Teaching Constraint Programming in the SFI CRT-AI Program

Janet Choi, Barry O'Sullivan, Helmut Simonis
The SFI Centre for Research Training in AI
Insight SFI Centre for Data Analytics
School of Computer Science and Information Technology
University College Cork, Cork, Ireland

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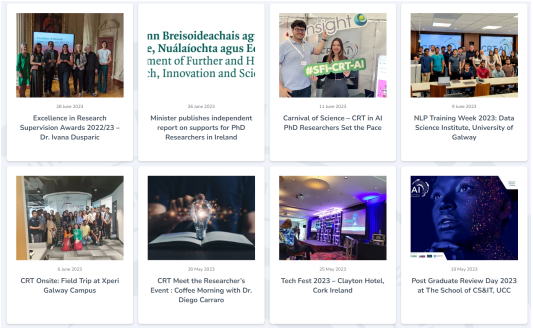
Overview

- Overview of CP training week run as part of research training program
- Run for national cohort of PhD students in AI
- Run four times so far
- Flipped structure in 2021
- 15-30 students per cohort
- Give them idea of what CP is like
- Give them some hands-on training on modelling with MiniZinc
- Raise awareness of CP at other universities

CRT-AI

- One of six national centres for research training
- Split across universities in Cork (UCC), Dublin (DCU, TC), Galway (NUIG) , Limerick (UL)
- Students travel to host universities for training weeks
- Also includes placement in industry
- https://www.crt-ai.ie/



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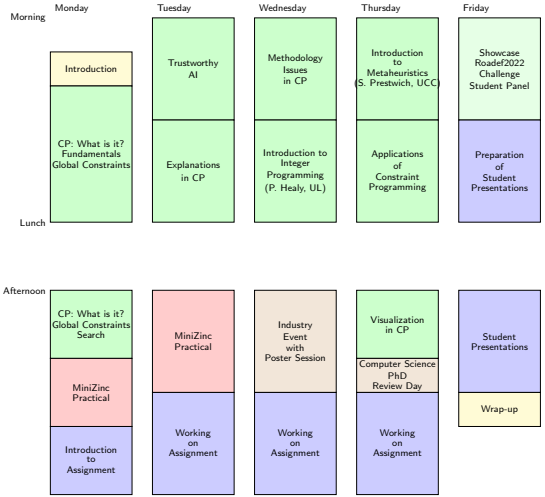
Structure of Constraint Training Week (2023 Version)



Introduction to CP

- Presentation based on ECLiPSe ELearning course
  - Only four first chapters (of 22)
  - Adapted to MiniZinc
- Core concepts
  - Variables
  - Domains
  - Constraints
  - Propagation
  - Search
  - Solution

A Subtractive Process

"Oh, bosh, as Mr. Ruskin says. Sculpture, per se, is the simplest thing in the world. All you have to do is to take a big chunk of marble and a hammer and chisel, make up your mind what you are about to create and chip off all the marble you don't want."-Paris Gaulois.

Source: https://quoteinvestigator.com/2014/06/22/chip-away/

Explaining Propagation

- Example: SEND+MORE=MONEY
- Constraints: Disequality, linear, alldifferent (forward checking)
- Describe reasoning in detail
- Explain at level of human reasoning
- Show visualization of reasoning
- Do not introduce algorithms formally

Propagation of equality (Iteration 1)

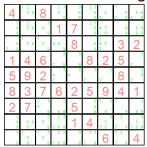
$$\underbrace{91 * E^{2..8} + 10 * R^{2..8} + D^{2..8}}_{204..728} = 90 * N^{2..8} + Y^{2..8}$$

$$N \geq 3 = \lceil \frac{204 - 8}{90} \rceil, E \leq 7 = \lfloor \frac{728 - 22}{91} \rfloor$$

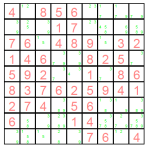
Global Constraints: Consistency Levels

- Example: Sudoku
- Constraint: Alldifferent
- Explain different consistency levels
- Show reasoning on small example
- Not enough time to describe algorithms formally

