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Optimizing Transfer Pathways in Higher Education

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Abstract

In higher education it is common for students to transfer from one institution to another for various reasons, with the hopes that prior earned credits will be accepted at the intuitions they are transferring into. A typical scenario for transfer students involves those admitted to community colleges planning to later transfer to 4-year universities in order to pursue bachelor's degrees. Research on the transfer process indicates that, on average, transfer students lose credit hours equivalent to one year of coursework. Given the vast number of transfer students nationwide, such significant loss of credit hours represents a significant waste of valuable educational resources that should be avoided in order to improve student success outcomes. However, finding efficient and effective transfer pathways between institutions is challenging, particularly when accounting for program requirements that are constantly changing, students changing their major plans, the creation of new courses, etc. Crafting a suitable plan for transfer students demands expert knowledge, effort, and sometimes collaboration among multiple institutions. Managing all of this complexity manually is partly accountable for the credit loss issue mentioned above. In this paper we consider the role that data and analytics can play in addressing this problem.

To gain a deeper understanding of this challenge, we first formally define the Optimal Transfer Pathway (OTP) problem, which involves finding a two-year to four-year degree plan that can be used to satisfy the degree requirements from both a community college and a 4-year university using a minimum number of credit hours. We consider the significant data requirements necessary to solve the OTP problem. These include collecting the Boolean formulas that describe all degree requirements, the courses that may be used to satisfy these requirements, as well as the transfer equivalencies that exist between institutions. The combinatorics associated with finding degree pathways between any associates degree and any bachelor's degree make this problem exceedingly difficult, and a proof of the $\mathcal{NP}$-Completeness of the OTP problem is provided. Thus, solving this problem through an exhaustive search in a reasonable amount of time is computationally infeasible. To address this issue, we treat the OTP problem as an assignment problem that seeks a feasible course-to-degree requirements assignment. In particular, we describe a 0-1 integer quadratic programming algorithm for the OTP problem that returns near optimal transfer plans in a reasonable timeframe. Experiments with this algorithm, using real degree requirement

data from two Arizona institutions, have yielded insightful results regarding degree completion plans. The solution was created using the JuMP mathematical optimization modeling language, implemented in the Julia programming language, and is solved using a commercial optimizer. The analytical results returned by this system allow students to clearly understand how each course is used to meet specific degree requirements, which courses are transferable or not, and the reasons for their transferability. Additionally, it facilitates the consideration of multiple completion plans by advisors, which is beneficial for future degree requirement designs. We conclude with a discussion on leveraging this algorithm to meet the more tailored requirements of individual transfer students.

Introduction

In this paper, methods for designing efficient transfer pathways are considered. First, we formally define the *Optimal Transfer Pathway* (OTP) problem and describe its key components, including the problem's objectives, the representation of degree requirements, and the transfer equivalency map. The complexity of the OTP problem is analyzed, which is shown to be $\mathcal{NP}$-complete. Following this, an integer quadratic programming approximation algorithm is proposed for the OTP problem. Experiments involving transfers between two Arizona institutions are conducted to demonstrate the efficacy of the proposed algorithm.

The Optimal Transfer Pathway Problem

In the *Optimal Transfer Pathway* (OTP) problem, the input consists of:

1. A Boolean formula (requirements tree) representing the complete set of degree requirements from community college CC associated with a particular associate degree, denoted AD,
2. A map of transfer equivalences that details how all courses offered at CC transfer (or not) to courses at university U, and
3. A Boolean formula (requirements tree) representing the complete set of degree requirements associated with a particular bachelor's degree at U, denoted BD.

The goal in the OTP Problem is to (1) select a minimal set of courses offered at CC that satisfy all degree requirements associated with program AD, while (2) maximizing the credits, through transfer articulation, that may be applied towards the satisfaction of the degree requirements in program BD, and (3) select a minimal set of courses offered at U that satisfy all remaining degree requirements in program BD that have not yet been satisfied through transfer articulation. The criteria for determining minimal/maximal are the total credit hours associated with the courses offered at CC and U. An important constraint associated with all of the courses selected is that they must also include the requisite courses.

Any degree program, i.e., major or academic program, at a college has a set of *degree requirements* that must be satisfied by students in order for them to earn the degree associated with the program. For instance, a program at the undergraduate level may require its students to satisfy a general education core, major requirements, elective requirements, minor requirements, etc. A convenient way of representing a set of degree requirements is as a *requirements tree*, as shown in Figure 1.

