

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Context . . . . .	1
1.1.1	Runnel software . . . . .	2
1.1.2	Problem of study . . . . .	2
1.2	Goals and objectives . . . . .	3
1.2.1	Main goal . . . . .	3
1.2.2	Specific objectives . . . . .	3
1.3	Methodology . . . . .	3
1.4	Chapter contents . . . . .	4
<b>2</b>	<b>Antecedents and background</b>	<b>5</b>
2.1	Geomorphology . . . . .	5
2.2	Digital terrain models . . . . .	9
2.2.1	Data acquisition for DTMs . . . . .	9
2.2.2	Types of DTMs . . . . .	9
2.3	Rectangular grid model analysis . . . . .	10
2.4	Drainage network detection algorithms . . . . .	11
2.5	Large DEM processing . . . . .	12
2.5.1	Drainage pattern recognition algorithms . . . . .	14
2.5.2	Water flow path calculation algorithms . . . . .	15
2.5.3	Strahler order calculation . . . . .	15
2.5.4	Terrain preprocessing algorithms . . . . .	16
2.6	Geographical information systems . . . . .	18
<b>3</b>	<b>Software analysis</b>	<b>19</b>
3.1	Base version of Runnel . . . . .	19

3.1.1	Data Input subsystem . . . . .	19
3.1.2	Model Analysis subsystem . . . . .	20
3.1.3	Model Rendering subsystem . . . . .	23
3.2	Detected issues . . . . .	25
3.2.1	Drainage network extraction . . . . .	25
3.2.2	Drainage pattern classification . . . . .	28
3.2.3	Water flow path calculation . . . . .	28
3.2.4	Data input . . . . .	31
3.3	Other desirable techniques to be implemented . . . . .	31
3.4	Proposed solution . . . . .	32
<b>4</b>	<b>Design and implementation</b>	<b>33</b>
4.1	Algorithm descriptions . . . . .	33
4.1.1	Peucker algorithm . . . . .	33
4.1.2	RWFlood algorithm . . . . .	35
4.1.3	Gleyzer algorithm . . . . .	38
4.1.4	Garbrecht-Martz flat resolution algorithm . . . . .	40
4.1.5	Garbrecht-Martz pit removal algorithm . . . . .	46
4.1.6	Normal vector similarity algorithm for terrace detection . . . . .	51
4.2	Implementation details . . . . .	51
4.2.1	RWFlood algorithm . . . . .	51
4.2.2	Gleyzer algorithm . . . . .	52
4.2.3	Garbrecht-Martz flat resolution algorithm . . . . .	53
4.2.4	Garbrecht-Martz pit removal algorithm . . . . .	53
4.2.5	Peucker algorithm fix . . . . .	55
4.2.6	Normal vector similarity algorithm for terrace detection . . . . .	56

<b>5</b>	<b>Results and discussion</b>	<b>57</b>
5.1	Drainage network extraction on raw terrain . . . . .	57
5.2	Preprocessing techniques . . . . .	62
5.3	Drainage network extraction on fully preprocessed terrain . . . . .	65
5.4	Strahler order calculation . . . . .	72
5.5	Terrace visualization . . . . .	75
5.6	High resolution DEM . . . . .	77
5.7	Execution time . . . . .	80
<b>6</b>	<b>Conclusions</b>	<b>83</b>
<b>7</b>	<b>Future work</b>	<b>84</b>
<b>8</b>	<b>Appendix A: Code listings</b>	<b>86</b>
8.1	RWFlood algorithm . . . . .	86
8.2	Gleyzer algorithm . . . . .	89
8.3	Garbrecht-Martz flat resolution algorithm . . . . .	93
8.4	Garbrecht-Martz pit removal algorithm . . . . .	99
8.5	Peucker algorithm fix . . . . .	106
8.6	Normal vector similarity algorithm for terrace detection . . . . .	107
<b>9</b>	<b>Appendix B: Full results</b>	<b>111</b>
9.1	Drainage network extraction on raw terrain . . . . .	111
9.2	Preprocessing techniques . . . . .	111
9.3	Drainage network extraction on preprocessed terrain . . . . .	111
9.4	Strahler order calculation . . . . .	126
9.5	Terrace visualization . . . . .	129
9.6	High resolution DEM . . . . .	130



