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| **CSE 7350/5350**  **David W. Matula** | **Wireless Sensor Network Project**  **Total Points: 400**  ***Updated: Fall 2012*** | **Due Date: 11 December 2012**  Early: 10 point bonus for Tuesday, Dec 4, 11:59pm CDT  Latest: Dec 12 (4pm) CDT  **Note:** After Wednesday, Dec 12 at 4pm, CDT late projects will incur a penalty with possible delay of grade. Have your project TIME STAMPED. |

**1 Introduction and Summary**

In this project you are asked to implement an algorithm for determining a coloring, terminal clique, and a selection of bipartite subgraphs that are produced by an algorithm for graph coloring in a random geometric Graph (RGG). These results model a wireless sensor network (WSN) with each bipartite subgraph providing a communication backbone. You are first asked in Part I to prepare several RGG’s as a randomized benchmark set. RGG’s on the plane (unit square or disk) model WSN’s on geographic regions and RGG’s on the whole sphere model WSN’s that span the globe. In Part II you are asked to implement the smallest last coloring algorithm for vertex coloring, terminal clique, and bipartite subgraph identification in the RGG’s. The coloring algorithm is to be applied to the randomized benchmark set from Part I and is also to be applied to several original graphs you are asked to create to exhibit the strengths and weaknesses of the coloring and backbone determination algorithms particularly for a few considerably larger RGG’s.

Regarding algorithm efficiency you are asked to verify a linear time bound O (|V|+|E|) for smallest last graph coloring and suitable time and space bounds for each algorithm you implement for preparing the RGG. You are asked to document your implementations in the form of a report to a technical manager with substantial use of graphic display of results. Section 3 provides more details on the grading issues and the format for the project report. Section 4 provides details on the RGG generation implementation requested as Part I of the project. Specifications for Part II on the graph coloring procedure implementation are given in Section 5.

**2 Benchmarks**

A Randomized Case Benchmark of 10 particular random geometric graphs output from Part I should be part of your graph set input to your Backbone Selection Program in Part II. Your program must find a smallest last vertex ordering, vertex coloring, terminal clique, and several bipartite backbones for each of these ten benchmark graphs as well as the graphs created as requested in Parts I and II.

**3 Project Format**

Your project submission should be equivalent to a 10 -15 page word-processor-composed report.

This should be initiated by a 2 - 3 page **Executive Summary** containing an **Introduction and**

**Summary**, a **Programming Environment Description**, and **References** as described in the following. The core of your report should contain the **Reduction to Practice** details and **Result Summary** as outlined in the following. With reference to the On Output perspective on the class home page, the output of Part II has a dual audience of “Manager” for the executive summary and “Rational Learner” for the core of the report, and these audiences should be kept in mind. In summary, the report should be oriented towards a technical manager with a wide perspective, say in *Scientific* *American* magazine style. Grading partition:

**3.1 Executive Summary**

**Introduction and Summary (50 points)**

Give a brief description, in layman's terms, of the project, including your major result. Consider this section to be a professionally worded *marketing* effort. That is, would the competent technical manager (your audience) be likely to want to read on and try to understand your claimed good results. Describe the strongest features of your implementation. Summarize your use of illustrations, figures, tables, and computer graphics employed that will reveal your results effortlessly to the reader. The summary should include a table of results for the 10 benchmarks described in Section 4. Give clear citations (e.g. [1]) to your sources listed in the **References** section including downloaded programs and previous student's projects that most influenced your work.

**Programming Environment Description (20 points)**

Give a description of the environment you used to develop the program including both hardware and software components, i.e., the specific type and brand of computer, the computer's processing speed, the amount of memory, the operating system, the language, any graphics tools, and special libraries, etc. The description should include metrics on the program resource utilization allowing judgment of “was the total used respectable or an overkill?” The purpose of this description is to allow comparisons and facilitate reproduction. Consider: would a knowledgeable colleague be able to judge the scope of your work from this description of the environment and resource utilization? The graphics package used to present the report and the package used to create the graph drawings and animated displays should also both be described.

