



City Research Online

City, University of London Institutional Repository

Citation: Bawden, D. ORCID: 0000-0002-0478-6456 and Robinson, L. ORCID: 0000-0001-5202-8206 (2020). Still minding the gap? Reflecting on transitions between concepts of information in varied domains. Information,

This is the accepted version of the paper.

This version of the publication may differ from the final published version.

Permanent repository link: <https://openaccess.city.ac.uk/id/eprint/23561/>

Link to published version:

Copyright and reuse: City Research Online aims to make research outputs of City, University of London available to a wider audience. Copyright and Moral Rights remain with the author(s) and/or copyright holders. URLs from City Research Online may be freely distributed and linked to.

City Research Online:

<http://openaccess.city.ac.uk/>

publications@city.ac.uk

1 *Review*2 **Still Minding the Gap? Reflecting on Transitions**
3 **between Concepts of Information in Varied Domains**4 **David Bawden ^{1,*} and Lyn Robinson ²**5 ¹ Centre for Information Science, City, University of London, Northampton Square, London, EC1V 0HB,
6 United Kingdom; d.bawden@city.ac.uk7 ² Centre for Information Science, City, University of London, Northampton Square, London, EC1V 0HB,
8 United Kingdom; l.robinson@city.ac.uk

9 * Correspondence: d.bawden@city.ac.uk

10 **Abstract:** This conceptual paper, a contribution to the tenth anniversary special issue of *information*,
11 gives a cross-disciplinary review of general and unified theories of information. A selective
12 literature review is used to update a 2013 article on bridging the gaps between conceptions of
13 information in different domains, including material from the physical and biological sciences, from
14 the humanities and social sciences including library and information science, and from philosophy.
15 A variety of approaches and theories are reviewed, including those of Brenner, Brier, Burgin and
16 Wu, Capurro, Cárdenas-García and Ireland, Hidalgo, Hofkirchner, Kolchinsky and Wolpert, Floridi,
17 Mingers and Standing, Popper, and Stonier. The gaps between disciplinary views of information
18 remain, although there has been progress, and increasing interest, in bridging them. The solution is
19 likely to be either a general theory of sufficient flexibility to cope with multiple meanings of
20 information, or multiple and distinct theories for different domains, but with a complementary
21 nature, and ideally boundary spanning concepts.

22 **Keywords:** information theory; entropy; review; general theories of information; unified theories of
23 information; philosophy of information; library and information science
24

25 **1. Introduction**

26 "Information is in everything. It has become the foremost concept in biology, physics, economics,
27 engineering, philosophy, decision-making, methodology of science, artificial intelligence, computer
28 science, etc. Naturally, in different domains, information appeared in different forms and shapes,
29 which depend on the context and environment... Due to such a diversity of information forms and
30 shapes, researchers have built many specialized information theories trying to reflect important
31 aspects of information" [1](p.1).

32 While we might consider this view, expressed by Burgin and Hofkircher, to be somewhat
33 exaggerated - we doubt if the average physicist or philosopher, even today, necessarily considers
34 information their most important concept - there is much truth in their summarisation. The
35 multiplicity of information theories, and of conceptions of information, leads to discontinuities and
36 incompatibilities; to gaps.

37 In a book chapter published six years ago [2], based on an earlier conference presentation [3], we
38 examined the usage of the term 'information' in various subjects and domains, considering, in
39 particular, these 'gaps', or discontinuities in understanding, between them. This, we hoped, would
40 shed light on the perennial question of whether there is some underlying sameness in the nature of
41 information, as understood in different domains; whether it is, in some sense, the 'same thing'. The
42 alternative, of course, is that there is little, or no, underlying sameness; rather the situation is confused
43 by the use of the same English word, information, for things and processes which have only a
44 superficial, or a very general, similarity [4].

45 In that chapter we examined five domains: information and communications technology;
46 information physics; information biology; social information; and philosophy of information.
47 Particular attention was given to the perspective of library and information science (LIS) , as this was
48 focus of the volume in which the chapter appeared. We argued that this focus was appropriate, as
49 LIS is the domain which, above all others focuses on information, and whose contributions are
50 somewhat under-rated outside the discipline; this focus will be maintained in the present article.
51 Three specific conceptions for 'gap bridging', by providing an account of information relevant across
52 all domains were given: those due Stonier, Bates, and Floridi respectively.

53 Our conclusions to this chapter were that it is worth trying to bridge the gaps, and that attempts
54 to do so have provided valuable insights. Not through the finding of simple and direct equivalences,
55 but rather through the identification of more subtle insights, perhaps through the use of boundary
56 spanning concepts such as complexity and entropy, or through the generation of entirely new
57 conceptions. The study of gap-bridging has often been equated with the construction of unified, or
58 general, theories of information, generally requiring a single definitive answer to the question 'what
59 is information'. However, such a grand theory may not be necessary, and indeed may not be feasible
60 [5-7]. We will consider gap-bridging ideas both within and without general theories.

61 In this paper, our intention is to consider developments in the six years since 'Mind the gap' was
62 written, and to extend the discussion to include a wider variety of theories and conceptualizations
63 beyond those mentioned in the original paper, and hence to assess whether we are any nearer to an
64 understanding of the sameness of information across domains. This analysis is based on a selective
65 literature review, with materials from bibliographic databases (Web of Science and Library and
66 Information Science and Technology Abstracts), from Google Scholar, and from reference and
67 citation following. In covering such a broad area in a relatively short paper, this will necessarily be
68 an overview, limited in the degree of detail in which each aspect can be discussed.

69 This paper is intended as a contribution to the debate about the nature of information; a debate
70 which is long-running as Capurro points out [8], but which appears to be gaining in intensity and
71 significance. However, since our focus is in gap-bridging proposals, and there is a substantial
72 literature relating to these, we will not address the question of the nature of information, nor of the
73 relations between data, information, knowledge, and similar entities, except where form part of a
74 gap-bridging theory,

75 An initial presentation of developments since 2013 is followed by a discussion of gap bridging
76 concepts, including the three in the original paper, and others which have emerged, or taken on an
77 importance, since its publication. The intention throughout is to update the original 'mind the gap'
78 chapter, without repeating its arguments in any detail.

79 **2. The information concept in different domains**

80 This part of the paper is structured in a similar, though simpler, way to that of the original
81 chapter: developments in science and technology; developments in humanities and social sciences,
82 including library and information science; and developments in philosophy of information.

