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Work In Progress: A Metro Map-Based Curriculum Visualization for Examining Interrelated Curricula

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Work In Progress: A Metro Map-Based Curriculum Visualization for Examining Interrelated Curricula

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Abstract

Prior research has indicated that academic curriculum can be difficult for students to understand: especially for new students or students considering multiple degree programs. Based on the existing curriculum visualization literature, we hypothesize that the visualization of multiple curricula in one diagram might aid students in understanding curricular requirements and analyzing the different course paths they could take to complete a desired degree program. This work in progress describes the design and implementation of a visualization of the degree programs within an engineering college at a large University, where the interrelated web of courses and majors is displayed in the form of a metro map. In this metro map, the course requirements of individual majors are represented by metro 'lines', with each represented by a 'station' on each line. If multiple majors require the same course to complete the degree, then the 'line' representing each major will connect to the 'station' for that course. Through this visualization, we aim to create a tool that students could use to better understand the path of their degree program, and the ways in which their program requirements interact with those of related programs. We describe our methods for collecting course data as well as the design and implementation of the visualization. We close with a proposed set of evaluations for determining the effectiveness of this tool, and describe the limitations involved in creating similar visualizations for additional universities.

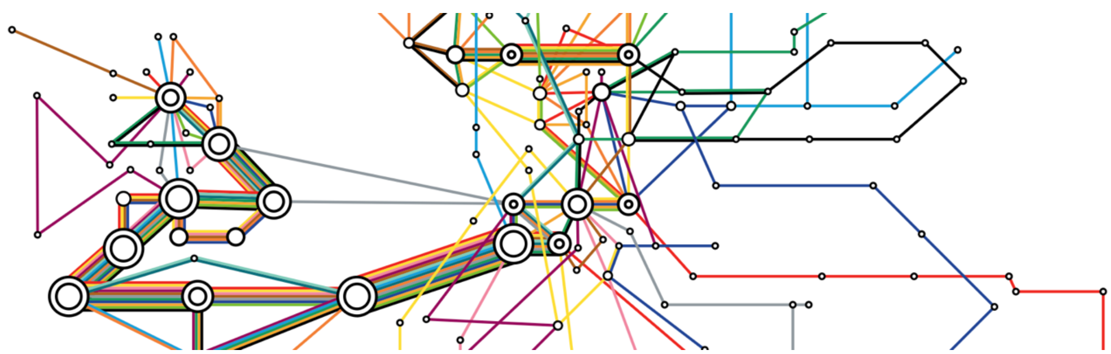

Figure 1: A section of the metro map representation of 15 engineering degree programs. Each chain of colored lines represents a degree, while each circular 'station' represents a single required course.

Introduction

An academic curriculum can be difficult for students to understand, especially when the courses within the curriculum require prerequisites and must be taken in a particular order. Curricula can be especially overwhelming for new students or students considering multiple degree programs as they contemplate how they might complete all required courses within a specific number of years. When posted to university web pages, curricula are usually shown in a textual form such as a list of course numbers and titles [1], presenting a view that does not include the complexities of the contained course prerequisites or other dependencies [2]. Academic advisors and department offices might attempt to clarify a student's path by using business or presentation software to translate course lists into flowcharts and checklists that illustrate those dependencies, but this translation is time consuming and prone to errors [3]. Additionally, these flowcharts generally only visualize one- or two-degree programs within a department, and do not provide comparisons between the degree requirements of those programs and other programs within the same college or university.

Previous work has sought to improve on these rudimentary illustrations by creating visualization tools which illustrate a curriculum or a university's course offerings in ways that make explicit prerequisite courses as dependencies [2]–[9], display recommended or commonly taken course schedules [3], [5], [7], [8], [10], or include within the visualization the concepts learned in each course [7], [11], [12]. However, these tools largely fail to address the visualization of multiple curricula and the courses and dependencies common among those curricula. The goal of this research is to create a concise visualization that displays the commonalities among multiple curricula, while accounting for the recommended course sequence and course prerequisites.