# List of Figures

1	Strahler order example . . . . .	6
2	Drainage patterns in river networks . . . . .	8
3	Spurious Strahler order increase in braided stream . . . . .	16
4	Runnel software subsystems . . . . .	19
5	Data Input subsystem modules . . . . .	20
6	Model Analysis subsystem modules . . . . .	21
7	Drainage Network Extraction module class diagram . . . . .	21
8	Drainage Pattern Classification module class diagram . . . . .	22
9	Water Flow Path Calculation module class diagram . . . . .	23
10	Model Rendering subsystem modules . . . . .	23
11	GLSL Shaders module class diagram . . . . .	24
12	Terrain Renderer module class diagram . . . . .	25
13	Comparison of RiverTools and Runnel Peucker algorithm results . . . . .	26
14	Comparison of RiverTools and Runnel O’Callaghan algorithm results . . . . .	27
15	Strahler order $\geq 3$ calculation on Peucker-based network in Runnel . . . . .	29
16	Runnel drainage pattern classification results . . . . .	30
17	Peucker algorithm example diagram . . . . .	34
18	RWFlood algorithm example diagram, flow direction assignment . . . . .	37
19	RWFlood algorithm example diagram, water accumulation . . . . .	38
20	Garbrecht-Martz imposed gradients example, first gradient . . . . .	44
21	Garbrecht-Martz imposed gradients example, second gradient . . . . .	45
22	Garbrecht-Martz imposed gradients example, combined gradient . . . . .	46
23	Window size occurrence plot . . . . .	54
24	Absence of drainage calculation in flat areas by Peucker algorithm . . . . .	57
25	Drainage cycles generated by Peucker algorithm . . . . .	58

26	RiverTools vs. RWFlood on raw terrain, higher areas . . . . .	59
27	RiverTools vs. RWFlood on raw terrain, lower areas . . . . .	60
28	RWFlood parallel flow example, central flats . . . . .	61
29	RWFlood parallel flow example, southwestern flats . . . . .	61
30	Peucker algorithm results on raw and flat-preprocessed flat zone . . . . .	62
31	O’Callaghan algorithm results on raw and flat-preprocessed flat zone . . . . .	63
32	RWFlood algorithm results on raw and flat-preprocessed flat zone . . . . .	63
33	RWFlood algorithm results on raw and flat-preprocessed flat zone (2) . . . . .	64
34	Example of depression breaching differences, Peucker algorithm . . . . .	65
35	Example of depression breaching differences, O’Callaghan algorithm . . . . .	65
36	Peucker algorithm results on raw and fully preprocessed DEM . . . . .	66
37	O’Callaghan algorithm results on raw and fully preprocessed DEM . . . . .	67
38	RiverTools and Runnel Peucker algorithm results on fully preprocessed terrain . . .	68
39	RiverTools and Runnel O’Callaghan algorithm results on fully preprocessed terrain	69
40	RWFlood algorithm results on raw and fully preprocessed DEM . . . . .	70
41	RiverTools and Runnel RWFlood algorithm results on fully preprocessed terrain . .	71
42	IGM map of main rivers in central Chile . . . . .	72
43	Strahler order calculation on preprocessed Peucker network before and after imple- menting the Gleyzer algorithm . . . . .	73
44	Strahler order calculation on preprocessed RWFlood network with the Gleyzer al- gorithm . . . . .	74
45	Gleyzer algorithm failure, local minimum . . . . .	74
46	Gleyzer algorithm with depression breaching . . . . .	75
47	Terrace visualization with 1 degree threshold on raw terrain . . . . .	76
48	Terrace visualization with 1 degree threshold on fully preprocessed terrain . . . . .	76
49	RiverTools and Peucker algorithm results on 4030x3080 DEM . . . . .	77
50	RiverTools and O’Callaghan algorithm results on 4030x3080 DEM . . . . .	78

51	RiverTools and RWFlood algorithm results on 4030x3080 DEM . . . . .	79
52	IGM map of major streams in Petorca province section . . . . .	80
53	Execution time plot for drainage algorithms . . . . .	81
54	Execution time plot for preprocessing algorithms . . . . .	82
55	Comparison of Peucker algorithm results before and after fixes . . . . .	112
56	Comparison of RiverTools and Runnel RWFlood algorithm results . . . . .	113
57	Comparison of Peucker algorithm results on raw and flat-preprocessed terrain . . . .	114
58	Comparison of Callaghan algorithm results on raw and flat-preprocessed terrain . .	115
59	Comparison of RWFlood algorithm results on raw and flat-preprocessed terrain . . .	116
60	Comparison of Peucker algorithm results on raw and depression-preprocessed terrain	117
61	Comparison of O'Callaghan algorithm results on raw and depression-preprocessed terrain . . . . .	118
62	Comparison of RWFlood algorithm results on raw and depression-preprocessed terrain	119
63	Comparison of Peucker algorithm results on raw and fully preprocessed terrain . . .	120
64	Comparison of O'Callaghan algorithm results on raw and fully preprocessed terrain	121
65	Comparison of RWFlood algorithm results on raw and fully preprocessed terrain . .	122
66	Comparison of RiverTools and Runnel Peucker algorithm results on fully prepro- cessed terrain (full size) . . . . .	123
67	Comparison of RiverTools and Runnel O'Callaghan algorithm results on fully pre- processed terrain (full size) . . . . .	124
68	Comparison of RiverTools and Runnel RWFlood algorithm results on fully prepro- cessed terrain (full size) . . . . .	125
69	IGM map of main rivers in central Chile (full size) . . . . .	126
70	Comparison of Strahler order calculation on preprocessed Peucker network before and after implementing the Gleyzer algorithm (full size) . . . . .	127
71	Strahler order calculation on preprocessed RWFlood network with the Gleyzer al- gorithm (full size) . . . . .	128
72	Terrace visualization with 1 degree threshold on raw terrain . . . . .	129
73	Terrace visualization with 1 degree threshold on fully preprocessed terrain . . . . .	129

