University Course Timetabling

From Theory to Practice

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This presentation: http://www.fi.muni.cz/~hanka/publ/mista15.pdf
University Course Timetabling: From Theory to Practice

1. Introduction to educational timetabling

2. Classical course and school timetabling
   - high school timetabling
   - curriculum-based timetabling
   - enrollment-based timetabling

3. Complex course timetabling
   - additional characteristics
   - case studies
   - challenges

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Wren 1996: Timetabling is the allocation, subject to constraints, of given resources to objects being placed in space-time, in such a way as to satisfy as nearly as possible a set of desirable objectives.

- Transport timetabling
- Sports timetabling
- Employee timetabling
- Educational timetabling
  - course timetabling
  - school timetabling
  - examination timetabling

Educational (event-based) timetabling is a consistent assignment of times, rooms and possibly teachers and students to the set of events with the best possible satisfaction of preferences for students, teachers and institution.

- An event can be an exam, class, lecture, course, part of the course, ...
- Consistency/feasibility requires all hard constraints to be satisfied.
- Preferential or soft constraints can be violated.

Categories:

- Curriculum-based timetabbling – ITC 2007
- High school timetabling – ITC 2011


http://www.cs.qub.ac.uk/itc2007

http://www.utwente.nl/ctit/hstt/itc2011
School timetabling, class-teacher timetabling

Problem can be defined using (ITC 2011, XHSTT format)

- **Times** and time group such as day or week
- **Resources** of distinct types such as teachers, rooms, classes
  - class = set of students attending the same events
- **Events** contains duration, time, event resources
  - course = set of events
- **Constraints**: currently 16 constraint types defined, e.g.,
  - event should be assigned a time
  - resource’s timetable should not have idle times
  - resource’s total workload should be limited

Real data instances from 12 countries

- [http://www.utwente.nl/ctit/hstt](http://www.utwente.nl/ctit/hstt)
Curriculum-based Timetabling

**Curriculum** = set of courses attended by the same group of students

⇒ two courses of the same curricula cannot be at the same time

**ITC 2007 and extensions**

- **course** = set of events having the same duration
- constraints related with courses
  - minimum working days, room stability
- constraints related with curriculum compactness
  - isolated events, time windows
- **University of Udine data instances** for base formulation
  for extended formulation

identification of another constraint set extension to solve real problem

- [http://satt.diegm.uniud.it/ctt/](http://satt.diegm.uniud.it/ctt/)
- **Bonutti, De Cesco, Di Gaspero, Schaerf** (2012), *Benchmarking curriculum-based course timetabling: formulations, data formats, instances, validation, visualization, and results* 
- **Bettinelli, Cacchiani, Roberti, Toth** (2015), *An overview of curriculum-based course timetabling* 
  *TOP, 23*(2), 313–349.
Enrollment-based Timetabling

**Enrollments:** distinct set of enrolled students is given for each course
- two courses of the same student should not be at the same time

**ITC 2002 and ITC 2007**
- course = one event of unit duration
  - enrollments introduce hard constraints
- ITC 2002: easy satisfaction of hard constraints
- ITC 2007: more emphasis on satisfaction hard constraints,
  - two additional soft constraint types added

**Artificial data instances**

Complex Course Timetabling
Commercial Applications

Timetabling system in University of Waterloo
- used 15 years since 1985

UniTime
- free, open-source system
- research from 2001
- used in practice from 2005
- case studies
  - 40,000 students: Purdue University, USA
  - 18,500 students (50%) at Masaryk University, Czech Republic

- Carter (2001), A Comprehensive Course Timetabling and Student Scheduling System at the University of Waterloo, Practice and Theory of Automated Timetabling III, LNCS 2079, 64–82.
- http://www.unitime.org
UniTime Practical Experiences

High diversity of problems: Masaryk University use case
- Faculty of Arts: enrollment-based, centralized → distributed input
- Faculty of Education: curriculum-based, distributed input
- Faculty of Sport Studies: curriculum-based with emphasis on traveling
- Faculty of Informatics: curriculum-based + enrollments

UniTime applied
- with minimal needs for software changes
  - more than 9000 students and 1900 events
  - "centralized" solution implemented within 8 weeks (Faculty of Arts)
- in case of significant institutional changes
  - building reconstruction, leaving timetabling manager

Getting institutional support is hard
Centralized timetabling for small to medium-sized problems

Decentralized data input, centralized solving

Coordination: timetabling on top of existing timetables
  - no problem for solvers:
    generally can be handled by fixing some problem parts

Example: Purdue University timetabling process

1. large lecture room timetabling
   - decentralized data input, centralized solving

2. departmental timetabling
   - centralized
     or coordinated timetabling
   - about 70 problems

3. computer laboratory timetabling
   - decentralized data input, centralized solving
Getting a feasible timetable is the first step

- user control over feasibility
  - users must decide which constraints can be relaxed
- detection and removal of unsatisfied hard constraints
  - report of violated hard constraints and/or
  - report of reasons resulting in unassigned events
    e.g. conflict-based statistics, explanations

- impact on solvers
  - conflict detection capabilities
  - all events must be finally assigned


