

Creating and Navigating Social and Classroom Spaces with Gravity

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Abstract

Gravity is one of the principle forces in the universe, its power always apparent, giving us three-dimensional creatures a constant sense of “up” and “down”. We propose the use of a metric for applying gravity, or similar “pulling” forces, to social environments by weighting and reordering set network structures where links cannot be added, but nodes may be rearranged. We begin by introducing gravity in social networks, describe previous web applications and uses, and then briefly experiment with the metric within a classroom setting. To that point, we describe and design requirements to effectively apply our metric to classrooms, as well as other social spaces. Finally, we assert that by flavoring network structures with our so-called “gravity”, we make those structures inherently more navigable in terms of personality similarity, and perhaps indirectly, communication and learning.

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1 Introduction

Optimizing community and social networks often refers to the addition of links to increase density (Entwisle, Faust, Rindfuss, & Kaneda, 2007), connect similar nodes (Newman & Dale, 2007), or improve information flows (Haythornthwaite, 1996). Some social settings, however, do not allow for additional links due to a set structure. An example of these structures are networks based on physical proximity wherein individuals seated, or living within a set distance from one another are considered to have a link to one another. Many of these physical structures such as an office, classroom, or living arrangement cannot be easily arranged to increase density, but can be optimized by reordering based on a strategic weighting of nodes. Grid-based physical structures and other networks, as they exist, are self-contained entities with a somewhat uncontrollable structure; they are taken for what they are, not necessarily as how they could be. What if, however, these previously un-touched structures were modified in an attempt to create something different, perhaps, something better?

If such a statement were to be considered, it may first be pertinent to describe what “better” in the means of a social network may be. In our terms for this particular discussion, we consider a network structure to have improved if it is inherently more navigable according to a pre-defined algorithm which will be explained in later sections. We argue that by utilizing and expanding on preexisting techniques, it may be possible to analyze and re-arrange various networks to fit a structure that is more inherently navigable by its very nature.

When thinking about navigating non-graph structures in real-world spaces, it becomes quickly apparent that there are number of common techniques for navigating new, unknown spaces. For example, when travelling around a new city, tourists may be guided, or pulled, toward landmarks such as statues and other recognizable objects (Werner, Krieg-Brückner, Mallot, Schweizer, & Freksa, 1997). Along the way, these same tourists may pass other less recognizable, yet memorable stores, buildings, or other landmarks that may aid navigation in the future.

Navigation within non-geometric spaces like networks of people in social environments, however, is inherently more difficult. Unlike the somewhat static and unchanging historical landmarks that may be observed in a physical space, the same affordances are not necessarily given to social networks. Our research is guided by a desire to optimize social environments and we posit the following exploratory questions: How do we determine which people are most important to personal goals or interests? If a person is more central within a social environment, are they still placed in a position optimal for navigation to and from themselves? In what circumstances would we want to navigate the network of a social environment?

One proposed scenario in which this type of network could be useful is in the organization of classroom spaces, or in the formation of location-based teams. In these situations, network structures may have formed arbitrarily, or with little premeditation and do not necessarily need to be maintained if they are not producing results, especially in a work environment. In such instances, it may be beneficial to

optimize the network in a way that will increase productivity. We argue that this is one of the most likely applications of our work.

To begin addressing the proposed questions, we apply the concept of *gravity* within the realm of social networks to aid navigation through these structures. This artificial form of gravity is intended to “pull” travelers through a network structure in the most efficient manner possible, with a minimal number of steps and no backtracking. We assert that this concept is applicable to certain kinds of social networks that may benefit from reorganization, such as classroom desk spaces or co-working business spaces.

In the following sections, we first explain the concept of artificial gravity within network structures in more detail. Following this, we present a brief study involving the manipulation of a classroom social network, and discuss our findings.

