University Course Timetabling
Solver Evolution

PATAT 2016

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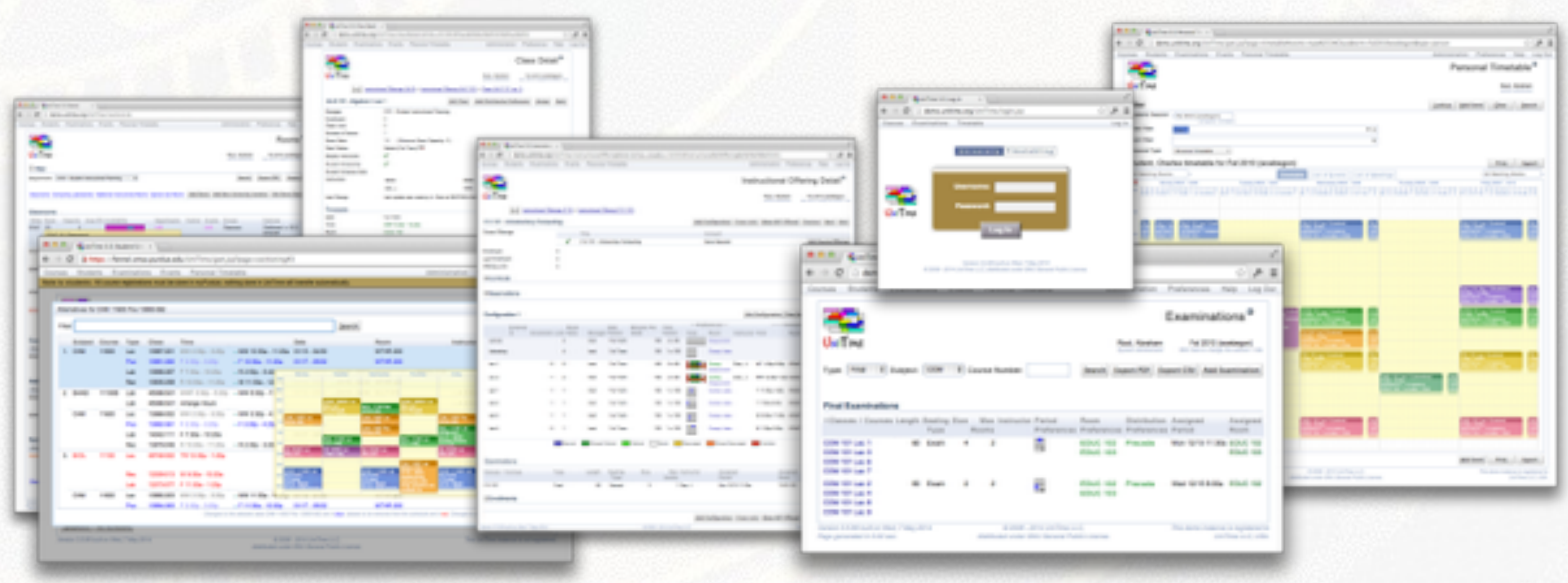
Agenda

- **University Course Timetabling: Solver Evolution**
  - Short introduction to UniTime
  - Course timetabling problem
  - CPSolver and its improvements since our last publication (2008)
  - Data sets from Purdue University
  - Conclusions

Introducing UniTime

What is UniTime?

- Comprehensive academic scheduling solution
- Four components: course timetabling, examination timetabling, student scheduling and event management
- Open source, web-based, written in Java using modern technologies
- Distributed data entry and timetabling in multi-user environments
- Started as a research project back in 2001
- Became an enterprise system for many timetabling needs of a university
  - *USA, Czech Republic, Pakistan, Croatia, Poland, Turkey, Peru, Kuwait, Canada, Malaysia, Spain, UAE, Palestine, Zambia, Kenya,…*
- Apereo Foundation project since March 2015



Course Timetabling

What is Course Timetabling?

