Overview of the Allocation Project: Year-Long Research, Experiments, and Future Recommendations

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Abstract

Over the past year, our team has explored and expanded our understanding of the challenges within the current allocation process. This report isn't meant to be exhaustive; instead, it serves as a guide to introduce key concepts at a surface level and provide context for more detailed analyses found in our other documents.

We begin by examining the existing allocation process, shedding light on the problems it poses. Motivated to find better solutions, we share our initial ideas for developing a replacement system aimed at addressing these flaws. We then delve into the creation of an experimental system—a technology probe—that we developed to gain deeper insights. This includes a discussion of the experiment we conducted to evaluate its effectiveness and the valuable knowledge we gained from it. Finally, we explore four crucial concepts in greater depth, discussing how they intersect and why they're essential for developing an improved system.

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Definitions

Throughout our work, there are several terms and phrases used. Some of these are quite obvious and defined multiple times for clarity, but for the benefit of the user, we will provide this section of our report to clarify them. While most terminology should be clear, there are only a few terms devised to simplify explanations.

Preference - The preference a team has for a project
Capability - A numerical score approximating both the skill level of a team, their fields of expertise and the type of project
Impact - An indicator variable of either 1 or 0, whether a team and project are a good fit. No zero score for impact will ever be allocated together
B Value - A numerical score calculated for each team for each pairing representing a rough estimate for how well they are matched.
Pairing – The pairing between a team and project.
Allocation – Confirming a pairing and removing them from the pool of choices.
Allocation Set – A full set of allocations including every team, such that every team included has a unique project.
Score – The sum of the b values of every pairing in an allocation.

Phase 1 - The Initial Exploration

A Brief Introduction to the Allocation Problem

When we first took on this project, our team struggled greatly to understand the purpose. Our goal was not to develop a replacement system, but rather to explore ideas and to gain understanding of the system. To that end, we began by defining the allocation problem, identifying requirements and constraints of such a system and proceeded to identify how a solution could be built. The detailed records of this investigation can be found in the report inside the Phase 1 folder.

As is likely already clear, and something that will be repeatedly emphasised across our work, is that allocating projects to teams is difficult. It has to be done clearly, with conviction in decisions, in a way that is as fair as possible to all teams whilst still having each decision made be justified. The goal of the allocation process is to maximise a bijective function between the teams and projects, a one to one mapping that gives every team the best possible chance they have of succeeding in completing their project without allowing any team to have a bad pairing.

Given the potential scale, this task is complex to a ridiculous degree. Semester 1 of 2024 had just under 100 teams and that many again projects, giving up to 100! Potential combinations, or a figure in the ballpark of 9.3×10^{157}. While this has been reduced as the current system is improved with the addition of the impact multiplier, breaking each group into roughly a third of the size, the problem remains difficult to optimise. While it can be done by hand one at a time, which is the current method which best provides a valid justification behind each choice, this creates a system which is rife with inefficiencies, a greedy nature due to the reduction of availabilities as the allocations progress, and a difficulty maximising the benefit due to the sheer number of dimensions that made the problem so mathematically complex.

Initial Concepts, Understanding and Ideas

The remainder of this phase is more clearly and deeply explored in the report pertaining to this phase, but it shall be briefly summarised here. Our team, after taking time to determine the requirements and considerations behind the allocation, determined that a good allocation system would be a combination of two components - a flexible UI environment to visualise the data in a simple and easily comparable and sortable manner, and an algorithm to reduce the burden of choosing the best possible options overall rather than just the best for that team.

We identified that any system would have to be fast, but also the allocation set produced would have to be accurate. Following that, we defined what an accurate allocation would be. For an allocation set to be accurate, it must be as close to the maximal benefit possible, for instance a maximum bipartite matching.

The other consideration that drove difficulty was the necessity for human involvement, human in the loop as it were. For the allocations to be fair, to reduce the complaining of teams and to be able to justify why a team was given a project, both to the students and the industry partners, each allocation must be done by a human. While some form of algorithm could be used, when allocating a pairing, and producing the final allocation set, by necessity each decision has to be made by a human.

Additionally, it should be noted that our exploration was rather limited in the sense that we focused our work on the concept of using the roughly approximate b values as a score for each pairing. Each b value is only an approximation, due to both some teams missing information that was used to calculate them, along with more intangible parameters that could not be evaluated, but rather kept in mind when allocating each team. Additionally, although we initially considered getting student input, it was quickly acknowledged that the students in the unit have little to no concept of what would be a good project for them, and just as the preference value was weighed significantly less, the requests of the students should mostly be ignored, to best provide them with what they need, rather than what they want. As such, we focused on ways to make sorting through the data of pairing b values more optimal, and the allocation process quicker.

