UniTime

Using UniTime to build optimised academic schedules

Tomáš Müller

June 2025

Agenda

What is UniTime

- A tool for building academic timetables/timetables
- Main component is a solver

Artificial Intelligence

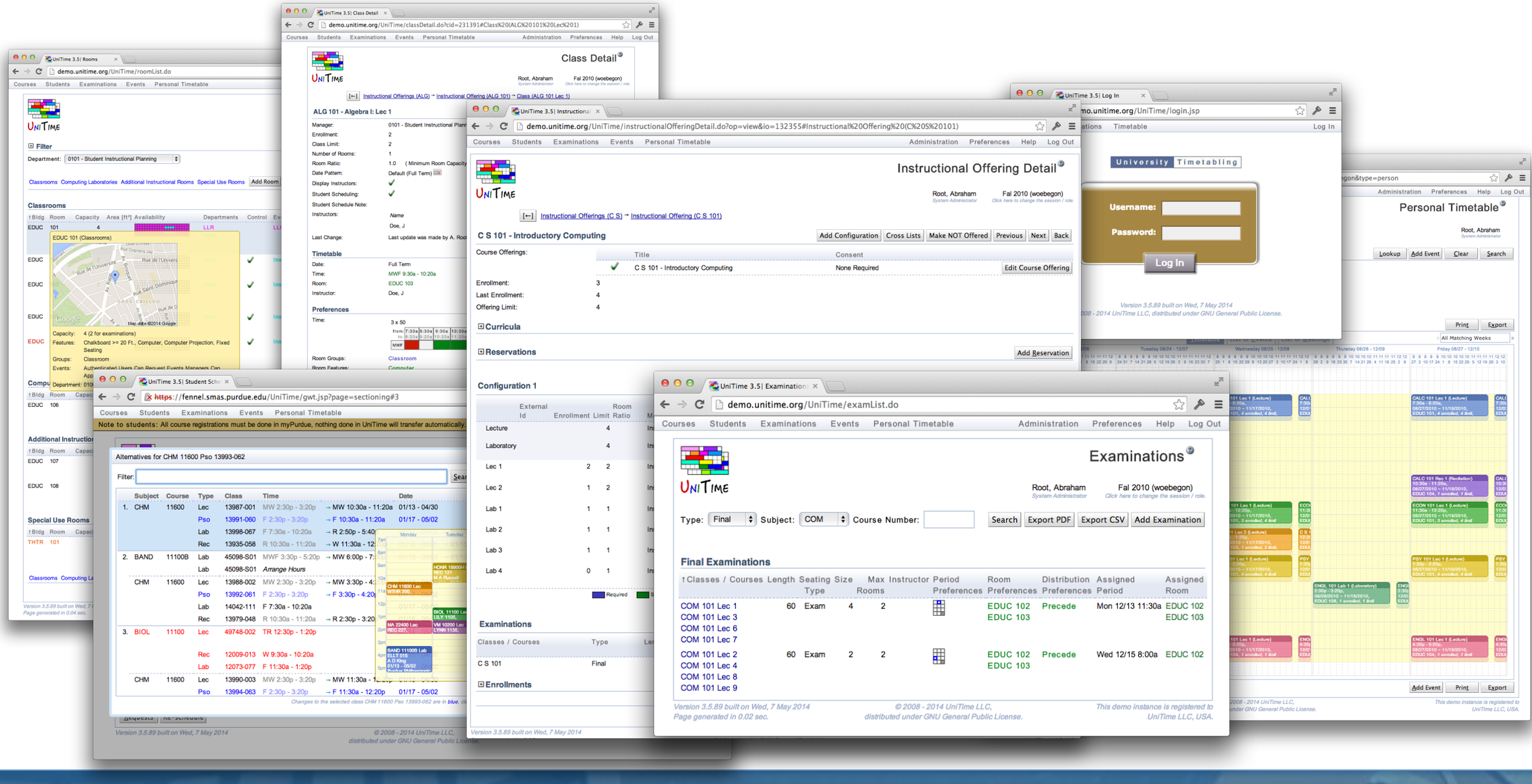
- Timetabling is a hard problem, with a lot of competing objectives
- Using a hybrid approach based on constraint programming (CP)
  - CP is a subfield of AI focusing on problem-solving

UniTime Solver

- Constraint Programming
- Algorithm basics
- A few details, pro & cons, etc.

What is UniTime?

