A Problem Classification Scheme - When to use CLP

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Overview

◆ Part 1
  – What is Constraint Logic Programming (CLP) ?
  – Competing techniques

◆ Part 2
  – Problem classification scheme

◆ Part 3
  – Problem failures
  – Modeling checklist
  – Comparison studies
  – What really works
What we discuss

- Overview of application domains
- Comprehensive study of industrial usage
  - large scale applications
  - prototypes, studies
- Common characteristics of applications
- Reasons for success/failure
What we don’t discuss

- How to solve problems
- Cost/benefit studies
- Software engineering studies
- Integration issues
- Tool selection
Approach

- **Look what has been done**
  - overview of applications and studies using CLP
  - centered on COSYTEC/ECRC experience
  - results from competing systems may not be up to date

- **Find common points**
  - group applications according to application characteristics

- **Try to explain effects**
  - based on CHIP; results with other tools may be different

- **Group success/failure**
  - personal view
  - new techniques/studies may change this
Part 1

Constraint logic programming
Computation domains

- Finite domains
- Linear arithmetic
- Boolean
- Intervals
- Pseudo Boolean
- Non-linear arithmetic
- Sets, sequences, lists
Incomplete finite domain solver

- **Domain**
  - finite sets of values
  - subsets of natural numbers

- **Need for enumeration**

- **Classification criteria**
  - constraint granularity
  - richness of constraint sets
  - propagation results
  - user definable constraints/control

- **Methods**
  - explicit domain representation
  - bound propagation/ removal of interior values
  - heuristics based on domains
Domain concept

- **Domain variables**
  - subset of natural numbers

- **Variable assignment**
  - `indomain`, non-deterministic instantiation

- **Search and backtracking**

```prolog
labeling([]).
labeling([H|T]):-
    indomain(H),
    labeling(T).
```
Syntactic propagation methods

- **Forward checking**
  - wait until only one variable is left in constraint
  - remove inconsistent values

- **Lookahead**
  - for each variable and each value check if consistent values exist
  - remove inconsistent values
  - repeat whenever constraints change

- **Partial lookahead**
  - bound propagation

\[ X \leq Y \]

\[ X > Y \]
Bound propagation: Linear terms

\[ a_1X_1 + a_2X_2 + \ldots + a_nX_n + c_1 = b_1Y_1 + b_2Y_2 + \ldots + b_mY_m + d_1 \]

\[ a_1X_1 + a_2X_2 + \ldots + a_nX_n + c_1 \in [\min_I, \max_I] \]

\[ b_1Y_1 + b_2Y_2 + \ldots + b_mY_m + d_1 \in [\min_R, \max_R] \]

\[ \min = \max(\min_I, \min_R) \]

\[ \max = \min(\max_I, \max_R) \]

\[[X, Y, Z]:: 1..10, 2*X + 3*Y + 3 \neq Z\]

\[ X \text{ in } \{1,2\} \]

\[ Y = 1 \]

\[ Z \text{ in } \{8,9,10\} \]
Symbolic constraints

- **Disequality**
  - X is different from Y

- **Alldifferent**
  - all elements in list are pair-wise different
  - more compact than single disequality, but no better propagation
  - pigeon hole principle -> need for stronger propagation

- **Element**
  - element(X,L,Y)
    - Y is the Xth element of the list L
    - works in both directions
Global constraints

- **Work on sets of variables**
  - global conditions, not local constraints

- **Semantic methods**
  - Operations Research
  - spatial algorithms
  - graph theory
  - network flows

- **Building blocks (high-level constraint primitives)**
  - as general as possible
  - multi-purpose
  - very strong propagation (within acceptable algorithmic complexity)
The Cumulative global constraint

- **Cumulative constraint**
  - Resource limits over periods of time
  - Upper/lower limits
  - Soft/hard limits
  - Gradual constraint relaxation

- **Application**
  - Resource restrictive scheduling, producer consumer constraints, disjunctive schedule, manpower constraints, overtime
The Diffn global constraint

◆ **Diffn constraint**
  – non overlapping areas on n-dimensional rectangles
  – distances between rectangles
  – limit use of areas

◆ **Application**
  – layout, packing, resource assignment, setup, distribution planning, time-tableing
The Cycle global constraint

