

# Contents

Dedication	v
Preface	vii
List of Tables	xv
List of Figures	xvii
1. Introduction	1
1.1 Robots . . . . .	1
1.2 Cluster Computing . . . . .	4
1.3 Overview of the Book . . . . .	6
2. Clusters and Robots	9
2.1 Parallel Computation . . . . .	9
2.1.1 Parallel Architectures . . . . .	11
2.1.2 Multiprocessor . . . . .	12
2.1.3 Multicomputer . . . . .	13
2.2 Clusters . . . . .	15
2.2.1 Terminology . . . . .	16
2.2.2 Cluster Configuration . . . . .	17
2.2.3 Programming the Cluster . . . . .	18
2.2.4 Configuring the Cluster . . . . .	19
2.2.5 Simple Cluster Configuration with OpenMPI . . . . .	19
2.2.6 Connecting the Cluster to the Robot . . . . .	20
2.3 Summary . . . . .	23
References . . . . .	23

3.	Cluster Programming	25
3.1	Approaches to Parallel Programming . . . . .	25
3.2	Programming with MPI . . . . .	29
3.2.1	Message-Passing . . . . .	30
3.2.2	Single Program Multiple Data (SPMD) Model . . . . .	31
3.2.3	Collective Communication . . . . .	32
3.3	Compiling and Running MPI Programs . . . . .	34
3.4	Analyzing Parallel Computation Time . . . . .	36
3.4.1	Speedup and Amdhal's Law . . . . .	37
3.4.2	Communication and Calculation . . . . .	38
3.4.3	Communication Models . . . . .	38
3.5	Summary . . . . .	41
	References . . . . .	42
4.	Robot Motion	43
4.1	Motion of a Mobile Robot in Two Dimensions . . . . .	45
4.2	Calculation of Location by Dead-Reckoning . . . . .	46
4.2.1	Partitioning: Block Data Decomposition . . . . .	47
4.2.2	Program Design . . . . .	48
4.2.3	Analysis . . . . .	52
4.3	Dead-Reckoning with Intermediate Results . . . . .	54
4.3.1	Partitioning . . . . .	55
4.3.2	Program Design . . . . .	56
4.3.3	Analysis . . . . .	57
4.4	Dead-Reckoning for a Team of Robots . . . . .	57
4.4.1	Partitioning . . . . .	59
4.4.2	Program Design . . . . .	60
4.4.3	Analysis . . . . .	61
4.4.4	Local and Global Buffers . . . . .	62
4.5	Summary . . . . .	64
	References . . . . .	64
5.	Sensors	67
5.1	Transforming Sensor Readings . . . . .	68
5.1.1	Partitioning: Single Robot Location . . . . .	71
5.1.2	Analysis . . . . .	71

5.1.3	Partitioning: Multiple Robot Locations . . . . .	73
5.1.4	Analysis . . . . .	74
5.2	Drawing a Map from Sonar Data . . . . .	75
5.2.1	Finding Straight Lines with the Hough Transform . . . . .	76
5.2.2	Partitioning . . . . .	77
5.2.3	Program Design . . . . .	78
5.2.4	Analysis . . . . .	80
5.2.5	Load Balanced Hough Calculation . . . . .	80
5.2.6	Analysis . . . . .	82
5.3	Aligning Laser Scan Measurements . . . . .	82
5.3.1	Polar Scan Matching . . . . .	84
5.3.2	Partitioning and Analysis . . . . .	86
5.3.3	Program Design . . . . .	87
5.4	Summary . . . . .	91
	References . . . . .	91
6.	Mapping and Localization . . . . .	93
6.1	Constructing a Spatial Occupancy Map . . . . .	95
6.1.1	Probabilistic Sonar Model . . . . .	96
6.1.2	Bayesian Filtering . . . . .	97
6.1.3	Partitioning by Map . . . . .	98
6.1.4	Program Design . . . . .	100
6.1.5	Analysis . . . . .	105
6.1.6	Partitioning by Sensor Readings . . . . .	107
6.1.7	Program Design . . . . .	108
6.1.8	Analysis . . . . .	109
6.2	Monte-Carlo Localization . . . . .	109
6.2.1	Partitioning . . . . .	112
6.2.2	Program Design . . . . .	112
6.2.3	Analysis . . . . .	114
6.2.4	Improving the Serial Fraction . . . . .	115
6.3	Summary . . . . .	118
	References . . . . .	118
7.	Vision and Tracking . . . . .	121
7.1	Following the Road . . . . .	123

7.2	Iconic Image Processing . . . . .	124
7.2.1	Partitioning . . . . .	125
7.2.2	Program Design . . . . .	126
7.2.3	Analysis . . . . .	127
7.2.4	Spatial Pixel Operations . . . . .	128
7.2.5	Partitioning . . . . .	130
7.2.6	Program Design . . . . .	130
7.3	Multiscale Image Processing . . . . .	132
7.3.1	Partitioning . . . . .	133
7.4	Video Tracking . . . . .	134
7.4.1	Spatial Histograms . . . . .	135
7.4.2	Condensation . . . . .	137
7.4.3	Partitioning . . . . .	138
7.4.4	Program Design . . . . .	139
7.5	Summary . . . . .	141
	References . . . . .	143
8.	Learning Landmarks . . . . .	145
8.1	Landmark Spatiograms . . . . .	147
8.2	K-Means Clustering . . . . .	149
8.2.1	Partitioning . . . . .	150
8.2.2	Program Design . . . . .	150
8.2.3	Analysis . . . . .	152
8.3	EM Clustering . . . . .	153
8.3.1	Partitioning . . . . .	154
8.3.2	Program Design . . . . .	154
8.3.3	Analysis . . . . .	156
8.4	Summary . . . . .	156
	References . . . . .	157
9.	Robot Architectures . . . . .	159
9.1	Behavior-Based Robotics . . . . .	159
9.2	Static Behavior-Based Architecture . . . . .	162
9.2.1	Partitioning . . . . .	164
9.2.2	Program Design . . . . .	165
9.2.3	Analysis . . . . .	169

9.3	Dynamic Behavior-Based Architecture . . . . .	172
9.3.1	Program Design . . . . .	173
9.3.2	Analysis . . . . .	176
9.4	Summary . . . . .	177
	References . . . . .	178
Appendix I: Summary of OpenMPI Man Page for mpirun		181
Appendix II: MPI Datatypes		187
Appendix III: MPI Reduction Operations		189
Appendix IV: MPI Application Programmer Interface		191
Bibliography		199
Index		207