Chapter 7: Optimization (Routing and Wavelength Assignment)

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ECLiPSe ELearning Overview

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Outline

1. Problem
2. Program
3. Search

What We Want to Introduce

- Optimization
- Graph algorithm library
- Problem decomposition
- Routing and Wavelength Assignment in Optical Networks
Problem Definition

Routing and Wavelength Assignment

In an optical network, traffic demands between nodes are assigned to a route through the network and a specific wavelength. The route (called lightpath) must be a simple path from source to destination. Demands which are routed over the same link must be allocated to different wavelengths, but wavelengths may be reused for demands which do not meet. The objective is to find a combined routing and wavelength assignment which minimizes the number of wavelengths used for a given set of demands.

Example Network

A

B

C

D

E

F

G

H

J

Problem 1: Find routing
Problem 2: Assign Wavelengths
Lightpath from A to C

Conflict between demands A to C and F to J: Use different frequencies
Conflict between demands A to C and F to J: Use different paths

Solution Approaches

- Greedy heuristic
- Optimization algorithm for complete problem
- Decomposition into two problems
  - Find routing
  - Assign wavelengths
Finding Routing

- Find routing which does not assign too many demands on the same link
- Lower bound for overall problem
- Do not use arbitrarily complex paths
- Start with shortest paths

Proposed Solution

- For each demand, use a shortest path between source and destination
- Shortest path = smallest number of links used
- Good for overall network utilisation
- May create bottlenecks on some links
How to Find Shortest Paths

- Well studied, well understood problem
- Many different algorithms for particular cases
  - Positive/negative weight
  - Path between pair of nodes/between node and all other nodes/between all nodes
  - One/all shortest paths or paths which are nearly shortest paths
- Don’t program this yourself!
- Library in ECLiPSe: `lib(graph_algorithms)`

Library `graph_algorithms`

- Provides different algorithms about graphs
- Based on opaque `Graph` structure created from nodes and edges
  - `make_graph(NrNodes, Edges, Graph)`
- Edges are terms `e(FromNode, ToNode, Weight)`
- Directed graphs as default, undirected graphs represented by edges in both directions
Basic Shortest Path Method

- \texttt{single_pair_shortest_path(Network, -1, From, To, Result)}
- Find path from node \texttt{From} to node \texttt{To} in graph \texttt{Network}
- Second argument describes weight function
  - -1: use number of hops
- \texttt{Result} given length of path and edges as list

Problem 2: Assign Wavelength

- Demands are routed on shortest paths
- Demands routed over the same link must have different frequencies
- Minimize maximal number of frequencies used
Model

- Domain variable for every demand
- Initial domain large, e.g. number of demands
- Disequality constraint between demands routed over same link
- Alternative: `alldifferent` constraints for all demands over each link
- Feasible solution: find assignment for variables

Optimization

- We are not looking for only a feasible solution
- We want to optimize objective
- Minimize largest value used
Library \texttt{branch\_and\_bound}

- \texttt{bb\_min(Goal,\textit{Cost},\textit{bb\_options}{})}
- \textbf{Goal} search goal
  - Like \texttt{search/6} or \texttt{labeling/1} call
- \textbf{Cost} objective (domain variable)
- \textbf{bb\_options} optional parameters
  - \texttt{timeout:Time} timeout limit in seconds
  - \texttt{from:LowerBound} known lower bound
  - \texttt{to:UpperBound} known upper bound

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**Example**

```prolog
... 
List :: 1..20,
... 
\texttt{ic:max(List,Max),}
\texttt{bb\_min(labeling(List),Max,}
\quad \texttt{bb\_options{timeout:100,from:10}),}
... 
```
**ic Constraint** \( \text{max}(\text{List}, \text{Var}) \)

- **Var** is the largest value occurring in **List**
- **Similar** \( \text{min}(\text{List}, \text{Var}) \)
- Do not confuse with \( \text{max} \) in core language

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### Main Program

```prolog
:-module(pure).
:-export(top/5).
:-lib(ic).
:-lib(ic_global).
:-lib(graph_algorithms).
:-lib(branch_and_bound).

top(Name,NrDemands,LowerBound,Assignment,Max):-
    problem(Name,NrDemands,Network,Demands),
    route(Network,Demands,Routes),
    wave(NrDemands,Routes,
        LowerBound,Assignment,Max).
```

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Routing

route(Network,Demands,Routes):-  
(foreach(demand(I,From,To),Demands), 
foreach(route(I,Path),Routes), 
param(Network) do 
    single_pair_shortest_path(Network,-1, 
                              From,To, 
                              _-Path) 
).

