PURDUE UNIVERSITY

# Purdue University
# Course Timetabling & Course Sectioning

## Space Management & Academic Scheduling

## Purdue University

March 2, 2007

# Agenda

- 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

- 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

- 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)

- Problem $\Theta = ( V, D, C)$
  - $V = \{v_1, v_2, \ldots, v_n\}$ is a finite set of variables
  - $D = \{Dv_1, Dv_2, \ldots, Dv_n\}$ is a set of domains
    - Domain is a finite set of values
  - $C = \{c_1, c_2, \ldots, c_m\}$ 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

- 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

- 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

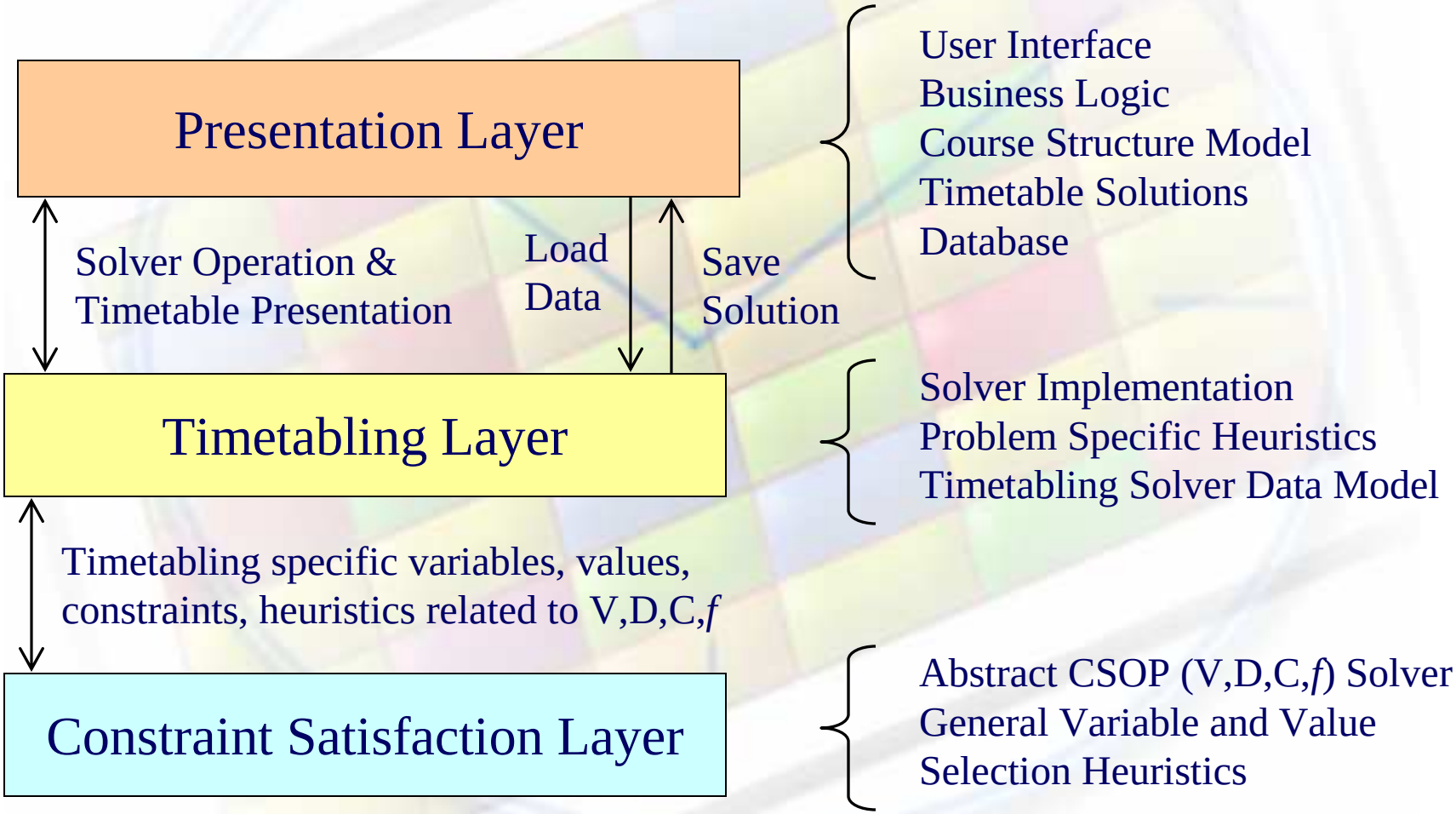
# Constraint Solver

- 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

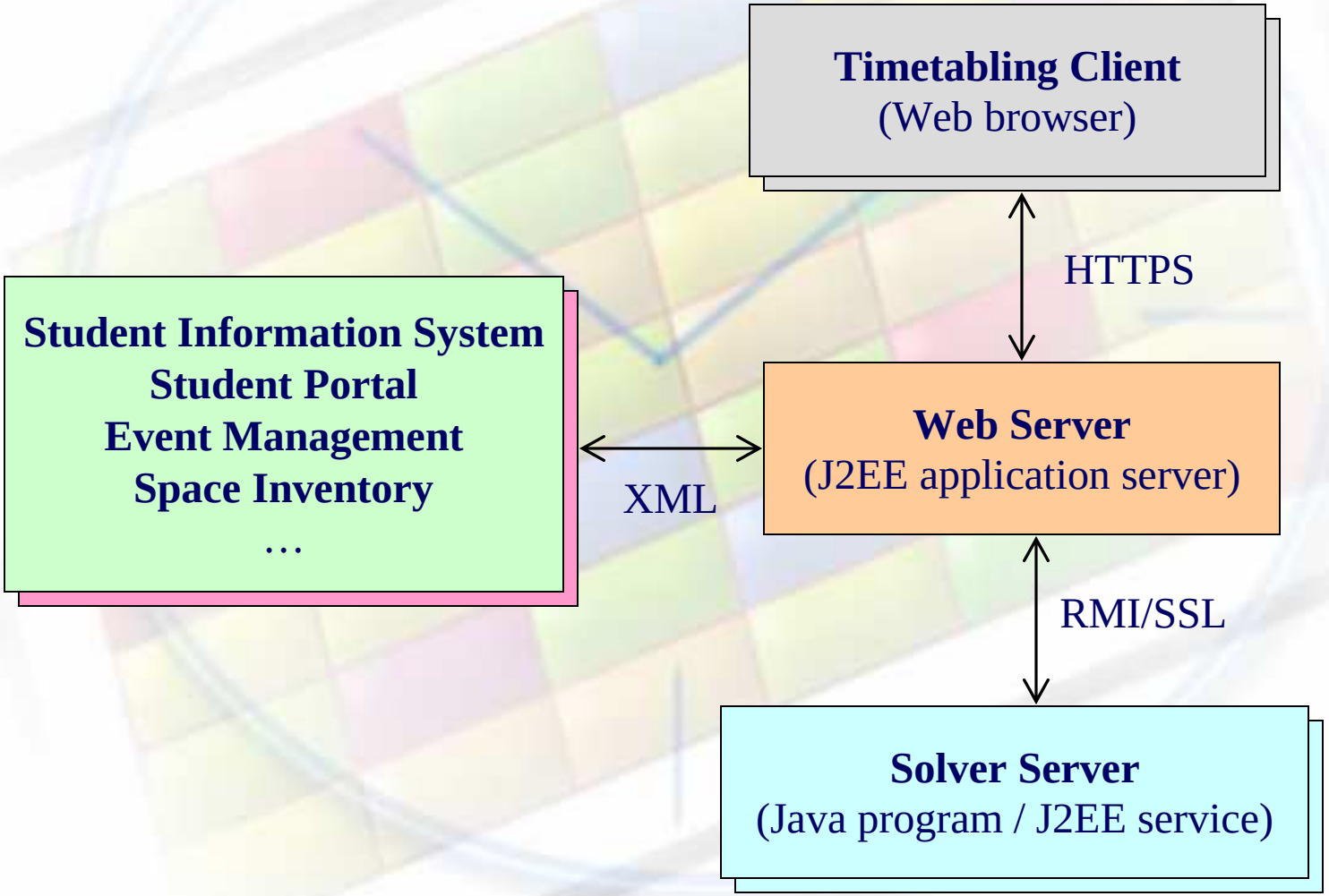
# Application of IFS

- 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

- 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)