**References (30 points)**

Provide an enumerated list of publications, texts, and programs in typical reference style as a

concluding part of the executive summary. You should include references to several papers related to WSN’s, RGG’s, graph coloring algorithms, the Smallest Last algorithm and to the major tools used in developing the report. For example:

[1] D.W. Matula, Wireless Sensor Network Project, www.lyle.smu.edu/cse/7350/, 2012

IMPORTANT: If you read previous student projects from the archives in the department office or online regarding the smallest last coloring implementation and displays, you should include a reference to each of them in your reference list.

**3.2 Wireless Sensor Network Backbone Report**

**Reduction to Practice (120 points)**

This is the core of your report and should cover the five following topics appropriately integrated.

• *Data structure Design*: Describe and illustrate the representation and organization of data

employed and discuss the relation to the algorithms employed for both Parts I and II.

• *Algorithm Descriptions*: Provide a description of the smallest last vertex ordering and graph

coloring algorithm sufficient for your report to be self-contained to someone familiar with other

graph search algorithms.

• *Algorithm Engineering*: Describe how the algorithm implementation is engineered to achieve

efficiencies in time and space and provide arguments for the efficiencies. In particular, carefully

substantiate the linear time and appropriate optimal space bounds for the smallest last vertex

ordering, and vertex coloring, in each case where your implementation realizes this bound.

• *Verification Walkthrough*: Present a walkthrough for an RGG in a unit disk with N=24 vertices

and R=0.30. Draw the graph, and walk through the Smallest Last vertex ordering, the graph

coloring and the determination of the backbone for the vertices colored with the first and second

colors. Display the backbone bipartite subgraph illustrating the domination provided by the first

color set and the planarity of the bipartite subgraph. Plot the degree when deleted values and the original degree values for the vertices ordered by the Smallest Last order.

• *Algorithm Effectiveness*: Include here a summary table of results as an overview of the

benchmarks and your additional test graphs. Give your conclusion on the strengths and

weaknesses of the RGG generation, coloring, and bipartite backbone selection algorithms on the one hand and your implementation on the other. Indicate applications where your implementation would be strongest and what kind of input would be most difficult to handle. Your analysis and conclusions relevant to your separately created test graphs can be a focal point of this topic.

**Benchmark Result Summary (80 points)**

You should provide a standard output for each randomized benchmark graph created in Part I as

specified in Section 4. You should provide output for each graph colored in Part II as specified in

Section 5.

**Display (100 points)**

These points are awarded on the basis of your overall use of illustrations, figures, tables, bar charts, and computer generated diagrams in your report. Hand drawn and/or computer generated figures may be utilized as appropriate.

**4 Part I: Random Geometric Graph Generation and Display**

This subproject utilizes pseudo random number generation to create several types of random

geometric graphs. A variety of methods possessing different time and space requirements may be

employed to prepare the output adjacency list data structure.

*Input:* N = number of sensors,

R = distance bound for adjacency,

T = graph type.

*Output:* N = number of sensors (vertices).

M = number of distinct pair wise sensor adjacencies (edges).

*Degree distribution*: Plot the number of vertices having degree *i* as a function of *i* for *i* = 0,1,…, max degree.

*RGG Display*: Provide a display of the vertices of the RGGs you generate, highlighting the vertices having the minimum degree, the maximum degree. Also for one minimum degree vertex and one maximum degree vertex for Benchmarks 1-3, highlight all the neighbors. This can be done by drawing edges to the neighbors, or by highlighting the neighbors, or by shading the disk of radius R around the specified min-degree (maxdegree) vertex. Draw all the edges only if the average degree is not too large, e.g. ≤ 30.

**General Procedure:** For planar input data generation we shall pick N points in two dimensions according to some specified distribution using pseudo random number generation, and determine the pairs of points within distance R of each other. Various types of summary information should be presented as requested. The graph adjacency structure should be produced and saved for input to the coloring and backbone selection procedures. Develop the random geometric graph’s adjacency list data structure for the 10 benchmark data sets created as specified, and also for two-to-four more such cases that illustrate your implementation features in size and “quality”.

*Uniform Square* The points are uniform over the unit square, 0 ≤ *x* ≤ 1 and 0 ≤ *y* ≤ 1.

*Uniform Unit Disk* The points are uniform over the disk (circle) of diameter unity.

*Dense Rim Unit Disk* The rim is the boundary region within distance R/2 of the boundary of the unit diameter disk. The interior includes all points at least R/2 from the boundary, i.e. the disk of diameter 1-R. The points are uniform over the rim and uniform over the interior, with the density in the rim twice the density of the interior, effectively a two tier distribution.