2 Related Works

2.1 Gravity

As water flows downhill towards a water basin or lake, we wish to be able to guide people in a similar manner through a social network structure. To further this metaphor, we also address that this method would be most akin to hiking along an unknown trail, and following the aforementioned water flowing to a basin without prior knowledge of its existence. Thus, we introduce the concept of gravity in social network spaces. To explain this concept in more detail, some new sets of terminology are required. Firstly, we deem that a graph is a *gravity graph* or *gravitationally flavored* if navigation from any node of the graph to any other node can be achieved in the shortest number of geodesic hops possible by a “weighted”, hop-by-hop decision of which node to select next on the path to the final node, with backtracking not being an option (much like gravity, we can only fall). Figure 1 and Figure 2 demonstrate this definition by means of comparing on contrasting a non-gravitationally flavored graph with a gravitationally flavored graph.

In the case of this graph (found in Figure 1), an individual attempting to navigate from Node 2 to Node 4 is drawn on a path from Node 2, followed by Node 3, followed by Node 1, and finally, Node 4 (distance of 3). We call this the *gravity path*. Gravity paths are created one node at a time, assuming no prior knowledge of the graph structure. To delve into the example above in more detail, when originating from Node 2 (and attempting to navigate to Node 4), an individual attempting to navigate the structure would have two possible “next hops”, Node 3 or Node 1. At this stage of the navigation, a simple algebraic function is exploited: summation. Numeric-wise, Node 3 is only of “distance” 1 (4-3) to 4, while Node 1 is “distance” 3 (4-1) from Node 4. However, the true shortest path from Node 2 to Node 4 is Node 2 to Node 1, and then Node 4 (distance of 2). We will continue to refer to this as the *shortest path*. Because the gravity path and shortest path between these two sets of nodes is not the same, this graph is not gravitationally flavored.

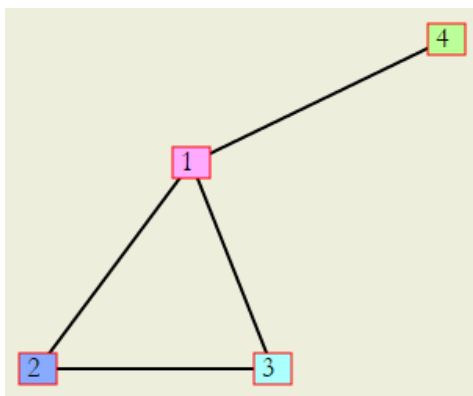


Figure 1. An example of a Non-Gravitationally Flavored Graph

Figure 2 presents a graph with the exact same physical structure as Figure 1, albeit with some of the nodes having modified locations (Node 3 and Node 1 have switched locations). By performing this modification to the placement of the nodes, this structure is now properly gravitationally flavored. If attempting to get from any node to any node, the shortest paths between these nodes will be identical to the gravity paths between these nodes.

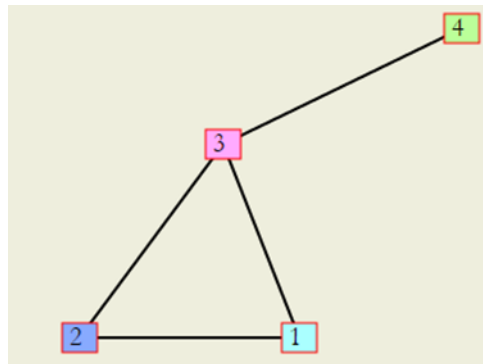


Figure 2. An example of a Gravitationally Flavored Graph

2.1.1 The Algorithm

The algorithm used to complete these gravity graph calculations is simple, but extremely greedy. It works by generating all possible permutations of paths that could exist for any permutation of the graph structure. It then performs a recursive walk through each of these paths and conducts comparisons between shortest paths and gravity paths. Due to its recursive and complex nature, this algorithm operates at a horrendous $O(n^3)$ and becomes highly unstable when working with networks greater than size ~ 12 in its current state. It is a future goal of this project to make modifications to allow the algorithm to function on larger networks, and with greater speed.

