

ACKNOWLEDGEMENTS

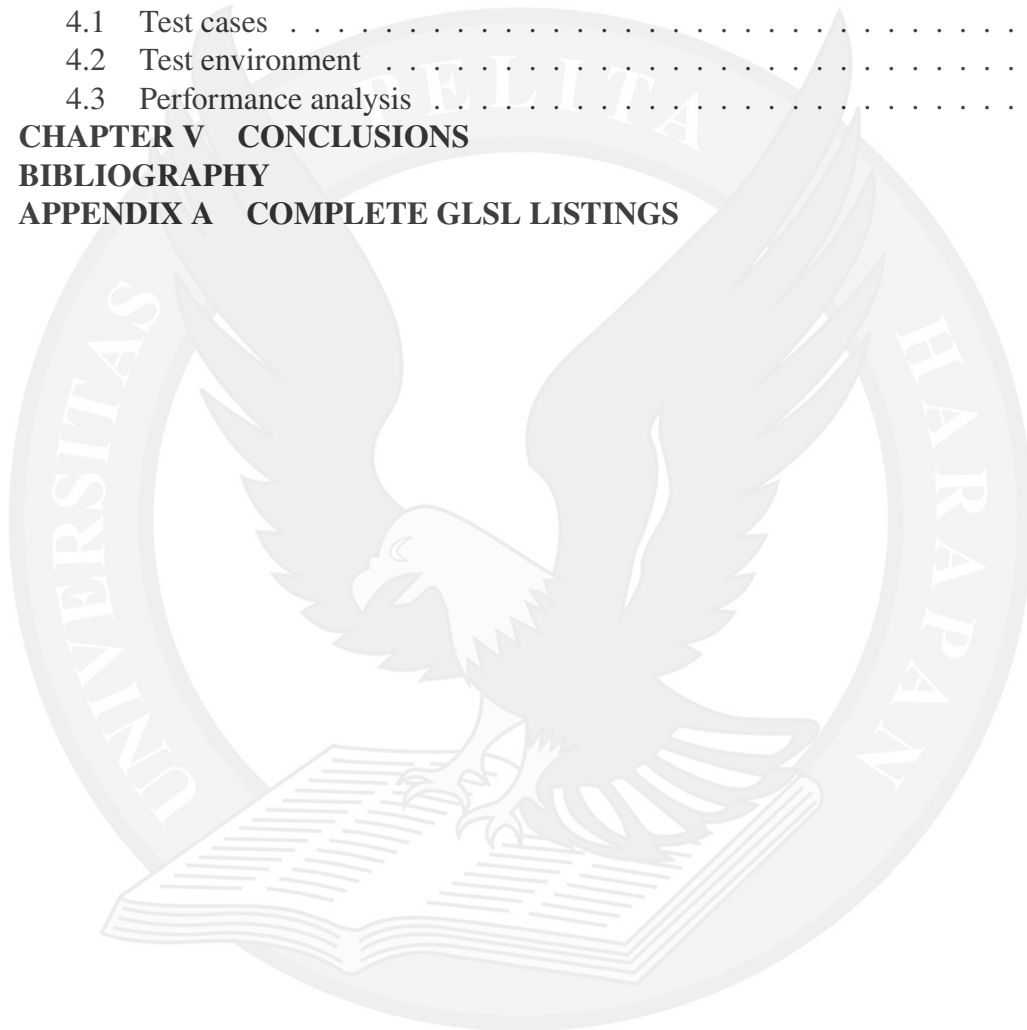
In no particular order, I would like to thank:

- Mr. Hendra Tjahyadi, S.T., M.T., Ph.D. as Associate Dean of Faculty of Computer Science.
- Ms. Irene A. Lazarusli, S.Kom., M.T. as Department Chair and Academic Advisor, for her constant help and lots of caring and patience in the past five years.
- Dr. Pujianto Yugopuspito as Thesis Advisor and Dr. David H. Hareva as Thesis Co-Advisor, for their patience, motivation, inspiration, enthusiasm, and invaluable guidance.
- my uncle, Mr. Tadius S. Gunadi, and my aunt, Dr. Lydia Pratanu, who have changed my life. Without them, this would not have been possible.
- my parents, for their unconditional love, encouragement, and support. Life has been hard on me, but they give me the strength to carry on.
- other family members for their support and confidence in me.

TABLE OF CONTENTS

TITLE PAGE	i
PERNYATAAN KEASLIAN KARYA TUGAS AKHIR	ii
PERSETUJUAN DOSEN PEMBIMBING TUGAS AKHIR	iii
PERSETUJUAN TIM PENGUJI TUGAS AKHIR	iv
ABSTRAK	v
ABSTRACT	vi
ACKNOWLEDGEMENTS	vii
TABLE OF CONTENTS	viii
LIST OF TABLES	x
LIST OF FIGURES	xi
LIST OF LISTINGS	xii
CHAPTER I INTRODUCTION	1
1.1 Background	1
1.1.1 Smoothed particle hydrodynamics method	1
1.1.2 GPU architecture	2
1.1.3 OpenGL	2
1.1.4 Vulkan	3
1.1.5 Shader	4
1.2 Problem definition	4
1.3 Literature review	4
1.4 Objectives and scope	6
1.5 Thesis outline	6
CHAPTER II FLUID SIMULATION	7
2.1 Navier–Stokes Equation	7
2.2 Smoothed particle hydrodynamics	8
2.3 Computing density	9
2.4 Computing pressure	9
2.5 Computing acceleration	10
2.6 Computing forces	10
2.7 Leapfrog integration	11
2.8 Kernel functions	12
2.8.1 Poly6 kernel	13
2.8.2 Spiky kernel	14
2.8.3 Viscosity kernel	15
2.9 Neighbor search	16
2.10 Simulation loop	16
CHAPTER III IMPLEMENTATION DETAILS	18
3.1 Data structures	18
3.2 Compute shader	19
3.3 SPIR-V format	20