The metro map is a popular design layout designed in the 1930s by Harry Beck for use in the London Underground train system [13]. It has since been imitated in transportation maps for cities around the world [13], making it a familiar visual form. A metro map consists of one or more intersecting 'lines', where each intersection represents a 'station,' and each station may be connected to one or more lines. In the field of visualization research, metro maps have been utilized to visualize concepts such as links between web pages [14], related scientific publications [15], and the relationships within a family tree [16]. Various algorithms have likewise been created to automatically generate the visual layout of a metro map when given a set of station coordinates and the lines to which each station is connected [17]–[20], but none have solved the problem of automatically laying out a set of stations and lines to optimally visualize a set of curricula or courses. To create a visualization of the requirements and overlaps of a set of curricula, we used the iconic visual of a metro map in which the lines represent individual curricula, and each station represents a course required by one or more majors.

We aim for our visualization [21] to be a tool that primarily first or second year students can use to grasp the pathway to completion for their degree program and other related degree programs. The visualization may be especially helpful for students debating whether to change their major or add an additional major, as it would allow them to quickly grasp which courses may aid them in completing requirements within both degree programs in consideration. We contribute a visualization of the overlaps between curricula represented in a novel format and implemented as an interactive webpage, and a technique for automatically generating a metro map layout based on a university course and degree program data.

Related Work

There have also been numerous visualizations of the course offerings of a university or multiple universities. Sommaruga and Catenazzi [1] represented the available courses of a university in

3D as the buildings in a city where each building has attributes corresponding to the details of the course, but did not link courses required within the same degree program or programs. Moreno, Bischof, and Hoover [9] along with Aldrich [6] each created visualizations of the prerequisite chains required to take a course in the form of dependency graphs and networks. Lastly, Raji et al. [10] visualized the way students completed degree programs in practice by demonstrating their 'flow' through degree programs. However, their visualization made no attempt to illustrate the recommendations or requirements of those programs. Though existing visualizations offer solutions to various needs of students, faculty, and administrators, we know of no curriculum visualization for students that has sought to display the requirements of multiple curricula within one visual.

A large body of work has focused on the algorithmic generation of metro map layouts based on the lines and stations of existing transportation networks. For a map to resemble a metro map, lines must be straightened so that they can intersect with stations at a vertical, horizontal, or 45-degree orientation [22]: a restriction that makes four the maximum number of lines that can pass through a station while moving in unrelated directions. An established method for drawing a metro map is to begin with a graph in which each node represents a station, each edge represents one or more lines, and each station has a corresponding set of geographically accurate coordinates. Using the coordinates as a starting point for each station, the layout of the map is then transformed into a metro map by finding coordinates for each station which optimize to a set of mathematical criteria designed to mimic a metro map's traits, such as prioritizing uniform edge lengths and keeping lines relatively straight [17]–[20], [22].

Additional research has dealt with the generation of metro maps using non-geographic data. These methods similarly begin with a graph and make use of the method of optimizing the map in relation to a set of mathematical criteria. However, these maps generally must create their starting coordinates based on a non-geographic source, and their generation algorithms introduce optimization criteria specific to their domain [15], [16], [23].

While past researchers have worked to algorithmically generate metro maps of geographic and non-geographic data, no known efforts have dealt with the domain of curriculum visualization. Due to this, no existing algorithmic generation is uniquely suited to the problem of generating a metro map of curricula. Although no previous research has attempted to represent a curriculum in a metro map format, there have been efforts to represent a single program's required lists of courses in innovative and useful ways. For this work, we define a 'curriculum' as a single degree program's list of required courses. Nuutinen and Sutinen [8] used concept mapping to allow students to plot out the courses they wished to take, Kriglstein [2] demonstrated how a curriculum could be displayed in various ontology formats, and Auvinen, Paavola, and Hartikainen [7] visualized course sequences by featuring their learning outcomes. Dependency graphs are used within Curri [4], ViCurriAs [3], and CurricVis [5]: three tools for the creation and exploration of a program's required courses within the context of those courses' prerequisites with the goals of streamlining curriculum development and student advising.

