Iterative Forward Search: Combining Local Search with Maintaining Arc Consistency and a Conflict-based Statistics

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Agenda

- Iterative Forward Search Algorithm
  - Extensions:
    - Conflict-based statistics
    - Maintaining arc consistency
    - Dynamic backtracking

- Experiments
  - Purdue University Timetabling Problem
  - Random binary CSP

- Conclusion
Iterative Forward Search

- Basic Approaches
  - Local search
  - Backtracking based search

- Iterative Forward Search Algorithm
  - Forward based search
  - Works in iterations
  - Extending a (partial) feasible solution
  - Interactivity
Iterative Forward Search Algorithm

A (partial) feasible solution

Unassigned variables
Iterative Forward Search Algorithm

A (partial) feasible solution

Select a variable

Unassigned variables
Iterative Forward Search Algorithm

Select a value

Select a variable

A (partial) feasible solution

Unassigned variables
Iterative Forward Search Algorithm

Select a variable

Select a value

A (partial) feasible solution

Some variables can be unassigned

Unassigned variables

Some variables can be unassigned
Iterative Forward Search Algorithm

Guided by

- Variable selection
  - First-fail principle
- Value selection
  - Best-fit value
- Solution comparator
  - Less unassigned variables, less violated soft constraints, …
- Termination condition
  - Solution is complete and good enough
  - Timeout or user interaction
Conflict-based statistics

- Idea
  - Memorize conflicts and discourage their potential repetition

- If \( B=c \) is unassigned because of the \( A=a \)
  - A counter \( \text{Stat}[A=a, B\neq c] \) is incremented

\[
A = a \implies \begin{cases} 
3 \times B \neq a \\
4 \times B \neq c \\
2 \times C \neq a \\
120 \times D \neq a 
\end{cases}
\]
Conflict-based statistics

To be used e.g. in value selection

- If $a$ is being selected for variable $A$
- And there is $B=b$ in a conflict with $A=a$

$\Downarrow$

Value $a$ is weighted by $\text{Stat}[A=a, B\neq b]+1$

Conflicts are weighted by their occurrences in the past
Maintaining Arc Consistency

Based on explanations

- $V_i \neq v_i \iff (V_1 = v_1 \land V_2 = v_2 \land \ldots \land V_j = v_j)$
- When a value is removed from a domain
  - An explanation is attached to the deleted value
- When a variable is unassigned (e.g., $V_x = v_x$)
  - All deleted values which contain $V_x = v_x$ in their explanations have to be recomputed

Computation

- FC: Explanation corresponds to the violated constraint
- MAC: Union of explanations
Dynamic Backtracking with MAC

- A special case of IFS with MAC
  - An unassigned variable is always selected
  - If there is a variable with an empty domain
    - A union of assignments of all values’ explanations is computed
    - Fail if the computed union is empty
    - The last assignment from the union is unassigned
    - Explanation: all the other assignments in the computed union
  - If a value $v_x$ is assigned to $V_x$
    - An explanation $V_x \neq v_x \iff (V_x = v_x)$ is attached to all values from the variables domain different from $v_x$
Experiments: Purdue University Timetabling

Timetabling Problem at Purdue University

Central timetable for large lecture classes

- 826 classes (forming 1782 meetings)
  - some of them (25%) with multiple sections
- 50 lecture rooms (with various equipment, up to 474 seats)
- 89,633 course demands from 29,808 students
- Utilization over 78% (~ 94% for the four largest rooms)

Timetables for individual departments

- Done manually for the moment
  - An area for our future work

Fall 2004
Experiments: Purdue University 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
- Instructor
- Additional (group) constraints
  - Between several classes (e.g. back-to-back, precedence)
- Other …

Each student states which courses he or she wants to attend (soft constraint)
Experiments: Purdue University Timetabling

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Experiments: Purdue University Timetabling

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- Other …
# Experiments: Purdue University Timetabling

<table>
<thead>
<tr>
<th>Test Case</th>
<th>IFS ConfStat</th>
<th>IFS TABU</th>
<th>IFS MCRW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assigned classes [%]</td>
<td>100.0 ± 0.00</td>
<td>97.67 ± 0.15</td>
<td>98.29 ± 0.16</td>
</tr>
<tr>
<td>Student conflicts [%]</td>
<td>1.97 ± 0.06</td>
<td>1.97 ± 0.07</td>
<td>2.05 ± 0.19</td>
</tr>
<tr>
<td>Preferred time [%]</td>
<td>85.64 ± 1.57</td>
<td>89.86 ± 0.69</td>
<td>89.63 ± 1.06</td>
</tr>
<tr>
<td>Preferred room [%]</td>
<td>50.39 ± 5.34</td>
<td>66.48 ± 3.42</td>
<td>64.84 ± 3.86</td>
</tr>
</tbody>
</table>

- DBT MAC was able to assign approx. 93% of variables
- IFS MAC was able to assign approx. 94% of variables

Best solution within 30 minutes, 10 runs
1 GHz Pentium III, Java 1.4.2
Experiments: CSP(20,15,43%,p_2)

Best solution within 60 seconds
Average from 10 runs
Experiments: minCSP(40,30,43%,p_2)

Best solution value within 60 seconds
Average from 10 runs
Conclusion And Future Work

- IFS algorithm with conflict-based statistics
  - Good results on Purdue University Timetabling Problem

- Future work
  - More results
    - Timetables for individual departments
    - On other (not only timetabling) problems
  - Solver improvements
  - Additional requirements from Purdue University
  - Application of conflict-based statistics in other search techniques