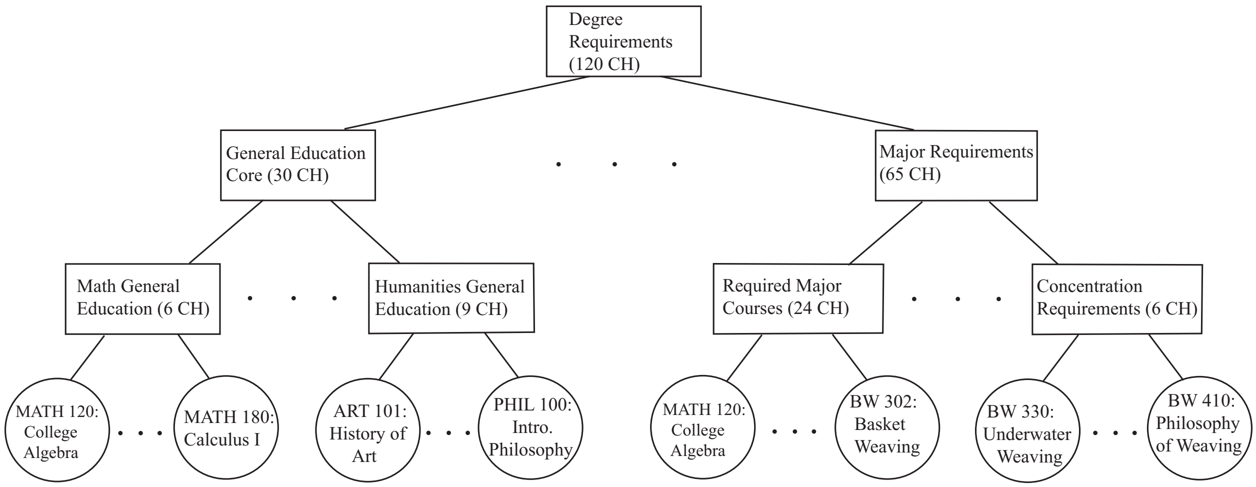

Figure 1: An example requirement tree associated with a degree program. Requirements are shown as rectangles, and the courses that must be successfully completed in order to satisfy a requirement are shown as circles.

Using this representation, degree requirements are drawn as rectangles, and the set of courses that can be used to satisfy a given degree requirement are shown as circles. Note that the set of leaves contained in a given subtree correspond to the set of courses that can be used to satisfy the degree requirement located at the root of the subtree.

The set of courses selected so as to satisfy a set of degree requirements is refereed to as a *curriculum* for the degree program. It is sometimes the case that a course in a curriculum can be used to satisfy more than one degree requirement; that is, the course can "double count" towards degree requirements. E.g., in Figure 1, the credits from the MATH 120: College Algebra course can be used to satisfy both the Math General Education as well the Required Major Courses requirements.

The formal framework we will use to represent a set of degree requirements in a requirements tree involves two types of structures, one for storing a collection of course requirements, i.e., course sets, and the other for storing a collection of requirements, i.e., requirement sets, as shown in Figure 2. A *course set* is simply a set of course requirements, along with the minimum number of credit hours required to satisfy the course set requirement. More specifically, a single course-set requirement, cs_j, consists of two elements:

$$cs_j = (\rho_j, \theta_j)$$

where ρ_j is a list of the $|\rho_j|$ courses in the course set, along with the minimum grade that must be earned in each, and θ_j is the number of credit hours that must be completed (while earning the minimum grades) from the courses contained in the course set. We will use $\text{cr}[c_i]$ to denote the number of credit hours associated with course c_i. With reference to a given student transcript, we will use $\text{gr}[c_i]$ to denote the highest grade value for course c_i on the transcript, assigning the value zero if course c_i is not on the transcript.

A *requirement set* is a collection of other degree requirements, which may be course sets or other requirement sets as child requirements in the requirements. In addition, a requirement set specifies

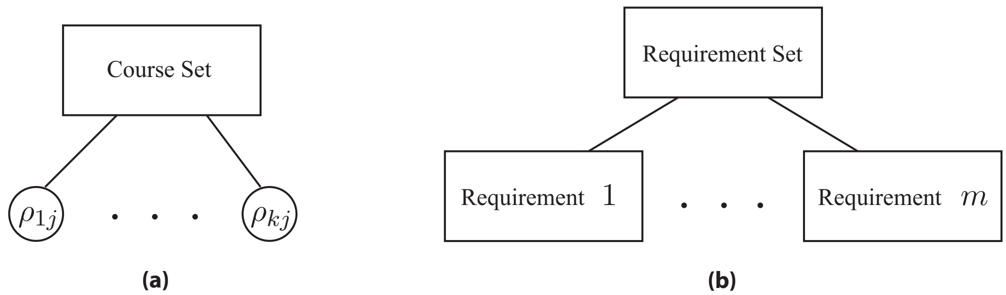

Figure 2: The two types of structures used to construct a requirements tree. **(a)** A *course set* requirement consists of a collection of course/minimum grade pairs $\{\rho_{1j}, \ldots, \rho_{jk}\}$, as well as the number of credit hours taken from the courses in $\{\rho_{1j}, \ldots, \rho_{jk}\}$ that must be successfully completed (i.e., earn at least the minimum grade) in order to satisfy the requirement. **(b)** A *requirement set* consists of a set of requirements, i.e., course sets or other requirements sets, along with a specification of how many of them must be satisfied in order to satisfy the requirement set as a whole.