2.1.2 The Utility

The gravity algorithm used to exist in a simple C shell, taking a text file of a network's adjacency matrix as its input. However, this was deemed to be non-user friendly, so a utility called Grapher was developed in 2009 to facilitate the design and manipulation of graphs (Dailey, Elder, & Perri, 2009). Building on this, a re-vamped version of Grapher was released in 2011 which featured the ability to run a ported version of the gravity algorithm on user-drawn graphs (Dailey, Whitfield, Weidman, & Denmead, 2012). With this version of the software also came the ability to generate websites from modified graphs for purposes of testing, which will be discussed in the next section.

2.1.3 Previous Experiments

This concept of modifying graph structures to perform navigation is not entirely novel. Previous works have utilized the concept to construct web pages to test how truly navigable these structures were (Dailey et al., 2012). To conduct this study, a series of webpages were created that were either gravitationally flavored, not gravitationally flavored (but hypothetically flavorable), or non-gravitationally flavorable graphs in a variety of sizes.

Participants were then "placed" inside of these web spaces and asked them to traverse the entire structure of the site, and then return to the page they were randomly started on. The webpages themselves were designed to be somewhat memorable, with each page having its own distinct background color, as well as an accompanying word. An example of this is shown in Figure 3.

Type of Graph	Mean Steps
Flavored	24.32
Not Flavored	28.77
Unflavorable	29.41

Table 1. Results of Initial Navigation Study

The initial results were promising, and are shown in Table 1. As was the hope with the study, it was found that website structures which were based on gravitationally flavored graphs were easier to

navigate than non-flavored graphs. This helps to support the notion that having a gravitationally flavored graph inherently makes navigation of that graph easier (Dailey et al., 2012).

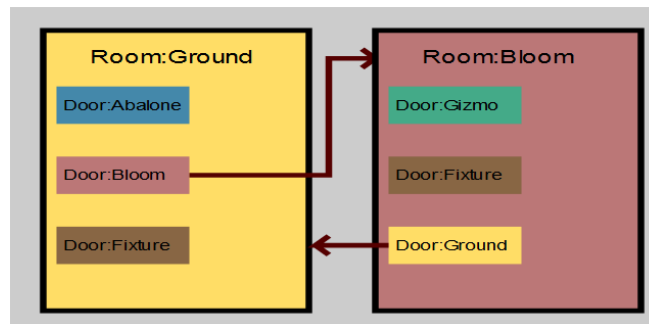


Figure 3. Example of constructed website navigation

Beyond constructing websites and testing navigational theories within networks, other work has been done to more formally define gravity graphs, specifically in terms of certain kinds of graphs which are unflavorable. These are graphs that, regardless of any permutation, are unable to ever be gravitationally flavored. One of the most common kinds of unflavorable graphs is that of a wheel, circle, or cycle (Miller, Weidman, & Denmead, 2013).

Understanding which structures are and are not gravitationally flavorable is relatively important as it may preclude certain networks from being modified with our gravity algorithm. As we continue to work in this area moving forward, we intend to more clearly define structures and features which make certain networks more easily gravitationally flavorable.

2.2 Ranking Nodes

While a number of social network concepts are based on ties between nodes, for the case of our work, we are only interested in characteristics of nodes. This is primarily due to the fact that the gravity algorithm in question was never intended to take the weight of edges into account. Beyond this also comes the issues of determining what unique identifiers (numbers) should be used to define each of the nodes in our social network graph. For the gravity algorithm to work correctly, each node must have its own independent, non-zero value. So, what value should we choose to properly represent each node in the network?

At the start of this line of inquiry, we considered using some of the more common forms of social network centrality that would allow a network to be arranged based on some existing network properties. However, these more traditional forms presented many problems based on our aforementioned criteria. One classical approach for ranking centrality did show some promise: eigenvector centrality. This type of centrality is based on the amount of “influence” each node has in a network. Each node is ranked relatively in relation to the other nodes in the network (Bonacich, 2007). In the case of several networks which we tested, eigenvector centrality was, in fact, able to produce unique values, albeit in decimal form. As our gravity algorithm is designed to run on whole numbers, we simply bumped the decimal point on each eigenvector centrality (e.g. 0.180 became 180).

