

# Rapid Development of University Course Timetables

Hana Rudová\*    Tomáš Müller<sup>o</sup>

\*Faculty of Informatics, Masaryk University  
Brno, Czech Republic  
hanka@fi.muni.cz

<sup>o</sup>Purdue University  
West Lafayette, USA  
muller@unitime.org

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## Complex university timetabling system

- course timetabling
- examination timetabling
- event timetabling
- student scheduling
  - under development

## Primary development for Purdue University

- applied since 2005
- decentralized coordinated timetabling for 40,000 students

## Applied and extended for other institutions: Masaryk University

- Faculty of Arts: 10,800 students, 1,570 courses, 49 rooms
  - generated timetables published 8 weeks after the first meeting with schedule manager
- Faculty of Education: 10,000 students, 2 timetabling problems

# Model of Timetabling Problem in UniTime

## Course structure

- course = set of **classes**
- students can be **split between some classes**
  - example: groups for seminars
- students can **visit several classes** a week
  - example: several lectures a week

	Demand	Mins Per Week	Limit	Manager	Date Pattern	Time Pattern	Preferences			Instructor
							Time	Room	Distribution	
<b>M E 263</b>		98	96							
M E 263H										
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		

# Model of Timetabling Problem in UniTime

## Constraint satisfaction problem

- domain variable = class
- domain of class = possible placements in timetable
- hard constraints
  - requirements on time and room placement of class
  - resource constraints: room, teacher
  - requirements on placement of groups of classes

# Model of Timetabling Problem in UniTime

Soft constraints = weighted constraints = optimization criteria

- preferences on time and room placement of classes
- preferences on placement of groups of classes
- classes of one student should not overlap
  - enrollment-based timetabling
  - student conflicts minimization

1h

	from: to:	7:00a 7:45a	7:55a 8:40a	8:50a 9:35a	9:45a 10:30a	10:40a 11:25a	11:35a 12:20p	12:30p 1:15p	1:25p 2:10p	2:20p 3:05p	3:15p 4:00p	4:10p 4:55p	5:05p 5:50p	6:00p 6:45p	6:55p 7:40p
Mon		Strongly Discouraged												Discouraged	Strongly Discouraged
Tue		Strongly Discouraged		Prohibited	Prohibited									Discouraged	Strongly Discouraged
Wed		Strongly Discouraged												Discouraged	Strongly Discouraged
Thu		Strongly Discouraged												Discouraged	Strongly Discouraged

	Required
	Strongly Preferred
	Preferred
	Neutral
	Discouraged
	Strongly Discouraged
	Prohibited

Standard room

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A – Poříčí 9

# Timetabling Process

## Initial timetabling

- automated generation of initial timetable
- **Iterative forward search**
  - constructive algorithm
  - subsequent extension of consistent timetable by other classes
  - no constraint propagation

## Interactive timetabling

- subsequent modification of classes by schedule deputies
- **Repair branch and bound**
  - applied on existing solution
  - removal of one class and finding its new placement
  - upper bound: at most  $N$  classes can be moved at the same time
    - typically:  $N=2$

# Interactive Timetabling

## Suggestions

<u>Score</u>	<u>Class</u>	<u>Date</u>	<u>Time</u>	<u>Room</u>	<u>Students</u>
+47	PSY 120 Lec 5	Full Term	MWF 7:30a	WTHR 200 → CL50 224	0
+104.6	PSY 120 Lec 5	Full Term	MWF 7:30a	WTHR 200 → LILY 1105	+32
	AGEC 217 Lec 3	Full Term	MWF 7:30a	LILY 1105 → CL50 224	
+107.725	PSY 120 Lec 5	Full Term	MWF 7:30a → MWF 4:30p	WTHR 200 → EE 129	+73
	ECE 270 Lec 1	Full Term	MWF 4:30p	EE 129 → FRNY G140	
+111.7	PSY 120 Lec 5	Full Term	MWF 7:30a → MWF 2:30p	WTHR 200 → EE 129	+115
	MA 261 Lec 3	Full Term	MWF 2:30p → MWF 7:30a	EE 129 → PHYS 114	
+111.7	PSY 120 Lec 5	Full Term	MWF 7:30a → MWF 2:30p	WTHR 200 → EE 129	+115
	MA 261 Lec 3	Full Term	MWF 2:30p → MWF 7:30a	EE 129 → PHYS 112	

(all 2037 possibilities up to 2 changes were considered, top 5 of 13 suggestions displayed)

## Selected Publications



Rudová and Murray.

University course timetabling with soft constraints.

*PATAT, LNCS 2740, 2003.*



Müller.

Constraint-based Timetabling

Ph.D. thesis, Charles University, 2005.



Rudová, Müller, and Murray.

Complex university course timetabling.

