



Purdue University  
Course Timetabling & Course Sectioning

Space Management & Academic Scheduling  
Purdue University

March 2, 2007



# Agenda

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- Motivation
  - Why we are doing what we are doing...
- A Little of Theory
  - Constraint Satisfaction Problem (CSP)
  - Course Timetabling / Student Sectioning Model
  - Constraint Solver
- Brief Overview of System Architecture
- Some Important Aspects of
  - Course Timetabling
  - Student Sectioning
- Application Demo
- Conclusion



# Motivation

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- Purdue University relies on efficiencies resulting from optimized scheduling
  - Cost of offering classes
  - Limited classroom space
- Demand-driven Scheduling
  - Collect student demand for courses and times
  - Develop optimized timetable and student schedules
- Academic Scheduling functionality is not included in any ERP packages
- Timetabling and Scheduling are active research areas with very promising results



# Motivation

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- Purdue timetabling research began 6 years ago
  - Collaboration with Masaryk and Charles Universities
  - Extensive knowledge of scheduling and constraint-based optimization
  - Published work has been well-received by research communities
- Constraint Programming Techniques
  - Powerful tool for solving optimization problems
  - Problem is described in natural way (variables, values, constraints)
  - Many practical applications in planning, timetabling and scheduling



# Constraint Satisfaction Problem (CSP)

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- Problem  $\Theta = (V, D, C)$ 
  - $V = \{v_1, v_2, \dots, v_n\}$  is a finite set of variables
  - $D = \{Dv_1, Dv_2, \dots, Dv_n\}$  is a set of domains
    - Domain is a finite set of values
  - $C = \{c_1, c_2, \dots, c_m\}$  is a set of constraints
    - A constraint limits the combination of values that can variables simultaneously take
  - Solution is an assignment of all variables  $\eta: V \rightarrow D$ 
    - That satisfy all the constraints from  $C$
- Optimization Problem  $\Theta = (V, D, C, f)$ 
  - $f$  is an objective function
    - That maps every partial feasible assignment to a number
    - Usually expressed by *soft* constraints



# Course Timetabling Model

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- Variables: Classes
- Domains: Time and room assignments
- Constraints: Non-overlap of time/room resources,  
Course structure requirements,  
Faculty time/room requirements,  
Class distribution, Building distances, ...
- Objectives: Minimize student conflicts,  
Maximize time/room/distribution preferences
- Problem model and constraints consider complexity of all university courses



# Student Sectioning Model

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- Variables: Students
- Domains: Assignment of students to classes
- Constraints: Class limits,  
Class conflicts (overlaps in time),  
Reservations,  
Course structure,  
Enrollment projections, ...
- Objectives: Maximize satisfaction of student course/free time requests, and other preferences



# Constraint Solver

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- Iterative Forward Search (IFS)
  - General constraint solver
    - It is working with variables, values, constraints, etc.
  - Hybrid algorithm
    - Mixture of Local Search and Systematic (backtracking-based) search
  - Gradually improves upon incomplete feasible assignments
    - Some variables can be unassigned, but no hard constraint is violated
  - Applicable to various problems and scenarios
  - Extensible
    - Search guiding (meta)-heuristics
    - Dynamic Arc Consistency
    - Conflict-based Statistics learning technique
    - Dynamic Backtracking