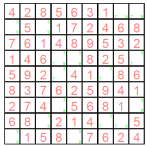
Forward Checking



Bounds Consistency

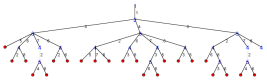


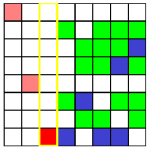
Domain Consistency



Search

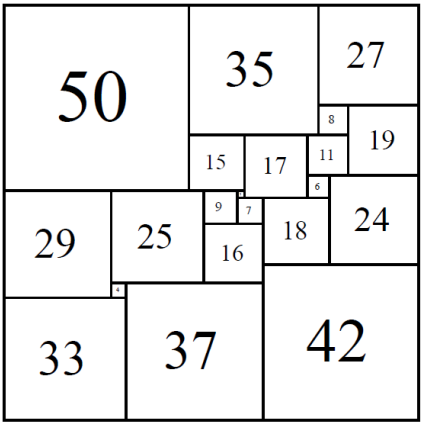
- Example: N-Queens
- Construct: solve annotations in MiniZinc
- Show effect of search strategy
- Using visualization to link tree search with state of propagation
- Show abstraction in trees to reduce complexity
- Traditional FD reasoning





Rectangle Placement as Example for Cumulative and Diffn

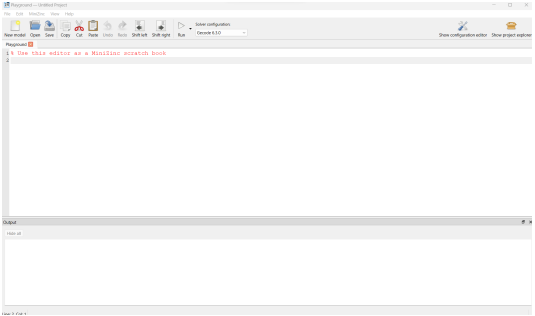
```
constraint forall (i in S)
    (x[i]+size[i]<=box);
constraint forall (i in S)
    (y[i]+size[i]<=box);
constraint diffn(x,y,size,size);
constraint cumulative(x,size,size,box);
constraint cumulative(y,size,size,box);

solve satisfy;
```



21 : 112A AJD 1978

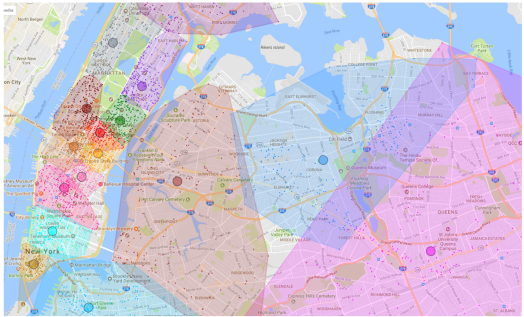
MiniZinc Language Principles and IDE

- Explain language elements of MiniZinc
- By example, not formal description
- Define core elements
  - data
  - variables
  - constraints
  - search
- Familiarize students with IDE
- Describe different back-end solvers



Applications

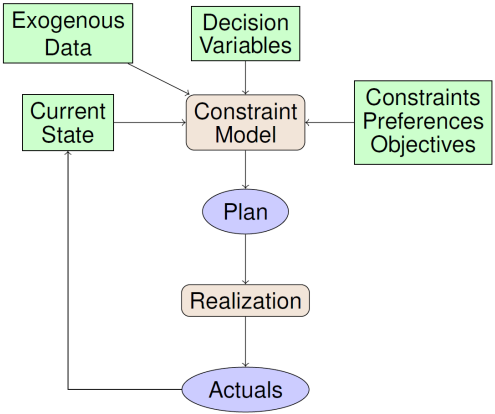
- Give examples of current/past application projects at UCC
  - Scheduling
  - Health Care Capacity Management
  - Service Planning and Scheduling
  - Constraint Acquisition
- Short descriptions of other applications using CP



