
DISTRIBUTED SYSTEMS: PARADIGMS AND MODELS

Academic Year 2010–2011

M. Danelutto



CONTENTS

Preface	1
Acknowledgments	3
1 Parallel hardware (needs parallel software)	1
1.1 Hardware for parallel/distributed computing	2
1.1.1 Evolution of CPUs	3
1.1.2 High performance computing architectures	6
1.1.3 Cloud	10
1.2 Parallel software urgencies	11
2 Parallel programming: introducing the concept	15
2.1 Concurrent activity graph	18
2.2 Functional and non functional code	19
2.3 Performance	19
2.4 Other non functional concerns	21
2.4.1 Load balancing	21
2.4.2 Reliability	23
2.4.3 Security	24
2.4.4 Power management	25
2.5 “Classical” parallel programming models	25
2.5.1 POSIX/TCP	26
2.5.2 Command line interface	28
2.6 Implementing parallel programs the “classical” way	29
2.6.1 The application	29
2.6.2 The concurrent activity graph	29

2.6.3	Coordination	29
2.6.4	Implementation	30
2.6.5	Code relative to the implementation handling termination but not handling worker faults	30
2.6.6	Adding fault tolerance (partial)	37
3	Algorithmic skeletons	45
3.1	Algorithmic skeletons: definition(s)	46
3.1.1	The skeleton advantage	48
3.1.2	The skeleton weakness	50
3.2	Skeletons as higher order functions with associated parallel semantics	50
3.2.1	Stream modelling	53
3.3	A simple skeleton framework	54
3.3.1	Stream parallel skeletons	54
3.3.2	Data parallel skeletons	55
3.3.3	Control parallel skeletons	59
3.3.4	A skeleton framework	60
3.3.5	Skeleton programs	61
3.4	Algorithmic skeleton nesting	62
3.4.1	Sequential code wrapping	63
3.4.2	Full compositionality	65
3.4.3	Two tier model	65
3.5	Stateless vs. statefull skeletons	66
3.5.1	Shared state: structuring accesses	67
3.5.2	Shared state: parameter modeling	69
4	Implementation of algorithmic skeletons	73
4.1	Languages vs. libraries	73
4.1.1	New language	73
4.1.2	Library	74
4.2	Template based vs. macro data flow implementation	76
4.2.1	Template based implementations	76
4.2.2	Macro Data Flow based implementation	82
4.2.3	Templates vs. macro data flow	86
4.3	Component based skeleton frameworks	86
	Problems	88
5	Performance models	89
5.1	Modeling performance	90
5.1.1	“Semantics” associated with performance measures	91
5.2	Different kind of models	92
5.3	Alternative approaches	95
5.4	Using performance models	96
5.4.1	Compile time usage	97
5.4.2	Run time usage	98

5.4.3	Post-run time usage	99
5.5	Skeleton advantage	100
5.6	Monitoring application behaviour	101
5.7	Performance model design	103
5.7.1	Analytical performance models	103
5.7.2	Queue theory	104
6	Skeleton design	109
6.1	Cole manifesto principles	110
6.1.1	Summarizing ...	112
6.2	Looking for (new) skeletons	112
6.2.1	Analysis	112
6.2.2	Synthesis	113
6.3	Skeletons vs templates	113
7	Template design	115
7.1	Template building blocks	117
7.1.1	Client-server paradigm	119
7.1.2	Peer-to-peer resource discovery	119
7.1.3	Termination	120
7.2	Cross-skeleton templates	121
7.3	Sample template mechanisms	122
7.3.1	Double/triple buffering	122
7.3.2	Time server	123
7.3.3	Channel name server	124
7.3.4	Cache pre-fetching	125
7.3.5	Synchronization avoidance	127
7.4	Sample template design	129
7.4.1	Master worker template	129
7.4.2	Farm with feedback	131
8	Portability	135
8.1	Portability through re-compiling	137
8.1.1	Functional portability	137
8.1.2	Performance portability	138
8.2	Portability through virtual machines	139
8.3	Heterogeneous architecture targeting	140
8.4	Distributed vs multi-core architecture targeting	142
8.4.1	Template/MDF interpreter implementation	143
8.4.2	Communication & synchronization	144
8.4.3	Exploiting locality	144
8.4.4	Optimizations	145
9	Advanced features	149
9.1	Rewriting techniques	149

9.2	Skeleton rewriting rules	151
9.3	Skeleton normal form	152
9.3.1	Model driven rewriting	154
9.4	Adaptivity	155
9.5	Behavioural skeletons	160
9.5.1	Functional replication behavioural skeleton in GCM	163
9.5.2	Hierarchical management	165
9.5.3	Multi concern management	170
9.5.4	Mutual agreement protocol	173
9.5.5	Alternative multi concern management	176
9.6	Skeleton framework extendability	178
9.6.1	Skeleton set extension in template based frameworks	179
9.6.2	Skeleton set extension through intermediate implementation layer access	179
9.6.3	User-defined skeletons in muskel	180
10	Skeleton semantics	185
10.1	Formal definition of the skeleton framework	185
10.2	Operational semantics	186
10.3	Parallelism and labels	190
10.4	How to use the labeled transition system	191
11	Parallel design patterns	193
11.1	Skeletons	194
11.2	Design patterns	194
11.3	Skeletons vs parallel design patterns	195
11.4	Skeletons \cup parallel design patterns	197
12	Survey of existing skeleton frameworks	199
12.1	Classification	199
12.1.1	Abstract programming model features	199
12.1.2	Implementation related features	200
12.1.3	Architecture targeting features	201
12.2	C/C++ based frameworks	201
12.2.1	P3L	201
12.2.2	Muesli	202
12.2.3	SkeTo	202
12.2.4	FastFlow	203
12.2.5	ASSIST	204
12.3	Java based frameworks	204
12.3.1	Lithium/Muskel	204
12.3.2	Calcium	205
12.3.3	Skandium	205
12.4	ML based frameworks	206
12.4.1	Skipper	206

12.4.2	OcamlP3L	206
12.5	Component based frameworks	207
12.5.1	GCM Behavioural skeletons	207
12.5.2	LIBERO	208
12.6	<i>Quasi</i> -skeleton frameworks	208
12.6.1	TBB	208
12.6.2	TPL	209
12.6.3	OpenMP	209
	List of Figures	211
	List of Tables	215
	Acronyms	217
	Index	219
	References	223