- **Cycle constraint**
  - Finds cycles in directed graphs with minimal cost
  - Assign resources, find compatible start dates

- **Applications**
  - Tour planning, personnel rotation, distribution problems, production sequencing
The Among global constraint

- **Among constraint**
  - How often do values occur in (sub)sequences
  - based on counting arguments
  - interaction between sequences

- **Applications**
  - production sequencing, time tabling, coloring problems, set covering
The Precedence global constraint

- **Precedence constraint**
  - Combine resource constraints and precedence networks
  - Reasoning on latency (position in network)
  - Co-operation between multiple resources

- **Applications**
  - resource restricted scheduling, channel routing, frequency allocation
The Sequence global constraint

- **Sequence constraint**
  - constraints on pattern inside sequences
  - combinatorial pattern matching
  - counting arguments

- **Applications**
  - Time tabling, personnel assignment,
  - work rules, scheduling with daily working time limits
The power of global constraints

- Multi-functional tools
- Building blocks
Constraint morphology

- Precedence
- Diffn
- Cumulative
- Sequence
- Cycle
- Case
- Alldifferent
- Permutation
- Disjunctive
- Prod/cons
- Among
- Setup
- Circuit
- Element
- Different
- Order
- Resource
- Tour
- Dependency

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Competing techniques

- Linear/integer programming
- Heuristic algorithms
- Decomposition methods
- Neighborhood search
  - simulated annealing
  - tabu search
  - genetic algorithms
- Relaxation methods
Linear/integer programming

- Express problems with linear equalities/inequalities
- Additions required to handle
  - disequality
  - disjunction
- Solve constraint systems with Simplex method
  - other methods exist
  - very well developed tool kits
- Some systems include simple modelling languages
  - generate model from data
- Search for integer solutions
  - cutting planes
  - branch and bound techniques
**Advantages**
- highly developed mathematical theory
- good tools
- large knowledge base

**Disadvantages**
- restriction in modeling
  - types of constraints
  - types of variables
- programming with constraints
  - incremental
  - meta programming/explanations
- some problem types do not give good results
  - scheduling
Heuristic algorithms

- Progressive building solutions by adding pieces one at a time
- Items added chosen by heuristics
- Good solutions for weakly constrained problems
- Bad results for strongly constrained problems
  - finding admissible solutions
- **Heuristics should take constraints into account**
  - dynamic, not static ordering required
- **Systems can be very fast**
  - no initial propagation cost
Decomposition techniques

◆ **Cut problem into more manageable parts**
  – helps handle large/complex problems

◆ **Different ways of decomposing problems**
  – Hierarchical
    ♦ **bottom-up and top-down**
    ♦ requires certain problem structure
  – Structural
    ♦ considering different degrees of freedom independently
  – Temporal/Spatial
    ♦ solving sub problems for limited time period or limited number of resources
Branch and bound

- Create successive sub problems by enumeration on variables
- Exploration of search tree
  - pruning of branches
  - lower bound approximation
- Standard OR technique
- Search strategies must be defined carefully
- Very good results for complex problems
- High development effort
Neighborhood search

- Search by finding initial solution and “improving” it
  - feasible initial solution
  - modification function
  - cost evaluation
- Allows different variations
  - steepest ascent
  - hill climbing
  - simulated annealing
  - tabu search
  - genetic algorithms
- Local optimization
Neighborhood search (2)

- **Constraint handling**
  - Constraints expressed in cost
  - Modification function checks constraints

- **Good for additive costs**
  - Local changes which improve costs

- **Difficult for very constrained problems**
  - Finding initial solution
  - Admissible modifications
Relaxation methods

- Solving “simpler” problem helps finding solution to complex problems
- Ignoring/simplifying certain constraints
- Obtain lower/upper bounds
- Proof of optimality
- Initial solutions
Part 2

Problem classification scheme
Problem classification scheme

- Overview of attempts to solve problems
- Some large, operational systems
- Many examples are studies, not ‘real’ systems
- Many models do not scale (I think)
- Shows which areas are susceptible to approach
Overview