83 *2.1. Information in Science and Technology*

84 The concept of objective information began within communication technology [9], was
85 introduced into the physical and biological sciences through Brillouin and Schrödinger, and
86 continues to extend its reach; see, for example, the contributions to the volumes edited by Davies and
87 Gregersen [10] and by Durham and Rickes [11].

88 Interest in, and use of, information concepts, and Shannon's information theory in particular,
89 within the physical sciences have continued to increase, and have been reviewed from the perspective
90 of gap-bridging [12-15].

91 The increasing acceptance of information as a physical quantity is indicated by the importance
92 given to it in an article on the next hundred years in physics by Nobel laureate Frank Wilczek [16],
93 who predicts that fundamental action principles, and thus the laws of physics, will be interpreted as
94 statements about information and its transformation.

95 He notes that there has been a unification fusing the physical quantity entropy and the
96 conceptual quantity information, and argues for the necessity for a strong formal connection
97 between entropy and action. This information-entropy relationship has been, and remains, at the
98 heart of discussions of information physics. In an influential review article, Parrondo, Horowitz and
99 Sagawa [17] analyse the introduction of information into thermodynamics, suggesting that to
100 reconcile the information/entropy relation with classical thermodynamics which makes no mention
101 of information requires two things: restating thermodynamic laws to incorporate information
102 explicitly, and clarifying the physical nature of information, so that it enters thermodynamic laws as
103 a physical entity, not an abstraction. These authors suggest that we are still several steps away from
104 a complete understanding of the physical nature of information; in particular, we need a general
105 physical theory of information to explain how the macroscopic world, and the subjectivity of
106 entropy, emerge from statistical mechanics. An example of continuing studies of this kind is given
107 by Müller [18], who shows how the entropy of a gas is partly comprised of information about the
108 location of the molecules. The information/entropy relationship in complex systems has been
109 analysed in detail in a book chapter [113], and set in context in a recent review article [114].

110 The information-entropy relationship, of course, relates to the second law of thermodynamics.
111 An example of the continuing penetration of information concepts into physics is given in the
112 demonstration that the third law of thermodynamics, generally expressed as the impossibility of
113 reaching absolute zero, is related to the maximum speed with which information can be erased [19].
114 There has also been continuing interest in reconstructing the formalism of quantum theory in
115 information terms [20,21].

116 Information concepts are playing an ever-increasing role in our understanding of the biological
117 realm, conceptually as well as through the techniques of bioinformatics. This follows Schrödinger's
118 initial insight that information may play a crucial role as a fundamental feature of living systems, and
119 may provide a link between the living and non-living worlds [22]; for reviews marking the 75th
120 anniversary of the publication of Schrödinger's book, see [115,116]. Later insights included Gatlin's
121 introduction of information theory concepts into biology [23], and Marjivan's conclusion that living
122 existence is 'informational', that there is an 'invisible hand' of information in biology [24]. Davies
123 provides an accessible recent review of progress towards a general theory of biological information
124 [25].

125 The contributions of Thomas Sebeok (1920-2001) to development of biosemiotics, or semiotic
126 biology, are being more widely recognised. This takes a very different view of information in
127 biology to the more common invocation of Shannon's information formalism, and focuses on
128 communication, signs and meaning within all living systems, thereby providing "a bridge between
129 biology, philosophy, linguistics and the communication sciences" [117]; see also [118-120].

130 Another means of bringing the concepts of information, meaning, and complexity into biology
131 is the concept of 'code biology', promoted particularly by Marcello Barbieri, the analysis of codes in
132 living systems at various levels from the genetic code to codes of culture [121, 122]. An anonymous
133 reviewer has suggested that the idea of mechanism in code biology may reasonably be compared to
134 the idea of maker's knowledge in Floridi's philosophy of information; an intriguing gap-bridging
135 analogy.

136 Lacking at present a generally accepted over-arching theory, we observe numerous studies
137 expanding understanding of information concepts in various areas of biology. To give a flavour of
138 these, we can mention: Integrated Information Theory, which studies consciousness as a function of
139 information processing at different levels [26]; the idea that spiders use their webs as an external
140 information-storing memory device [27]; and the realization that biological cells perform a kind of
141 optimal processing during development [28].

142 Of significance to both the physical and biological sciences, and of particular relevance to this
143 review, is a new definition of semantic information, intended to complement Shannon's syntactic
144 information, and defined as syntactic information that a physical system has about its environment
145 which is causally necessary for the system to maintain its own existence [29]. It is notable that,
146 although these authors note that a definition of semantic information is of interest, *inter alia*, to
147 philosophy, they do not cite any of the philosophical theories discussed later; a symptom, perhaps,

148 of a systemic problem of this topic, to be discussed in the conclusions. An alternative definition of
149 information, rooted in semiotics, and related to many other conceptions, has been proposed by
150 Cárdenas-García and Ireland [30].

151 Although there is continuing, and indeed increasing, interest in the study of information as a
152 component of the physical world, and as intrinsic to the biological realm, the information-related
153 theories advanced within this domain do not generally extend to the human and social worlds. For
154 such gap-bridging theories, we must current look to philosophy, as discussed below.

155 *2.2. Information in Humanities and Social Sciences*

156 In the area of humanities and social sciences (HSS), qualitative analyses of the nature of
157 information, without being developed into fuller theories, continue, recent examples being due to
158 Bosancic and Matijevic [31], Capurro [8] and Chapman [32]. Janich, answering the question 'what is
159 information?' in a book with that title, argues for a view of information as a cultural artefact, rooted
160 in philosophy of language, and denying any real relation between Shannon information and
161 thermodynamic entropy [33]. Clearly, such a viewpoint will not lend itself to development of any
162 kind of integrated theory of information. Nor will the increasingly prevalent use of information,
163 entropy, and complexity, within literature (see, for example, the reviews by Hayles [34], and by
164 Groes [35], although they are a further reminder of the increasing reach of these ideas. This
165 increasing reach may be seen as an outworking of Luciano Floridi's 'Fourth Revolution' [123], as the
166 centrality of information, and information technologies, in our society is increasing reflected in art
167 and literature, and explicitly recognised in the work of creative artists; see, for example, the recent
168 study by Gorichanaz [124].

169 The same limitations may perhaps also be said to apply to two very significant contributions
170 from HSS, those of Brier and of Capurro, which emphasise hermeneutics, communication, and
171 meaning, and may therefore be categorised as humanist, or neo-humanist, approaches.