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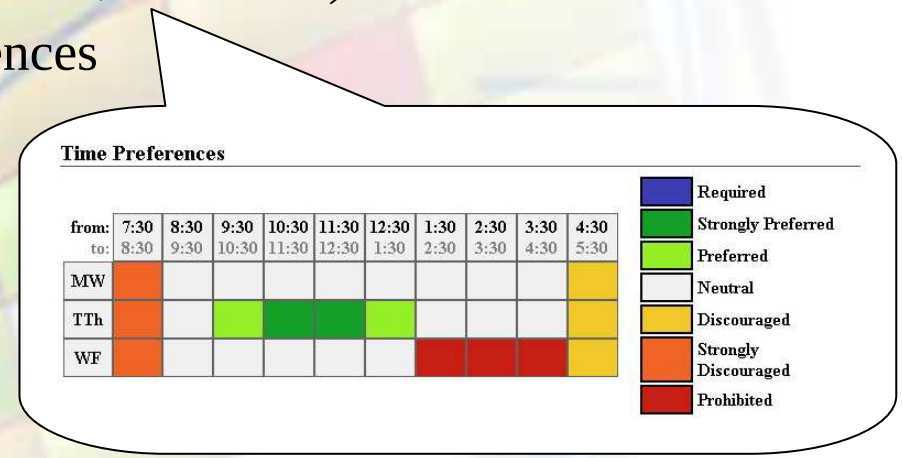

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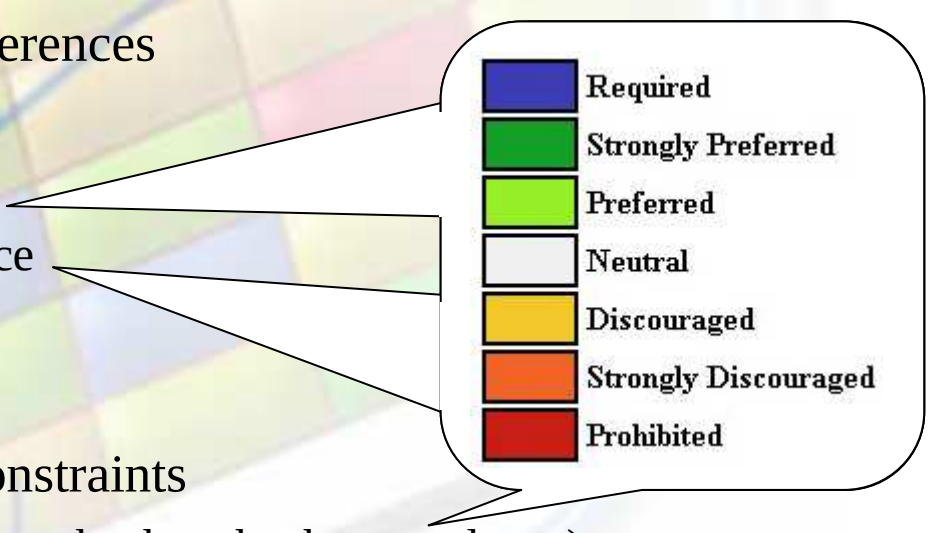
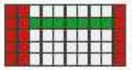
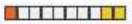
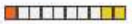