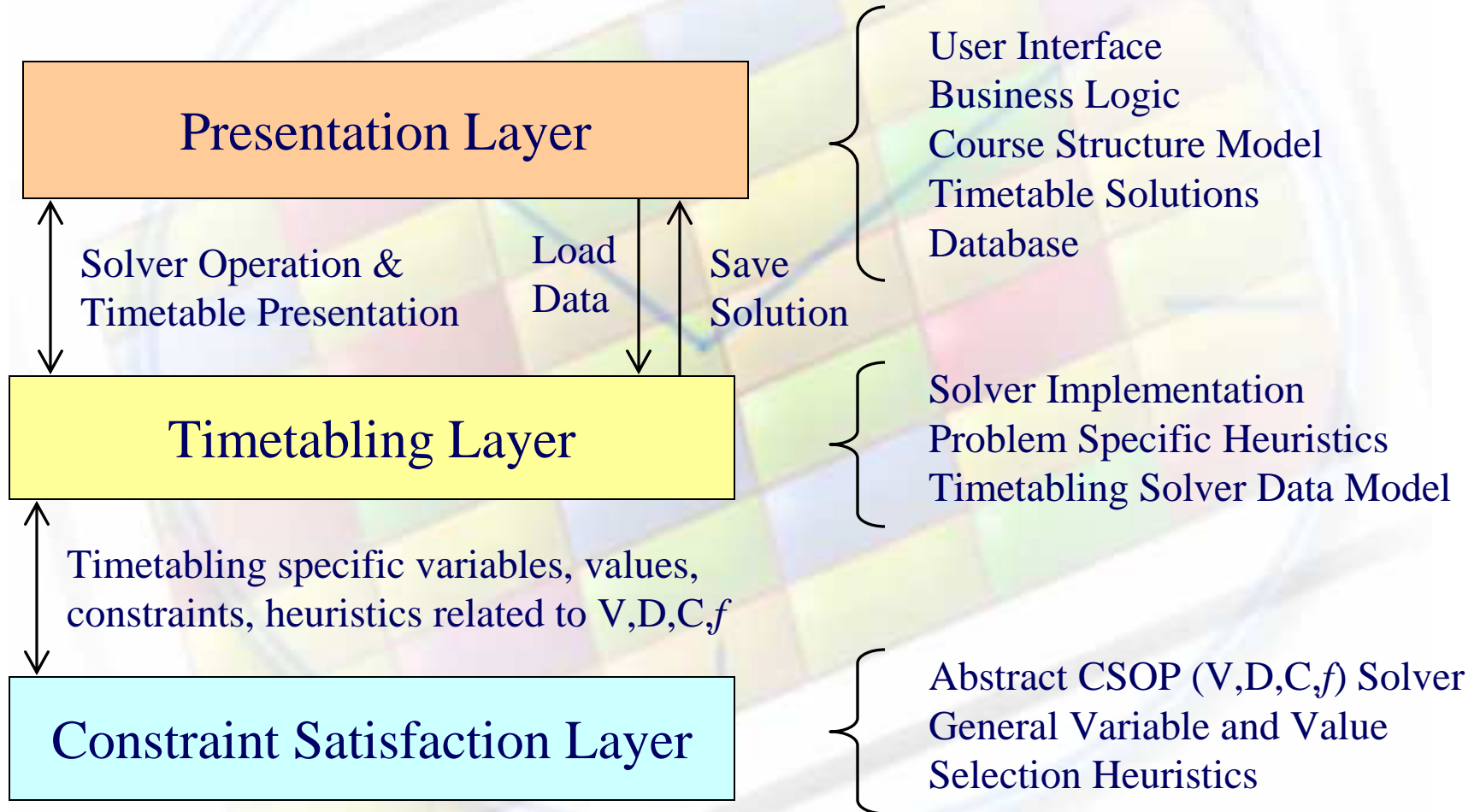


# Application of IFS

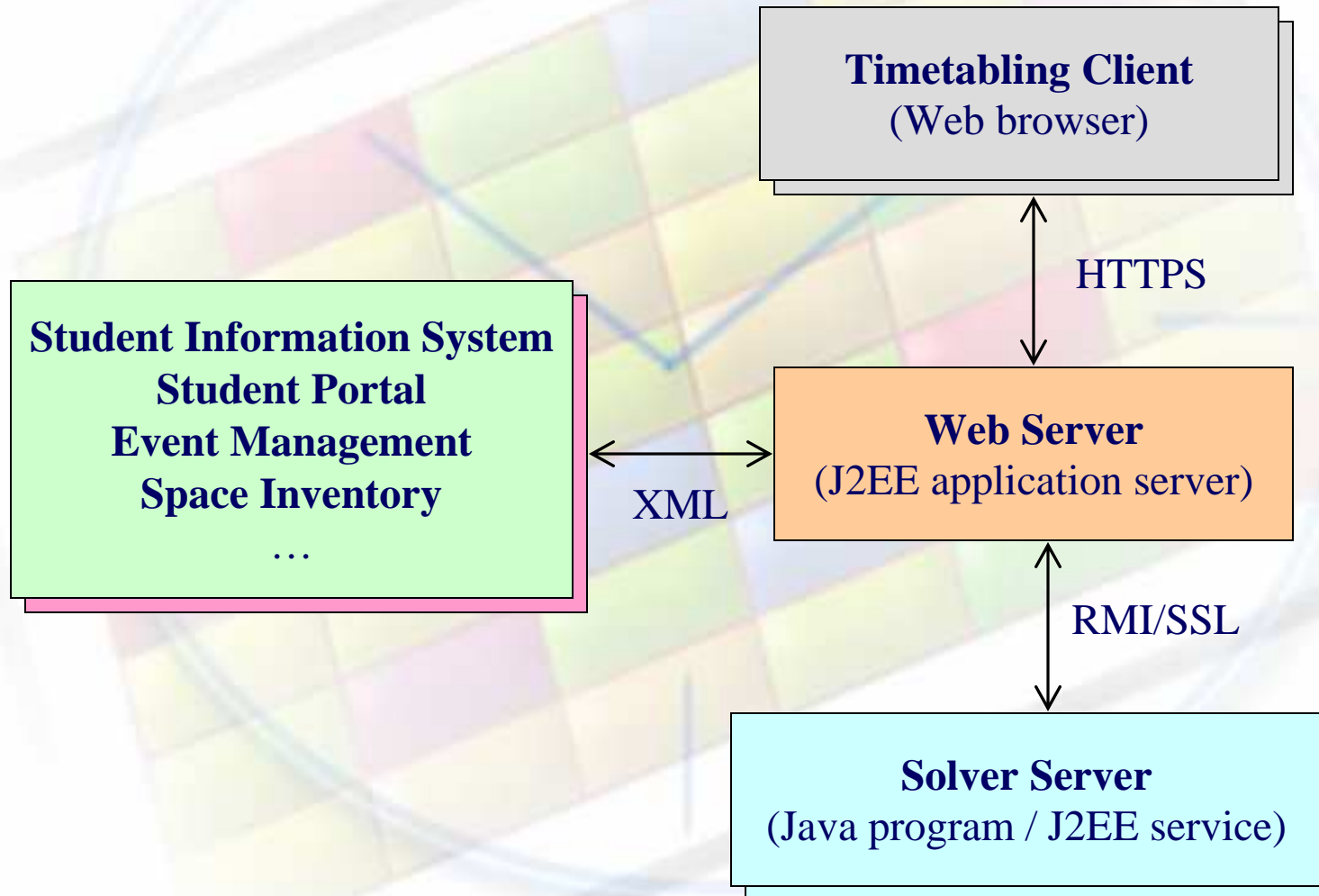
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- Initial Problem Approach
  - All data are given, a solution is computed
- Minimal Perturbation Problem Approach
  - Problem definition can vary in time
    - Environment changes ( broken machines, delayed flights, ... )
    - New properties based on a solution found so far
  - Goal
    - Adopted solution should differ as little as possible from the previous/initial one
- Interactive Approach
  - Help user to construct a solution
  - What if ...

# System Architecture



# System Architecture





# Purdue University Course Timetabling

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- University-wide problem size
  - 9 000 classes, 570 rooms
  - 39 000 students with 259 000 class requests
  
- Problem Decomposition
  - Central timetable for large lecture classes
    - Approximately 900 classes, 54 rooms
    - Utilization over 78% (~ 97% for four largest rooms)
  - Timetables for individual departments
    - 70 timetables with sizes from 10 to 1200 classes
    - Built on top of large lecture timetable
    - Departmental schedule managers are responsible for their own solutions
  - Central computer laboratory timetable

# Purdue University Course Timetabling

- For each class
  - Student requirements
  - Time requirements & preferences
    - Meeting patterns (e.g., 3 x 50 min, 2 x 75 min)
