 |
| # L | 725 | 400 | 726 |
| # XL | 40 | 123 | 240 |
| Total | 7416 | 17536 | 8993 |

**Table 1A:** Total cell count designated by size and treatment groups.

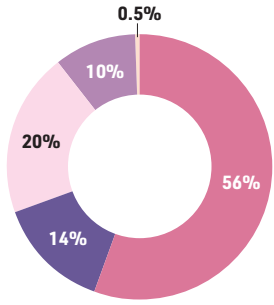
| Total Cell Counts | Vehicle Distal | Control Tumor | Vehicle Adjacent |
|---|---|---|---|
| Average Size | 1.99 ± 0.50 | 1.44 ± 0.04 | 1.82 ± 0.09 |

**Table 1B:** Calculated mean size of the three treatment groups based on a scale of 1-5 (XS-XL) with ± SE.

| Total Cell Counts | Vehicle Distal | Control Tumor | Vehicle Adjacent |
|---|---|---|---|
| # XS | 55.66 | 72.95 | 61.13 |
| # S | 14.16 | 16.97 | 13.67 |
| # M | 19.71 | 6.43 | 10.78 |
| # L | 9.92 | 2.73 | 10.63 |
| # XL | 0.55 | 0.92 | 3.79 |

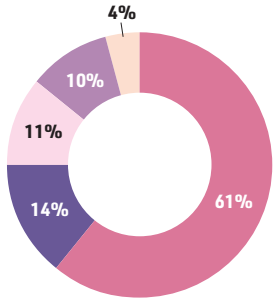
**Table 1C:** Size proportions percentages of healthy and non-healthy mice tissue across the three treatment groups.

**Figure 2: Size Distribution in Healthy and Tumor-Bearing Mice**

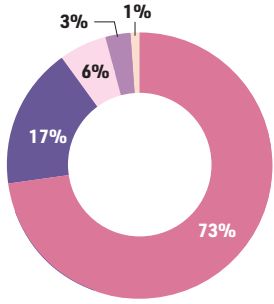

### Vehicle Distal

**Figure 2A:** Graphical description of the dispersion of sizes in a normal adipose tissue sample.




### Vehicle Adjacent

**Figure 2B:** Graphical description of the dispersion of sizes in a normal adipose tissue sample.




### Control Tumor

**Figure 2C:** Graphical description of the dispersion of sizes in abnormal adipose tissue samples.

**Figure 3: Comparative Schematic of Differences Between Normal and Cancer-Associated Adipocytes**

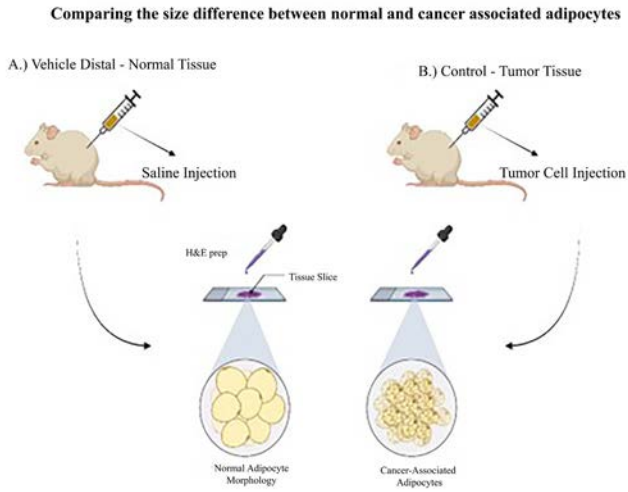



**Figure 3:** Schematic illustrating the morphological differences between normal and cancer-associated adipocytes. There were two treatment groups: vehicle distal and tumor-control. The vehicle group was injected with a saline solution and the control group was injected with tumor cells. Tissue samples were taken from both treatment groups and stained using H&E. Tissue samples taken from the vehicle group exhibited normal adipocyte morphology while tissue taken from the control group exhibited altered morphology, resembling CAA's. Healthy adipocytes display normal cell size, round shape, and large unilocular lipid droplets. CAAs display smaller cell sizes, irregular shapes, and dispersed lipid droplets.

# Results

First, we analyzed the total cell counts (**Table 1A**) and the average cell sizes (**Table 1B**) across all three treatment groups. The vehicle distal group, considered healthy tissue and not disturbed with post-injection trauma, had the largest average cell size (1.99 ± 0.5) combined with the lowest overall cell count ($n$ = 7,416). This suggests that adipocytes are generally bigger and occupy larger areas under normal conditions. Adipocytes of the vehicle adjacent group, which was also considered healthy tissue but was exposed to post-injection trauma, underwent moderate morphological changes. The average size of these cells was 1.82 ± 0.09 and the total cell count ($n$ = 8,993) was slightly larger than in the vehicle distal group. Interestingly, adipocytes of the control tumor group, which modeled for human BC, exhibited profound changes in morphology. The control tumor adipocytes had the smallest average cell size (1.44 ± 0.04) and a remarkably larger overall cell count ($n$ = 17,536) as compared to the other groups. Additionally, the number

of XS cells in the control tumor ($n$ = 12,811) was about two times bigger than in vehicle adjacent ($n$ = 6,070) and about three times bigger than in vehicle distal ($n$ = 4,161). Further, the healthy vehicle distal group, as compared to the cancerous control tumor group had six times as many L-sized cells ($n$ = 240 vs $n$ = 40) and two times as many XL-sized cells ($n$ = 240 vs $n$ = 123).

Next, we looked at the percent distribution of different cell sizes across the three treatment groups (**Table 1C**). For the purposes of this study, M- and L- sized cells were considered to be the normal adipocytes, as they are the most representative of healthy tissue. The proportion of M- and L-sized cells varied across the groups: 29.63% in vehicle distal (**Figure 2A**), 21.41% in vehicle adjacent (**Figure 2B**), and 9.17% in control tumor (**Figure 2C**). Further, the proportion of XL cells in the vehicle adjacent was 4.2 times larger (3.79%) than in control tumor (0.92%) and 6.9 times larger than in vehicle distal (0.55). Among all sizes, XS cells bear the most morphological resemblance to CAA's. As expected, the vehicle distal group had the lowest proportion of XS-sized cells (55.66%), while the control tumor had the highest proportion (72.95%).

# Discussion

The results of this study support our original hypothesis that adipocytes in BC tumor tissue would be smaller and less consistent in size. By comparing average cell sizes and their distributions across the treatment groups, we discerned a general trend for morphological changes in adipose tissue. Adipose tissue near a cancerous tumor (control tumor group) undergoes a reduction in size as compared to healthy tissue (vehicle distal). These changes were not due to injection-driven stress, as size distributions differed between the control tumor and vehicle adjacent groups.

The results of the present study further show that in the tumor-bearing control and healthy mice group, the most prevalent cell size is XS. In vehicle distal, the XS cell size is 55.66% of the total cell sizes, in the vehicle adjacent XS cell size is 61.13% of the total cell sizes and in the control, XS is 72.95% of the total cell size types (**Figure 2**). Also, the control group contains the greatest number of cells (17,536) compared to the normal adipose tissue samples.

In the control group, almost three-fourths of the total cell sizes are XS. Our results are consistent with the understanding that BC cells create a microenvironment to promote the proliferation of cancer-associated adipocytes.[2] CAAs are smaller in cell size, irregularly formed, and deficient in lipid content. Adipose cells adjacent to invasive tumor sites are involved in the progression of BC (**Figure 3**). The interactions between CAAs and BC shape the tumor microenvironment towards an oncogenic-driven state, promoting cell proliferation and tumor metastasis.

Specifically, CAAs are distinctive biomarkers for BC. The data support previous study findings that adipose tissue in BC tends to be smaller and irregular compared to healthy adipose tissues (**Figure 3**).[2] In addition, the results support the findings that BC cells are hallmarks of uncontrollable cell growth. The control tumor cell count is reported to be two times as abundant compared to the healthy adipose tissue in vehicle adjacent and 2.5 times as ample in comparison to vehicle distal.

In vehicle distal healthy adipose tissue, XS constituted two-thirds of the total cell sizes. The site of the vehicle adjacent relative to the control tumor is closer to the injection site compared to vehicle distal. In vehicle distal normal adipose morphology, XS is more than one-half of the total cell-size count. The differences in the proportion of XS cells in vehicle adjacent and vehicle distal can be attributed to the proximity of both healthy mice tissues to the tumor site injection. Hence, the vehicle adjacent is closest to the tumor sight compared to the vehicle distal and constitutes slightly more XS cells. Cells adjacent to cancerous breast cells are more likely to become less uniformed, lipid-filled, and regularly sized cells which are most likely occurring in vehicle adjacent.

Based on our research, we speculated that the tumor site will have fewer regular cells in comparison to the normal adipose tissue sights. Normal cell types were defined as M-L cell sizes. There was a higher percentage of healthy-sized adipocytes observed in the vehicle adjacent and vehicle distal groups in comparison to the tumor control. This finding supports our hypothesis that tumor-containing tissue will have fewer normal adipocytes because the BC cells are proliferating and promoting CAAs which consequently results in an observed scarcity of normal adipose tissue and cells. Our findings align with the current literature because CAAs are observed to be smaller and irregularly shaped due to the lack of lipid content.[2]

# Summary

In our study, we have observed differences in average adipocyte size and distribution based on the treatment group. Moreover, tumor-bearing tissue contains the highest amount of XS cells and XS cells are the dominant cell-size group across all treatment groups. The tumor tissue displayed a higher number of adipocytes resembling CAAs, as opposed to non-cancerous tissue. Further, both healthy vehicle groups contained a great amount of XS cells despite their proximity to the tumor injection site; however, vehicle distal contained the lowest number of XS. This suggests that the distance of the adipose tissue to the cancerous site plays a role in the number of XS cells expressed. Our findings support previous studies on the topic of adipose tissue remodeling supporting the growth and progression of breast cancer.[2]

For future directions, we would like to study differences in the shape of adipocytes in addition to size. Analyzing the shapes of adipocytes could provide even more meaningful variations among treatment groups since CAAs are both smaller in size and have abnormal figures.[2] In addition, the lipid content in the cells could be examined to further confirm the presence of CAA and cancerous cells and differentiate healthy cells. Genetic analysis could be done to identify changes in gene expression that led to a smaller size in tumor-surrounding adipose tissue. Using immunofluorescence, the tumor tissue could be screened for genes identified in the literature as CAA-specific to further confirm the identity of the adipose tissue.[17] We could also stain for adipose-derived growth factors and compare intensity among treatment groups. Adipose tissue is known to be the main contributor to normal breast morphology and energy maintenance, and conducts numerous metabolic functions in the body.[2] By studying this phenomenon of adipose tissue's role in BC, we are closer to creating therapeutics and preventative screening to help reduce the possible effects of BC in future patients.

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6

**Joshua Gray**

Dr. Fan Yang

**Department of Media and Communication Studies**

# Defining Best Practices in Crisis Communications for Institutions of Higher Education: Lessons Learned From the COVID-19 Pandemic

# Biography

**Joshua Gray** is a graduate of the UMBC Class of 2022 with dual Bachelor of Arts degrees in dance and media and communications and a minor in public administration and policy. He was a member of the Linehan Artist Scholars Program. Joshua is also a member of Phi Kappa Phi Honors Society and Omicron Delta Kappa Leadership Honor Society. In his senior year, Joshua was named an Undergraduate Research Award Scholar and completed research on political ideologies in Black Religious Institutions. His senior capstone project was an exploration of best practices in institutions of higher education as a reflection of the COVID-19 pandemic. Joshua currently serves as an All Source Intelligence Analyst in the United States Army.

Joshua would like to thank Dr. Patton and Dr. Yang of the Media and Communication Studies Department for their care and support during the inception and completion of this research project.

# Research Journey

This research reflects the communications channels and networks that emerged out of the COVID-19 pandemic and how they showed up at a particular university. The project seeks to identify best practices in higher education crisis communications.

This research draws inspiration from *The Society of the Spectacle* by Guy Debord to explore the best practices in crisis communications. My engagement with this media theory text revealed the importance of culturally competent and community-specific communication strategies in order to dismantle the "spectacle" and unite people based on the commonalities of lived experiences. From that analysis, several oral history interviews with university personnel involved in crisis communications were conducted at the University of Maryland, Baltimore County to identify in what ways the university's practices reflect or disrupt the logic of *The Society of the Spectacle*. Unearthed were three high-level best practices that lead to effective crisis communications strategies that are culturally competent and community-specific.

This paper is a research capstone completed in the Media and Communications Studies Department under the mentorship of Professor Fan Yang.

# Abstract

Institutions of higher education have the burden of managing internal and external crisis communications. The nature of a crisis is that it is unexpected, which then facilitates a knee-jerk response. Specifically, crises such as coronavirus disease (COVID-19) have redefined the need and scope of crisis communications. Considering this responsibility, what COVID-19 communications definitively tell us about crisis communications and the prominent approaches to meet the needs of such high-stakes situations is explored. The primary intention of this research is to make the case for culturally responsive crisis communications. The paper uses the work of scholar Guy Debord, *The Society of the Spectacle*, to define what crisis communications should not be: a Spectacle. Based on that understanding, a case study of the University of Maryland, Baltimore County (UMBC) is developed in order to demonstrate crisis communications strategies that "disrupted the Spectacle" and were rooted in characteristics of the university's culture. Finally, based on *The Society of the Spectacle* and UMBC's case study, three best approaches are offered to improve crisis communications: (1) Leaders are symbols of institutional culture... make sure they are visible; (2) Involve all stakeholders in crisis communications planning and; (3) Diversify the mediums used for crisis communications. This research ultimately acts as a guide to effectively and appropriately respond to a crisis within an institution of higher education.

# Introduction

Many in higher education crisis communications vividly remember the days and weeks leading up to the first closure due to the COVID-19 pandemic. Crisis communications practitioners worldwide had to take their plans and strategies, prepared for moments such as this, to operationalize messaging that would convey the ever-evolving state of the pandemic and their institution's response to it. Through emails, social media posts, mass text messages, robocalls, and so much more, this uncertain and terrifying disease had to be announced and responded to. Students had to be flown from study abroad experiences as borders were closed, sanitation and personal protective equipment had to be disseminated, campus buildings and services had to be shut down, students needed to be sent home, and employees needed to be let go to ensure the financial health of the institution. The decisions that had to be made were plentiful, and the high-level and convoluted communications that needed to be conceived of and delivered to community members already on high alert shook the cores of institutions far and wide.

As the pandemic persists and institutions of higher education still wade in the complexities of the pandemic's uncertainties, effective communications practices are more important than ever before. Since the early days of the pandemic, universities have had to shut down and open up their operations several times, and their communications strategies act as the nucleus of their crisis management.

In moments of crisis on college campuses, institutions have the burden of managing internal and external communications practically, appropriately, and immediately. The nature of a crisis is that it is unexpected, which then facilitates a knee-jerk response. Considering this responsibility, what are the prominent methods used in colleges and universities to manage crisis communications? Specifically, crises such as coronavirus disease COVID-19 have redefined the need and scope of crisis communications. COVID-19 has led to what some are referring to as "crisis contagion," which describes how the "pandemic rapidly spread causing a range of 'knock-on' impacts" (Macnamara, 2021). In other words, COVID-19 developed from being a health crisis to crises of travel, economics, work, social isolation, and more. Within institutions of higher education, these crises needed to be communicated to parents, students, faculty, staff, neighboring communities, governance boards, and local, state, and federal political actors. This "crisis contagion" made the work of a communications professional extraordinarily challenging and will forever leave an impact on the industry. What, however, does COVID-19 communications definitively tell us about crisis communications and the prominent approaches to meet the needs of such high-stakes situations? Furthermore, how can discoveries in this body of work inform the

development of best practices used within institutions of higher education to respond to crises by deploying strategic and proven communication approaches?

## What Constitutes a Crisis

A crisis can be defined in more ways than one. Depending on the industry, organization, or circumstance, the term can morph into thousands of variations appropriate for the moment or task. However, one comprehensive and context-specific definition for this research is provided in the book *Managing Communications in a Crisis* by Peter Ruff and Khalid Aziz. That definition is that "a crisis is any incident or situation, whether real, rumored or alleged, that can focus negative attention on a company or organization internally, in the media or before key audiences" (Ruff and Aziz, 2003). This definition includes four primary components that are useful to consider when defining crisis communications: event, perception, impact, and audience.

Firstly, all crises are events that occur in real-time. In other words, something happens to or within an institution that interrupts its operations and culture. Events that may be referred to as a crisis include disasters (such as in the case of COVID-19), personnel failures, service failure, negligence, financial problems, safety warnings, industrial action (or inaction), crime, personal violence, accidents, death, injury, or even external criticism. These all affect the existence of an organization. The impact of nearly all crises, and what makes a crisis a crisis is that it has a negative impact on the organization and conflicts, to some degree, with their triple bottom line: people, planet, and profit (Kraaijenbrink, 2019). This event consequently leads community stakeholders to have a negative perception of the organization or institution as a result of the event occurring. Response and management of that event also impact stakeholder perception. Finally, people are the ones that judge the event and then render a verdict on the efficacy of the organization to protect their best interests and that of the communities they represent. Through the lens of event, perception, impact, and audience, this word with iterative and multifactorial meanings can be better conceptualized and understood.

## Defining Crisis Communications

As crises arise within institutions and organizations, practitioners of various backgrounds then mobilize a crisis management strategy to address the challenge they are up against. The *Encyclopedia of Crisis Management* states that "in its most comprehensive form, crisis management is marked by five primary activities: signal detection, preparation and prevention, containment and damage control, business recovery, and learning" (Zimmerman, 2013).

Crisis communication is an essential component of any crisis management strategy and can easily be said to be the guardian of all five activities. Effective communications strategies before, during, and after a crisis can establish credibility, reassure stakeholders, and transcend crises even in the most challenging circumstances.

Crisis communications, specifically, can be defined as a social process deployed to "reduce risk through individual, group, or institutional action." Furthermore, crisis communications can be defined as "interactive and consist of multiple messages extending often over very long periods of time and changing conditions, and designed for many different groups (by language, age, and other demographic characteristics), places, and decisions or actions." This process intends to reduce fear and anxiety, guide people in the high risk/exposure areas to safety, adopt and implement protective actions such as vaccines, shelters, et cetera, keep people away from entering dangerous areas, reduce exposure to the risks through timely, accurate, and appropriately disseminated information, and connecting supplies and services with the people who need them (Zimmerman, 2013).

Advancements in media technology have made crisis communications significantly more effective, efficient, and accessible. Rather than antiquated models of information sharing such as only one-way, two-way, or multidirectional communications, there are now several ways to widely disseminate information to a large mass of stakeholders. As stated in the *Handbook of Public Relation*s, the impact of new media technologies has widened the reach of institutional communications to now include point-to-point, point-to-multipoint, point-to-server narrowcast, server broadcast, and server narrowcast:

| | |
|---|---|
| *Point-to-point* | A single user sends a message to a single receiver. |
| *Point-to-multipoint* | A single user sends a message to a server, which can then be accessed by anyone with appropriate software. |
| *Point-to-server narrowcast* | A single user sends a message to a server, which is then available to only a specific group of users who have log-in names and passwords. |
| *Server broadcast* | A server contains stored information that is available to any user with an appropriate software client. |
| *Server narrowcast* | A server provides information to only a specific set of authorized users. |

**Figure 1:** Directional Communication Changes as a Result of New Media Technology (Springston, 2001).

With these multidirectional channels for communications opened up, crisis communications can now, with more timeliness and ubiquity, address crises that arise. Integral to crisis communications is the ability to efficiently engage with communities for whom the institution has an obligation to protect. New media technologies, such as social media, instant messaging, newsletters, blogs, robocalls, and more, have made that obligation significantly more manageable and practical.

### Background on the COVID-19 Pandemic

The COVID-19, or coronavirus disease 2019, pandemic was first identified in December of 2019 in Wuhan, China, and quickly spread to other countries due to its high transmissibility and international travel. The disease is caused by a virus named SARS-CoV-2 that causes respiratory symptoms that are similar to those experienced when someone has a cold, the flu, or pneumonia. COVID-19 was declared a pandemic by the World Health Organization on March 11, 2020. The novelty of this virus shocked the health community, which meant that all other industry domains were equally shocked, including higher education. With millions of cases and over a million deaths in the United States at the time of this writing, the role of crisis communications to alert and prevent further spread is critical (cdc.gov).

Given the advent of masking and vaccination protocols, the impact of COVID-19 has lessened significantly since its inception but surely remains a prominent aspect of today's reality. Lives are still being taken, people are still being infected, and the institutional ramifications of an ongoing crisis of this magnitude must still be studied in order to better equip institutions in handling this iterative crisis, and like ones to come.

## Methodology and Research Design

Both scholarship and ethnographic research were used to explore the topic of crisis communications in institutions of higher education. In order to understand the context of crisis communications, both current practices and recent developments, scholarship is examined through a critical lens to make arguments about effective and ineffective methods of engaging in crisis communications. Additionally, scholarship and primary accounts are used as supportive structures to make arguments about the use of communications techniques to respond to the COVID-19 pandemic. Finally, ethnographic methods, such as interviews and surveys, are used to build a case study of the University of Maryland, Baltimore County (UMBC), and how the university's administration addressed the pandemic. Both crisis communications practitioners within

the institution and those at partner institutions share their experiences with the pandemic to help define best practices as determined by the challenges of the pandemic.

# Thesis

COVID-19 significantly impacted the crisis communications landscape and challenged traditionally held notions of best practices. However, the pandemic allows for a redefinition of crisis communications to center human interactions and cultural awareness. Rather than perpetuating public relations techniques in crisis communications, which center on the reputation of the organization or institution, COVID-19 has revealed that best practices should also include culturally responsive models of crisis communications. At institutions such as UMBC, all crisis communications work centered on being enveloped in the institution's culture, which was an effective practice that one could recommend other institutions of higher education replicate within their strategic communications plans. Institutional communications plans should heavily focus on community-driven communications strategies in order to maximize impact and reach.

