Chapter B: Lessons Learned

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ECLiPSe ELearning

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Main Message

- New ELearning course for ECLiPSe
- Modelling and programming with constraints
- Based on sample problems solved and explained in detail
- A view on core constraint programming skills
- Strong dependence on visualization to explain behavior
Interesting Things to Come

- Which global constraints a system should contain
- How to interpret search trees
- The open challenge of debugging global constraints

Background

- Gift grant from Cisco Systems/Silicon Valley Community Foundation
- Cisco owns open-sourced ECLiPSe system
- How to expand user-base?
- Self-taught course in constraint programming
- Intended for Cisco engineers/programmers
- Open source/available to community
Overview of Course
What do you need to know about CP?
What is CP good for?
A Core Set of Global Constraints
Visualization

Format
- Video lectures
- Slides
- Handout
- Exercises

Examples
- Website
  [http://4c.ucc.ie/~hsimonis/ELearning/index.htm](http://4c.ucc.ie/~hsimonis/ELearning/index.htm)
- Slides
  [../introduction/slides.pdf](../introduction/slides.pdf)
- Handout
  [../introduction/handout.pdf](../introduction/handout.pdf)
- Video
  [../wavedemo/DEMO/web/web.html](../wavedemo/DEMO/web/web.html)
Central Topics

- Basic structure of constraint programs
- Global constraints
- User-defined search
- Optimization
- Symmetry breaking
- Choosing the right model
- Limits of propagation

Explaining Concepts

- Explain as you go
- Constraints introduced when used by application
- Concepts/algorithms explained by example
Example: Domain consistent \texttt{alldifferent}

\begin{verbatim}
:-lib(ic).
:-lib(ic_global_gac).

top:-
    [X,Y] :: 1..2,
    Z :: 2..5,
    [T,U] :: 3..5,
    V :: [2,4,6,7],
    ic_global_gac:alldifferent([X,Y,Z,T,U,V]).
\end{verbatim}
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Making constraint domain consistent

Find maximal matching (in blue)

Orient graph (edges in matching from variables to values, all others from values to variables), mark edges in matching
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Making constraint domain consistent

Find strongly connected components (green and brown), mark their edges

X 1
Y 2
Z 3
T 4
U 5
V 6
7

Find unmatched value nodes (here node 7, magenta)
Making constraint domain consistent

Find alternating paths from such nodes (in magenta), mark their edges.

All unmarked edges can be removed.
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Making constraint domain consistent

Resulting graph, constraint is domain consistent

Extended Example

:-lib(ic).
:-lib(ic_global_gac).

top:-
    X :: 1..2,
    Y :: [1,2,7],
    Z :: 2..5,
    [T,U] :: 3..5,
    V :: [2,4,6,7],
    ic_global_gac:alldifferent([X,Y,Z,T,U,V]).
No propagation in expanded example

Problem shown as bipartite graph

Find maximal matching (in blue)
No propagation in expanded example

Orient graph (edges in matching from variables to values, all others from values to variables), mark edges in matching

Find strongly connected components (green and brown), mark their edges
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No propagation in expanded example

Find unmatched value nodes (here node 7, magenta)

Find alternating paths from such nodes (in magenta), mark their edges
No propagation in expanded example

Continue with alternating paths

No propagation in expanded example

Continue with alternating paths, all edges marked, no propagation, constraint is domain consistent
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No Theoretical Background

- Target audience
  - Engineers
  - Application programmers
- Not a course in theoretical computer science
- Different from current textbooks on CP

This was easy ten years ago:

- Based on industrial experience
  - Assignment problems
  - Scheduling
  - Transportation
  - Personal planning
In the meantime

- Dramatic improvements for competitors
  - MILP
  - SAT
- Improvements in hardware performance

New Areas

- Configuration
  - In search of a nice example
- Placement
  - Not in ECLiPSe
- Networks
  - In form of MIP/FD hybrids
Problems Handled in Course

- Must have puzzles!
- Send+More=Money
- Sudoku
- N-queens
- Shikaku (see Wednesday’s talk)

Practical Example Problems

- Test plan generation (BIBD)
- Progressive party problem
- Routing and wavelength assignment
- Optical network design
- Car sequencing
- Costas arrays
- Sports scheduling
- Still to come
  - Production scheduling
  - Nurse rostering
  - Airport stand allocation
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Intention

- Realistic, life like problems
- Must address scalability issues
- Often, problem not completely specified
- Issue: Hard to verify by hand
- Complexity still limited, not real problems
- No attempt at integration

What is CP good for: A Problematic View

- CP works if it out-performs everything else
- See which technique produces best (optimal) solutions
- Which technique runs fastest
- A publication game (I like to play too!)
  - Somebody defines the problem
  - Minute detail, no choices left
  - Counting runtime, choices, backtracks
  - Tiny improvements count
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From RWA Chapter

<table>
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<th>Network</th>
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Question

- Is MIP-FD decomposition really better than MIP-SAT?
- Both are good enough
- Both are clearly better than complete MIP
- This is only one possible problem variant
  - For other variant difference is much more significant
A More Meaningful Evaluation

- When is a solution good enough?
- How long does it take to get there?
  - Total development time, not runtime
  - For whom: beginner, expert, genius?
- What happens if you change the problem?
- Can you explain what is happening?
- How easy it is to integrate into workflow?

Problem: How do we measure/report this?