# Important Aspects of Course Timetabling

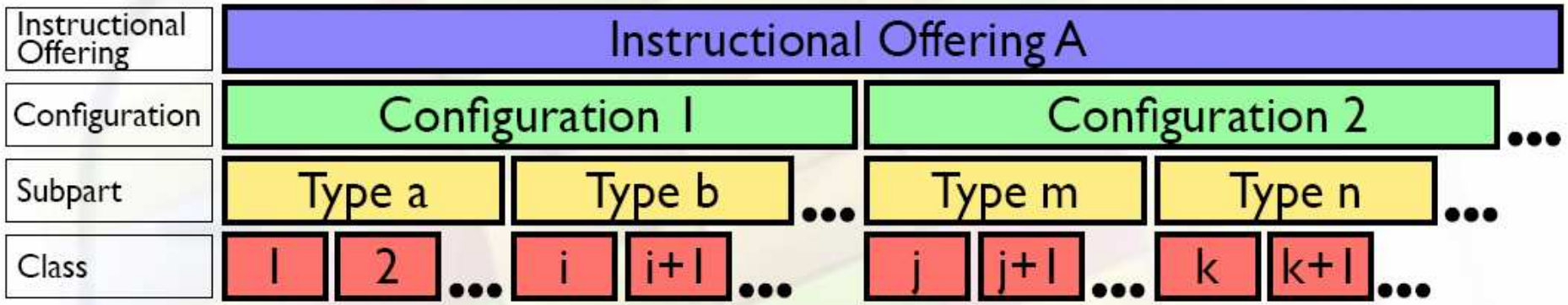
- Interaction between problems
  - Only committed solutions are visible and considered by other problems
    - Consistency is ensured between committed solutions
    - Room sharing
      - At any time, a room is either unavailable, available for use on a first come (commit) first served bases, or allocated 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---- Time | Room | Distribution | Instructor |
|---|---|---|---|---|---|---|---|---|
| **MA 170** STAT 170 | 62 | | 40 | | | | | |
| 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



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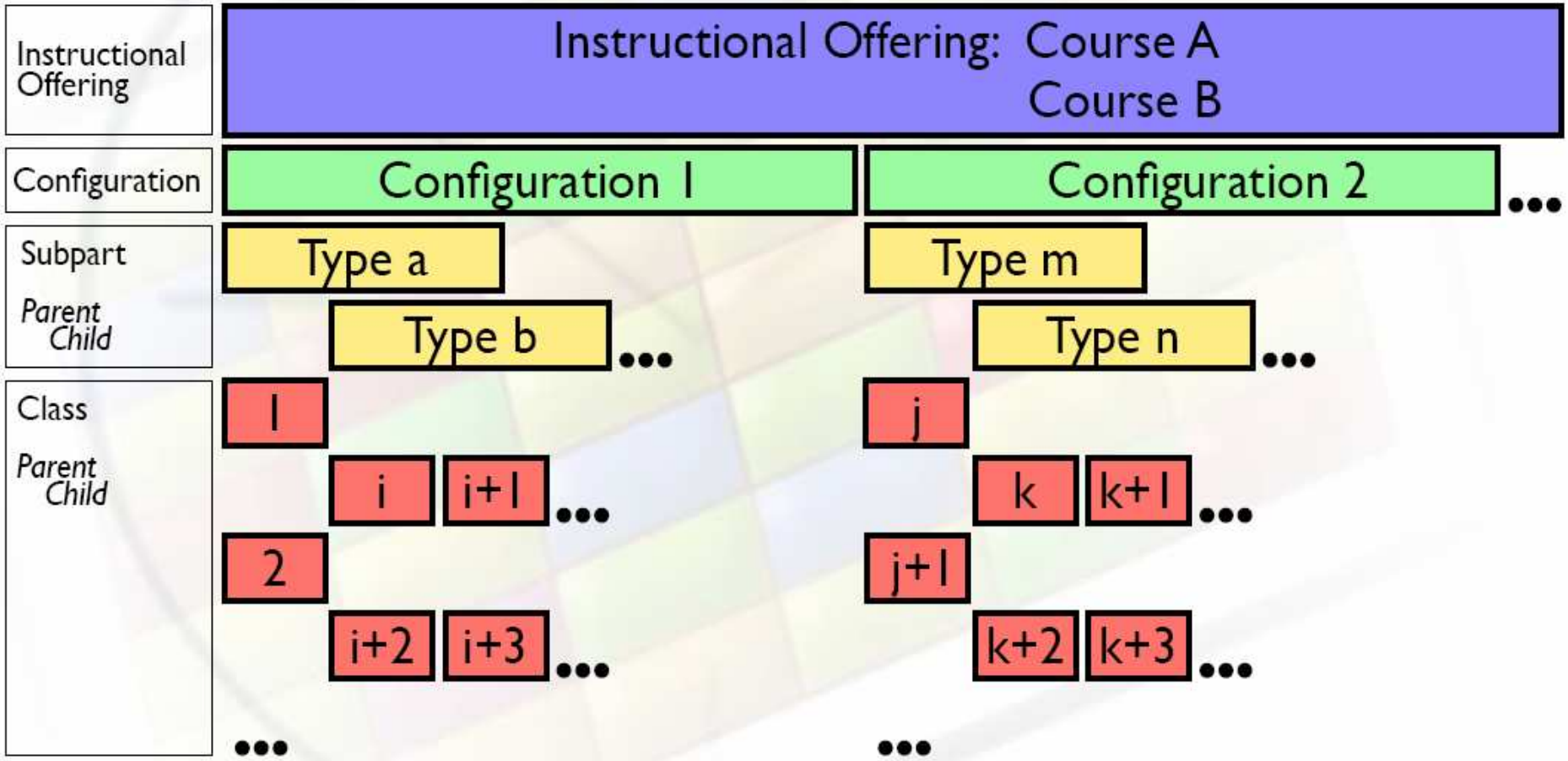