  - Room requirements & preferences
    - Capacity
    - Required equipment
    - Room / building preference
    - Building distances
  - Instructor
  - Additional (distribution) constraints
    - Between several classes (e.g. back-to-back, precedence)
  - Other
    - Departmental balancing, efficient utilization of time and rooms, ...

Each student states which courses he or she wants to attend (soft constraint)

# Purdue University Course Timetabling

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Time Preferences

from:	7:30	8:30	9:30	10:30	11:30	12:30	1:30	2:30	3:30	4:30
to:	8:30	9:30	10:30	11:30	12:30	1:30	2:30	3:30	4:30	5:30
MW	Strongly Discouraged									Discouraged
TTh			Preferred	Strongly Preferred	Strongly Preferred	Preferred				
WF	Strongly Discouraged						Prohibited	Prohibited	Prohibited	Discouraged

# Purdue University Course Timetabling

- For each class
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    - Required equipment
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  - Other
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A legend box with a rounded top and a pointer pointing to the 'Room / building preference' item in the list. It contains seven color-coded entries:

Blue	Required
Green	Strongly Preferred
Light Green	Preferred
White	Neutral
Yellow	Discouraged
Orange	Strongly Discouraged
Red	Prohibited






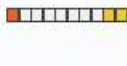
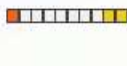
# Important Aspects of Course Timetabling

