

# Trajecta: a model-driven approach for curricular analysis with Process Mining

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## Abstract

Curricular analysis aims to gain insight into the strengths and weaknesses of a curricular plan, identifying problems such as deviations in students' trajectories and bottlenecks, as well as evaluating the flexibility and constraints of the paths. Educational Process Mining (EPM) offers a process-centric perspective on curricular data. A key challenge for EPM is the availability of tools for curricular analysis that non-technical users can interpret, are open-source, and are readily available for use. In this paper, we present the Trajecta tool, which provides a model-driven approach for curricular analysis using Process Mining, benefiting both students and academic managers in managing curricular data. The tool offers a web interface, a Java component with a generic metamodel for modeling curricular programs, and a microservices Python component that leverages the PM4Py library to provide process mining functionalities. It was evaluated using an example application with real data from the Computer Science program at the Facultad de Ingeniería (FING), Universidad de la República (UdelaR).

## Keywords

Educational Process Mining, Curricular analysis, Students' trajectories, Model Driven Engineering

Metadata description	Value
Tool name	Trajecta
Current version	1.2
Legal code license	GPL-3.0
Languages, tools and services used	Java, Python, Ecore, PM4Py, JavaScript, HTML, Flask, Servlets, choices.js, vis.js, Google Charts
Supported operating environment	Microsoft Windows, GNU/Linux - Requires Firefox, Chrome, or Edge internet browser
Download/Demo URL	<a href="https://gitlab.fing.edu.uy/open-coal/trajecta.git">https://gitlab.fing.edu.uy/open-coal/trajecta.git</a>
Documentation URL	<a href="https://gitlab.fing.edu.uy/open-coal/trajecta">https://gitlab.fing.edu.uy/open-coal/trajecta</a>
Source code repository	<a href="https://gitlab.fing.edu.uy/open-coal/trajecta">https://gitlab.fing.edu.uy/open-coal/trajecta</a>
Screencast video	<a href="https://gitlab.fing.edu.uy/open-coal/trajecta/-/raw/main/demo.mp4">https://gitlab.fing.edu.uy/open-coal/trajecta/-/raw/main/demo.mp4</a>

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## 1. Introduction

Curricular analysis [1] aims to gain insights into the strengths and weaknesses of a curricular plan. This includes identifying problems like students' trajectory deviations, curricular units that define bottlenecks and their impact, and evaluating paths' flexibility and constraints to detect improvement opportunities. Process Mining [2] plays a key role in this domain. Curricular plans serve as a reference model for students to navigate their studies throughout their career, and the actual individual trajectories of students over this reference model define possible paths within it. Educational Process Mining (EPM) [3] provides such a view over curricular data.

In [4], the state of the art in Process Mining for curricular analysis is presented and discussed. One key specific challenge identified in that work concerns the availability of tools for curricular analysis that can be interpreted by non-technical users, i.e., tools that can be understood and used by domain experts. Although some tools exist, such as [5, 6], they are not freely available for use by students and academic managers. Additionally, to support comparative studies between careers at different institutions and even across different countries, a common language is needed to model curricular plans and trajectories.