- Comprehensive academic scheduling solution



What is UniTime?

- Comprehensive academic scheduling solution
- Five components

Courses: time & rooms
- time preferences
- room requirements
- availability
- course structure
- avoid time clashes
- student course demand
- distributions

Events: room bookings
- course-related events
- personal schedule
- approval process
- unavailabilities

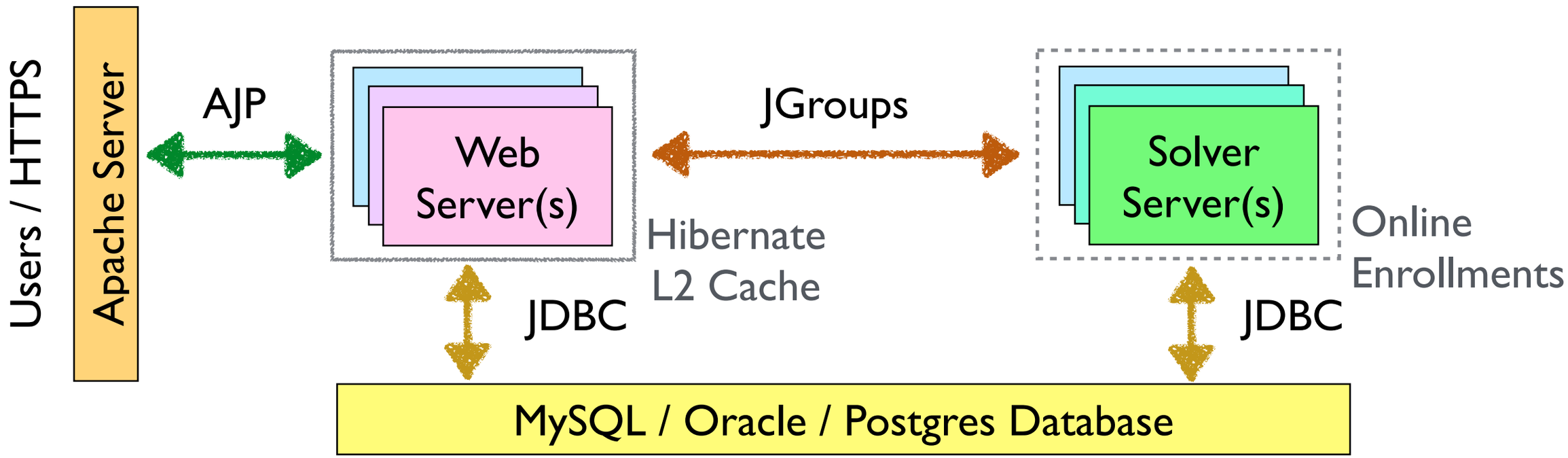
Exams: period & rooms
- minimise student conflicts
- period & room prefs
- distributions
- room sharing or splitting

Instructors: teaching assignments
- teaching load
- qualifications / skills
- preferences
- course spreading

Students: class schedule
- course requirements
- alternatives / free times
- reservations
- section balancing
- schedule quality