Design Considerations

Gestwicki [5] describes the problem of curricular requirements being overwhelming and difficult to understand: with students lost in a sea of required course numbers and titles, and even upperclassmen needing assistance to determine which requirements they have yet to fulfill, which courses will allow them to fulfilling those requirements, and what courses must be taken as a prerequisite to a required course. Faculty and administrators likewise have difficulty keeping up with curricular requirements, especially when new courses are added, or degree programs and prerequisites for courses are changed. This burden increases when new students enter without a declared major, or existing students decide to change majors. As curricular requirements for different degree programs or colleges might be stored on different webpages and represented with different advisor-created diagrams [3] these students then must juggle multiple representations of curricula, discovering themselves any connections between the required courses.

In an attempt to ease this issue, we sought to make it easy for students to grasp 3 key concepts through viewing a single visualization of curricula: (1) which courses must be completed in order to fulfill the requirements of a specific degree program, (2) which courses are required by multiple curricula, allowing their completion to help a student fulfill requirements in multiple degree programs, and (3) which courses are prerequisites or corequisites to a specific course, meaning those courses must be completed in advance of, or concurrently with, the course in question. By creating a visual that displays all three concepts at once, we aim to address the needs of students and administrators who interact with multiple related degree programs.

Metro maps are a form useful for displaying connections between multiple pieces of information and promoting exploration of connected topics. When metro maps based on narrative facts about historical events were evaluated, users were able to better acquire knowledge and explain that knowledge to others than non-map users [24]. We hypothesize that curricular requirements have a similar narrative of courses required to complete a pathway, with metro maps as a suitable form for showing the possible branches of, and interaction between, the story of a curriculum.

By representing each curriculum as a pathway within a larger map, we saw opportunities to support the curricular navigation of individual students. If given the ability to input courses they had already completed, the map could modify itself to visually check off those courses, giving students a “you are here” sign for the completion of their and related curricula. Along with aiding students who might be working to choose a degree program or change course into a new one, a metro map of degree programs could also show students a degree program (such as a minor) that they had already fulfilled requirements for, even if it was one they were not considering completing.

In order to display curricular information as a metro map, choices had to be made as to how to lay out curricular requirements as a concise set of lines and stations while still including as much useful information as possible. Our first decision was that elective requirements that could be fulfilled using hundreds of different courses, such as “general education” requirements or “free electives,” would not be represented on our map. While we could have represented each as a station with the title of “free elective,” we decided the visualization would be more accurate if each station represented a single course. Additionally, advisors in all units are aware of these requirements, meaning this was an area where students generally didn’t need additional aid.

The second decision was similar to the first, in that we did not represent the upper-level elective requirements of each major. This was mainly due to degree-specific elective requirements not being available in a single form or from a single data source. In later forms of the visualization, these elective requirements could be represented as branches off the main 'line' for a degree. While some institutions and programs have advanced curricular requirements such as internships, this was not considered in our map due to the programs at our institution not containing these requirements. Lastly, we decided not to represent minors as degree programs in our initial visualization, as many of the minors at the institution we visualized have electives as the majority of their requirements.

