

**THE BASIC PICTURE**  
a structural basis  
for constructive topology

Giovanni Sambin

including two papers  
with Per Martin-Löf and with Venanzio Capretta

to the memory of  
my mother Elena Danieli, open heart and acute mind,  
who showed me how one can be brave and creative  
and of  
my father Paolo, tireless worker and rigorous historian,  
who taught me how to be tolerant and faithful to my principles

© Giovanni Sambin 2006

Giovanni Sambin,  
Dipartimento di Matematica Pura ed Applicata, Università di Padova, Italy.  
[sambin@math.unipd.it](mailto:sambin@math.unipd.it)

Per Martin-Löf,  
Department of Mathematics, University of Stockholm, Sweden.  
[pml@math.su.se](mailto:pml@math.su.se)

Venanzio Capretta,  
Department of Mathematics and Statistics, University of Ottawa, Canada.  
[Venanzio.Capretta@mathstat.uottawa.ca](mailto:Venanzio.Capretta@mathstat.uottawa.ca)

This research has been supported by the Italian Ministero dell'Istruzione, Università e Ricerca,  
project “Metodi costruttivi in topologia, algebra e fondamenti dell'informatica”.

# Contents

<b>-1 Preface</b>	<b>7</b>
-1.1 Preface . . . . .	7
-1.2 Metareflections: a virtual dialogue with readers. . . . .	14
<b>0 Elements of intuitionistic predicative mathematics</b>	<b>21</b>
0.1 The tools of elementary predicative mathematics. . . . .	22
0.1.1 Sets. . . . .	22
0.1.2 Sorts. . . . .	24
0.1.3 Logic. . . . .	25
0.1.4 Subsets. . . . .	25
0.1.5 Functions . . . . .	27
0.1.6 Relations. . . . .	27
0.1.7 Infinite unions and intersections. . . . .	27
0.1.8 Opposite of a subset. . . . .	28
0.1.9 Singletons and finite subsets. . . . .	29
0.1.10 Implication of two subsets. . . . .	30
0.1.11 The structure of subsets . . . . .	31
0.2 Operators on subsets and higher-order relations. . . . .	32
0.2.1 Saturation and reduction operators. . . . .	33
0.2.2 Basic covers and closure operators. . . . .	33
0.2.3 Definition of sup-lattice. . . . .	34
0.2.4 Presentation of sup-lattices. . . . .	35
0.3 Implementation. . . . .	36
0.3.1 Sets and functions. . . . .	37
0.3.2 Intuitionistic logic. . . . .	38
0.3.3 Subsets. . . . .	38
0.3.4 Relations. . . . .	40
0.3.5 Functions-as-programs and functions-as-relations. . . . .	41
<b>1 Basic pairs: symmetry and duality in topology</b>	<b>45</b>
1.1 Basic pairs. . . . .	45
1.2 Images of subsets: symmetry and duality. . . . .	48
1.3 Interior and closure, cover and positivity. . . . .	52
1.4 Formal open and formal closed subsets. The isomorphism theorem. . . . .	56
1.5 Operators on subsets determined by a relation. . . . .	58
1.5.1 Fundamental adjunctions and fundamental symmetry. . . . .	61
1.5.2 The special case of functions. . . . .	64
<b>2 Continuity is a commutative diagram</b>	<b>67</b>
2.1 The essence of continuity. . . . .	69
2.1.1 Continuity of functions . . . . .	75
2.2 Equivalence between relation-pairs. . . . .	76
2.3 The category of basic pairs and relation-pairs. . . . .	80
2.4 Other definitions of continuous relation. . . . .	81