# Avoiding Crisis Communications Becoming a Spectacle

*The Society of the Spectacle*, written in 1967 by philosopher Guy Debord, might be one of the most influential and prominent media and communication texts. In the book, Debord details how human beings have become disconnected from their lived experiences due to technological, political, and cultural influences that dominate our consciousness. Debord goes on to criticize the *"fetishism of the commodity"* or the hyper-fixation that society has on the production of commodities and accumulation of wealth (Debord, 1967). Today, our actions and ways of navigating life tend to merely serve our commodity-driven world, and in the process, we are disconnected from others. This is because human beings are constantly overwhelmed by images that warp our perception of truth and lead to an over-reliance on media and consumerism to define how one should live their life.

In the book, Debord explicitly describes a spectacle as "... not a collection of images; it is a social relation between people that is mediated by images." He says, "The spectacle cannot be understood as a mere visual excess produced by mass-media technologies. It is a worldview

that has actually been materialized, that has become an objective reality" (Debord, 1967). Furthermore, the spectacle relies on passive acceptance to maintain its salience and continue dominating human existence.

One can draw many comparisons between crisis communications and *The Society of the Spectacle*, considering the nature of a crisis is a spectacle within itself. As described earlier in this research, the very nature of a crisis is that it is an event that dominates public consciousness and has significant consequences for those impacted. The parallels between crisis and "the spectacle" can best be found in the quote:

> The root of the spectacle is that oldest of all social specializations, the specialization of power. The spectacle plays the specialized role of speaking in the name of all the other activities. It is hierarchical society's ambassador to itself, delivering its messages at a court where no one else is allowed to speak. The most modern aspect of the spectacle is thus also the most archaic (Debord, 7).

Crises are usually simply scaled-down versions of the spectacle that are particular to groups of people and institutions, except for a global crisis such as the COVID-19 pandemic that has implications far and wide. However, the role of crisis communications is to directly target and combat the influence of the spectacle in dominating people's consciousness, thus affecting their ability to act rationally. A crisis should not be synonymous with the spectacle. Yet the logic of *The Society of the Spectacle* has affected crisis communications response to the pandemic in institutions of higher education in two primary ways. Firstly, the initial media spectacle as a response to the pandemic hindered people's ability to get holistic and practical information. Secondly, society's fetish with technology has built barriers between people and resorting to technologically mediated communication during the pandemic has exacerbated our disconnection from one another (Harvey, 2003).

### Media Spectacle

At the onset of the pandemic, the world, including institutions of higher education, was solely reliant on the media to provide updates about the novel coronavirus. Crisis communications, in a way, were frozen as practitioners awaited updates and "the science" from the high-profile physicians and political actors that were holding daily press conferences televised by either local or national news outlets. This was also during a time when institutions began to shut down, and guidance to social distance was beginning to be both emphasized and mandated. Media sources invariably began to overwhelm our lives with horrifying images of dead bodies being piled into medical vans and tractor-trailers,

hospital beds sitting in the hallways of overflowing medical facilities, and people going without the ventilation machines they needed because of shortages. These images became our reality and catastrophized the everyday experience of people who were locked in their homes. The spectacle of the pandemic became the focus, with less significance being given to those living in these circumstances.

### The Need for Human-to-Human Connection

If not managed tactfully, crisis communications naturally mirror the spectacle defined by the media. This issue, crisis communications becoming a spectacle, speaks to the need for crisis communications not to be based solely on news media and general technologically mediated communications but rather to coalesce human experiences and ground response in what people are living, feeling, and personally navigating. However, during crises, this can be particularly difficult, especially when the crisis forces people to disconnect from others for their own safety. As mandates to self-isolate became prominent during the pandemic and institutions of higher education shut their doors, it seemed our only modes of connection were news media and other technological apparatuses such as video conferencing technologies and online learning systems like Blackboard, Canvas, and Google Classroom (Gewirtz, 2021). Debord's critique of techno-fetishism is particularly salient here because, in particular, higher education's over-reliance, and now over-comfortability, with technology limits its ability to recognize people as people.

A prominent way institutions of higher education tried to combat this fetish of technology, thus disenchanting technology of its powers over our society, was by finding remote ways of bringing people together that did not rely heavily on the technology but instead on the community showing up in that space. For example, just as politicians and physicians tried to have town halls to ensure a face and voice told the tale of the coronavirus rather than relying on the spectacle to do so, so did institutions of higher education. Town halls around a number of different topics became the premiere way across institutions to imbue a sense of community and humanity in crisis response. The University of Wisconsin-Madison was one such institution that relied heavily on town halls to communicate updates about where their institution was in response to the pandemic. From the period of July 22, 2020, to January 21, 2022, the university had 28 different town halls on topics such as "instructional continuity," "diversity and belonging in the student experience," and "what employees and grad students need to know for the Spring Semester" (covidresponse.wisc.edu). Vanderbilt University is another school that leaned heavily into this mode of communication. They hosted 19 town halls from the period of May 11, 2020, to January 13, 2022, on topics such as "VUMC [Vanderbilt University Medical Center] experts discuss medical aspects of COVID-19 for students and families" and "faculty to focus on adaptive teaching" (news.

vanderbilt.edu). These town halls lessened the power of the spectacle to dominate consciousness. This mode of communication provided a means for people to come together, despite the circumstances, to have informed, culturally sound, and humanistic conversations, which is the ideal formula for effective crisis communications.

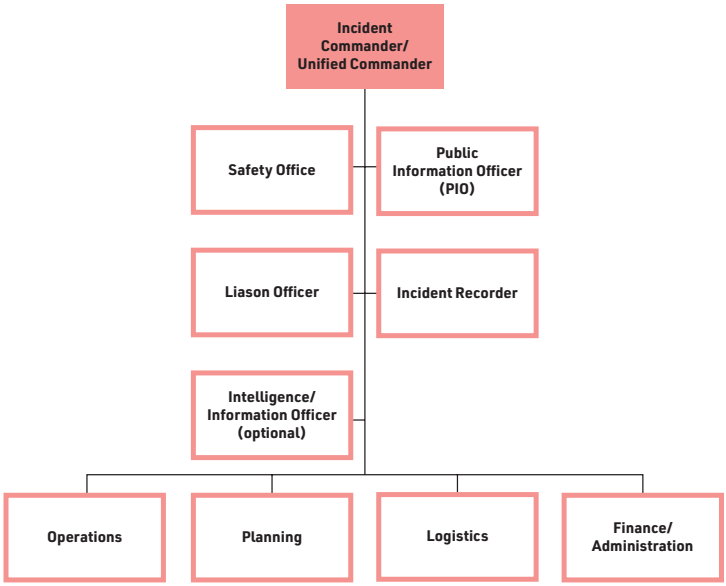
# Disrupting the Spectacle through Effective Crisis Communications: UMBC

*The Society of the Spectacle* provides a theoretical lens through which crisis communications can be evaluated. Essentially, the argument is that practitioners must break down the technological and mediated barriers that restrict our ability to connect on a human-to-human level to best manage crisis communications. As mentioned, many institutions of higher education did just this through their many programs, initiatives, and crisis response structures. The University of Maryland, Baltimore County (UMBC) is one of those institutions that rooted their crisis communications response in dismantling the spectacle and allowing for community and humanity to be at the core of their strategy. These principles of dismantling the spectacle, thus leaving room for community and humanity, is how culture is sustained in institutional crisis communications. This idea, and the contexts that facilitate culture, will be explored in the way UMBC handled their communications during the pandemic.

### University Profile and Crisis Communications Framework

The University of Maryland, Baltimore County is a public research university located in Baltimore, Maryland. Founded in 1966, the university has developed into a national leader in innovation, undergraduate teaching, graduate education, value, and workplace environment. With roughly 14,000 undergraduate and graduate students, 919 full-time and part-time faculty, and hundreds of additional staff members, UMBC is a mid-sized institution (about.umbc.edu). Additionally, UMBC was recognized in 2017 as a minority-serving institution which is best described by Dr. Yvette Mozie-Ross, UMBC's Vice Provost for Enrollment Management and Planning, as a "middle ground between Historically Black Colleges and Institutions and Traditionally White Institutions" (Kassir, 2021). This diversity is reflected in the faculty, staff, and surrounding communities. The multifariousness of UMBC presents both significant benefits and detriments to the ways in which messages are communicated to these various constituencies.

Communications, generally, are housed within the Office of Institutional Advancement at UMBC. Within this office, the direct chain of command for crisis communications is the Vice President for Institutional Advancement, Associate Vice President for Engagement, Director of Community Engagement and Director of Communications and Content Strategy, and Government and Community Relations Manager (in that order) (oia.umbc.edu). The Associate Vice President, who directly oversees UMBC's institutional crisis communications, described that "in an emergency, which this [COVID] was when the pandemic started, there is an emergency operations center that is convened by UMBC police, and that pulls in key leaders throughout the campus, and the Chief of Police is in charge" (Akchin).




Within the operations plan and its established control center, the Public Information Officer, which in this case happened to be the Director of Community Engagement, is primarily responsible for obtaining and disseminating information from the Incident Commander, collecting information being shared from other universities and responding agencies, engaging with appropriate media actors, providing press briefings and news releases, and maintaining a log of all activity related to the incident. From the perspective of the Public Information Officer, this role was divided between them and the institution's Director of Communications, who has a stronger background in media relations (Lilly). Key communications positions that manage a crisis in more of an emergency state are the Public Information Officer, Liaison Officer, and Incident Recorder (UMBC Emergency Operations Plan).

To the average eye, this structure is militant and atypical of protocols one might see in a college, and that is because it takes an incredibly systematic and structured approach to meet the immediate needs of the community. When taking on crisis communications and crisis management roles, such as with the pandemic, law enforcement agencies often turn to military expertise to develop comprehensive and effective strategies and practices.

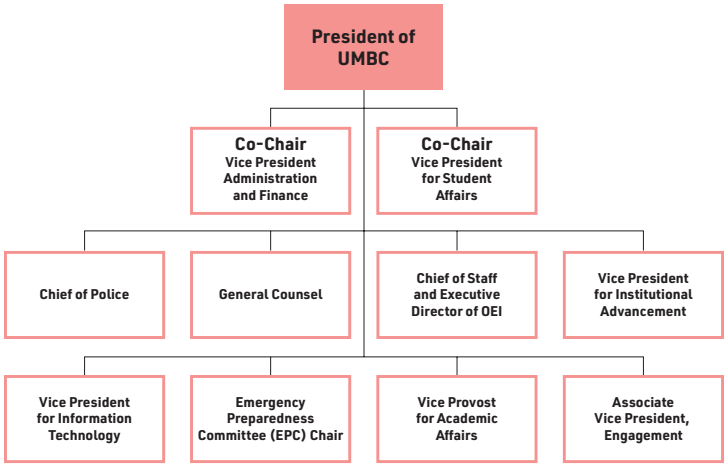
### Understanding the Phases of Crisis Communications

When asked how they define the difference between crisis and emergency communications at UMBC, the Director of Community Engagement referred to the two as a Venn diagram of sorts. According to them, "emergency communications are incredibly time-delineated" (Lilly). In the case of the coronavirus, the pandemic began as an issue with minimal immediate danger, and as it developed into a pandemic with significant implications, including shutting down the university, the issue developed into an emergency. At that point, response required urgent action and for those in the communications line of authority to move fairly quick. Additionally, the scope of an emergency is significantly more narrow and specific to a particular event.

Within the UMBC Emergency Operations Plan, there are two levels to the "Crisis Communications Matrix:" Emergency Mass Notification Systems and Non-Emergency Mass Communication. The first level is triggered "in the event of an incident that requires mass notifications of a localized segment or the entire university community," as determined by the type of incident, speed of incident, and proximity of the incident to campus. Alternatively, a non-emergency mass communication response may include university closures, infrastructure failure, drills, and weather preparation instructions. These levels and mechanisms are critical in meeting an emergency's demand for immediate response. In the case of the coronavirus, UMBC relied solely on non-emergency mass communications to convey the ever-changing state of the virus and the university to the public.

Crisis communications, on the other hand, "tend to be longer in nature and tend to be things that threaten the very fabric of the university." According to the Director of Community Engagement, " a crisis is a crisis because it is going to be opposed to our values" and "because of our values, we know our community will be deeply affected by this crisis" (Lilly). When it came to addressing the more prolonged communications demands of the pandemic, this work was taken out of the hands of the initial Incident Management Team (led by the UMBC Police Department) and given over to the Crisis Management Executive Team (CMET). The purpose of this group was to have the senior leadership of UMBC "meet as needed to review the program and incidents, develop strategy, prioritize actions, and provide policy and administrative guidance" (UMBC

Emergency Operations Plans). On this CMET is the Vice President for Institutional Advancement and Associate Vice President for Engagement to manage crisis communications and engage with the many populations the university must protect in a crisis. From this group, the COVID-19 Planning and Coordinating Committee was later developed to respond to the ever-changing state of the pandemic. Throughout each phase of crisis management, however, crisis communications practitioners were present as an integral part of protecting the many university populations and communicating the changes coming out of these many groups.




## Methods of Sustained Crisis Communications

At UMBC, the first institutional message regarding the coronavirus was sent out to the campus community on January 26, 2020, with the subject line " Protecting against Cold, Flu, and the Coronavirus: What You Need to Know." In it was a comprehensive list of resources for prevention and treatment, information about what it means to be immunocompromised, and the state of "2019-nCoV Coronavirus" as university leaders tracked it. In the earlier days of what was soon to be announced as a pandemic, the Director of University Health Services was sending mass communications to the campus community, not university leadership. This eventual shift from University Health Services to the co-chairs of CMET sending communications indicates when the severity of COVID-19 took a turn for the worse from the leadership's perspective.

Over the month after the first institutional message came out about COVID-19, communications were sent weekly. With subject lines such as "Influenza and Coronavirus Update," "COVID-19 (Coronavirus) Update," and "COVID-19 Update for UMBC Community," the tone of these emails became bleaker, and the information provided became more severe as time went on. Beginning on March 2, 2020, a significant

communications shift marked another turn in the severity of the coronavirus. Firstly, the Vice President for Finance and Administration and Vice President of Student Affairs began sending the communications as the co-chairs of CMET. This is also when UMBC suspended all university-related travel to countries under a CDC Risk Assessment 1, 2, or 3 and began to prepare students, faculty, and staff for a lock-down. Furthermore, the timing of COVID-19-related messages shifted to three times a week to ensure that community members were as up to date as possible. Messages to come would only further prepare people for what was inevitable, shutting the university down on March 13, 2020 (UMBC Community News, 2020).

On March 6, 2020, the university took its most effective stride towards providing information and support to the university's community by launching their COVID-19 inbox, covid19@umbc.edu, and website, covid19.umbc.edu (UMBC Community News, 2020). The website acted as a way to centralize information about the pandemic and guidance coming from the university. The first iteration of the website included dropdown menus that offered "UMBC Updates & Status," "Background & Prevention," "Travel," "Communications," and "Online Instruction Resources" (archive.org). This covid19.umbc.edu website became a hub for all information regarding COVID-19. According to indications on the Wayback Machine, the website saw its most use in the earlier days of its creation in March and April 2020.

The COVID-19 inbox, as it is described within the university's leadership, allowed people to communicate directly with the crisis communications team to get specific information pertinent to their situation. The Associate Vice President for Engagement described this email as incredibly helpful in a one-to-one way for filling in the gaps of what people may have missed in institutional messages or just telling people that the university did not have all of the information yet but would provide updates when appropriate. The inbox, according to them, was also helpful in seeing the trends and being able to gauge anxiety levels based on how many emails the inbox received a day. The number of emails received, and the contents of those emails denoted whether or not "there was something we [the administration] were not clear about, or is there a new anxiety or pain point" (Akchin).

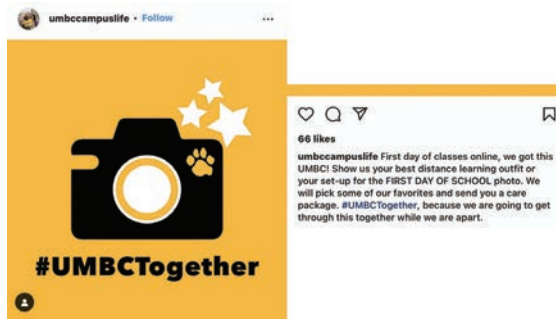
As we are still amid a pandemic with oscillating effects, the university has committed to maintaining both of these technologies with diligence in order to soothe angst and provide information to community members.

### Crisis Communications Has to be a Cultural Campaign

Not long after the university's physical shutdown, the hashtag "#UMBCTogether" started popping up on social media and within institutional messaging. On the covid19.umbc.edu website, the following blurb was posted about the campaign:

> In the midst of challenging times, the UMBC community always finds ways to support each other. Check out how Retrievers are staying #UMBCTogether even though we're physically apart.

The website also included links to the hashtag used by the UMBC Women's Center, faculty, Dean of the College of Engineering and Information Technology, and the Office of Campus Life. This hashtag acted as a conduit for community while physically distanced from the campus and each other. #UMBCTogether reaffirmed the campus's commitment to a vital community dedicated to academic excellence, institutional culture, and healthy student life through new semesters, special events, commencement ceremonies, and first-year convocations. In this prolonged period of crisis, this campaign, conceived of by the administration and endorsed by faculty, staff, and students, allowed for continuity of mission and cultivation of culture. It is just one way the university rejected the notion of the spectacle and prioritized community lived experiences while distanced.




#UMBCTogether was mainly promoted during lockdown at the beginning of the pandemic, even though it is still highly in use. However, a different cultural campaign arose for the mass return to campus in the Fall of 2021. "Community brought us together. Masks Keep us here." This message was put on flyers and plastered on television screens, campus billboards, university social media accounts, et cetera. An entire communications toolkit was developed in order to promote the use of

masks on campus, as that was the primary tool used to protect people against contracting the coronavirus. With the slogan in large font to the left, this flyer had hand-drawn images of people with masks on to the right. The people are of various shades, which is indicative of the university's racial diversity. There is also one person on the flyer wearing a headwrap to represent ethnic/religious diversity.


Again, a crisis is such because it opposes institutional values and affects the people within that institution. Two core institutional values at UMBC are community and diversity, and the #UMBCTogether and "Community brought us together. Masks keep us here." campaigns embody these two core values and invite participation and vitality amid the pandemic. Crisis communications, as evident by these campaigns, were rooted in institutional culture and values and, pragmatically put, helped ensure that the ethos of the university was not affected, which ensured the institution's political, economic, and social prosperity.

### What Could Have UMBC Done Better?

Although many characteristics of UMBC's response to the pandemic were aligned with best practices and were culturally competent, there were also moments in the university's response that did not lend themselves to an effective response. In conversations with staff involved in crisis communications, to various degrees, within the institution, three deficits in the university's response were identified.

Firstly, the lack of congruence with how the university communications typically disrupted pre-established standards. At UMBC, one of the primary tools for communications and connecting to others is myUMBC. myUMBC is the university's portal for students, faculty, and staff information and myUMBC gives community members access to Blackboard, personal files, Google Suite, event listings, affinity group forums, and more. However, this platform, which is the nexus for information at all other moments, was abandoned during the pandemic. Although it was shared earlier that the development of the covid19.umbc.edu website was an ideal practice for centralizing information, it is also essential to continue to tap into the systems that people are used to using. University-wide

communications, as well as office-specific and divisional communications, are uploaded to myUMBC. Yet, no information was shared about how updates related to COVID-19 could also be found through the portal, not just through the COVID-19 website. Furthermore, breakdowns in information storage/ dissemination also happened at smaller levels between offices and divisions, creating confusion and weakening the delivery of messages. The university could have done a better job at aligning platforms so that communications were not being placed in different locations.

Another deficit identified, complementary to the above point, was the lack of cohesion among the offices and divisions. As stated, there was an institutional crisis communications plan that guided the entire university. Beyond the messaging coming out of this small team of senior administrators, there was little guidance given to the offices and divisions around campus about how to manage their internal crisis communications. From design elements to specific messaging about facts, figures, and timelines, there was little guidance to ensure that information was accurate and presented in the most appropriate way. In follow up to this concern, staff recommended expanding the university's crisis communications strategy to include staff and faculty that could be "triggered" in the case of a crisis. These "point people" would be convened to make sure there was some type of standardization among the units a round campus.

Finally, a prominent ethos at UMBC is the power of shared governance on campus. However, crisis communications practitioners thought that shared governance was not used to its total capacity in responding to the pandemic. Shared governance at UMBC comprises the five representative senates and, in its expanded definition, includes divisional and departmental supervisors. The senior administration primarily managed the response to the pandemic and superficially included shared governance leaders. If the university-wide crisis communications plan had incorporated shared governance, the university could potentially have expanded its reach and gotten information out to pertinent communities more efficiently. However, as the university's Director of Emergency Preparedness put it, including shared governance would not have been as beneficial since shared governance leaders did not have the wherewithal, training, and comprehensive understanding to communicate effectively with their constituencies. (Schailble, 2022)

# Best Practices in Crisis Communications

This research intends to use the theoretical framework of the spectacle and the practical framework of UMBC's crisis communications response to the pandemic to support industry ideals and best practices for institutions of higher education. As one can imagine, there are myriad ways to engage in effective crisis communications. Maybe not so many are the ways in which practitioners can engage in crisis communications that are rooted in culture and communications studies. Given the framework of what crisis communications should not be, the spectacle, and what practices looked like at one university, UMBC, the following section will highlight three main approaches institutions of higher education can take to bolster the impact of their crisis communications strategy. These approaches are based on scholarly literature and are aligned with this research's rejection of the spectacle and acceptance of people-centric crisis communications.

It is critical to note that the success of all of these approaches hinges on the codification of an institutional crisis communications strategy. Whether that be a strategy separate from other communications strategies or a fully integrated one, it is critical to have a specific plan. Literature states that "emergency communication systems at educational institutions lack specificity, making these systems less effective during a crisis" (Abukhalaf and von Meding, 2020). A specific plan, tailored to the community's needs, must be in place for these approaches to be effective in the greater institutional structure. Additionally, having that crisis communications plan be aligned to institutional emergency and crisis response plans is critical to ensure congruence with all areas of response. Finally, any codified plan will best serve the community if it is aligned with Incident Command System (ICS) and National Incident Management System (NIMS) standards. NIMS and ICS are agencies that standardize the management of all incidents. These agencies prioritize every campus community developing and organizing emergency and crisis preparedness/ operation plans that can forecast and manage a wide range of emergencies (Connolly, 2016). This alignment would mean that crisis communications responses relevant to multiple institutions and systems match baseline standards.