Courses at source school	Equivalent Courses at destination school
ACC 105: Survey of Accounting	ACCT 250: Survey of Accounting
ANT 210: Cultural Anthropology	ANTH 200: Cultural Anthropology
BIO 181IN: General Biology I	MCB 181R: Introductory Biology I, and MCB 181L: Intro Biology I Lab
⋮	⋮
PSY 132: Psychology and Culture	PSYC 218: Psychology and Culture
SPA 101: Elementary Spanish I	SPAN 101: First Semester Spanish

Table 1: An example of the Transfer Equivalences Map

how many of the child requirements must be satisfied in order to satisfy the requirement set as a whole, and how many credit hours must be earned in doing so. The map of transfer equivalences contains a list of courses from the source school, i.e., the community college, along with their equivalent courses at the destination school, i.e., the four-year university. Properly specifying this map could prevent students from retaking courses in the two-year to four-year degree plan, thereby reducing the total credit hours required for earning both of the two degrees. An example of the map of transfer equivalences is shown in Table 1. The left column of this table includes a list of transferable courses from the source school, while the equivalent courses are listed in the corresponding row under the right column.

Given two requirement trees, one from a community college and the other from a university, two complete course catalogs from these two schools, and a map of transfer equivalencies, the OTP Problem is formally specified as follows:

Instance: Requirement trees, T_{CC} and T_U, for an associates program at a community college and a bachelor's degree at a university, respectively, the set of courses C_{CC} and C_U offered by the

community college and university, respectively, along with a mapping, $A : c_1 \in C_{CC} \longrightarrow c_2 \in C_U$, detailing how courses from the community college articulate as courses at the university.
Question: Can a two-year to four-year degree plan with the minimal number of credit hours be constructed that satisfies all requirements in T_{CC} and T_U, where all courses in the first two years are from the community college, and all courses in the next two years are from the university?

Theorem. *The decision version of the OTP Problem is $\mathcal{NP}$-complete.*

Proof: In the decision version of the OTP Problem, the question is whether or not a two-year to four-year degree plan exists that satisfies all requirements in the two-year community college and 4-year university, and with total credit hours at most k? Because it is possible to check in polynomial time whether a given degree plan satisfies all requirements in specified programs of a community college and a university, and has at most k credit hours, OTP is in $\mathcal{NP}$. The OTP problem can be shown to be $\mathcal{NP}$-complete through a reduction from the $\mathcal{NP}$-complete Knapsack problem.[1,2] Given an instance of the Knapsack problem, which includes a set of n items, the number of each item x_i is restricted to zero or one, each item with a weight w_i and a value w_i, along with a maximum weight capacity W, such that $\sum_{i=1}^{n} w_i \cdot x_i \leq W$ and $x_i \in \{0, 1\}$, an instance of OTP problem can be constructed in polynomial time as follows. Requirement tree T_U consists of a single course set $C = \{c_1, c_2, \ldots, c_n\}$, that has n course requirements and required minimum number of credits W. Set requirement tree $T_{CC} = \emptyset$ and transfer equivalency map $A = \emptyset$. Next, set the credit hours of each course requirement equal to $cr[c_1] = w_1, \ldots, cr[c_n] = w_n$, set $\sum_{i=1}^{n} w_i = S$. Let $x_i = 1$ denote that course i is excluded in the produced degree plan, and $x_i = 0$ denote that course i is included in the plan. Then, any solution to the OTP problem using these instances exists only if set $I = \{i \mid x_i = 0, 1 \leq i \leq n\}$ can be found, such that $\sum_{i=1}^{n} w_i \cdot x_i \leq S - W$ and $x_i \in \{0, 1\}$. $\square$

Optimization Algorithm

In this section, an optimization algorithm that makes use of $0-1$ integer programming is described to address the OTP problem. Consider that the catalog of the starting school contains p courses, denoted $a_1, \ldots, a_p$, and the catalog of the destination school contains q courses, denoted $b_1, \ldots, b_q$. Let $cr[i]$ denote the credit hours associated with course i. To determine the set of courses that will be included in the curriculum at the starting school, a $p \times 1$ binary-valued assignment matrix is defined as follows,

$$c_{A_i} = \begin{cases} 1; & \text{if course } i \text{ is included in the curriculum at the starting school,} \\ 0; & \text{otherwise.} \end{cases}$$

At the destination school, in order to decide which courses can be counted as transferred courses, a $q \times 1$ binary-valued assignment matrix is specified.

$$t_i = \begin{cases} 1; & \text{if course } i \text{ is counted as a transferred course at the destination school,} \\ 0; & \text{otherwise.} \end{cases}$$

The full curriculum, which is used to satisfy the degree requirements at the destination school, consists of courses that either belong to the study plan at school B or are counted as transferred courses. To extract this full curriculum, a $q \times 1$ binary-valued assignment matrix is specified.

$$c_{B_i} = \begin{cases} 1; & \text{if course } i \text{ belongs to the full curriculum at the destination school,} \\ 0; & \text{otherwise.} \end{cases}$$

Consider that the specified program at the starting school contains r course set requirements, and the program at the destination school has s course set requirements. In order to specify how each course is used to satisfy its corresponding course set requirements at the starting school, a $p \times r$ binary-valued assignment matrix is defined as follows.