<b>3 Spaces as basic pairs with convergence</b>	<b>83</b>
3.1 Turning a basic pair into a concrete space. . . . .	83
3.2 Defining implication on the concrete side. . . . .	88
3.3 Relation pairs preserving convergence and totality. . . . .	91
3.3.1 The category of concrete spaces. . . . .	94
3.4 Towards formal topology. . . . .	95
<b>4 Basic topologies</b>	<b>97</b>
4.1 Formal notions: how and why. . . . .	97
4.2 The definition of basic topologies. . . . .	99
4.2.1 Some examples of basic topologies. . . . .	101
4.2.2 Representable basic topologies. . . . .	102
4.2.3 Discrete basic topologies. . . . .	102
4.2.4 Finitary and elementary basic topologies. . . . .	102
4.2.5 Basic topologies on the concrete side. . . . .	102
4.3 Rewriting the definition of basic topology with relations. . . . .	103
4.4 Some constructions of basic topologies. . . . .	105
4.4.1 Finer covers, stronger positivities and subtopologies. . . . .	105
4.4.2 Improper basic topologies. . . . .	107
4.4.3 Simple positivity. . . . .	108
4.4.4 The trivial topology. . . . .	109
4.4.5 Equivalent presentations of formal closed and formal open subsets. . . . .	110
4.5 Dense basic topologies. . . . .	111
4.5.1 Bases for closed subsets. . . . .	112
4.5.2 Closure defined impredicatively. . . . .	115
4.5.3 Impredicative definition of cover. . . . .	116
<b>5 Continuous relations</b>	<b>119</b>
5.1 Continuous relations. . . . .	119
5.1.1 Equivalent presentations of continuous relations. . . . .	121
5.2 The category of basic topologies. . . . .	124
5.2.1 Subobjects in the category of basic topologies. . . . .	127
5.2.2 Image of a basic topology under a relation. . . . .	128
5.3 Topologies induced by a subset. . . . .	129
5.3.1 Topology induced by an open subset. . . . .	132
5.3.2 Subtopology induced by a closed subset. . . . .	133
5.4 Presentation of the category of suplattices. . . . .	135
<b>6 Elementary topologies</b>	<b>139</b>
6.1 From arbitrary relations to preorders. . . . .	140
6.1.1 Basic topology generated by a relation. . . . .	141
6.1.2 Hereditary subsets. . . . .	144
6.1.3 Preorders as basic pairs. . . . .	145
6.2 Elementary topologies. . . . .	148
6.2.1 Elementarization of basic topologies. . . . .	151
6.2.2 The Sierpinski topology. . . . .	152
<b>7 From basic topologies to formal topologies</b>	<b>153</b>
7.1 From basic topologies to formal topologies . . . . .	154
7.2 Formal topologies. . . . .	156
7.2.1 Some counterexamples. . . . .	159
7.3 Basic topologies with convergence. . . . .	160
7.3.1 Some results on complete lattices with a further binary operation. . . . .	163
7.3.2 Existential operations on subsets. . . . .	163
7.3.3 Implication on formal open subsets. . . . .	167
7.3.4 Equivalent forms of distributivity for an existential operation. . . . .	168