Wavelength Assignment

wave(NrDemands,Routes,LowerBound,Var,Max):-  
dim(Var,[NrDemands]), 
Var[1..NrDemands] :: 1..NrDemands, 
ic:max(Var,Max), 
setup_alldifferent(Routes,Var,LowerBound), 
bb_min(assign(Var),Max, 
        bb_options{from:LowerBound, 
                   timeout:100}).
assign(Var):-
    search(Var,0,most_constrained,indomain,complete,[]).

- Similar to first_fail
- Select variable with smallest domain first
- For tie break, select variable in largest number of constraints
Creating `alldifferent` Constraints

setup_alldifferent(Routes,Var,LowerBound):-
  (foreach(route(I,Path),Routes),
   fromto([],A,A1,Pairs) do
     (foreach(Edge,Path),
      fromto(A,AA,[l(Edge,I)|AA],A1),
      param(I) do
        true
     )
  ),
  group(Pairs,1,Groups),
  ...

Creating `alldifferent` Constraints (II)

... (foreach(_-Group,Groups),
  fromto(0,A,A1,LowerBound),
  param(Var) do
    length(Group,N),
    A1 is eclipse_language:max(N,A),
    (foreach(l(_,I),Group),
     foreach(X,AlldifferentVars),
     param(Var) do
      subscript(Var,[I],X)
    ),
    ic_global:alldifferent(AlldifferentVars)
  ).
Generating Data

```
problem(Name,NrDemands,Network,Demands):-
    network_topology(Name,NrNodes,Edges),
    make_graph(NrNodes,Edges,Directed),
    make_undirected_graph(Directed,Network),
    (for(I,1,NrDemands),
        fromto([],A,[demand(I,From,To)|A],Demands),
        param(NrNodes) do
            repeat,
            From is 1+(random mod NrNodes),
            To is 1+(random mod NrNodes),
            From \= To,
            !
    ).
```

Example Network: MCI
network_topology(mci,19, 
  [e(1,2,1), e(1,5,1), e(1,6,1), e(2,3,1), 
   e(2,5,1), e(2,12,1), e(3,4,1), e(4,5,1), 
   e(4,8,1), e(4,10,1), e(5,6,1), e(6,11,1), 
   e(6,12,1), e(6,18,1), e(7,8,1), e(7,9,1), 
   e(8,10,1), e(8,11,1), e(8,12,1), e(9,10,1), 
   e(10,17,1), e(10,19,1), e(11,12,1), e(12,13,1), 
   e(12,18,1), e(13,14,1), e(14,18,1), e(15,18,1), 
   e(16,17,1), e(16,18,1), e(17,18,1), e(17,19,1)])

Searchtree
First Solution

Continue Search
Optimal Solution

- Optimal solution found with minimal backtracking
- Reaching lower bound avoids enumeration proof of optimality
- Not guaranteed to be optimal for original problem
- Given decomposition destroys flexibility in finding solution
Further Experiments

- Vary number of demands to be handled
- Make 100 runs with randomized demands

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<th>Network</th>
<th>Nr Demands</th>
<th>Avg LB</th>
<th>Avg Sol</th>
<th>σ Sol</th>
<th>Avg Gap</th>
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Observations

- These are not hard problem instances
- In general, graph coloring can be much more difficult
- Fast, simple solution to RWA problem
- Quality gap to be determined
  - Chapter 17: Solving RWA with MILP
  - Chapter 18: A Hybrid model for RWA

Network Problems

- `graph_algorithms` library
- Shortest path, articulation points, critical links
- Matching, strongly connected components
- Max-flow/min-cut
- Interface to AT&T graphviz visualizer
Conclusions

Optimization in ECLiPSe

- branch_and_bound library
- Not restricted to ic library
- Simple extension of search
- Importance of lower bounds
- For best results, needs support in constraint model

More Information

Brigitte Jaumard, Christophe Meyer, and Babacar Thiongane.
ILP formulations for the routing and wavelength assignment problem: Symmetric systems.

Helmut Simonis.
A hybrid constraint model for the routing and wavelength assignment problem.
http://4c.ucc.ie/~hsimonis/rwa.pdf

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Solving the static design routing and wavelength assignment problem.
CSCLP 2009, Barcelona, Spain, June 2009.