Topic 18: Conclusion
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Course 1DL442:
Combinatorial Optimisation and Constraint Programming,
whose part 1 is Course 1DL451:
Modelling for Combinatorial Optimisation

Outline

1. Constraint Problems
2. Constraint Programming Technology
3. Constraint-Based Modelling
4. History, Success Stories, and Opportunities

Outline

Many important real-life problems are NP-hard or worse and can only be solved exactly and fast enough by intelligent search, unless P = NP:

- Assignment: personnel rostering, resource allocation, ...
- Configuration of products, design, experiment set-up, ...
- Packing: container or vehicle loading, carpet cutting, ...
- Routing of robots, vehicles, ...
- Scheduling, planning, ...
- ... hybrid problems, such as time-tabling and transportation logistics ...

Definition

In a constraint problem, values have to be **found** for all the decision variables within their **given** domains so that:

- All the given constraints on the decision variables are **satisfied**.
- Optionally: A cost is **minimal**, or a benefit is **maximal**.

Search spaces are often larger than the universe!
NP-hardness is not where the fun ends, but where it begins!

Outline

Constraint programming (CP) offers languages, methods, and tools for:

what: Modelling constraint problems in a high-level declarative language.

how: **Solving** constraint problems intelligently,
either by strategy-guided systematic search plus inference,
or by strategy-guided local search plus inference.

Slogan of CP: Constraint Program = Model [+ Search]

CP solvers are complementary in strength to those of:

- Operations Research (OR): linear programming (LP), integer LP (ILP), mixed integer programming (MIP), ...
- Boolean satisfiability (SAT), satisfaction modulo theories (SMT), ...
- ...

This leads to hybrid solving technologies!
In Algorithms and Data Structures 3 (1DL481), taught in period 3 (January to March), there are assignments on local search and MIP, SAT, SMT modelling.

Scope of Constraint Programming

CP has a wide scope, because it addresses:

- satisfaction problems and optimisation problems
- discrete decision variables and continuous decision variables
- linear constraints and non-linear constraints

in principle in any combinations thereof, by:

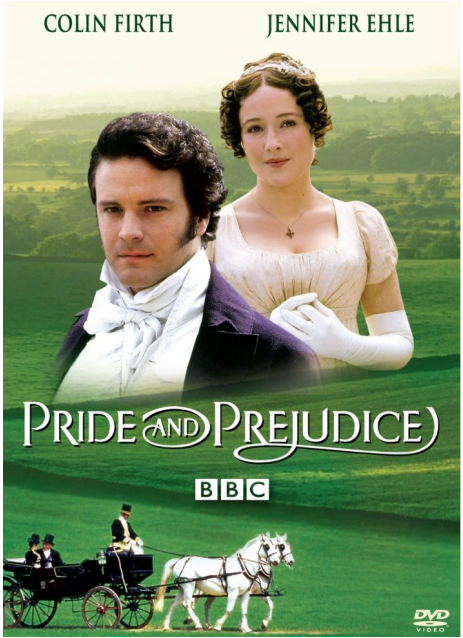
- systematic search, if optimality is more crucial than speed
- local search, if speed is more crucial than optimality

Outline

The constraint predicates (`AllDifferent`, `Circuit`, `Table`, ...) and structured variable types (sets, ...) allow us *both* to model the structure of a problem *and* to exploit that structure when solving the problem.

Dozens of constraint predicates (see the Catalogue) declaratively encapsulate complex inference algorithms.

There is no standardised CP modelling language: distinct CP solvers may support distinct predicates, possibly under distinct names and signatures, as well as distinct types.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Pride:

Constraint programming represents one of the closest approaches computer science has yet made to the Holy Grail of programming: the user states the problem, the computer solves it.

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The contribution of the article should be the reduction of an engineering problem to a known optimization format. [. . .] showcases pseudo code [. . .] submit this work to a journal interested in code semantics [. . .].

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Outline

Stand-Alone Languages and Solvers:

- ALICE by Jean-Louis Laurière, France, 1976
- CHIP at ECRC, Germany, 1987–1990; Cosytec.com, France, 1990–1992
- OPL, by P. Van Hentenryck, USA, and ILOG, France: modelling language for both IBM ILOG CP Optimizer and IBM ILOG CPLEX Optimizer
- Comet, by P. Van Hentenryck and L. Michel, USA
- MiniZinc, at Monash University, Australia
- ...

Libraries (the ones listed before ";" are open-source):

- Prolog: ECLiPSe, ...; SICStus Prolog, ...
- C++: Gecode, Google CP-SAT; IBM ILOG CP Optimizer, CHIP, ...
- Java: Choco, Google CP-SAT, JaCoP, MiniCP, ...; ...
- Objective-C: Objective-CP; ...
- Scala: OscaR.cp, OscaR.cbls; ...
- ...

MiniZinc Challenge 2024: 16 (of 20) Problems and Winners

Problem and Model	Backend and Solver	Solving Technology
aircraft-disassembly	CP-SAT (by Google)	portfolio: LCG, MIP, CBLS
cable-tree-wiring	CP-SAT (by Google)	portfolio: LCG, MIP, CBLS
community-detection	MZN/Gurobi	MIP
compression	PicatSAT	SAT
concert-hall-cap	MZN/Gurobi	MIP
fox-geese-corn	MZN/Gurobi	MIP
hoist-benchmark	Chuffed	hybrid: LCG = CP + SAT
monitor-placement-1id	CP Optimizer (by IBM)	CP
neighbours	CP-SAT (by Google)	portfolio: LCG, MIP, CBLS
peaceable_queens	Gecode-Dexter	portfolio: CP, LNS
portal	Chuffed	hybrid: LCG = CP + SAT
tiny-cvrp	MZN/Gurobi	MIP
train-scheduling	CP-SAT (by Google)	portfolio: LCG, MIP, CBLS
word-equations	PicatSAT	SAT
yumi-dynamic	CP-SAT (by Google)	portfolio: LCG, MIP, CBLS

Success Stories by CP Users and Contributors:

Success stories: CP is the **technology of choice** in configuration, rostering, routing, scheduling (such as job shop), timetabling, . . .

CP in Popular Culture

Opportunities for CP

Rapid prototyping (with high solving performance) when:

- The constraints are, still or again, subject to experiments.
- The partition into hard and soft constraints is not yet determined.

The combinatorial structure is impure, due to side constraints.

It is time to consider all or more problem constraints.

Domain knowledge is exploitable for problem-specific search.

It is a configuration problem.

It is a personnel rostering problem.

It is a scheduling (such as job shop) or timetabling problem.