7.3.5 Assuming that convergence equals meet. . . . .	170
7.3.6 Basic topologies with an operation for convergence. . . . .	172
7.4 The category of formal topologies and formal maps. . . . .	173
7.4.1 Presentation of the category of frames and locales. . . . .	175
7.5 Simple formal topologies. . . . .	175
7.5.1 The positivity axiom. . . . .	176
7.5.2 The positivity predicate impredicatively and classically. . . . .	178
7.5.3 Imposing positivity. . . . .	179
<b>8 Formal points and formal spaces</b>	<b>181</b>
8.1 Formal points. . . . .	181
8.1.1 Formal spaces and the extensional topology. . . . .	183
8.1.2 Choicefree mathematics and choice sequences. . . . .	185
8.1.3 Specialization ordering. . . . .	186
8.1.4 Formal points and completely prime filters. . . . .	186
8.1.5 The functor $FP$ . . . . .	188
8.2 Continuous functions and the category of formal spaces. . . . .	189
8.2.1 Formal points as formal maps. . . . .	191
8.2.2 Formal spaces as infinitary notions. . . . .	193
8.3 Bispatial formal topologies. . . . .	194
8.4 On the notion of continuous relation and formal map. . . . .	196
<b>9 Reduction, saturation and opposite</b>	<b>199</b>
9.1 Beginning predicative pointwise topology. . . . .	199
9.1.1 Equational compatibility. . . . .	202
9.1.2 Defining closure by double negation. . . . .	204
9.2 Locales with saturation, reduction and opposite. . . . .	206
9.2.1 Combinations of $-$ , $\mathbf{a}$ and $j$ . . . . .	209
<b>10 Putting predicative topology in algebraic terms</b>	<b>213</b>
10.1 Overlap algebras. . . . .	214
10.1.1 Links between overlap and properness. . . . .	217
10.1.2 Relations as symmetric pair of adjunctions . . . . .	219
10.1.3 o-relations and o-basic pairs. . . . .	221
10.1.4 The category $\mathbf{OA}$ of overlap algebras and o-relations. . . . .	222
10.1.5 Operators induced by the adjunctions. . . . .	222
10.1.6 Preorders as o-basic pairs. . . . .	224
10.1.7 An algebraic characterization of total and of singlevalued relations. . . . .	225
10.2 Arrows between o-basic pairs: the algebraic form of continuity. . . . .	227
10.2.1 Equality of o-relation-pairs. . . . .	229
10.3 o-basic topologies. . . . .	230
10.3.1 o-basic topologies with a simple $j$ operator. . . . .	232
10.3.2 o-basic topologies induced by an element. . . . .	234
10.4 o-continuous relations and the category o-BTop. . . . .	234
10.4.1 Quotients. . . . .	235
10.5 o-concrete spaces and o-formal topologies. . . . .	236
10.5.1 o-formal points. . . . .	238
<b>11 The basic picture: a bird's eye view</b>	<b>241</b>
11.1 A bird's eye view. . . . .	241
11.2 Some benefits of the minimalist foundation. . . . .	243
11.2.1 Fusion of logic and topology. . . . .	243
11.2.2 Computable and infinitary in one framework. . . . .	243
11.2.3 Positivity increases control of the infinite. . . . .	244
11.2.4 Brouwer's continuity principles. . . . .	244
11.2.5 Different axioms for positivities. . . . .	244

11.2.6 Aesthetics and symmetry; from 1-many to 1-2-many. . . . .	245
11.2.7 The dark side of the moon: mathematical treatment of existential statements.	245
11.3 From completeness to invariance. . . . .	246
11.3.1 The problem of completeness. . . . .	246
11.3.2 The language of overlap algebras. . . . .	247
11.3.3 From completeness to invariance. . . . .	248
11.4 A different topology in different foundations. . . . .	252
11.4.1 New foundations must give new math. . . . .	254
11.4.2 Collapse with classical logic. . . . .	254
11.4.3 Basic pairs and basic topologies in an impredicative setting. . . . .	256
11.4.4 Collapse in the computational view. . . . .	256
11.4.5 Invariance under continuous relations? . . . . .	256
<b>12 Future and past</b>	<b>259</b>
12.1 Open problems and future work. . . . .	259
12.1.1 Suggestions for future developments. . . . .	259
12.1.2 Open questions. . . . .	261
12.1.3 Open problems . . . . .	271
12.2 Chronicle and credits. . . . .	276
12.2.1 A self-dialogue: my laboratory. . . . .	281
12.2.2 What's next: a manifesto for tolerance. . . . .	283
<b>13 Generating positivity by coinduction (by P. Martin-Löf and G. Sambin)</b>	<b>285</b>
13.1 Sets of axioms. . . . .	286
13.2 The game theoretic interpretation. . . . .	287
13.3 Cover and positivity as winning strategies. . . . .	288
13.4 Continuous relations respecting axioms. . . . .	291
<b>14 Nonstandard elements as formal points (by V. Capretta and G. Sambin)</b>	<b>295</b>
14.1 Inductively generated basic pairs. . . . .	296
14.2 Formal points. . . . .	297
14.3 An example: continued fractions. . . . .	299