ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

12-3240 / P12-6579

IVT Institut für Verkehrsplanung und Transportsysteme
Institute for Transport Planning and Systems

Comparison of Hierarchical Network Design Shape Grammars for Roads and Intersections

Basil J. Vitins, Nadine Schüssler, Kay W. Axhausen IVT, ETH Zurich

Motivation

- Growing urban systems.
- Different standards for network design between countries.
- Missing evidence for standards in network design handbooks.
- Search space reduction for transport network design.
- Growing number of software solutions for urban simulation and shape grammars, within urban design.

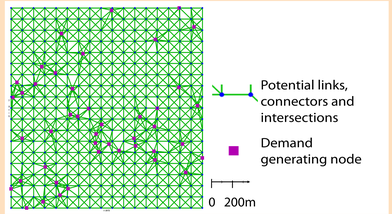
Initial settings

Objective function *f*

$$f = \left(\sum_{o=1}^{O} \sum_{d=1}^{D} demand_{od} \cdot traveltime_{od} \right) \cdot \gamma + I + p \cdot (I - B)$$

O: Origin demand generating node.
D: Destination demand generating node.
γ: Weighting factor (value of time as a recoure)
I: Infrastructur costs as annuity
p: Penalty factor, $p = 0$ when $I - B < 0$
B: Budget

Search space



Infrastructure costs USA 2000 (1, 2)

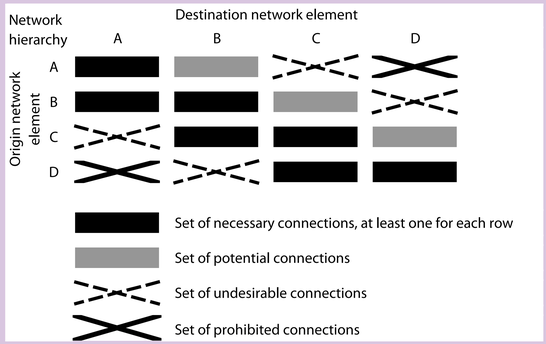
Network elements	Links [Mio $/lane-km]		Intersections [Mio $]	
	Built-up area	Outlying area	Built-up area	Outlying area
Freeway	1.6	1.3	9.3	6.2
Highway	1.4	1.2	1.2	2.5
Interstate	1.3	0.8	-	-
Major arterial	1.3	1.1	0.3	0.1
Collector street	0.8	0.6	-	-

Network Design Shape Grammars

Definition

Shape Grammars describe in the form of rules how network elements of different types may be added to each other, e.g. if a four lane road can be crossed by an access road. The rules depict how an existing planning state and geometry are extended to a more desirable state.

Example set of shape grammars for joining network elements of different hierarchical levels:



Advantages

- Application in planning processes.
- Robust and reliable implementation.
- Easy implementation, compared to state-of-the-art transport network optimization.
- Low computational requirements without a costly bi-level network optimization approach
- Inclusion of spatial planning and architecture shape grammars.

Disadvantages

- Unknown impact of shape grammars in urban systems.
- Lack of a fundamental evidence base for shape grammars.

Applications

- Transport, land use and urban planning (3, 4, 5).

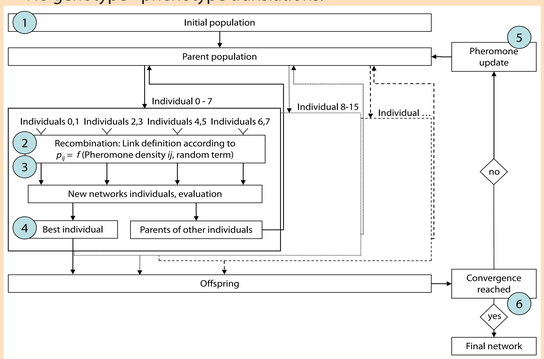
Integrated Ant Colony and Genetic Algorithm (IACGA)

Overview

The IACGA merges a standard Ant Colony Optimization (ACO) and a Genetic Algorithm (GA), taking advantages of both methods.

Advantages

- Learning ability.
- Population based approach, including recombination methods.
- Accounting large search rooms.
- No genotype - phenotype translations.

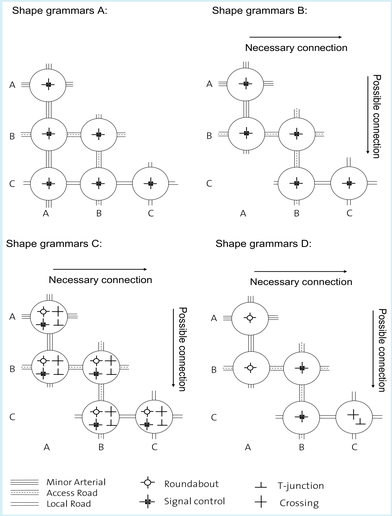


Pseudo code

start
(1) Initial population definition containing *P* random individuals.
repeat
for $i = 0, i < P,$ **do**
Choose 4 pairs of individuals randomly.
for each pair **do**
(2) Recombination for new network individual: Choose network elements according to $p_{ij} = f$*(pheromone density on link i-j, random term)* until budget *B* is depleted.
(3) Implementation of the hierarchical shape grammars.
endfor
(4) The generated individual with highest score is selected and proceeds to the offspring population. The remaining pairs and one random parent of the selected individual return to the parent population.
endfor
(5) The pheromone density on each link is updated according to the scores of the new offspring population. A share of the density evaporates, as a learning strategy (like in ACO).
until (6) convergence criterion is met.
end

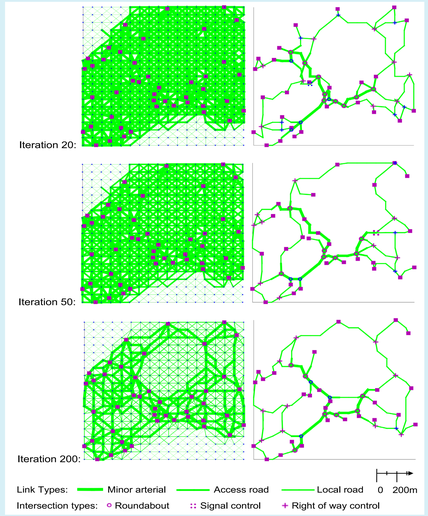
Results

Shape grammars considered



Convergence behavior

Pheromone densities (left) and best intermediate networks (right).



Differences of the shape grammars regarding the objective function *f*

Shape grammar	Initial setting 1 (n = 53) Average score	Relative difference	Wilcoxon rank-sum	Initial setting 2 (n = 11) Average score	Relative difference
A	-143'200	-		-300'192	-
B	-147'132	2.75%	0.0087%	-317'145	5.65%
C	-144'798	-		-297'301	-
D	-157'690	8.90%	0.048%	-466'909	57.05%

References

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Contact: Basil J. Vitins
IVT
ETH Hönggerberg
CH - 8093 Zürich
Phone: +41 44 633 27 02
E-mail: vitins@ivt.baug.ethz.ch
Internet: http://www.ivt.ethz.ch/people/bvitins/index_EN