- Hardware design
- Compilation
- Financial problems
- Placement
- Cutting problems
- Stand allocation
- Air traffic control
- Frequency allocation
- Network configuration
- Product design
- Production step planning
- Production sequencing
- Production scheduling
- Satellite tasking
- Maintenance planning
- Product blending
- Time tabling
- Crew rotation
- Aircraft rotation
- Transport
- Personnel assignment
- Personnel requirement planning
Hardware design

- **Different domains**
  - Circuit verification
    - check consistency with specification
  - Diagnosis
    - find/explain fault in defective machine
  - Testing
    - prepare tests to confirm proper operation
  - Synthesis
    - create hardware design from specification
  - Layout
    - create geometrical structure from design
Characteristics

- **Specialized solvers**
  - problem specific
  - not reusable for other domains

- **Narrow domain**
  - industrial usage restricted to few companies

- **Constraint methods used in conventional algorithms**
  - example D-Algorithm

- **Successful in right environment**
  - CVE (Siemens)
    - hardware verification tool for ASIC circuits
Compilation

- **Register allocation**
  - graph coloring problem
- **Instruction scheduling**
  - pipelining/parallel execution
- **Microcode labeling (ECRC)**
  - distributing microcode over address space; simplified addressing
- **DSP scheduling (ECRC, cc(FD), COSYTEC)**
  - cyclic scheduling
Characteristics

- **Graph coloring problems**
- **Simple scheduling**
  - cyclic problems
  - disjunctive resources
  - machine assignment problems
- **Difficult to achieve in real-time**
Financial problems

- **Portfolio management (SEVE - CDC)**
  - which shares to buy/sell
  - assumption on economic development
  - mixed mode solver
  - operational since 92
- **Asset/liability (Amro Bank)**
- **Stock option trading (C. Lassez)**
- **Constraint Spreadsheet (Hyvonnenn)**
Characteristics

- **Continuous domain**
  - use rationals or reals
- **Non-linear constraints common**
  - linearisation
  - implement non-linear solver on top of linear one
- **Problem often incremental**
  - not all constraints known from beginning
  - programming with constraints (explanation, what-if)
- **Large problem instances**
- **Possible alternative techniques**
  - non-linear interval solvers
- **Requires proprietary information**
  - model (not only data) often confidential
Placement

- **HIT container stacking (ICL)**
  - where to put containers to easily retrieve them later

- **Lorry loading (EBI)**
  - loading unloading of boxes in lorry
    - support constraint
    - stacking order
    - first in / last out

- **Container loading (Michelin)**
  - added degree of freedom

- **Map labeling (ECRC, Bull, COSYTEC, Gist)**
  - where to put labels on map
  - preference position not always achievable
  - depends on right model
Characteristics

- **2D**
  - often overconstrained
  - strong preferences not always achievable
  - very good results can be obtained

- **3/4D**
  - very hard or very easy
  - needs powerful heuristics

- **General**
  - very poor results with syntactic methods
  - some common constraints very hard to express
  - specialized domain heuristics not easy to compute
Cutting problems

- **Cutting stock (ECRC)**
  - cutting rectangles from rectangles
  - 2D finite problem

- **Made (Dassault)**
  - combining sheet metal pieces for aircraft parts
  - approximated by combination of rectangles

- **Glass cutting (Oz)**

- **Wood cutting for furniture (Prolog III)**
Characteristics

- **Strong competition from MIP**
  - continuous roll cutting

- **Problems to handle irregular shapes**
  - leather, clothes
  - problem for any mathematical model

- **Good heuristic solutions**
Stand allocation

- **APACHE (COSYTEC)**
  - stand allocation for airport

- **HIT (ICL)**
  - assign ships to berths in container harbor

- **Train platform assignment (Ilog, Siemens)**
  - assign trains to platforms in at stations

- **Refinery berth allocation (ISAB)**
  - where to load/unload ships in refinery
APACHE

◆ Stand allocation system
  – originally developed with Air France, CDG2
  – packaged for large airports

◆ Complex constraint problem
  – technical & operational constraints
  – incremental re-scheduler

◆ Cost model
  – maximize no. passengers in contact
  – minimize towing, bus usage

◆ Status
  – technology demonstrator
Characteristics

- **Base constraint relatively easy**
  - Graph coloring in interval graphs
  - Complete propagation possible for alldifferent
  - additional constraints/cost model more complex

- **Rescheduling requirements**
  - constraints change with every delay
  - resolving problem without disturbing all of previous solution

