Rapid Development of University Course Timetables

Hana Rudová*     Tomáš Müller◦

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

◦Purdue University
West Lafayette, USA
muller@unitime.org

MISTA 2011
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

<table>
<thead>
<tr>
<th>Class</th>
<th>Demand</th>
<th>Limit</th>
<th>Manager</th>
<th>Date Pattern</th>
<th>Time Pattern</th>
<th>Preferences</th>
<th>Distribution</th>
<th>Instructor</th>
</tr>
</thead>
<tbody>
<tr>
<td>M E 263</td>
<td>98</td>
<td>96</td>
<td>LLR</td>
<td>Full Term</td>
<td>3 x 50</td>
<td>WTHR</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 x 75</td>
<td>Computer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lecture</td>
<td>150</td>
<td>96</td>
<td>L E</td>
<td>Full Term</td>
<td>2 x 50</td>
<td>ME 120</td>
<td>ME 236</td>
<td></td>
</tr>
<tr>
<td>Recitation</td>
<td>100</td>
<td>96</td>
<td>L E</td>
<td>Full Term</td>
<td>2 x 50</td>
<td>Classroom</td>
<td>Windows XP</td>
<td></td>
</tr>
<tr>
<td>Laboratory</td>
<td>50</td>
<td>84-120</td>
<td>LAB</td>
<td>Even Wks</td>
<td>1 x 50</td>
<td>Windows XP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lec 1</td>
<td>150</td>
<td>96</td>
<td>LLR</td>
<td>Full Term</td>
<td>3 x 50</td>
<td>WTHR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rec 1</td>
<td>100</td>
<td>48</td>
<td>L E</td>
<td>Full Term</td>
<td>2 x 50</td>
<td>ME 120</td>
<td>Back-To-Back</td>
<td>J. Novak</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ME 236</td>
<td>M E 263 Rec 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Classroom</td>
<td>M E 263 Rec 2</td>
<td></td>
</tr>
<tr>
<td>Lab 1</td>
<td>50</td>
<td>14-20</td>
<td>LAB</td>
<td>Even Wks</td>
<td>1 x 50</td>
<td>Windows XP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lab 2</td>
<td>50</td>
<td>14-20</td>
<td>LAB</td>
<td>Even Wks</td>
<td>1 x 50</td>
<td>Windows XP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lab 3</td>
<td>50</td>
<td>14-20</td>
<td>LAB</td>
<td>Even Wks</td>
<td>1 x 50</td>
<td>Windows XP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rec 2</td>
<td>100</td>
<td>48</td>
<td>L E</td>
<td>Full Term</td>
<td>2 x 50</td>
<td>ME 120</td>
<td>Back-To-Back</td>
<td>J. Novak</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ME 236</td>
<td>M E 263 Rec 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Classroom</td>
<td>M E 263 Rec 2</td>
<td></td>
</tr>
<tr>
<td>Lab 4</td>
<td>50</td>
<td>14-20</td>
<td>LAB</td>
<td>Odd Wks</td>
<td>1 x 50</td>
<td>Windows XP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lab 5</td>
<td>50</td>
<td>14-20</td>
<td>LAB</td>
<td>Odd Wks</td>
<td>1 x 50</td>
<td>Windows XP</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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 contraints: 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

<table>
<thead>
<tr>
<th>1h</th>
<th>from:</th>
<th>7:00a</th>
<th>7:55a</th>
<th>8:50a</th>
<th>9:05a</th>
<th>10:00a</th>
<th>10:55a</th>
<th>11:10a</th>
<th>12:00p</th>
<th>1:00p</th>
<th>2:00p</th>
<th>3:00p</th>
<th>4:00p</th>
<th>5:00p</th>
<th>6:00p</th>
<th>6:55p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tue</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thu</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Standard room
A 51
A – Poříčí 9
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

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

*(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  

Rudová, Müller, and Murray.  
Complex university course timetabling.  
Faculty of Arts

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
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

Information System

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

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
<th>Last Enrollment</th>
<th>Room Limit</th>
<th>Room Ratio</th>
<th>Date Pattern</th>
<th>Mins Per Week</th>
<th>Time Pattern</th>
<th>Room Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>BJ BJA100</td>
<td>Jazykový kurz I</td>
<td>0</td>
<td>100</td>
<td>FF</td>
<td>Každý týden</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AJ AJ01000</td>
<td>Jazykový kurz</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Přednáška</td>
<td>Cross list</td>
<td>100</td>
<td>FF</td>
<td>Každý týden</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seminář</td>
<td></td>
<td>100</td>
<td>FF</td>
<td>Každý týden</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Před 1</td>
<td>Classes</td>
<td>100</td>
<td>0.90 FF</td>
<td>Každý týden</td>
<td>50</td>
<td>1h</td>
<td>G G22 G MULT</td>
<td></td>
</tr>
<tr>
<td>Sem 1</td>
<td></td>
<td>50</td>
<td>FF</td>
<td>Každý týden</td>
<td>100</td>
<td>2h</td>
<td>G G21 G POČ</td>
<td></td>
</tr>
<tr>
<td>Sem 2</td>
<td></td>
<td>50</td>
<td>FF</td>
<td>Každý týden</td>
<td>100</td>
<td>2h</td>
<td>G G21 G POČ</td>
<td></td>
</tr>
</tbody>
</table>
Course Constraints