Broad Research and First Plan

This reasoning was the foundation for both our research directions and the formulation of our initial system plan. We devised an idea for a flexible UI that could be used to display the results of an algorithm that determined the best fit allocation set, and allow the user to explore those options to see whether conflicts could be resolved with different allocations.

We quickly identified that the React framework would allow us to efficiently develop a modular system. It was something we were all familiar with, would have no issues with cross-compatibility, and due to its component functionality style, we could easily add, remove and change different parts of the display as needed. This flexibility would allow us to try different designs, and work on them concurrently. The purpose of the user interface was to display the pairings, and display many of them in a way that could be sorted through and compared. As the semester reached the end we developed a medium fidelity plan for how we expected the UI to look.

Along with the UI decisions, we also explored different options for developing an algorithm. We identified that any algorithm would need to be fast, deterministic in that it produced the same results each time to balance fairness, as randomness could not be justified, and accurate. The goal of the algorithm would be to quickly produce an allocation set that had the best possible score, without causing any team to have a significantly bad pairing. An overall common good was one argument, minimising bad choices, and another was ensuring the highest score was the most important aspect, ensuring the most teams got their best match, at the expense of a few.

We settled in the end on implementing an Integer Linear Programming solution, along with the Gale-Shapely matching algorithm, giving variety in choices, as an assistive algorithm to be run in the UI. The hope was that by presenting a best outcome, the user could then go further in filtering ideas.

As such, we reached the end of the first semester with a beginning of a plan, and a rudimentary understanding of what was required to make a good system. In hindsight, it is quite clear that we focused too heavily on designing an optimal algorithm, over understanding the complexities and requirements. For more details on why that is undesirable, read the report in Phase 3 about fairness and algorithms.

Phase 2 - The Experiment

Experimental System Development

Over the break, our team began developing the experimental system. For the full details on this process, refer to the documentation found in the Phase 2 folder. In short, using an agile-style methodology we planned sprints and user stories that have since been misplaced, to work to produce the system we imagined during the phase 1 exploration. As a team we worked over the six weeks to develop and test the system based on the student data from semester 2.

At the end, we had produced a system that contained several major UI elements, the most significant being the list view display. This display showed a selection of pairings, with the option to sort them by whatever category was preferred. Several of these were implemented, with direct navigational features, in order to produce a system that allowed a user to quickly explore a wide range of pairings, comparing them against each other and determining which would be the best fit for each team.

Additionally, we implemented an Integer Linear Programming algorithm, which produced the best fit allocation set for the current state of the problem. Allocations that were made or rejected were incorporated into the system, so it would update and produce a new state as it went. The weekly reports in the Phase 2/Development can provide insight into the weekly plans and understanding of how the system was built, while the Analysis and Documentation folder contains the details on the system post completion.

Experiment Overview

The purpose of our experiment was to perform a technology probe; to gain understanding of the requirements of an allocation system. We undertook this by recording both the semester 2 actual allocation performed by Professor Lovell, as well as having him perform the allocation using our system.

From these recordings we could study the allocation process much closer, and attempt to identify what were the most important aspects. In combination with Professor Lovells commentary, we were able to compare the recordings to our previous understanding. This allowed us to identify the salient components of the actual allocation, at a much deeper level than simply talking about it. There are numerous components, particularly the thought process and the simple flow of the user that need to be taken into account. By observing this, and comparing it to the requirements, considerations and what we considered important previously, our team was able to redefine the project, and clarify the importance of certain features in a good allocation system.

Additionally, we attempted to record each action taken at each time for the actual allocation recording. It was hoped that by doing this, we would be able to gain insight into any patterns in the process, or when the process became more or less complex. Unfortunately, this did not demonstrate any new information beyond the obvious

Results and New Understanding from Experiment

After performing the experiment, it became clear that our previous understanding of what made a good system was wildly off. As such, we focused on identifying the most important aspects of the actual allocation, and comparing them to where we fell short in our system.

Most notably, the overall UI was poorly designed, with too much data in difficult ways to understand. We have presented a large amount of data, each pairing and all their details, in a way that did not make it clear how to differentiate. The nature of our UI made comparisons needlessly complicated, and the different representations of data made it hard to get a scope of the options balanced against themselves. Additionally, we noted that our algorithm, which worked incredibly well, was actually a detriment to the overall requirements, particularly the human justification aspect.