*Journal of Scheduling, 14(2): 187-207, Springer, 2011.*

## Timetables generated by UniTime for Spring 2011 and Fall 2011

- initial timetabling & interactive timetabling

## Fall 2010: manual solution

- partial timetables created by 44 departmental schedule deputies  
= input for the central schedule manager creating the timetable

## Spring 2011

- the number of available classrooms decreased from 65 to 49
- timetable necessary within 8 weeks
- training of 44 schedule deputies infeasible due time horizon
- manually created partial timetables as the primary input
- other data from Information System of Masaryk University

# Input Data

## Partial timetables

- MS Excel tables
  - same as before automated timetabling
- time assignment for all classes
- room assignment for 69 % of classes
- designated teachers for classes
- preferred room equipment
  - only extension of MS Excel tables
  - standard room, multi-media lab, computer lab

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## Information System

- 49 rooms: identifier, building, capacity, equipment
- 584 teachers
- 1,570 courses
- 70,689 last-like semester enrollments (course, student)

# Course Structure

----Preferences----										
Last	Enrollment	Limit	Room	Date	Mins	Per	Time			
			Ratio	Manager	Pattern	Week	Pattern	Time	Room	Distribution
<b>BJ BJA100</b>	<b>0</b>	100	<b>Jazykový kurz I</b>							
AJ AJ01000			Jazykový kurz							
Přednáška	<b>Cross list</b>	100		FF	Každý		50			
					týden					
Seminář		100		FF	Každý		100			
					týden					
Před 1	<b>Classes</b>	100	0.90	FF	Každý		50	1h		G G22 G MULT
					týden					
Sem 1		50		FF	Každý		100	2h		G G21 G POČ
					týden					
Sem 2		50		FF	Každý		100	2h		G G21 G POČ
					týden					

# Course Constraints

## Cross-lists identification

- based on partial timetable: automatically
- remaining: manually
- 1,570  $\rightarrow$  1,421 courses

## Classes

- 1,917  $\rightarrow$  1,746 classes
- students of course
  - split among classes: much more common – automatically
  - share among classes: entered manually

Assign times and rooms to all classes

Optimization criteria

- **student conflicts minimization**
  - last-like enrollment data
- **room equipment preferences**
  - all classes: standard room, multi-media lab, computer lab
- **building preferences** = keep selected building of room
  - 69 % of classes: preferred building in UniTime
- **room selection preferences** = keep selected room
  - 69 % of classes: strongly preferred room in UniTime

Standard room

A – Poříčí 9

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# Goals (continues)

For all classes

- **time preferences** = keep selected time
  - UniTime: selected time strongly preferred
  - one period before and after selected time preferred

1h

	from: 7:30a	8:20a	9:10a	10:00a	10:50a	11:40a	12:30p	1:20p	2:10p	3:00p	3:50p	4:40p	5:30p	6:20p	7:10p	8:00p
	to: 8:15a	9:05a	9:55a	10:45a	11:35a	12:25p	1:15p	2:05p	2:55p	3:45p	4:35p	5:25p	6:15p	7:05p	7:55p	8:45p
Mon																
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	to: 8:15a	9:05a	9:55a	10:45a	11:35a	12:25p	1:15p	2:05p	2:55p	3:45p	4:35p	5:25p	6:15p	7:05p	7:55p	8:45p
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- **discourage early and late times**
  - due to renovation times extended from 7:30 am to 8:45 pm
  - UniTime: default preferences for all classes

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## Summary

- missing initial room assignment for 31 % of classes
- for 48 % of classes: initial placement infeasible

## Results for Spring 2011

Solution	Fully automated	First published	Finalized
Selected time kept (%)	89.8	89.9	87.66
Selected room kept (%)	62.9	65.6	64.05

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Student conflicts	812	871	1,119
Time preferences (%)	92.34	92.53	89.20
Room preferences (%)	82.99	83.38	74.65

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Selected room kept (%)	62.9	65.6	64.05
Student conflicts	812	871	1,119
Time preferences (%)	92.34	92.53	89.20
Room preferences (%)	82.99	83.38	74.65
Broken hard constraints	0	10	71
Interactive time changes (%)	-	1.4	10.85
Interactive room changes (%)	-	6.7	20.95

Similar results for Fall 2011

# Conclusion & Future Work

## Faculty of Arts: Spring 2011

- harder problem due to building renovations
- schedule manager evaluated her workload to 30 %
- work done on problem analysis and data conversions
- UniTime: no work on constraint solver, few minor changes in GUI

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## Faculty of Arts: Fall 2011

- surprisingly no work on analysis, conversions and UniTime

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## Faculty of Arts: Fall 2011

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## Research challenges

- effective combination of various criteria (soft constraints)
- teacher timetables
  - compact vs. spread, unpopular times vs. fairness, lunches, too many hours, ...

Data entry by all 44 schedule deputies

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  - compulsory courses with almost no overlaps
    - about 100 student conflicts among 1,500 classes
  - optional courses with possibly higher overlaps
    - about 300 additional student conflicts for 250 additional classes  
mostly conflicts between a compulsory and an optional class
- Teacher and curriculum timetables

- Similar problem size
- More time for solution
- Data entry by 40 schedule deputies
- Curriculum-based timetabling
  - compulsory courses with almost no overlaps
    - about 100 student conflicts among 1,500 classes
  - optional courses with possibly higher overlaps
    - about 300 additional student conflicts for 250 additional classes
    - mostly conflicts between a compulsory and an optional class
- Teacher and curriculum timetables
- Combined study with work
  - timetabling of Fridays & Saturdays
  - each course: up to 6 meetings at different times
  - each of 2,200 meetings: about  $300 \times 30$  possible placements!
    - 12 weeks, 2 days, 12.5 possible times, 30 rooms