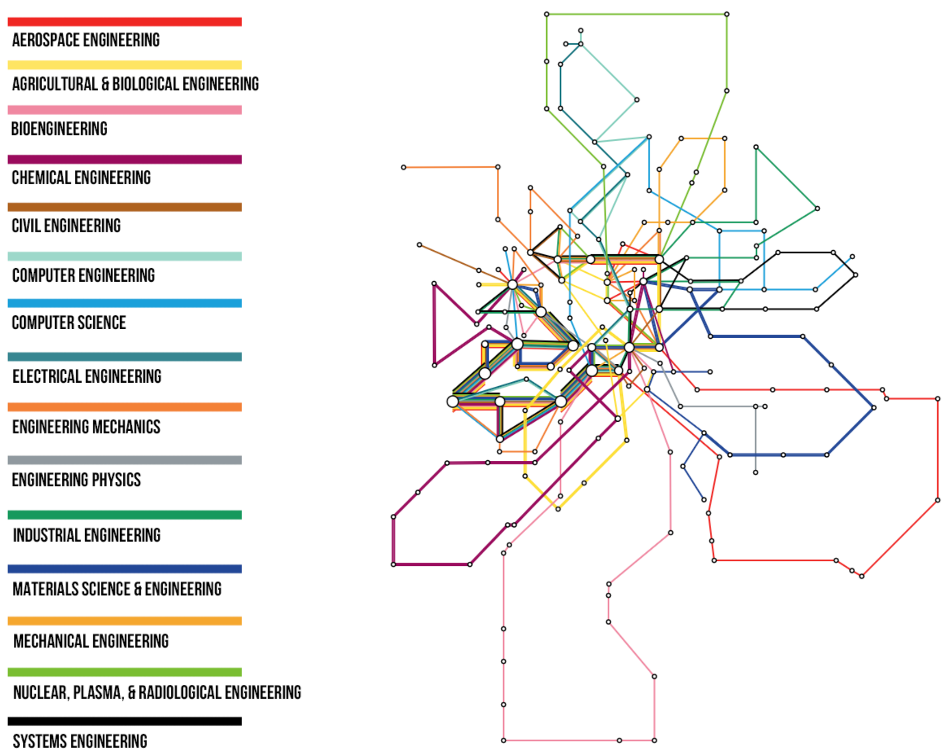

Figure 2: The full metro map, representing 15 degree programs within the engineering college.

Implementation

As a proof of concept, we have created a metro map representation of the curricula in the 15 degree programs within the University of Illinois' College of Engineering. These degree programs represent 17 different curricula, as two of the degree programs have separate "concentrations" requiring a different set of courses taken. The two concentrations of those degree programs are represented a single line that splits into two directions at the point where the curricula diverge.

Data Collection

Information on curricular course requirements, course information such as title and description, and information about course prerequisites was gathered from the University of Illinois Academic Catalog. Initial collection was performed via web scrapping of the relevant APIs, and curriculum data was cleaned by hand for accuracy as the web pages detailing curricular requirements were not uniform. Data detailing course information and course prerequisites were stored using a spreadsheet format. Details of major curricular requirements were stored in a list in which each item of a list represented a required course. Instances where multiple courses could fulfill one requirement were represented by a list within a list. Each list of curricular requirements was ordered by course prerequisites, so that each course always appears in the list after its prerequisites.

Creating a Graph of Courses and Curricula

To translate curricular data into a graph format that could be operated upon, we used the open source library NetworkX [25]. Similarly to the graphs used to create other metro map visualizations, in our graph every node represents a single course, and every edge was assigned one or more degree programs depending on how many programs 'moved' from one course to another. In the graph, cases where a single requirement can be filled by completing one of a set of different courses are represented by split paths, in which the degree program is assigned to multiple outgoing edges connected to each course that could fulfill that requirement, rejoining at the next singly-required course.

Implementation of Metro Map Generation

Stott et al. [18] describe a process of embedding stations on the intersections of an integer grid according to the nearest integers to each station's coordinate values, and a hill-climbing algorithm to optimize metro map criteria. The criteria used in the hill-climbing algorithm include (1) maximizing the angles between incident edges of a node, (2) encouraging approximately equal edge lengths for the incident edges of each node and across the entire map, (3) encouraging the incident edges representing the same line to be colinear to make each metro line as close to a straight line as possible, and (4) making line segments as octilinear (oriented vertically, horizontally, or at a 45-degree angle) as possible. The individual criteria are given weights, in order to prioritize certain criteria over others.

To generate our metro map, we used the same technique of creating initial x-y coordinate points by aligning stations to an integer grid, and using a hill-climbing method to optimize the visual characteristics of the metro map. However, as our nodes did not have innate geographical coordinates, our grid embedding had to begin with a different technique. We instead placed nodes on an integer grid within similar quadrants as the other nodes within the same degree program or programs, putting nodes shared among the greatest number of curricula in the center of the grid. This was achieved through assigning integer coordinates based upon a nodes' number of edges and based upon the coordinates from a force-directed layout of the graph. We then used a hill-climbing algorithm that optimizes for the criteria described by Stott et al. [18] as well as a minimization of the edge crossing problem, where lines visually cross and reduce readability, as described by Bekos et al [26]. We weighted our evaluation to prioritize the spacing of incident edges, a lack of edge crossings, and directing edges to octilinear orientations, while still taking into account the balancing of edge lengths and the straightness of lines. The end output was a pair of coordinate points for each station, which when plotted would resemble a classical metro map design.