- Usability labs?
- Instrument IDE?
- Cost of parallel development
- Commercial sensitivities
- Can this be published?
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Global Constraint Catalog (A-C)

- all differ from at least k pos
- all equal
- all min dist
- alldifferent
- alldifferent between sets
- alldifferent consecutive values
- alldifferent cst
- alldifferent except 0
- alldifferent interval
- alldifferent modulo
- alldifferent on intersection
- alldifferent partition
- alldifferent same value
- allperm
- among
- among diff 0
- among interval
- among low up
- among modulo
- among seq
- among var
- and
- arith
- arith or
- arith sliding
- assign and counts
- assign and nvalues
- atleast
- atleast nvalue
- atleast nvector
- atmost
- atmost nvalue
- atmost nvector
- balance
- balance interval
- balance modulo
- balance partition
- between min max
- bin packing
- bin packing capa
- binary tree
- bipartite
- calendar
- cardinality atleast
- cardinality atmost
- cardinality atmost partition
- change
- change continuity
- change pair
- circuit
- circuit cluster
- circular change
- clause and
- clause or
- clique
- colored matrix
- coloured cumulative
- coloured cumulatives
- common
- common interval
- common modulo
- common partition
- cond lex cost
- cond lex greater
- cond lex greater or
- cond lex less
- cond lex lesseq
- cond lex lesseq

Core Global Constraints

- element
- alldifferent
- gcc
- lex-ordering
- bin packing
- sequence
- cumulative
- regular
- diffn/disjoint/geost

Not sure about:

- min weight
- alldifferent
- gcc with cost
- cycle
- nvalue
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Sources

- Good survey papers and PhD thesis
  - W. van Hoeve: `alldifferent`
  - C. Quimper: `alldifferent, gcc`
  - Z. Kiziltan: `lex ordering`
- Clear descriptions of specific constraints
  - P. Shaw: `bin packing`
  - G. Pesant: `regular`

Families of Constraints

- Matching/flow based global constraints
  - Build graph
  - Find matching/flow
  - Reorient links
  - Find SCC
  - (BFS reachable)
  - Remove unmarked edges
Examples

- alldifferent
- gcc
- alldifferent matrix
- gcc matrix
- same
- sequence

Some Constraints Still Opaque

- cumulative
- cycle
- geost
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Which Variant to Implement

- **gcc**
  - Low/high limits or variables for counters
  - Open/closed version

- **cumulative**
  - Capacity limit or variable
  - End limit
  - Task surface

Use in Course

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Open Challenge

- How do we implement/test global constraints?
- No publication, ever
- No methodology

Techniques Used

- Profiling
- Line coverage
- Generic GAC
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Generic GAC: **alldifferent_sum**

\[
\text{alldifferent_sum}(L,N) :-
\begin{align*}
\text{ic:alldifferent}(L), \\
\text{sum}(L) &\neq N, \\
\text{labeling}(L)
\end{align*}
\]

infers ac.

Propia library (Le Provost, Wallace)
Worst Case Scenario: Progressive Party Problem

- Progressive Party Problem
- Adding stronger global constraint, bin packing (P. Shaw)
- Found different solution
  - Variable selection changed by improved propagation?
  - Consistent value removed by bug in constraint?

How do we understand behavior?

- Mental model
- Formal analysis
- Debugging
- Tracing
- Life visualization
- Post-mortem analysis
Design Choices

- No deep integration with solver
- Post-mortem visualization
- Intermediate file format
- No view of detailed propagation
  - Tool not intended for debugging constraint engine

Conceptual Model

- Stable state at defined program points
- Granularity
  - Assign value
  - Post constraint
- Show stable state after propagation
- Do not show individual propagation steps
Visualizers

- Search tree
- Variables
- Constraints

Visualization Tool

- Developed in Java
- Show two panes: tree and state
- Navigate along timeline
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Visualization Tool: Car Sequencing

How many visualizers do we need?

- Develop few primitives
  - Cell based view
  - Domain vector
- Allow aggregation
  - Vector/matrix
  - General layout
- Which global constraints require more?
  - Task based view for cumulative
  - Matching/flow based representation does not scale
How to Interpret Visualization

- Search tree
  - Good/bad choices
  - Place of backtracking
- State
  - Missing propagation

Costas Array Search tree (Size 16)

- Deep backtracking
- Third choice wrong
- Last choice wrong
- Value selection strategy useless
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Missing Propagation

The model is doing this

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Missing Propagation

It could be doing that!

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Comparison (Search Tree, size 16)

Initial Model

Improved Model

Progressive Party Problem, 9 Time Periods
2 Restarts Before Solution Found

Value Choice Strategy Not Focused
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Progressive Party

- Clearly impossible to explore search space
- Either many solutions or good value selection
- Value selection at end rather poor
- Probably many solutions

From Shikaku Presentation (Wednesday)
What is still missing?

- Explanation of failures
  - Procedural: Show propagation which leads to failure
  - Declarative: Find conflict set
- Comparison of trees

How was this generated?

- Slides produced with LaTeX `beamer` class
- Templates for chapters
- Visualization imported as pdf files
- Using `inkscape` as SVG to PDF converter
- Allows to produce multiple versions from one source
  - slides
  - handout
  - article
Recorded and produced with Camtasia Studio
Long takes, minimal editing
Screen capture at full resolution
Produce video in different target formats
- Web based (640x480)
- iPhone (480x320)
- HD video possible

Metrics without Program Development

- Slides: 2-4 days per chapter
- Video: 1:10 ratio for finished product
  - 2-3 trials
  - No fine grain editing
  - Only for bulk production
Conclusions

- New ELearning course for ECLiPSe
- Open source material, Creative Commons BY-NC-SA license
  - Application driven
  - Modelling with global constraints
  - Customizing search
- Effort only justifiable through Cisco grant

If you are not using visualization, why not?
- Generic tools, not just for ECLiPSe