$$x_{A_{ij}} = \begin{cases} 1; & \text{if course } i \text{ can fully or partially satisfy course set } j \text{ at the starting school,} \\ 0; & \text{otherwise.} \end{cases}$$

Similarly, a $q \times s$ binary-valued assignment matrix is used to support the course-to-course-set assignment at the destination school.

$$x_{B_{ij}} = \begin{cases} 1; & \text{if course } i \text{ can fully or partially satisfy course set } j \text{ at the destination school,} \\ 0; & \text{otherwise.} \end{cases}$$

Our goal is to find two curricula, one from the starting school and the other from the destination school. These two curricula can be used to satisfy degree requirements of specified programs from the two schools while minimizing the total number of credit hours. We can express this as the following 0-1 quadratic programming problem:

$$\min \left(\sum_{i=1}^{p} c_{A_i} \cdot cr[a_i] + \sum_{i=1}^{q} (c_{B_i} - t_i) \cdot cr[b_i] \right), \tag{1}$$

subject to: 1) Transfer Constraints, not shown for ease of exposition,
2) Graduation Constraints, not shown for ease of exposition.

Consider the objective function in Equation (1), which has two terms. The first term calculates the credit hours of the curriculum at the starting school, and the second term calculates the credit hours of the curriculum at the destination school. Thus the objective function, which is the sum of these two terms, returns the total credit hours of the transfer plan. We next consider how to stipulate the Transfer Constraints and Graduation Constraints.

Experimental Results

In this section, we demonstrate the efficacy of the algorithm described in the previous section. We will consider a two-year to four-year transfer plan for earning the Bachelor of Arts degree in Art History program at the University of Arizona. This plan is manually crafted by academic advisors from the University of Arizona for students who come from Pima Community College and hope to earn this Bachelor of Arts degree.

In order to create a degree plan that can be used to satisfy the degree requirements from both Pima Community College and the University of Arizona with a minimum number of credit hours, we analyze the degree requirements trees from these two institutions first. Figure 3 shows the requirement tree of the Associate of Arts program at Pima Community College. Each node of the tree denotes a *course set* or a *requirement set*. All the leaf nodes represent *course sets*, while the internal nodes represent *requirement sets*. Table 2 provides descriptions for each node in the requirement tree. The root node at level zero corresponds to the *requirement set* of this program. To satisfy the degree requirements of the Associate of Arts program, all the 10 requirements at level one of the tree need to be satisfied, from which the sum of credit hours must be greater than or equal to 60. Similarly, Figure 4 shows the requirement tree of the Art History program at the University of Arizona. And the descriptions of this requirement tree are listed in Table 3. All the 15 requirements at level one of this requirement tree need to be satisfied, from which the sum of credit hours must be greater than or equal to 120. The course catalogs we use for both Pima Community College and the University of Arizona are from the year 2021.[3,4] The transfer equivalencies map is provided by the Office of Transfer Credit and Articulation at the University of Arizona.[5]

The two-year to four-year degree plan for the Associate of Arts program to the Art History program is provided under the Course Column in Table 5. Courses from the first four terms are taken at Pima Community College with a total of 64 credit hours, and the courses for the remaining four terms are taken at the University of Arizona with a total of 62 credit hours. The equivalent courses counted at the University of Arizona are listed under the Equivalency Column. The transfer process results in a loss of 3 credit hours, which are from the two courses STU 107 and STU 210UA. These two courses are designed for transfer students with topics focused on university transfer exploration, preparation and college success.[6,7] Due to the course learning outcomes, these two courses are not transferable. To understand how each course is used to satisfy the degree requirements tree from the community college and the four-year university respectively, the corresponding *course set* requirement is presented under the Requirement Source column and the Requirement Destination column in Table 5. Indeed, the degree plan created by our algorithm can be used to satisfy the degree requirements of both the associate degree and the bachelor's degree at these two institutions. Considering other available courses listed under *course sets* that interest students provides the opportunity to further customize the degree plan.

It is worth noting that changing a major can be a normal part of the college experience, as it may reflect a student's growth, self-discovery, and a deeper understanding of their academic and professional desires. To demonstrate the efficacy of our algorithm that works in this scenario, another example is considered for creating a transfer plan from the Associate of Arts program at Pima Community College to the Biochemistry program at the University of Arizona. The structure of the degree requirement tree is provided in Figure 5, and the descriptions of the requirements are listed in Table 4. The two-year to four-year degree plan for this example with a total of 125 credit hours is provided in Table 6. It is interesting to note that most courses taken at Pima Community College are transferred to satisfy the General Education or Elective requirements at the University of Arizona. This suggests that the analysis of the degree requirements trees between majors and consideration of the transfer equivalencies map contributes to crafting a degree plan that minimizes the total number of credit hours.