# Important Aspects of Course Timetabling

- 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 preferneces lowers individual preference weights

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

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

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

  - Departmental balancing constraint
    - Classes from a department are evenly spread across available times

# 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

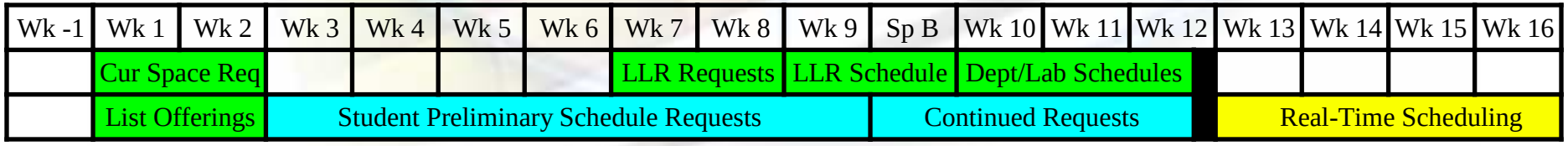
# Important Aspects of Course Timetabling

- 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

| Score | Class | Date | Time | Room |
|---|---|---|---|---|
| 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 |

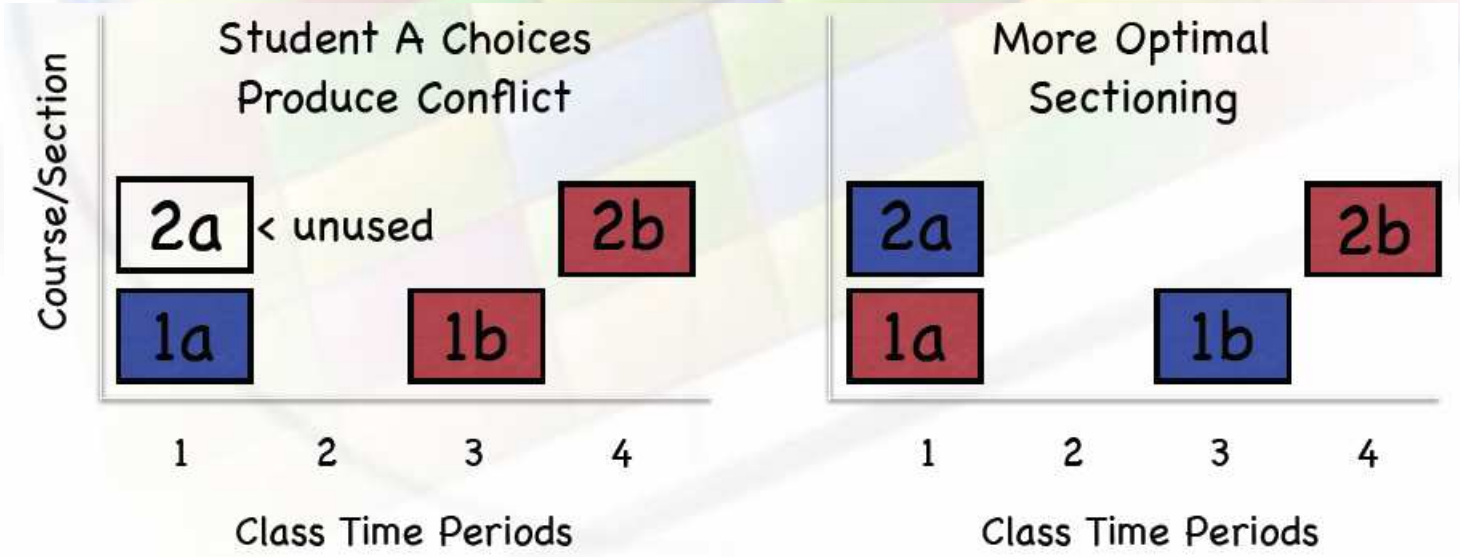
# Purdue University Student Sectioning

- 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



# 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

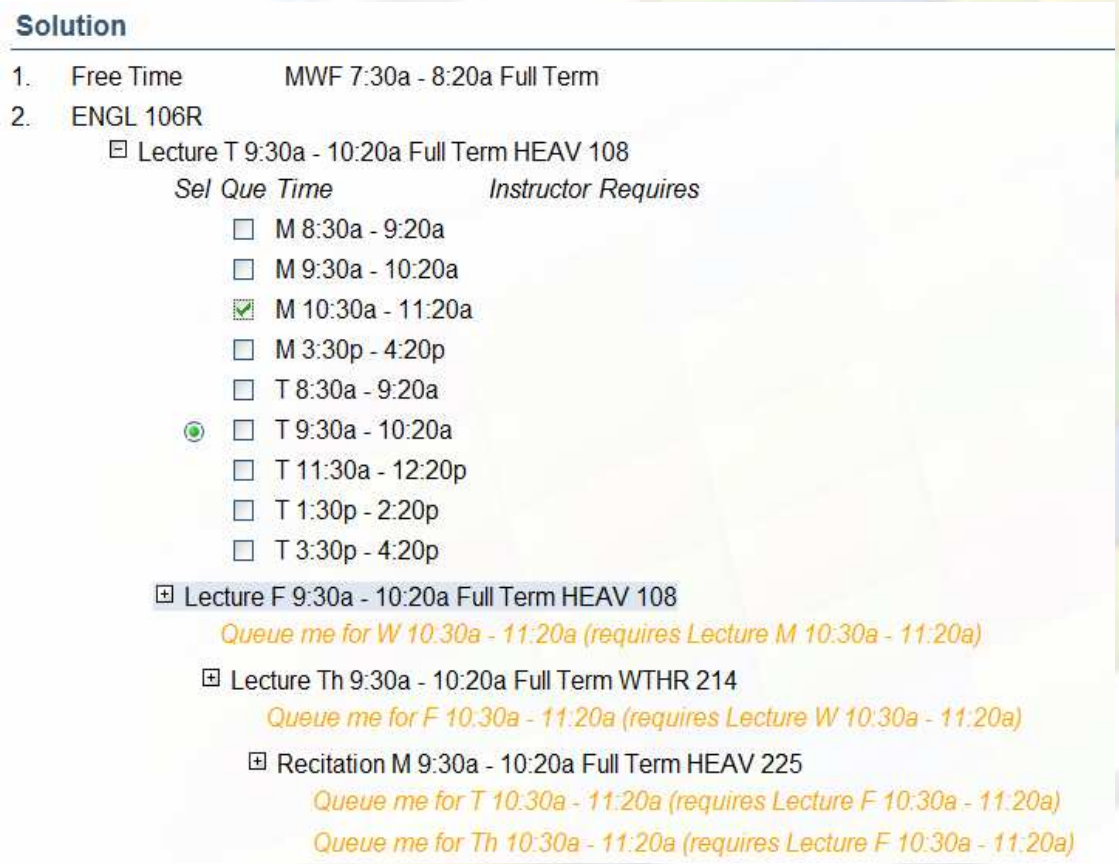


# Important Aspects of Student Sectioning

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

# Important Aspects of Student Sectioning

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




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

