University Course Timetabling and International Timetabling Competition 2019

Tomáš Müller[1], Hana Rudová[2], Zuzana Müllerová[3]

[1] Purdue University, USA
[2] Masaryk University, Czech Republic
[3] UniTime, s.r.o., Czech Republic

This presentation: `http://www.itc2019.org/papers/patat18-slides.pdf`

ITC 2019: `http://www.itc2019.org`

What should you expect from this plenary talk?

Characteristics of existing competitions

- course timetabling
- educational timetabling
- others

Timetabling in practice

- UniTime system & ITC 2019
- timetabling problems at
  - ITC 2019
  - Masaryk University
  - Purdue University

International Timetabling Competition ITC 2019

- overview and organization

ITC 2002: first course timetabling competition

- Events
  - to be scheduled in 5 days each having 9 hours
- Rooms
  - features to be required
  - size must not be exceeded
- Students in events cannot have any overlap
  - enrollment-based timetabling
- Three types of soft constraints on compactness for students

ITC 2002: organization

- Organized by:
  - Metaheuristics Network, PATAT
  - Ben Paechter et al.

- Data instances generated by computer
- Feasible solutions required
- Optimal solutions with no soft constraint violation exist
- Early, late and hidden data instances

- Finalists demonstrated their programs to organizers
- Single processor machine
- Short limited time (300-500 s)

- 13 teams

ITC 2007: competition with three tracks

international
TIMETABLING COMPETITION

Tracks:

- examination timetabling
- post enrolment based course timetabling
- curriculum based course timetabling

Organization:

- early, late, hidden data sets
- executables tested by organizers
- single processor
- short limited time: 300-500 s
- infeasible solutions accepted: distance to feasibility
- 5 finalists per track

ITC 2007: examination timetabling

- 1996: Carter et al. examination data set
  - 13 real-world problems
  - various modifications
  - studied by many researchers
  - simplified problem

- *Qu, Burke, McCollum, Merlot, Lee (2009), A survey of search methodologies and automated system development for examination timetabling. Journal of Scheduling*

- ITC 2007
  - real-world aspect emphasized

    data, constraints, evaluation

ITC 2007: post enrollment course timetabling

- Extension of ITC 2002 problem
- Same: hard and soft constraints kept
- Two new hard constraints
  - hard constraints not easy to satisfy
  - not assigned events
- Still rather distant to real-world
  - generated instances
  - optimal solution with no soft constraint violation exist

ITC 2007: curriculum-based timetabling

- Curriculum: group of courses with same students
- Real-world instances: University of Udine
  - slightly simplified with respect to the real problem
- Very rich research area
  - high level of support given by organizers
    Bonutti, De Cesco, Di Gaspero, Schaerf (2012), Benchmarking curriculum-based course timetabling: formulations, data formats, instances, validation, visualization, and results. Annals of Operations Research
  - *Bettinelli, Cacchiani, Roberti, Toth (2015), An overview of curriculum-based course timetabling. TOP*
- Data sets with updated results still maintained
  - `http://tabu.diegm.uniud.it/ctt/`
  - extended problem formulation, new data sets
  - latest results in 2017
  - 17 out of 21 competition problems now solved to optimality!

ITC 2011: high school timetabling

- Class as a group of students taking same courses
- Real-world instances
  - the largest with 2,675 students and 80 rooms
  - about 3/4 instances solved to optimality!
- XHSTT: XML standard for data instances
  - *Post, Kigston et al. (2014), XHSTT: an XML archive for high school timetabling problems in different countries. Annals of Operations research*
- Data sets with updated results still maintained
  - `https://www.utwente.nl/en/eemcs/dmmp/hstt/`
- Resulting in high interest in high school timebling
- 17 participants
- Three rounds
  1. order by the best submitted solutions for published instances
  2. order based on hidden instances in given time (1,000 seconds)
  3. order by the best submitted solutions for all instances including hidden

Nurse rostering competitions

Rich research area

- 2005-6: benchmark problems `http://www.cs.nott.ac.uk/~tec/NRP/`
- *Burke, De Causmaecker, Berghe et al. (2004), Journal of Scheduling 7(6):441–499*