172 Søren Brier's cybersemiotics, a transdisciplinary framework, where signs, meaning, and
173 interpretation are fundamental, and where, to quote the title of Brier's best-known text 'information
174 is not enough' [36-39]. Based on Pierce's semiotics, and to a degree overlapping with the biosemiotics
175 approach noted above, it focuses on signs producing meaning in biological systems, including the
176 human and the social, and eschews a purely logical and mathematical foundation. It has been highly
177 influential, Brenner denoting it as "one of the most significant and original recent contributions to
178 information theory" [40](p.154). It is not, however, easy to see how it bridges the gap to the physical
179 world, although Brier's arguments are cogent in pointing out the lacuna between some objective
180 logical formulations of information and the richness of lived meaningful experience. Mingers and
181 Standing provide a somewhat similar theory of information based on signs and messages, but one
182 which allows that information exists in the absence of observers/recipients, and also includes the
183 Floridi-like requirement that information be true or correct; hence the theory is denoted as one of
184 objective and veridical information [41].

185 Capurro recommends a concept of information that connects human and non-human angeletic
186 phenomena, without attempting to ignore their differences, noting that this has some commonality
187 with Brier's cybersemiotics [42]; for a comparison with other information theories, see [43].

188 Although systems such as those of Brier and of Capurro, are likely to lead in themselves to
189 unified theories, it may be that they will be complementary to more objective schemes, the gaps being
190 bridged through this complementarity, as is implied by Brier [39].

191 Finally in this section may be mentioned the work of Hidalgo [44], who gives a broad qualitative
192 analysis of economic, social and business issues in terms of Shannon information, complexity, and
193 information entropy.

194 *2.3. Philosophy of Information*

195 There has been continued interest in the development of general theories, or unified theories, of
196 information, bridging the gaps between the idea of information in different domains. Brenner gives
197 a helpful comparison of several [40], and later developments are briefly reviewed below.

198 In the original 'mind the gap' paper, we identified several such philosophical contributions to
199 the concept of information, mentioning three in particular: the attempts by various philosophers.
200 most notably Fred Dretske, to develop Shannon's information theory to include meaning and
201 knowledge; Karl Popper's Three-Worlds ontology, and particularly his World Three of objective
202 knowledge; and Luciano Floridi's Philosophy of Information.

203 The first of these is generally considered to have met with little success. Rather, the ideas
204 advanced have been incorporated into more recent and more extensive philosophical approaches,
205 most notably that of Floridi, who develops his analysis of information on a basis of Shannon's theory
206 and extends it to meaningful information, and to knowledge. We may conclude that it is these this
207 approach which will take forward the ideas pioneered by Dretske and others.

208 The ontology put forward by Popper [45], once heralded as a theory of information suitable to
209 form a foundation for information science [46], and by implication other social sciences, has generally
210 fallen into disfavour as an unnecessary complication, or even a mystification, of the concept of
211 information. Notturmo, himself an advocate of the value of Popper's ideas, wrote that "most
212 contemporary philosophers regard World 3 as an unfortunate product of Popper's old age: as
213 incoherent, irrelevant and perhaps, if the truth be told, a bit ridiculous ... [but] .. most philosophers
214 who reject Popper's theory of World 3 simply do not understand it" [47](pp. 139 and 145). While we
215 have argued that a reappraisal of Popper's ontology is overdue, and would be worthwhile [43], it
216 remains for the moment out of favour in philosophical circles, although it continues to be referenced
217 within LIS; see, for example, [48].

218 It is worth noting that Floridi has acknowledged the of the influence of Popper's idea of World
219 Three of objective knowledge in the development of his philosophy of information [49](p. 95); the
220 point is discussed by Bawden and Robinson, and by Floridi, in a set of essays on Floridi's *The Logic of*
221 *Information* [50]. Burgin also notes a relation between his General Theory of Information and Popper's
222 ontology [51](pp. 58-59 and 551). As with Dretske, therefore, we may see Popper's insights being best
223 carried forward within these more recent and more developed philosophical frameworks.

224 Floridi's Philosophy of Information (PI) has been developed over a long period, and described
225 in numerous publication, encapsulated in his *The Philosophy of Information* [52], as noted in the original
226 'mind the gap' chapter. The scheme has been considerably extended since then, as set out Floridi's
227 *The Ethics of Information* [53] and *The Logic of Information* [49]; a further volume, the last of a tetralogy,
228 of the politics of information is forthcoming. This is an ambitious 'philosophy for the information
229 age', which is now bearing fruit, as we will note later, in providing detailed analyses of the
230 philosophical and ethical aspects of the developing information society, and its enabling digital
231 technologies. It is founded in an integrated theory of information at all levels, and has proved the
232 most fruitful of such approaches so far. Core to this is a General Definition of Information, with
233 information equated to 'well-formed, meaningful, and truthful data', a view which Floridi notes is in
234 accordance with Shannon's formalism. Data is understood as a lack of uniformity, a notable difference
235 or distinction. Information is converted to knowledge through being inter-related. This provides an
236 integrated view, which incorporates various forms of information, including physical,
237 environmental, and biological information, as the information and knowledge created and
238 communicated by Floridi's 'inforgs': humans and other information processing entities.

239 Floridi emphasises that PI is not intended to provide a single, unified theory of information in
240 all domains, but rather to provide a formal framework for linking and relating the various aspects
241 and manifestations of information, and hence for integrating, though not in a reductionist way, all
242 information-centred disciplines [54]. As an example of its extensibility, Walton has presented a model
243 which extends Floridi's concepts by explicitly integrating evolutionary, static and dynamic views of
244 information, highlighting relations between information in the physical world and information as
245 symbolic content, and has used this to analyse the relation between information, truth, and meaning
246 [55-57].

247 A somewhat similar approach, bridging gaps through a broad and formal approach, has been
248 taken by Mark Burgin, in his General Theory of Information (GTI) [51,58-60], extended to include an
249 evolutionary perspective [61]; a helpful summary is given by Burgin and Feistel [62]. Developed over
250 several decades, the GTI is a mathematical theory, aiming to incorporate previous approaches,

251 including those of Shannon, Bar-Hillel, Dretske, and others. It aims, as Brenner puts it in a review of
252 Burgin's 2010 book, to "explain relations between a huge diversity of meanings of the word
253 *information*, making it possible to unify these understandings" [63](p.224). Burgin's GTI offers a
254 parametric definition of information as that which has a capacity to cause changes in a system, so that
255 information may be seen as a form of energy. This concept is used to integrate earlier formal
256 definitions of information from various information theory perspectives into a single mathematical
257 framework, with a series of ontological and axiological principles which express what information is,
258 and how it may be measured. This approach may, in principle, encompass all forms of information
259 including the physical, biological, mental, and social, and encompassing syntactic, semantic, and
260 pragmatic information. It recognises the distinction between the two basic classes of structural, or
261 embedded, information, which may be related to physical entropy, and symbolic information, which
262 assigns meaning, and is associated with living creatures [62, 64, 65]: "Information constitutes a bridge
263 between lifeless physics and living beings struggling for survival" [62](p. 141). There is a clear analogy
264 here with Floridi's categories of environmental and semantic information. The GTI also addresses the
265 relation between data, information and knowledge [66]. From it has been developed a series of
266 multiple taxonomies relating all aspects of information in context, based on a triad of physical world,
267 mental world, and world of structures [67]. Burgin's GTI, though an ambitious and broad formalism,
268 has not as yet, been extended in any detail into social and ethical domains, as Floridi's has, but it may
269 be regarded as an alternative general formalism with a similar potential for wide applicability.