Examining other means of ranking individuals in a social network required venturing outside of more classical methods. While the field of literature in this area is surprisingly sparse, there are a number of proposed techniques to developing ranking systems for individuals in a number of scenarios.

One of the more commonly explored environments for ranking individuals in a network comes from crowdsourcing networks, where finding expertise is critically important. Somewhat different than traditional social networks, there are several proposed methods for ranking the expertise of individuals. One method involves creating a score based on a user’s availability, activity level, and expected ability to provide information as these attributes relate to a specific task (Schall, 2012). In such crowdsourcing networks, these techniques tend to create better collaborations on projects than more traditional methods.

Similar to ranking individuals in online collaborative spaces, other techniques have been introduced to help organize physical workplace structures. As a possible area where this algorithm may be useful, workplace structures are of interest, so we thought it prudent to explore methods of providing numerical labels to those within such a network. One method, specifically, proposed to calculate a score for each individual within a working group by measuring both their sociability and achievements (Yang, Shen, Kou, Nie, & Yu, 2014). While this ranking system was found to have its applications, it was shown

that these rankings were time sensitive, and much better suited for recognition tasks than organization structure construction.

One of the primary reasons we are interested in optimizing organizational structure is to optimize information flow through a given network. Previous work has demonstrated that by using algorithms based on prediction and ranking, it may be possible to predict how information will disseminate through complex networks (Song, Chi, Hino, & Tseng, 2007). By incorporating this model, it becomes more possible to predict how efficiently information will move through a network.

As a final inspiration for our own ranking model, we chose to explore how authors are ranked in digital library management systems. Within certain circles of the academic community, the topic of ranking authors has become popular, with no clear answer in place for deciding how to rank these individuals. Similar to some of the previously mentioned expertise recommendation networks, the goal of these analyzed author networks is to find individuals with the most knowledge about a particular topic. Some of the foremost researchers on this topic recommend using a method that incorporates multiple pieces of data such as the venues where the author has spoken, paper citations in certain topic, and the number of citations of the author by others (Gollapalli, Mitra, & Giles, 2011).

2.2.1 Our Ranking System

After exploring several alternative ranking methodologies for grouping individuals, we propose our final ranking system for the purposes of our gravity work. As each different type of network we wanted to explore contained a number of similar elements, we chose to create a unified system for measuring characteristics of those within each network.

Previous work has shown that when students are asked to self-arrange where they sit in a classroom, their personality variables play a major role in where these students end up sitting (Weinstein, 1985). Considering this concept, we used a modified version of the Meyers-Briggs personality test in order to construct our ranking system (Myers, 1962). This test traditionally uses a series of statements that are selected by the test-taker in a binary fashion. At the end of the survey, each of the totals from the binary comparisons are totaled and used to construct a personality profile. While this traditional way of constructing each personality profile is effective at the individual level, we found it difficult to produce significantly different personality profiles within a larger group.

As each individual's ranking is required to be unique in order for our algorithm to work, we chose to create a variation on the Myers-Briggs test to allow for a more refined or polarized personality score. To accomplish this, rather than have our participants respond to each personality item with a binary response, we asked them to pick which statement they agreed with more, and then instructed them to respond with how strongly they agree with the selected statement on a scale from 1 to 100. This allowed us to not only generate accurate Meyers-Briggs personality test results (many of our participants reported that their personality types were the same as the traditional test), but we were able to tease out a diverse set of personality metrics that we could use to "rank" the individuals within our observed social networks. We ultimately decided to rank individuals within each social network within different personality dichotomies. For example, we would consider one network ranking scheme based on extroverted personality scores, or in another networking ranking, we would rank people based on their intuition scores.

2.3 Classroom Arrangements

Beyond working with hypothetical network structures, we were also very interested in applying the principles of gravity to a classroom setting. Oftentimes, classrooms are arranged at the discretion of the students, or in some form of systematized fashion created by an instructor. We sought to explore whether or not a classroom arranged by our gravity algorithm would create a more engaged classroom setting. As it has been previously shown that learning in any particular situation is partially dependent on physical and psychological contexts in which learning takes place (Jenkins, 1974), it seems apparent to be ever-thinking of ways to improve the layout of a classroom. Perhaps the most classical classroom setup, oftentimes desks are arranged in even rows and columns in a grid-like fashion (McCorskey & McVetta, n.d.).