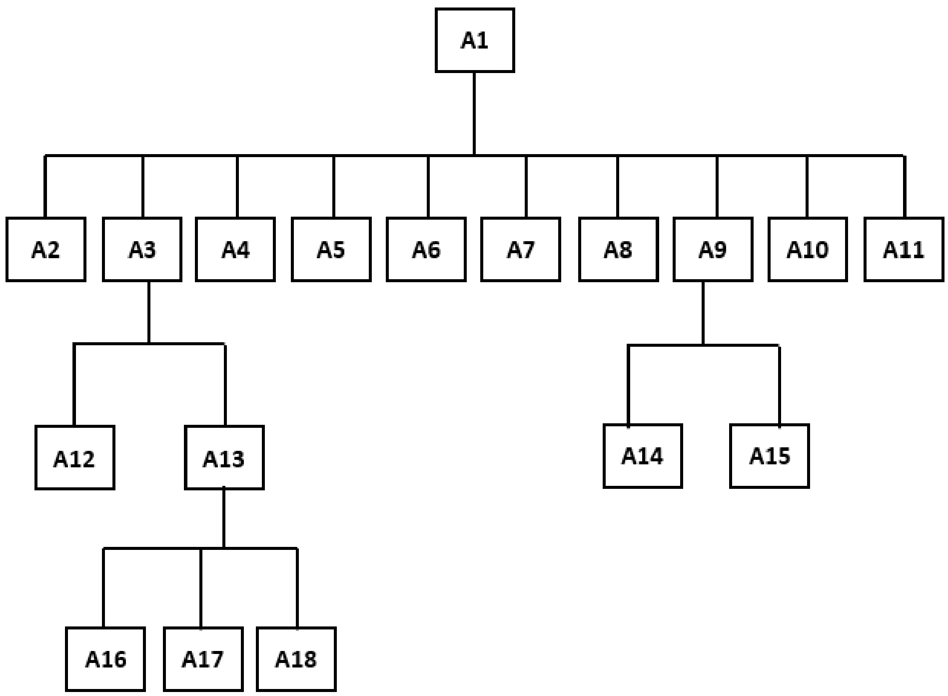

Figure 3: Degree requirement tree of the Associate of Arts program at Pima Community College. Each node of the tree denotes a *course set* or a *requirement set*. All the leaf nodes represent *course sets*, while the internal nodes represent *requirement sets*. In this requirement tree, there are 4 *requirement sets* and 14 *course sets*. Note that the course requirements under each *course set* are not displayed in the requirement tree for the sake of exposition.

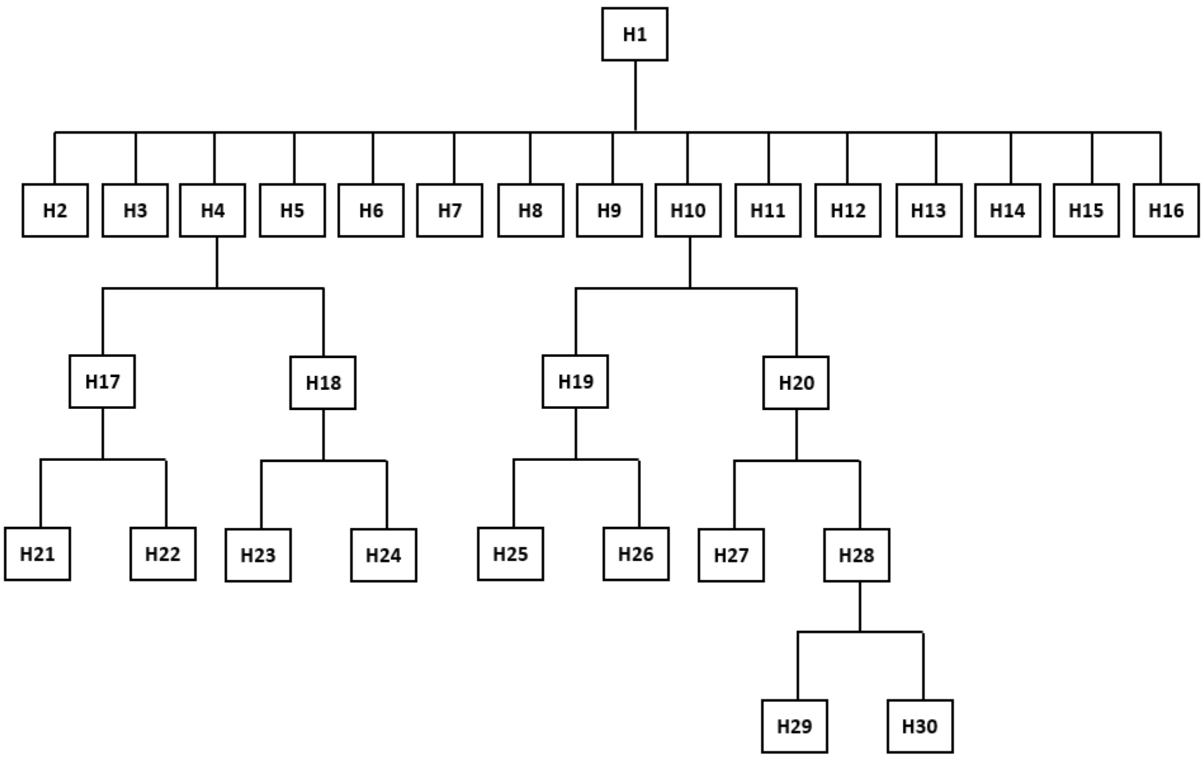

Figure 4: Degree requirement tree of the Art History program at the University of Arizona. In this requirement tree, there are 10 *requirement sets* and 20 *course sets*.

