DEPARTMENT OF MATHEMATICS

TECHNICAL REPORT

IMPROVING BIPARTITE GRAPHS USING MULTI-strategy SIMULATED ANNEALING

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Visualizing Bipartite Graphs Using Multi-strategy Simulated Annealing

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Abstract: The technique of simulated annealing combined with various greedy methods is applied to random bipartite graphs of different sizes and densities in order to reduce the number of edge crossings. Experimental results demonstrate that when random moves are combined with systematic steps within simulated annealing, the edge intersections in bipartite graphs can be reduced considerably in a reasonable amount of execution time. In particular, one of the cooling techniques used during the experiments reduces the execution time by half without sacrificing the quality of the layouts. Finally, we conclude by discussing work-in-progress of a prototype tool, which can facilitate the process of visualizing various layouts of bipartite graphs during the experiments.

1. Introduction

1.tion

The technique of *simulated annealing* has been applied to several optimization problems including the problem of producing aesthetically pleasing graph drawings [Davidson 89]. Some of the history of simulated annealing as well as its applications to other areas are described in [McLaughlin 89, Johnson 89]. In the case of minimizing edge intersections in bipartite graphs, if a heuristic rearranges a graph into one that has fewer intersections, the new graph is always accepted. An arrangement with more intersections is accepted whenever a randomly-generated probability taken from the uniform distribution between 0 and 1 is less than $e^{-\Delta/T}$ where Δ is the increase in the number of intersections and T is what is called the *temperature* of the system. So, if the increase in the num-

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TABLE I : *Description of multi-strategy simulated annealing*

	DRASTIC STEP	MODEST STEP
STRATEGY I	*Averaging*	*Greedy Adjacent Pair Switching*
STRATEGY II	*Averaging*	*Greedy Insertion*
STRATEGY III	*Random Pair Switching*	*Greedy Adjacent Pair Switching*
STRATEGY IV	*Random Rearrangement*	*Limited Random Insertion*
STRATEGY V	*Random Rearrangement*	*Random Pair Switching*
STRATEGY VI	*Random Rearrangement*	*Random Insertion*

TABLE II : *Summary of the experimental planning*

Metrics	1. Reduction of edge intersections as a percentage 1. Execution time
Input Parameters	
Input Parameters, (contd.)	

six charts represents an average time/improvement of the twenty graphs experimented on for that particular size and cooling method. With regard to execution time, the average time taken by the *symmetric swap* cooling method is about half that of the other two cooling methods without any loss in improvement. Thus, it appears to be the best cooling method of the three tested. With regard to improvement, both the range and the shape of all improvement graphs for all cooling methods are very similar. For all three cooling methods, *Strategy IV* takes the longest amount of time and *Strategy II* takes the next longest. Also for all cooling methods experimented on, the other four

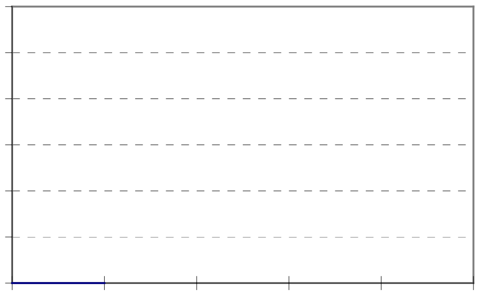

TABLE III : *Relative comparison of execution time for geometric cooling*

		Density 0.1-0.2	**Density 0.3-0.4**
Size=20-30	STRATEGY I	0.78-1.46	1.03-1.25
	STRATEGY II	1.43-1.77	1.40-1.63
	STRATEGY IV	2.56-3.15	2.24-2.71
	STRATEGY V	0.78-1.46	0.95-1.08
	STRATEGY VI	1.11-1.46	1.04-1.08
Size=40-60	STRATEGY I	1.03-1.07	1.01-1.02
	STRATEGY II	1.50-1.56	1.49-1.51
	STRATEGY IV	2.62-3.05	2.38-2.50
	STRATEGY V	1.00-1.07	1.00-1.01
	STRATEGY VI	1.07-1.24	1.01-1.07

TABLE IV : *Relative comparison of performance for geometric cooling*

		Density 0.1-0.2	**Density 0.3-0.4**
Size=10-30	STRATEGY I	0.89-1.00	1.00-1.00
	STRATEGY II	0.50-0.76	0.41-0.61
	STRATEGY IV	0.66-0.81	0.63-0.81
	STRATEGY V	0.58-0.77	0.53-0.74
	STRATEGY VI	0.58-0.74	0.57-0.73
Size=40-60	STRATEGY I	0.94-1.06	1.00-1.07
	STRATEGY II	0.35-0.52	0.40-0.49
	STRATEGY IV	0.45-0.66	0.52-0.61
	STRATEGY V	0.41-0.60	0.48-0.55
	STRATEGY VI	0.43-0.62	0.51-0.57

TABLE V : *Relative comparison of execution time for standard*

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STRATEGY II

STRATEGY IV

STRATEGY V

STRATEGY VI

The rationale behind the use of such a tool is to allow the user to decide whether the improvement of the layout is aesthetically pleasing. Typical graph operations such as scale, load, save and highlight are currently supported. Finally, the graph visualization tool is being expanded to allow the user to maintain control over the experiments. The person who conducts the experimental study would be able to use the tool in order to set the experimental framework (e.g. select the desired combinations of strategies to run). Also, he/she can set values to appropriate parameters (e.g. size, density) or change the metrics (e.g. measure only execution time or final number of intersections). Finally, the user may be given the option to actively interact with the experimental system and have the ability to interrupt the experiments. For instance, if the user considers a layout to be legible and aestheti-