

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Technical motivation . . . . .	1
1.2	Limits of our scope, or: what this book is not about . . . . .	4
1.3	History and prior work . . . . .	4
1.3.1	Prior work on CETI . . . . .	5
1.3.2	Formal theories of communication problems . . . . .	6
1.3.3	Similar work in other areas . . . . .	7
1.4	Overview of our contributions . . . . .	7
1.4.1	Philosophical context . . . . .	8
1.4.2	An example: computational goals . . . . .	9
1.4.3	Overview . . . . .	12
1.4.4	Contributions of this book in the context of its relationship to other work . . . . .	15
<b>2</b>	<b>Theory of finite goal-oriented communication</b>	<b>27</b>
2.1	An informal overview of the theory . . . . .	28
2.1.1	Goals: a formal explication of meaning . . . . .	28
2.1.2	Sensing functions . . . . .	31
2.1.3	Capabilities and limits of universal users . . . . .	32
2.2	Model of communication and goals . . . . .	34
2.2.1	Agents: users, servers, and their environment . . . . .	34
2.2.2	Goals of communication . . . . .	35
2.2.3	Universal users . . . . .	39
2.2.4	Helpful servers . . . . .	42
2.3	Sensing and universality . . . . .	43
2.3.1	Sensing: safety and viability . . . . .	44
2.3.2	Sensing is necessary and sufficient for finite goals . . . . .	47
2.3.3	Extensions and variants of sensing: alternative constructions . . . . .	49
2.3.4	Safety requirements in the basic universal setting . . . . .	56

<b>3</b>	<b>Verifiable goals for communication</b>	<b>59</b>
3.1	Notation and definitions . . . . .	59
3.2	Control-oriented goals . . . . .	61
3.2.1	Transparent goals . . . . .	62
3.2.2	Searching . . . . .	63
3.3	Computational goals . . . . .	66
3.3.1	Main definitions in this setting . . . . .	67
3.3.2	Characterization of functions with polynomial time universal protocols . . . . .	69
3.3.3	Main consequences of the characterization . . . . .	72
3.3.4	Beyond PSPACE-completeness: more examples of universal protocols for computational problems . . . . .	74
3.3.5	Communication in spite of indeterminacy . . . . .	75
3.4	Intellectual curiosity . . . . .	75
3.4.1	A primer on computational depth . . . . .	76
3.4.2	Formalizing a goal of intellectual curiosity . . . . .	79
3.4.3	Constructing universal reviewers: sensing functions for goals of intellectual curiosity . . . . .	81
3.5	Tests . . . . .	81
3.5.1	A test of computational ability . . . . .	83
3.5.2	Examiner strategy for a test of computational ability . . . . .	86
3.5.3	Promises and verifiability . . . . .	89
<b>4</b>	<b>Conditions for efficiency in finite executions</b>	<b>91</b>
4.1	Running time lower bounds via passwords . . . . .	92
4.1.1	Lower bound for nontrivial goals . . . . .	92
4.1.2	Extension to parameterized nontriviality . . . . .	94
4.2	A Bayesian refinement of helpfulness . . . . .	96
4.2.1	Basic notions: priors and benchmarks . . . . .	97
4.2.2	Uniform viability . . . . .	100
4.2.3	An efficient universal protocol for close priors . . . . .	103
4.3	Effective conditions for efficient users . . . . .	106
4.3.1	Servers with a designated class of properly functioning states . . . . .	106
4.3.2	Effective refinements of sensing . . . . .	108
4.3.3	A universal user for servers that are easy to use and hard to break . . . . .	111
4.4	Lower bounds in the absence of a common prior . . . . .	114
4.4.1	A generic lower bound when no common prior exists . . . . .	114
<b>5</b>	<b>Computational complexity of goals</b>	<b>119</b>
5.1	Generic complexity classes for interactive computation . . . . .	120
5.1.1	Model of interactive computation . . . . .	120
5.1.2	Bounded resources and simulation . . . . .	122
5.1.3	Composition . . . . .	124

5.1.4	Basic agents: the toolkit . . . . .	129
5.2	On the computational complexity of goal-oriented communication . . . . .	130
5.2.1	The complexity of interpreting versus the complexity of learning to communicate . . . . .	130
5.2.2	Helpfulness for generic classes of users . . . . .	131
5.3	Sensing modules . . . . .	132
5.3.1	Safety and viability for generic classes of agents . . . .	132
5.3.2	On the necessity of sensing and its safety requirements . . .	134
5.4	Universal users for enumerable classes . . . . .	136
5.4.1	Enumerable complexity classes . . . . .	137
5.4.2	Sensing suffices for universal protocols for enumerable user classes . . . . .	143
5.5	The complexity of universal users for computational problems . . .	145
5.5.1	Competitive interactive proofs for generic classes . . . .	146
5.5.2	Computational goals for logspace agents . . . . .	152
<b>6</b>	<b>Theory of goal-oriented communication in infinite executions</b>	<b>159</b>
6.1	Goals and sensing for infinite executions . . . . .	160
6.1.1	Goals in infinite executions . . . . .	161
6.1.2	The computational complexity of strategies . . . . .	166
6.1.3	Achieving goals and helpful servers . . . . .	167
6.1.4	Sensing for goals in infinite executions . . . . .	170
6.2	On universal users in infinite executions . . . . .	174
6.2.1	Universality and sensing in infinite executions . . . . .	176
6.2.2	Sensing in the basic universal setting for infinite executions . . . . .	181
6.2.3	Universality without feedback . . . . .	185
6.2.4	Quantification of errors and delays . . . . .	187
6.2.5	On the non-triviality of strong sensing functions . . . .	197
6.3	Extensions . . . . .	199
6.3.1	Varying state sizes . . . . .	199
6.3.2	Concurrent session multi-session goals . . . . .	204
6.3.3	Partial robustness . . . . .	206
6.4	Embedding goals in finite executions into infinite executions . .	206
<b>7</b>	<b>The power of relaxed models</b>	<b>211</b>
7.1	Universal protocols for any computable decision problem . . .	212
7.1.1	Efficient universal protocols for infinite executions . . .	213
7.1.2	Universal protocols with bounded mistakes for finite executions . . . . .	216
7.2	Protocols for goals with exploration and resettable servers . .	223
7.2.1	Multi-session goals with exploration sessions . . . . .	224
7.2.2	Resettable servers . . . . .	226