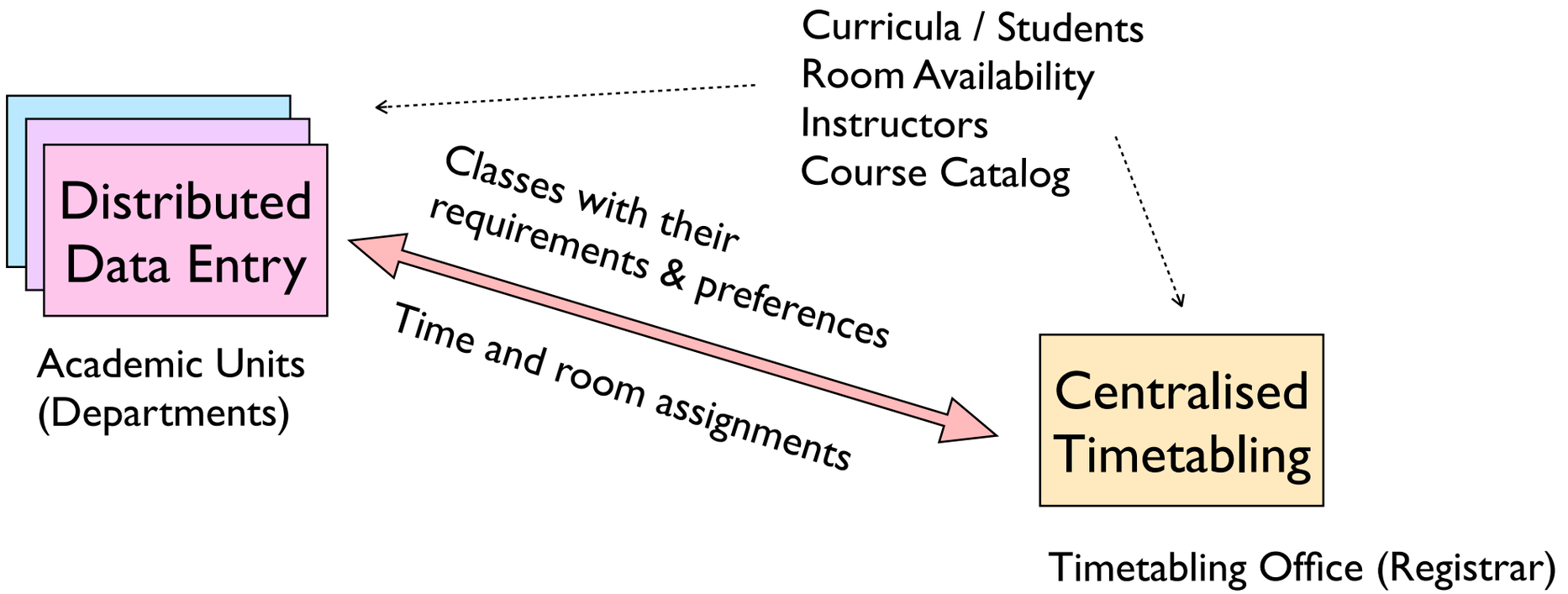
What is UniTime?

- Comprehensive academic scheduling solution
- Five components
- Open Source, web-based, written in Java using modern technologies



What is UniTime?

- Comprehensive academic scheduling solution
- Five components
- Open Source, web-based, written in Java using modern technologies
- Distributed data entry and timetabling in a multi-user environment



What is UniTime?

- Comprehensive academic scheduling solution
- Five components
- Open Source, web-based, written in Java using modern technologies
- Distributed data entry and timetabling in a multi-user environment
- Using state of the art optimisation algorithms

International Timetabling Competition 2019

ITC 2019
- course timetabling with students
- 3 sets of problems (10 each)
- 600+ registrations
- 20+ solvers
- 20+ publications

https://www.itc2019.org

Constraint Programming

Constraint Satisfaction Problem Θ = (V, D, C)

- V = $\{v_1, v_2, \ldots, v_n\}$ is a finite set of variables
- D= $\{Dv_1, Dv_2, \ldots, Dv_n\}$ is a set of domains
  - Domain is a finite set of values
- C = $\{c_1, c_2, \ldots, c_m\}$ is a set of constraints
  - A constraint limits the combination of values that can variables simultaneously take
- Solution is an assignment of all variables $\eta: V \rightarrow D$
  - That satisfy all the constraints from C