*Uniform Sphere* The points are uniform over the surface of the unit radius sphere. The points may be determined by first picking three uniform random x, y, z values each in the interval [-1, 1], then if the point x, y, z is within unit distance from the origin, normalizing the point to a boundary point on the sphere by dividing each coordinate by the distance of the point from the origin. You may implement the distance check for edges by determining if the normalized x, y, z coordinates for each pair of points on the surfaces of the sphere are within distance R.

Benchmark Data Sets

Benchmark N R Distribution

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| --- | --- | --- | --- |
| 1 | 1000 | 0.10 | Square |
| 2 | 1000 | 0.12 | Disk |
| 3 | 1000 | 0.12 | Dense Rim Disk |
| 4 | 2000 | 0.20 | Sphere |
| 5 | 2000 | 0.06 | Square |
| 6 | 2000 | 0.10 | Square |
| 7 | 4000 | 0.05 | Square |
| 8 | 6400 | 0.12 | Sphere |
| 9 | 6400 | 0.08 | Disk |
| 10 | 12800 | 0.06 | Square |

For Benchmarks 1-3 you should draw the graph and the edges by plotting the points in the x, y plane. For Benchmarks 5-10 show only the points (no edges). For the sphere display (Benchmark 4), plot the points projected on the x, y plane corresponding to positive z values (a hemisphere). Draw the edges of the sphere for Benchmark 4.

**5 Part II: Graph Coloring and Bipartite Backbone Selection**

This subproject utilizes the smallest-last coloring algorithm to provide a vertex coloring of the graph to implement the backbone selection procedure.

*Input*: A graph in adjacency list form.

*Output*: A coloring of the vertices of the graph, suitably presented to an audience of type “rational investigator” that wants to visualize and understand the results for possible application of the program as implemented (see my class website perspective “on output”).

**5.1 Tables and Displays in Report**

Your report should include the following for each graph, along with any additional information you feel would “sell” your implementation.

**Sequential Coloring Plot**

For all graphs provide a plot of the degree when deleted function in the smallest last order. You should also show in the same plot the corresponding original degree (upper bound function) and the number of distinct adjacent colors when the color is assigned (lower bound function).

**Color Class Size Distribution**

For all graphs provide a plot of the size distribution table for the independent sets of vertices colored with color *j* for *j* = 1, 2, …, maxcolor.

**Graph Coloring Summary Table**

Provide a summary table for coloring results on your benchmark RGGs including for each graph: ID-number, N (number of vertices), R, Distribution type, M (number of edges), min degree, avg. degree, max degree, max degree when deleted, number of colors, max color class size (size of the two largest color classes), terminal clique size, and number of edges in the largest bipartite subgraph determined for each of the two bipartite subgraph selection procedures. For RGG’s on the sphere also give the corresponding number of faces for the largest bipartite subgraph. These results should be provided also for your own example graphs.

**Backbone Selection Procedures and Displays**

*Bipartite backbone selection by independent set pairings:* For the four largest color classes of each of the Benchmark graphs, determine which three of the six possible bipartite subgraphs have the most edges. Draw “the best” in perceived quality of each of these three bipartite subgraphs for the square and disk graphs. For the graphs on the sphere also determine the number of faces in the resulting planar bipartite subgraphs and draw a hemisphere projection of the “best” bipartite “backbone” showing points and edges.

**5.2 [to be updated] Bipartite backbone by independent relay set construction:**

Make the vertex set with the first color the primary set of the backbone. Determine all vertices adjacent to three or more primary set vertices as relay set R3 and those adjacent to exactly two primary set vertices as relay set R2. Color the vertices of the set R3∪R2 by traversing members of R3 in the original SL order and in a second pass following through members of R2 in the same order. Take the resulting first new color set from the relay set R3∪R2 as the independent relay set to be paired with the primary set, with this primary and independent relay set forming the first bipartite backbone. Repeat the procedure on the remaining vertices generating a second bipartite backbone and then a third bipartite backbone. Display the largest of the three bipartite backbones, as the desired output. Give its size in terms of number of vertices, number of edges, and number of components (if not connected), and number of faces using Euler’s Formula.