The physical layout of classrooms has been covered extensively in the past, with a focus on physically modifying classroom structures to better suit particular lecture styles. For example, some professors who claim to facilitate a more discussion-based classroom opt to use a U-shaped class setup, as opposed to the traditional row formation (McCorskey & McVetta, n.d.).

Within different room arrangements, the behaviors of students have been observed from a grade school level, all the way through the collegiate level in an attempt to elicit unique and revealing responses. One study explored students' seating preferences contrasted with how territorial these

students were about their own seats. Interestingly, unlike work grounded in non-row classroom layouts, it was found that certain students preferred to have seats at the end of rows, as they had a need to define their own territory (Kaya & Burgess, 2007).

Beyond territorial-based questions, other researchers have concerned themselves with understanding how students communicate in classrooms, through different physical setups. Within grade school environments, some research has shown that forming classrooms in a circle, or semicircle lead to greater classroom participation than the standard row-based classroom (Marx, Fuhrer, & Hartig, 2000; Rosenfield, Lambert, & Black, 1985).

When considering classroom arrangements, others have looked beyond the physical layouts, and instead, focused on the students themselves and how they are seated in an instructional setting. One study found that students who tended to sit in seats with greater access to instructor communication tended to have more aggressive, assertive, or competitive personalities (or were, in general more extroverted) (Totusek, Staton-spicer, Totusek, & Staton-spicer, 1982).

Along a similar line of personality comparison, some research has focused on social status as a means of analyzing seating arrangements. While perhaps not as applicable to large college seminars, work conducted in elementary and middle school classrooms shows that those students who were considered more “likeable” or “popular” tended to sit in the center of a classroom (Yvonne H.M. van den Berg & Cillessen, 2015). Likewise, when asked to seat themselves in the classroom, those that were more popular or likeable were more desired to be sat by within the classroom (Yvonne H.M. van den Berg & Cillessen, 2015).

As an extension to the previously mentioned study, further work was conducted to see if likeability or popularity could be manufactured in a classroom merely by proximal association within new seating arrangements. Perhaps unsurprisingly, it was found that previously “unliked” children, after a period of several weeks, became much more “liked” by those around them, suggesting that classroom structure itself can play a role in modifying attributes of a network (Yvonne H M Van Den Berg, Segers, & Cillessen, 2012).

This desire to modify observed networks structures, and then proceed to modify them based on some set of principles is clearly not a new concept. However, previous work seems to demonstrate a greater call to understand how these classroom network structures form, not necessarily taking an action to make them better. Even further than this, it seems as though the practice of using algorithms based on attribute data of those in a classroom to re-arrange a classroom are even less common.

One clear example of this stems from a group of researchers in Japan, who crafted a genetic algorithm based on observed behaviors between students (Shin-Ike & lima, 2011; Shin-ike & lima, 2012). The initial results from their work are promising, with students reporting a greater liking of their modified seating arrangements, and creating a greater sense of comfort in their classrooms (Shin-Ike & lima, 2011).

In a similar mindset to this, we sought to take knowledge gleaned from these many resources related to classroom organization and re-organization, and create something new. As such, our classroom analysis model was based on personality constructs, and we sought to work in a classroom that was not necessarily a row-based room. This served as the foundation for our own algorithmic analysis.

3 Methods

As a means of grounding, to explore the effects of our gravity algorithm, we aimed to analyze two different forms of networks to determine how they would change if we would apply gravity to them. The two types of networks chosen were randomly generated networks, as well as an actual social network. The randomly generated networks, as well as the eigenvector centralities on all of the networks was performed in UCINET (Borgatti, Everett, & Freeman, 2002), and all of the gravity calculations were performed in Grapher.