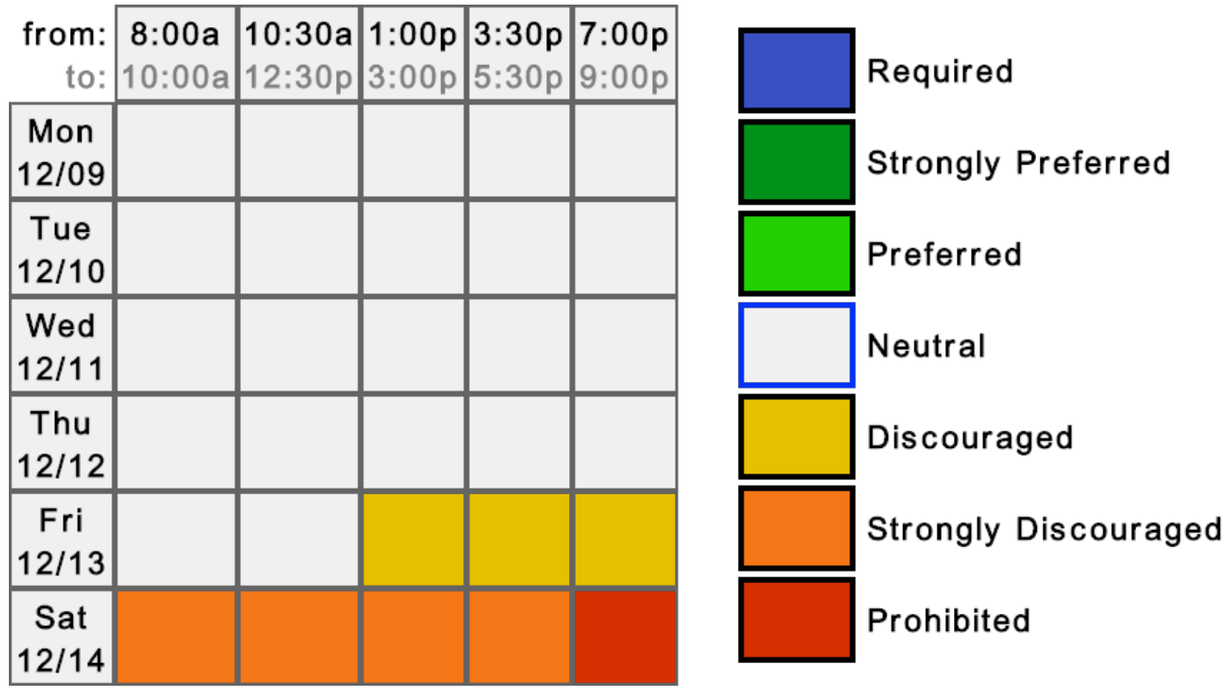
Optimisation Problem Θ' = (V, D, C, *f*)

- *f* is an objective function
  - That maps every partial feasible assignment to a number
  - Usually expressed by *soft* constraints and penalties

Examinations Example

Example: Examination Timetabling

- Variables: individual examinations
- Domains: period and room for each exam
- Hard Constraints:
  - Examination size ≤ room capacity
  - Period and room requirements
  - No two exams in the same room at the same period
  - No student taking two exams during the same period
  - …
- Soft constraints:
  - Period and room preferences
  - Back-to-backs
  - Not more than 2 exams on a day
  - Large exams first
  - …



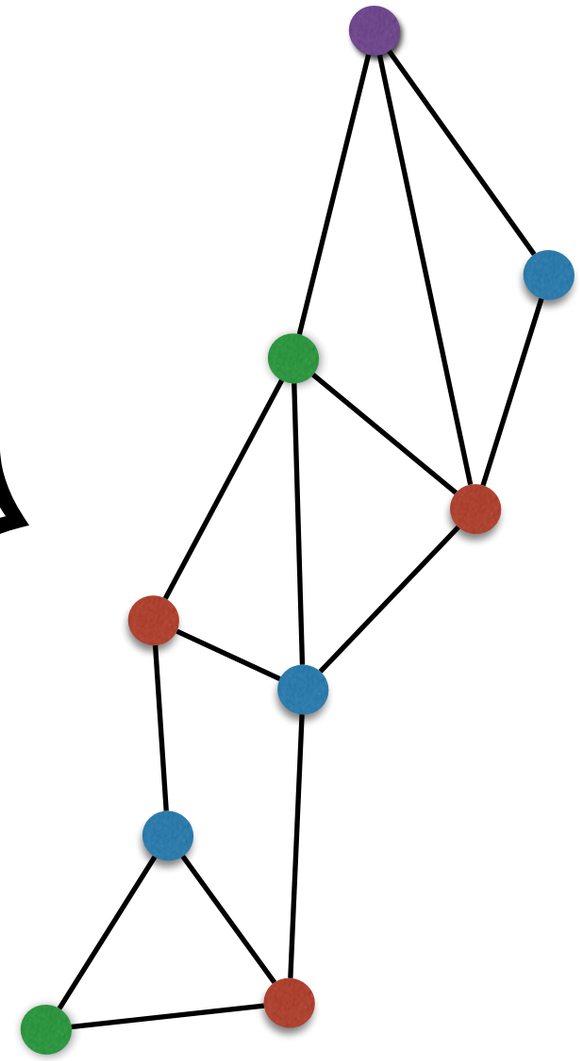
UniTime

Timetabling is hard

Example: Examination Timetabling

- Variables: individual examinations
- Domains: period and room for each exam
- Hard Constraints:
  - Examination size ≤ room capacity
  - Period and room requirements
  - No two exams in the same room at the same period
  - **No student taking two exams during the same period**
  - …
- Soft constraints:
  - Period and room preferences
  - Back-to-backs
  - Not more than 2 exams on a day
  - Large exams first
  - …