270 Joseph Brenner and Wu Kun have developed what they consider to be a revolution in
271 philosophy, based on a convergence of the science and philosophy of information, and an
272 'informational turn' in both science and philosophy, leading to a metaphilosophy with information
273 at its centre [68, 69, 70]. This examines the role of information, with its both physical and non-physical
274 components, in complex processes across various domains, using a non-standard logic, Logic in
275 Reality (LIR), for its analyses. LIR is a physical theory, and through it information may be directly
276 related to aspects of the physical and biological worlds [71, 72]. There is a clear similarity here with
277 Floridi's conception of PI as philosophy for [52] the information age. Some of the similarities and
278 differences are analysed by Brenner and Wu [40, 70, 73] and by Floridi [74].

279 We should also mention a further approach to a theory of information applicable across domains
280 due to Wolfgang Hofkirchner, of whose work Brenner commented that in it "the concept of a Unified
281 Theory of Information has been developed most completely" [69]. Hofkirchner's aim is to seek a
282 theory, a 'superconcept', which would encompass all the different manifestations of information,
283 including the physical and the nonphysical. This ambitious programme is manifested as a framework
284 based on complex systems theory and emergent properties [75-78], the most elaborate and
285 sophisticated account of information in terms of complexity and emergence; for earlier suggestions
286 of this sort, see [79]. Hofkirchner's theory however seems not to have been developed further, nor
287 applied by others, in recent years.

288 3. Bridging the Gaps

289 In the original chapter, we identified three significant conceptions of an integrated view of
290 information across domains, due respectively to Tom Stonier, a scholar of science and society, Marcia
291 Bates, a professor of library and information science, and Luciano Floridi, a philosopher and ethicist.
292 We now briefly review developments in each of these, without repeating our original analysis, before
293 introducing some new developments.

294 Stonier proposed a conception of information as integrated across the physical, biological,
295 mental, and in three books [80, 81, 82] and summarised in two journal articles [83, 84]. Information
296 is, for Stonier, most fundamentally a physical entity analogous to matter and to energy, being the
297 capacity to create and maintain organization within a system. He argues that this organizing function
298 of information is expressed in the biological world, and then in the human intelligence, and in
299 meaning, expressed in recorded information.

300 Stonier's views have been highly influential, and his books have together been cited over 1000
301 times. Morán-Reyes suggests that a framework for LIS could be developed based on Stonier's theory

302 of information, but does not set this idea out in detail [85]. It is fair to say that there has been little
303 explicit development of Stonier's specific proposal, and that his work is held up, rather, as an early
304 example of a unified gap-bridging theory of information.

305 Bates presented an integrated concept of information, from the physical world through the
306 biological realm to meaning and to human knowledge, starting from the idea that information is the
307 degree of order in any system [86, 87]. It may be seen, as Bates remarks, as an extension of the ideas
308 of Goontilake [88] and of Madden [89], which considered the relations between information in the
309 biological realm and the human social world of communicable knowledge. Whilst undeniably
310 ambitious and wide in scope, the idea suffers from a plethora of forms of information (Information-
311 1, Information-2, Data-1, Data-2, and Knowledge) without formal definition, and without clear
312 demarcation between them. In particular, it remains unclear how the gap between information in the
313 physical realm, and in the realm of meaning is bridged. Bates' work has certainly been influential (her
314 two papers have each been cited over 200 times), particularly within library and information science,
315 but it appears that there have been no significant extensions to, or developments of, her ideas.

316 Floridi's PI, as noted above, is a sophisticated and wide-ranging conception, set out in a
317 considerable number of books and articles; a comprehensive overview is given in a set of monographs
318 [52, 53, 90, 49], and in an accessible short introduction [91]. For critical assessments of his scheme as
319 a gap-bridging programme, and comparisons with others, see [7, 92, 93, 94].

320 PI has received a great deal of attention and application in the years since the original 'mind the
321 gap' chapter was written. Virtually all of this attention has been focused on applications to human
322 information, to the development of what Floridi terms 'mature information societies', and to the
323 appropriate and ethical use of new technologies: examples are privacy [95], data ethics [96], big data
324 [97], information governance [98], artificial intelligence [99], and the politics of information societies [100].

325 Floridi's PI has been particularly extensively analysed within the LIS discipline, and indeed
326 proposed as a suitable theoretical foundation for that domain: for overviews, see [50, 101], and for
327 examples of individual contributions to the debate see [93, 102-106]. This is the only example of one
328 of the general theories from philosophy being adopted within, and potentially contributed to by, a
329 discipline other than the one in which it was developed. For comparison, Mingers and Standing note
330 that Floridi's PI is rarely referenced in the information systems literature [41](p.96).

331 At its most fundamental level, PI addresses the nature of reality itself, through the philosophical
332 stance of 'informational structural realism', which holds that there is an observer-independent reality,
333 whose ultimate nature is neither physical or mental, but informational, and defined by the
334 interactions between informational entities [52, 107, 108]. Also fundamental to PI is the principle of
335 Levels of Abstraction (LoA) which allows information in any context to be considered at different levels
336 [52, 109, 110]; see also Chapman [111] on the advantages of a 'layered' perspective on information, of
337 which Floridi's LoA is one example. There is an interesting analogy between PI, with its concepts of
338 a once-only move to an infosphere populated by inforgs and Stonier's suggestion that the emergence
339 of machine intelligence presages an evolutionary discontinuity [83].