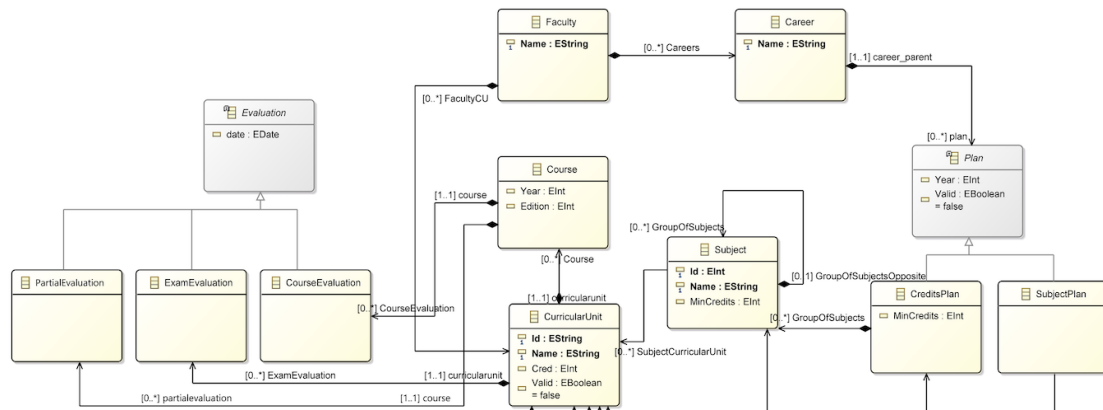
To close this gap, we propose the Trajecta tool, which supports curricular analysis for both students and academic managers, helping them manage curricular data. The Trajecta tool offers a model-driven approach for modeling curricular programs. It is based on a metamodel that defines common yet generic concepts and relations for key elements, such as plans and courses, which can be used to model different careers from various institutions. It provides key functionalities, such as curricular trajectory path recommendations for students, and the application of key process mining analysis techniques, including discovering students' trajectory models, analyzing deviations, identifying bottlenecks, and generating data statistics for academic managers. The tool was evaluated using real data for the Computer Science career at the Facultad de Ingeniería (UdelaR), validating its support for curricular modeling and analysis.

The rest of the document is organized as follows: Section 2 describes the functionalities of the tool, Section 3 introduces the architecture of the tool and technologies used, Section 4 discussed the maturity of the tool and finally Section 5 presents some conclusions and future work.

## 2. Trajecta Tool

The tool follows a model-driven approach, which, at its core, is a metamodel for curricular programs depicted in Figure 1, allowing the modeling of a wide range of study programs. It integrates key concepts, such as institutions and their careers, along with concrete study plans for a career, i.e., a set of partially ordered curricular units that a student must complete. Moreover, it supports more dynamic concepts, such as instances of curricular units (i.e., courses over a given period), various types of periodic evaluations (partial, course, and exam), and students' enrollments in courses and assessments, along with their corresponding grades. A curricular plan is defined by creating a model that complies with the metamodel, which serves as the reference model for the curricular plan and is used for subsequent analysis and evaluation.

The tool provides two main categories of functionalities, each one designed for a specific user: i) curricular trajectory recommendation, which aims for students that want to know the

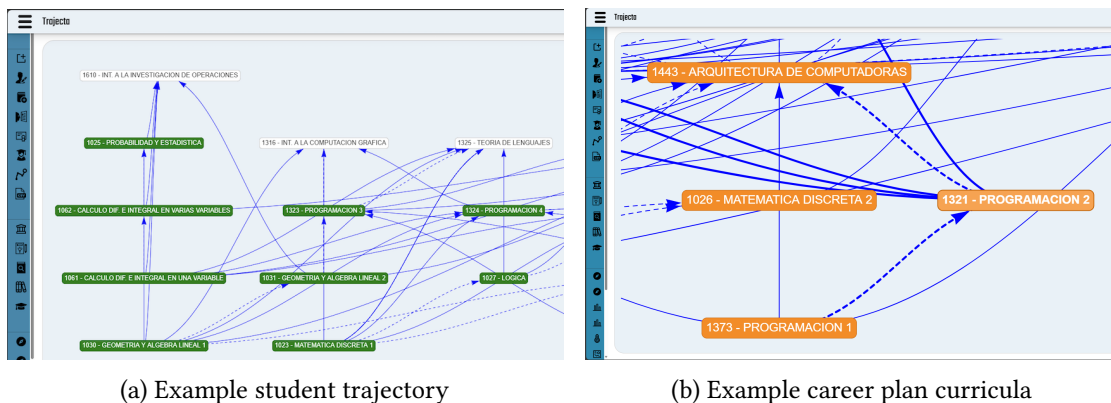


**Figure 1:** Generic curricular programs metamodel

available paths they can follow at any given moment, and ii) curricular trajectory analysis, which aims for academic managers that want to evaluate how students are traversing the curricula defined, where are the deviations, the bottlenecks, and different statics. In the following, these two categories and the main functionalities provided are introduced, illustrating the tool's use with an application example using real data from the Computer Science career at the Faculty of Engineering (Udelar).