Requirement	Name	Minimum Credit	Satisfy
A1	Associate of Arts Degree Requirement	60	10
A2	AGEC-A Mathematics	3	
A3	AGEC A Other	6	1
A4	AGEC Fine Arts	3	
A5	Student Success Course I	1	
A6	AGEC A &B Biological and Physical Sciences	8	
A7	AGEC Humanities	3	
A8	AGEC A & S Social and Behavioral Sciences	6	
A9	AGEC English Composition	6	2
A10	Student Success Course II	2	
A11	Elective	22	
A12	AGEC A Other Option I	6	
A13	AGEC A Option II	6	1
A14	WRT 101 Course	3	
A15	WRT 102 Course	3	
A16	Biological and Physical Sciences or Mathematics	6	
A17	Social and Behavioral Sciences	3	
A18	Humanities and Fine Arts	3	

Table 2: Degree requirements description of requirement tree shown in Figure 3.

Requirement	Name	Minimum Credit	Satisfy
H1	Art History Degree Requirement	120	15
H2	Art History 400 Level Electives	3	
H3	Elective	43	
H4	First-Year English Composition	3	1
H5	GE General Math Strand	3	
H6	Upper Division Art Electives	9	
H7	Art History Major Emphasis	21	
H8	Core Courses	6	
H9	Studio Art Course	4	
H10	Second Language Fourth Semester	1	1
H11	Tier II Natural Sciences	3	
H12	Tier II Individual & Societies	3	
H13	Tier II Humanities	3	
H14	Tier I Natural Sciences /170s	6	
H15	Tier I Traditions & Cultures/160s	6	
H16	Tier I Individuals & Societies/150s	6	
H17	Option 1	6	2
H18	Honors Option	3	1
H19	Option 2	8	2
H20	Fourth Semester Second Language	1	1
H21	Option 2 ENGL 101 or ENGL 107	3	
H22	Option 2 ENGL 102 or ENGL 108	3	
H23	Honors Option 1	6	
H24	Honors Option 2	3	
H25	Additional Arabic Courses	3	1
H26	Arabic Language	5	1
H27	Fourth Semester Second Language Option I	1	
H28	Fourth Semester Second Language Option II	8	2
H29	Arabic Language	5	
H30	Additional Arabic Courses	3	

Table 3: Degree requirements description of requirement tree shown in Figure 4.

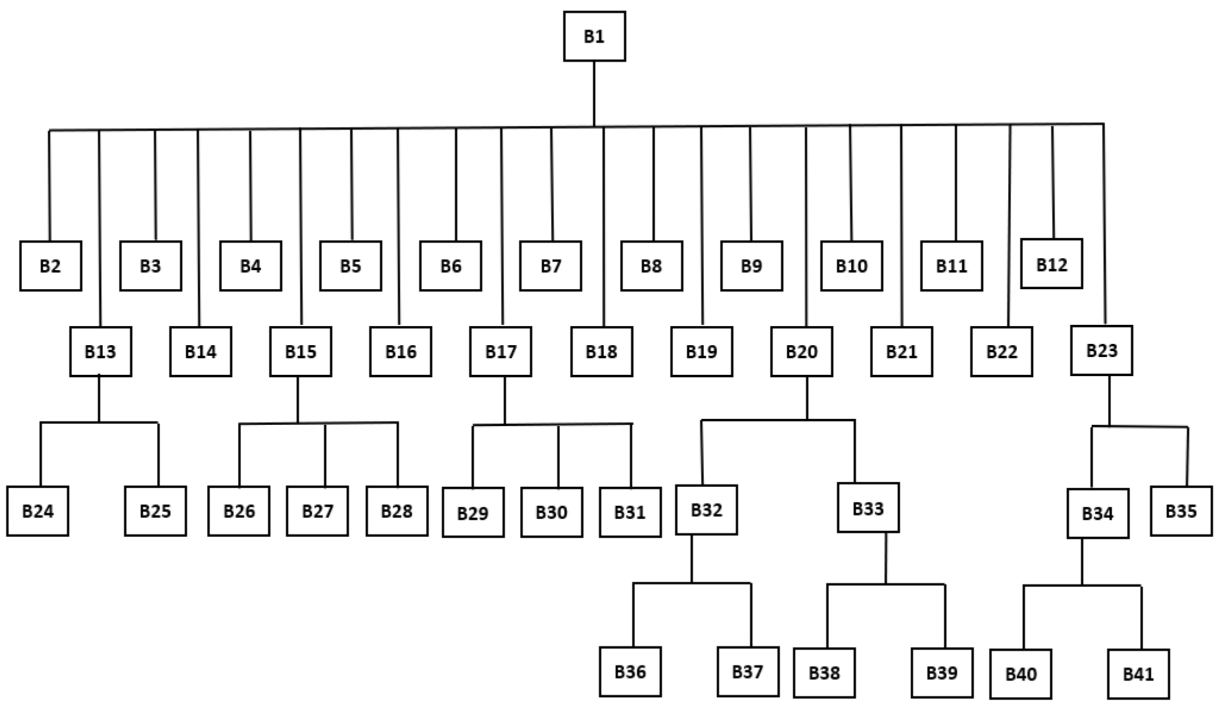

Figure 5: Degree requirement tree of the Biochemistry program at University of Arizona. In this requirement tree, there are 9 *requirement sets* and 32 *course sets*.