### Approach #1: Leaders are Symbols of Institutional Culture… Make Sure They are Visible

When situations go awry in institutions of higher education, more likely than not, all eyes will turn to institutional leadership to set the tone and lead course correction. In a crisis, leaders have a significant amount of authority to share information with a large mass of people, considering they naturally have the most social and political capital to act on. In crisis communications, however, leaders are often not used to their fullest potential by being as visible as possible. In *Crisis Leadership in Higher Education: Theory and Practice*, Ralph Gigliotti says that "in many instances, the success or failure of an organization is contingent upon the actions and decisions of its leaders. More than a formal position or responsibility, however, leadership is understood to be a process of social influence that may be accomplished by any organizational actor." Gigliotti goes on to say that leadership is a communication endeavor and that the two are inextricably linked (Gigliotti, 2019).

Furthermore, leaders tend to be the ones that establish and facilitate culture within institutions. The cultural, social, and political influence leaders have is the greatest asset a crisis communications strategy can have. Jim Macnamara, in "New insights into crisis communication from an "inside" *emic* perspective during COVID-19," says, "leaders and senior managers need to be visible and engaged, particularly with employees and closely connected stakeholders such as customers (students in this case)" (Macnamara, 2021). In the case of the COVID-19 pandemic, institutions relied heavily on "the experts" to speak the truth of the situation and less on university leadership. At UMBC, most of all communications did not come from the university president but rather the CMET co-chairs. This first approach to bolstering your crisis communications strategy calls on practitioners to prepare their university presidents, provosts, and senior-most officials to get in front of the university's constituencies to take control of the spectacle and speak to the heart of the university; still informed by "the science" and facts of the matter, but handled with significantly more cultural consciousness.

### Approach #2: Involve All Campus Stakeholders in Crisis Communications Planning

As alluded to earlier in this paper, crisis communications become a spectacle when it gets too far out of the hands of the people whom it most directly affects. For this reason, it is critical to have students, faculty, staff, and other stakeholders involved in crisis communications planning and execution. The time for only top-down communications is over. In an international survey of higher education's response to the pandemic, "Were Higher Education Institutions Communication Strategies Well Suited for the COVID-19 Pandemic" authors write explicitly about the significance of having students involved in crisis communications. They say,

> Many university communication strategies relied on top-down communication and did not make extensive use of the student body to help communicate messages concerning correct health messaging and changes to campus policies. This is a missed opportunity as students (may speak several languages and) are often able to use social media in innovative ways that can assist in delivering timely, digestible and targeted messages (Calonge et al., 2021).

Students accessing students means that institutional messages are brought down from the ivory tower and put in the hands of the most significant population on the campus. Working in partnership with students empowers them to take responsibility for the messages received and hold themselves and their peers accountable for acting in accordance with those messages. However, crisis communications practitioners should also include other publics who are "community members, industry partners, government officials... faculty, staff, alumni, and donors." Research suggests that crisis communications should "take a dialogic approach with these publics to keep them informed and offer them the opportunity to serve as resources" (Janoske et al., 2021). Recall that at UMBC, a deficit to the university's response to COVID-19 was that community members felt they were not being involved in decision-making enough through their shared governance structures.

The bottom line of the second approach is that crisis communications should not exist in a bubble disconnected from the people whose lived experiences best inform those communications.

### Approach #3: Diversify the Mediums Used for Crisis Communications

The tried and true forms of crisis communications people typically think about when they hear the term should never be neglected. Messages sent out via email, text, robocall, or any other medium, depending

on the circumstances, appropriately communicate the information that needs to be shared with the correct populations. However, it is also critical to humanize and personalize crisis communications as much as possible and break away from our techno-fetishistic norms. A lot can be hidden through written text and news media, which is impossible when in a physically shared space or even perceived as a physically shared space (video conferencing). In discussing *The Society of the Spectacle* as a model of what crisis communications should not be, this research also named, as an example, town halls as a means of dismantling the spectacle and humanizing crisis communications. This final approach calls for crisis communications to depart from traditional highly mediated communications to interpersonal and "seen" communications. Town halls are an example of a format that allows the campus community to see its leadership, current state, and the impact of the institution's crisis climate.

# Conclusion

One immutable fact about crisis communications is that it is truly life or death. This discipline has the burden of informing mass groups of people about life-threatening incidents. In institutions of higher education, populations are highly dense, and the potential for threat is exacerbated. For this reason, it is essential to have specific ways of engaging the campus community that are effective and avoid creating additional barriers between people and the truth of the matter. The spectacle is simply one way of viewing these barriers caused by our society's hyper-fixation on media and technology that decentralizes human-to-human connections. In his rebuke of commodification, techno-fetishism, and highly mediated forms of information sharing, Debord sets the foundation for this argument and the culture-based antidote that dismantles and disenchants the spectacle.

Many universities across the nation did "the work" to center culture and humanity in their crisis communications responses. UMBC was one university that, at every turn, reiterated its commitment to the community and the experiences of its stakeholders. Although not without deficits that did not align with solutions offered herein, this institution had many tangible and "seen" components of its strategy that greatly supported the institution's community through the most challenging moments of the COVID-19 pandemic.

Finally, the three approaches named as solutions to the spectacle help to ground crisis communications in people-oriented ways of conceiving of and delivering messages. Enhancing the visibility of leadership, involving various campus communities in crisis communications planning, and diversifying the mediums used all support a transformative strategy that can best inform and protect all impacted by the state of an institution of higher education. When empowered in the process and earnestly considered, campus communities can be better engaged to rise to the occasion and meet even the most challenging campus crisis, such as a pandemic, with diligence and immediacy.

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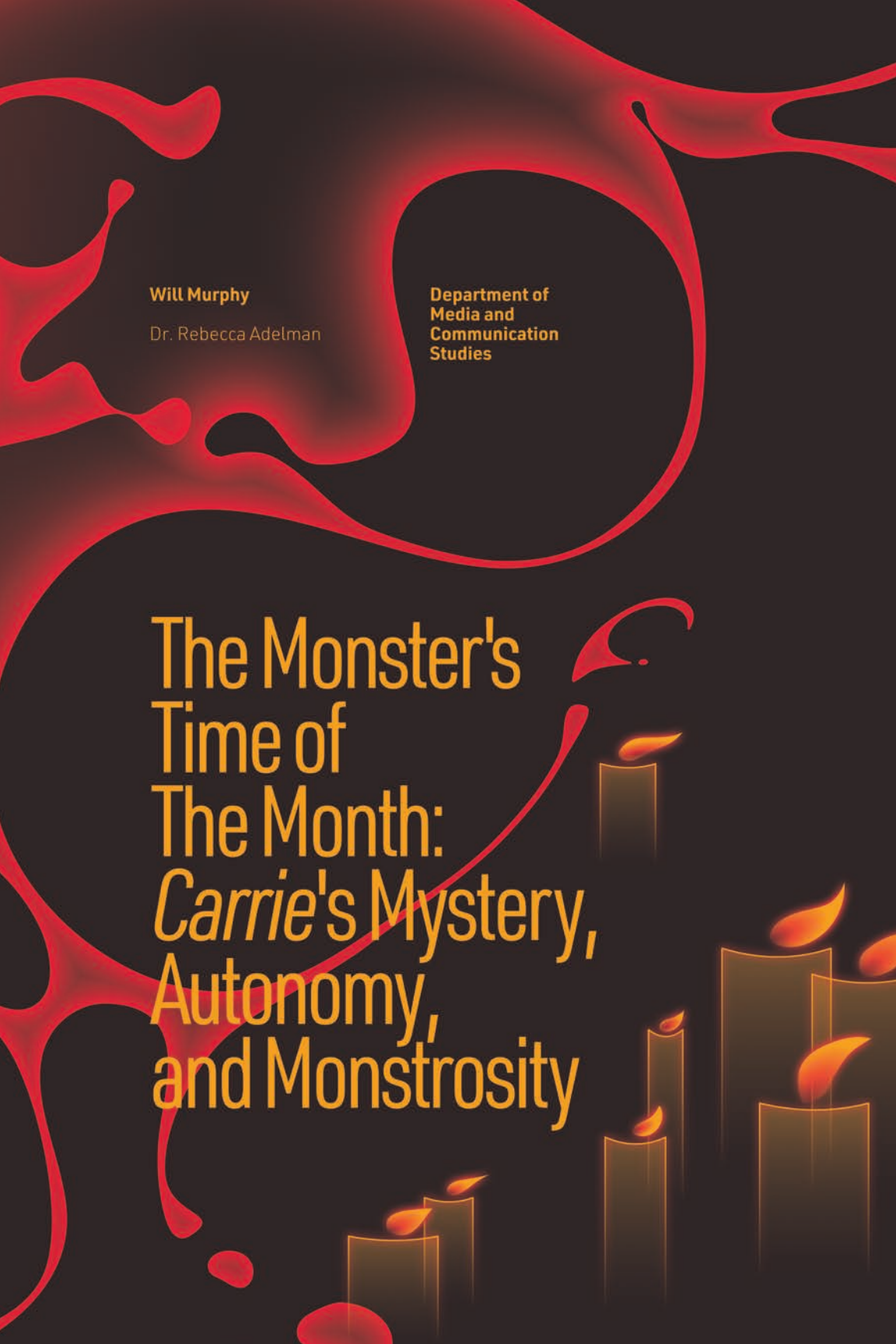
7

**Will Murphy**

Dr. Rebecca Adelman

**Department of Media and Communication Studies**

# The Monster's Time of The Month: *Carrie*'s Mystery, Autonomy, and Monstrosity



# Biography

**Will Murphy** graduated from UMBC in Spring of 2022 with a dual degree in media and communication studies and theater. Since his graduation, he has begun working as a Research Analyst to address issues of cultural competency and inequity in health communications research. Outside of work, he enjoys kayaking and working with theater groups in the DMV area in the areas of dramaturgy and intimacy choreography.

Will would like to thank Dr. Rebecca Adelman for her thoughtful feedback and continuous guidance during the development of the paper. He would also like to thank his friends for talking about menstruation so often with him, and letting him know that these stories are interesting, timely, and essential to talk about.

# Research Journey

Since my first period, I've always liked stories about menstruation. I watched *Carrie* (1976) for the first time not because of a particular interest in horror, but because I wanted to see such an important piece of menstrual mythology. In 2022, when I began my capstone course for the media and communication studies major, I had the chance to choose a topic about which I cared deeply. I chose to write about one of the most famous menstruation stories, *Carrie*.

The process of understanding *Carrie* required contextualizing dominant themes of 1960s and 1970s films, of horror movies, of "menstrual moaning" and other period narratives. The film is a period piece in two ways–first, in its claustrophobically close-up images of menstruation, and second, in how it reflects the dominant fears and tensions of its time. The 1974 Stephen King book on which Brian De Palma based his film emerged just one year after Roe v. Wade, following deeply contested efforts to ratify the Equal Rights Amendment. The controversy of the female body in all its power and its autonomy is at the center of the film and my project. My research suggests that the cyclical blood and violence in *Carrie* is as persistent as the continuous categorizations and negotiations of a woman's body and autonomy.

# Abstract

This project discusses *Carrie*, a 1976 film that deals in the bloody tensions of autonomy and monstrosity through the story of one girl's paranormal entrance into womanhood. I seek to address how the evolution of feminine power on a religious and political scale is reflected in the horror of *Carrie*; and how mystery, sexuality, and monstrosity are articulated and shaped by the signs and motifs of the era. This project discusses the film through a semiotic and historical lens, incorporating previous literature into a perspective that analyzes the representation of menstruation and monstrosity within the country's anxieties surrounding gender and autonomy.

Though the bloody legacy of *Carrie* persists through homages and remakes, its true permanence stems from its paranoid, paranormal obsession with the power and unwieldiness of the pubescent, menstruating female body. As an essential example of female villainy within postmodern horror, the film's representation of the developing female body reflects anxieties around gender and sexuality as prominent features of American paranoia.

# Introduction

In the pale lighting of a cramped, decaying Victorian house, the ghostly maternal figure of Margaret White begins her lecture. "And God made Eve from the river there." Her daughter folds into herself more and more with every line, but she continues. "And the Lord visited Eve with the curse, and the curse was the curse of blood!" Her daughter, frozen in a position of forced prostration, protests. "And Eve was weak. Say it. Eve was weak!" In the shadow of her mother's imposing figure, Carrie White is a monster moving through the arduous pains of repression and the horrors of puberty. Her attempts to quell her emotions and control her supernatural powers, amidst the cruelty of high school gym class and the punishing religious fervor of her mother, set the stage for director Brian De Palma's 1976 horror film *Carrie*, based on Stephen King's novel of the same name.

*Carrie* is a seminal film in contemporary horror, connecting a culture paranoid with the developing political power of women to the horror of a maturing monster perpetually ill-equipped to manage her interior evil. The film follows Carrie White, a quiet and shy girl sheltered from the supposed evils of body and sex by her religious fanatic mother. The movie examines Carrie as she is bullied by high school girls during her traumatic entrance into puberty with the arrival of her first period. As a result of the suffocating punishment of her bullies and her body, Carrie is further tormented by telekinetic powers that erupt in uncontrollable destruction when she is provoked. Carrie transitions between ignorant innocence and an incessant rage, a victim of two forces she fails to control. Miss Collins, the gym teacher who punishes Carrie's bullies and attempts to guide the young girl away from the terror of her home life, provides temporary refuge through a more progressive view of puberty and womanhood. She ushers Carrie into her first prom, assisted by Sue Snell, the repentant bully who lends her boyfriend, Tommy, as a prom date. Carrie slowly crawls out of the isolation and misery of her home life into a fantasy of peace, adorned with makeup, a prom dress, and a charming date who acts as a pseudo-knight-in-shining-armor. However, her respite is once again tarnished with the arrival of blood. Chris, the lead bully, enlists her boyfriend to help punish Carrie by dumping pig's blood on her just as she is crowned prom queen. As a distraught Carrie looks out and imagines a sea of laughing classmates and mentors, she harnesses her telekinesis to destroy those who broke her trust. She demolishes the gym, killing her teachers and peers. On her return home, she wrecks the car of Chris and Billy, Chris' equally cruel boyfriend, who attempt to run her over following the prom. Her story ends when Margaret White attempts to murder her as well, and Carrie crucifies her mother and sets the house ablaze, letting herself die in the fire.

Since its premier in 1976, *Carrie* became a defining movie of its genre, inspiring a sequel and several remakes that further explore the life and legacy of the tortured sixteen-year-old girl and her iconic trail of destruction (Bradley). The original text and film emerged during a period of U.S. history rife with tensions of gender, religion, and autonomy. Stephen King's 1974 book came out one year after Roe v. Wade, the U.S. Supreme Court's landmark decision protecting a pregnant person's right to have an abortion (Blackmun and Supreme Court of The United States; King). This case was not alone in magnifying the changes in legal and social interpretations of women's rights. In 1972, Congress passed the Equal Rights Amendment, which would establish constitutional language to protect individuals from discrimination on the basis of sex and gender. The subsequent campaign to earn the necessary 38 state ratifications amplified debates around gender, religion, and class ("History of the Equal Rights Amendment"). The 1970s were defined by uproarious debate and revolutionary change, and they were equally marked by the fervorous pushback against efforts for equality.

Such social forces provide more than a backdrop for the events and reception of *Carrie*; tensions of the era are integral pieces in the construction of Carrie's monstrosity. *Carrie* was created at a critical juncture in U.S. history, tucked in between women's liberation, the rise of the moral majority, and the incoming satanic panic. The movie presents a melodramatic mirror of the country's own process of making the interior exterior: Carrie's body is the host for discourse to become gruesomely visual in a reimaging of these debates.

Scholars such as Aviva Briefel and Shelley Stamp Lindsey have examined how the film *Carrie* merges the supernatural with female adolescence to create the "monstrous-feminine," which writer Barbara Creed defines as the gendered construction of the female monster through an inextricable link to her reproductive body and sexuality—the creation of an abject yet threatening being. Other research has delved into issues of sexuality, audience spectatorship, and the religious imagery and gendering in the horror genre. I aim to study *Carrie* through a semiotic and historical lens, incorporating previous literature into a perspective that analyzes the representation of menstruation and monstrosity within the country's anxieties surrounding gender and autonomy. Though the monstrous-feminine expands back to pre-Enlightenment theories of witchcraft and sexual differences, its iteration in *Carrie* is shaped by the historical motifs of the era and the evolution of feminine power on a religious and political scale (Strömquist 65). *Carrie* parallels the tensions and fears of its time, emerging in an age obsessed with the mystery, autonomy, and monstrosity of the female body. As an essential example of female villainy within postmodern horror, the film's representation of the menstruating, developing body reflects anxieties around gender and sexuality as prominent features of American paranoia.

# Understanding Horror: Making the Interior Exterior

In the locker room, Carrie is out of place. Through a haze of steam, of towels flirtatiously tossed around the room alongside giggles and gossip, the young girl is set apart from the collective, bonding experiences of her gender. A gentle woodwind melody underscores the image of youthful, carefree exuberance, where even the painfully awkward outcast may find some peace in her exile. Carrie leisurely washes her body, pleasurably running her hands up and down her pale skin in the locker room's shower. The camera vacillates erotically between wide shots of naked girls and close-ups of Carrie's private exploration of her body until suddenly blood begins to stream down her leg. Melodic flute morphs into *Psycho*-inspired strings as she holds the blood in her hands, marveling at it in fear and horror. Carrie flings herself in hysterics onto her mocking classmates, who scream "Plug it up! Plug it up!" as they pelt her with tampons and towels. She is at once exposed, dirty, and terrified; monster and victim converge during her horrific entrance into puberty.

*Carrie* transitions from a story about an outcast moving through the pains of social isolation into a film dealing with the horrors of sex and menstruation during the shower scene, when the viewer is drawn teasingly close to Carrie's body as a site of eroticism until her menstruation reveals her monstrosity. The interior as sexual, private, and mysterious is pushed to the exterior as violent, monstrous, and destructive. The swift move from familiar to alien, from novel to shocking, is a popular trait of American horror. From *Psycho* (1960) to *Get Out* (2017), horror movies place the monster in plain sight, often occupying some area of familiarity before they are exposed (Ryan; Dewan). *Carrie* reveals its villain at the same time it casts her as a victim, obscuring clear definitions of agency, as violence simultaneously plagues the monster and her victims. Issues of agency and autonomy are central to Carrie's narrative arc. Her agency, which I define here as control over one's actions, and her autonomy, or control of her body, are in constant flux. The contradictory construction of agency, autonomy, and monstrosity is linked to Carrie's cyclical relationship with blood, of the internal destruction of the body becoming gruesomely visceral.

Postmodern horror of the late 20th-century upset the narrative security of the genre through its shift in style, turning away from conventional depictions of villainy towards a simultaneously exposed and obscured monstrosity. The nebulous threat of these films takes time to be revealed; it hides in the corners of comfort. Carrie occupies a familiar positioning of innocence and outcast, but her developing monstrosity makes easy categorization untenable. Her body is gruesome and her violence visual, but the audience is denied a secure understanding

of her role (Falconer 126). *Carrie* and its narrative peers adapted to the increased paranoia of its time, delighting in confronting and violating the viewer's expectations in a subversive interaction with cultural anxieties (Phillips; Knöppler). These films resonate with a broader culture, shifting the intangible to visual but maintaining its ambiguity. In *Carrie*, victim, monster, and protagonist are folded into a character that embodies the social preoccupation with sexuality and the paranoia of gender. The film insists on making the horrific interior of the menstruating body exterior, and the genre frequently focuses on the developing body as physical proof of inner monstrosity (McGee 183).

Horror films are not alone in their obsession with making physical the anxieties of their time. In the late 1930s, teenage girls became staple characters of Hollywood films. They represented a body and culture in transformation, showing both the ambitions and potential of the future as well as the threat to established social order. Following WWII into the Cold War, popular movies like *Janie* (1944) and *One, Two, Three* (1961) extended this pattern, making their innocent yet possibly promiscuous female protagonists an allegory for the potential erosion of patriarchal authority in domestic and national contexts. America was threatened by penetration—its national identity was as fragile and in need of protection as the hymen, and movies positioned young women as susceptible to corruption from unfamiliar or foreign bodies. Films of the mid-1900s would typically tease and contain this threat, ultimately assuring the security of American culture when the patriarchal figure could protect the innocence of the girl or safely pass her into a husband's control. However, the onset of birth control and disputes over the autonomy of women in the 1960s and 1970s amplified the terror of the developing body. Cold War anxieties and the Soviet alternative to femininity that proposed an androgynous professionalism lent a global perspective to panics of moral decay and threats to American values (Nash 46).

Horror as a genre provides rich texts for understanding anxieties around body and identity. A combination of relaxed censorship laws in the 1960s and advances in special effects technology provided new tools for representing destruction of the body (Falconer 125). Horror films are most popular during times of social upheaval, and the following decade saw an increase in interest towards psychological films that thrust the anxieties of the American public into a subversively physical form (Phillips). *Carrie* embodies this shift in style and represents a moment of history where virginity could not be so easily controlled and contained. The inability to manage Carrie's transforming body pushes the interior mystery of the female body to an exterior monstrosity.

# Mystery and Monstrosity

"Baby, come on now. Don't you know?" asks Miss Collins, as she holds Carrie's shaking body in the shower. Carrie's eyes dart around the room, attempting to see if her bullies will return, if her telekinetic powers will explode again. Her hysterical ignorance is laughable to her classmates and frustrating to Miss Collins, but she remains horrified by the advent of her first period. Menstruation marks the transformation from innocent child to monstrous-feminine; the visual association of becoming a woman is rooted in Carrie's blood and a need to "plug it up" and contain it. Blood marks Carrie as a monster, but a pitiful one who can't understand the inescapable horror of her body.

