DM841
DISCRETE OPTIMIZATION

Introduction to Gecode

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[*Based on slides by Christian Schulte, KTH Royal Institute of Technology*]

Outline

1. Constraint Languages

2. Gecode

Resume

- Modelling in CP
  - Examples: graph labelling with consecutive numbers, cryptoarithmetic
- Overview on Constraint Programming
  - modelling
  - search = backtracking + branching
  - propagate (inference) + filtering

Constraint Programming:
representation (modeling language) + reasoning (search + propagation)

Outline

Constraint Programming Systems

(modeling)
Expressive language stream
+
(efficient solvers)
Algorithm stream

CP systems typically include

- general purpose algorithms for constraint propagation (arc consistency on finite domains)
- built-in constraint propagation for various constraints (eg, linear, Boolean, global constraints)
- built-in for constructing various forms of search

Logic Programming

Logic programming is the use of mathematical logic for computer programming.

First-order logic is used as a purely declarative representation language, and a theorem-prover or model-generator is used as the problem-solver.

Logic programming supports the notion of logical variables

- Syntax – Language
  - Alphabet
  - Well-formed Expressions
    E.g., 4X + 3Y = 10; 2X - Y = 0
- Semantics – Meaning
  - Interpretation
  - Logical Consequence
- Calculi – Derivation
  - Inference Rule
  - Transition System

Logic Programming

Example: Prolog

> *A logic program is a set of axioms, or rules, defining relationships between objects.*
>
> *A computation of a logic program is a deduction of consequences of the program.*
>
> *A program defines a set of consequences, which is its meaning.*

Sterling and Shapiro: The Art of Prolog, Page 1.

To deal with the other constraints one has to add other constraint solvers to the language. This led to Constraint Logic Programming

Prolog Approach

- Prolog II till Prolog IV [Colmerauer, 1990]
- CHIP V5 [Dincbas, 1988] http://www.cosytec.com (commercial)
- CLP [Van Hentenryck, 1989]
- Ciao Prolog (Free, GPL)
- GNU Prolog (Free, GPL)
- SICStus Prolog
- ECLiPSe [Wallace, Novello, Schimpf, 1997] http://eclipse-clp.org/ (Open Source)
- Mozart programming system based on Oz language (incorporates concurrent constraint programming) http://www.mozart-oz.org/ [Smolka, 1995]

Other Approaches

Libraries:
Constraints are modeled as objects and are manipulated by means of special methods provided by the given class.

- CHOCO (free) http://choco.sourceforge.net/
- Kaolog (commercial) http://www.koalog.com/php/index.php
- ILOG CP Optimizer www.cpoptimizer.ilog.com (ILOG, commercial)
- Gecode (free) www.gecode.org
  C++, Programming interfaces Java and MiniZinc
- G12 Project
  http://www.nicta.com.au/research/projects/constraint_programming_platform

Other Approaches

Modelling languages:

- OPL [Van Hentenryck, 1999] ILOG CP Optimizer
  www.cpoptimizer.ilog.com (ILOG, commercial)
- MiniZinc [] (open source, works for various systems, ECLiPSe, Geocode)
- Comet
- AMPL

- Catalogue of Constraint Programming Tools:
  `http://openjvm.jvmhost.net/CPSolvers/`

- Workshop "CPSOLVERS-2013"
  `http://cp2013.a4cp.org/node/99`

CP Languages

Greater expressive power than mathematical programming

- constraints involving disjunction can be represented directly
- constraints can be encapsulated (as predicates) and used in the definition of further constrains

However, CP models can often be translated into MIP model by

- eliminating disjunctions in favor of auxiliary Boolean variables
- unfolding predicates into their definitions

CP Languages

- Fundamental difference to LP
  - language has structure (global constraints)
  - different solvers support different constraints
- In its infancy
- Key questions:
  - what level of abstraction?
    - solving approach independent: LP, CP, ...?
    - how to map to different systems?
  - Modeling is very difficult for CP
    - requires lots of knowledge and tinkering

Summary

- Model your problem via Constraint Satisfaction Problem
- Declare Constraints + Program Search
- Constraint Propagation
- Languages

Outline

1. Constraint Languages

2. Gecode

Gecode

an open constraint solving library

Christian Schulte
KTH Royal Institute of Technology, Sweden

Gecode People

- Core team
  - Christian Schulte, Guido Tack, Mikael Z. Lagerkvist.
- Code
  - contributions: Christopher Mears, David Rijsman, Denys Duchier, Filip Konvicka, Gabor Szokoli, Gabriel Hjort Blindell, Gregory Crosswhite, Håkan Kjellerstrand, Joseph Scott, Lubomir Moric, Patrick Pekczynski, Raphael Reischuk, Stefano Gualandi, Tias Guns, Vincent Barichard.
  - fixes: Alexander Samoilov, David Rijsman, Geoffrey Chu, Grégoire Dooms, Gustavo Gutierrez, Olof Sivertsson, Zandra Norman.
- Documentation
  - contributions: Christopher Mears.
  - fixes: Seyed Hosein Attarzadeh Niaki, Vincent Barichard, Pavel Bochman, Felix Brandt, Markus Böhm, Roberto Castañeda Lozano, Gregory Crosswhite, Pierre Flener, Gustavo Gutierrez, Gabriel Hjort Blindell, Sverker Janson, Andreas Karlsson, Håkan Kjellerstrand, Chris Mears, Benjamin Negrevergne, Flutra Osmani, Max Ostrowski, David Rijsman, Dan Scott, Kish Shen.