⇛

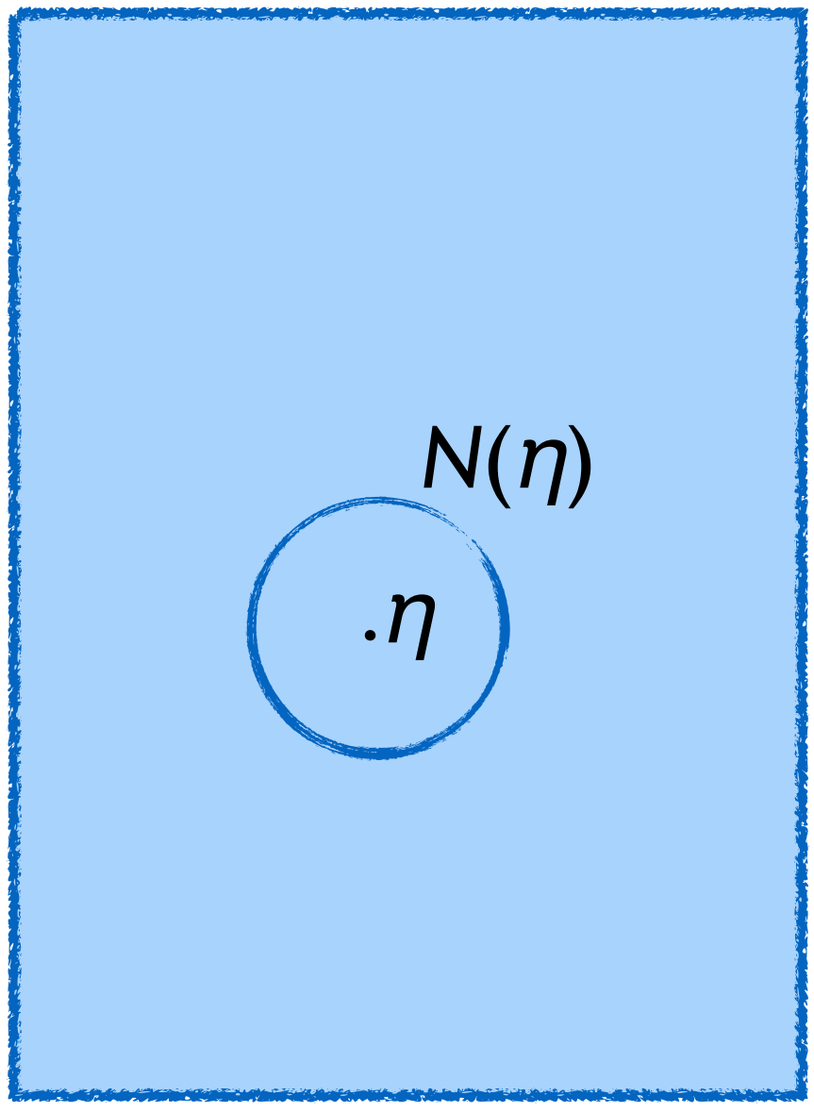


Graph colouring

Exams: vertices
Students: edges
Colours: periods

Local Search

Search Space



In each iteration

- Generate a candidate solution $y \in N(x)$
- Evaluate a solution
  - Discard when conflicting
  - When accepted assign $x = y$
- Check if termination conditions are met