- The process of assigning **times** and **rooms** to **classes**

Constraints

- Rooms of various sizes, equipment and availability
- Faculty with requirements and preferences
- Courses that are to be offered, organized in a structure
- Students with their course demands *(curricula, pre-registration, etc.)*

Goal

- Assign classes in both time and space in a way that
  - All hard constraints and other requirements are met
  - All the desirable objectives are satisfied as much as possible
- Objectives: student conflicts, time and room preferences, class distributions, fairness, travel, etc.

Courses

Classes are organized in a course structure

- Intuitive data entry and display of classes and their requirements
- Helps to define a way how students can enroll into the course
- Additional relations can be derived from the structure

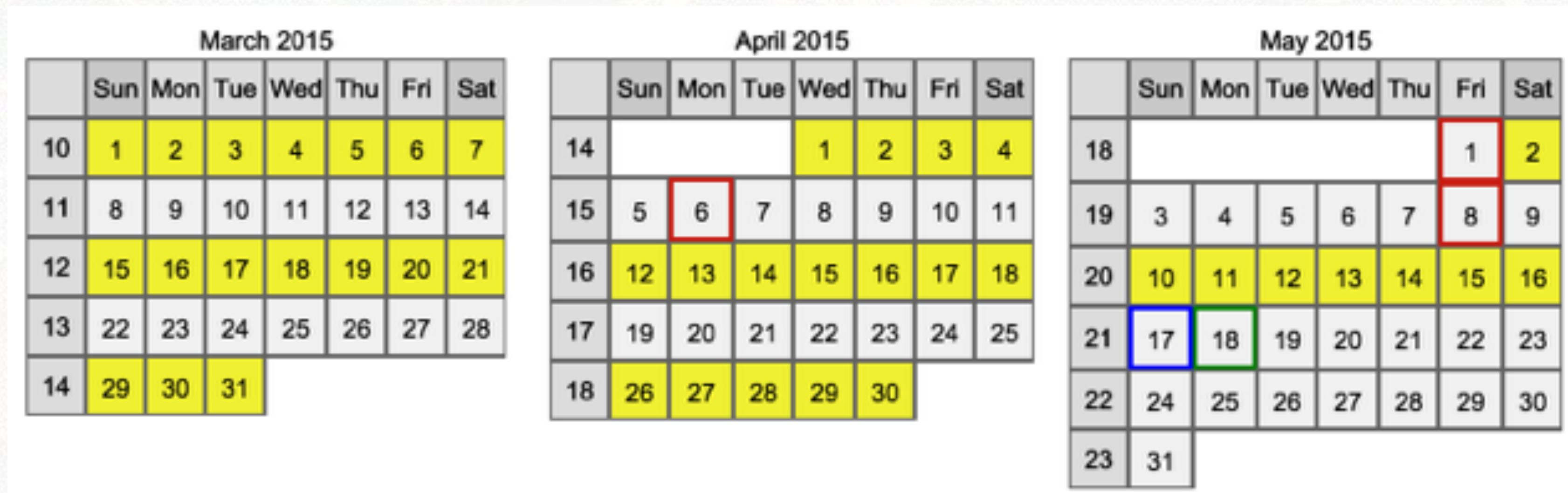
					----Preferences----			
	Limit	Date Pattern	Minutes Per Week	Time Pattern	Time	Room	Distribution	Instructor
MA 170 STAT 170	40	**Statistics I** Introductory statistics						
Lecture	40	Full Term	50	1 x 50		Classroom		
Laboratory	40	Full Term	150	3 x 50		EDUC CompPr	Same Room	
Lec 1	40	Full Term	50	1 x 50		ThtrSeat Classroom		G. Newman
Lab 1	20	Full Term	150	3 x 50		EDUC CompPr	Same Room	J. Smith
Lab 2	20	Full Term	150	3 x 50		EDUC CompPr	Same Room	J. Smith

Required · Strongly Preferred · Preferred · Neutral · Discouraged · Strongly Discouraged · Prohibited