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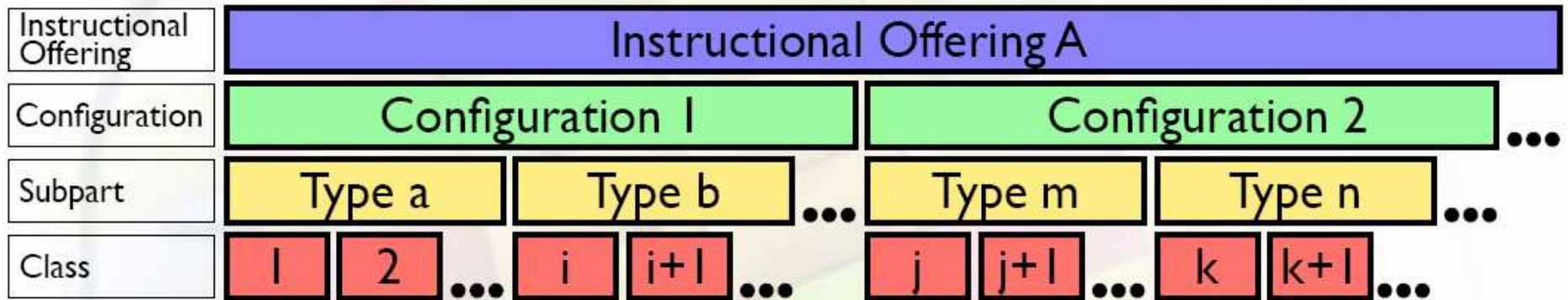
- Interaction between problems
  - Only committed solutions are visible and considered by other problems
    - Consistency is ensured between committed solutions
    - Room sharing
      - At any time, a room is either unavailable, available for use on a first come (commit) first served bases, or allocated to a particular department
    - Mutual constraints (e.g., student enrollments) are considered only between the current problem and solutions to committed problems
  - If there are many relations between two (or more) departments
    - E.g., many students are taking classes from both departments
    - These departments can be solved together
      - A timetable containing all classes of these departments is created
    - Or agree on a solution order
      - E.g., the more difficult problem can be solved and committed, the second timetable is built on top of the first.

# Important Aspects of Course Timetabling

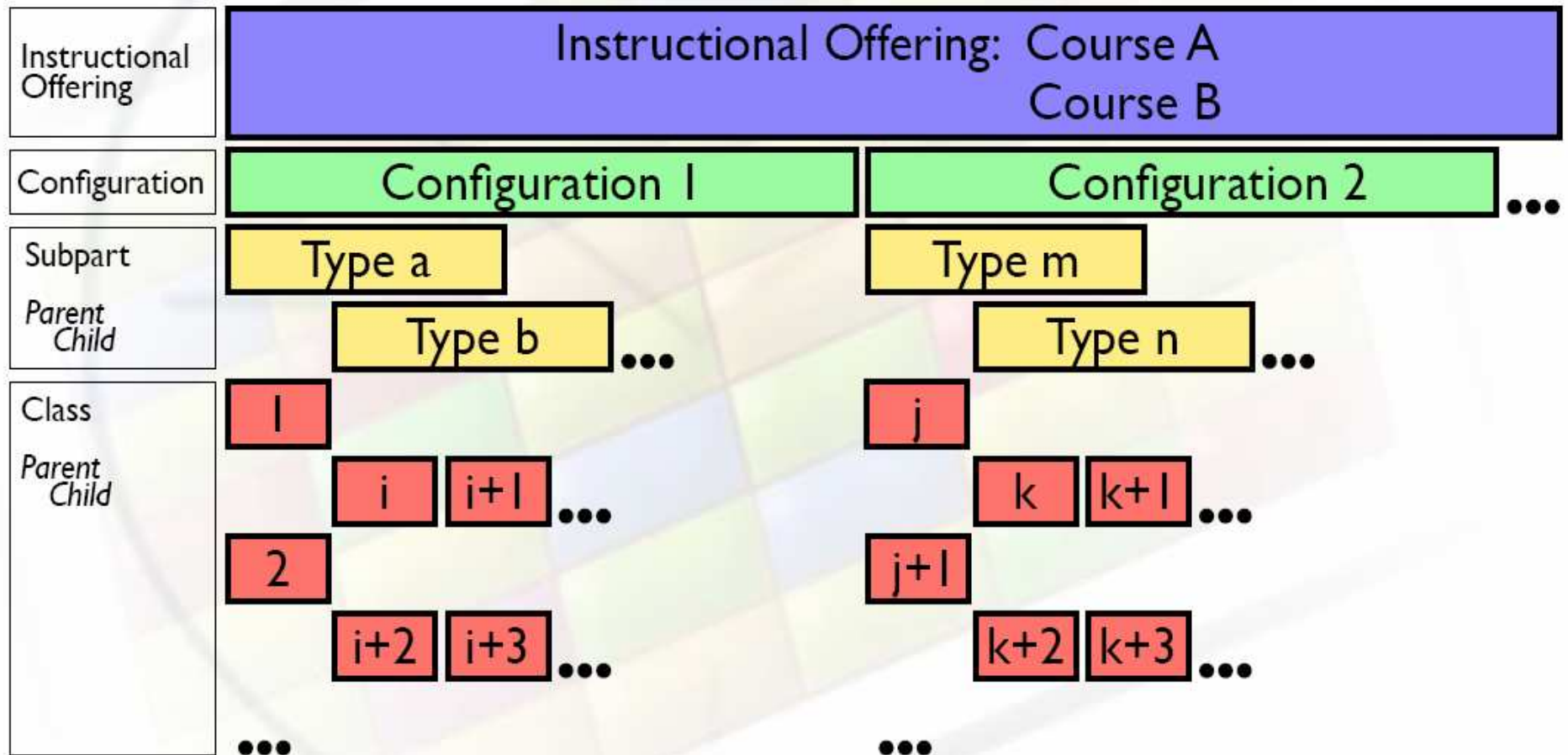
- Data Management (instructional offering structure)
  - Classes are organized in a visual representation of the course structure
    - GUI allows intuitive entry and display of class and constraint data
    - Preferences and requirements can be set at multiple levels
    - Some constraints are automatically deduced from the structure