Timetabling Process: Static vs. Dynamic Timetabling

- Changes of existing timetable is necessary

- Minimal perturbation problem
  1) original problem, 2) its solution, 3) requested changes to the problem
  find solution of new problem with minimal additional changes

- Interactive timetabling: very common problem!
  small requested changes to the problem and its solution
  interactive response ... proposing suggestions of solution
  many iterations

- Research: static problems are mostly solved
  fragmented, no standard benchmarks

### 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>
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<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)*

[Search Deeper]
Algorithm: Repair branch and bound (base version)

- applied on existing solution
- removal of one event $e$ and search for its new placement
- branching
  - values of unassigned event $e$
  - values of events conflicting with new assignment
- bounds
  - at most $n$ events can be moved at once
  - quality of $a$-th best found solution
- timeout
  - promising branches must be explored earlier

Results for Interactive Problem

Purdue University: Large Lecture Room Problem

<table>
<thead>
<tr>
<th>Events</th>
<th>1840</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time limit (s)</td>
<td>1840</td>
</tr>
<tr>
<td>No suggestion found (%)</td>
<td>1.6</td>
</tr>
<tr>
<td>Optimal suggestion found (%)</td>
<td>98.4</td>
</tr>
<tr>
<td>Number of suggestions</td>
<td>232.8</td>
</tr>
<tr>
<td>Number of backtracks</td>
<td>66367.9</td>
</tr>
<tr>
<td>Time spent (s)</td>
<td>128.6</td>
</tr>
</tbody>
</table>

- maximal depth $n = 3$ (2 additional changes allowed)
- 75% suggestions found

## Course Structure: Example

<table>
<thead>
<tr>
<th>Course</th>
<th>Demand</th>
<th>Limit</th>
<th>Mins Per Week</th>
<th>Manager</th>
<th>Date Pattern</th>
<th>Time Pattern</th>
<th>Preferences</th>
<th>Instructor</th>
</tr>
</thead>
<tbody>
<tr>
<td>M E 263</td>
<td>98</td>
<td>96</td>
<td>150</td>
<td>LLR</td>
<td>Full Term</td>
<td>3 x 50, 2 x 75</td>
<td>WTHR, Computer</td>
<td></td>
</tr>
<tr>
<td>M E 263H</td>
<td>100</td>
<td>96</td>
<td>100</td>
<td>M E</td>
<td>Full Term</td>
<td>2 x 50</td>
<td>ME 120, ME 236, Classroom</td>
<td>J. Novak</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>
</tbody>
</table>

| Lecture | 150 | 96 | LLR | Full Term | 3 x 50, 2 x 75 | WTHR, Computer | |
| Recitation | 100 | 48 | M E | Full Term | 2 x 50 | ME 120, ME 236, Classroom | 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 | |
| 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: Realization

- Instructional offering
  - different names for the same course
  - example: ME 263, ME 263H
- Configuration
  - different teaching styles for course
  - example: for present/daily and distant form of study
- Subpart
  - parent-child relationship and related constraints
    important additional constraints for experimental problems
  - example: lecture, seminar, laboratory
- Event
  - timetabling at this level
  - example: ME 263 Lec 1

Student Sectioning I.

- **Goal:** assign students to sections for large course subparts

- **Simplified approach** (Carter 2001, Müller et al. 2007)
  - initial student sectioning
  - standard timetabling with events
  - final student sectioning

- **Student sectioning approaches**
  - initial student sectioning (Amintoosi, Haddadnia 2005, ...)
  - final student sectioning (Dostert, Politz, Schmitz 2015, ...)

- **References**
  - Carter (2001), *A Comprehensive Course Timetabling and Student Scheduling System at the University of Waterloo*,
  - Dostert, Politz, Schmitz (2015), *A complexity analysis and an algorithmic approach to student sectioning in existing timetables*, Accepted in Journal of Scheduling.
Student Sectioning II.

- **Iterated approaches** (Aubin, Ferland 1989, Hertz, Robert 1998)
  - iterations between time and student assignments
- **Combined approach** (Kingston 2014)
  - student sectioning transformed to standard timetabling
- **Sectioning with student preferences**
  - Sampson, Weiss 1995, Müller, Murray 2010, ...

- **Important problem part to be considered in experimental problems**

Complex Curricula and Enrollments

Curriculum-based timetabling benchmarks
- compulsory and elective courses due to human data preprocessing

Complex curricula necessary in practice
- required/recommended study plan needs to be involved
- possible combination with enrollments
Compulsory courses:
- IB102 Automata, Grammars, and Complexity 100%
- PB154 Database Systems 100%
- IB015 Non-Imperative Programming 80%
  (2nd: 80%, 3rd: 20%)

Elective courses:
- MB103 Continuous Models and Statistics 80%
  or  MB203 Continuous Models and Statistics B 20%
- PB161 C++ Programming 50%
  or  PB162 Java 50%

Specialization:
- PV066 Typography I 20%
  and PV078 Graphical Design I 20%
Complex Curricula with Enrollments: Representation

Curriculum model

- **conflicting group**: courses with conflicts
  - example: compulsory courses
- **non-conflicting group**: courses with no conflicts
  - example: choice of one elective course from the group