The entrance point of menstruation to monstrosity positions the viewer suffocatingly close to the site of transgression. In the locker room, the naked bodies are tempting sites of eroticism, drawing in the viewer with voyeuristic excitement as the steam hides and reveals the characters' shapes. As the water falls down Carrie's form, her body is shown in fragments. The camera dissects her figure, switching from her hands holding her chest, down to her stomach, and then onto her legs. Her fingers move over a key necklace as she closes her eyes, leans her head back, and sighs as she washes herself. The dissolve transition from key to pleasure, back to close-ups of Carrie's inner thighs, teases an erotic access to her body. The sight of blood emerging from the same location of eroticism abruptly shifts the perspective from enticement to repulsion and shame. The mystery of the female body, guarded and withheld through patriarchal surveillance, is shown to hide monstrosity behind its sexual appeal.

Carrie's period reveals the mysterious power and horror of the female body, following conventions in the genre that penalize sexual desire and deviancy. Slasher films of the 1980s punish promiscuity and protect the heroine whose cunning and androgynous design places her in closest proximity to the male monster (Briefel 25). In other genitalia-obsessed horror, like *Sleepaway Camp* (1983) and *Ginger Snaps* (2000), the victim-villains internalize and impulsively spread violence in the prominent locations for changing bodies on display (e.g., high schools, bathrooms, beds) (McGee 174). Such films maintain the strict division of sexes and reveal a horrific core concealed beneath the haze of sexual desire. Just as the viewer and Carrie take comfort in the pleasurable exploration of the body, the threat is revealed, and both must reckon with the internal mystery transformed into monstrosity through menstruation.

The mystery of Carrie's body is a crucial component in the film's construction of monstrosity. It is a product of censorship and shame, echoing back across several historical attempts to categorize and control female bodies. The 1970s brought the cultural preoccupation with sex, agency, and morality to the forefront of legislative debates and social movements, but this obsession was shaped by a long legacy of mutilation,

religious paranoia, and Enlightenment-fueled binaries of sex and gender in Western ideology. In the majority of Western menstruation mythology, women are both sexless and sinful, and the menstruating body is a representation of an impurity and uncleanliness that must be hidden. From religious beliefs around menstruation in Greek mythology and art from 600 B.C.E., to the scientific reframing of female sexuality and genitalia born out of the Age of Reason, the vagina has denoted both positions of sameness and opposition to men, but women were regardless believed to have an inherent defect as a central trait of femininity (Strömquist 65). The monstrous-feminine is maintained through scientific and religious judgments on the genitalia and sexuality of women's bodies. The dominant mythologies of the sins of women in Western culture revolve around the unwieldy sexuality that menstruation hints at. Menstruation is an entrance point for sexual agency and desire, and in *Carrie* it is also the moment that exposes monstrosity.

Carrie reflects the shame of menstruation in her classmates' admonishments of "plug it up," her principal's disgust of menstrual blood, and Margaret White's lectures on original sin. Most of all, Carrie embodies the monstrosity of female sexuality; she is birthed by a monstrous woman and dies in a rage of destruction and violence. Menstruation connects women to the potential of life and creation or death and destruction, and in *Carrie*, the bloodshed of both options point to an inner violence in women's bodies. It echoes the teachings of a dominant culture that enforce secrecy and the maintenance of mystery around bleeding bodies (McHugh 418).

Carrie attempts to protest the classification of her body as monstrous. Before going to the prom, she pleads with her mother. "Everything isn't bad Mama. Everything isn't a sin!" Margaret White tears at her hair and wails, warning her daughter that her actions will be punished, that she will meet ridicule at the dance. Carrie's mother promises to have seen the true nature of men and the inherent sin of women. Her diatribes against modern lifestyles and rants about "the curse of blood" terrify and frustrate Carrie, who uses her powers to force her mother into silence and stillness until she can escape to prom. This moment of rebellion distills the untenable classification of Margaret White as prophet and monster and represents Carrie's entrance into sexual maturity.

Margaret White first appears at the door of Sue Snell's house, draped in a severe black cloak. Mrs. Snell, the matriarch of the traditional nuclear family, allows her in to lecture on the need for Jesus in "Godless times." She attempts to give Mrs. Snell "The Teenager's Path to Salvation Through the Cross of Jesus," a text she promises will help Sue stay on God's path but instead foreshadows her own crucifixion at the hands of her daughter. Mrs. Snell and eventually Miss Collins regard Margaret White as an exhausting religious zealot.

Though she vocalizes prominent tensions of sexuality, gender, and religion, Margaret White's hysteria marks her an outcast. Her positioning in the film is also unique; she does not fit into the mold of liberated woman or content housewife. Like her daughter, her insanity and monstrosity rests in the danger between both binaries. She is painfully aware of the pitfalls and inherent horrors of femininity, but her knowledge fails to provide any protection to herself or her daughter. Instead, her passion is pathetic; she is a monster in her deviance of social norms. She is a disturbing presence in the film, lecturing moral absolutism while failing to fulfill normalcy at a religious or political level. She is an unmarried, violent, abandoned woman whose zealotry is unnervingly misaligned with the religious aesthetics of the decade.

Margaret White's fretful tirades of original sin and inherent monstrosity within the bodies of all women does not oppose the conservative messaging of the time. The body's ability to create and destroy life was at the center of the era's political debates. Rather, its expression is not in line with the rhetoric of evangelism in the 1960s and 1970s. Evangelicals, through decades of internal tension and changing political affiliations, began to establish a mythology deeply in line with that of traditional American values. This group's "born again mentality" found a rebirth of Christianity that borrowed the anti-choice sentiment of Catholicism and the paranoia of changing social tides and attempted to manipulate it into political action. A perceived battle between independent evangelical institutions and an "all-encompassing government," and a fear of government policies alien from the interests of its religious institutions was at the forefront of the evangelicals' worries throughout the 1970s (Brown). The institutions' media-marketing strategies positioned the rise of the religious right snugly in the country's corporate mold and attracted a large audience. A promise of rebirth and a commitment to political policies that would shield those perhaps most alien from the political movements of the 1960s was central to establishing the leaders who would lead the resurgence of conservative activism in the 1980s commonly termed the "New Right" (Packer; Shales).

In relation to the political and religious transformation in the US that sets the stage for the horrors of Carrie's femininity, Margaret White remains acutely aware of her monstrosity, bemoaning sexuality and modernity while representing a more traditional, conservative horror. She throws herself around the room and slaps herself in a masochistic denial of repressed impulses, but she is tormented by the same efforts of containment and control that Carrie faces (Falconer 126). Her enforcement of Carrie's repression and her attempts to negate her inherent monstrosity through violent religious fervor create a hybrid of monster and oracle who understands the inescapability of monstrosity in women across history. Similar to her daughter, she internalizes and then violently projects the religious messaging and abuse she has received.

Pain is central to an audience's relationship to the monster. Author Aviva Briefel, in "Monster Pains: Masochism, Menstruation, and Identification in the Horror Film," proposes that the monster's pain, not the pain of its victims, determines audience positioning in horror. This fits snugly into the narrative formula for *Carrie*. The suffering of Carrie's victims seems to be an afterthought; their attempts to escape and pleas for help are backdrops to the eerie stillness of Carrie's skeletal figure gliding across the gymnasium floor. Briefel theorizes that male monsters appear alienated from their audience, closing the viewers from identification when they self-mutilate before they turn their violence outwards to their next victims. Female monsters, however, have no need to construct an internal horror before it turns outwards. Instead, menstruation marks them as monsters from the moment they enter puberty and foreshadows the inevitable movement of evil from interior to exterior. *Carrie* is an early example of this gendered dichotomy, in which women's horror is built-in, expressed in response to "abuse by parents, partners, rapists, and other offenders" (Briefel). Their sole act of masochism is ultimately to eliminate themselves through death, just as Carrie uses telekinetic powers to collapse the house around her.

Briefel suggests that the audience is brought uncomfortably close to the menstruating monster who demands empathy in her pitiful monstrosity and writes that the female body is brought so close as to be knowable and predictable in its terror. Though Carrie's narrative trajectory does follow certain aspects of this formula—the advent of her first period in the shower mars the purity of her body and propels her into monstrous sexuality, and her repentant baptism at home following her massacre seems to start this predictable cycle again—her terror is not so easily classified. Carrie's descent into monstrosity is not knowable or easily understood even if bloodshed is predictable. The mystery of Carrie's body is at the center of her monstrosity. The principal dismisses her so he can avoid such proximity to the revulsion of a menstruating body, Margaret White chastises her for entering a puberty she didn't know existed, and Miss Collins wonders in exacerbation what is so wrong with Carrie White. Her innocence frustrates and inconveniences those around her, isolating her more and more as the audience is thrust closer still to the bodily root of her evil.

Carrie White does not know enough to understand her monstrosity, and only viewers experienced in the growing pains of menstruation and early puberty are wise enough to understand the monstrous implications of her blood, understanding that they are by extension cursed to contain the same villainy. More than that, *Carrie*'s true horror is that its titular character avoids easy categorization. The viewer does not know Carrie White outside of knowing that she is a monster.

There is little in the form of self-identification in Carrie's actions. With doe-eyed confusion, she responds to the abuse inflicted on her with

vague worry and meager opposition. She is kind with a malleable personality; she attempts to mitigate her anger both through an ancient God and modern fashion. Most of all, Carrie is a helpless monster who shows that even the sweetest woman contains an unavoidable horror threatening to spill out and violate the rules of the game. Carrie's monstrosity draws on the political terror of an increasingly capable monstrous-feminine entering into an autonomous sexuality through which she can destroy and create as she pleases. This creature is pitiful and powerful, a modern witch whose subversion of social order cannot be contained in the body. Her politics and her ravenous pursuit of power threaten to pull good wives out of marriages, rip embryos away from uteruses, and tear men away from the positions of influence that allow them to maintain the patriarchal status quo.

Margaret White diagnoses her daughter's plight just before Carrie goes to prom. As Carrie uses her telekinesis to force her mother away from her, Margaret White prophesizes her end, quoting Exodus when she warns "Thou shalt not suffer a witch to live" (Bretherton). In her role as witch, Carrie shows how the internal pain and bleeding of a woman's body projects onto a destruction of community and social order. Her power is unleashed through menstruation, referencing a historical mythology that approaches menstruation and childbirth with terror and attempts at regulation. Centuries of efforts to constrain and control the unwieldy witch range from male self-mutilation as a means to access the power of blood and gain the abilities of the monster, to the scientific subjugation and dissection of the female form, to patriarchal regulation of birth control and bodily autonomy (Knöppler). Carrie's plight and postmodern horror constructs echo these mythologies.

As Margaret White reminds the audience just before she attempts to kill Carrie, "Evil never dies." Instead, the cycle of abuse, control, sexuality, and monstrosity continue. Within its predictability lies its threat. Carrie bleeds and baptizes, moving hopelessly between conservative control and progressive disguise. Margaret White is crucified in death, her bushy hair mirroring the same wild terror of the prayer closet's Jesus. Sue Snell, as the only survivor of Carrie's rampage, convulses in her bed with nightmares of Carrie's bloody hand pulling her to the same fate of explosive and uncontainable horror. Though Carrie's power is neutralized in death, the film dictates that the same pattern of abuse, pain, and sexual monstrosity remains in every woman.

# Agency and Autonomy

In the 1960s and 1970s, the female body was a focal point for debates regarding race, class, gender, and sexuality. Efforts for women's liberation in second-wave feminism demanded a reassessment of social order that would disrupt gender hierarchies on a domestic and national scale. In the push for ratifying the Equal Rights Amendment and the movement for bodily autonomy and access to safe and legal abortions, feminists critically examined patriarchal political and religious systems and attempted reform in and out of these organizations (Foxworth). The religious motifs and symbolism in *Carrie* are shaped by the historical evolution of feminine power on a political scale, though the film deals specifically with the juxtaposition of purity and power in White women only.

For the first three-quarters of the film, Carrie is torn between the diametrically opposing perspectives of femininity represented by Margaret White and Miss Collins. Though raised under the domineering Christian teachings of her mother, Carrie's telekinesis offers an opportunity to reinterpret her femininity. She seeks information in the school library, scanning books titled *Hidden Powers of the Mind*, *New Gods in America*, *What Great Religions Believe*, and *The Tarot*. Her quest for knowledge parallels a surge of religious expression outside of the Christian faith in the 1970s. While the emerging religious right contested the mutual exclusivity of feminism and spirituality, many women sought spiritual connection outside of the rigid conventional organizations, leading to an expansion of women's spirituality particularly in the absence of male presence (Foxworth). Carrie's powers, which Margaret White prays will be given up and pardoned through God, reference the expansion of women's spirituality, as well as the presence of witchcraft in historically autonomous female monsters.

When Margaret White bewails the sins of Eve and the evils of sex following Carrie's first period, her cries echo the vilification of the sexual body, and particularly the menstruating body, in Christian mythology and practices. Early Christian sources approached menstruation as an abnormal deviation from the ascetic, masculine ideal. The conclusion of a menstrual cycle symbolized a return to God and a sign of spiritual progress (Day). Margaret White's hatred of menstruation references a religious condemnation of women's bodies and the assumed sexuality to which menstruation alludes, in addition to the more recent religious implications of a villainous sexual woman.

As an alternative to this fervent repulsion of femininity, Miss Collins encourages Carrie to embrace her body and its potential appeal. She leads Carrie to a mirror, saying, "You're always walking around with your hair down, all moping around . . . I want you to look at yourself. Would you look at that? Come on. Now, that's a pretty girl." She offers advice and a newfound agency in self-expression, suggesting that Carrie use

mascara to accentuate her eyes or curl her hair to frame her face. In one sense, Miss Collin's guidance contrasts with the conservative values and aesthetics of Margaret White, but it leads Carrie less to liberation and more towards the prospective nuclear family, of masking her monstrosity in pursuit of a partner. Her value is in her physical appearance and the possibility of peace in assimilation. Physical embellishments obscure Carrie's monstrosity but fail to contain the destruction that becomes irrevocably tangible through menstruation.

Carrie's attempts to gain autonomy from her mother and agency in her expression reflect feminist ambitions to transcend social status and patriarchal regulation. However, her failed efforts to avoid her metaphysical monstrosity reveal the female body as uncontainably violent, a threatening vessel for destruction especially in its autonomy. Carrie's narrative arc is preoccupied with her inability to have control over her body and the daunting challenges of choice. The threat of agency appears with the advent of her first menstrual cycle, in a moment that marks transformation from girl to woman and the unveiling of the monstrous-feminine. She is at once outside of the protection of her mother, the matriarch, who even through God cannot spare Carrie from her powers or relieve herself from her own hysteric insanity rooted in her past sins. Carrie lacks patriarchal surveillance too: she has no father to refer to, and the paternally powerful principal, Mr. Morton, brings Carrie in for inspection and then dismisses her out of disgust.

Following her traumatic escape from the locker room, Carrie sits outside of the principal's office in a shot that mirrors the spatial composition of a confession booth. Behind the glass window to the room, Miss Collins tells the male principal of Carrie's ignorance, pacing in frustration. "Until a half hour ago, I don't think she knew there was such a thing . . . It's just her period." Mr. Morton stutters around mentioning the language of menstruation, looking down at his pipe and recoiling when he sees blood on Miss Collins' white gym shorts. He is anxious to finish the conversation with Miss Collins and quickly dismisses Carrie from school, approving the punishment of her bullies and satisfying his duties as principal and patriarch.

In the liminal space between the binary of girl and woman, the internal gore of femininity is repulsive to the men of *Carrie*. The murky terrors of female puberty are mysteries to men not out of a dearth of information, like in the case of Carrie's own relationship to her body, but out of a perceived grotesqueness of the developing body. Though the entrance to sexuality holds some level of assumably intrinsic appeal to *Carrie*'s leading men, packed behind the allure of sex is a creature best left contained, controlled, and far removed from them. The sounds of anxious, swelling strings when Carrie bleeds and the extreme close ups to the sights of bloody transgression endorse the men's perception. The film's narrative as the product of a male director, screenplay writer, and

author points to a certain astuteness in the perception of a maturing female body as simultaneously alluring and repulsive. Femininity in *Carrie* is frustrating to the film's men and its inherent monstrosity is repeatedly women's work to manage; they are the only characters who remain acutely aware of menstruation as an entrance to power.

*Carrie* parallels the country's fear of feminine power on a religious and political scale, and the film maintains the validity of the monstrous-feminine as a threat paradoxically in its autonomy and its uncontrollable villainy. Carrie's eventual agency in her body and its destructive power plays out in a massacre, allegorically paralleling a nation's preoccupation with birth, death, and the regulation and control of women's reproductive bodies. In classic postmodern form, *Carrie* resonates with the country's political fears but partially violates traditional narratives in which the threat of femininity is placated or contained. Carrie's explosive end encompasses the inescapable and uncontainable internal horror of her body forced external as well as a rare moment of choice to wield her power in pursuit of total destruction. Clear definitions of autonomy are blurred by this dual function of violence in which the telekinesis extends a monstrosity but also consumes and suffocates its wielder. Carrie enters the film as a pitiful victim, subject to the abuse and ridicule of her classmates and her mother. Even though she ultimately selects a path of destruction, her menstruation in the first scene serves as a prophetic warning that the blood that first streams down her leg will compound and destroy her.

Blood and abuse act cyclically in *Carrie*. Both in the literal sense of the menstrual cycle and in the reenactment of menstruation when she is covered in pig's blood at the prom, both instances precede violence and destruction. Abuse from the other women of the film–especially Margaret White and Chris Hargensen, Carrie's school bully–prompts violent telekinesis from Carrie, who acts in retaliation to the internal pain of her developing body and the external torment of her mother and peers. Though Carrie appears much like a cornered animal until her demise, Chris is a crude, irreverent teenager who uses her sexuality to manipulate and control those around her. She represents a brazen sexuality as a foil to Carrie's virginal meekness, commanding her boyfriend to participate in her plot to punish Carrie and lecturing her friends who refuse to revolt against the gym teacher.

Though her name and agency initially position Chris in a deceptively androgynous role, her relationship with her boyfriend Billy Nolan exposes her as another iteration of the monstrous-feminine, one who is aware of the power of her sexuality and seeks to exploit it. In the car with Billy, Chris teases the possibility of sex, coyishly withdrawing the offer when he appears interested. In the parked car outside of a busy bar, crowded with teenagers, Chris enjoys the authority that comes from her exposed and bold advances, as well as the pleasure of dangling the offer

in front of an increasingly frustrated Bobby. When she moves away again and whips out a hairbrush, lecturing him on patience, he becomes upset. "Well what for?" he asks, pleading for sex. "We do this all the time." At her repeated refusal, he grins and tells her, "I know what you like about me. This." The playfulness turns abruptly serious, as Bobby grabs her by her arms and wrestles her into the corner of the car and closer to him. Chris squirms in the seat away from him and yells, "Dumb shit!" Bobby slaps her across the face, the second instance of abuse that night. She recoils momentarily with a look of familiar frustration as he tells her how "fucked up she is." Chris once again draws close to Bobby, looking up at him with a doe-ish expression as she kisses down his torso and moans his name. "Bobby, Bobby," she repeats. "I hate Carrie White."

Chris' power stems from her sexuality; it enables her to manipulate men and enact vengeful plots on the women who seek to undermine her. This weapon is a fragile one, however. Though she vainly fashions her body to be the most powerful, the most appealing, she is ultimately at the mercy of any man when her promises of sexual reward prove too frustrating or her anger turns on them. She embraces her sexuality regardless, leveraging sex in order to perpetuate the abuse she receives onto the women who turn against her. At the prom, she slaps Bobby when he attempts to pull the rope that will release the pig's blood on Carrie and grabs it instead, licking her glossy lips as she leans her head back in pleasure and performs her final revenge. As a character with perhaps the most evident examples of agency, she utilizes the allure of her body to unleash the cruelty it masks, the inverse of Margaret White's attempts to obscure her body to hide her inner monstrosity. Both exist as examples of the monstrous-feminine in different addresses to the sexual, reproductive body.

Margaret White is a punishing figure whose religious fervor afflicts Carrie's entrance into puberty. Even her last name hints at an obsession with Christian motifs of purity. Margaret White incessantly denies her daughter any semblance of choice, believing that it is a gateway to the devil. When Carrie returns home from school after her period, her mother strikes her to the floor, making her curl up in meek submission. Opening her Bible to a page entitled "The Sins of Women," she hits Carrie again as her daughter looks up at her in confusion, pleading, "Why didn't you tell me, Mama? I didn't sin!" Margaret White is relentless; "The first sin was intercourse. The first sin was intercourse. The first sin was intercourse ... Say it woman!" She drags Carrie into a cramped closet covered with religious iconography. The haunting eyes of a bloody, bushy-haired Jesus look down on Carrie as she recites prayers for hours, only emerging hours later with her hair obscuring her face once more. Back in her room, she looks at her reflection in horror, with another portrait of Jesus glaring over her panicked inspection. Her body distorts in the mirror as shrill strings sound and the glass shatters over a statue of the Virgin Mary,

and Carrie hastily telekinetically reassembles it before her mother can punish the transgression.

Margaret White's insistence that menstruation reveals Carrie's inner evil, and that redemption lies solely in the punishment and concealment of the monstrous and sexual feminine body fuels the cyclical route of abuse that *Carrie* plays out. In the film's final scenes, when Margaret White speaks of Carrie's conception, she tells her daughter, "[He] promised never again ... And then, that night, I saw him looking down at me that way. We got down on our knees to pray for strength. I smelt the whisky on his breath. And he took me ... And I liked it." The event of marital rape, and Margaret White's hatred in her body's pleasure of it, as the beginning of Carrie's story, reveals Carrie's menstruation as a reiteration of her birth: an interior evil, either in the hidden monstrous-feminine or in the effects of a violent sexuality, are made exterior in birth and in the destructive force of menstruation.

Even the milder alternatives of femininity in Sue Snell and Miss Collins, which depart from Margaret White's fanatic religiosity and Chris Hargensen's villainous hyper-sexuality, represent a cycle of abuse. Sue Snell, the one survivor of Carrie's rage, knows the power in the promise of sexual reward. She convinces her boyfriend Tommy to take Carrie out to prom one day, walking with him behind the school bleachers as she asks him, "Tommy, if I asked you to do something very special for me, would you do it?" Miss Collins, meanwhile, punishes the cruelty of Carrie's bullies with mandatory exercise that exhausts the teenage girls and enrages Chris, who attempts to confront the gym teacher. Miss Collins grabs Chris and hits her, threatening, "One more word from you and I'm gonna knock you down."