## 2.1. Curricular trajectory recommendation

Students can model their academic trajectory by entering information about their career goals, course plans, and evaluation results, which are then visualized as a graph. Figure 2a presents an example of a trajectory for a student of the Computer Science career at the Faculty of Engineering (Udelar). The tool provides recommendations on curricular units that the student can enroll in, using a color-coded scheme: green for fully approved, yellow for partially approved, and white for available curricular units for enrollment.



**Figure 2:** Curricular trajectory recommendation category functionalities

Students can access detailed information about curricular units, including prerequisites, associated subjects (e.g., mathematics), and other attributes. The curricula can be visualized as a directed graph, where arrows represent prerequisite relationships. For example, Figure 2b illustrates that enrollment in “Programación 2” (Programming 2), of the Computer Science career at the Faculty of Engineering (UdelaR), requires prior approval of “Programación 1” (Programming 1). This supports students in planning their studies, understanding the requirements for specific courses, and identifying available options at each stage of their career.

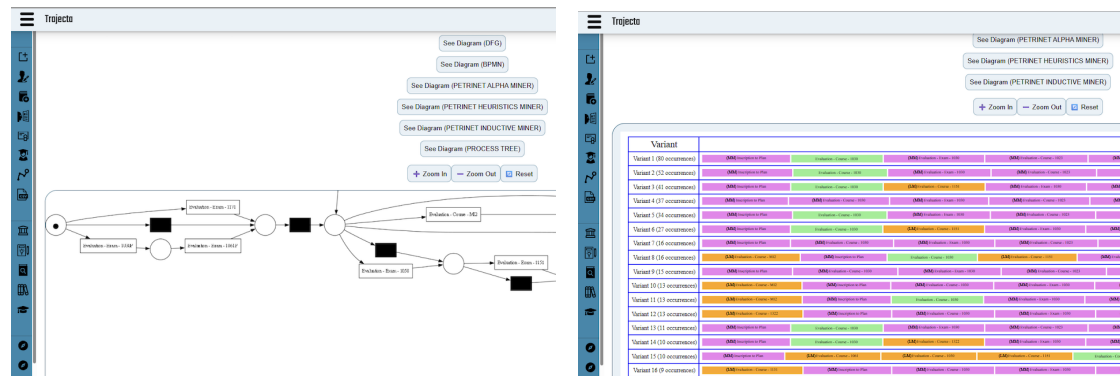
## 2.2. Curricular trajectory analysis

For academic managers, Trajecta integrates process mining techniques through the PM4Py [7] library. This functionality allows managers to analyze student activity logs and compare them with a reference model, i.e., the curricular plan.

The tool currently supports:

1. Discovery of students’ academic trajectories,
2. Statistical analysis of curricular units and curricular plans,
3. Visualization of performance graphs and trajectory graphs in multiple formats,
4. Evaluation of students’ performance over time,
5. Conformance checking for deviations between student trajectories and curricular plans.

Although these are commonly used process mining perspectives for curricular analysis, the user interface presents its functionalities in educational terminology to be easily understood by domain people. Through these capabilities, academic managers gain insight into how students progress, where deviations occur, and how curricular structures influence academic performance. Figure 3a depicts an example of Petri net discovery of students’ trajectories, showing other discovery options provided by the tool, and Figure 3b presents an example of deviations showing alignments between variants of student trajectories with respect to the curricular plan (reference model).