	Demand	Mins Per Week	Limit	Time Pattern	----Preferences----			Distribution	Instructor
					Time	Room			
<b>MA 170</b>	62		40						
STAT 170									
Lecture		50	40	1 x 50		Classroom			
Laboratory		150	40	3 x 50		ENAD Dell 2.8 machines	BTB		
Lec 1		50	40	1 x 50		Classroom		S. Bell	
Lab 1		150	20	3 x 50		ENAD Dell 2.8 machines	BTB	J. Beckley	
Lab 2		150	20	3 x 50		ENAD Dell 2.8 machines	BTB	J. Beckley	

# Course Structure Model



# Course Structure Model



# Important Aspects of Course Timetabling

- Competitive Behavior (fairness of the solution)
  - Preferred times and rooms
    - Minimization of the overall cost (objective function) typically favors those who provide the most preferences
- Normalization of time preferences
  - Increasing the number of preferences lowers individual preference weights
- Departmental balancing constraint
  - Classes from a department are evenly spread across available times

from:	7:30a	8:30a	9:30a	10:30a	11:30a	12:30p	1:30p	2:30p	3:30p	4:30p
to:	8:20a	9:20a	10:20a	11:20a	12:20p	1:20p	2:20p	3:20p	4:20p	5:20p
MWF	0	0	0	-40	0	0	0	0	0	0

from:	7:30a	8:30a	9:30a	10:30a	11:30a	12:30p	1:30p	2:30p	3:30p	4:30p
to:	8:20a	9:20a	10:20a	11:20a	12:20p	1:20p	2:20p	3:20p	4:20p	5:20p
MWF	0	-5	-5	-20	-5	0	0	0	0	0

from:	7:30a	8:30a	9:30a	10:30a	11:30a	12:30p	1:30p	2:30p	3:30p	4:30p
to:	8:20a	9:20a	10:20a	11:20a	12:20p	1:20p	2:20p	3:20p	4:20p	5:20p
MWF	4	-1	-1	-4	-1	1	1	1	1	1

# Important Aspects of Course Timetabling

## ■ Data Consistency Checking

### ■ Ability to find a solution

- Input data often contain inconsistencies preventing a complete solution from being found
- Therefore, the first stage of the timetabling process is to verify data and identify the weaknesses