Time

Date Patterns

- Weeks of instructions (All weeks, Even/Odd weeks, Week 5, …)



Time Patterns

- Possible time slots within a week

Space

Rooms

- Each department may have a different set of rooms
- Some times may be unavailable or given to a different department

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Workdays × Daytime

from: / to:	7:30a 8:00a	8:00a 8:30a	8:30a 9:00a	9:00a 9:30a	9:30a 10:00a	10:00a 10:30a	10:30a 11:00a	11:00a 11:30a	11:30a 12:00p	12:00p 12:30p	12:30p 1:00p	1:00p 1:30p	1:30p 2:00p	2:00p 2:30p	2:30p 3:00p	3:00p 3:30p	3:30p 4:00p	4:00p 4:30p	4:30p 5:00p	5:00p 5:30p	5:30p 6:00p	6:00p 6:30p
Mon																						
Tue	BIOL	BIOL	BIOL	BIOL	BIOL	BIOL	BIOL	BIOL	BIOL	BIOL	BIOL	BIOL	BIOL	BIOL	BIOL	BIOL	BIOL	BIOL	BIOL	BIOL	BIOL	BIOL
Wed	CIVC	CIVC	CIVC	CIVC	CIVC	CIVC	CIVC	CIVC	CIVC													
Thu	CIVC	CIVC	CIVC	CIVC	CIVC	CIVC	CIVC	CIVC	CIVC													
Fri	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

- Room coordinates, travel times

Minimal Room Size

- Calculated from class limit and room ratio

Room Preferences

- Particular room or building
- Room group
- Room feature

Room Groups:	Geology Classroom (Department) Classroom
Rooms:	B 11
Buildings:	Y - Porici 7, budova Y
Room Features:	Data Projector
Available Rooms:	34 (A 51, A 53, A 54, A 55, ...)