- **Solver can be very fast**
  - few seconds

- **Proof of optimality very complex due to symmetry**
  - needs separate lower bound calculation
Air traffic control

- **CENA**
  - slot capacity
- **Thomson**
  - landing approach
- **Matra**
  - mission planning (military)
Characteristics

- **Temporal and spatial constraints**
  - Box model
- **General ATC problem very hard to express**
  - trajectories as 4D objects
  - “closeness” of trajectories
- **Large problem sizes**
- **Special case solutions interesting**
Frequency allocation

- Thomson
- SICS
- Celar Benchmark (Bull, Ilog, COSYTEC)
Characteristics

- **Optimization difficult**
  - symmetry reduction

- **Solver too weak**
  - cliques in graphs

- **Locally overconstrained**
  - some constraints are actually preferences

- **Model may vary depending on degree of exactness**
  - disequality/distance constraints
Network configuration

- **Locarim (France Telecom, COSYTEC)**
  - cabling of building
- **Planets (UCB, Enher)**
  - electrical power network reconfiguration
- **Load Balancing in Banking networks (ICON)**
  - distributed applications
  - control network traffic
- **Water Networks (UCB)**
FRANCE TELECOM - LOCARIM

- Intelligent cabling system for large buildings
  - developed with Telesystemes for France Telecom

- Application
  - input scanned drawing
  - specify requirements

- Optimization
  - minimize cabling, drilling, switches
  - shortest path

- Status
  - operational in 5 Telecom sites
  - generates quotations
Characteristics

- Different types of problems
- Many related to warehouse location
  - with/without capacity
- Mixed methods worthwhile
  - finite domain solver
  - rational solver
- Competition from MIP
  - simple model
  - nice mathematical properties
Product design

- **Key system generation (Vachette, Bull)**
  - design key structure for large buildings
  - one key opens multiple doors
  - security restrictions in different levels
  - parts of key control different locks
  - interaction of different access groups

- **Mechanical design (Cisa)**
Production step planning

- **COCA (Dassault)**
  - define in which order the production steps are performed
  - basis for scheduling
  - very large problem
    - several 10000 steps
    - decomposition possible
Characteristics

- **Temporal and spatial constraints**
  - some steps must be done before others

- **Access to location**
  - not possible to work on two adjacent compartments concurrently

- **Rotation state of aircraft frame**
  - allows /excludes access

- **Safety rules**
  - operations may not be performed at the same time
Production sequencing

- **Amylum (Beyers)**
  - Glucose production

- **Cerestar (Beyers)**
  - Glucose production

- **Car Sequencing (ECRC, COSYTEC)**
  - Assembly line scheduling

- **Bowater (Bull, COSYTEC)**
  - Carton printing, reuse of colors

- **MOSES (COSYTEC)**
  - Animal feed production
Characteristics

- **Forbidden sequences**
  - this product must never follow that product
  - this product should not follow that product

- **Setup cost/time**
  - cleaning time
  - downgrading product
  - waste

- **Combination with scheduling**
  - due dates
  - machine choice

- **Additional constraints**
  - capacity
Production scheduling

- **Plane (Dassault)**
  - mid/long term scheduling
- **Made (Dassault)**
  - short term work cell scheduling
- **Saveplan (Sligos)**
  - production scheduling
- **ATLAS (Beyers, COSYTEC)**
  - herbicide manufacturing
- **MOSES (COSYTEC)**
  - animal feed production
- **Trefi Metaux (Sligos)**
  - heavy industry production scheduling
Chemical packaging & inventory control system
- developed for US agro-chemical supplier
- joint development with Beyers & Partners

Extensive use of CHIP interfaces
- XGIP GUI interfacing to RDBMS
- multi-user UNIX & PC system

Scheduling
- formulation & packaging
- checks highlights problems

Benefits and status
- operational since Jun 93
- better control, reduced stock
VCA - ORDO-VAP

◆ Production scheduling for glass factory
  – integrated with Ingres Information system
  – manual and automatic scheduling

◆ Constraints
  – multi-stage manufacturing
  – consumer/producer
  – varying production rates, setup
  – balance manpower utilization
  – minimize downtime

◆ Status
  – 2 phases
  – operational in March 96
  – will replace manual operation
Characteristics