340 Floridi's approach, therefore, seems well-suited to reconciling concepts of information in
341 different domains, including the physical and the biological; there seems, however, to have been little
342 or no application of Floridi's concepts 'up-stream' in the physical and biological realms, certainly not
343 compared to its applications to social and ethical issues. Nonetheless, it seems evident that of the
344 three gap-bridging proposals identified in the original chapter, Floridi's is the one which has been,
345 and remains, particularly actively researched and applied.

346 4. Conclusions

347 Any gap-bridging proposal for information must address what has come to be known as
348 Capurro's trilemma [5]. This suggests that we must understand the meaning of information in
349 different domains in one of three ways: it has the same meaning in all contexts (univocity); it has one
350 true meaning in a specific context, but may be applied as an analogy in others (analogy); or it may
351 have multiple, equally valid, meanings in different contexts (equivocity). Each of these poses different
352 problems for gap-bridging proposals [43]. The first is plainly unhelpful, if not simply incorrect. The

353 second lends itself to overly simple analogies, and the third makes any unified theory impossible,
354 and any gap-bridging impossible.

355 The literature reviewed in this paper suggests that there are two ways to proceed: via general
356 theory of sufficient flexibility to cope with multiple meanings of information, as with Floridi's LOA
357 approach; or via distinct theories for different domains, but with a complementary nature, and
358 perhaps boundary spanning concepts, as with cybersemiotics and angeletics.

359 Of the gap-bridging theories reviewed here, Floridi's PI has been more developed towards
360 information society and ethics, with clear applications and impact, while Hofkirschner uses his
361 unified theory to address the problems of sustainable information societies [78]. The approaches of
362 Burgin, and of Brenner and Wu, have been more developed towards links with the physical sciences.
363 There has been little uptake, or comparison, of these frameworks within other disciplines, although
364 Morán-Reyes has given a comparison, albeit limited in detail, of the theories of Stonier, Burgin and
365 Floridi, from the perspective of LIS [85].

366 The best way of understanding the relationship between physical entropy and the various
367 formulations of information remains to be determined, as does the debate, originating with Shannon
368 and Wiener, as to whether information should be associated with order or with its opposite.
369 "Unfortunately", Joseph Brenner wrote in 2014, "the link of [philosophical] views to science, while
370 adding a further dimension to the discussion often remains insufficiently elaborated" [40](p.137); the
371 same is surely true today.

372 It is notable that, as mentioned earlier, Kolchinsky and Wolpert's paper [29], introducing a new
373 definition of semantic information for the sciences, cites none of the philosophical theories mentioned
374 here; in general, studies on the information concept within the physical sciences are restricted to their
375 own domain. The various general and unified theories of information have all, in various ways,
376 sought an extension to the physical and biological realms, but not seems fully satisfactory, and none
377 has been used in developing theory within the sciences.

378 The gaps then, remain, although there has been progress, and increasing interest, in bridging
379 them. This need not depress us. The nature of information, and the best ways in which we may
380 understand it, are surely open questions, which will never be finally solved, but about which much
381 understand may be gained. If, as Floridi tells us, all open questions are philosophical [112], then we
382 should continue to philosophize, and our hope is that cross-disciplinary reviews such as this may act
383 as a stimulus.

384

385 **Author Contributions:** Conceptualization, D.B. and L.R.; Investigation, D.B. and L.R.; Writing, D.B and L.R. All
386 authors have read and agreed to the submitted version of the manuscript.

387 **Funding:** This publication has received no funding.

388 **Conflicts of interest:** The authors declare no conflict of interest.

389 References

390 1 Burgin, M.; Hofkirschner, W. Introduction: omnipresence of information as the incentive for
391 transdisciplinarity. Chapter 1 of *Information Studies and the quest of transdisciplinarity: unity through*
392 *diversity*, M. Burgin and W. Hofkirschner (eds.). Singapore: World Scientific, 2017.
393 doi:10.1142/9789813109001_0001.

394

395 2 Robinson, L.; Bawden, D. Mind the gap: transitions between concepts of information in varied
396 domains. In *Theories of information, communication and knowledge: a multidisciplinary approach*. F.
397 Ibekwe-SanJuan and T. Dousa (eds.), Berlin: Springer, 2013, pp 121-141.

398

399 3 Bawden, D. Mind the gap: transitions between concepts of information in varied domains.
400 Proceedings of the international conference on 'Information Ecology and Libraries', Comenius
401 University Bratislava, 10-12 October 2011, Bratislava: Vydafatel, pp 7-13. Open access version at
402 <http://openaccess.city.ac.uk>.

403
404 4 Bawden, D. The shifting terminologies of information. *Aslib Proceedings*, **2001**, 53(3), 93-98.
405
406 5 Capurro, R.; Fleissner, P.; Hofkirchner, W. Is a unified theory of information feasible? A Trialogue.
407 In *The quest for a unified theory of information. Proceedings of the 2nd International Conference on the*
408 *Foundations of Information Science*. W. Hofkirchner (ed.). Abingdon: Routledge, 1999, pp. 9-30.
409
410 6 Capurro, R.; Hjørland, B. The concept of information. *Annual Review of Information Science and*
411 *Technology*, **2003**, 37, 343-411.
412
413 7 Furner, J. Philosophy and information studies. *Annual Review of Information Science and Technology*,
414 **2010**, 44, 161-200.
415
416 8 Capurro, R. A short note on the history of the concept of information. *Information*, **2010**, 10(10),
417 305; doi:10.3390/Info10100305.
418
419 9 Gleick, J. *The information: a history, a theory, a flood*. London: Fourth Estate, 2011.
420
421 10 Davies, P.; Gregersen, N.H. (eds.) *Information and the nature of reality: from physics to metaphysics*.
422 Cambridge: Cambridge University Press, 2010.
423
424 11 Durham, I.T.; Rickes, D. (eds.) *Information and interaction: Eddington, Wheeler, and the limits of*
425 *knowledge*. Cham, Switzerland: Springer, 2017.
426
427 12 Bawden, D.; Robinson, L. "Deep down things": in what ways is information physical, and why
428 does it matter for LIS? *Information Research*, **2013**, 18(3), paper C03 [online], available at
429 <http://InformationR.net/ir/18-3/colis/paperC03.html>.
430
431 13 Bawden, D.; Robinson, L. "A few exciting words": information and entropy revisited. *Journal of*
432 *the Association for Information Science and Technology*, **2015**, 66(10), 1965-1987.
433
434 14 Bawden, D.; Robinson, L. "Waiting for Carnot": information and complexity. *Journal of the*
435 *Association for Information Science and Technology*, **2015**, 66(11), 2177-2186.
436
437 15 Bawden, D., Robinson, L.; Siddiqui, T. "Potentialities or possibilities": Towards quantum
438 information science? *Journal of the American Society for Information Science and Technology*, **2015**, 66(3),
439 437-449.
440
441 16 Wilczek, F.. Physics in 100 years. arXiv:1503.07735, **2015**; doi:10.1063/PT.3.3137.
442
443 17 Parrondo, J.M.R.; Horowitz, J.H.; Sagawa, T. Thermodynamics of information. *Nature Physics*,
444 **2017**, 11, 131-139.
445
446 18 Müller, J.G. Information contained in molecular motion. *Entropy*, **2019**, 21, 1052; doi:
447 10.3990/e21111052.
448
449 19 Masanes, L.; Oppenheim, J. A general derivation and qualification of the third law of
450 thermodynamics. *Nature Communications*, **2017**, 8, 14538; doi:10.1038/ncomms14538.
451
452 20 Chiribella, G.; D'Ariano, G.M.; Perinotti, P. Informational derivation of quantum theory. *Physical*
453 *Review A*, **2011**, 84, 012311; doi:10.1103/PhysRevA.84.012311.
454

