G53CLP
Constraint Logic Programming

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Overview of CP

Computer Programs

a collection of source code and libraries which have been compiled into an executable or otherwise interpreted to “run" in (active) computer memory, where it can perform both automatic and interactive tasks with data.

- *Wikipedia*

Programming Paradigms

- Procedural
  - Sequences of instructions
  - Need to consider both how problem is solved and what the solution is
  - Languages: C; Pascal; C++

- Declarative
  - State the logic of the problem
  - Interested in only what the solution is
  - Languages: Logic (Prolog); CP

Logic Programming - Prolog

- PROgramming in LOGic: PROLOG
  - 1980s
- Brings logic into computer programs
- Express specifications for *problem solving* in formal logic
  - relations
  - logical variables

Logic Programming - Prolog

- Declarative programming style
  - problems expressed in terms of high level descriptions;
  - not as a set of instructions for performing an algorithm.

- Emphasis on "what is true", "what needs to be done" rather than "how to do".

Constraint Solving

- Arose from AI & computer graphics in 1960s, 1970s

- Constraint satisfaction
  - Solve problems by exploring constraints which must be satisfied by the solution
  - Set of variables taking values within domains satisfying constraints

Constraint Logic Programming

Logic Programming

+

Constraint Solving

=

Constraint (Logic) Programming
CLP or CP

These ideas were unified under a common conceptual and practical framework, constraint programming

Constraint programming is not restricted to CLP

Constraint Logic Programming

1987 **CLP** Jaar & Lassez

- Realised that logic programming is a type of constraint programming

1990 **CHIP** (Constraint Handling in Prolog)

- First commercial tool

1990 **Prolog III** Colmerauer et al.

- One of the first logic programming language

1994 **ILOG**

- C++ library
- Millions dollars revenue in 2005

2009 **IBM ILOG**

- ILOG integrated with IBM

Constraint Programming

Constraint programming is the study of computational systems based on constraints. The idea of constraint programming is to solve problems by stating constraints (conditions, properties) which must be satisfied by the solution.

Roman Barták, 1998

(see reference)

Constraint Programming

- Using computer to implement algorithms for solving CSPs

"a programming paradigm where relations between variables can be stated in the form of constraints."

"constraints differ from the common primitives of other programming languages in that they do not specify a step or sequence of steps to execute but rather the properties of a solution to be found."

- *Wikipedia*

Constraint Programming

- Basic idea
  - Solve the problems by simply giving the constraints (relations between objects in problems) which must be satisfied

```
  S E N D
+ M O R E
---------
= M O N E Y
```

```
  1000*l[S] + 100*l[E] + 10*l[N] + l[D]
+ 1000*l[M] + 100*l[O] + 10*l[R] + l[E]
= 10000*l[M] + 1000*l[O] + 100*l[N] + 10*l[E] + l[Y];
```

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***."

Eugene C. Freuder
Constraint Programming: In Pursuit of the Holy Grail
1999

Constraint Programming

- ***User states the problem***
  - n-queen problem
  - Sudoku
  - Cryptarithmetic

```
   1000*l[S] + 100*l[E] + 10*l[N] + l[D]
+  1000*l[M] + 100*l[O] + 10*l[R] + l[E]
=  10000*l[M] + 1000*l[O] + 100*l[N] + 10*l[E] + l[Y];
```

Constraint Programming

- ***Computer*** uses pre-defined algorithms to ***solve the problem***
  - Understand how algorithms work
  - Aim of this module!

  - Improve the search efficiency
    - Constraint propagation to assist decision making
    - Efficient search techniques, provided by constraint library or language

Constraint Programming

```
   S E N D
 + M O R E
 ---------
 = M O N E Y
```

```
enum Letters {S, E, N, D, M, O, R, Y};

var int l[Letters] in 0..9;

solve {
   alldifferent(l) onDomain;
   //l[S] <> 0;
   //l[M] <> 0;

      1000*l[S] + 100*l[E] + 10*l[N] + l[D]
   +  1000*l[M] + 100*l[O] + 10*l[R] + l[E]
   =  10000*l[M] + 1000*l[O] + 100*l[N] + 10*l[E] + l[Y];
};
```

Constraint Programming

- New and rich language
  - Model the problems using logical expressions
  - Easy to understand
    - Representation close to the original problems
  - Simple formulation/representation
  - Easy to implement/develop
  - Flexible and general-purpose
    - easy to change for different instances