3.4	Work division and work groups	20
3.5	Buffers	20
3.6	Shader storage buffer object	21
3.7	Data dependency and synchronization	24
3.8	Simulation parameters	25
3.9	Initializing particles	26
3.10	Visualization	26
CHAPTER IV RESULTS		27
4.1	Test cases	27
4.2	Test environment	27
4.3	Performance analysis	27
CHAPTER V CONCLUSIONS		38
BIBLIOGRAPHY		39
APPENDIX A COMPLETE GLSL LISTINGS		A1



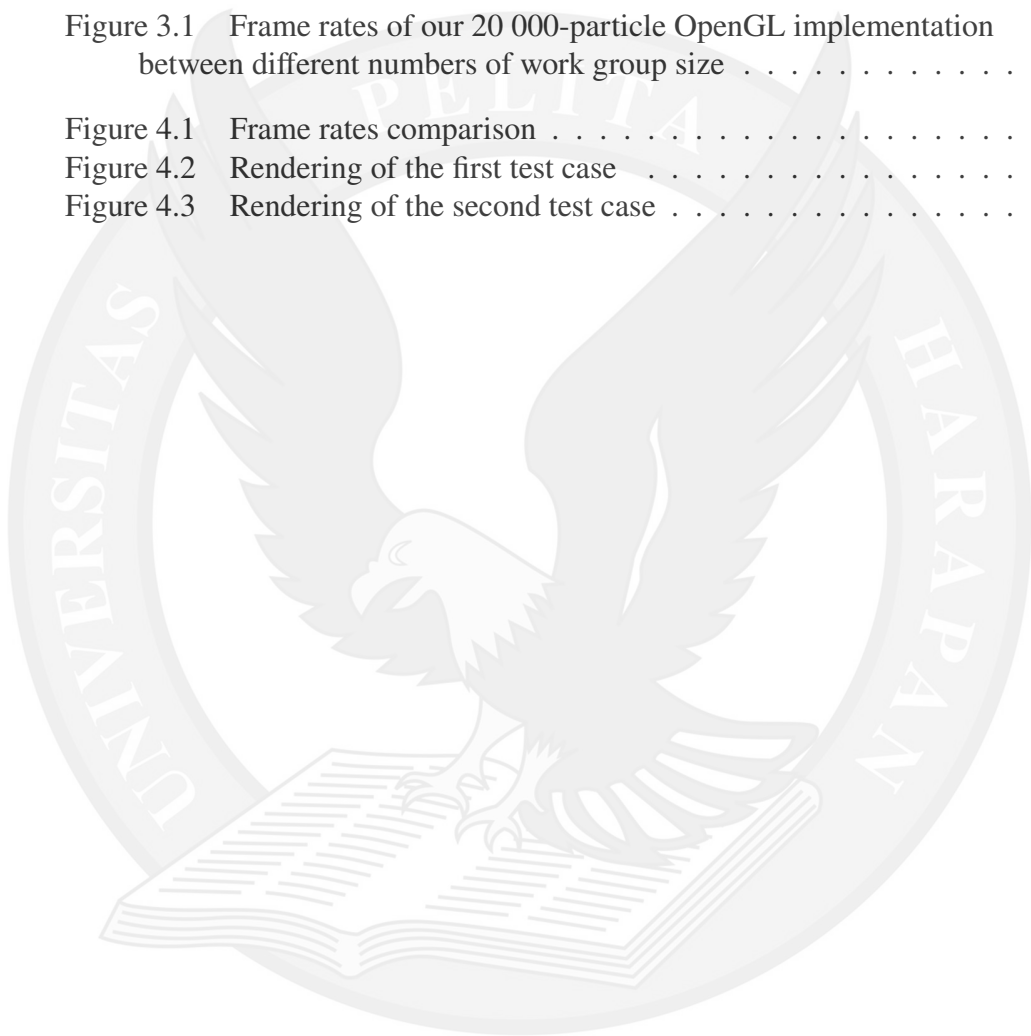
LIST OF TABLES

Table 4.1	Frame rates table	29
Table 4.2	OpenGL API calls statistics collected from 20 seconds of run-time	29



LIST OF FIGURES

Figure 2.1	Plot of W_{poly6} kernel, retrieved from [18]	13
Figure 2.2	Plot of W_{spiky} kernel, retrieved from [18]	14
Figure 2.3	Plot of $W_{\text{viscosity}}$ kernel, retrieved from [18]	15
Figure 3.1	Frame rates of our 20 000-particle OpenGL implementation between different numbers of work group size	21
Figure 4.1	Frame rates comparison	28
Figure 4.2	Rendering of the first test case	33
Figure 4.3	Rendering of the second test case	37



LIST OF LISTINGS

Listing 3.1	Old particle data structure	18
Listing 3.2	New particle data structure	19
Listing 3.3	Binding a single buffer to multiple indexed buffer binding points in Vulkan	22
Listing 3.4	Binding a single buffer to multiple indexed buffer binding points in OpenGL	23
Listing 3.5	Dispatching 3 compute shaders in OpenGL with memory barriers for synchronization	24
Listing 3.6	Dispatching 3 compute shaders in Vulkan with pipeline barriers for synchronization	24
Listing A.1	Compute shader 1—compute density and pressure	A1
Listing A.2	Compute shader 2—compute forces	A2
Listing A.3	Compute shader 3—integrate and handle collision with the edges	A3
Listing A.4	Vertex shader	A5
Listing A.5	Fragment shader	A5