### ■ Providing feedback to the user

- Solver must be able to provide information in an easily readable form

- Conflict-based statistics identify problem areas

☐ 15851× C S 110 Lec 1  
☐ 6384× MW 1:30p - 2:20p Full Term EE 129 KING, ERIC J  
☐ 6318× Instructor KING, ERIC J  
☐ 5771× C S 110 Lec 2 ← MW 1:30p - 2:20p Full Term EE 129 KING, ERIC J  
☐ 3541× MW 12:30p - 1:20p Full Term LILY 1105 KING, ERIC J  
☐ 3019× Instructor KING, ERIC J  
☐ 2931× C S 110 Lec 2 ← MW 12:30p - 1:20p Full Term LILY 1105 KING, ERIC J  
☐ 3467× MW 12:30p - 1:20p Full Term EE 129 KING, ERIC J  
☐ 3408× Instructor KING, ERIC J  
☐ 2932× C S 110 Lec 2 ← MW 12:30p - 1:20p Full Term EE 129 KING, ERIC J  
☐ 2459× MW 1:30p - 2:20p Full Term LILY 1105 KING, ERIC J  
☐ 1268× Room LILY 1105  
☐ 1265× BIOL 221 Lec 1 ← MWF 1:30p - 2:20p Full Term LILY 1105 SANDERS, DAVID  
☐ 1191× Instructor KING, ERIC J  
☐ 1191× C S 110 Lec 2 ← MW 1:30p - 2:20p Full Term LILY 1105 KING, ERIC J  
☐ 15840× C S 110 Lec 2  
☐ 2588× BIOL 221 Lec 1  
☐ 338× AGECE 217 Lec 3

# Important Aspects of Course Timetabling

- Interactive Changes (ability to alter a solution)
  - Solutions can be manipulated manually or by fully automated solver
  - Ability to incorporate changes into an existing solution is critical in real-life problems
    - 1) Minimal Perturbation Problem
      - Solution to a modified problem is as close as possible to the initial solution
    - 2) Interactive Mode
      - Solver is guided by the user, providing an evaluated list of choices
      - Backtracking with limited depth is used

<u>Score</u>	<u>Class</u>	<u>Date</u>	<u>Time</u>	<u>Room</u>
0	PHIL 330 Lec 1	08/21-12/17	MWF 4:30p	CL50 224 → WTHR 200
	PSY 120 Lec 4	08/21-12/17	MWF 4:30p	WTHR 200 → CL50 224
+0.8	PHIL 330 Lec 1	08/21-12/17	MWF 4:30p	CL50 224 → EE 129
	AGEC 217 Lec 2	08/21-12/17	MWF 4:30p	EE 129 → CL50 224
+5.75	PHIL 330 Lec 1	08/21-12/17	MWF 4:30p	CL50 224 → LILY 1105

