

# CONSTRAINT PROGRAMMING

## Syllabus: ISyE 4134 Constraint Programming

### ISYE 4134 A, Online Class

**Interactive Sessions: MW 5:00–6:15 p.m EST.**

### Instructors:

- Professor Pascal Van Hentenryck
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### The Teaching Assistants

### Catalog Description

This course (ISyE-CP) is an introduction to constraint programming (the “force”), from its modeling language to its computational methodology and its applications to scheduling, routing, and resource allocation.

### Course Description

The course is intended primarily for senior undergraduates, Master students, and incoming PhD students. The course is an introduction to the “force” with an emphasis on modeling and solving optimization problems. It is not primarily a course about the implementation of constraint programming systems, although the class will cover the working of constraint programming solvers since this is critical to model problems correctly.

### Prerequisites: ISyE 3133, CS 2316 (both with an A ideally)

The course involves numerous assignments in the OPL programming language. If you find learning a new programming language difficult and/or if you dislike programming, this is the wrong class for you. *We also recommend that you test the concepts that you learn in the video using the OPL system, so that you get familiar with the syntax and semantics of the language. Practicing the language is really important for later projects.*

### Videos, Texts, and other resources

Professional videos of the lectures as well as PDFs of the lecture slides will be made available on the course website. They will cover all the material needed for learning the course outcomes. The OPL Studio system will be available for your assignments. It contains a sophisticated online documentation that should help design the projects. But the videos should be sufficient to learn OPL, including three especially devoted to the topic.

### Minimum Technology Requirements

A modern laptop (or equivalent) is necessary to attend this course. Students will download the IBM Optimization studio which will be used for most of the assignments. Graduate students should install Java on their machines as well as they will use it for one of the assignments.

## Attendance

*This is an online class.* The material is presented in high-quality videos and complemented with interactive online sessions. The online material is organized in modules. The material is released on Tuesday at 12:00am EST for the Wednesday class and at Thursday at 12:00am EST for the next Monday class. *The interactive sessions are provided as a way for you to ask questions, review the material with the instructors, and discuss your assignments.*

Students are expected to have reviewed the videos before the interactive sessions. The interactive sessions review the material, include Q/A sessions, and go over the assignments and projects. They also include one-on-one sessions with the instructors and the teaching assistants. Experience has shown that significant learning happens in these sessions. The interactive sessions are not recorded.

## Course Outcomes

By the end of this course the students should understand the modeling methodology and computational paradigms underlying constraint programming. Understand how to use constraint programming to model and solve problems in a variety of engineering and scientific fields.

- Describe the fundamental properties of good constraint programming models and how they differ from other methodologies.
- Be able to determine when/how to use constraint programming for practical applications in areas such as scheduling, routing, and resource allocation.
- Achieve fluency in the modeling language OPL for constraint programming.
- Recognize when additional features (e.g., new constraints and dedicated search procedures) are necessary to solve a problem and understand what this involves.

## Grading

The grades will be based on 15 project assignments, a mid-term exam, and a final exam. The percentage for each assignment is listed in the table below. Graduate students have one additional project. Some of the assignments are routine, others are significantly more challenging. It is strongly recommended to start the assignments early. They have been adapted to online learning and to make sure that the learning process is gradual based on the instructor's experience in teaching online, in academia, industry, and to K-12 students. All assignments are due at 11:59pm EST on the due date. In case of disagreements in dates and points between the missive and the Canvas modules, the canvas module is the truth, the only truth, and the whole truth. The mid-term will last around 3 hours and is similar to an easy project (it will not require any significant creativity). The final will take place over 4 hours. The dates below will be adjusted

Project	Due	% Undergrad	% Grad
Τηε Γαλαξψ	August 27	5	5
Ηαν Σολο	August 29	5	5

Λυκε Σκψωαλκερ	Sept 3	5	5
Στορμ Τροοπερσ	Sept 5	5	5
Θεδι Σχηοολ	Sept 12	10	10
Τηε Ρεπυβλιχ	Sept 19	10	10
ΧΟςΙΔ-24	Sept 26	15	15
Ποδραχεσ	Oct 9	15	15
Τηε Εμπιρε Στρικεσ Βαχκ	Oct 17	15	15
Τηε Ρετυρν οφ τηε Θεδι	Oct 21	10	10
Μιδ-Τερμ	Oct 22	150	150
Τακοδανα	Oct 27	10	10
P2Δ2	Nov 3	15	15
Τηε Φορχε Αωακενσ	Nov 10	20	20
Μιλλενιυμ Φαλχον	Nov 17	10	10
Πρινχεσσ Λεια	Dec 1	n/a	100
Φιναλ	Dec 5 (6-8:50pm)	200	200
Total		500	600

### Assignments

Assignments are graded on a scale that aligns with the below. Some of the assignments are extremely challenging even for experts in the field. This is the nature of optimization problems. One of the goals of the course is to help you understand this reality.