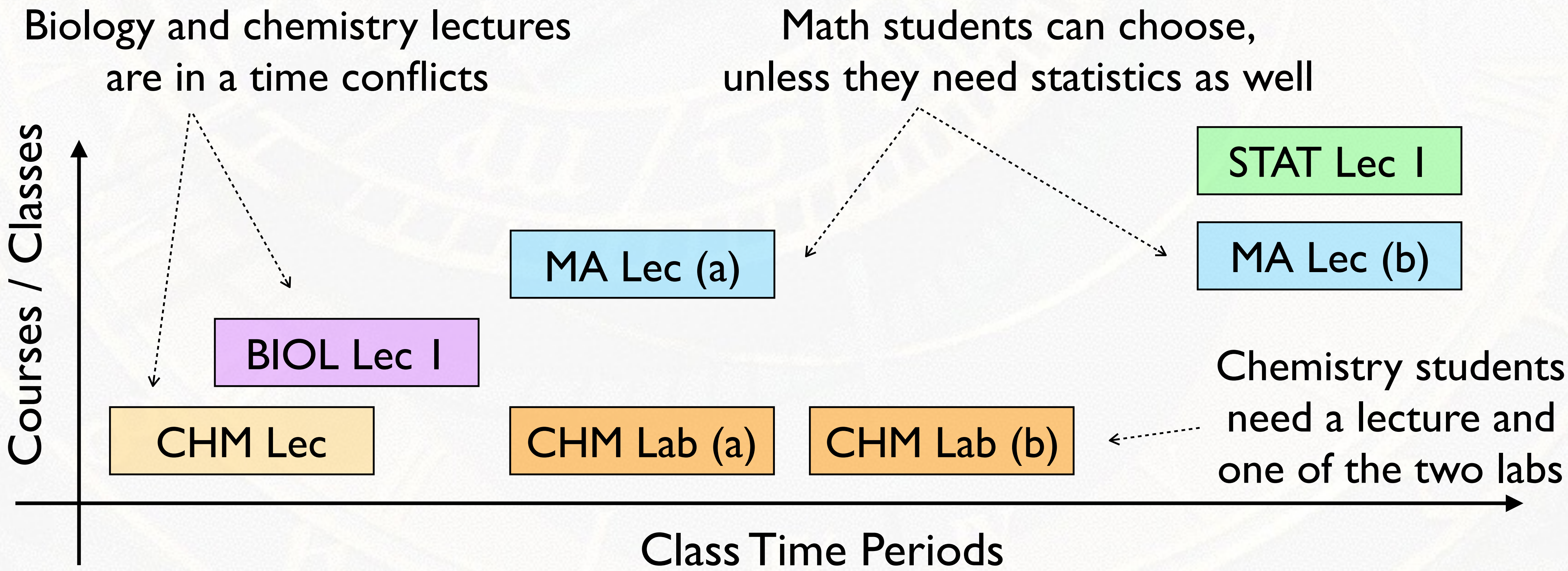
Students

Each student has a list of courses he/she wants to attend

- Using pre-registrations, curricula, last-like enrollments, or a combination

Conflict: A student cannot take a combination of courses

- Because there is a (time) conflict
  - *Classes are offered at overlapping times or one after the other in rooms that are too far apart*
- Or, there is not enough space in a non-conflicting combination of classes



Distributions

Distribution Constraints

- Relationship between two or more classes
  - Precedence
  - Back-To-Back
  - Same Room
  - Same Days
  - Meet Together
  - Spread in Time
  - At Most 6 Hours A Day
  - Can Share Room
  - …
- Set directly between classes / subparts or on an instructor

Problem Formulation

Model

- Variable: class
- Value: time and room placement

Hard Constraints

- Room size, sharing, availability
- No instructor / room can have two classes at the same time
- Required or prohibited preferences

Soft Constraints (Objectives)

- Time, room, and distribution preferences
- Student conflicts
- Additional criteria (too big rooms, back-to-back instructors, …)

Solver

Local-search based, however

- Operates over feasible, though not necessarily complete, solutions
- Feasibility is ensured automatically

Iterative Forward Search

```
while (termination.canContinue(solution)) {
  Neighbour n = neighbourSelection.select(solution);
  if (n != null) n.assign(solution);
  if (solutionComparator.isBetterThanBest(solution)) solution.saveBest();
}
```

- Guided by neighborhood selection, termination, and solution comparison heuristics
- Select variable and its value, unassigns conflicting variables with the new assignment

- Conflict-based Statistics
  - If $A=a$ is unassigned because of a $B=c$, a counter **CBS[**$A \neq a$**,** $B=c$**]** is incremented
  - Conflicts are weighted by their past occurrences
- Additional Variants
  - MPP: original solution, modified problem → minimize differences
  - Interactive: branch and bound of limited depth proposing schedule changes