Cross-lists identification

- based on partial timetable: automatically
- remaining: manually
- 1,570 → 1,421 courses

Classes

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

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
A 51
For all classes

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

### 1h

<table>
<thead>
<tr>
<th>from:</th>
<th>7:30a</th>
<th>8:20a</th>
<th>9:10a</th>
<th>10:00a</th>
<th>10:50a</th>
<th>11:40a</th>
<th>12:30p</th>
<th>1:20p</th>
<th>2:10p</th>
<th>3:00p</th>
<th>3:50p</th>
<th>4:40p</th>
<th>5:30p</th>
<th>6:20p</th>
<th>7:10p</th>
<th>8:00p</th>
</tr>
</thead>
</table>

- Mon
- Tue
- Wed
- Thu
Goals (continues)

For all classes

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

- **discourage early and late times**
  - due to renovation times extended from 7:30 am to 8:45 pm
  - UniTime: default preferences for all classes
Goals (continues)

For all classes

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

1h

<table>
<thead>
<tr>
<th>from:</th>
<th>7:30a</th>
<th>8:20a</th>
<th>9:10a</th>
<th>10:00a</th>
<th>10:50a</th>
<th>11:40a</th>
<th>12:30p</th>
<th>1:20p</th>
<th>2:10p</th>
<th>3:00p</th>
<th>3:50p</th>
<th>4:40p</th>
<th>5:30p</th>
<th>6:20p</th>
<th>7:10p</th>
<th>8:00p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tue</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thu</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- discourage early and late times
  - due to renovation times extended from 7:30 am to 8:45 pm
  - UniTime: default preferences for all classes

**Summary**

- missing initial room assignment for 31% of classes
- for 48% of classes: initial placement infeasible
## Results for Spring 2011

<table>
<thead>
<tr>
<th>Solution</th>
<th>Fully automated</th>
<th>First published</th>
<th>Finalized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selected time kept (%)</td>
<td>89.8</td>
<td>89.9</td>
<td>87.66</td>
</tr>
<tr>
<td>Selected room kept (%)</td>
<td>62.9</td>
<td>65.6</td>
<td>64.05</td>
</tr>
</tbody>
</table>
## Results for Spring 2011

<table>
<thead>
<tr>
<th>Solution</th>
<th>Fully automated</th>
<th>First published</th>
<th>Finalized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selected time kept (%)</td>
<td>89.8</td>
<td>89.9</td>
<td>87.66</td>
</tr>
<tr>
<td>Selected room kept (%)</td>
<td>62.9</td>
<td>65.6</td>
<td>64.05</td>
</tr>
<tr>
<td>Student conflicts</td>
<td>812</td>
<td>871</td>
<td>1,119</td>
</tr>
<tr>
<td>Time preferences (%)</td>
<td>92.34</td>
<td>92.53</td>
<td>89.20</td>
</tr>
<tr>
<td>Room preferences (%)</td>
<td>82.99</td>
<td>83.38</td>
<td>74.65</td>
</tr>
</tbody>
</table>
## Results for Spring 2011

<table>
<thead>
<tr>
<th></th>
<th>Fully automated</th>
<th>First published</th>
<th>Finalized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selected time kept (%)</td>
<td>89.8</td>
<td>89.9</td>
<td>87.66</td>
</tr>
<tr>
<td>Selected room kept (%)</td>
<td>62.9</td>
<td>65.6</td>
<td>64.05</td>
</tr>
<tr>
<td>Student conflicts</td>
<td>812</td>
<td>871</td>
<td>1,119</td>
</tr>
<tr>
<td>Time preferences (%)</td>
<td>92.34</td>
<td>92.53</td>
<td>89.20</td>
</tr>
<tr>
<td>Room preferences (%)</td>
<td>82.99</td>
<td>83.38</td>
<td>74.65</td>
</tr>
<tr>
<td>Broken hard constraints</td>
<td>0</td>
<td>10</td>
<td>71</td>
</tr>
<tr>
<td>Interactive time changes (%)</td>
<td>-</td>
<td>1.4</td>
<td>10.85</td>
</tr>
<tr>
<td>Interactive room changes (%)</td>
<td>-</td>
<td>6.7</td>
<td>20.95</td>
</tr>
</tbody>
</table>

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
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

Faculty of Arts: Fall 2011
- surprizingly no work on analysis, conversions and UniTime
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

Faculty of Arts: Fall 2011
- surprisingly no work on analysis, conversions and UniTime

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
Faculty of Education: Fall 2011

- Similar problem size
- More time for solution
- Data entry by 40 schedule deputies
Faculty of Education: Fall 2011

- 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
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 classesmostly 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