*Carrie* positions choice suffocatingly close to the threat of violence. Abuse, monstrosity, and sexuality are entangled in a prophetic cycle that none of the women seem able to escape. Instead, they vacillate between receiving and projecting violence, finding power only in their sexual allure and their influence over other women. The film insists on the perpetuation of this cycle: Margaret White tears at her hair in erotic madness, unable to regulate and contain her monstrosity despite her religious commitments; Chris Hargensen chooses to replicate the abuse she faces from men in her torture of Carrie; and Carrie finds little respite in the disguises of makeup, her mother's religious regulations, or in an idyllic fantasy of normalcy at prom.

Within this predetermined cycle, *Carrie* warps clear definitions of agency and autonomy. The film emerges during a wave of feminism that embraced the woman as sexual and guarded her right to choose her future, but *Carrie*'s women are denied the ability to escape a fate of monstrosity and sexual abuse. Their sexuality is as villainous as their birth; though Carrie attempts to circumvent her destiny, her monstrosity is only felt at a greater magnitude.

Just as Creed would insist that the monstrous-feminine is not a passive creature, and instead part of a cinematic process that perpetuates the "belief that woman's monstrous nature is inextricably bound up with her difference as man's sexual other," modern feminist theory requires that *Carrie* be understood beyond limiting constraints of the "male gaze" (Creed; Whelehan). The shower scene, for example, teases the reveal of the body and instead exposes the monster, but it goes beyond repulsion or shock value. *Psycho*-inspired instrumentals warn an audience of a gruesome horror about to be unleashed, but women and viewers familiar with the experience of menstruation are unlikely to meet the moment with shock. Instead, Carrie's leisurely and pleasurable exploration of her body before the arrival of her period holds a possible homoerotic pleasure for its female viewers. The arrival of blood does not simply repulse an ignorant spectator; instead, it affirms that femininity is a basic anatomical evil, primed to spill out and rip apart the protective structure of patriarchal hierarchy. Viewers who menstruate are implicated in this monstrosity, and Carrie's journey through womanhood as an experience rife with physical and sexual abuse, inescapable pain, and a stripping of agency or free-will ascribe an unremarkable and monolithic quality to womanhood—that suffering and monstrosity is predestined and natural. Carrie's intrinsic villainy is entangled in her attempts for bodily autonomy and control, and the film's construction of monstrosity depicts a menstruating monster as simultaneously pitiful and horrifying, passive and threatening.

# Conclusion

Carrie's monstrosity captures both the mystery and autonomy of her developing body: progressive self-expression manifests in deception built out of make-up and prom apparel, and her attempts at agency link choice to abuse and pain. *Carrie* obscures the political implications of a sexual, reproductive body and an autonomous woman in a strange allegory of high school romance and school bullies in order to produce the primary effort of a horror film—fear (Phillips). *Carrie* does not reveal a new type of monster in the form of zombies, aliens, or vampires. Instead, it resonates with a broader culture that views women as ill-equipped for autonomy yet horrifyingly powerful, holding an interior evil that can disrupt community order. The erosion of order on a political scale, and more importantly the paranoia of this change, symbolically resonates in *Carrie*'s new construction of the menstruating witch.

In a time of monstrous change, *Carrie* constructs a villain suffering in the fractured binaries of gender and sexuality. *Carrie* attends to the American paranoia, resonating with and shocking the public who came to know Carrie White and her story of cyclical monstrosity. Its depiction

of villainy, victimhood, and the innate properties of femininity do more than set a pattern for gendered monsters in horror; it shows how the monstrous-feminine exists in a perpetual state of violence within a larger cycle of Western mythology that continuously seeks to contextualize and contain the mysterious power of women's bodies. *Carrie* continues in the path of Adam and Eve and trials of witchcraft to narratively reprimand the woefully horrible woman and explain the anxieties of gender that grip a community.

The legacy of *Carrie* continues in its sequels, remakes, and in horror films that continue to contend with binaries of gender and sexuality. When studied through the prism of Brian De Palma's 1976 film, the American woman's ravenous quest for economic, social, and political power becomes a narrative that echoes across covens and gym lockers, exemplifying the female body as always transcending any efforts of regulation. Today, in the midst of recurring fights for reproductive justice and bodily autonomy of gender diverse individuals and women, the liminal spaces between male and female and girl and woman are once again at the forefront of American paranoia, haunted by *Carrie*'s undying menstrual monster.

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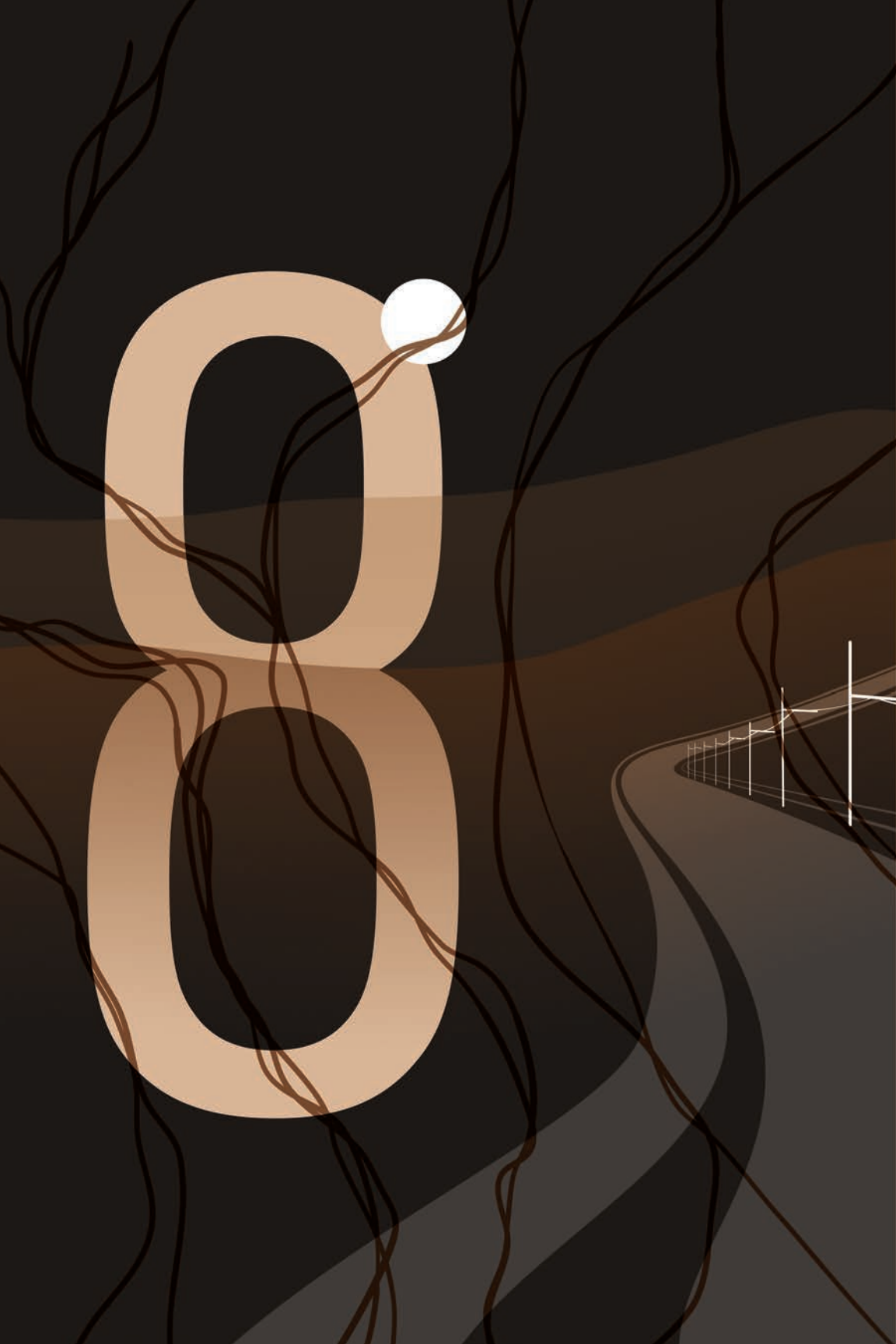

**Alexa Smith**

Dr. Denise Meringolo

**Department of History**

# Braddock Heights and the Traditional Rebel Knights: Community Healing in a Small Town with a Difficult History

# Biography

**Alexa** (Lexi) **Smith** is a history and economics double-major student with a public history minor. She is also a member of the Honors College and a Humanities Scholar. She plans to graduate in spring 2023 and hopes to attend graduate school to earn her Ph.D. in history. After graduate school, she hopes to work as a professor of history.

Alexa would like to honor the late Adam Blusnavage, as his gifts to her family of Braddock Heights books and memorabilia upon his passing enabled her to write this paper. She would also like to thank her research mentor, Dr. Denise Meringolo, Dr. Melissa Blair, Dr. April Householder and the Undergraduate Research Award program, which provided funding for this project, the staff of the Maryland room at the C. Burr Artz Public Library, and the Braddock Heights Community Association. Finally, she extends her gratitude to her interviewees, Bernard Smith and Keith Beachley.

# Research Journey

Writing a research paper of this nature about the town where I grew up is perhaps the greatest challenge I have taken on as a student of history. However, after spending the better part of twenty-one years in Braddock Heights, I have learned how vital it is to discuss every part of a place's history, not just the details that are quaint or easy to swallow. This project was initially supposed to be a documentary. After realizing how unskilled I am in the art of filmmaking, this paper is my best attempt to reach through to my readers and show how I have come to the conclusion that although the town is quiet these days, the silence is, at least in part, brought on by a difficult history. In her Public History class, Dr. Meringolo teaches that there are ways to heal from difficult histories and restore communities that have been shaken, a lesson that inspired this project. By bringing together snippets of truth found in newspapers, books, interviews, and a lifetime of living in the place which I have examined, I hope to create a unified written record of these events and plot a path forward.

# Abstract

This research project examines the town of Braddock Heights, Maryland as a case study on the 1980s resurgence of the Ku Klux Klan. I examine the previous events and preexisting conditions that fueled white supremacy in the community, as well as analyzing the actions of the Klan and others' responses from 1980-2015. My research assesses the extent to which community healing has occurred in Braddock Heights and proposes further action. I utilized primary and secondary sources to answer my research questions, as well as testimony from Braddock Heights residents. My research fits into previous literature in that the project studies the impact of the Klan on a specific community. However, my work varies from past research in that other case studies tend to examine communities during the 1920s resurgence of the Klan, while this presentation studies a community during the 1980s resurgence. Previous works studying the 1980s resurgence tend to focus on larger areas of the United States. Though those studies answer important questions, it is equally important to understand why the Klan was able to hold a given community in its grasp in recent memory and how this community recovered. I examine the latter two questions in my work.

# Introduction

The term "Ku Klux Klan" typically evokes a mental image of post-Reconstruction-era white men with Southern accents carrying antiquated pistols on their hips and covering their heads in triangular hoods, causing terror wherever they go. However, the Klan gained ground in more of the United States than just the Deep South, and the group had followers for much longer than just the decades after the Reconstruction. The Klan experienced a resurgence in the 1920s, after which membership fluctuated, increasing with events such as school integration in the 1950s and fading due to successful Congressional probes in the late 1960s. However, during the late 1970s and early 1980s, increasing militancy and collaboration with other white supremacist groups helped the Klan gain a significant following in many communities.[1] One area affected by the 1980s resurgence of the Ku Klux Klan was the small Western Maryland town of Braddock Heights.

The area now known as Braddock Heights was initially home to Susquehanna Indigenous peoples, then a community of Black families who settled along the ridge of Braddock Mountain during the nineteenth century.[2] However, by the 1890s, rumors of iron ore deposits nearby had attracted wealthy white developers to the area, some who purchased a great deal of property and others who contributed the capital to build infrastructure for the newly-founded town of Braddock Heights.[3] Affluent Marylanders flocked to the mountain town on vacations during the first half of the twentieth century before the area became a quiet, year-round residential community populated largely by white families.[4]

This peaceful atmosphere was disrupted in 1980, however, when the first of several Ku Klux Klan rallies was held in Braddock Heights on the property of David White Ament, a known Klansman and the grandson of one of the first wealthy white men to purchase land on Braddock Mountain.[5] The rallies continued for several years before attracting legal action from local government bodies, and eventually gave way to tensions that remained throughout the 1990s and early 2000s.[6] As late as 2015, the Ku Klux Klan attempted to hold a rally in Braddock Heights. The Klan was able to prevail in Braddock Heights largely due to systemic inequalities between white and Black community members. The town was partially able to recover in the twenty-first century due to the presence of community support and opportunities for dialogue, but more work must be done before its recovery is complete.

# Literature Review

There is no existing scholarly work on the presence of the Ku Klux Klan in Braddock Heights, Maryland. As a matter of fact, only one work exists on the history of Braddock Heights at all: Anne B. Hooper's *Braddock Heights: A Glance Backward*, a self-published work written by a community member. Thus, it is necessary to take a step backward and examine sources on the resurgence of the Ku Klux Klan during the 1980s and 1990s, as well as case studies surrounding the presence of the Klan in other areas of America, in hopes of gaining an understanding of existing literature in the field. Literature on the Ku Klux Klan during the 1980s and 1990s is sparse in comparison to that which discusses the group during the 1920s, but the existing publications on this third Klan revival tend to focus on its merging with other white supremacist groups, as well as why the Klan was able to experience a third revival at all. The approach of studying the Ku Klux Klan's presence in a specific community, on the other hand, is relatively popular, and tends to focus on cases where Klan activity is viewed as atypical or running contrary to prevailing narratives.

E.M. Beck's "Guess Who's Coming to Town: White Supremacy, Ethnic Competition, and Social Change" is an oft-cited work that takes a quantitative approach to investigating why Ku Klux Klan activity and recruitment was prominent in certain areas of the U.S. South during the 1980s and not in others. This work discusses the "threat and competition" theory of white supremacist activity, which states that "prejudicial attitudes, discrimination, and hostility toward a minority group are the result of economic competition and power threats to the hegemonic dominant group."[7] Beck disproves this theory using a Negative Binomial regression model, a statistical method used to compute the probability that a particular county experienced exactly a certain number of Klan events during the years 1980-1990.[8] He does not find a strong correlation between competition between groups in an area for scarce resources and Ku Klux Klan activity. Rather, he finds that Klan activity was more heavily concentrated in urban areas and state capitals regardless of the economic competition occurring there.[9] Beck uses his data to make several other claims as well. He asserts that two outliers in the data were areas where numerous white supremacist groups were working together and that such "exceptionally vigorous racist groups" produced a higher volume of activity than would otherwise be expected.[10] Additionally, Beck finds that an increase in the level of inequality of white incomes was positively correlated with more frequent Klan activity, suggesting both sociological and economic motives for the resurgence of the Klan during the 1980s.[11]

Rory McVeigh's "Structured Ignorance and Organized Racism in the United States" takes an alternative approach to explaining the Ku Klux Klan's success when it comes to recruiting new members in certain areas during the 1980s, 1990s, and 2000s. McVeigh attributes much of this success to economic and educational inequality, claiming that white supremacist groups such as the Klan have been able to take advantage of "structured ignorance" to gain followers. "Structured ignorance" is a theory of white supremacist activity based on the idea that every individual makes decisions based on incomplete information.[12] McVeigh suggests that economic and educational inequality can create this phenomenon: individuals observe economic inequality and instability, yet lack the educational access to find "an alternative explanation for what they observe," and thus begin to believe white supremacist conspiracies.[13] He then displays how the resurgence of the Klan beginning in the 1980s was distinct from previous resurgences due to the Klan's new ties with other white supremacist organizations, such as Neo-nazis and skinheads.[14] McVeigh also discusses the "threat and competition" theory, in his paper referred to as the "ethnic competition theory," but claims that it is "more useful in explaining violence...initiated by these organizations than in explaining the movement itself," using demographic data and interview testimonies to defend this position.[15] This is similar to Beck's argument that the "threat and competition" theory cannot fully explain why certain areas experienced a larger share of white supremacist activity. Ultimately, McVeigh concludes that "structured ignorance" leads members of some communities to "view organized racism as a reasonable response to the problems they face in their daily lives."[16]

Whether Beck's and McVeigh's theories are applicable to the case of Braddock Heights is a difficult question to answer, as the community provides a much smaller sample size than exists in either of their studies. Additionally, any conclusions about economic inequality or educational outcomes that one can draw from demographic data on Braddock Heights may not apply to members of the Klan who traveled to the Braddock Heights rallies from other areas. McVeigh's theory of "structured ignorance," however, is visible in the record of Grand Dragon Dale Rousch's 1975 speech at a Gamber, Maryland rally, a community located only half an hour away from Braddock Heights. Rousch espoused common racist and anti-Semetic conspiracy theories while his audience laughed and applauded.[17] The audience's positive response to these inaccurate ideas indicates that perhaps McVeigh's "structured ignorance" was a contributing factor to Klan activity in the area.

*The Ku Klux Klan: A History of Racism and Violence*, a resource on the history of the Klan created by the Southern Poverty Law Center (SPLC), discusses the Klan's history from its founding to the end of the twentieth century. Though the SPLC does not defend an explicit thesis in this work, when discussing the Klan revival of the 1980s, they too choose to

focus on the ground gained by the Klan when it allied itself with other white supremacist groups such as Neo-nazis and skinheads. The SPLC places special focus on the case of Glenn Miller, a Neo-nazi turned Klansman who instructed his followers in paramilitary training and carried out acts of white supremacist violence.[18] In including this information, the writers show how dangerous the Klan still was in the 1980s, especially in combination with the other white supremacist groups that were emerging at the time.

These militant tendencies are visible in Braddock Heights's historical record. An image captured in 1980 shows David Ament reclining in his backyard with a large rifle after a feud with Maryland Grand Dragon Anthony LaRicci, vowing to "defend his property."[19] Authorities also removed explosive black powder from Ament's home.[20] Though there are no records of the Braddock Heights Klan allying itself with other white supremacist groups, some of the trends that prevailed on a nationwide scale clearly took hold in the town.

Numerous other scholarly works have focused on studying the presence of the Ku Klux Klan in a specific community. Most of these works examine the Klan of the 1920s and the 1930s rather than the 1980s, and emphasize that the presence of the Klan in the community in question runs contrary to prevailing narratives, i.e., that the Klan only organized in formerly Confederate states. In "The Ku Klux Klan in a Central California Community: Tulare County During the 1920s and 1930s," Newell G. Bringhurst examines the broadening geographic base of the Klan during the early twentieth century, specifically in the San Joaquin Valley region of California.[21] Bringhurst discusses the characteristics of the Klan in Tulare County and the ways in which its presence impacted the surrounding community.[22] Throughout his work "White Sheets in Mecosta: The Anatomy of a Michigan Klan," Calvin Enders does similar work surrounding the presence of the Ku Klux Klan in Michigan and the Midwest as a whole during the 1920s.[23] Other publications of this nature include *Hooded Empire: The Ku Klux Klan in Colorado* and "The Invisible Government and the Viable Community: The Ku Klux Klan in Orange County, California During the 1920s."[24]

While numerous historians choose to focus on the resurgence of the Ku Klux Klan during the late twentieth century, most of their works use a broad lens and focus on nationwide phenomena surrounding the Klan, such as its tendency to merge with other, newer white supremacist organizations. Most of the scholarship that studies the presence of the Klan in a specific area of the United States examines earlier iterations of the Klan. Though these studies answer important questions, it is equally important to understand why the Klan was able to hold a given community in its grasp in recent memory and how this community recovered. I will examine the latter two questions in this work.

# Racism in Braddock Heights

## 1900-1960

Discrimination against Black residents of Braddock Heights and racial tensions began decades before the first Ku Klux Klan rally took place in Braddock Heights. This is unsurprising considering segregation's prominent role in Maryland's history. Infamous racist policies in the state such as red-lining in Baltimore City continue to impact communities today.[25] The impact of segregation is clear in the historical record of less populated areas such as Braddock Heights as well. Community member Anne B. Hooper notes in her history of the town, Braddock Heights: A Glance Backward, that the Black community in the area "endured locally the restrictions common to their race in this period," stating that Black residents were not allowed use of the Braddock Heights pool or park, two areas that were commonly used for amusement and socialization.[26] The lawn fetes and dinners held by Black residents typically occurred in the Braddock Springs area, far from the rest of the community.[27] Additionally, in 1951, a tollhouse that acted as a memorial for one of the most well-loved Black residents of Braddock Heights was demolished to make way for new construction, an event covered by Lee McCardell of the Evening Sun. McCardell wrote both a tribute to this adored community member, Lewis Smith, and a report on the destruction of the tollhouse, where Smith lived for many years.[28] In a town that prided itself on its historic roots, one struggles to believe that the tollhouse would have been demolished had it evoked nostalgic memories of a white man, or been an important site of history for the town's white residents.[29]

## 1960-1985

By the 1970s, many of the original Black families of Braddock Heights had left the town for other areas.[30] Simultaneously, the Ku Klux Klan was experiencing a resurgence in other parts of Maryland. In 1967, the Klan was responsible for acts of arson against a Black community in Laurel, Maryland, and several years later, the hate group made headlines when it sponsored a picnic in the small town of Rising Sun.[31] Anthony LaRicci organized a rally in the village of Gamber, located around an hour east of Braddock Heights, in 1975.[32] Frederick's *The Post* attributed the rise in KKK activity to "the current political climate," going on to discuss the inflammatory speeches given by Klan members at the 1975 rally surrounding issues such as race-integration busing in schools.[33] These national and regional issues would soon come to a head in Frederick county's quiet mountain community.