Constraint-Based Clustering as Part of Service Planning

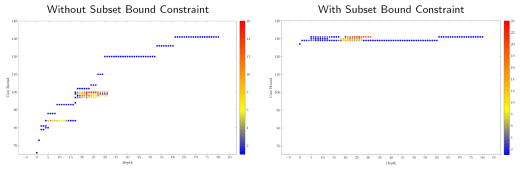
Methodology

- Describe the process of developing applications
- Focus on transferable skills for other domains
  - Requirements capture
  - Data management
  - Use case handling
  - Interaction with stakeholders



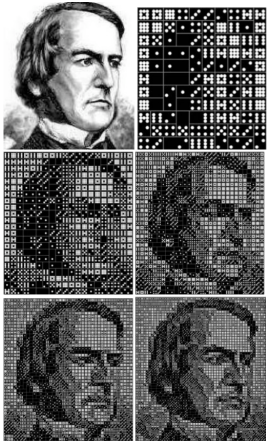
Visualization

- Based on CP 2021 tutorial with G. Tack, Monash university
- Show how solutions and solution process can be visualized
- Gap in current tool-set
- Most students have some Python based visualization skills
- Use JSON output of MiniZinc, big improvement



Other Topics

- Introduction to MIP
- Introduction to Local Search
- (Flow-based methods)
- (Multi-criteria Optimization)
- Research oriented talks
  - Trustworthy AI
  - Explanations in CP
  - Opt-Art
  - Student-led session on ROADEF Challenge 2022
- Industry Meeting
  - Company presentations
  - Poster sessions



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Programming Challenge

- Hands-on training in MiniZinc modelling
- Textual problem description
- No predefined model structure/no checker
- A different problem each year
  - 2019 Interview Assignment and Scheduling
  - 2021 Test Scheduling Problem (CSPLIB073)
  - 2022 Assembly Line Balancing (SALBP)
  - 2023 Dublin Port Berth allocation
- Evening, open-ended sessions in lab
- Estimated two weeks preparation time

Challenge 2023: Dublin Port Berth Allocation

- Multi-part description in textual form
- Some data files in MiniZinc format
- Dublin port offers REST feeds, not used
  - Real-world data too messy
  - A step too far for non-CS students
- Each day an additional element of problem is introduced
- Students work in teams, using MiniZinc
- Other tools allowed, but limited support

CRT-AI Constraint Week 2023 - Programming Challenge

Helmut Simonis

May 15th, 2023

Abstract

This document describes the problem for this year's Programming Challenge in the CRT-AI 2023 Constraint Week. The problem is a common issue for ports around the world: where do you berth (place) the ships arriving at your harbour so that they can be unloaded and loaded with minimal disruption and delay.

1 Introduction

Dublin port is the largest port in Ireland, handling 60% of the overall volume of freight arriving and departing Ireland by ship. The port handles a mix of different ship types:

1 - **RoRo** roll-on, roll-off ships carry vehicles which are driven on and off the ship. Typical examples are ferries and car carriers.

2 - **LoLo** lift-on, lift-off ships carry containers that are lifted by cranes on and off the ship.

3 - **Bulk** bulk carries transport products like ore, coal, or products like wheat, which fill the holds on the ship.

4 - **Liquid Bulk** liquid bulk carriers typically are oil tankers, which carry crude or processed oil in their holds, which can be pumped on and off the ship to special tank farms on land.

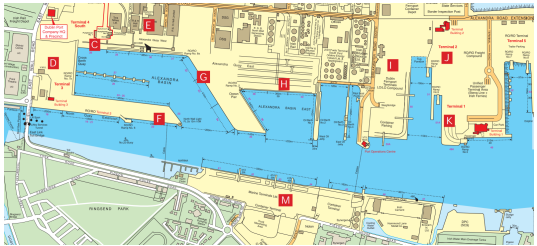
5 - **Cruise** cruise ships transport passengers only, and require special facilities for the boarding and disembarking of passengers

The overall layout of the port is shown in Figure 1, taken from the 2023 edition of https://www.dublinport.ie/about-dublin-port/yearbook/, the facilities occupy both sides of the mouth of the river Liffey.