As a result, the grades will be assigned to your individual project write up based on the following scale (with grades in between tiers being assigned based on the specific formulation):

- Submitting junk or infeasible solutions: 0%;
- Submitting solutions of low quality: around 30%;
- Submitting solutions of good quality: around 70%;
- Submitting solutions of great quality: 100%;

*This rubric will be applied rigorously.* Hence it is important for you to make sure that you have working solutions for the projects. Start early. **Every assignment must have detailed comments on the meaning of each decision variables and each constraint / group of constraints.** Assignments with no comments will not be graded. Assignments should prove optimality within 5 minutes unless explicitly mentioned otherwise.

The class starts slow, with easy projects initially. The pace then picks up quickly and the last projects are challenging. Plan ahead and do not be fool by the simplicity of the early projects. They are an opportunity for you to master the OPL language.

### Regrading

If the grader has made a mistake in grading an assignment, we will be happy to correct it. All requests for regarding must be submitted with 7 days from the test date.

## **Extensions, Late Assignments**

Late projects will be accepted with a 20% penalty per day late. Students will have one late day, which they can use on any project that will excuse them from this penalty for 24 hours. The late day will be automatically applied to the late assignment with the most points at the end of the semester; there is no need to let course staff know about using your day. Projects handed in more than three days late will not be graded. However, students must hand in a working version of all projects in order to pass the class. A working version of a project produces a solution of some kind to the project. A Dean's excuse or a note from health services is required for any kind of exception to be made to the rules above. Once you have one of these, you should talk with the professor, who is the only person who can give extensions.

## **Letter grade**

The overall grades are the summation of grades from assignments. For undergraduates, the final letter grades will be assigned based on

$$A \geq 450, B \geq 400, C \geq 350, D \geq 300.$$

Similar percentages are used for graduate students

## **Collaboration Policy**

In order to help the course staff evaluate each student in ISYE-CP as fairly and individually as possible, we have written a collaboration policy by which we expect all students to abide. Please read this policy carefully, as it may differ from collaboration policies in classes you have taken previously. ISYE-CP has a lenient collaboration policy to encourage teaching and learning with your peers. At the same time, your work must, in the end, represent your own understanding of the material. In that spirit, our overall policy is that you can talk about almost anything and work out solutions together, but that no notes may be taken away from collaboration sessions and your final write-up must be your own work (so-called "whiteboard collaboration").

The midterm and final exams are purely individual work and no collaboration is allowed. Hence make sure that you understand the material well, when (whiteboard) collaborating on projects. The exams are a significant portion of your work.

## **Permissions**

You must ensure that your course documents have permissions which do not permit other students to view them. Ask an IT consultant for help with permissions if necessary.

## **Projects**

You should not be looking at anyone else's write-up, nor should you permit anyone to look at your write-up. An obvious consequence of this policy is that you cannot debug the code of anyone else, and no one, with the exception of the instructors and the teaching assistants, can debug your code.

## **Excused Absences from Assignments**

We only accept notifications from Dean's office [https://gatech-advocate.symplicity.com/care\\_report/index.php/pid167160](https://gatech-advocate.symplicity.com/care_report/index.php/pid167160) or Institute Approved Absences <https://registrar.gatech.edu/info/institute-approved-absence-form-for-students>.

Please inform the instructor of your approved absences timely. If the notification from Dean's office is for instructor's discretion and your absence prevents you from completing assignments or tests, please discuss the accommodations with the instructor as soon as possible. Since it is difficult to create a different but fair test, and solutions to assignments may have already been published, the accommodation might not be a makeup test or assignment.

## **Course Outline**

1. Basic Concepts
  - 1.1. Getting started
  - 1.2. Basic concepts I
  - 1.3. Basic concepts II
  - 1.4. OPL Primer
2. Elements of Constraint Programming
  - 2.1. Reified constraints
  - 2.2. Optimization
  - 2.3. Expressions
3. Theoretical Foundation
  - 3.1. Computational Model
4. Global Constraints
  - 4.1. The element constraint
  - 4.2. The table constraint
  - 4.3. Combinatorial Constraints
  - 4.4. The pack constraint
  - 4.5. The circuit constraint
  - 4.6. The lex constraints
5. Modeling in Constraint Programming
  - 5.1. Symmetry breaking
  - 5.2. Subexpression elimination
  - 5.3. Redundant constraints I
  - 5.4. Redundant constraints II
6. Search in Constraint Programming
  - 6.1. Search tree and Impact
  - 6.2. Restart and nogoods
7. Implementation of Constraint Programming
  - 7.1. Packing
  - 7.2. AllDifferent
  - 7.3. NoOverlap
8. Scheduling in Constraint Programming
  - 8.1. Interval variables and noOverlap
  - 8.2. The Sequence Constraints
  - 8.3. Cumulative Constraints