- **Large systems operational**
- **Complete environments**
  - integration
  - frameworks
- **Many types of constraints**
  - precedence
  - disjunctive /cumulative resources
  - producer/consumer
  - machine assignment
  - setup
  - due dates/release dates
- **Well developed methodology**
Satellite tasking

- **Dassault**
  - low earth orbit satellite configuration power management

- **Alcatel**
  - earth observation scheduling
    - memory
    - transmission times
    - energy use
    - observation windows
Maintenance planning

- **Sema**
  - aircraft maintenance
- **Coopers & Lybrand**
- **Hong Kong Public Transport**
  - maintenance jobs on train/subway service
- **Edia - SNCF**
Characteristics

- **Cost model very weak**
  - interested in sum of costs

- **Problem set not known a priori**
  - some jobs may be postponed/canceled

- **Problem separable in time periods**
  - sequential/independent optimization
  - reduces complexity
  - provides lower bounds/heuristics
Product Blending

- **Forward (TECHNIP, COSYTEC)**
  - gasoline blending
  - crude mix
- **Sanofi (ILOG, COSYTEC)**
  - cosmetics
- **Michelin**
  - rubber blending, rework optimization
Oil refinery production scheduling
- joint development by TECHNIP and COSYTEC
- incorporates ELF FORWARD LP tool

Schedules daily production
- crude arrival -> processing -> delivery
- design, optimize and simulate

Product Blending
- explanation facilities
- handling of overconstrained problems

Status
- generic tool developed in 240 man days
- operational since June 94
- Operational at FINA, ISAB, BP
Characteristics

◆ **Strong domain for LP/IP**
  – constraint model only based on inequalities
  – finite domain solvers don’t offer much
  – continuous domains/cutting plane methods

◆ **Constraints can provide explanation facility**
  – programming with constraints
  – advantage over LP packages

◆ **Handles smaller problem size than LP/MIP systems**
Time tabling

- **School/university time tables**
  - which courses are held
    - when
    - by whom
    - in which room

- **Exam scheduling**
  - which exams to place when in which rooms, possibility to combine exams in same room

- **Training course scheduling (Nat West)**
  - which courses to run in which week of year
    - limited accommodation
    - course sequences
    - course repetition
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**Personnel**

**Resource**

**Time**
Characteristics

- **Experimental systems**
- **Solvers too weak**
  - easy problems simple
  - hard problems impossible
- **Relaxation of constraints required**
  - overconstrained problems
  - strong preferences
- **Balancing of time table**
  - equal quality for everybody
- **Dedicated, specialized packages exist**
Crew rotation

- Pilot (SAS, COSYTEC)
  - re-planning
- DAYSY (Lufthansa, COSYTEC, Sema, U. Patras)
  - day to day management
- Air Littoral (PrologIA)
  - use of Simplex
- Servair (GSI)
  - capacity planning/scheduling/assignment
- NWRR (COSYTEC)
  - train driver rotations
- SuperBus (PrologIA, Brunel U.)
  - public transport
**Intelligent re-scheduling**
- SAS have 115 aircraft, 3 home bases, 3000 cabin 2000 flight
- initial development by COSYTEC continued by SAS Data

**Solve open flights**
- delay, illness, cancellation, new flight
- 50% in 5 minutes for 100 crew
- 80% in 5 hours for 1000 crew

**Black box solver**
- based on cycle constraint
- constraint + legality checker

**Status**
- operational Sept 1995
Characteristics

- Very complex constraints
  - evolving over time

- **Difficult to express/check**
  - dedicated rule checking systems

- Very large problem sets
  - several thousand crew
  - several ten thousand flights

- Crew preferences
  - incompatible with each other

- Soft/Hard rules
  - Government regulations, safety regulations, seniority rules

- Needs **very expressive/powerful solver**

- Competition: very strong monthly planning tools based on LP
Aircraft/Train rotation

- **SNCF - Bull**
  - capacity planning: which trains to move overnight
  - specialized algorithm: min flow

- **SNCF - Ilog**
  - train engine rotation
  - specialized algorithm: TSP

- **BA - IC Parc**
  - aircraft rotations
  - repair methods
Problem scheme

- **List of services**
  - Dep 10:00 CDG Arr 10:05 LHR
- **Covering services with available engines**
- **Passive movement to make machines available at right place**
- **Maintenance/service stops**
- **Balancing/minimizing engine usage**
- **Location continuity**
  - Start/stop at depot/home base
Characteristics

