

Contents

1	Introduction	1
1.1	Modeling Dynamic Events	1
1.2	Subjective Time and Physical Time	5
1.2.1	Definition of Events and Time	5
1.2.2	Discrete-Event Systems and Dynamical Systems	7
1.3	Hybrid Dynamical Systems	8
1.3.1	Interaction in a Hybrid Dynamical System	9
1.3.2	Existing Approaches	10
1.4	Interval-Based Hybrid Dynamical System	12
1.4.1	Definition of Intervals	13
1.4.2	Dynamic Structures Exploited by Humans	14
1.4.3	Interval-Based Hybrid Dynamical System	18
1.4.4	Expressive Power and Limitations	23
1.5	Overview of the Thesis	26
2	Interval-Based Hybrid Dynamical System	29
2.1	System Architecture	29
2.2	Linear Dynamical Systems	32
2.2.1	Formulation	32
2.2.2	Class of Linear Dynamical Systems	33
2.2.3	Probabilistic State Inference	36
2.2.4	Likelihood Calculation of the Linear Dynamical System	38
2.3	Interval-Based State Transitions of the Automaton	39
2.3.1	Interval-Based State Transition	39
2.3.2	Probabilistic Inference of the Intervals	41
2.4	Inference of the Interval-Based Hybrid Dynamical System	45
2.4.1	Forward Algorithm	45
2.4.2	Viterbi Algorithm	48

2.4.3	Calculation Cost	53
2.5	Verification of the Inference Algorithms	53
2.6	Discussion	56
3	Learning Method for the Interval-Based Hybrid Dynamical System	59
3.1	Difficulties in Identification of Hybrid Dynamical Systems	59
3.1.1	In Case the Number of Subsystems is Known	60
3.1.2	In Case the Number of Subsystems is Unknown	61
3.2	Two-Step Learning Method for the Hybrid Dynamical Systems	61
3.2.1	Parameters	61
3.2.2	Two-Step Learning Method	62
3.3	Hierarchical Clustering of Dynamical Systems	63
3.3.1	Overview of the Clustering Algorithm	63
3.3.2	Initialization of the Clustering Algorithm	67
3.3.3	Constrained System Identification Based on Eigenvalues	68
3.3.4	Distance Definition between Dynamical Systems	73
3.3.5	The Cluster Validation Problem	74
3.4	Parameter Refinement via the Expectation-Maximization Algorithm	75
3.4.1	Overview of the Expectation-Maximization Algorithm	75
3.4.2	Parameter Estimation of the Automaton	77
3.5	Experiments	78
3.5.1	Evaluation of the Clustering Algorithm Using Simulated Data	79
3.5.2	Evaluation of the Refinement Process Using Simulated Data	82
3.5.3	Evaluation on Real Data	83
3.6	Discussion	86
4	Analysis of Timing Structures in Multipart Motion of Facial Expression	89
4.1	Timing Structures in Facial Expression	89
4.1.1	Introduction	89
4.1.2	Related Work	93
4.2	Facial Scores	93
4.2.1	Definition of Facial Scores	93
4.2.2	Facial Parts in Facial Scores	94
4.2.3	Modes in Facial Scores	95
4.3	Timing Structures in Facial Scores	97
4.3.1	Definition of Timing Structures	97
4.3.2	Distributions of Timing Structures	98

4.4	Experiments	98
4.4.1	Configuration of the Experiments	100
4.4.2	Facial Feature Tracking	100
4.4.3	Automatic Acquisition of Facial Scores	101
4.4.4	Comparison of Timing Structures between Intentional and Spontaneous Smiles	105
4.5	Discussion	108
5	Modeling Timing Structures in Multimedia Signals	111
5.1	Timing Structures in Multimedia Signals	111
5.2	Modeling Timing Structures in Multimedia Signals	114
5.2.1	Temporal Interval Representation of Media Signals	114
5.2.2	Definition of Timing Structure in Multimedia Signals	115
5.2.3	Modeling Timing Structures	117
5.3	Media Signal Conversion Based on Timing Structures	119
5.3.1	Formulation of Media Signal Conversion Problem	120
5.3.2	Interval Sequence Generation via Dynamic Programming	121
5.3.3	Calculation of Interval Transition Probability	122
5.4	Experiments	124
5.4.1	Evaluation of Interval Sequence Generation Algorithm Using Simulated Data	125
5.4.2	Evaluation of Image Sequence Generation from an Audio Signal	127
5.5	Discussion	130
6	Conclusion	133
6.1	Summary	133
6.2	Future Work	134
6.2.1	Extension of the Interval-Based Hybrid Dynamical System	134
6.2.2	Modeling Multiparty Interaction	137
6.2.3	Hybrid Computing in Robotics	140
6.2.4	Relation to Human Consciousness	142
A	Matrix Formulas	145
A.1	Basics	145
A.2	Differential Formulas of Matrices	146
A.2.1	Formulas	146

A.2.2 Examples	147
B Estimation of the Transition Matrices and Bias Vectors of Linear Dynamical Systems	149
C Gershgorin's Theorem	153
D Active Appearance Model	155