- 8.4. The House Problem II
- 8.5. The House Problem III
- 8.6. The Perfect Square Problem
- 8.7. State Constraints
- 8.8. The Trolley Application
- 8.9. Optional Activities
- 8.10. Standard Scheduling Problems
- 8.11. Calendars
9. Advanced Topics
  - 9.1. Large neighborhood search
  - 9.2. Scripting models
  - 9.3. Routing
  - 9.4. CP in Python
10. Implementation in MiniCP
  - 10.1. Semantics of CP
  - 10.2. Operational Model of CP
  - 10.3. Inference
  - 10.4. Search
  - 10.5. Advanced Inference
  - 10.6. Advanced Search

## Homework

N/A

## Collaboration & Group Work

See earlier.

## Projects

See earlier.

## Exams

During the mid-term and final exams, you cannot communicate with anyone and/or use the web to search the web.

- The mid-term will take place on October 22rd.
- The final will take place on December 5th.

## Course Expectations & Guidelines

Following [Georgia Tech policies and procedures](#) and [Course Policies](#), the policies are described below for this class.

### 1. Academic Integrity

Georgia Tech aims to cultivate a community based on trust, academic integrity, and honor. Students are expected to act according to the highest ethical standards. For information on

Georgia Tech's Academic Honor Code, please visit <http://www.catalog.gatech.edu/policies/honor-code/> or <http://www.catalog.gatech.edu/rules/18/>. Any student suspected of cheating or plagiarizing on a project or an assignment will be reported to the Office of Student Integrity, who will investigate the incident and identify the appropriate penalty for violations. We use software tools to detect similarities between assignments.

## **2. Accommodations for Students with Disabilities**

If you are a student with learning needs that require special accommodation, contact the Office of Disability Services at (404)894-2563 or <http://disabilityservices.gatech.edu/>, as soon as possible, to make an appointment to discuss your special needs and to obtain an accommodations letter. Please also e-mail an instructor as soon as possible in order to set up a time to discuss your learning needs.

## **3. Student-Faculty Expectations Agreement**

At Georgia Tech we believe that it is important to strive for an atmosphere of mutual respect, acknowledgement, and responsibility between faculty members and the student body. See <http://www.catalog.gatech.edu/rules/22/> for an articulation of some basic expectation that you can have of us and that we have of you. In the end, simple respect for knowledge, hard work, and cordial interactions will help build the environment we seek. Therefore, we encourage you to remain committed to the ideals of Georgia Tech while in this class.

### **Interactive sessions**

These are optional sessions, but, if in attendance, the camera is required to be on. Please mute yourself in the online interactive sessions if you are not speaking. Please provide questions for the Q&A in advance on the forum and/or in the chat of the interactive sessions. Your instructors will moderate them for the benefits of the class. We strongly encourage to ask questions and participate as it greatly improves the learning experience. There is an extra credit to the final grade that will be awarded by the instructors to those who are interacting frequently during the interactive sessions and have their videos on. The one-on-one sessions in the breakout rooms are limited to 10 minutes when there are other students waiting.

### **Online Forum**

The class uses an online forum called Ed Discussion. There are a few rules to observe on the forum

- The first replies will be to conceptual questions. Debugging questions will be answered last.
- Instructors and teaching assistants do not respond to questions by email. Use Ed instead, and private posts if necessary.
- Instructors and teaching assistants do not answer debugging questions on Ed. Use the online sessions and breakout rooms for debugging.
- Questions should be conceptual in nature.
- No code should be posted in Ed public posts.
- There is an extra credit to the final grade that will be awarded by the instructors to those students who answer many questions of their peers over the course of the semester.

## **Additional Class Policies**

### **Personal Communication**

Yoda will reply only to brief email and urgent messages that are not appropriate for Ed discussion. Unfortunately, he cannot keep up with lengthy messages or multiple message exchanges related to a single question. The interactive sessions will provide the vehicles to ask as many questions as you want. Personal questions can also be addressed to course staff through private Ed posts.

### **Campus Resources for Students**

Check the [academic resources](#) at Georgia Tech, which include the library, databases, the Communication Center, Counseling Center, The Division of Student Life, or Women's Resource Center).