Solver Evolution

Benchmark Data Sets

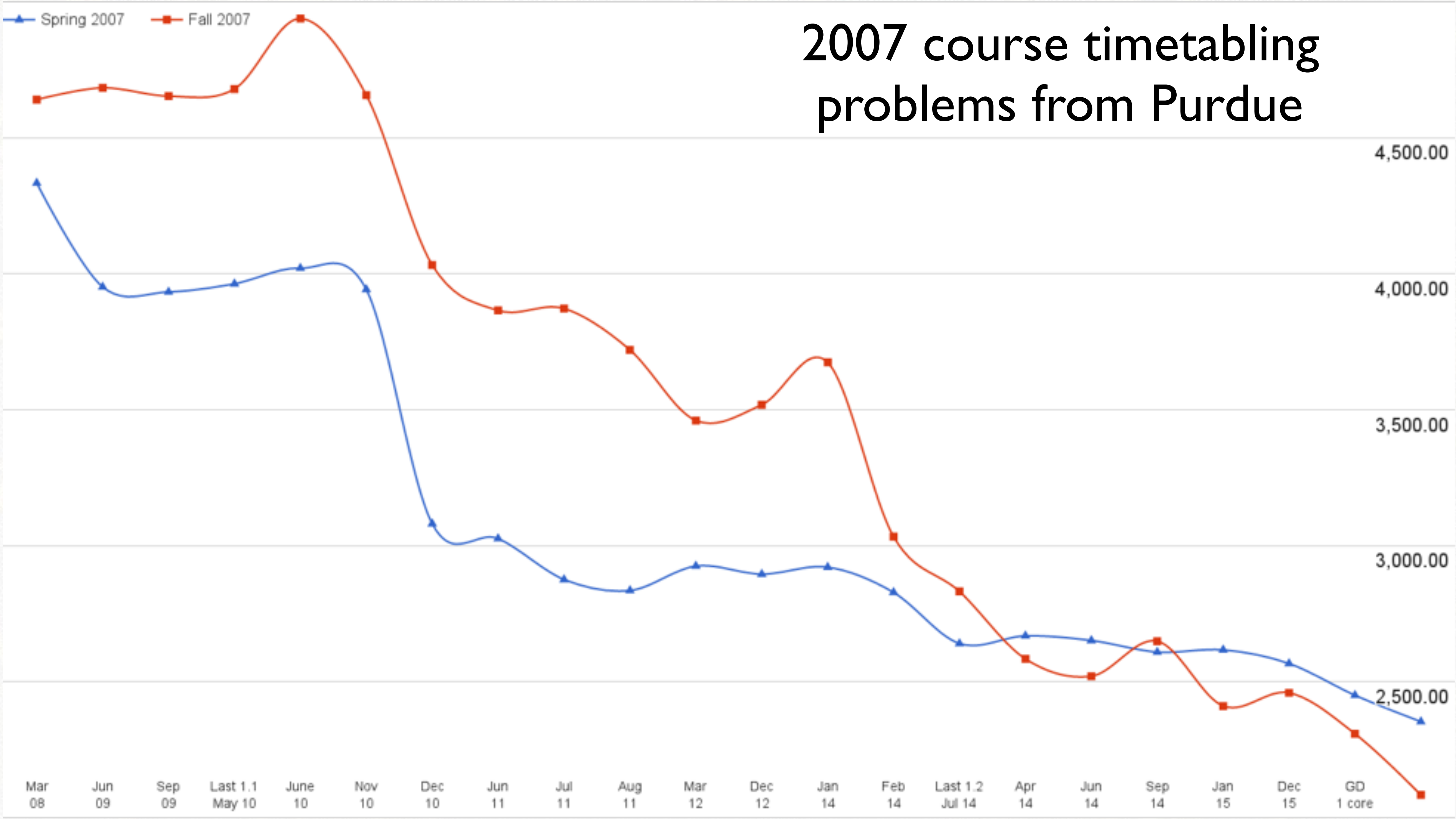
- From Purdue University, Fall 2007 and Spring 2007
- The results are presented on the combined problem (of 8 departmental problems)
- Over 2,400 classes, around 30k students and 200 rooms
- Available at http://www.unitime.org/uct_datasets.php in XML format
- Complete real world instances in an anonymized form (no names, etc.)

Experiment

- 10 independent runs for each solver build and (combined) instance
  - *since the paper (March 2008) till the one released with UniTime 4.1 (Dec 2015)*
- Same configuration, solution evaluated using the latest solver
  - Except of the last two data points where a different algorithm was used

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

Solver Evolution



More details are available in the paper.

Solver Evolution

Results

- There was 50% improvement in the solution quality since UniTime 3.1
  - 33% less student conflicts
  - 15% improvement in time preferences
  - 40% in room preferences
  - 80% in distribution preferences
- Besides of these, there have been a lot of new constraints and other features added into the solver over the years.