Requirement	Name	Minimum Credit	Satisfy
B1	Biochemistry Degree Requirement	120	22
B2	Tier II Humanities	3	
B3	Tier I Individuals & Societies/150s	6	
B4	Tier I Traditions & Cultures/160s	6	
B5	Tier II Arts	3	
B6	Tier II Individual & Societies	3	
B7	Elective	40	
B8	Upper Division Science Electives	6	
B9	Second Semester Organic Chemistry Lecture	3	
B10	Introductory Biology I	4	
B11	Introductory Biology II	4	
B12	Physics I	3	
B13	Mathematics	6	2
B14	Physics II	3	
B15	First Semester General Chemistry	4	1
B16	First Semester Organic Chemistry Lecture	3	
B17	Second Semester General Chemistry	4	1
B18	First Semester Organic Chemistry Lab	1	
B19	Introduction to Biochemical Research	1	
B20	First-Year English Composition	3	1
B21	Biochemistry	12	
B22	Second Semester Majors Organic Chemistry Lab	1	
B23	Fourth Semester Second Language	1	1
B24	Math I	3	
B25	Math II	3	
B26	CHEM 161/163	4	
B27	Chem 141/143	4	
B28	CHEM 151	4	
B29	CHEM 162/164	4	
B30	CHEM 144/142	4	
B31	CHEM 152	4	
B32	Option 1	6	2
B33	Honors Option	3	1
B34	Fourth Semester Second Language Option II	8	2
B35	Fourth Semester Second Language Option I	1	
B36	Option 2 ENGL 101 or ENGL 107	3	
B37	Option 2 ENGL 102 or ENGL 108	3	
B38	Honors Option 1	6	
B39	Honors Option 2	3	
B40	Arabic Language	5	
B41	Additional Arabic Courses	3	

Table 4: Degree requirements description of requirement tree shown in Figure 5.

Term	Course	Credit	Equivalency	Credit	Requirement Source	Requirement Destination
1	ART 105	3	ARE 130	3	AGEC Fine Arts	Elective
	STU 107	1			Student Success Course I	
	CHM 140IN	4	CHEM 130	4	AGEC A &B Biological and Physical Sciences	Elective
	MAT 142	3	MATH 105	3	AGEC-A Mathematics	GE General Math Strand
	SPA 101	4	SPAN 101	4	Elective	Elective
2	SPA 102	4	SPAN 102	4	Elective	Elective
	STU 210UA	2			Student Success Course II	
	WRT 101	3	ENGL 101	3	WRT 101 Course	Elective
	ART 110	3	ART 100E	3	AGEC Fine Arts	Elective
	BIO 201IH	4	PSIO 201	4	Elective	Elective
3	SPA 201	4	SPAN 201	4	Elective	Elective
	WRT 102	3	ENGL 102	3	WRT 102 Course	Elective
	ART 131	3	ARH 202	3	Elective	Core Courses
	HUM 131	3	CLAS 160D2	3	Elective	Tier I Traditions & Cultures/160s
	ECN 150	3	ECON 150C1	3	AGEC A & S Social and Behavioral Sciences	Tier I Individuals & Societies/150s
4	SPA 202	4	SPAN 202	4	AGEC A Other Option I	Fourth Semester Second Language Option I
	PHI 101	3	PHIL 111	3	AGEC Humanities	Elective
	AST 102IN	4	ASTR 170B1	4	AGEC A &B Biological and Physical Sciences	Elective
	ART 130	3	ARH 201	3	AGEC A Other Option I	Core Courses
	HIS 142	3	HIST 150C3	3	AGEC A & S Social and Behavioral Sciences	Elective
5	ENGL 109H	3				Honors Option 2
	EAS 160A3	3				Tier I Traditions & Cultures/160s
	HNRS 170A1	3				Tier I Natural Sciences /170s
	ARH 320	3				Art History Major Emphasis
	GWS 330	3				Tier II Humanities
6	ART 100A	2				Studio Art Course
	ART 100C	2				Studio Art Course
	HIST 150C2	3				Tier I Individuals & Societies/150s
	ARH 325	3				Upper Division Art Electives
	ARH 340A	3				Art History Major Emphasis
	ARH 436	3				Art History Major Emphasis
7	GEN 170A1	3				Tier I Natural Sciences /170s
	MUS 200R	1				Elective
	ARH 462	3				Art History 400 Level Electives
	ARH 484	3				Art History Major Emphasis
	ARH 499	5				Art History Major Emphasis
8	AIS 220	3				Tier II Individual & Societies
	WFSC 223	3				Tier I Natural Sciences /170s
	ART 353	3				Upper Division Art Electives
	ARH 394	4				Art History Major Emphasis
	ARH 400	3				Upper Division Art Electives

Table 5: Two-year to four-year degree plan for the Associate of Arts program to the Art History program. Column Course shows the complete set of courses in the degree plan. Courses from the first four terms are taken at Pima Community College, while the courses for the remaining four terms are taken at the University of Arizona. The non-transferable courses are marked in red.