# Important Aspects of Student Sectioning

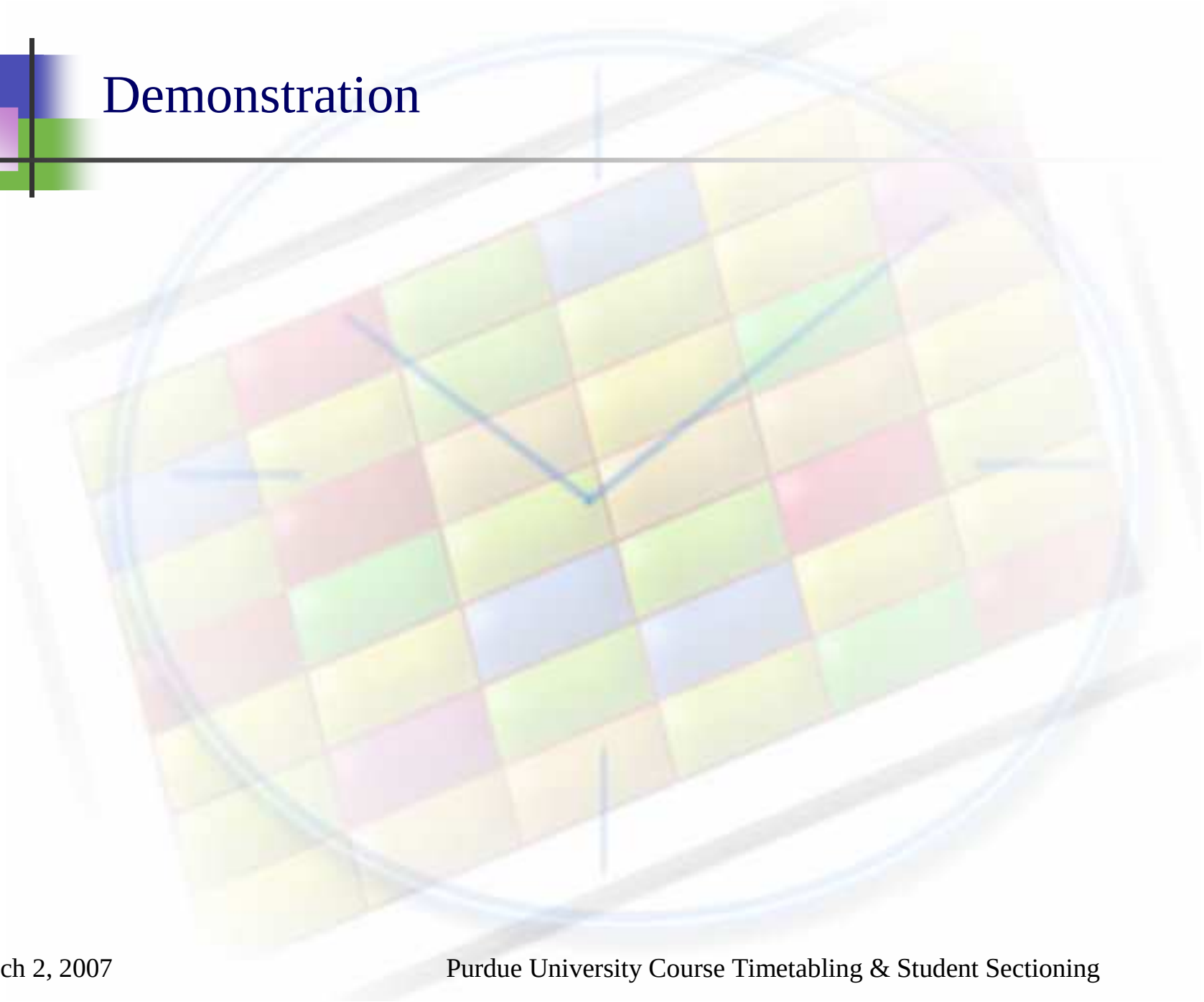
- Reservations
  - Academic area / major / minor reservations
  - Group reservations (learning-communities)
  - Individual reservations

  - Can be set on a course or on a particular class (or set of classes)

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

| *Academic Area* | *Type* | *Reserved* | *Requested* | *Projected* | *Last Term* |
|---|---|---|---|---|---|
| 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 |
| | | **100** | **100** | **100** | **98** |

# Demonstration



# Conclusions

- 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