MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

# DECISION ANALYTICS

## Assignment 1: Constraint Programming

### DUE DATE

This assignment should be submitted to Canvas before 11:59pm on **Friday 11/11/2022**.

Please submit a single ZIP file with your student number and name in the filename. Your submission should contain **exactly 2 files**:

- A detailed documentation of all code you developed, including the tests and evaluations you carried out. Please make sure that you include a .pdf document with every result you produce referencing the exact subtask and lines of code it refers to.
- All Python code you developed in a single .py file that can be executed and that generates the outputs you are referring to in your evaluation. The file needs to be readable in a plain text editor, please do NOT submit a notebook file or link. Please also make sure that you clearly indicate in your comments the exact subtask every piece of code is referring to.

**Please do NOT include the input files in your submission.**

You can achieve a total of 50 points as indicated in the tasks.

### TASK 1 (logic puzzle, 17 points)

In this task you will develop a constraint satisfaction model that solves the following logical puzzle:

> *James, Daniel, Emily, and Sophie go out for dinner. They all order a starter, a main course, a desert, and drinks and they want to order as many different things as possible.*
>
> *The carpaccio starter is not combined with the vegan pie as main course and the filet steak main course is not followed by ice cream as desert. (1)*
>
> *Emily does not have prawn cocktail or onion soup as starter and none of the men has beer or coke to drink. (2)*
>
> *The person having prawn cocktail as starter has baked mackerel as main course and the filet steak main course works well with the red wine. (3)*
>
> *One of the men has white wine as drink and one of the women drinks coke. (4)*

*The vegan pie main always comes with mushroom tart as starter and vice versa; also, the onion soup and filet steak are always served together. (5)*

*Emily orders beer as drink or has fried chicken as main and ice cream as desert; James orders coke as drink or has onion soup as starter and filet steak as main. (6)*

*Sophie orders chocolate cake but does not drink beer nor likes fried chicken; Daniel orders apple crumble for dessert but has neither carpaccio nor mushroom tart as starter. (7)*

*Who has tiramisu for dessert?*

A. Identify the objects, attributes and predicates for the puzzle and create the decision variables in a CP-SAT model [1 point].
B. For each of the seven sentences in the puzzle define the explicit constraints contained in the sentences in conjunctive normal form and add them to the CP-SAT model [14 points]. Identify clearly, which sentence you are referring to.
C. The puzzle also contains some implicit constraints. Define and implement these implicit constraints in the CP-SAT model [1 point].
D. Solve the CP-SAT model and determine the starter, main course, dessert, and drink ordered by each of the diners [1 point].

**TASK 2 (Sudoku, 5 points)**

In this task you will develop a constraint satisfaction model for solving the following Sudoku puzzle:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | 3 | |
| 7 | | 5 | | 2 | | | | |
| | 9 | | | | | 4 | | |
| | | | | | 4 | | | 2 |
| | 5 | 9 | 6 | | | | | 8 |
| 3 | | | | 1 | | | 5 | |
| 5 | 7 | | | 6 | | 1 | | |
| | | | 3 | | | | | |
| 6 | | | 4 | | | | | 5 |

The goal is to fill the remaining digits into grid so that no digit occurs twice in any of the rows, in any of the columns, or in any of the 3x3 sub-grids.

A. Identify and crate the decision variables for the Sudoku puzzle in a CP-SAT model and implement the constraints that specify the digits, which are already given in the puzzle specification [1 point].
B. Define and implement the constraints that no digit can occur twice in any of the rows or columns [1 point], or in any of the 3x3 sub-grids [1 point].

C. Solve the CP-SAT model and determine how many solutions can be found for the above instance [1 point]. Output all these solutions [1 point].

**TASK 3 (project planning, 28 points)**

In this task you will develop a constraint satisfaction problem model for deciding what projects can be taken on and what companies need to be contracted to deliver on these projects. The Excel file **Assignment_DA_1_data.xlsx** on Canvas contains the data to be used in this task. It comprises four sheets:

- In the **Projects** sheet you will find a list of projects, for each projects the jobs that need to be carried out and the months this needs to happen (e.g. Project E required Job J in month M8 and Job A in month M9).
- In the **Quotes** sheet you will find a list of contractors and their quotes for each of the jobs they are qualified to carry out (e.g. Contractor A charges €230 for Job A). A contractor can only work in one project at a time.
- In the **Dependencies** sheet you will find a matrix of project dependencies indicating which projects are pre-requisites for the delivery of other projects (e.g. Project B can only be taken on, if also Project A is taken on), and which projects are conflicting with each other (e.g. Project B and Project C are mutually exclusive and cannot be both taken on).
- In the **Value** sheet you will find the value of each project (e.g. Project A is worth €500).

The goal is to determine which projects can be delivered and what subcontractors should be contracted while making sure that the overall profit margin is at least €2160.

A. Load the excel file **Assignment_DA_1_data.xlsx** and extract all relevant information [1 point]. Make sure to use the data from the file in your code, please do not hardcode any values that can be read from the file.
B. Identify and create the decision variables in a CP-SAT model that you need to decide what projects to take on [1 point]. Also identify and create the decision variables you need to decide, which contractor is working on which project and when. Make sure to consider that not all contractors are qualified to work on all jobs and that projects do not run over all months [3 points].
C. Define and implement the constraint that a contractor cannot work on two projects simultaneously [3 points].
D. Define and implement the constraint that if a project is accepted to be delivered then exactly one contractor per job of the project needs to work on it [4 points].
E. Define and implement the constraint that if a project is not taken on then no one should be contracted to work on it [4 points].
F. Define and implement the project dependency and project conflict constraints [3 points].

G. Define and implement the constraint that the profit margin, i.e. the difference between the value of all delivered projects and the cost of all required subcontractors, is at least €2160 [5 points].
H. Solve the CP-SAT model and determine how many possible solutions satisfy all the constraints [1 point]. For each solution, determine what projects are taken on [1 point], which contractors work on which projects in which month [1 point], and what is the profit margin [1 point].