- **Less constrained than crew problems**
  - no unions to worry about

- **Location continuity**
  - added dimension over scheduling

- **Large problem sizes**
  - all of French train services; decomposition possible

- **Unknown qty of passive transport required**
  - difficult to express a priori with constraints

- **Results show problems of expressing/solving with syntactic methods**
  - resolve problem with dedicated, non incremental algorithm
Transport

- EVA (EDF, Gist, COSYTEC)
  - nuclear waste transport

- EBI
  - warehouse - customer transport

- TACT (COSYTEC)
  - integrated transport food manufacturing

- PASZA (COSYTEC)
  - feed mill transport

- SIPE
  - bus transport
EDF - EVA

- **Transportation of nuclear waste**
  - developed by GIST + COSYTEC
  - plans evacuation and transport for 54 sites

- **Constraints**
  - availability of transport vehicles and vessels
  - number and capacity of storage tanks
  - compatibility of waste to vessels
  - size of convoy, time

- **Status**
  - operational since Oct 94
  - 6 month plan in 5 minutes
TACT

◆ Transport planning and assignment
  – plans activities for factories
  – assigns activities to teams, drivers, lorries, fork lifts

◆ Problem solver
  – generates minimum no trips
  – balance production, optimizes resources

◆ Rules, constraints
  – production, storage, legal, vet
  – roster, workforce, unavailability

◆ Status
  – operational Feb 1995
  – developed Aug 94-Jan 95
Characteristics

- **Location continuity**
  - start end of trips
  - depots

- **Passive transportation**
  - unknown quantity

- **Important scheduling component**
  - driven by crucial resource (lorries, drivers, supply/demand side)

- **Producer/Consumer behavior**
  - JIT delivery
  - limited stock, shelf life

- **Even more difficult if work rules must be handled**
  - total driving time, breaks, rest periods, start/end time, rota
Personnel assignment

- **Servair (GSI, ITMI, COSYTEC)**
  - train bar/restaurant
- **RFO (Gist, COSYTEC)**
  - reporters/technicians for TV/radio
- **Banque Bruxelles Lambert (Ilog)**
  - bank personnel
- **Nurse scheduling (Ilog, Bull)**
  - hospital
- **Crisis Management (Bull)**
  - Olympic winter games 1992
**Assignment of technical staff to tasks**
- overseas radio broadcaster - Radio France Outre-mer
- joint development by GIST and COSYTEC

**Features**
- schedule manually, check, automatic
- rule builder to specify cost formulas

**Optimization**
- minimize overtime, temporary staff
- compute cost of schedule

**Status**
- operational Dec 95
- to be installed worldwide in 9 sites
SERVAIR - CREW

◆ Crew rostering system
  – assign service staff to TGV train timetable
  – joint implementation with GSI

◆ Problem solver
  – generates tours/cycles
  – assigns skilled personnel

◆ Constraints
  – union, physical, calendar

◆ Status
  – operational since Mar 1995
Characteristics

- **Work rules**
  - as for transport and rostering

- **Balancing**
  - spread difficult/tedious jobs
  - total work time per month

- **Perfect problems very hard**
Personnel requirement planning

- **Ghost (Sligos)**
  - capacity planning credit card service

- **Havas (COSYTEC, EBI)**
  - ground crew management

- **911 planning (2LP)**
  - emergency center capacity planning
Characteristics

- Rather small problem size
- Covering demand per time unit
- Lower bound constraints
- Alternative models
  - integer programming: inequalities
  - capacity planning: cumulative
- IP approach quite strong
Part 3

Evaluation
Which problems failed

- Not much information available
- Paper by J.Y. Cras, ILPS 1994
- Difference between
  - project failure
    - customer is not happy
  - problem failure
    - constraint researcher is not happy
Project failure

- **Project management**
  - technically too ambitious
  - due dates not achievable
  - effort not estimated correctly

- **End - user acceptance**
  - end user not involved early on

- **Business process change**
  - need disappears while system is being developed
  - problem changes beyond recognition
Problem failure