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

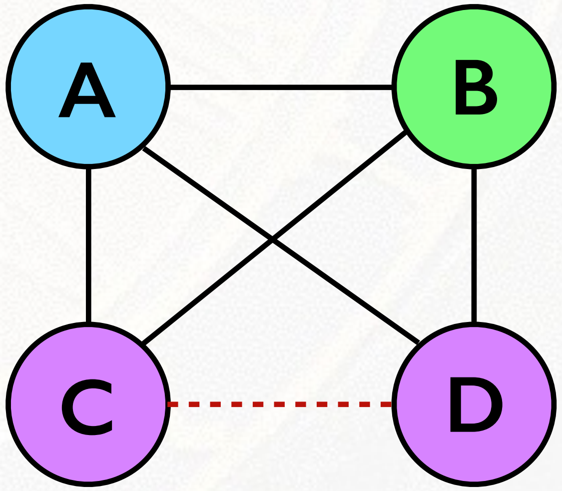
Solver Improvements

A lot comes from many small changes here and there

- There have been two major releases since 2008 and most of the solver code has been rewritten at least once
  - Making use of Java 5 generics and the ability to split the objective into individual criteria in CPSolver 1.2
  - More versatile assignment model and the ability to use multiple solver threads in CPSolver 1.3

Distribution Preferences

- Partial satisfiability of soft distribution preferences
- Imagine a different room constraint between four classes
- Not satisfied (full penalty) → 83.3% satisfied
- Forward checking along hard constraints



Solver Improvements

Student Scheduling

- Initial sectioning using aka Carter's homogenous sectioning (students with similar course selection are kept together)
- During or after the search: swap students between alternative classes

Improvements

- Move a single student into an alternative class (if there is space in it)
- Swap student between classes with different parents

					----Preferences----			
	Limit	Date Pattern	Minutes per Week	Time Pattern	Time	Room	Distribution	Instructor
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Configuration 1	40							
Lecture	40	Full Term	50	1 x 50		Classroom		
Laboratory	40	Full Term	150	3 x 50		EDUC CompPr	Same Room	
Recitation	40	Full Term	100	1 x 100		THTR		
Lec 1	20	Full Term	50	1 x 50		ThtrSeat Classroom		Newman, George
Lab 1	10	Full Term	150	3 x 50		EDUC CompPr	Same Room	Smith, John William
Lab 2	10	Full Term	150	3 x 50		EDUC CompPr	Same Room	Smith, John William
Lec 2	20	Full Term	50	1 x 50		ThtrSeat Classroom		Newman, George
Lab 3	10	Full Term	150	3 x 50		EDUC Comp CompPr	Same Room	Doe, Joe
Lab 4	10	Full Term	150	3 x 50		EDUC Comp CompPr	Same Room	Doe, Joe
Rec 1	40	Every Other Week	100	1 x 100		THTR ThtrSeat		Newman, George
Configuration 2 (DO)	10							
Distance Learning	10	Full Term	250					
Dist 1	10	Full Term	250	Arr 5 Hrs		N/A		Newman, George