Supported by PATAT

- traditional
  - early, late, hidden data
  - limited time, executables tested by organizers

The first INRC in 2010

- problems of different size allowed
  - sprint track for interactive use
  - middle distance track allowed a few minutes
  - long distance track for overnight solving

The second INRC-II in 2014 – 2016

- multi-stage problem formulation for consecutive weeks

Competitions from related areas

Cross-domain Heuristic Search Challenge 2011 supported by PATAT

- design search algorithm working across different problem domains

ICAPS conference competitions

- international planning competitions from 1998

MiniZinc Challenge related to CP conference

- competitions of constraint programming solvers on a variety of benchmarks
- from 2008

GECCO conference competitions

- several competitions each year

ROADEF Challenge

- French Operational Research and Decision Support Society
- from 1999
- 2018: cutting optimization problem
- 2016: inventory routing problem
- 2014: arrival and departure times for trains

Importance of competitions

Benchmark data sets

- move toward real-world problems and data sets

Web site maintaining results

- curriculum-based timetabling

  `http://tabu.diegm.uniud.it/ctt/`

- high-school timetabling

  `https://www.utwente.nl/en/eemcs/dmmp/hstt/`

- ITC 2019

  `https://www.itc2019.org`

⇒ Easy comparison of approches

- many works, many citations

Complex educational scheduling system

- open-source, commercial support
- course and examination timetabling, student scheduling, event management
- research from 2001
- in practice from 2005

  in production at 63 institutions based on voluntary registrations

  290 registrations from 84 countries

ITC 2019 data from UniTime

- Purdue University, Masaryk University, AGH University of Science and Technology, Lahore University of Management Sciences, İstanbul Kültür University, Bethlehem University, Universidad Yachay Tech, Turkish-German University, University of Nairobi, Maryville University, University of Adelaide

Outline: timetabling problems

- Faculty of Informatics, Masaryk University
  - base problem using student pre-enrollments
- ITC 2019
  - generalized problem
- Faculty of Education, Masaryk University
  - lots of dual major programs with complex curricula
- Faculty of Sport Studies, Masaryk University
  - travel distances, lifelong studies with work
- Purdue University, USA
  - last-like course remands, complex course structure, rich time patterns

- *Rudová, Müller, Murray (2011), Complex university course timetabling, Journal of Scheduling, 14(2), 187–207*
- *Müller, Rudová (2016), Real-life Curriculum-based Timetabling with Elective Courses and Course Sections. Annals of Operations Research, 239(1):153-170*

Faculty of Informatics: base characteristics

Times

- week: 5 days, 12 timeslots a day
- timetable for one week: full semester, even/odd weeks

Rooms

- up to 20+23 rooms with capacities from 15 to 248 seats
- standard rooms, computer labs

Students

- up to 1,890 students with 12,668 course demands

Courses

- up to 220 courses split to 596 classes
- class = event such as seminar or lecture
  - once a week, avg. duration 2 timeslot
- course = (1 lecture) or (N seminars) or (1 lecture + N seminars)

Feasible solution

Hard distribution constraints among set of classes

- `NotOverlap`, `SameRoom`

  same teacher (`SameAttendees` in ITC 2019)

For each class assign

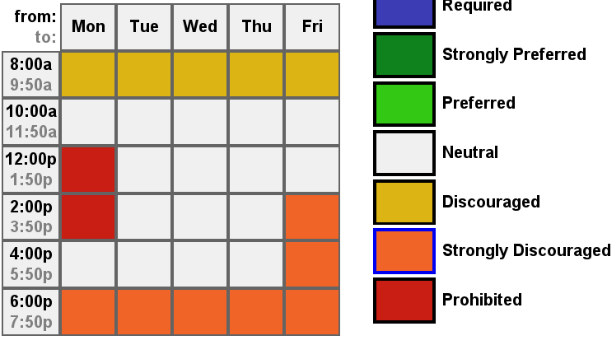
- starting time
- room
- set of students

Solution generation in UniTime

1. initial student sectioning
   - constructive approach clustering similar students together
2. assign time and room for all classes
   - Iterative Forward Search
3. final student sectioning
   - Local Search

Time penalization

1 x 100



Room penalization

- same scale
- buildings, rooms, features
- ITC 2019: penalty value for each domain value

Optimization II.