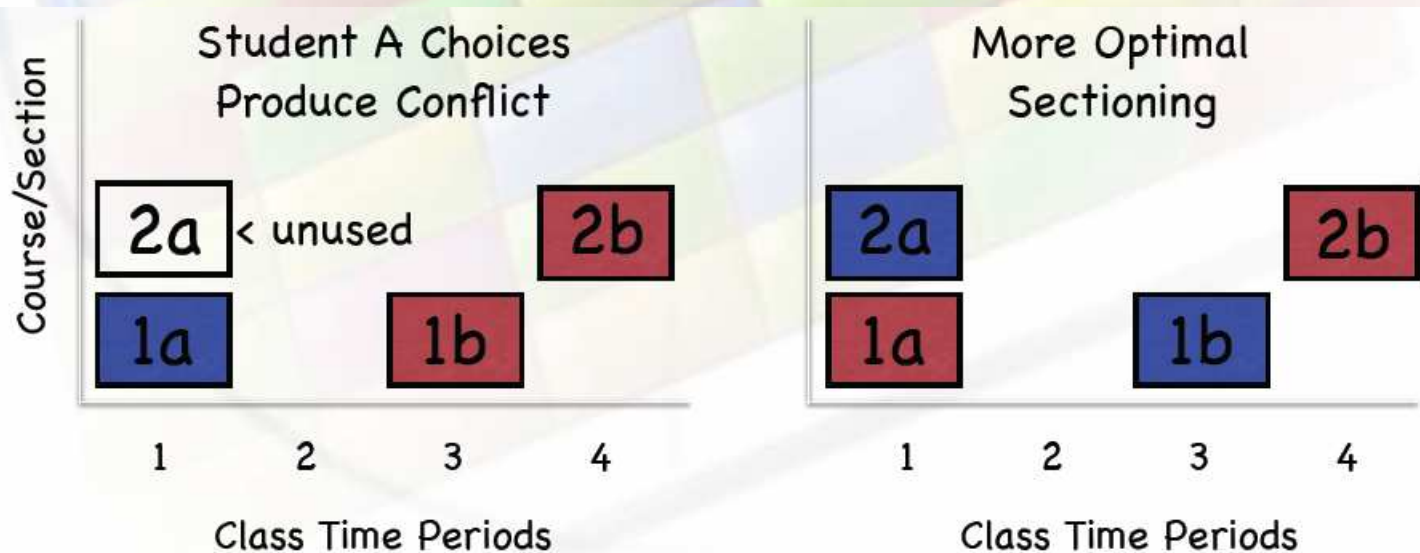
# Purdue University Student Sectioning

- Student Course Requests (*existing students*)
  - Before a timetable is made
  - Requested courses, free times, priorities, alternatives, wait-list?, ...
- Course Timetabling (*existing students*)
  - Student conflicts are considered
    - Last-like term enrollments + course requests from existing students
- Batch Sectioning
  - Sectioning of pre-registered students
- Real-Time Sectioning (*existing students + incoming freshmen*)
  - Incomming students, changes of already sectioned/enrolled students
  - Changes in course timetable
  - Processing of wait-lists

Wk -1	Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6	Wk 7	Wk 8	Wk 9	Sp B	Wk 10	Wk 11	Wk 12	Wk 13	Wk 14	Wk 15	Wk 16
	Cur Space Req						LLR Requests	LLR Schedule	Dept/Lab Schedules								
	List Offerings	Student Preliminary Schedule Requests						Continued Requests				Real-Time Scheduling					

# Important Aspects of Student Sectioning

- Reservation of space for expected (incoming) students
  - Based on last-like term enrollments
  - In each section, a given number of spaces is reserved for new students
    - These reservations are updated as the students are enrolled into classes
  - To avoid student conflicts by individual class time choices
    - E.g., students **A** and **B** each require courses 1 and 2, section *a* of each course meets at the same time



# Important Aspects of Student Sectioning

- Students still need to have some choice (*course requests*)
  - Course priorities
  - Free time requests
  - Alternative course requests
  - Wait-lists

## Primary Course Requests

Add Request

	Type	Course / Free Time		Waitlist	1st Alternative Course	2nd Alternative Course	
1.	Free Time	3 x 50	MWF	7:30a - 8:20a			↓ 🗑
2.	Course	ENGL	106R	<input type="checkbox"/>	ENGL 108R		↑ ↓ 🗑
3.	Course	BIOL	110	<input checked="" type="checkbox"/>			↑ ↓ 🗑
4.	Course	MA	153	<input type="checkbox"/>	MA 159		↑ ↓ 🗑

## Alternative Course Requests

Add Alternative Request

A1.	Course	LATN	101	<input type="checkbox"/>			↑ 🗑
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# Important Aspects of Student Sectioning

- Students still need to have some choice (*online sectioning*)

## Solution

1. Free Time MWF 7:30a - 8:20a Full Term
2. ENGL 106R
  - ☐ Lecture T 9:30a - 10:20a Full Term HEAV 108

Sel	Que	Time	Instructor	Requires
<input type="checkbox"/>		M 8:30a - 9:20a		
<input type="checkbox"/>		M 9:30a - 10:20a		
<input checked="" type="checkbox"/>		M 10:30a - 11:20a		
<input type="checkbox"/>		M 3:30p - 4:20p		
<input type="checkbox"/>		T 8:30a - 9:20a		
<input checked="" type="checkbox"/>		T 9:30a - 10:20a		
<input type="checkbox"/>		T 11:30a - 12:20p		
<input type="checkbox"/>		T 1:30p - 2:20p		
<input type="checkbox"/>		T 3:30p - 4:20p		
  - ☐ Lecture F 9:30a - 10:20a Full Term HEAV 108  
*Queue me for W 10:30a - 11:20a (requires Lecture M 10:30a - 11:20a)*
  - ☐ Lecture Th 9:30a - 10:20a Full Term WTHR 214  
*Queue me for F 10:30a - 11:20a (requires Lecture W 10:30a - 11:20a)*
  - ☐ Recitation M 9:30a - 10:20a Full Term HEAV 225  
*Queue me for T 10:30a - 11:20a (requires Lecture F 10:30a - 11:20a)*  
*Queue me for Th 10:30a - 11:20a (requires Lecture F 10:30a - 11:20a)*

- Choice between available sections
- Wait-listing for sections that are not available
- (Limited) ability to choose time and instructor