Implementation of the Visualization

The final visual of the metro map was created as a webpage using HTML5, JavaScript, and D3 [27]. Visual choices were made to mimic the metro map style as much as possible. The map utilizes the colors of the iconic London Underground Map, with a color assigned to each individual degree program so that degree programs with many intersections have dissimilar colors. This color assignment is designed to increase readability [23]. Shared edges in the map show the color of each degree program layered in a common sequence, so that edges of the same color are viewed as straight lines as often as possible. Each station grows in incrementing visual size according to the number of metro lines that pass through that station.

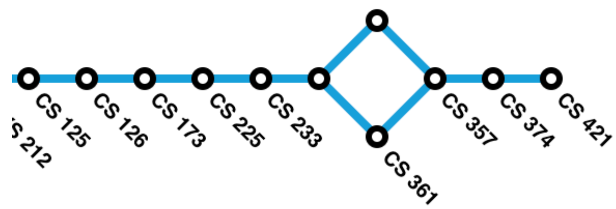

Figure 3: A degree program (Computer Science) in which two separate courses can be taken to fulfill the same requirement.

An interactive legend feature for each course was implemented for increased navigation. Mousing over the station representing a course provides a tooltip with additional information, including a course's numerical code, title, number of hours, and description of topics. Along the bottom of the tooltip, a row of colored dots indicates every major that requires the course.

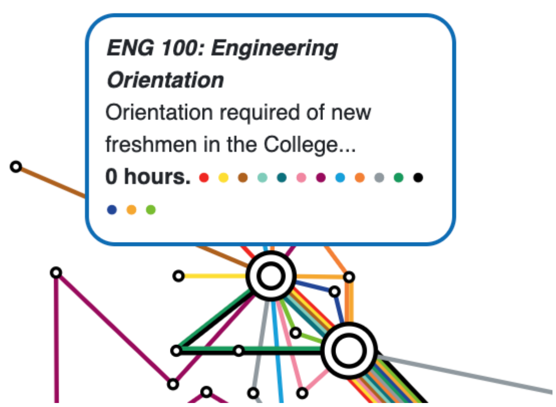

Figure 4: The tooltip for a course providing the course's numerical code, title, description, number of hours, and a row of dots indicating that the course is required by all 15 majors.

Our proof of concept demonstrates the core required courses of 15 degree paths and the recommended order for those courses when taking into account prerequisite requirements. It also illustrates the courses that are required among multiple degree programs, and the point at which those courses are required within the context of each curriculum. This meets the first two of our three design goals as defined in section 3. However, the visualization does not make explicit the prerequisite or corequisite course dependencies, simply folding the prerequisite courses into the ordering of the required curricula. It likewise does not meet the full range of opportunities we saw in the metro map format as it does not consider a student's unique path through a curriculum, nor does it provide support for understanding the pathways to completing elective requirements. In future work we plan to revise this visualization to address the articulation of prerequisites and corequisites, as well as develop ways to greater support students' individual navigation through curricula.

Conclusion and Future Work

Past research in curriculum visualization has considered how to make the “shape” of a degree program [5] more easily understandable by students, faculty, and administrators by visualizing required courses in the forms of dependency graphs, ontologies, and maps. This paper builds upon this work by investigating a visualization form, the metro map, that might visualize curricula’s required courses and those courses’ prerequisites by also visualizing the overlap between curricula. In doing so, we present a method for creating a metro map layout that draws inspiration from previous methods while accounting for the unique challenges of representing university curricula.

In future work, we will evaluate the metro map we created with users, in order to determine whether it is an effective visualization of curricula. This evaluation would focus on first year students who are undeclared and later year students in the process of changing majors, as we believe those students stand to benefit most from our visualization. The evaluation should also include students not in those situations, in order to determine whether the metro map can be a more multi-purpose tool for students determining their pathway through a single curricula [1].

We also plan to increase the efficiency of our algorithm for creating the layout of a curricular metro map, which currently becomes quite slow when scaled to a larger number of courses or curricula. This would allow us to add support for the easy generation of curricular metro maps for other colleges and universities through the input of a data source of that school's courses and degree programs.

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