Term	Course	Credit	Equivalency	Credit	Requirement Source	Requirement Destination
1	WRT 101	3	ENGL 101	3	WRT 101 Course	Elective
	SPA 101	4	SPAN 101	4	Elective	Elective
	STU 107	1			Student Success Course I	
	ART 105	3	ARE 130	3	AGEC Fine Arts	Elective
	EDU 201	3	TLS 204	3	Elective	Tier II Individual & Societies
2	SPA 102	4	SPAN 102	4	Elective	Elective
	STU 210UA	2			Student Success Course II	
	PHI 101	3	PHIL 111	3	AGEC Humanities	Elective
	PHI 123	3	PHIL 160D3	3	Elective	Tier I Traditions & Cultures/160s
	MUS 130	1	MUS 200I	1	Elective	Elective
	AFA 130	3	AFAS 200	3	Elective	Tier II Humanities
	MAT 252	3	MATH 215	3	AGEC-A Mathematics	Elective
3	BIO 181IN	4	MCB 181R, MCB 181L	4	AGEC A &B Biological and Physical Sciences	Introductory Biology I
	SPA 201	4	SPAN 201	4	Elective	Elective
	WRT 102	3	ENGL 102	3	WRT 102 Course	Elective
	REL 200	3	RELI 150B1	3	AGEC A & S Social and Behavioral Sciences	Tier I Individuals & Societies/150s
	WRT 216	3	ENG 210	3	Elective	Tier II Arts
4	BIO 182IN	4	ECOL 182R, ECOL 182L	4	AGEC A &B Biological and Physical Sciences	Introductory Biology II
	SPA 202	4	SPAN 202	4	AGEC A Other Option I	Fourth Semester Second Language Option I
	HIS 103	3	HIST 160B2	3	AGEC Humanities	Tier I Traditions & Cultures/160s
	HIS 161	3	HIST 150C2	3	AGEC A Other Option I	Tier I Individuals & Societies/150s
5	ENGL 109H	3				Honors Option 2
	MATH 122A	1				Elective
	MATH 125	3				Math I
	CHEM 243B	1				Second Semester Majors Organic Chemistry Lab
	CHEM 244A	1				First Semester Organic Chemistry Lab
	BIOC 296B	1				Introduction to Biochemical Research
	ART 119	3				Elective
6	MATH 122B	4				Elective
	PHYS 140	3				Physics I
	BIOC 462A	4				Biochemistry
	WFSC 474	4				Upper Division Science Electives
	CHEM 161	3				CHEM 161/163
7	MATH 129	3				Elective
	CHEM 162	3				CHEM 162/164
	CHEM 163	1				CHEM 161/163
	MATH 263	3				Math II
	BIOC 463A	4				Biochemistry
8	CHEM 164	1				CHEM 162/164
	PHYS 240	3				Physics II
	CHEM 241B	3				Second Semester Organic Chemistry Lecture
	CHEM 246A	3				First Semester Organic Chemistry Lecture
	CHEM 325	2				Upper Division Science Electives
	BIOC 462B	4				Biochemistry

Table 6: Two-year to four-year degree plan for the Associate of Arts program to the Biochemistry program. Courses from the first four terms are taken at Pima Community College, while the courses for the remaining four terms are taken at the University of Arizona.

Summary

In higher education, many students are choosing to transfer between institutions due to various reasons, such as financial considerations, educational goals, career aspirations and so on. It has been widely acknowledged that providing academic support to transfer students is a challenging task due to the complexity of the transfer process and students' background. Based on the study of the mechanics of the transfer process, we have gained a better understanding of the root cause of the challenge.

As the transfer process can be treated as a computable problem, we proposed a tree data structure that can represent the degree requirements of academic program. To study the complexity of the transfer process, we formally defined the Optimal Transfer Pathway (OTP) Problem. A proof of the $\mathcal{NP}$-Completeness of the OTP problem is provided. An algorithm based on integer quadratic programming was proposed, which can generate near optimal solutions to satisfy degree requirements in a reasonable timeframe. The efficacy of the algorithm has been demonstrated through experimental results in creating transfer plans for two distinct scenarios.

There are several directions for future research in this field. With the increasing demand for efficient transfer plans, the pursuit of algorithms with lower time complexity is valuable. Although the OTP problem is $\mathcal{NP}$-Complete, it is worthwhile to explore heuristic algorithms by delving deeper into the components of the transfer process. Additionally, investigating more student-specific requirements, such as creating degree plans that maximize pass rates or reduce the time to degree completion, would be an interesting area to explore alongside algorithm development.

References

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