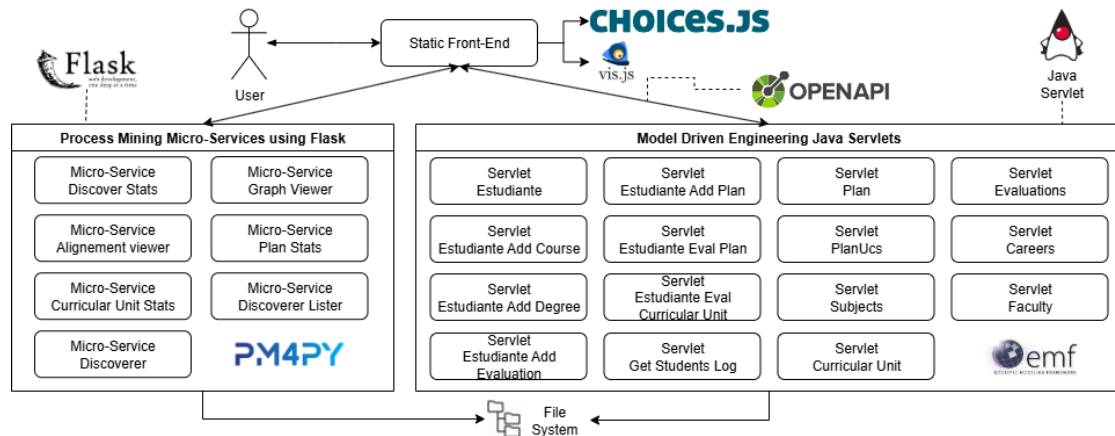


(a) Discovered Petri net from the computer science students’ event log (b) Alignment graph between students from 2018 to 2021 to the curricular plan

**Figure 3:** Curricular trajectory analysis category functionalities

### 3. Architecture

The tool is presented as a web application, where the front-end can be deployed on any static server or service, such as GitHub Pages, or accessed directly from disk by opening the .html files. It uses *vis.js* to visualize the trajectory of a student and the curriculum of a career plan. It employs *choices.js* to enable searching within the select inputs of the tool. The backend is divided into microservices: the process mining ones are written in Python and use PM4Py [7], and the model-driven ones are written in Java and use the Eclipse Modeling Framework (EMF)<sup>1</sup>.



**Figure 4:** Tool Architecture with libraries used

The Java application provides functionalities for curricula trajectory recommendation, including a metamodel with EMF support. The Python microservices support the process mining functionalities for the category of curricular trajectory analysis. The Java component also converts a student trajectory that is written in EMF to an event log. The Python component, designed with microservices, allows for easy extension of functionalities.

### 4. Maturity of the tool

The tool has been evaluated using real data from the Computer Science program at the Faculty of Engineering (UdelaR). The model-driven approach was validated through the modeling of the curricular plan and the use of its functionalities by university students (with access to the front-end component and Java functionalities)<sup>2</sup>. The process mining component, i.e., the PM4Py microservices backend, was validated using real data from the computer science career, specifically students' trajectories from 2018 to 2021. The event logs contain 2,297 cases (students) and 27,920 events, along with 1,708 variants, spanning from February 7, 2018, to March 5, 2021. Some performance limitations were identified during log discovery and graph visualization, such as the discoveries being executed in a background thread and not notifying

<sup>1</sup><https://eclipse.dev/emf/>

<sup>2</sup><https://trajecta.fapret.com/>

the user when they are finished. Although initial tests were conducted primarily by students for the model-driven part, we plan to extend it for the process mining analysis component.

## 5. Conclusions

We have presented the Trajecta tool, which provides a model-driven approach for curricular analysis with Process Mining. The tool is open-source and available for free use. It provides support for non-technical users and facilitates the modeling and analysis of different careers, serving as a basis for comparative analysis. We are integrating additional process mining functionalities to support specific educational analyses, focusing on more user-friendly visualizations than those already provided. We are also evaluating the adaptability of the metamodel to model various types of study programs at different universities. This will also provide the basis for comparative process mining analysis between different institutions and countries.

## Declaration on Generative AI

During the preparation of this work, the authors used Grammarly to check grammar and spelling, paraphrase, and reword. After using them, the authors reviewed and edited the content as needed, taking full responsibility for the publication's content.

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