3.1 Classroom Reorganization

One of our primary goals after working with the initial concepts of this algorithm was to bring it into the real world, so to speak. Thus, we worked within a classroom in our college of 16 students in a first-run attempt of using the algorithm to modify a classroom structure. To determine our original class structure, we observed the way in which the classroom was setup and filled out a seating chart where each student was assigned a unique ID that was randomly generated, and not tied to any attribute of that person. However, simply creating a seating chart was not enough. To make the classroom structure resemble a social network, it was necessary to construct ties between the students in a logical way.

To accomplish this, we chose to place ties between students who sat next to each other (to the right or left of the student, where applicable), as well as with those seated immediately around them in terms of in front, or behind the students. The resulting social network that arose from our small class structure is shown in Figure 4.

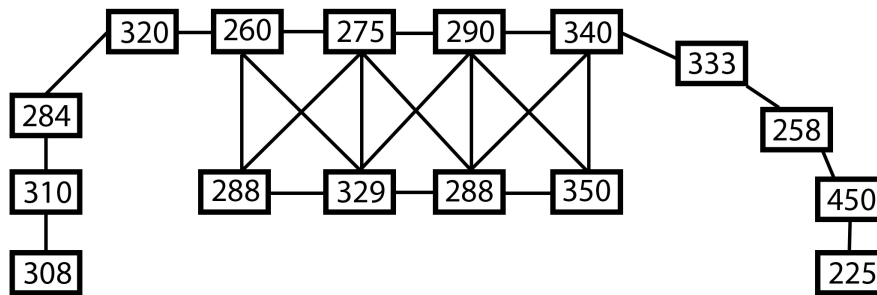


Figure 4. Preliminary Class Structure

After constructing the social network of our classroom, we administered our previously described, Myers-Briggs modified personality test to everyone in the classroom. At the end of the personality test, we also posed several questions to the students asking them to rank aspects of their current class arrangement. These questions included items that asked the students to rank how much they “liked” the people they sat around, how well they were able to keep on task in the current classroom arrangement, how likely they were to stay focused in the current arrangement, as well as how likely they would be to socialize outside of the classroom with those who sat around them. These brief questions were intended to be our measures for determining how much the students could discern a difference between classroom layouts after we modified the room using our algorithm.

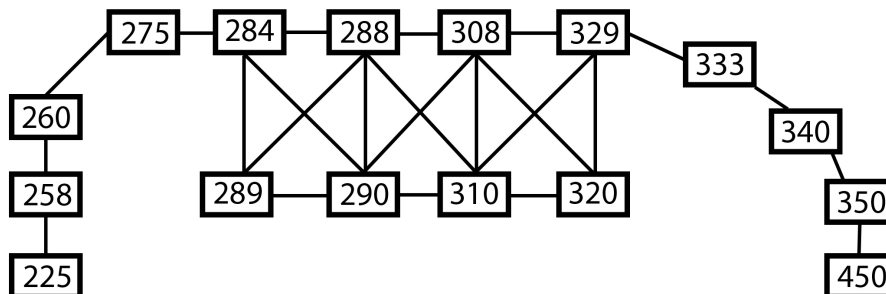


Figure 5. Modified Classroom Network Structure

After analyzing the surveys of all of the students, we performed an analysis of the network and were able to find a compatible network arrangement that suited the needs of our algorithm. This modified network is shown in Figure 5. Once the modified network structure was found, we then proceeded to rearrange the students in our classroom for one class session and measure their feedback on the new seating arrangements. They were asked a similar array of questions from the original survey, following a pre-test/post-test question style.

Limited in scope, and therefore in results, we mention and discuss the initial results from this classroom study as a means to frame discussion for future work in this area, with our proposed algorithm. Rather than present clear results, we work to present a newly developed, still not fully tested framework that shows great promise as a potential classroom organizational tool.

4 Results

After allowing our designated classroom to experience their modified arrangement, we captured their opinions of their new classroom setup. We were primarily interested in how well these individuals “liked” those who were sitting around them, how these individuals would affect how well each participant could

focus or concentrate on classroom discussions, how much the participant might socialize with these individuals outside of the classroom, as well as how much shared commonality they might share with their new seatmates.