Gecode

Generic Constraint Development Environment

- **open**
  - easy interfacing to other systems
  - supports programming of: constraints, branching strategies, search engines, variable domains

- **comprehensive**
  - constraints over integers, Booleans, sets, and floats
    - different propagation strength, half and full reification, …
  - advanced branching heuristics (accumulated failure count, activity)
  - many search engines (parallel, interactive graphical, restarts)
  - automatic symmetry breaking (LDSB)
  - no-goods from restarts
  - MiniZinc support

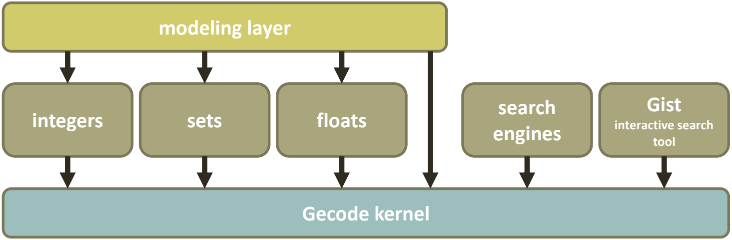
Gecode

Generic Constraint Development Environment

- **efficient**
  - *all* gold medals in *all* categories at *all* MiniZinc Challenges
- **documented**
  - tutorial (> 500 pages) and reference documentation
- **free**
  - MIT license, listed as free software by FSF
- **portable**
  - implemented in C++ that carefully follows the C++ standard
- **parallel**
  - exploits multiple cores of today's hardware for search
- **tested**
  - some 50000 test cases, coverage close to 100%

SOME BASIC FACTS

Architecture



- Small domain-independent kernel
- Modules
  - per variable type: variables, constraint, branchings, …
  - search, FlatZinc support, …
- Modeling layer
  - arithmetic, set, Boolean operators; regular expressions; matrices, …
- All APIs are user-level and documented (tutorial + reference)

Openness

- MIT license permits commercial, closed-source use
  - motivation: public funding, focus on research
  - not a reason: attitude, politics, dogmatism
- More than a license
  - **license** restricts what users **may do**
  - **code and documentation** restrict what users **can do**
- Modular, structured, documented, readable
  - complete tutorial and reference documentation
  - new ideas from Gecode available as scientific publications
- Equal rights: Gecode users are first-class citizens
  - you can do what we can do: APIs
  - you can know what we know: documentation
  - on every level of abstraction

Constraints in Gecode

- Constraint families
  - arithmetics, Boolean, ordering, ….
  - alldifferent, count (global cardinality, …), element, scheduling, table and regular, sorted, sequence, circuit, channel, bin-packing, lex, geometrical packing, nvalue, lex, value precedence, …
- Families
  - many different variants and different propagation strength
- All global constraints from MiniZinc have a native implementation
- Gecode ⇆ Global Constraint Catalogue: > 70 constraints

  abs_value, all_equal, alldifferent, alldifferent_cst, among, among_seq, among_var, and, arith, atleast, atmost, bin_packing, bin_packing_capa, circuit, clause_and, clause_or, count, counts, cumulative, cumulatives, decreasing, diffn, disjunctive, domain, domain_constraint, elem, element, element_matrix, eq, eq_set, equivalent, exactly, geq, global_cardinality, gt, imply, in, in_interval, in_intervals, in_relation, in_set, increasing, int_value_precede, int_value_precede_chain, inverse, inverse_offset, leq, lex, lex_greater, lex_greatereq, lex_less, lex_lesseq, link_set_to_booleans, lt, maximum, minimum, nand, neq, nor, not_all_equal, not_in, nvalue, nvalues, or, roots, scalar_product, set_value_precede, sort, sort_permutation, strictly_decreasing, strictly_increasing, sum_ctr, sum_set, xor

History

- 2002
  - development started
- 1.0.0
  - December 2005
- 2.0.0
  - November 2007
- 3.0.0
  - March 2009
- 4.0.0
  - March 2013
- 4.2.0 (current)
  - July 2013

43 kloc, 21 klod

77 kloc, 41 klod

34 releases

81 kloc, 41 klod

164 kloc, 69 klod

168 kloc, 71 klod

Tutorial Documentation

- 2002
  - development started
- 1.0.0 — 43 kloc, 21 klod
  - December 2005
- 2.0.0 — 77 kloc, 41 klod
  - November 2007
- 3.0.0 — 1 klod
  - March 2009
- 4.0.0 — 164 kloc, 69 klod
  - March 2013
- 4.2.0 (current)
  - July 2013

Modeling with Gecode (98 pages)

Modeling & Programming with Gecode (522 pages)

Future

- Large neighborhood search and other meta-heuristics
    - contribution expected
- Simple temporal networks for scheduling
    - contribution expected
- More expressive modeling layer on top of libmzn
- Grammar constraints
    - contribution expected
- Propagator groups
- …

- Contributions anyone?

Deployment & Distribution

- Open source ≠ Linux only
  - Gecode is native citizen of: Linux, Mac, Windows
- High-quality
  - extensive test infrastructure (around 16% of code base)
- Downloads from Gecode webpage
  - software: between 25 to 125 per day (total > 40000)
  - documentation: between 50 to 300 per day
- Included in
  - Debian, Ubuntu, Fedora, OpenSUSE, Gentoo, FreeBSD, …

Integration & Standardization

- Why C++ as implementation language?
  - good compromise between portability and efficiency
  - good for interfacing

  well demonstrated

- Integration with XYZ…
  - Gecode empowers users to do it
  - no "Jack of all trades, master of none"

  well demonstrated

- Standardization
  - any user can build an interface to whatever standard…
  - systems are the wrong level of abstraction for standardization
  - MiniZinc and AMPL are de-facto standards