Neighbours

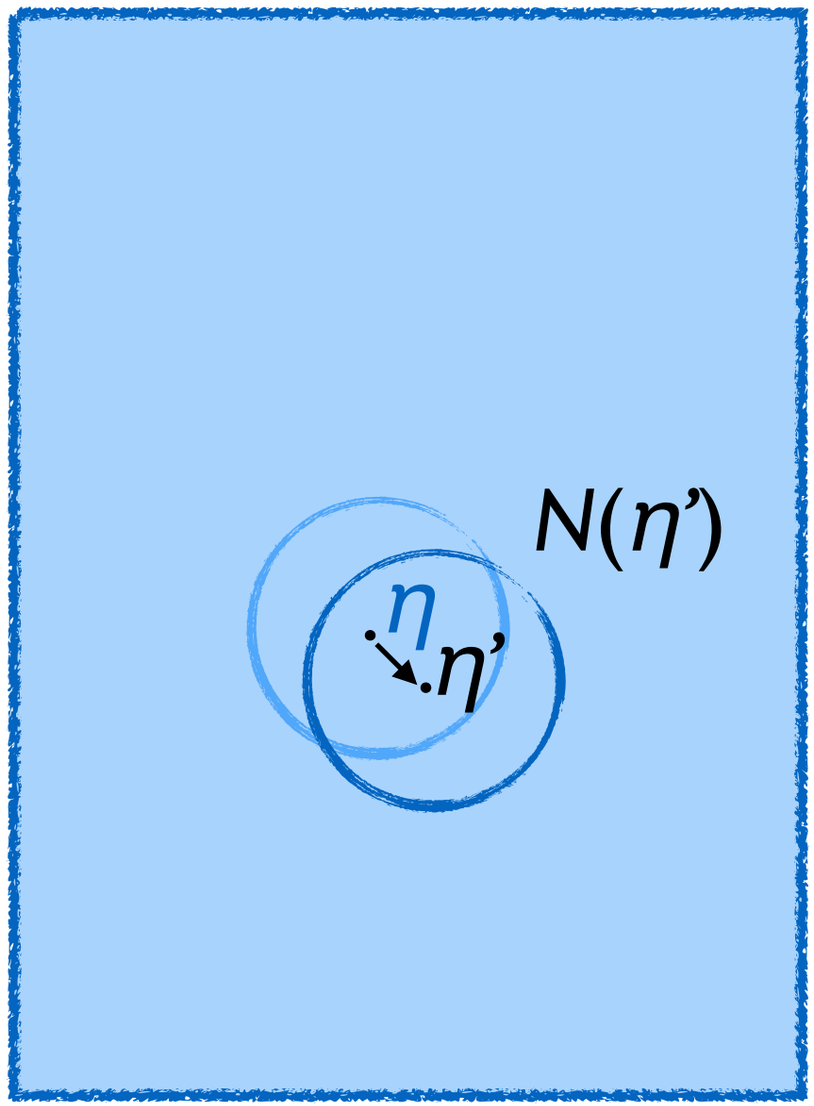
- Swap period/room
- Swap exams
- Assign exam, resolve/unassign conflicts
- Limited-depth search
- Kempe chain, MIP, …

Acceptance criteria

- Hill Climbing $F(y) \leq F(x)$
- Simulated Annealing $P(\text{accept}) = e^{-\Delta E/T}$
- Great Deluge $F(y) \leq Bound$

Local Search

Search Space



In each iteration

- Generate a candidate solution $y \in N(x)$
- Evaluate a solution
  - Discard when conflicting
  - When accepted assign $x = y$
- Check if termination conditions are met

Neighbours

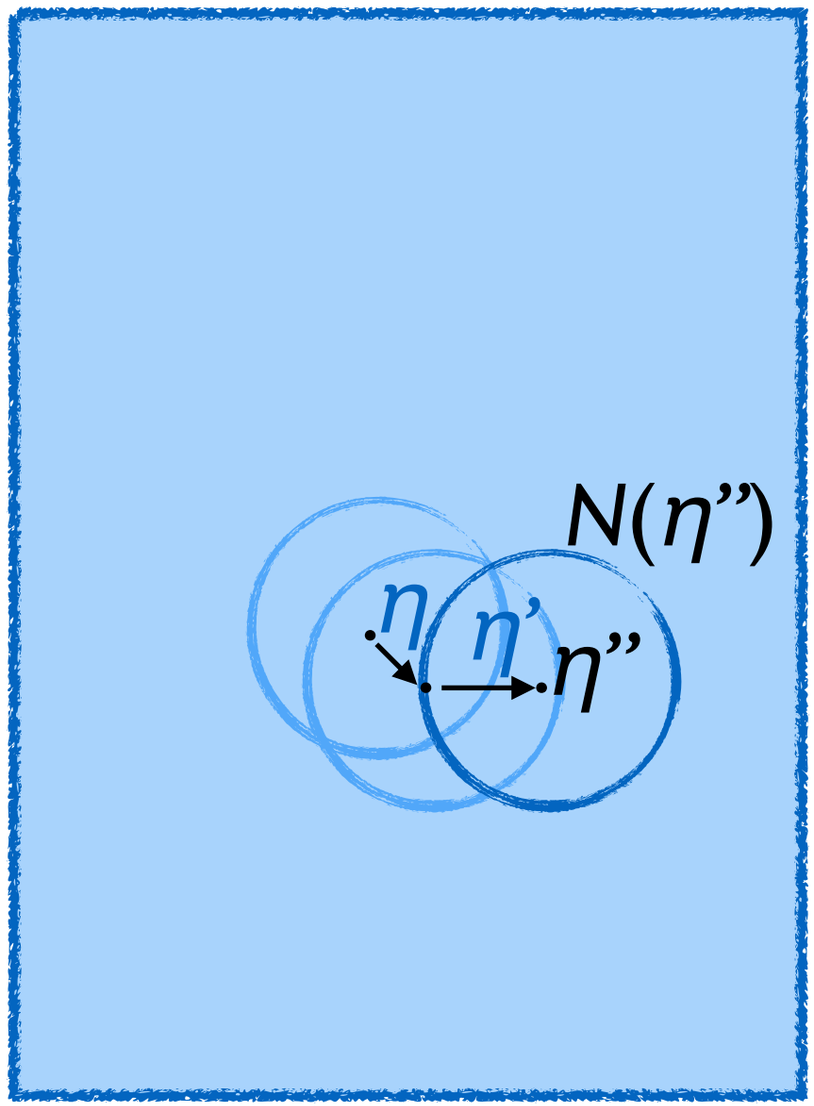
- Swap period/room
- Swap exams
- Assign exam, resolve/unassign conflicts
- Limited-depth search
- Kempe chain, MIP, …