Student conflicts

- minimize the number of student conflicts

$$\sum_{\forall class1, class2:\ overlap(class1, class2)} SameStudents(class1, class2)$$

- $overlap(class1, class2)$
  - overlapping in time
  - + rooms too far given the gap between classes

- students for each class generated from
  - student course demands (pre-enrollments)
  - curricula: compulsory, elective and optional courses

Distribution penalization

- soft distribution constraints
- for a pair of classes: penalization for every pair in a violation
  - maximal penalty for N classes: $\texttt{penalty} \times N \times (N-1)/2$

Fall 2018: first published timetable on August 20

Rooms	20+23*
Courses	220
Classes	596
Students	1,890
Student course demans	12,668◇
Student conflicts	8.2 %
Time penalization	72.3 %
Room penalization	84.24 %
Distribution penalization	84.16 %

*3 large, 11 standard, 6 computer, 23 special purpose

◇including 14 students with 15-19 course demands, 0 students $\geq$ 20 course demands

Overview of ITC 2019 problem: generalized problem

- Schedule times and rooms for classes
  - eligible domain values and their penalties
- Time overlaps
  - consider: start and end timeslot & days of week & weeks in semester
- Rooms
  - conflicts in a room prohibited
  - unavailable times
- Distribution constraints among classes
  - hard & soft with penalties for violations
- Student course demands
  - course structure defines how to section students into classes of a course
- Classes with hard capacity limits
- Soft student conflicts for overlapping classes
- Travel times
  - conflicts for students and `SameAttendees` distribution constraint

Faculty of Education: curriculum-based timetabling

Problem in Fall 2011: first used in practice

- 7,500 students
- 260 curricula

  mostly two different majors combined

Complex curricula

- compulsory, elective and optional courses
- alternatives in the course structures, e.g. multiple seminars
- courses shared in multiple curricula

Curricula for each year

- target share for each pair of courses

  = number of students attending both
- ALG, CAL: 1.0 ENGL, SPAN: 0.0

  ENGL, CHM: 0.6×0.2 ... 12 %

Required	ALG 101	100.0%
Required	CALC 101	100.0%
Elective	ENGL 101	60.0%
Elective	SPAN 101	40.0%
	BIOL 101	10.0%
	CHM 101	20.0%

Curriculum → enrollments

Student generation

- transform curricula into course demands respecting target shares
- assign students to courses with the desired number of students
- minimize the difference between

    target share and actual share

        for all pairs of courses

Approach

1. construction phase: adding students to courses
2. Great Deluge phase: swapping students

Müller, Rudová (2016), Real-life Curriculum-based Timetabling with Elective Courses and Course Sections. Annals of Operations Research, 239(1):153-170

ITC 2019 with enrollment-based timetabling includes curricula

- curricula already transformed into course demands

Faculty of Sport Studies: traveling & lifelong study

Problem in Fall 2012: first used in practice

- 1,450 students
- 25 curricula

Travel distances

- travel time between each pair of rooms
- ITC 2019: in timeslots
- significant impact on student conflicts

Lifelong study

- teaching on Fridays only
- courses not taught each week

⇒ different timetable each week

- need more complex implementation of distribution constraints
  - `DifferentDays`, `SameWeeks`, ...

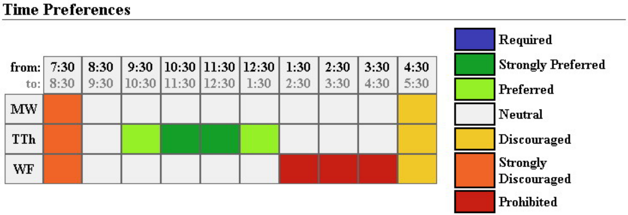
Purdue University

- In practice from 2005
- 40,000 students, 9,000 classes, 700 rooms
- ITC 2019 test problem
  - from Fall 2007
  - original published at Journal of Scheduling
  - 6 schools, large lectures, computer labs
  - 29,514 students, 2,418 classes, 207 rooms
- Decentralized timetabling
- Complex course structure
- Multiple meetings for class a week