74	Comparison of RiverTools and Peucker algorithm results on 4030x3080 DEM . . . .	131
75	Comparison of RiverTools and O’Callaghan algorithm results on 4030x3080 DEM .	132
76	Comparison of RiverTools and RWFlood algorithm results on 4030x3080 DEM . . . .	133
77	IGM map of major streams in Petorca province section . . . . .	134

## List of Algorithms

1	Peucker algorithm for drainage network extraction . . . . .	33
2	RWFlood algorithm for flow direction assignment . . . . .	35
3	RWFlood algorithm for flow accumulation calculation . . . . .	36
4	MakeDictionaries function for Gleyzer algorithm . . . . .	39
5	StreamOrdering recursive function for Gleyzer algorithm . . . . .	40
6	Function to calculate the gradient towards lower terrain for Garbrecht-Martz imposed gradients algorithm . . . . .	41
7	Function to calculate the gradient away from higher terrain for Garbrecht-Martz imposed gradients algorithm . . . . .	42
8	Function to calculate the final imposed gradient for Garbrecht-Martz imposed gradi- ents algorithm . . . . .	43
9	Garbrecht-Martz depression breaching & filling algorithm . . . . .	48
10	ComputeContributingArea function for Garbrecht-Martz depression breaching & fill- ing algorithm . . . . .	49
11	ComputePotentialOutlets function for Garbrecht-Martz depression breaching & fill- ing algorithm . . . . .	49
12	ComputePotentialBreachingSites function for Garbrecht-Martz depression breaching & filling algorithm . . . . .	49
13	ChebyshevDistance function for Garbrecht-Martz depression breaching & filling al- gorithm . . . . .	50
14	PerformFilling function for Garbrecht-Martz depression breaching & filling algorithm	50
15	SelectBreachingSite function for Garbrecht-Martz depression breaching & filling al- gorithm . . . . .	50



16	PerformBreaching function for Garbrecht-Martz depression breaching & filling algorithm . . . . .	50
17	Normal vector similarity algorithm . . . . .	51

## Listings

1	RWFlood algorithm class header file . . . . .	86
2	flood function in RWFloodAlgorithm.cpp . . . . .	87
3	calculateWaterAccumulation function in RWFloodAlgorithm.cpp . . . . .	88
4	getNumberStrahlerHorton function in arbol.cpp . . . . .	89
5	computeNetworkStrahlerOrdering function in arbol.cpp . . . . .	90
6	makeInflowingEdgeMap function in arbol.cpp . . . . .	90
7	makeUpstreamNodePerEdgeMap function in arbol.cpp . . . . .	91
8	streamOrdering function in arbol.cpp . . . . .	91
9	extractFlatIds function in garbrechtmartz.cpp . . . . .	93
10	run function in garbrechtmartz.cpp . . . . .	94
11	gradientTowardsLowerTerrain function in garbrechtmartz.cpp . . . . .	94
12	gradientAwayFromHigherTerrain function in garbrechtmartz.cpp . . . . .	96
13	combineGradients function in garbrechtmartz.cpp . . . . .	97
14	findHalfIncrementIds function in garbrechtmartz.cpp . . . . .	98
15	applyIncrements function in garbrechtmartz.cpp . . . . .	99
16	run function in gmpitremove.cpp . . . . .	99
17	computeContributingArea function in gmpitremove.cpp . . . . .	101
18	findPotentialOutlets function in gmpitremove.cpp . . . . .	102
19	findPotentialBreachingSites function in gmpitremove.cpp . . . . .	103
20	performBreaching function in gmpitremove.cpp . . . . .	104
21	nodeDistance function in gmpitremove.cpp . . . . .	105
22	calculateGrid function in peuckerdrainagenetwork.cpp . . . . .	106
23	Software defect fix for calculateGrid function in peuckerdrainagenetwork.cpp . . . . .	107
24	Header file for TerraceDetectionAlgorithm virtual class . . . . .	107
25	Header file for NormalVectorSimilarityAlgorithm class . . . . .	107
26	Implementation of NormalVectorSimilarityAlgorithm class . . . . .	108