Acceptance criteria

- Hill Climbing $F(y) \leq F(x)$
- Simulated Annealing $P(\text{accept}) = e^{-\Delta E/T}$
- Great Deluge $F(y) \leq Bound$

Local Search

Search Space



In each iteration

- Generate a candidate solution $y \in N(x)$
- Evaluate a solution
  - Discard when conflicting
  - When accepted assign $x = y$
- Check if termination conditions are met

Neighbours

- Swap period/room
- Swap exams
- Assign exam, resolve/unassign conflicts
- Limited-depth search
- Kempe chain, MIP, …

Acceptance criteria

- Hill Climbing $F(y) \leq F(x)$
- Simulated Annealing $P(\text{accept}) = e^{-\Delta E/T}$
- Great Deluge $F(y) \leq \textit{Bound}$

UniTime

Solver Framework

Problems

- Course Timetabling
- Examination Timetabling
- Instructor Scheduling
- Student Scheduling

Constraint-based Model

- Variables
- Values
- Constraints
- Criteria

Solver

Configuration

- Parameters

Algorithms

- IFS
- HC
- SA
- GD

Neighbourhoods

- General
- Problem Specific

UniTime Solver

Construction Phase

- Incomplete but feasible
- Pick an unassigned variable
- Find the best assignment
  - Unassign conflicts
- Conflict statistics
  - To prevent cycling
  - Provides feedback when over-constrained

Improvement Phase

- Complete and feasible
- Random selection of a candidate change
- Various acceptance criteria
  - HC, SA or GD
- Reheating
- Parameter adjustments
- Until time runs out

$$A \neq a \Leftarrow \begin{cases} 3 \times B = a \\ 4 \times B = c \\ 2 \times C = a \\ 120 \times D = a \end{cases}$$

Pros and Cons

Pros

- Usually very fast and scalable (compared to other methods)
- Flexible
  - Easy to extend
  - Exceptions are fairly easy to model
- Can start from an existing solution
  - Distance from previous solution can be also minimised
  - Can be used to provide suggestions *(interactive timetabling)*

Cons

- Cannot guarantee optimality
- Small changes can have large consequences
- Large changes may be expensive to make
- Often requires implementation of the model and at least a few problem specific heuristics/neighbourhoods

Other Approaches

Mixed Integer Programming *(Operations Research)*

- Using boolean or integer variables
- All constraints must be linear
- Existing (commercial) solvers that are getting very good
- Can guarantee optimality or provide upper bounds
- Heuristic approaches needed for large problems
  - Large neighbourhood search, fix & optimise, ruin & recreate

Comparison

- The first two places at ITC 2019 were using MIP solvers
  - Both using some version of fix & optimise
- Problem had to be segmented into smaller sub-problems
- The winner solver can provide better results than UniTime
  - But require lots of time and computational resources
- See ITC2019.org for more details

Conclusion

Thank you!

See www.unitime.org for more details about UniTime!

An online demo is available at https://demo.unitime.org