Rudová, Müller, Murray (2011), Complex university course timetabling, Journal of Scheduling, 14(2), 187–207

Course vs. class vs. meeting

- Class meets once a week
  - Monday 10:00 – 12:00
- Class meets several times a week
  at same time & same room
  - Tuesday, Thursday 9:00 – 10:30
  - Monday, Wednesday, Friday 9:00 – 10:00
- Possible domain values
  - MW, WF, TTh



Course structure

	Demand	Mins Per Week	Limit	Manager	Date Pattern	Time Pattern	Preferences: Time	Preferences: Room	Preferences: Distribution	Instructor
M E 263 M E 263H	98		96							
Lecture		150	96	LLR	Full Term	3 x 50 2 x 75		**WTHR** **Computer**		
Recitation		100	96	M E	Full Term	2 x 50		**ME 120** **ME 236** **Classroom**		
Laboratory		50	84-120	LAB	Even Wks	1 x 50		**Windows XP**		
Lec 1		150	96	LLR	Full Term	3 x 50 2 x 75		**WTHR** **Computer**		**J. Smith** C. Bing
Rec 1		100	48	M E	Full Term	2 x 50		**ME 120** **ME 236** **Classroom**	**Back-To-Back** **M E 263 Rec 1** **M E 263 Rec 2**	**J. Novak**
Lab 1		50	14-20	LAB	Even Wks	1 x 50		**Windows XP**		
Lab 2		50	14-20	LAB	Even Wks	1 x 50		**Windows XP**		
Lab 3		50	14-20	LAB	Even Wks	1 x 50		**Windows XP**		
Rec 2		100	48	M E	Full Term	2 x 50		**ME 120** **ME 236** **Classroom**	**Back-To-Back** **M E 263 Rec 1** **M E 263 Rec 2**	**J. Novak**
Lab 4		50	14-20	LAB	Odd Wks	1 x 50		**Windows XP**		
Lab 5		50	14-20	LAB	Odd Wks	1 x 50		**Windows XP**		
Lab 6		50	14-20	LAB	Odd Wks	1 x 50		**Mac Os X**		

Course structure at ITC 2019

- Configuration
  - different teaching styles for course
  - example: for base and practice form of study
- Subpart
  - parent-child relationship and related constraints
  - example: lecture, seminar, laboratory
- Class
  - timetabling at this level
  - example: ME 263 Lec1

Course	Introduction to Mech. Eng. ME 263					
Configuration	Base study study			Practice study		
Subpart	Lecture			Lecture		
Parent		Recitation			Recitation	
Child					Laboratory	
Class	Lec1			Lec3		
Parent		Rec1	Rec2		Rec5	Rec6
Child					Lab1	Lab2
	Lec2			Lec4		
		Rec3	Rec4		Rec7	Rec8
					Lab3	Lab4

Course structure at ITC 2019

Relations between classes

- already in distribution constraints
- `NotOverlap` among classes of one subpart
- `SameAttendees` between parent-child classes

Each student must be

- in one configuration
- in one class of each subpart of the selected configuration
- in one parent class for each parent-child relationship

Course	Introduction to Mech. Eng. ME 263					
Configuration	Base study study			Practice study		
Subpart	Lecture			Lecture		
Parent		Recitation			Recitation	
Child					Laboratory	
Class	Lec1			Lec3		
Parent		Rec1	Rec2		Rec5	Rec6
Child					Lab1	Lab2
	Lec2			Lec4		
		Rec3	Rec4		Rec7	Rec8
					Lab3	Lab4

Timetabling process

- Centralized timetabling
  - one schedule manager works on the problem
  - Faculty of Informatics, Faculty of Sport Studies, Masaryk University
    cca 2,000 students
- Centralized timetabling with decentralized input
  - data entry by several departmental schedule managers
  - one timetable generated
  - Faculty of Education, Faculty of Arts, Masaryk University,
    +5,000 students
- Decentralized timetabling
  - solving timetabling problems on top of existing timetables
  - example: large lecture rooms first, other problems next
    ITC 2019: computer science on top of fixed large lecture room classes
  - Purdue University, 40,000 students