- 455 21 Jaeger, G. Information the reconstruction of quantum physics. *Annalen der Physik*, **2018**, 531(3);
456 doi:10.1002/andp.201800097.
- 457
- 458 22 Schrödinger, E. *What is life? The physical aspect of the living cell*. Cambridge: Cambridge University
459 Press, 1944.
- 460
- 461 23 Gatlin, L.L. *Information theory and the living system*. New York: Columbia University Press 1972.
- 462
- 463 24 Marijuan, P.C. Information and life: towards a biological understanding of informational
464 phenomena. *Triple-C*, **2004**, 2(1), 6-19.
- 465
- 466 25 Davies, P. *The demon in the machine*, London: Allen Lane, 2019.
- 467
- 468 26 Tononi, G.; Boly, M.; Massimini, M.; Koch, C. Integrated information theory: from consciousness
469 to its physical substrate. *Nature Review Neuroscience*, **2016**, 17, 450-461.
- 470
- 471 27 Japyassu, H.F.; Laland, K.N. Extended spider cognition. *Animal Cognition*, **2017**, 20, 375-395.
- 472
- 473 28 Potkova, M.D.; Tkačik, G.; Bialek, W.; Wieschaus, E.F. Optimal decoding of cellular identities in a
474 genetic network, *Cell*, **2019**, 176(4), 844-855.E15.
- 475
- 476 29 Kolchinsky, A.; Wolpert, D.H. Semantic information, autonomous agency and non-equilibrium
477 statistical physics. *Interface Focus*, **2018**, 8: 20180041; doi: 10.1098/rsfs.2018.0041.
- 478
- 479 30 Cárdenas-García, J.F.; Ireland, T. The fundamental problem of the science of information.
480 *Biosemiotics*, **2019**, 12, 213-244; doi:10.1007/s12304-019-09350-2.
- 481
- 482 31 Bosancic, B.; Matijevic, M. Information as a construction. *Journal of Librarianship and Information*
483 *Science*, **2019**, published online April 16 2019; doi:10.1177/0961000619841657.
- 484
- 485 32 Chapman, D. What can we say about information? Agreeing a narrative. *Proceedings*, **2017**, 1(3),
486 49; doi:10.3390/IS4SI-2017-03915.
- 487
- 488 33 Janich, P. *What is information?* Translated by E. Hayot and L. Pao. Minneapolis: University of
489 Minnesota Press, 2018.
- 490
- 491 34 Hayles, N.K. *How we became post-human: virtual bodies in cybernetics, literature, and informatics*.
492 Chicago: University of Chicago Press, 1999.
- 493
- 494 35 Groes, S. Information overload in literature. *Textual Practice*, **2017**, 31(7), 1481-1508.
- 495
- 496 36 Brier, S. *Cybersemiotics: why information is not enough*. Toronto: University of Toronto Press, 2008.
- 497
- 498 37 Brier, S. Cybersemiotics: an evolutionary world view going beyond entropy and information into
499 the question of meaning. *Entropy*, **2010**, 12(8), 1902-1920; doi:10.3390/e12081902.
- 500
- 501 38 Brier, S. The transdisciplinary view of information theory from a cybersemiotic perspective, in
502 *Theories of information, communication and knowledge: a multidisciplinary approach*, F. Ibekwe-SanJuan,
503 T. Dousa (eds.), Dordrecht: Springer, 2013, pp 23-49.
- 504
- 505 39 Brier, S. How to produce a transdisciplinary concept for a universal theory of information.
506 Chapter 2 of *Information Studies and the quest of transdisciplinarity: unity through diversity*. M. Burgin
507 and W. Hofkirchner (eds.). Singapore: World Scientific, 2017. doi:10.1142/878981001_0002.

508
509 40 Brenner, J.E. Information: a personal synthesis. *Information*, **2014**, 5(1), 134-170;
510 doi:10.3990/info5010134.
511
512 41 Mingers, J.; Standing, C. What is information? Toward a theory of information as objective and
513 veridical. *Journal of Information Technology*, **2018**, 33(2), 85-104.
514
515 42 Capurro, R. Past, present and future of the concept of information. *Triple-C*, **2009**, 7(2), 125-141.
516
517 43 Bawden, D.; Robinson, L. Super-science, fundamental dimension, way of being: library and
518 information science in an age of messages. In *Information cultures in the digital age: a festschrift in*
519 *honor of Rafael Capurro*. M. Kelly, J Bielby. (eds). Wiesbaden: Springer VS, 2016, pp 31-43.
520
521 44 Hidalgo, C. *Why information grows: the evolution of order, from atoms to economics*. London: Allen
522 Lane, 2015.
523
524 45 Popper, K.R. *Objective knowledge: an evolutionary approach (revised edition)*. Oxford: Clarendon
525 Press, 1979.
526
527 46 Brookes, B.C. The foundations of information science. Part 1: philosophical aspects. *Journal of*
528 *Information Science*, **1980**, 2(3/4), 125-133.
529
530 47 Notturmo, M. A. *Science and the open society*. Budapest: Central European University Press, 2000.
531
532 48 Gnoli, C. Mentefacts as a missing level in theory of information science. *Journal of Documentation*,
533 **2018**, 74(6), 1226-1242.
534
535 49 Floridi, L. *The logic of information: a theory of philosophy as conceptual design*. Oxford: Oxford
536 University Press, 2019.
537
538 50 Gorichanaz, T.; Furner, J.; Ma, L.; Bawden, D.; Robinson, L.; Dixon, D.; Herold, K.; Obelitz Søe, S.;
539 Van der Veer Martens, B.; Floridi, L. Information and Design: Book Symposium on Luciano
540 Floridi's 'The Logic of Information'. *Journal of Documentation*, **2020**, in press.
541
542 51 Burgin, M. *Theory of information: fundamentality, diversity and unification*. Singapore: World
543 Scientific, 2010.
544
545 52 Floridi, L. *The philosophy of information*, Oxford, Oxford University Press, 2011.
546
547 53 Floridi, L. *The ethics of information*. Oxford: Oxford University Press, 2013.
548
549 54 Floridi, L. Mapping the philosophy of information, in Floridi, L. (ed.), *The Routledge Handbook of*
550 *the Philosophy of Information*, London: Routledge, 2016, pp. 1-3
551
552 55 Walton, P. A model for information. *Information*, **2014**, 5(3), 479-507; doi:10.3990/info5030479.
553
554 56 Walton, P. Measures of information. *Information*, **2015**, 6(1), 23-48; doi:10.3390/info6010023.
555
556 57 Walton, P. Information and meaning. *Information*, **2016**, 7(3), 41; doi: 10.3390/info7030041.
557
558 58 Burgin, M. Information theory: a multifaceted model of information. *Entropy*, **2003**, 5(2), 146-160;
559 doi:10.3390/e5020146.
560