Translation into enrollment model

- and possible combination with enrollments

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### Curriculum: Example

<table>
<thead>
<tr>
<th>Groups</th>
<th>Course</th>
<th>Percentage of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2nd year</td>
</tr>
<tr>
<td>P 02</td>
<td>IB 102</td>
<td>100.0%</td>
</tr>
<tr>
<td>P 02</td>
<td>PB 154</td>
<td>100.0%</td>
</tr>
<tr>
<td>P 02</td>
<td>IB 015</td>
<td>80.0%</td>
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<tr>
<td>MB103/203</td>
<td>MB 103</td>
<td>80.0%</td>
</tr>
<tr>
<td>PV02</td>
<td>PB 161</td>
<td>50.0%</td>
</tr>
<tr>
<td>PV02</td>
<td>PB 162</td>
<td>50.0%</td>
</tr>
<tr>
<td>MB103/203</td>
<td>MB 203</td>
<td>20.0%</td>
</tr>
<tr>
<td>GRAF 02</td>
<td>PV 066</td>
<td>20.0%</td>
</tr>
<tr>
<td>GRAF 02</td>
<td>PV 078</td>
<td>20.0%</td>
</tr>
</tbody>
</table>

- **Compulsory courses**: IB 102, PB 154, IB 015
- **Elective courses**: MB 103, PB 161, PB 162
- **Specialization**: PV 066, PV 078
<table>
<thead>
<tr>
<th>Group</th>
<th>Course</th>
<th>01</th>
<th>02</th>
<th>03</th>
</tr>
</thead>
<tbody>
<tr>
<td>F 01</td>
<td>IB 000</td>
<td>100.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F 01</td>
<td>PB 001</td>
<td>100.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F 01</td>
<td>PB 151</td>
<td>100.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F 01</td>
<td>VB 035</td>
<td>100.0%</td>
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<tr>
<td>MB 101/201</td>
<td>MB 101</td>
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<td></td>
<td></td>
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<tr>
<td>PV 01</td>
<td>IB 001</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>F 01</td>
<td>IB 111</td>
<td>50.0%</td>
<td></td>
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<tr>
<td>MB 101/201</td>
<td>MB 201</td>
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<td></td>
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<tr>
<td>F 02</td>
<td>IB 102</td>
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<td></td>
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<td>F 02</td>
<td>PB 154</td>
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<td>BEZ SP 03</td>
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<tr>
<td>GRAF 03</td>
<td>VV 033</td>
<td>20.0%</td>
<td></td>
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</tr>
</tbody>
</table>
Compactness and Spread

Existing approaches

- curriculum-based timetabling
  - isolated event, time windows, minimum working days per course, student minimum and maximum load
- high school timetabling
  - limit idle times, spread events, limit busy times, cluster busy times
  - can be easily achieved with limited number of time periods
- other works
  - lunch break – important constraint

Important questions to be responded

- How to handle compactness and spread for curricula?
  - In relation with student sectioning and elective courses?
- How to generally handle compactness and spread for teachers?
  - individual requests can be handled
Goal: fair timetable for teachers and students (stakeholders)

- Minimize sum of quadratic deviations from average
  - Di Gaspero, Schaerf 2008
  - generalized balanced academic curriculum problem and workload balancing

- Lexicographic max-min fairness
  - Mühlenthaler, Wanka 2014
  - curriculum-based timetabling and fairness for curricula
  - optimal outcome for the worst-off stakeholder
  - example: \((4, 2, 1, 0, 0) \prec (4, 4, 3, 1, 0)\)

Fairness II.

- Jain’s fairness index
  - Mühlenthaler, Wanka 2014
  - curriculum-based timetabling and fairness for curricula

\[
J(X) = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n \cdot \sum_{i=1}^{n} x_i^2}
\]

fair distribution example: \(\frac{(2 + 2 + 2)^2}{3 \cdot (2^2 + 2^2 + 2^2)} = 1\)

- \(J(X) \in (0, 1)\)
- combined with standard criteria by Pareto optimization

- Importance of fairness in further studies
  - combine fairness for different entities and standard criteria
  - fairness for students with course sections and electives


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Summary & Future Views

1. Timetabling process
   - coordination and decentralization
   - construction of feasible timetable
   - static vs. dynamic timetabling

2. Timetabling model
   - course structure
   - complex curricula and enrollments
   - student sectioning

3. Important optimization criteria
   - compactness and spread
   - fairness

Most discussed extensions of benchmark problems
- new optimization criteria

Change of the process and problem structure is also necessary
Summary & Future Views

Benchmarks
- people concentrate on reasonable problems
- web pages with current best results allows for a good comparison
- people try to work on the best ever solutions

Do we really need the best ever solution?
What is the best solution in reality?

Move to more realistic problems & approaches: new benchmarks
- extension of timetabling model is necessary
- problems corresponding to real timetabling process need to be solved
- inclusion of new optimization criteria for better timetable acceptance

◦ http://satt.diegm.uniud.it/ctt/
◦ http://www.utwente.nl/ctit/hstt