# Important Aspects of Student Sectioning

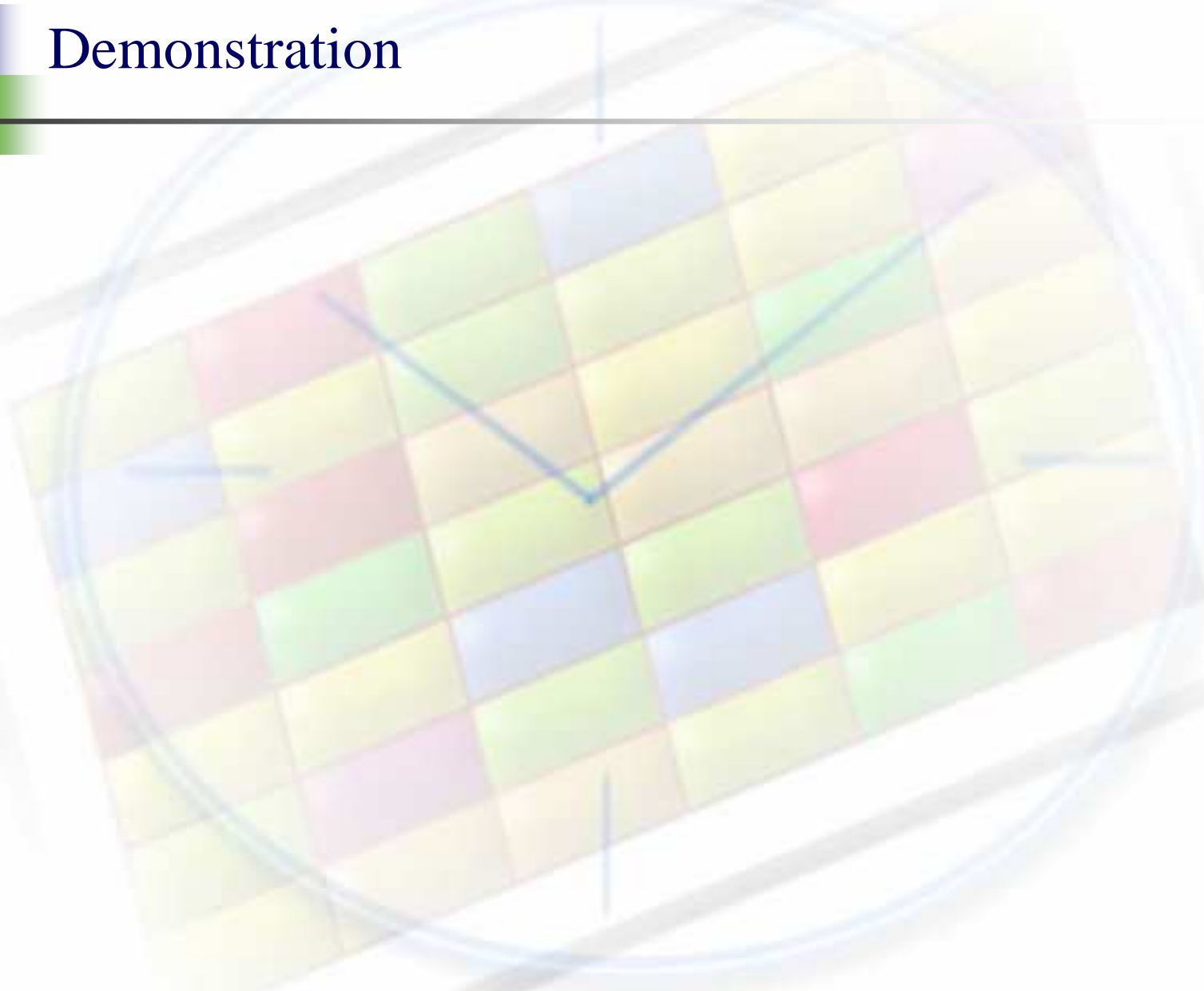
- Reservations
  - Academic area / major / minor reservations
  - Group reservations (learning-communities)
  - Individual reservations
  - Can be set on a course or on a particular class (or set of classes)

## **A&AE 203 - Aeromechanics I (105)**

<i>Academic Area</i>	<i>Type</i>	<i>Reserved</i>	<i>Requested</i>	<i>Projected</i>	<i>Last Term</i>
Aeronautics and Astronautics		67	67	67	65
Electrical & Cmptr Engineering		3	3	3	3
First Yr Engineering		27	27	27	27
School of Liberal Arts		1	1	1	1
Science		2	2	2	2
		<b>100</b>	<b>100</b>	<b>100</b>	<b>98</b>



# Demonstration





# Conclusions

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- Course Timetabling
  - System used for LLR problem from Spring 05 schedule
  - University-wide from Fall 07 schedule
- Student Sectioning
  - Planned for Fall 08 / Spring 09
  
- More Information
  - <http://www.smas.purdue.edu/research>