561 59 Burgin, M. Foundations of information theory. *arXiv.0808.0768v1[cs.IT]*, 2008.
562
563 60 Burgin, M. The General Theory of Information as a unifying factor for information studies: the
564 noble eight-fold path. *Proceedings*, **2017**, *1*, 164-169; doi:10.3390/IS4SI-2017-04044
565
566 61 Burgin, M. Evolutionary information theory. *Information*, **2013**, *4*(2), 124-168.
567
568 62 Burgin, M.; Feistel, R. Structural and symbolic information in the context of the General Theory
569 of Information. *Information*, **2017**, *8*(4), 139; doi:10.3390/info8040139
570
571 63 Brenner, J.E. Mark Burgin's Theory of Information. *Information*, **2012**, *3*(2), 224-228. Available at
572 <https://www.mdpi.com/2078-2489/3/2/224xml>.
573
574 64 Burgin, M.; Feistel, R. Structures and structural information. *Proceedings*, **2017**, *1*, 217-221.
575 Available at <https://www.mdpi.com/2504-3900/1/3/217>.
576
577 65 Feistel, R.; Ebeling, W. Entropy and the self-organization of information and value. *Entropy*, **2016**,
578 *18*(5), 193-206; doi:10.3990/e18050193.
579
580 66 Burgin, M. Data, information, and knowledge. Unpublished manuscript, 2004. Available at
581 <https://www.math.ucla.edu/~mburgin/papers/knowninfpp2.pdf>.
582
583 67 Burgin, M.; Dodig-Crnkovic, G. Prolegomena to information taxonomy. *Proceedings*, **2017**, *1*, 210-
584 214; doi:10.3390/IS4SI-2017-04035.
585
586 68 Brenner, J.E. Three aspects of information science in reality: symmetry, semiotics and society.
587 *Information*, **2015**, *6*(4), 750-772; doi:10.3390/info6040750.
588
589 69 Brenner, J.E. Philosophy of information: revolution in philosophy. *Proceedings*, **2017**, *1*(3), 101;
590 doi:10.3390/IS4SI-2017-03964.
591
592 70 Wu, K.; Brenner, J. Philosophy of information: revolution in philosophy. Towards an
593 informational metaphilosophy of science. *Philosophies*, **2017**, *2*(4), 22;
594 doi:10.3390/philosophies2040022.
595
596 71 Brenner, J.E. The logical dynamics of information: Deacon's "Incomplete Nature". *Information*, **2012**,
597 *3*(4), 676-714; doi:10.3390/info3040676.
598
599 72 Brenner, J.E. The logic of the physics of information. *Information*, **2014**, *5*(3), 389-403;
600 doi:10.3390/info5030389
601
602 73 Brenner, J.E. Levels of abstraction; levels of reality. In Demir, H. (ed.) *Luciano Floridi's Philosophy*
603 *of Technology: critical reflections*. Dordrecht: Springer, 2012, pp 201-222.
604
605 74 Floridi, L. The road to the Philosophy of Information. In *Luciano Floridi's Philosophy of Technology:*
606 *critical reflections*. Demir, H. (ed.). Dordrecht: Springer, 2012, pp. 245-271.
607
608 75 Hofkirchner, W. How to achieve a unified theory of information. *Triple-C*, **2009**. *7*(2), 357-368.
609
610 76 Hofkirchner, W. Toward a new science of information. *Information*, **2010**, *2*(2), 372-382;
611 doi:10.3390/info2020372.
612

613 77 Hofkirchner, W. *Twenty questions about a unified theory of information*. Litchfield Park AZ:
614 Emergent Publications, 2010.
615
616 78 Hofkirchner, W. *Emergent information: a unified theory of information framework*. Singapore: World
617 Scientific, 2013.
618
619 79 Bawden, D. Organised complexity, meaning and understanding: an approach to a unified view
620 of information for information science. *Aslib Proceedings*, **2007**, 59(4/5), 307-327.
621
622 80 Stonier, T. *Information and the internal structure of the universe*. Berlin: Springer Verlag, 1990.
623
624 81 Stonier, T. *Beyond information: the natural history of intelligence*. Berlin: Springer Verlag, 1992.
625
626 82 Stonier, T. *Information and meaning: an evolutionary perspective*. Berlin: Springer Verlag, 1997.
627
628 83 Stonier, T. Towards a new theory of information. *Journal of Information Science*. **1991**, 17(5), 257-
629 263.
630
631 84 Stonier, T. *Biosystems*, **1996**, 38(2-3), 135-140.
632
633 85 Morán-Reyes, A.A. Contribution to the ontological status of information: development of the
634 structural-attributive approach. *Library Trends*, **2015**, 63(3), 574-590.
635
636 86 Bates, M.J. Information and knowledge: an evolutionary framework for information. *Information*
637 *Research*, **2005**, 10(4), paper 239 [online]. Available at <http://informationr.net/ir/10-4/paper239.html>
638
639 87 Bates, M.J. Fundamental forms of information. *Journal of the American Society for Information*
640 *Science and Technology*, **2006**, 57(8), 1033-1045.
641
642 88 Goonatilake, S. *The evolution of information: lineages in gene, culture and artefact*. London: Pinter
643 Publishers, 1991.
644
645 89 Madden, D. Evolution and information. *Journal of Documentation*, **2004**, 60(1), 9-23.
646
647 90 Floridi, L. *The fourth revolution: how the infosphere is shaping human reality*. Oxford: Oxford
648 University Press, 2014.
649
650 91 Floridi, L. *Information - a very short introduction*. Oxford: Oxford University Press, 2010.
651
652 92 Capurro, R. On Floridi's metaphysical foundation of information ecology. *Ethics and Information*
653 *Technology*, **2008**, 10(2-3), 167-173.
654
655 93 Compton, B.W. Parallax ontology and the philosophy of information. *Library Trends*, **2015**, 63(3),
656 555-573.
657
658 94 Adams, F.; de Moraes, J.A. Is there a philosophy of information? *Topoi*, **2016**, 35(1), 161-171
659
660 95 Floridi, L. On human dignity as a foundation for the right to privacy. *Philosophy and Technology*,
661 **2016**, 29(4), 307-312.
662
663 96 Floridi, L.; Taddeo, M. What is data ethics? *Philosophical Transactions of the Royal Society A*, **2016**,
664 28 December 2016; doi:10.1089/rsta.2016.0360.
665