In 1959, David White, one of the first wealthy men to purchase a vast tract of land in Braddock Heights, passed away at the age of 99. He left his estate and vast Georgian home in the hands of his daughter, Jean Bast, and his grandson, David W. Ament.[34] Ament later took charge of

the house and the property that ran through the yard of the home and behind numerous other houses, colloquially referred to as the "backfield" by those who lived there.[35] Despite his grandfather's local fame, Ament was scarcely known in the area, with his neighbors recognizing him as "the man who sometimes rode his motorcycle down the street wearing a gun on his hip, and the man who put five-ton rocks around his lawn next to the firehouse to keep people coming to play bingo there from parking on his property."[36] However, in the spring of 1980, when plans for a Klu Klux Klan rally on Ament's estate became known to the Braddock Heights community, he became notorious within the town.[37]

The rally drew headlines, with news helicopters landing in the fields next to Braddock Heights's convenience store.[38] However, when Chip Brown of The Washington Post sought to interview community members for an article on the 1980 rally, few individuals were willing to speak on the record. One resident who was willing to talk with a reporter, Doug Thompson, remarked in shock, "Up here there's nothing overhead but birds and God...It's turned the community upside down."[39] Several other interviewees expressed shock, such as County Commission President Mary Williams, who remarked that she "couldn't believe it could happen in Frederick County."[40] Brown also interviewed several individuals who hoped that the rally would not receive a great deal of attention, such as Lt. Grover Sensabaugh, who asserted that "the community...played right into the hands of the Klan by making a big deal of this."[41] Others, such as Lord Nickens, the head of the Frederick county NAACP, worried about the possibility of violence if individuals arrived at the rally site to oppose the Klan.

Several of Brown's interviewees alluded to the racial tensions that were present in the community previously and at the time. Tom Mills, executive editor of the *Frederick News Post*, expressed confusion at the possibility of a rally occurring, but stated that he "could have imagined that the Klan would have been greeted with open arms" ten years previously.[42] This implies a history of consistent racism in Braddock Heights, calling into question the legitimacy of the shock that some community members expressed. When speaking with a reporter, a Black homeowner asserted that "if [he] had a rally for a black militant group in the neighborhood [he] would probably be run out, shot out or burnt at the stake. The state police wouldn't come to [his] house friendly like they did," adding that his neighbors "just sit and do nothing" about the Klan.[43] Brown mentioned Ament in his article, but neglected to mention his status as the grandson of a well-known Braddock Heights community member, rather depicting him as a nutty old man that most community members had not heard of and did not associate with. This source displays the discomfort that the 1980s revival of the Klan inspired amongst Braddock Heights' white residents.[44] While outwardly disapproving of the rally, most white interviewees were hesitant to take direct action, rather expressing the idea

that residents should ignore the rally and let it pass, along with shock that such an event was happening in the first place.[45] Brown depicts Braddock Heights residents as people who are eager to return to the uneventfulness of small-town life while failing to mention that the town was not immune to historical trends and that this uneventfulness never truly existed.

The rally took place at the end of June, purportedly drawing around one hundred people, including a large number of media members from out of town.[46] However, that event didn't mark the end of the Klan's influence in Braddock Heights. In October of the same year, the Klan held another rally on Ament's estate. This gathering was smaller, attended by around two dozen Klansmen, and it made far fewer headlines than the June rally, with the Washington Area Spark remarking that it was "mostly ignored."[47] In August of 1981, the group received permission to hold yet another rally in the same location, despite the county sheriff's department's recommendation that the permit be denied.[48] In total, at least five Ku Klux Klan rallies occurred in Braddock Heights between 1980 and 1985.[49]

## 1985-2015

By 1985, Klu Klux Klan rallies in the area largely moved to Rocky Ridge, a rural community around a half an hour north of Braddock Heights.[50] Sources state that the final rally on Ament's property attracted around 75 people, while the first rally at Rocky Ridge was expected to host 200 Klansmen.[51] Perhaps this move was made to facilitate increased attendance, though the rallies did not actually produce such a large turnout.[52] Additionally, in late 1986, the Frederick chapter of the NAACP successfully sued the Frederick County Commissioners to prevent them from issuing public rally permits to the Klan "as long as the Klan [excluded] blacks and other non-whites from the events."[53] However, Ament's presence continued to serve as a force of racism and white supremacy in the town. He was a frightening presence toward other community members, and the threat of violence in return for actions such as inviting a Black guest to the neighborhood remained.[54] Clearly, Braddock Heights felt the impact of Ament's presence.

Ament had left his estate for a nursing home by 2000. Then, in 2005, an electrical shortage started a fire in his vacant Georgian house, leaving a charred ruin in its place.[55] Braddock Heights residents referred to the house as an eyesore, but it also served as a guarantee that the town's history with the Klan would not be erased, sparking informal dialogue amongst community members.[56]

### 2015-Present

After Ament's death, Klu Klux Klan activity in Braddock Heights paused for nearly ten years. However, in 2015, the Traditional Rebel Knights of the Klu Klux Klan – the final evolution of the group of Klan members who hosted rallies on Ament's property – announced that they were holding a private rally on the estate. In response, residents of Braddock Heights planned a candlelight walk that took place on the same night as a form of counterprotest, though the walk avoided Jefferson Boulevard, where the Klan rally would be visible.[57] Kelsi Loos reported on this event for *The Frederick News-Post*.

Community members did not seem nearly as hesitant to be quoted in Loos's article as they were in Brown's article twenty-five years earlier. In addition to testimony from local residents, the head clergy of multiple churches in the area provided input, discussing how they planned to address the rally in their sermons.[58] Additionally, contributors to Loos's article express largely positive opinions on the counterprotest. In another contrast to Brown's article, the piece did not specifically highlight the perspectives of Black Braddock Heights residents or other residents of color.

Ultimately, the 2015 counterprotest was the last time that the community members of Braddock Heights directly confronted the town's history with racism and the Klu Klux Klan. A few years after the rally, the owner of a construction company purchased Ament's derelict estate and bulldozed it, building a new house for his daughter, her husband, and their five children on the property. One could argue that since the final reminder of Braddock Heights's relationship to the Klan is gone, the town has fully healed from these events. However, the symptoms of a community that was once plagued by white supremacist terror still remain. For one, the town has failed to diversify: as of 2019, 93.1% of Braddock Heights residents are white, while only 1.8% are Black.[59] Additionally, the important role of Braddock Heights's Black community in the founding of the town remains largely unacknowledged.

# Analysis

### Contributing Factors to the Presence of the Klan in Braddock Heights

As *The Post* stated in 1975, national and regional issues were certainly a contributing factor in the increase in Klan activity in Maryland during the late 1970s and 1980s, as was McVeigh's "structured ignorance."[60] However, another factor that cannot be ignored is the historical power imbalance between the Black and white residents of Braddock Heights, especially the power of David White and his descendents.

As previously stated, Black residents of Braddock Heights were segregated from areas of the town such as the pool and the park during the first half of the twentieth century.[61] These areas have historically served

as important places of socialization for Braddock Heights residents, and prohibiting Black community members from entering these places likely served as a significant barrier to these individuals interacting with their neighbors. Additionally, Black Braddock Heights residents were known to socialize in the Braddock Springs area, which was separated by a highway intersection from the rest of the community.[62] Both of these factors served to cut Black residents off from the rest of Braddock Heights.

The history of the town's Black community was also not prioritized in its historical record. Firstly, the demolition of the Braddock Springs tollhouse represents the erasure of a figure who was important to Braddock Heights's Black community and the deprioritization of history that was significant to Black Braddock Heights residents over white residents.[63] Furthermore, *Braddock Heights: A Glance Backward* only discusses the first white people to live in the town in its "Background and Foundations of a Community" section, which is placed at the front of the book and covers the founding of Braddock Heights. Despite being some of the first people to live in the area, Braddock Heights's Black community is not mentioned until close to the end of the book, and only a few pages are dedicated to their history.[64] *Braddock Heights: A Glance Backward* is one of the few collections of the town's history that exists, and this deprioritization of Black individuals and histories in the book certainly had an impact on the way that residents viewed their community's values and past, and it continues to do so.

Compare this ostracization and deprioritization to the privilege enjoyed by Braddock Heights's white residents, especially the wealthy white individuals who settled in the area at the beginning of the twentieth century. White affluence has been a common theme in Braddock Heights history since its establishment as a vacation destination, when wealthy guests would visit the Hotel Braddock and dine on plentiful meals prepared by staff members, most of them Black.[65] One guest was reportedly so determined to show off her riches whilst on vacation that she "arrived with eleven trunks full of long satin dresses with matching hats and shoes and was never seen in the same ensemble twice."[66] This same wealth enabled David White to build a business venture and an intimidating reputation on the many acres of land that he purchased in Braddock Heights during the early twentieth century, land that his grandson eventually used to host Klan rallies.[67] The individual racism of David Ament and his fellow Klansmen was certainly responsible for the presence of the Ku Klux Klan in Braddock Heights, but the systemic inequality that has historically existed in the town and signaled to the community that the needs of Black residents would continually be deprioritized and ignored in favor of the needs and wants of white residents also created an environment where the Klan could exist, as were "structured ignorance" and an increase in white supremacist activity on a national and regional level.[68]

## Braddock Heights's Healing

The historical record and current data show that the Ku Klux Klan caused harm to the Braddock Heights community. Klan leaders wielded their return to Braddock Heights as a threat to persuade the town's civic leaders to bend to their will, fostering distress at the time. Maryland Grand Dragon Samuel Royer stated that "if [community leader] Connie Wrench and her bunch write any more derogatory letters to the editor of The Frederick Post, then I'll be back here with my Klansmen and hold another party."[69] Demographic data also shows that the community has failed to diversify, suggesting that the town's past difficult history presents a challenge to moving forward in the present.[70] How does a community heal from thirty-five years of Ku Klux Klan activity? Despite the challenges that Braddock Heights has faced, the town has been able to partially heal through collaboration and dialogue, as exemplified by its relatively united response to the 2015 planned Klan rally. The ruins of Ament's home also served as a source of dialogue after 2005. The charred relic drew the immediate attention of visitors and newcomers, and locals responded with a lesson about Braddock Heights's history with the Klan.[71] These discussions provided Braddock Heights residents with the opportunity to process their history and educate others on the challenges that a small town can experience when faced with white supremacy. In addition, community centers such as churches served as places where dialogue and healing could take place after the 2015 Klan rally. Pastors and community members alike showed a willingness to acknowledge the harmful events that had occurred, actively displaying their disapproval through response and counterprotest, and promote conversation.[72]

However, as the town's demographic data shows, its healing is incomplete. The population of Braddock Heights remains overwhelmingly white and affluent for a variety of reasons, including high housing prices.[73] However, one might also figure that it would be difficult for any neighborhood to diversify when only a few decades previously, residents weren't afraid to walk out of their houses and issue death threats to their neighbors who hosted Black guests.[74] Furthermore, remembrance of the Black families who resided in the community is still too often abandoned in favor of discussions about the white, wealthy residents of early Braddock Heights. Additional action by the community, such as open dialogue for all residents on Braddock Heights's history with racial discrimination and historical preservation efforts in order to memorialize the town's Black community and those who were oppressed under the hateful ideologies of the Klan, is needed before the town can fully heal from its past.

# Conclusions

At first glance, one might struggle to understand how a tiny, quiet community like Braddock Heights could have become the host of several Ku Klux Klan rallies from 1980-2015. However, after an analysis of the works of previous scholars discussing the underlying reasons for Klan activity, national and regional events that led to a resurgence of militant white supremacist organizations, and the role of power disparities between Black and white residents in Braddock Heights, the reasons for these historical events have become more clear. Additionally, an examination of Braddock Heights in the twenty-first century reveals some of the ways in which the community has healed, as well as areas where additional healing is needed. Braddock Heights is an example of a community where local white supremacist activity exists in the recent memory of many residents, and the study of the conditions that facilitated this activity and the factors that contributed to healing is valuable to history.

# Notes

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24. Enders, "White Sheets," 60.

25. Richard Rothstein, "From Ferguson to Baltimore: The Fruits of Government-Sponsored Segregation," *Journal of Affordable Housing & Community Development Law* 24, no. 2 (2015): 205, https://www.jstor.org/stable/26408163.

26. Hooper, *Braddock Heights*, 65.

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28. McCardell, Lee. "A Braddock Heights Factotum." *Evening Sun*. September 26, 1951.

29. Hooper provides several examples of the pride that Braddock Heights residents took in their history during the 1950s, namely the 1950 "50th Anniversary" celebration held by the Braddock Heights Community Association, featuring "a pictorial history of the community and an antique car and buggy display." Two years later, the Community Association held a celebration with an "Old South" theme.

30. Hooper, *Braddock Heights*, 62.

31. Bob Simpson, "Standing Against the Maryland Klan 1971: A Personal Memory," *Washington Area Spark*, January 2, 2013, https://washingtonareaspark.com/2013/01/02/standing-against-the-maryland-klan-1971-a-person al-memory/.

32. Sandler, "KKK."

33. Sandler, "KKK."

34. Hooper, *Braddock Heights*, 50.

35. Bernard Smith, interview by Alexa Smith, 16 February 2021.

36. Brown, "Klan's Planned Rally."

37. Brown, "Klan's Planned Rally."

38. Keith Beachley, interview by Alexa Smith, 10 April, 2022.

39. Brown, "Klan's Planned Rally."

40. Brown, "Klan's Planned Rally."

41. Brown, "Klan's Planned Rally."

42. Brown, "Klan's Planned Rally."

43. Brown, "Klan's Planned Rally."

44. Sources do not show a named branch of the Klan based in Braddock Heights until the mid-2010s, but other Klan leaders such as Anthony LaRicci were present at the rallies and associated with Ament.

45. Brown, "Klan's Planned Rally."

46. Flickr, "Klan Rallies."

    George Dorsey , "Klan Rally a Ho-Hum Affair," *The News*, June 30, 1980.

47. "Klan Rallies for Second Time in Braddock Hts., Md.: 1980." Washington Area Spark, Flickr, posted October 27, 2019, https://www.flickr.com/photos/washington_area_spark/48968882912/in/album-72157632308050 065/

48. "KKK Rally Approved."

49. "U.S. District Court decision on Klan rally permits," *The Frederick News-Post*, October 10, 1986.

50. Mike Clem, "Klan Rally Open to Members Only," *The News*, January 19, 1987.

51. Bryan Denson, "Klan Leader Says Membership Climbing," *The News*, July 5, 1985.

52. At one Rocky Ridge rally, only 24 robed Klansmen were present.

    David Rice, "Ku Klux Klan gets Permit for Rally," *The News*, July 7, 1986.

53. The News Staff, "Judge puts limits on Klan rally permits," *The News*, October 7, 1986.

54. Bernard Smith, interview by Alexa Smith. Upon seeing one of Bernard's friends, a Black man, standing in his backyard during the celebration, a neighbor approached him and "said 'you can't have a Black guy here.' He pointed up the hill [toward David Ament's house] and said 'that guy's a Klansman, and if he sees that guy he'll come down here and shoot you all.'"

55. Hooper, *Braddock Heights*, 50.

56. Bernard Smith, interview by Alexa Smith.

57. News reports written before the event stated that the counterprotest would travel through Jefferson Boulevard, but this change was made at the last minute for safety reasons.

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60. McVeigh, "Structured Ignorance," 896.

61. Hooper, *Braddock Heights*, 65.

62. Hooper, *Braddock Heights*, 65.

63. McCardell, "Factotum."

64. Hooper, *Braddock Heights*, 62-65.

65. Hooper, *Braddock Heights*, 16.

66. Hooper, *Braddock Heights*, 16-17.

67. Hooper, *Braddock Heights*, 50.

68. McVeigh, "Structured Ignorance," 896.

69. Denson, "Klan Leader."

70. "ACS Demographic and Housing Estimates."

71. Bernard Smith, interview by Alexa Smith.

72. Loos, "Community."

73. The median price of a house in Braddock Heights is currently over $500,000 according to Realtor.com.

74. Bernard Smith, interview by Alexa Smith.

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**James Angle**

Dr. Renée Lambert-Brétière

**Department of Modern Languages, Linguistics and Intercultural Communication**

# ¿Me hace sonar gay esta voz? Does this voice make me sound gay? An intercultural study on the perception of speaker sexuality in Spanish

# Biography

**James Angle** is a recently graduated applied linguistics major with two minors in Spanish and Russian, and a certificate in intercultural communication. Having since graduated with departmental honors, completing both an honors thesis and URCAD presentation, he is now working on transforming this research to present for community college students and working full time as a public services librarian in reference.

None of these things would have been possible if it were not for Dr. David Beard and Dr. Thania Muñoz D. for their feedback and suggestions, the UMBC LGBTQ+ Faculty and Staff Association for their generous funding, and for the work, suggestions, help, and moral support of Dr. Renée Lambert-Brétière. James would also like to thank those who take the time to read his work.

# Research Journey

While completing a B.A. in applied linguistics during the time of writing, it is obvious that language and its uses fascinate me. However, this idea came to me when talking to a friend. Many English speakers assume that I'm gay simply from the way I speak without knowing anything about me. It occurred to me that I didn't know if the same phenomenon would occur if I were to speak a different language, like Spanish. Even though I had done many research papers before, this felt out of my expertise. Luckily, my advisor and the classes I took were able to guide me through the process and prepare me for each step so that by the time the paper was actually due, most of it was already written. As a member of the LGBT community, I believe it is important to understand how the heteronormative world views us in order to battle misconceptions and prejudices that harm our community. Through the completion of this research project, we are better equipped to understand not only the speech features commonly used to predict sexuality of Spanish-speaking men, but also the characteristics and adjectives people ascribe to men they assume to be gay.

# Abstract

Recently, the idea of a "gayccent" has become a pop-culture phenomenon. However, studies have shown that an "accent" is not enough to clue listeners into a speaker's supposed sexuality. So, if not the voice, what allows people to evaluate a speaker's sexuality? To test what characteristics Spanish speakers associate with gay men, often proximity to femininity, a survey in Spanish was utilized. Ten participants for the survey watched selected portrayals of gay men and their speech in media and responded to open-answer questions about what they saw. Using participant responses, a qualitative analysis of how gay male speech is portrayed in Spanish language media was done to illustrate how accepted stereotypes of gay men are constructed and reinforced and how these notions are detrimental to minority communities in the Spanish-speaking world. This research will lead to a more profound understanding of stereotypes that Spanish-speaking gay men face in their respective cultures. Furthermore, knowing what stereotypes and assumptions lead people to judge sexuality will help combat discrimination gay men face in real life, as well as change their portrayal in media, which will then lessen the impact of stereotypes.

# Introduction

This research aims to discover what characteristics or factors influence listeners' assumptions about the sexual orientation of characters in Spanish language media. In other words, "what makes a character gay?" Recently, the idea of a "gayccent" has become a pop-culture phenomenon, illustrating that some listeners do feel they can make an educated inference on the sexual orientation of certain speakers and characters. However, studies have shown that an "accent" is not enough to clue listeners into a speaker's supposed sexuality. So, if not the voice, what allows people to evaluate a speaker's sexuality? Through my research and survey, I aim to discover what explicit factors and characteristics viewers use to identify the sexuality of characters in Spanish language media. Gay male speech could be any kind of speech employed by gay men, while the concept of gay male speech has come to be representative of certain characteristics. Current perceptions of gay male speech include such characteristics as higher pitched voices, a "lisp" or slur, and the incorporation of feminine speech styles into the repertoire. While "gayccents" have become one of the more well-known ways of assuming a character's sexuality, voice alone does not draw a complete picture. This study aims to complete said picture and use a holistic approach to analyze the portrayals of Hispanic gay men.

While for parts of society and certain researchers these characteristics are accepted as true (see for example Swanson, 2015), they largely fall into the category of stereotypes. On the other hand, the majority of researchers acknowledge the fallacy of these theories and the problems of simply assigning these features the label of gay. However, studies indicate that many listeners can ascertain the sexuality of a gay male speaker at rates greater than simply chance (Gaudio, 1994). So, then what about gay men allows for listeners to guess their sexuality with success? This research hopes to answer this question and provide insight into what factors allow listener identification of male sexuality in the lesser studied Spanish. Furthermore, the completion of the study will allow insight into the different portrayals, understandings of, and methods used by Spanish-speaking participants to distinguish the portrayals of gay men and how the respective listeners perceive them. This paper will focus on characteristics or styles listeners use to assess speaker sexuality in regards to how gay male characters are portrayed in various Hispanic countries' media. Findings and research from current scholars on the pitch, styles, and public perception of Spanish speaking gay men and characters will be discussed in this section in order to provide background and bring relevance to my own topic.

We must now turn our attention to a brief overview on the history of gay male depictions in Spanish language media. Though unique to each specific country, Spanish language media followed a general

pattern, with the first non-derogatory or stereotypical portrayal of a gay man appearing in the 2001 telenovela *Primer Amor*. In popular media from English and Spanish speaking countries we are still relatively new to the era of gay representation in media. In a 2016 study on representation in Spanish language media conducted by GLAAD[1], it was found that of the 516 individual characters on scripted primetime series, 10 of the only 14 LGBT characters were gay men. While slowly increasing in both amount and quality of representation, the question often asked is "why does it matter?"

As reported by the Los Angeles Blade, an LGBTQ news, rights, politics, and entertainment publication, anti-LGBTQ+ hate has significantly increased on Spanish-language radio and in online spaces (Blade, 2022). Furthermore, Spanish-language misinformation and right-wing extremism are thriving on platforms such as Facebook, Instagram, Twitter, YouTube, and TikTok (Blade, 2022). Most recently, Hispanic media outlets, YouTubers, singers, and talk show hosts, who altogether have millions of followers and listeners, decry homosexuals, mostly men, for supposedly trying to groom and indoctrinate children.

While anti-LGBTQ+ violence and hate speech are on the rise, portrayals of gay men in Spanish-language media have continued to stall. Ricardo Ramírez argues that while telenovelas have made LGBTQ+ identities more visible to wider audiences, they have not destabilized the status quo, and contribute to the reproduction of sexist, homophobic, and/or classist discourses (Ramírez, 2020). Ramírez goes on to say that in telenovelas, especially in Chile, gay men are often either "funny locas" or "serious machos" (Ramírez, 2020). The funny locas are often effeminate gay men who gossip and spend more time with women, subverting gender roles and becoming characters of ridicule who are meant to be laughed at. Serious machos on the other hand, act more in accordance with "machista" gender order, which will be discussed in more detail in a later section of this study. Serious machos, despite being gay, do not involve themselves with other gay people, places, or ideas. If they are married or dating, it is with another serious macho character, and both are heavily desexualized. Ramírez concludes that these portrayals only serve to uphold dominant social discourses and create "safe" gay characters who are usually only plot devices and not main or important characters. They serve to reinforce societal ideas like machismo. Gay men are consistently othered and looked down upon, further perpetuating the belief that they are inferior, not "real" men, and are not worthy of respect.