Constraint Programming

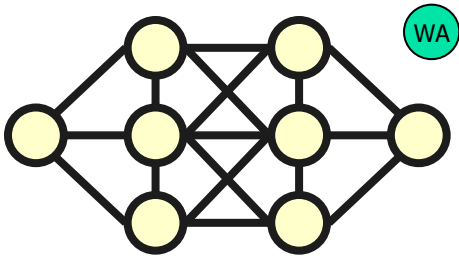
- Programming languages
  - Conventional logic programming PROLOG III
    - logic solution procedure is not efficient
  - CHIP (Constraint Handling in PROLOG)
    - Modification of logic programming
    - Constraint logic programming
    - Search techniques are used
  - General programming tools
    - IBM ILOG OPL

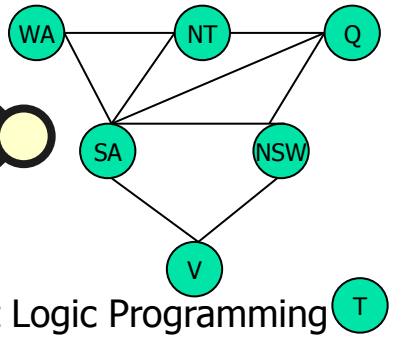
Constraint Programming

- Two branches of CP
  - Constraint satisfaction
    - CSP with finite domain
    - Solved by search
    - Main content of G53CLP
  - Constraint solving
    - Variables of infinite domain
    - Solved by algebra and numeric methods

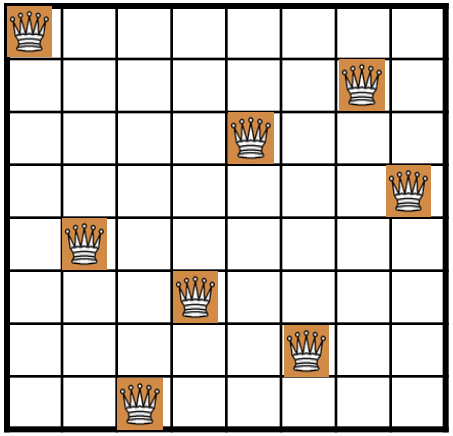
CP Applications – in G53CLP

- A number of puzzles
  - n-queen problem
  - Map coloring
  - Cryptarithmetic problem
  - Sudoku
  - …





	1		3			4	8	6
		2	8				9	3
					4		5	
		6			1			7
3	7	4				5	6	1
5			6			8		
	4		9					
7	3				5	6		
1	2	5			8		4	



CP Applications – in G53CLP

- A number of **combinatorial problems** – more important real world applications
  - Scheduling & Planning
  - Timetabling
  - Resource allocation
  - Assignment problems
  - Knapsack problems
  - Transport
  - …

CP Applications – in real world

- Real world applications of CP
  - Lufthansa
    - Daysy system: personnel planning after air traffic disturbances
  - Nokia
    - Automatic configuration of mobile phone software
  - Renult
    - Production planning

CP Advantages

- Short development time
  - Fast prototyping
- Compact code size
  - Ease of understanding
- Good performance
  - Good results

```
enum Letters {S, E, N, D, M, O, R, Y};

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   +  1000*l[M] + 100*l[O] + 10*l[R] + l[E]
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};
```

CP Limitations

- Many problems are combinatorial
  - Search of problem is exponential
  - CP techniques studied
    - Constraint propagation can reduce the search space
    - Heuristics may be used

Constraint Programming

Constraint programming is an emergent software technology for declarative description and effective solving of large, particularly combinatorial, problems especially in areas of planning and scheduling.

- Barták, 1998

Constraint Programming

Were you to ask me which programming paradigm is likely to gain most in commercial significance over the next 5 years I'd have to pick Constrained Logic Programming (CLP), even though it's perhaps currently one of the least known and understood.

- Dick Pountain, 1995

CP in Practice

- Software development
  - Supported completely by commercial software
    - Constraint Solver by IBM ILOG OPL
    - …
  - Rapid prototyping
  - Easy maintenance

References/Resources

- Roman Barták. On-line Guide to Constraint Programming. http://ktiml.mff.cuni.cz/~bartak/constraints/intro.html
- Eugene C. Freuder. In Pursuit of the Holy Grail. ***Constraints***, 2(1): 57-61, 1997.
- Thom Frühwirth and Slim Abdennadher. Essentials of Constraint Programming. http://www.informatik.uni-ulm.de/pm/fileadmin/pm/home/fruehwirth/pisa/index.html
- Alain Colmerauer. An introduction to PROLOG-III. ***Communications of the ACM***, 33(7): 69-90, 1990.

References/Resources

- LIOG OPL, IBM http://www-01.ibm.com/software/integration/optimization/cplex-optimization-studio/
- Gecode (Generic Constraint Development Environment) http://www.gecode.org/
- Eclipse Prolog http://eclipse.crosscoreop.com/
- SICStus prolog http://www.sics.se/isl/sicstuswww/site/bibliography.html