666 97 Mittelstadt, B.D.; Floridi, L. The ethics of big data: current and foreseeable issues in biomedical
667 contexts, *Science and Engineering Ethics*, **2016**, 22(2), 303-341.
668

669 98 Floridi, L. Soft ethics, the governance of the digital and the General Data Protection Regulation.
670 *Philosophical Transactions of the Royal Society A*, **2018**, 15 October 2018; doi:10.1098/rsta.2018.0081.
671

672 99 Floridi, L.; Cows, J. A unified framework of five principles for AI in society. *Harvard Data Science*
673 *Review*, **2019**, 1(1); doi:10.1162/99608f92.8cd50d1.
674

675 100 Floridi, L. The green and the blue: naïve ideas to improve politics in a mature information
676 society. In *The 2018 Yearbook of the Digital Ethics Lab*, Cham, Switzerland: Springer, 2019, pp. 183-221.
677

678 101 Bawden, D.; Robinson, L. Curating the infosphere: Luciano Floridi's Philosophy of Information
679 as the foundation for Library and Information Science, *Journal of Documentation*, **2018**, 74(1), 2-17.
680

681 102 Floridi, L. LIS as applied philosophy of information: a reappraisal. *Library Trends*, **2004**, 52(3),
682 658-665.
683

684 103 Dinneen, J.D.; Brauner, C. Practical and philosophical considerations for defining information
685 as well-formed, meaningful data in the information sciences. *Library Trends*, **2015**, 68(3), 378-400.
686

687 104 Fyffe, R. The value of information: normativity, epistemology, and LIS in Luciano Floridi. *portal:*
688 *Libraries and the Academy*, **2015**, 15(2), 267-286.
689

690 105 Van der Veer Martens, B. An illustrated introduction to the infosphere, *Library Trends*. **2015**,
691 63(3), 317-361.
692

693 106 Van der Veer Martens, B. New grounds for ontic trust: information objects and LIS *Education for*
694 *Information*, **2017**, 33(1), 37-54.
695

696 107 Ward Bynum, T. On the possibility of quantum informational structural realism, *Minds and*
697 *Machines*. **2013**, 24(1), 123-139.
698

699 108 Ward Bynum, T. Informational metaphysics. In *The Routledge Handbook of the Philosophy of*
700 *Information*. L. Floridi (ed.). London: Routledge, 2016, pp. 203-218.
701

702 109 Floridi, L. The method of levels of abstraction. *Minds and Machines*, **2008**, 18(3), 303-329.
703

704 110 Floridi, L. The method of abstraction. In Floridi, L. (ed.), *The Routledge Handbook of the Philosophy*
705 *of Information*. London: Routledge, 2016, pp. 50-56.
706

707 111 Chapman, D. Information in layers. *Proceedings*, **2017**, 1(3); doi:10.3990/IS4SI-2017-03960.
708

709 112 Floridi, L. What is a philosophical question? *Metaphilosophy*, **2013**, 44(3), 195-221.
710

711 113 Nicolis, G. and Nicolis, C. Complexity, entropy and information. Chapter 4 of *Foundations of*
712 *complex systems: emergence, information and prediction (2nd edn.)*. Singapore: World Scientific, 2012, pp.
713 114-148.
714

715 114 Preiser, R. Identifying general trends and patterns in complex systems research: an overview of
716 theoretical and practical implications. *Systems Research and Behavioral Science*, **2019**, 36(5), 706-714.
717

718 115 Gazzaniga, M.S. Following Schrödinger's code: a personal journey. *Journal of Cognitive*
719 *Neuroscience*, **2019**, 31(12), 1777-1781.
720
721 116 Moberg, C. Schrödinger's What is Life: the 75th anniversary of a book that inspired biology.
722 *Angewandte Chemie International Edition*, **2019**, Early View. doi:10.1002/anie.201911112
723
724 117 Tønnessen, M., Sharov, A. & Maran, T. Biosemiotics: making sense of nature. *LifeScience Today*
725 *blog*. 15 September 2016. <http://blogs.springer.com/lst/biosemiotics-making-sense-nature/>
726
727 118 Hoffmeyer, J. Biosemiotics: towards a new synthesis in biology. *European Journal for Semiotic*
728 *Studies*, **1997**, 9(2), 355-376.
729
730 119 Barbieri, M. A short history of biosemiotics. *Biosemiotics*, **2009**, 2(2), 221-245.
731
732 120 Kull, K. Thomas A. Sebeok and biology: building biosemiotics. *Cybernetics and Human Knowing*,
733 **2003**, 10(1), 47-60.
734
735 121 Barbieri, M. *Code biology: a new science of life*. Cham: Springer, 2015.
736
737 122 Barbieri, M. What is code biology? *Biosystems*, **2018**, 164, 1-10. doi:
738 10.1016/j.biosystems.2017.10.005.
739
740 123 Floridi, L. *The fourth revolution: how the infosphere is shaping human reality*. Oxford: Oxford
741 University Press, 2014.
742
743 124 Gorichanaz, T. Understanding and information in the work of visual artists. *Journal of the*
744 *Association for Information Science and Technology*, **2019**, Online EarlyCite.
745 <https://doi.org/10.1002/asi.24286>.
746
747
748
749
750
751
752
753
754
755
756
757
758
759