Solver Improvements

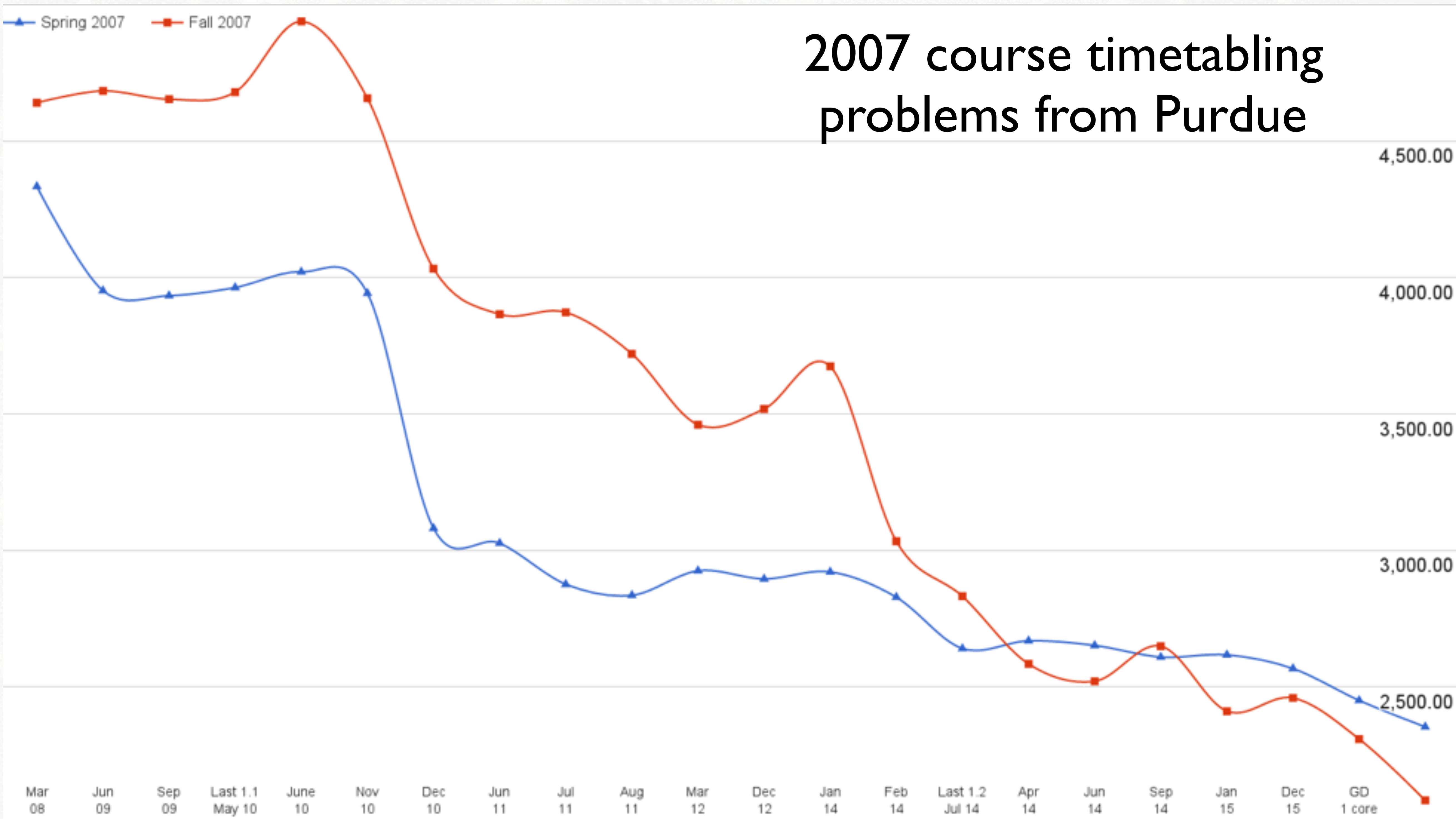
Plug-in different algorithms and search heuristics

- Additional algorithms and heuristics available out of the box
- IFS, Great Deluge, Simulate Annealing
- For course timetabling: using GD after a complete solution is found, never leaving the space of complete feasible solutions
- Besides of the usual neighborhoods, we also use a brach & bound of a limited depth
  (same that is used by the interactive solver to propose changes)

Ability to use parallel solver threads

- Two models
  - Parallel threads share a common solution (proposing changes to it)
  - Each thread works with its own solution (assignment)
- For course timetabling: second model is used, sharing properties of the best solution ever found

Solver Evolution



More details are available in the paper.

Conclusion

- **Key points**
  - Open-source university timetabling system UniTime
  - A very general course timetabling problem that fits many institutions
  - (Large) benchmark data sets from Purdue University
    - With the potential to have more data sets in the future
  - A lot of work has been done on the solver since our last publication
  - Solver framework can also be used to test new algorithms and heuristics
    - Or on different timetabling problems
- **For more details, please see me at the conference**
  - Or visit www.unitime.org

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