Contents

Abstract **xix**

Überblick **xxi**

Acknowledgements **xxiii**

Conventions **xxv**

1 Introduction **1**

1.1 Malleability of Time 2

1.2 Scope and Context of this Thesis 3

1.3 Contributions 5

1.4 Structure 6

2 Time Design **9**

2.1 A Time-Design Space 10

2.1.1 Conceptual vs. Physical Interaction 11

2.1.2 Multiple Time Domains 15

2.2 User: Conducting Gesture Recognition 16

2.2.1 Design 18

2.2.2 Feature Detectors 20

Wiggle Profile 21

Up-Down Profile 21

Four-Beat Neutral-Legato Profile 22

2.2.3 Profile Selection 24

2.2.4 Discussion 25

2.3 User: Rhythmic Analysis of Human Motion 25

Terminology 26

2.3.1 Design 26

Movement Detection 27

Interval Analysis 27

Frequency Analysis 29

Data Fusion 30

Impulse Folding 31

Impulse Clustering 31

2.3.2 Discussion 31

2.4 Medium: MPEG-7 33

2.5 Medium: Automatic Beat Detection 34

2.6 Technology: Video Frame Interpolation 37

2.7 Technology: Audio Time-Stretching 40

2.7.1 Basic Phase Vocoder 42

2.7.2 Scaled Phase-Locked Phase Vocoder 44

2.7.3 The PhaVoRIT Algorithm 45

Multiresolution Peak-Picking (MRPP) 46

Sinusoidal Trajectory Heuristics (STH) 47

Silent Passage Phase Reset (SPPR) 47

2.7.4 Discussion 48

2.8 Closing Remarks 49

3 The Problem of Mappings **51**

3.1 Beat Timing in Conducting Gestures 52

Related Work 53

3.1.1 Experiment Scope and Objectives 54

3.1.2 Hypotheses 55

3.1.3 Experiment Setup 57

Participants 58

Procedure 58

3.1.4 Results 59

Conductors vs. Non-conductors 59

Effect of Conducting Experience 60

Effect of Musical Instrument Experience 61

Effect of a Metaphor on Conducting 64

Summary of Results 65

3.1.5 Discussion 65

3.1.6 Design Implications 68

3.2 Rhythmic Correction 68

3.2.1 Concept 69

3.2.2 Experiment 70

3.2.3 Results 72

3.3 Latency in Audio Time-Stretching 73

3.3.1 Interpreting Time-Stretched Audio 76

Black-Box Approach 77

Hop-Factor Approach 77

Overlap-Add Approach 78
Other Considerations 80
3.3.2 Startup Latency 81
3.3.3 Dynamic Latency 83
3.3.4 Discussion 85
3.4 Synchronization 85
3.4.1 A Closed Loop System 86
3.4.2 Responding to Timebase Changes 88
3.4.3 Discussion 90
3.5 Closing Remarks 92

4 Semantic Time **95**

A Conceptual Model Problem 96
4.1 Related Work 96
4.2 Time as a Hierarchy 99
4.3 Synchronization as Constraints 101
4.4 An Algebra for Time 102
4.4.1 Rhythm Maps 103
4.4.2 Concatenation 104
4.4.3 Scaling 105
4.4.4 Averaging 107
4.4.5 Algebraic Properties 108
4.5 Closing Remarks 111

5 The Semantic Time Framework **113**

5.1 Design Principles 117

5.2 Semantic Time Framework Version 1 (STFv1) 119

5.2.1 Design 119

Timebases 120

Streams 120

Effects 120

Graphs 122

5.2.2 Implementation 124

5.2.3 Discussion 124

5.3 Semantic Time Framework Version 2 (STFv2) 126

5.3.1 Design 127

Time Maps 128

Nodes 128

Pipelines 128

Synchronizers 129

5.3.2 Implementation 130

5.3.3 Discussion 131

5.3.4 Example: *HelloSTF* 132

5.3.5 Example: *MetroSync* 135

5.3.6 Comparison With Other Frameworks 137

5.4 Closing Remarks 138

6 Sample Systems **141**

6.1 Personal Orchestra 142

6.1.1 Personal Orchestra 1 (*The Virtual Conductor*) . . . 144

6.1.2 Personal Orchestra 2 (*You're the Conductor*) 147

6.1.3 Personal Orchestra 3 (*Maestro!*) 148

6.1.4 POlite 152
6.1.5 Discussion and Future Directions 155
6.2 DiMaß 155
6.2.1 Design 159
6.2.2 An Improved Synchronization Algorithm 161
6.2.3 Forwards and Backwards Scrubbing 164
6.2.4 Beat Tapper 164
6.2.5 Discussion and Future Directions 166
6.3 iRhyMe 167
6.3.1 Quartz Composer 168
6.3.2 Implementation 169
6.3.3 Discussion 170
6.4 Closing Remarks 170

7 Future Work **173**
7.1 Time-Design Space 173
7.2 Semantic Time 174
7.3 Semantic Time Framework 175
7.4 Design Patterns 176
7.5 Semantic Time Applications 176

8 Conclusions **179**

A Sampling and Quantization Overview **183**
A.1 Sampling 183
A.2 Quantization 184
A.3 Resampling 185

A.4 Closing Remarks 192

B Fourier Theory Overview **193**

B.1 The Fourier Transform 193

B.2 Windowing 194

B.3 The Short-Time Fourier Transform 195

B.4 Closing Remarks 196

C Source Code Listings **197**

C.1 HelloSTF 197

C.1.1 HelloSTFController.h 197

C.1.2 HelloSTFController.m 199

C.2 MetroSync 202

C.2.1 MetronomeView.h 202

C.2.2 MetronomeView.m 204

Bibliography **209**

Index **227**

Curriculum Vitae **231**