Moving forward, this paper will be organized into different sections beginning with this introduction to the topic and themes of this research before moving onto the literature review. Next will be the methodology section followed by that of the results from the survey. Results from each clip will be analyzed one by one with a brief summation

1 GLAAD is an American non-governmental organization that was founded in protest against the derogatory coverage of gay and lesbian people, but now encompasses the entire LGBT spectrum in respect to its media monitoring.

followed by analysis. Following that will be conclusions from this study and a look towards the future of this topic and research along with a list of references and tables.

# Literature Review

When the general public thinks of gay men, what comes to mind? Obviously differing depending on the area, there are, however, certain attributes commonly associated with gay men in different Spanish-speaking countries. Geng and Gu (2021) would argue that labeling certain features as "gay" is "too general and too specific" (p.11) all at once. Amongst gay males in Spanish-speaking countries there are huge amounts of diversity that even common sense would dictate that not one general rule or set of "gay" features would allow us to understand all of the different ways gay men choose, or do not choose, to verbally express themselves. Podesva et al. (2001) instead propose that a better framework should be used, one that indexes linguistic features to activities, stances, and acts committed by different gay communities, which would allow for linguistic features to index and cross over to "social meaning on a micro-level," (p. 177). In general, a more holistic and well-rounded view of the speech of gay men is starting to be considered and studied, taking into account other features like location, race, age, and language spoken, rather than simply the appearance of so-called "gay" features, even if employed by some gay male speakers.

In a study conducted by Munson (2007), listeners judged the gay male speakers as sounding less masculine than their straight counterparts, with the results significantly correlated with measures of perceived sexual orientation. This further demonstrates that the clearer a speaker's perceived sexuality, the more likely the listener was to ascribe qualities such as "masculine" or "feminine" to their speech. Even though the confines of what exactly is included in masculinity are beyond the scope of this paper, it is still possible to state that there is no clear way to scientifically conclude that straight men are more masculine than gay men or vice versa. What is considered masculine is largely the product of the time period and location, with no set or certain definition besides that which society creates. So, if we can agree that masculinity is self-created and vastly different depending on the person, time-period, culture, and geographic location, then what is influencing listeners' perception on the levels of masculinity or femininity they perceive gay men and their voices to possess? Podesva et al. (2001) argue that stereotypes relating to masculinity and femininity in gay men are largely what influence listeners' perceptions of perceived sexuality. Masculine speech is often associated with deeper pitch, more aggressive and direct styles, and usually compared to that of "the powerful person in these relationships," or those

between a man and a woman, while feminine speech is often stereotyped as more polite, of a higher pitch, and making less use of vulgar terms (Broadbridge, 2003). If these characteristics are the accepted stereotypes of "masculine" and "feminine" speech, how and where are they portrayed in such a way that they are so easily able to affect society and the public? The answer is through the media. The rise of television and its quick entry to many homes allow programs, TV shows, commercials, and anything else that's broadcast to be seen by anyone in the home regardless of age. These stereotypes, often of minorities, are then seen, internalized, and accepted as true, especially when the viewer does not have real life evidence or people to counteract these new beliefs. In their research on Dutch media portrayals of gay men, lesbians, and bisexuals, Meer and Pollmann were able to establish that the more an individual watched TV, the more likely they were to have a more stereotypical view of gay men (2021).

Despite some progress in various Latin American countries, machismo, and all it entails, continues to affect and burden growing boys and gay men within their own communities. Díaz (1997) begins by challenging the way Latino masculinity is constructed in the minds of young Latino boys. He juxtaposes the ideas that if masculinity was something of a privileged status as "carriers and defenders" where all men had ample opportunity to establish self-worth and self-esteem, albeit inflated, that both gay and straight men would grow to be confident and "unacceptably" oppressive towards women, which we can see is not the case. Díaz then argues that not all men are masculine and that to be masculine one must prove this through certain acts, which in turn creates anxiety and self-doubt in men. Men must spend their whole lives trying to achieve an unattainable goal of being the "masculine" man. This then causes men to act out in "hypermasculine" ways in order to assert and rid themselves of this doubt. Wrapped up in this is the idea that homosexual men are not really men or are "failed" men. For many Latinos, homosexuality has been thought of in terms of gender identity rather than sexual orientation, making it much harder to see gay men as masculine or even as "real" men. While acknowledging some modern changes and nuances in how different countries and cultures execute their own machismo-bound rules, gay men in Spanish-speaking countries are often failures at being men because through loving, taking care of, and having sex with other men, they are subverting traditional gender roles largely imposed by the colonial Spanish invaders (Cruz, 2012). Because they do not remain in the confines of machismo, gay Hispanic and Latino men "fail" the test required to be considered "real" men. Thus, because they are not "real" men they are failures and are often seen as feminine and anything but masculine as the term allows them to define it. Often, gay Hispanic and Latino men are not only looked down upon for subverting gender roles and "failing" as men, but for giving up the power they could have in

society under machismo (Díaz, 1997). It is often seen as confusing why gay men would "want" to be more like women when machismo offers them more.

I believe that Mack (2010), in her perception experiment in regard to Spanish spoken in Puerto Rico, would agree. She was able to find that there was a significant relationship between perceived gayness and height, with gay men being perceived as shorter than men sounding straight. There was, however, no perceived link between gayness and age, nor social class. However, height was a linked factor to both age and social class, with the taller one perceived to be the older and higher up the social scale. This then implies that if gay-sounding men were perceived to be shorter than their straight-sounding counterparts, then they sound both younger and lower down on the social scale. With respect to acoustic data, Mack found a statistically significant correlation between the perceived sexual orientation of the speaker and the F2 frequencies of two tokens of mid front vowels /e/ in la manera and /e/ in el tiempo. The higher the F2 frequency, the higher the correlation of perceiving the speaker as sounding gay. There were, however, no significant correlations between perceived speaker sexuality and individual F1, F0 frequencies, estimated vocal tract length, average dispersion, or the F2 frequencies of /i/ in *la vida* or *el día*, /u/ in *el mundo*, or pretonic /a/ in *la manera* (Mack, 2010).

# Methodology

In order to gather meaningful data for my study on the perception of gay male speech in Spanish, I utilized a qualitative methodology. Through the use of a survey conducted in Spanish with the aim of ten participants total, I intended to collect my participant data. Upon termination of the study, ten individuals had responded to the survey. All individuals who participated in the study were UMBC students at the time of completion, and were paid $20.00 for the time it took them to take the survey. Participants were made aware of the opportunity to participate by professors in class announcements on Blackboard in their advanced level Spanish language and culture classes. Funding to pay the participants was provided by the UMBC LGBTQ+ Faculty and Staff Association. Of all participants, 70% of respondents identified as female, while the remaining 30% identified as male. Similarly, 70% identified as heterosexual and the remaining 30% was split with 20% being homosexual and 10% being bisexual. 40% of respondents identified as either Hispanic, Latino/a, or both, while the remaining 60% did not. Similarly, 40% claimed to speak Spanish in the home, while 60% did not. However, 50% claimed to speak Spanish every day, while the remaining 50% did not claim to speak Spanish every day. When selecting questions to ask the participants,

I was interested in any linguistic features that the participants think correlate to sexuality, and especially what they think about the general sexuality portrayed and what characteristics or features led them to think this, whether indeed linguistic or physical or emotional as well.

The format of the survey consisted of four clips with free response questions presented after each one. After watching preselected clips from each show participants were asked to answer several free response questions relating to what they had seen in the videos, pertaining to the theme of this academic research. The first country that I utilized a clip from was Argentina, entitled *Argentina Tierra de Amor y Venganza*, a fairly popular and current Argentine telenovela that was recently renewed for a second season and amassed a viewing of 13.7 million viewers in its first season (Argentina, 2019). In this first clip we see two young friends Nino and Malek, spending time together and talking. Suddenly Malek's father comes home unexpectedly and catches him playing around and acting as an announcer for his favorite radio program. Malek then acts ashamed and introduces Nino to his father, at which point he exclaims that he's glad his son finally has a male friend to play with instead of listening to the radio all day like a single old woman. At this point the other women around jump in to defend him and explain that there was nothing wrong with what he was doing.

The second clip from *La Fan*, an American telenovela produced by Telemundo, features the character of Miguel Varonil, who the participants were asked to observe. In this clip we see Miguel has what seems like an innocent conversation with an actress he knows, and as the scene progresses it gets slightly more intense, and they jab at each other. Though less popular, this show was watched by many people and was nominated for over eight "Your World Awards."

The third show utilized for this project was *Mil Formas de Amar* that featured two gay men as major characters and was produced by Mexican company Tv Azteca. In the scene the viewers learn of Cristobal's secret. An employee of his father's company discovers him with another man hiding behind a building and making out. She threatens to expose him before his high-profile wedding to a woman, unless he pays her a large sum of money. The woman triumphantly leaves Cristobal distraught and desperate to find the money. The scene ends with the viewer observing him take out a gun from a drawer of his desk.

Lastly, we have the immensely popular Mexican telenovela *Rubí*, which has been named the top telenovela of all time by the United States' largest provider of Spanish-language content: Univision (ABC, 2005). The scene begins with a man, Loreto, in the middle of a wedding dress shop.

This paper also recognizes the diversity of the Spanish-speaking world and does not attempt to minimize the progress certain countries are making in diversity and protections for LGBT people and minorities.

For this reason, clips were pulled from various Spanish-speaking countries in an effort to diversify the different portrayals participants would see and show how different countries portray gay men. This research also acknowledges that the genre known as telenovela is often over-the-top, dramatic, and at times stereotypical. However, given their prominence and popularity in and out of the Spanish-speaking world, they were found to be acceptable to include in this project as they truly are a staple of Hispanic TV and are watched by so many.

In regard to the excerpts used for the survey, each clip was chosen to try to represent different areas of the Spanish-speaking world, as well as to diversify those represented. Similarly, each clip was originally released at a different time and while many might be familiar with the show *Rubí*, clips from less famous shows were used as well. Ultimately, the reasons for which I chose the selected Spanish clips was because I thought they provided a diverse enough representation of gay men in media, different actors, timeframes, and scenarios, without being too obscure, inaccessible, or ill-fitting for the format of the survey. I also believe that they are honest depiction of gay men in the media in that these are real portrayals that appeared on television, received awards, and are generally accepted by mainstream audiences. Given that this is a qualitative study focused on the perception of gay male speech, instead of having ratings or preselected responses for the participants, I asked participants to answer open-ended questions about what they watched or heard. I was interested in what the participants were thinking about the media clips in general, what they were seeing, i.e., what was being portrayed in the media that made them think of characters as gay.

Through having independent and random individuals participate in my study, I aimed to gather a wide scope of the public's real-world opinions on gay men and their speech. Through the participants' responses I was able to have a better understanding of what features or characteristics clue a listener into the perceived sexuality of the speaker. In the survey I began by asking the participants what gender and sexuality they identified as, as well as if Spanish is their native languages what language they use the most, and if they identified as Hispanic or Latino. I used the responses from the participants to answer the question: what makes a character sound or appear gay and how do you know? In the next section analysis will be conducted upon how real viewers perceived the speech and actions of gay men and characters in Spanish language televised media.

# Limitations of the Study

After completion of the study and collection of the data it is important to recognize the limitations of this work. While a minimum threshold of ten participants for the study was achieved, having a much larger sample would have been ideal and provided more insight. As English is the dominant language used and heard around the UMBC campus, it makes sense that there would be less Spanish speakers willing and able to participate in the survey, especially given its status as a non-prestigious language. In terms of the survey participants, 70% identified as women and only 40% identified as hispano/a or latino/a. Due to the nature of some of the questions asked in the survey regarding gay Latin and Hispanic men and the role machismo plays in their lives, a higher percentage of women and non-Hispanic and Latino participants are not necessarily the best representatives to give input on the issue. However, this is not meant to undermine their input or ideas. Moving forward, a similar survey should be utilized that has an equal number of women and non-Hispanic and Latino respondents to men and Hispanic and Latino respondents in order to help eliminate bias.

# Results and Analysis

To begin, I simply asked the participants what they thought of the two boys in the first clip. Of the ten participants of the survey, two singled out that compared with Nino, Malek was more feminine, writing that "he stands in a more feminine way"[2] and "Malek seems somewhat effeminate and very exuberant." However, the other eight participants simply stated that they thought the two boys were "best friends, intimate/close friends" and were simply "expressing their pleasure which is why they want to play." These responses demonstrate that 80% of the participants did not pick up on his supposedly heightened level of femininity enough to comment on it, while those who did still commented that the boys seemed to be friends. However, when asked if they could make a guess on the sexuality of the boys in the scene, only three participants directly said that they could not guess a sexuality from the scene with one responding, "nothing shows me what the sexuality of the boys is." While on the other hand, six participants gave clear answers that yes, the boys were "homosexuals" and "I suppose that they're gay", clearly demonstrating that there must have been some clue or indication they saw in the clip that allowed them to come to this conclusion. The last response makes a further distinction: the participant wrote that he could not guess the sexuality of Nino, but that for Malek "I believe so."

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**2** All quotes from participants have been translated by the author of this paper

More than half of the participants gave clear answers that they could make judgments about the boys' sexualities, while 80% of them simply said they were friends in the first question. So, what is informing their decisions? The three participants who answered that they could not guess the sexuality of either boy gave similar answers when asked to identify a sexuality and state their reasons for doing so, saying "I would not know to declare Malek's sexuality because for me, the manners or forms of expression do not influence the perception I have about the sexuality of others," and similarly that "nothing about what he said or did made me think that he could be homosexual." However, the other seven respondents stated that Malek was "gay unless bisexual" with most saying simply gay and listing the factors that informed their decision. More than half of the respondents listed the fact that Malek "likes theater and listens to the radio" as factors that informed their decisions. Another respondent shared that the fact that he preferred those activities over playing baseball informed their decision. The other factors that the participants mentioned when forming their opinions were things like "he is dressed well," "isn't ashamed of singing or going around dancing," "cares for his appearance," and "his melodic high-pitched voice." Through these responses, certain characteristics come to light that demonstrate what these participants associate with gay men or being gay.

Despite many participants associating these characteristics with male homosexuality, some do clarify that they are stereotypes or that "those are stereotypically feminine and gay characteristics." Participants can recognize these traits and assign them to "gay behavior", thus informing their decisions to call Malek gay, and at the same time, recognize that they are stereotypical. When asked who they agreed with, the domineering father who disapproved of Malek's behavior or the women of the home who defended him, all but one participant said that they agreed with the women who defended Malek and reassured him. While the other participant did not say they agreed with the women defending him, they did explicitly say they did not agree with the father, even writing that "it hurts me that the behavior of his child is so important to him. I am very glad my parents are progressive." Furthermore, when asked if they found anything strange or wrong with respect to Malek's behavior, every single participant answered no to some effect with one saying "no, I don't think there is anything wrong with Malek" and another writing "no, everyone has the right to be a happy and free person." And while still answering no, one participant did write that "as a bisexual man, I would wish that there had been more representation of varied homosexuals, that not all are extravagant and feminine." This person was not condemning or finding problems with Malek's behavior, even if stereotypical, but rather with the lack of diverse repetition available for gay men in the media. Although participants did recognize stereotypical behaviors and

assign them the label of gay and pass that to the character of Malek, no respondents saw the behaviors themselves as bad or problematic.

Through observing the reaction of the father, it is clear that some people, men and society who the father represents, do see a problem with it. One participant shared that "the father says that his son is like a spinster/old maid because he likes to listen to theater or the radio. The women are correct, enjoying theater does not mean he is a girl or that he is single at all. It does not mean anything. The women know that the man means to say he is feminine, that listening to the radio makes one weak" which explains that through the father's comments, he is calling his son feminine and weak, two characteristics commonly associated with gay men in Latin culture (Díaz, 1997). One participant even writes that the father is "a sexist/macho/male chauvinist" while another says that they were able to identify Malek as homosexual "because of the way in with his father looked at him in the scene" indicating that the father's negative view and attitude meant that his behavior is not appropriate and therefore must be gay in this context. While these characteristics were not viewed negatively by the participants, the straight male gaze within the show does continue to view them that way. It is also worth noting that even though the terms gay or homosexual were never used in this clip, the characteristics employed and reaction of the father were enough to convince more than half of the total participants.

After viewing the second scene from *La Fan* I asked participants if the sexuality of Miguel was obvious after watching the scene, and if so, how did they know? Two out of ten participants were not as sure as the rest with one stating that one could think he was gay through the movements of his hands and clothes, but also wrote that "pay attention to the clothes of the woman. The majority of men would not look at her dress, only her chest. On the other hand, he does look at her chest" perhaps suggesting that while adhering to some stereotypes, Miguel defies others making the task of guessing his sexuality more difficult. The second participant also says that his sexuality is not necessarily evident, again calling attention to his comment on the woman's appearance: "the character makes comments about the woman's appearance that leaves his sexual orientation in doubt." However, the rest of the participants would challenge this with one claiming that yes, his sexuality is evident and that "the woman is dressed to call attention to herself, but it is lost on the man in the scene," going in contrast to what the previous two respondents thought. The rest of the participants echo similar sentiments, one even writing "I believe it is quite obvious." When asked what Miguel did to influence their opinion four out of ten respondents answered that it was hand and body movements that most influenced their opinion, while three mentioned his higher pitch or tone of his voice. The last two mentioned his enthusiastic or over dramatic mannerisms or facial expressions. One participant even

responded that Miguel "fits the stereotype of gay men," while another singled out that to them he appeared to be uncomfortable around the women and was definitely not "interested in her."

Now that the participants have again claimed to have been able to assign a perceived sexuality to a character and describe what characteristics helped them come to the conclusion that the character was gay, I asked them, taking everything into consideration, if Miguel was more of a masculine or feminine character. This question garnered a more mixed response than previous questions. Two respondents stated that Miguel was a mixture of both "his voice is not very high-pitched, but his clothes are important to him, probably more than to a straight man" and that "he is wearing a buttoned shirt with a bowtie, he has a beard and is very tall (and not so thin). These are more masculine characteristics. However, body language and conversation with the woman make his appearance more feminine." Both share that to them he had certain male and female attributes where one wasn't able to have more of an effect than the other. Three participants shared that they thought he was definitely more masculine, defending their opinion with the fact that he is not wearing women's clothes nor trying to imitate feminine traits or that he is "tall, appears strong and is assertive," which to them make him more masculine than feminine. Lastly, the remaining participants agreed that Miguel was a feminine character. Those who thought he was feminine listed things like his "behavior," "his clothing," and "the way he talks" that made him appear feminine. Here, we see again the same characteristics mentioned in the first part of the question that originally linked Miguel to being gay, now linked to him being feminine. This creates a connection between gay men and femininity, giving life to the stereotype that gay men are feminine.

My first question for the third video is if they would have guessed Cristobal's sexuality had it not been explicitly stated. While one participant stated that the video was too short to make any conclusions, the other nine participants all agreed that no, they would not have been able to tell. Several respondents gave their reasoning for this, stating that "his voice was masculine, and he was not afraid of physically fighting with another person. He demonstrated his masculinity in controlling the woman physically, his appearance appears very masculine, and his appearance and manner of speaking is not indication to take into account his sexual preference." Several responses mention the aggressive way he acted towards the woman as proof that he was masculine which goes contrary to the established stereotype that gay men are feminine.

The next question asks the participants why they think Cristobal considers suicide when the possibility of others finding out he is gay is revealed, and if that has to do with machismo. In response to the first question participants state, "he is ashamed and feels ashamed," "he believes that to be outed as gay would be worse than dying," and that he "is afraid

that his family will reject him." One participant even wrote that "Cristobal feels that his life had ended." All of these responses demonstrate that it is clear to them that because of the threat of extortion, Cristobal is scared his family will reject him and would rather die than be found out as gay. Upon their elaborations of why Cristobal would think this way, six participants explicitly state that they do believe it has to do with machismo: "I believe it is because of machismo," "I agree that it has to do with machismo," "because he probably views his sexuality as something that should be hidden" and that "machismo is also part of all that." Through their responses we can see a clear connection between Cristobal's desire to kill himself to hide his secret and machismo. Cristobal would literally rather die than be discovered as gay, because of the force machismo plays in his life. Several respondents share how influential the concept of machismo must be in Cristobal's life: "I believe that machismo is the reason Cristobal thinks about killing himself," "machismo is what gives value to Cristobal as a person. If he is not seen as a true man then he can be despised." Both quotes demonstrate even more that because machismo was so ingrained within him, it was the failure to live up to those standards that drove him to such ideas.

Through the character of Cristobal, we have seen a gay man portrayed without the aforementioned stereotypes, and even though he did not adhere to them, he was still at risk of being outed as gay. The lack of stereotypes in his portrayal made it harder for the viewers to read him as a gay man, suggesting that it is stereotypes that are used to both depict and identify gay men in Spanish language media. However, not being a stereotype did not spare Cristobal shame. The ingrained concept of machismo made him suicidal over the thought that others would perceive him as gay, which unfortunately mirrors many real-world viewers in Latin American countries and cultures as described by this response "machismo is always a problem for women and for the LGBTQ+ community because the person feels more powerful over other people. Machismo is not just insults; machismo is much more than words."

I first ask participants to describe Loreto in five words after having watched the fourth and last clip. Four participants responded in part with feminine and effeminate, seven participants included words like "extravagant," and "exaggerated," and seven also responded using words like "dramatic," and "expressive," these being the most common descriptors used. Other words like "fashionable," "elegant," and "stubborn," were used, while one participant simply answered "Gay. Gay. Gay. Gay. Fantastical." When asked to identify his sexuality, if they were able to, many participants used the very same descriptors from the previous question to justify their responses: "he is very dramatic" and "his expression and movement of his hands, his attitude." Another respondent shared that they were able to tell his sexuality "by how dramatically he gives his opinions." Many of the first characteristics that respondents noticed

about Loreto were the very same ones they used to determine his sexuality, making him a heavily stereotyped character.