In terms of derived expectations from the actual allocation, the most notable was the unfair method of allocating, that being the greedy process. Given only one person was working on the allocation, they were forced to allocate one team at a time. This, naturally, resulted in a greedy nature as each project was allocated and removed from the pool one by one. And while this could be improved by going back and checking for each allocation whether the allocated options could be rearranged, the nature of the current system meant that this was disincentivized, something visible in the recorded actions. The overall result was that a random order was taken, with the first teams chosen getting their best matching project, and the last getting the remainder. Additionally, the current system was very manual, having only one real graph and table to use to sort through the options, without any corrective options.

Based on these observations, our team identified four salient components of a successful allocation system, that when implemented correctly adhering to the requirements of the system. They were:

1. Proper research and understanding into how to display a pairing and its relevant data.
2. A detailed range of options and knowledge of how to show the b values in different ways to identify important points.
3. A significant effort into reducing the greedy nature or atleast its impact on the fairness of the process.
4. A deep understanding of the concept of fairness in respect to this project, and how algorithms can be used to improve it.

Phase 3 - The Deep Investigation

Exploration of Key Concepts

As outlined, our team identified the four concepts above. We believe that a proper understanding and consideration of them during the planning phase will lend to designing strong fundamentals for any allocation system trying to accomplish our goals. To that end, we divided each concept, one for each of us, and conducted a deep investigation into those specific topics.

From this research, it became clear that of all the topics, their main overlap is significant planning, but more specifically, defining goals for the system. In order to properly make the system fair, to optimise it and to ensure that it was functioning for the expected flow, an incredibly precise and clear understanding of how it would work, and how the choices could be defended will be needed. At some point, the reasoning, justification and approach becomes arbitrary. Will the system be fair as best it can to everyone, or aim for an overall best case at the cost of others? How is the fairness of an algorithm even decided? What specific data will be needed to show, and for that, which type of representation would be best suited to do it? The four reports in each subdirectory explore the topics in depth, but the true importance is to balance each topic together as it becomes necessary to combine each one.

Ideally, it would be essential to first minimise the greedy nature. The report has explored some mathematical concepts behind managing this, but one of the most effective ways is to organise the presentation of the data. By using an algorithm to pick out the data in a specific way, taking care to ensure it is presented in a way that preserves the fairness of the system through proper visualisation. Additionally, one could consider the goal of that visualisation, whether it intends to show raw data or specific pairings.

Displaying the pairings is an essential point, as showing the data simply as points, or graphs or by colour can only convey so many details of each pairing. Given circumstances where a closer comparison is needed, being able to show a pairing in different ways depending on the scope or detail required is also essential. Perhaps an algorithm could identify a grouping of pairings to be compared for a specific team, and this would require a different style of pairing, more detail and easily comparable with some kind of visual chart, than when looking at a full list distinct from each other only by a colour scale.

How a Good System Could Be Constructed

All this research is done, and hopefully some of it is helpful. But how to put it into practice?

As has been mentioned numerous times through this report, and others, it is absolutely essential to first identify the goals of the project clearly. The most important part of any allocation system developed is that the human factor is absolutely preserved. The integrity and justifiability of all the allocations is non-negotiable, as any students or industry partners that have questions must be able to find the allocation reasonable. That means, no matter how good it seems, the allocation cannot be set by any kind of algorithm, nor can the system be set up in such a way to influence a choice.

Define the fairness of the system, to an arbitrary point. At some level a decision must just be made and held to. There is no exact one-size-fits-all solution, but rather many valid options. If these aren’t clearly clarified at the beginning, the overall system could conflict when attempting to balance the fairness and efficiency.

The last stage before beginning any UI or functionality planning, consider the user flow. Are they expected to constantly be changing views? Should they be commonly undoing allocations for better ones? While this could be done whilst planning the UI and will certainly have overlap, having a proper understanding of the flow will allow for each section to be built from the ground up, with that same understanding. Identifying overlap between layouts that will be needed, or the way pairings should be shown depending on how they should be compared, and where each algorithm fits in, even if its not clear what sort to use, having a sense of how it can interact, as well as clearly defining why it is a valid implementation and meets the criteria is essential. At the end of this stage, every step of the user experience should be both explainable, and justifiable as fair to all the students, in a clear and concise manner, even if it is not yet fully formed how the components will work together.

Where to go from here

Our team's design was lacking, as we focused mostly on individual components and forced them together when we designed our experimental system. If the recording of that experiment is available, the discussions during it were incredibly valuable to get a sense of what is important when trying to view the data. As a team we have little advice for the overall design, beyond carefully considering how much data is visible at once, and readable.

For more details in each topic, look to the subdirectories of Phase 3. Inside each is a report on each of the four key concepts. They are sourced, and should provide a repository of information about the topic. We intended to design them to serve as a reference more than a static report, and hopefully the ideas explored inside can be a foundation to build off of.