7.2.3	A generic constant-error protocol for goals with exploration sessions and resettable servers . . . . .	230
<b>8</b>	<b>The error complexity of strategies in infinite executions</b>	<b>233</b>
8.1	On the number of errors incurred with password-protected servers . . . . .	234
8.2	On-line learning is equivalent to one-round goals . . . . .	237
8.2.1	Fixed length multi-session goals . . . . .	237
8.2.2	Generic users for goals implicitly specified by sensing .	238
8.2.3	Model of mistake-bounded on-line learning . . . . .	240
8.2.4	Equivalence of on-line learning and generic universal users for one-round goals . . . . .	242
8.3	Universal user strategies from on-line learning algorithms . .	245
8.3.1	Parity strategies . . . . .	245
8.3.2	Linear threshold strategies . . . . .	246
8.3.3	Demonstrating optimality via Littlestone's method . .	251
8.3.4	Generic users for other classes of strategies: a survey .	253
8.4	Overcoming the limitations of basic sensing with richer feedback . . . . .	256
8.4.1	Limitations of basic sensing . . . . .	256
8.4.2	Richer feedback . . . . .	259
<b>9</b>	<b>Communication with a changing network protocol</b>	<b>263</b>
9.1	Model of communication under a changing network protocol .	264
9.1.1	Setting and goal of communication . . . . .	264
9.1.2	Model of network protocols and bounded changes . . .	267
9.2	Decoding messages sent under a modified network protocol .	271
9.2.1	Algorithms for deterministic extractors and inverting transducers . . . . .	271
9.2.2	The user decoding strategy and its implementation . .	278
9.2.3	Analysis of the user decoding strategy . . . . .	281
9.3	Communication across an unreliable network . . . . .	284
9.3.1	A review of the key sub-protocols of TCP . . . . .	285
9.3.2	A modified end-user scheme for reliable communication . . . . .	293
9.3.3	Analysis of the modified stop and wait scheme . . . .	302
9.3.4	An improved end-user scheme for reliable communication . . . . .	316
9.4	On extending the schemes to networks connecting many users	326
9.4.1	Approaches for protocols using the same addresses . .	327
9.4.2	Approaches for protocols using different addresses . .	329

<b>10 Conclusions and directions for future work</b>	<b>331</b>
10.1 Directions for future work . . . . .	332
10.1.1 Concrete universal systems . . . . .	333
10.1.2 Reducing the overhead of concrete systems . . . . .	334
10.1.3 Connections to the usability of computer interfaces . . . . .	336
<b>A Background on probability</b>	<b>343</b>
A.1 Fundamentals of discrete probability . . . . .	343
A.2 Inequalities . . . . .	344
A.2.1 The basics: Union Bound and Markov's Inequality . . . . .	344
A.2.2 Tail bounds: Hoeffding's Inequality . . . . .	345
A.3 Probability for infinite executions . . . . .	347
A.3.1 On the measurability of various sets of executions . . . . .	347
A.3.2 The Borel-Cantelli Lemma . . . . .	348
<b>B Interactive proofs</b>	<b>351</b>
B.1 Introduction . . . . .	351
B.1.1 Motivation and definitions . . . . .	352
B.1.2 Example: Interactive proofs for Graph Non-Isomorphism . . . . .	355
B.1.3 The complexity of the prover . . . . .	356
B.2 Interactive proofs for PSPACE . . . . .	358
B.2.1 Polynomial encodings . . . . .	359
B.2.2 Arithmetization . . . . .	361
B.2.3 The Sum-Check protocol . . . . .	361
B.2.4 Interactive proofs for Quantified Boolean Formula validity . . . . .	366
<b>C Game theory</b>	<b>373</b>
C.1 Zero-sum games and the Min-max Theorem . . . . .	373
C.1.1 Definitions . . . . .	373
C.1.2 Basic multiplicative weights strategy . . . . .	374
C.1.3 The Min-max Theorem and Loomis' Corollary . . . . .	377
C.2 Nonstochastic bandits: games with exploration . . . . .	378
C.2.1 Estimating the reward in the bandit setting . . . . .	379
C.2.2 Optimizing the reward in the limit . . . . .	384
<b>Bibliography</b>	<b>387</b>



<http://www.springer.com/978-3-642-23296-1>

Universal Semantic Communication

Juba, B.

2011, XX, 400 p., Hardcover

ISBN: 978-3-642-23296-1