- Wrong problem
- Wrong solver
- Wrong model
- Wrong test case
Wrong problem

- **Solving the wrong problem**
  - focusing on technology rather than need of customer
- **Pure problem**
  - specialized methods/algorithms exist
- **Relaxation essential**
  - if no constraints are hard, then there is no propagation
- **Too generic**
  - solving “the generic scheduling” problem
  - using problem specific knowledge is key to success
Wrong solver

- **Wrong domain**
  - ex. solving sets of inequalities by bound propagation
  - find most general solution where only one particular solution is required

- **Solver too weak**
  - idea of solving hard problems by simple methods
  - this is why global constraints were introduced
Wrong model

- **Bad choice of variables**
  - avoid 0/1 domain variables
  - avoid very large domains

- **Constraints do not propagate**
  - important to express all constraints inside model
  - not enough if constraints do not propagate

- **Bad strategy**
  - use problem specific knowledge
  - try different methods

- **Cost model too weak**
  - important when doing search
  - proving optimality only possible with good lower cost bound
Wrong test case

- Problem does not scale
  - classical AI problem
  - test with real data
  - see whether actual solution satisfies constraint model
  - ideally, test with full size data

- Not enough test cases
  - easy to over-optimize one test case (benchmarks)
  - day to day system requires test data from all time periods
    - seasonal demand variation
    - peak business
    - special cases (holidays)
Modeling check list

- Soft constraints
- Overconstrained problems
- Preferences
- Balancing
- Non-local cost
- Planning type problems
- Passive transport
Comparison studies

- Comparing two methods is much more difficult than testing one
- Most tests topical or small scale
- Some comparison of benchmark results
- Tests shown
  - CLP - OR
  - CLP - LP/MIP
  - CLP - AI
  - CLP - local search
  - CLP/FD - CLP/R
CLP - OR (specialized algorithms)

- Warehouse location
- Job shop
- Patterson / Alvarez benchmarks
CLP - LP/MIP

- Warehouse location
- Setup scheduling
- Cutting stock
- ATC slot allocation
- Progressive party problem
- Network flow (Train rotations)
- Disposing problem (Bisdorff)
- 2LP
- Banking networks
CLP - AI

- Car sequencing
CLP - Local search

- Car sequencing
- Map labeling
- Scheduling (BT)
CLP vs CLP

- Comparison of different solver methods for some applications
- Warehouse location
- Hoist scheduling
- Bisdorff
What really works

- **Which of the problems should be solved by CLP**
  - CLP appropriate tool
  - competing techniques have no clear advantage

- **Methodology**
  - how to express constraints
  - standard models
  - sets of heuristics available
Scheduling

- **Good methodology**
  - see PAP 95 tutorial on planning and scheduling

- **Constraints competitive**
  - benchmark results are comparable to best dedicated systems

- **Good strategies known**
  - both AI and OR type heuristics

- **Projects can still be complex**
  - interfaces
  - integration
  - strategies
Allocation

- **Solver rather simple**
  - disequality/alldifferent/diffn
  - pure problem easy
  - complete propagation for significant sub-problems

- **Rescheduling rapid**
  - solver finds solution in few seconds

- **Much simpler than scheduling**
  - do not generalize if not required
Transport

- **Solver quite complex**
  - location continuity
  - unknown amount of passive transport
- **Multiple loading/unloading a problem**
  - interaction of all activities in one tour
- **Good strategies required**
- **Problem size can be limiting**
  - several hundred nodes OK
- **Handling of personnel work rules makes things very complex**
Crew rotation

- **Work rules can be very complex**
  - point systems
  - large amounts of data (ex pilot qualification for airports)
- **Preferences not handled well**
- **Does not handle long periods**
  - too many activities
  - not enough connection between early and late activities
- **Rest periods**
  - expressing constraints already complex
  - deducing information very hard
- **No other tool handles constraints well**
  - Column generation: generate & combine method
How to continue?
Sources

- Examples drawn from multitude of sources
- Some are “personal communication” only
- Literature list
Summary

- **CLP - Emphasis on finite domains**
  - not enough data for other problem solvers
- **Application classification**
  - what has been done in the field
- **Explaining problems**
  - why projects/problems fail
- **Modeling checklist**
  - what to watch out for