Ships can be placed at specific locations called berths in the harbour which are defined by the type of ship that can be handled, the maximal length and depth of the ship that the berth can accommodate, and the location in the port. The numbering of the berths in Dublin port has evolved over time, with most unused numbers being further upriver. Table 1 lists the berths currently available in the harbour, we use a consecutive number to identify the berth, instead of the more irregular name given in the second column.

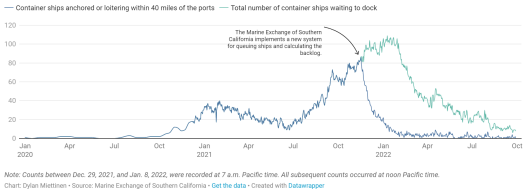
Exercise: Monday

- Constraints form an assignment problem
- Arrival/departure fixed in time
- Find feasible berth for each ship
- Find correct domain for each type of ship
- Berths have length and depth restrictions



Exercise: Tuesday

- Extension to scheduling
- If there is no room, ships are delayed outside port until berth becomes available
- Link to real-world problem: Port of Los Angeles in 2021
- Decide which ships to delay how much
- Objective: Minimize overall delay
- Fairness required
  - Understand motivation/limits
  - Find way to express constraint

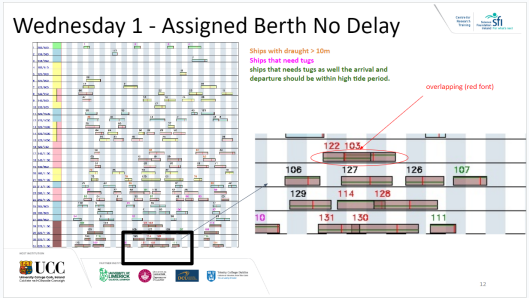


Exercise: Wednesday

- Adding time windows and cumulative resources
- Due to tides, some ships can only enter/leave harbour at high tide
- Large ships require one or two tugs
- Tugs are required before arrival and after departure
  - Introduce linked temporal variables
  - Introduce cumulative resource constraint

Student Presentation: Friday

- Evaluation is by team, not by individual
- Each team is presenting their results in a short talk
- Questions by lecturers
- Shows engagement of teams
- Some presentations far exceed expectations
- Example shown: Team RO-RO
  - Bunyarit Puangthamawathanakun (DCU), Gauri Vaidya (UL) and Cathy Roche (TCD)



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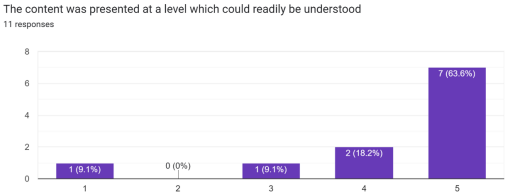
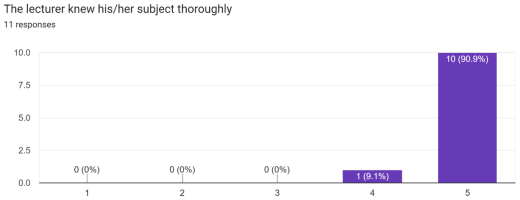
Feedback: Understandable

- Compares favourably to other training weeks
  - Interactive elements of the training
  - Link to practical example uses throughout the course
- The use of MiniZinc presents a challenge to many students.
  - Especially for students *with* previous programming experience
  - Challenge of writing a model, rather than an algorithm
- MiniZinc problems: complex syntax, limited debugging capability.



Feedback: Lecturer

- Course size allows good interaction between lecturers and students
- Lecturers are available for questions during project
- Interaction within cohort is encouraged
- Students asked for more interaction with older cohorts
  - Perhaps easier to ask "stupid" questions?



Summary

- Overview of CP course for Irish PhD students in AI
- Give an idea of CP and its uses
- Provide some hands-on training
- Delivered as an intense one-week training module
- More like a Summer School than a semester course
  - Too intense vs. enjoyable challenge