When asked if Loreto's character was a complete stereotype or rather that it was true to some gay men, the majority of participants shared that they thought that "he is a complete stereotype." Even though many thought that Loreto's character was a heavily stereotyped portrayal, they did share that it is possible to be both. Loreto can be a walking stereotype, but it's true that there are some gay men who do indeed act like that, "it is very possible that there are gay men that act like that, I believe that both things can be true." When asked to describe Loreto as either masculine or feminine, eight out of ten participants responded that he was feminine, citing similar reasons that they thought he was gay in previous questions like the "way that he speaks, moves his hands, and his body language," again linking stereotypical "gay" behaviors to femininity and thus gay men to femininity as well.

Despite these four clips coming from different regions of the Spanish-speaking world, being produced in different time periods, and displaying men with different appearances, the participants were able to single out characteristics that united three out of the four characters as gay. The only character that the respondents were not able to single out as gay was the one who did not invoke all of the different, stereotypical, characteristics listed by participants in the survey. Even though none of these characters was physically intimate with another man in any way, the main characteristic that "makes" a man gay, participants were still able to confidently assign them the label of gay. This suggests that it is not inherently gay actions, kissing or having sex with another man, that make a man gay in Spanish-speaking media, but rather his appearance or personality. Despite learning that Cristobal was gay, none of the respondents claimed to have been able to tell, solely because he did not make use of common gay stereotypes. And because Cristobal did not adhere to accepted gay stereotypes, he was not thought of by participants as feminine. In fact, Cristobal's aggressive behavior and rough way of acting were noted as characteristics that made him not just "not feminine," but rather "masculine." The association of aggression and male domination in conversation and behavior with masculinity brings us to the concept of machismo.

Under the Latin American concept of machismo, men are thought to be "strong, tough, sturdy," and "sexually adventurous," and because gay men are thought to not be these things due to their same-sex attraction, the portrayals of gay men that do make it to Spanish language media adhere to stereotypes that actively place them in the subordinate non-masculine role. Even when we have a character like Cristobal who does not adhere to gay stereotypes, the concept of machismo still has great impact in his life. He is not a stereotype, but because gay men in general are stereotyped so heavily and thought to be less than and not "real men," he

would rather kill himself than be outed. While coming from a telenovela and obviously overdramatized, the burden and stigma that machismo continues to place on gay men is very real and has disastrous effects on their lives and mental health: it forces open gay men to be ashamed and creates terror in closeted gay men that one day they might be outed. Whether a stereotype or not, Hispanic and Latino gay men cannot win. Because the concept of machismo so strictly enforces the behavior of both gay and straight men, making feminine and "gay" behaviors unacceptable, it only allows for shallow and stereotypical representations of gay men in media. As one respondent said, "gay men are not taken seriously as characters and are often the comedic relief when present. More diverse representation of gay men in Spanish language media will help dispel commonly accepted stereotypes about gay men, which is necessary, because as we can see through the responses of the survey, gay men are stereotyped and portrayed as less than men, feminine, dramatic, and high-pitched comic relief."

# Conclusions and Looking Towards the Future

Through the examination of previous experiments and studies realized by other researchers, we were able to establish some of the auditory reasons that Spanish speaking men were identified as gay, namely the way in which male speakers produced certain sounds: a higher F2 reading of /e/. While Mack and Munson (2012) were able to illustrate that English-speaking listeners did not pick up on these acoustic differences as a gay "lisp," unless the question explicitly made reference to sexuality, we did not see a similar conclusion made in Mack's (2010) study on gay male Spanish speakers. However, from the numerous clips participants were asked to watch for the study, it is clear that what most individuals noticed were not specific linguistic factors, but rather characteristics relating to personality, behavior, mood, and emotions. The characteristics most commonly given for respondents' justification of a character or person's sexuality were things that are commonly classified as gay stereotypes. Despite the survey utilizing shows from four different Spanish-speaking countries, there were obvious similarities in the qualities that participants were able to single out of the characters represented. From the four clips the participants were asked to watch in each survey, when they were able to perceive the sexuality of the speaker, surveyed individuals all came to their conclusions based on similar characteristics: high-pitched voice, hand and wrist movements, exaggerated-ness and overdramatic-ness, over-emotionality, and interest in "feminine" hobbies or activities. It is clear that Spanish speakers who watched varied Latin American

Spanish-language media assign very similar characteristics and stereotypes to gay men, which the dominant heteronormative American culture does as well. While taking different forms, even the idea of a gay "lisp" was present in both languages! The survey's findings support the idea that the two language groups conceptualize and stereotype gay men in very similar ways despite the difference between them. Furthermore, they also support the hypothesis of Levon, in that listeners ascribe preconceived stereotypes regarding speakers' sexuality to their perceptions of pre-existing linguistic features employed by the speakers, and states that "stereotype endorsement significantly conditions listeners' perceptual evaluations of gender and sexuality regardless of group membership," (Levon, 2014). However, Levon's study was only conducted on English-speaking men. Through Levon's previous research in conjunction with the findings from my own study, the data suggests that we can make a similar conclusion for speakers of Spanish as well. It appears that Spanish speakers similarly use stereotypes to perceive and guess the sexuality of speakers, regardless of their actual group membership, illuminating the processes that they use to perceive the sexuality of the speaker and revealing them to be very similar to that of English speakers. As the English-speaking U.S. culture has toxic masculinity, the Hispanic world has machismo. All but one participant in the Spanish language survey claimed that machismo is still a problem in society, with one sharing that "machismo continues to be a big problem in society and results in all of the violent femicides that continue happening each day in Latin America." This quote clearly expresses that they believed it to be the root cause of violent attacks on women. This research has revealed that, unfortunately, Spanish speakers associate gay men with femininity and are able to perceive their sexuality, because of the characteristic stereotypes that Spanish-language media continue to represent them with.

It is fair to conclude from the data collected and analyzed that it is time and necessary to abolish the idea of a gay "lisp" that allows listeners to perceive a speaker's sexuality. For the majority of the participants, it was non-linguistic stereotypes that informed listener's perceptions of the character's sexuality, not the height of their F2 values. I agree with Erez Levon in that it is time to "move beyond looking for static connections between variables and perceived social correlates," and instead focus on how society shapes and reinforces ideas, perceptions, and stereotypes of sexualities, (2014). As Lee (2011) states, "Novels, television series and films can reach different and wider audiences than medical journals, non-fiction books, essay collections and even autobiographies. People read a novel or watch a film or television episode for any number of reasons – perhaps based on other work by that writer, or based on the opening paragraph or scene, or on a positive review." People are not always necessarily interested in gay or minority representation nor do they even know much about the topic when consuming a piece of media. However,

"that is why fictional depictions are important for increasing the understanding of a wide audience," because they expose people that would usually never know about or interact with gay men and other minorities to them. "No one single voice can represent all experience in any minority group. The more depictions that are available, the more likely it is that a general audience will hear about, and understand, the relevant issues," (2011) regarding gay men and other minorities. The continued use of the same tired and stereotypical aspects of gay men in Spanish-speaking media creates caricatures of gay men that become boiled down to the very characteristics the participants in this study identified. Furthermore, the depictions teach people who may not know any actual gay men or people that this is how gay men act and what they sound like. This leads to problematic views of gay men, especially the stereotypes that gay men are feminine or not as "real" as straight men. Through having more diverse gay men in media and more diverse depictions of gay men in media, this normalized stereotype of gay men as high pitched, dramatic, emotional, and girly will be less and less normalized until those characteristics are not those predominately associated with gay men. Media representation and portrayals are very important and do have consequences. Continuing to portray Hispanic gay men in these same and stereotypical ways will continue to harm LGBTQ+ communities, because as participant responses and further analysis have shown, most media depictions of gay male characters do not show them as real men or even real people.

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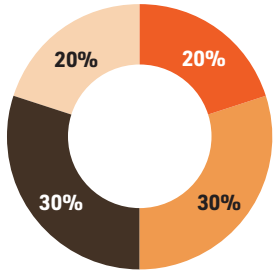
# Appendix A

**Questions the participants were asked about the videos and the order they were asked in, or the choices participants could choose from.**

| | |
|---|---|
| Declaración de consentimiento | Sí, doy mi consentimiento para participar en este estudio<br>No, no doy mi consentimiento para participar en este estudio<br>1 |
| ¿Qué piensa Ud. sobre los dos chicos jóvenes Nino y Malek en esta escena? | 2 |
| ¿Puede adivinar la sexualidad de los chicos? | 3 |
| Si tendría que declarar la sexualidad de Malek, el chico en el suéter azul, ¿qué diría que es? ¿Cúales cosas informaron su decisión? | 4 |
| El padre de Malek y las mujeres tienen reacciones distintas con respecto al comportamiento de Malek. ¿Con quién está de acuerdo, las mujeres o el padre de Malek? | 5 |
| En su opinión ¿hay algo raro o malo con respecto al comportamiento de Malek? | 6 |
| ¿Qué es su reacción al personaje de Miguel Varonil? | 7 |
| ¿Es evidente la sexualidad de los personajes en la escena? ¿Cómo sabe? | 8 |
| ¿Qué hizo Miguel para influir su opinión? | 9 |
| ¿Miguel es un personaje más femenino o masculino? Explique su respuesta. | 10 |

| | |
|---|---|
| En la escena descubrimos que Cristóbal es gay. ¿Habría adivinado usted que Cristóbal es gay si no fuera explícito en la escena? ¿Por qué? | 11 |
| Después de la amenaza de extorsión, Cristobal está angustiado y despúes de esta escena saca un arma porque él está pensando en suicidarse. ¿Por qué piensa así Cristóbal en ese momento? ¿Tiene que ver con el machismo? | 12 |
| ¿Qué papel tiene el machismo en la vida de Cristobal? | 13 |
| ¿Qué papel tiene el machismo en la vida de usted? | 14 |
| ¿Cree que el machismo sigue siendo un problema y por qué? | 15 |
| Describa al personaje de Loreto en 5 palabras. | 16 |
| En su opinión ¿qué es la sexualidad de Loreto y cómo sabe? | 17 |
| La representación del personaje de Loreto ¿es un estereotipo completo o cree que es fiel a algunos hombres homosexuales? ¿Por qué? | 18 |
| ¿Es Loreto un personaje masculino o femenino? Explique su respuesta. | 19 |
| Para usted, ¿cuáles son características masculinas y femeninas? | 20 |
| ¿Qué hace un hombre un hombre de verdad? | 21 |

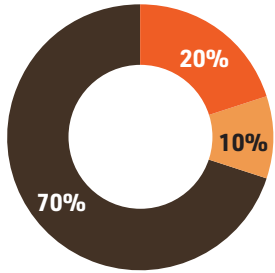
# Appendix B




**¿Cuántos años tiene Ud.?**

10 Responses

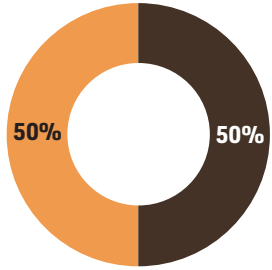
- 18 – 20
- 21 – 29
- 30 – 39
- 60+
- 40 – 49
- 50 – 59




**¿Cómo se identifica?**

10 Responses

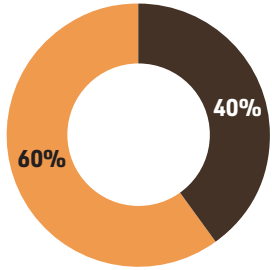
- Heterosexual
- Homosexual
- Bisexual
- Prefiero no contestar




**¿Habla español cada día?**

10 Responses

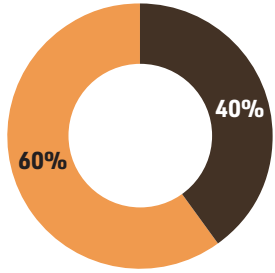
- Sí
- No




**¿Habla español en casa?**

10 Responses

- Sí
- No

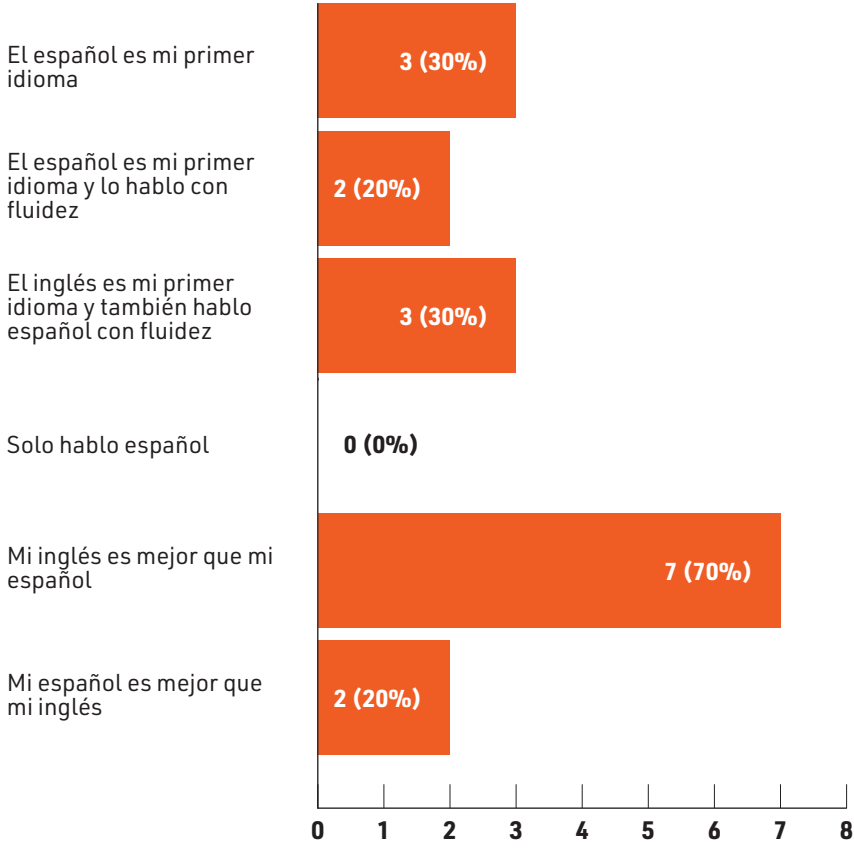



**¿Se identifica como hispan/a o latino/a?**

10 Responses

Sí

No



# Editors and Designer Biographies

**Jordan Fisher** had the pleasure of designing this year's *UMBC Review*. Jordan is pursuing a Bachelor's of Fine Arts degree in design. He is expected to graduate in Spring of 2025. He designed the *UMBC Review* while working as a graphic designer at commonvision, UMBC's Print and Design center. With the bold, fresh, and youthful visual language of this volume of the *UMBC Review*, Jordan speaks to the theme of transition and rejuvenation as the campus returns in-person and welcomes UMBC's new president, Valerie Sheares Ashby. He honors the authors of this journal by representing each paper on the front and back cover, reflecting on how each paper joins together to create a journal the campus community is proud of. He also carefully illustrated pieces for each paper's introduction. Designing for an academic publication taught Jordan lessons in discipline and time management, and skills in book design, illustration, typography, and presenting his ideas and work to his peers. This invaluable experience will serve Jordan long after college, as he continues his work in the graphic design industry. Jordan would like to thank Ms. Laura Schraven for her mentorship and contributions to the design of this edition of the *UMBC Review*, as well as for her reassurance and encouragement along the way. He would also like to thank the editors for their hard work on perfecting the content of the *UMBC Review*, as well as their encouragement and feedback. He would like to thank Emma Muccioli along with all his other commonvision coworkers for playing a key role in his blossoming professional life. Finally, Jordan would like to express his gratitude for his grandparents, Denise Brenner and Thomas Brenner, and his mother, Rose Fisher, for their everlasting love and empowerment.

**Madelyn Pollack** had the privilege of serving as the associate CAHSS editor for the 24th edition of the *UMBC Review*. Madelyn is a Humanities Scholar in the Honors College and is pursuing a Bachelor of Arts degree in history with minors in judaic studies and public history, expecting to graduate in the Spring of 2024. She is part of the Accelerated B.A./M.A. program in the History department and expects to graduate with a Masters of Arts degree in historical studies on the public history track in the Spring of 2025, after which she hopes to work in a public history career. Being part of the Review team this year has allowed Madelyn to broaden her Humanities-based skillset to become a stronger writer, collaborator, and communicator and has helped solidify her love for learning. Madelyn is so grateful to have worked alongside such a dedicated and hardworking team of editors, advisors, and authors and is so proud of the publication that was put together this year!

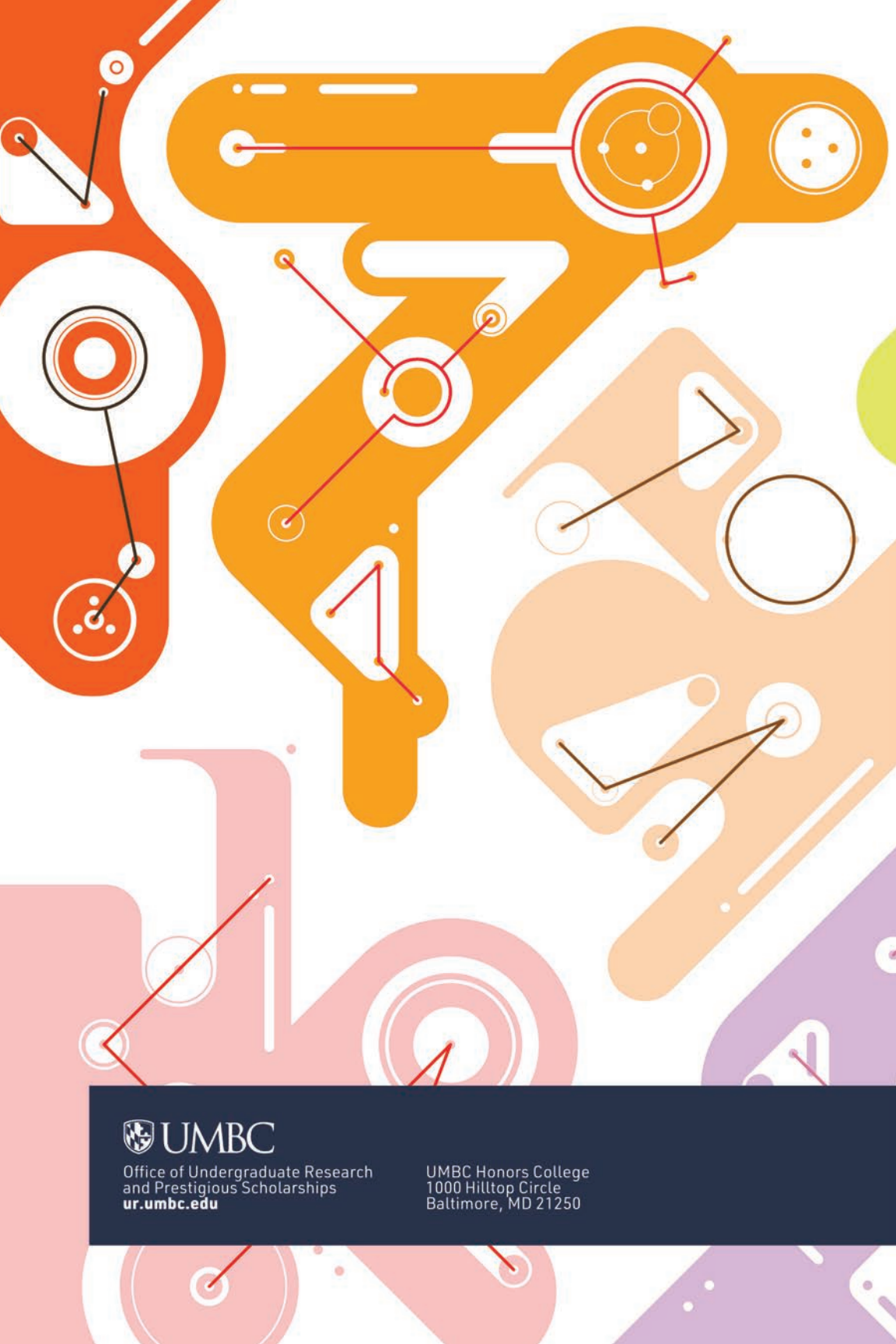
# Editors and Designer Biographies Continued

**Oliver Santos** has been honored to serve as the associate STEM editor for the *UMBC Review*'s 24th issue. Oliver is a junior and is expected to graduate in spring 2024 with degrees in mathematics, English, and political science, as well as an Honors College certificate. After graduating, he hopes to pursue an MFA in creative writing and, eventually, a Ph.D. in mathematics. As a member of the *UMBC Review* team, Oliver has been able to hone his skills reading and critiquing academic writing, and he is grateful for the opportunity to learn about fields outside his areas of study. Oliver would like to thank his fellow editors, Madelyn Pollack, Irina Sbornova, and Clair Volkening for their time and effort. He would also like to thank the *UMBC Review*'s graphic designer, Jordan Fisher, for all his work designing and typesetting the journal. Finally, Oliver would like to thank the *UMBC Review*'s advisors, Dr. April Householder, Dr. Molly Jones-Lewis, and Ms. Laura Schraven for their tireless support.

**Irina Sbornova** served as the STEM editor for the current volume of the *UMBC Review*. Irina is a senior, graduating in the Spring of 2023 with a dual degree in biological sciences and psychology. In the near future, she plans to pursue graduate studies and obtain a Ph.D. in neuroscience. Working as an editor has allowed Irina the opportunity to experience 'the other side' of publishing - an invaluable perspective for any future researcher. She has a great appreciation for science and, through this position, hoped to evoke the same feeling in as many students as possible. During her time as an editor Irina has gained a lot of new knowledge in the fields

that she was not previously familiar with. She would like to thank all the authors and all other members of the *UMBC Review* team for their hard work this year!

**Clair Volkening** was thrilled to serve as the CAHSS editor for this year's *UMBC Review*. Clair is a senior and will be graduating in May 2023 with a Bachelors in English and a minor in music. She is a member of the Humanities Scholars Program and the Honors College. After graduation, Clair hopes to pursue a career in publishing children's/YA novels and to eventually move abroad to earn her MFA in creative writing. Working as an editor has not only allowed Clair to learn the ins and outs of academic publishing, but to also learn from her fellow editors and authors. She thanks Madelyn, Irina, and Oliver for being such wonderful co-editors and Dr. Molly Jones-Lewis and Dr. April Householder for being a huge help throughout the editing and publishing process. Finally, she would like to thank Jordan Fisher and Laura Schraven for creating the gorgeous book you're holding right now!



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