For each of these comparisons between the original classroom setup, and the gravity-modified classroom, we ran a series of paired-sample t-tests to determine any significant differences between the two setups.

When asked how well our participants “liked” those who were sitting around them in the new classroom arrangement, we found that our participants reported liking those around them more in the new classroom setup over the original, though not significantly [$t(14) = -1.21, p = .22$].

When asked how much the new seating arrangement would keep the students on-task during class, we found that there was no difference in staying on-task when comparing the original and gravity arrangements [$t(14) = -.425, p = .68$]. Likewise, it was found that there was no significant difference in the ability of our participants to focus on the classroom discussion in the new layout, as compared to the original [$t(14) = .315, p = .76$].

Prior to conducting this study, we had assumed that individuals would arrange themselves in the classroom based on how well they may have known their classmates previously. When testing for this, we did find that people tended to socialize more with individuals in the original classroom setup, when compared with our gravity arrangement, though not significantly [$t(14) = -1.05, p = .31$].

Finally, we had thought that by organizing our classroom based on an extrovert/introvert personality profile, that we would place students together that had hypothetically similar personality styles. We were able to find that people felt they had more in common with the individuals around them in our gravity-arranged classroom, though again, not significantly [$t(14) = -1.38, p = .19$].

5 Discussion

For many of our classroom network re-arrangements, we were able to find a number of results that would support our gravity arrangement being preferable over the original classroom structure. However, we were unable to determine any of these results significantly. While these original results make us optimistic of our algorithm’s ability to organize a classroom, we are not certain if we can make any assertions at this time.

In the future, it may be worth running several iterations of each social network, possibly based on different personality constructs. Perhaps using extroversion/introversion did not give us a sensitive enough difference between individuals in the classroom to find significant differences. We also argue that more time would be required in different arrangements before a significant difference could be observed. Without this extended period of time, it would be difficult to truly understand the effect of the changed structure. Finally, it may be worth performing the study earlier on in a semester, before members of the classroom become comfortable with any new people sitting around them. We would like to run this study in the future over a period of several weeks to explore these questions more.

Beyond discussing the outcomes of our limited study, we would now like to shift the focus to the discussion of the gravity algorithm, and its potential applications and uses. From its inception, the concept of gravity in abstract spaces has always been difficult to work with due to the computational power it requires. However, as technology has become more powerful, and we continue to optimize the algorithm, we believe the time is right to unleash to concept to a wider audience.

Because the algorithm is able to accept any number-based ranking system into consideration, we argue that is an extremely open and accessible tool to re-arrange network structures based on an almost infinite number of attributes. We could choose to analyze social networks based on personalities, popularity, age, attractiveness, monetary income, and more, so long as the data is quantifiable. This demonstrates, to us, that the gravity algorithm is widely applicable to a number of different analyses. Regardless of how limited our original study was, the validity of the algorithm is once again shown to have tremendous scope. Originally used to construct websites, we have been able to retrofit the gravity algorithm to work with any kind of network, even human networks.

With this gravity algorithm, it is now possible to analyze and re-organize a wide array of network structures in terms of information flow. In the future, we would like to work with corporations, local business, and more. The use of this algorithm could potentially open new areas of corporate organizations, placing and ranking individuals on how effectively they can work as part of a group or team in relation to the network as a whole.

We ultimately wish to show with this paper, that this concept of gravity within social networks is a feasible design for application in networks with set structures. Winston Churchill said, ‘We shape our buildings, thereafter they shape us.’ This is typically the narrative of social networks as well. With the

potential to reshape that narrative, through the structuring of social networks, we challenge the typical narrative and welcome future research and new and creative applications. Through this algorithm, we could strengthen education in classrooms, or make group work meetings flow more smoothly and effectively. We argue that the gravity algorithm is primed and nearly ready for use, and thus we present our gravity concept to be received and reviewed by the community.

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