ITC 2019: characteristics of data instances

- Problem size
  - one faculty: 500 classes, 2,000 students, and 50 rooms
  - large part of university: 2,500 classes, 32,000 students, or 200 rooms
- Room utilization possibly high in some rooms, e.g. large rooms
- Student course demands
  - pre-enrollments or last year's enrollments: lots of conflicts
  - curricula: base or diverse
  - no demands but constraints `SameAttendees` or `NotOverlap`
- Course structure: simple or complex
- Times
  - classes once a week or several times
  - use of the weeks: all, first/second semester half, even/odd weeks
  - lifelong study: irregular timetable each week (Fridays, Saturdays)
- Travel times: one building vs. campus
- Distribution constraints: different sets and amounts

Changes to real-life problems

- removed some less important aspects, computational complexity kept

ITC 2019 distribution constraints: 19 types

Constraint	Opposite	Pairs
`SameStart`		$\surd$
`SameTime`	`DifferentTime`	$\surd$
`SameDays`	`DifferentDays`	$\surd$
`SameWeeks`	`DifferentWeeks`	$\surd$
`SameRoom`	`DifferentRoom`	$\surd$
`Overlap`	`NotOverlap`	$\surd$
`SameAttendees`		$\surd$
`Precedence`		$\surd$
`WorkDay(S)`		$\surd$
`MinGap(G)`		$\surd$
`MaxDays(D)`		days over `D`
`MaxDayLoad(S)`		timeslots over `S`
`MaxBreaks(R,S)`		breaks over `R`
`MaxBlock(M,S)`		blocks over `M`

ITC 2019 distribution constraints: base ideas

- `WorkDay(S)`
  - classes not more than `S` timeslots between start and end a day
- `MinGap(G)`
  - classes at least `G` timeslots apart
- `MaxDays(D)`
  - classes cannot spread more than `D` days a week
- `MaxDayLoad(S)`
  - not more than `S` timeslots for classes a day
- `MaxBreaks(R,S)`
  - maximally `R` breaks a day (break has more than `S` timeslots)
- `MaxBlocks(M,S)`
  - maximal block length in `M` timeslots
    (break between two blocks has more than `S` timeslots)

ITC 2019: International Timetabling Competition

https://www.itc2019.org

Rich real-world data set with diverse characteristics

- collected in UniTime from all continents (except Antarctica)

Support from PATAT and EURO WG on Automated Timetabling

- three free PATAT 2020 registrations
- 1000/500/250 EUR for the 1st, 2nd and 3rd place
- two times during the competition: 300/200/100 EUR to the three best competitors at this point (to publish quality of best solutions)
- special track at PATAT 2020

Sponsors

ITC 2019 organization

- Three groups of data instances released subsequently
  - early, middle, late
  - a feasible solution exists for each instance
  - XML format published at PATAT 2018
- Web service validator
  - based on UniTime solver
  - computing penalty of the solution = weighted function student conflicts, time & room & distribution penalty
  - valid solutions (only feasible!) can be submitted to the website
- Consequence
  - no time limit
  - any number of cores or machines
  - commercial solvers allowed
- Website maintained after the competition

Rules and ordering

- Competition rules published at the website
- Ordering based on points in the F1 championship
  - instances released later with a much higher number of points

	Instance		
Position	Early	Middle	Late
1st	10	15	25
2nd	7	11	18
3rd	5	8	15
4th	3	6	12
5th	2	4	10
6th	1	3	8
7th		2	6
8th		1	4
9th			2
10th			1

ITC 2019 timeline

1. August, 2018: announce at PATAT 2018 with sample data sets
   - 6 test instances including large Purdue sets
2. November 15, 2018: publish the first group of data – early
3. February 1, 2019: first deadline for results of early instances
4. June 1, 2019: second deadline for results of early instances
5. September 18, 2019: publish the second group of data – middle
6. November 8, 2019: publish the third group of data – late
7. November 18, 2019: end of competition
8. January 15, 2020: finalists published
9. February-March, 2020: submissions to PATAT 2020 Special Track
10. August, 2020: publications and winners at PATAT 2020
11. Fall, 2020: submissions to PATAT 2020 journal special issue

https://www.itc2019.org