Robinson, L. & Bawden, D. (2013). Mind the gap: transitions between concepts of information in varied domains. In: F. Ibekwe-SanJuan & T. M. Dousa (Eds.), Theories of Information, Communication and Knowledge. (pp. 121-141). Springer. ISBN 978-94-007-6973-1



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Original citation: Robinson, L. & Bawden, D. (2013). Mind the gap: transitions between concepts of information in varied domains. In: F. Ibekwe-SanJuan & T. M. Dousa (Eds.), Theories of Information, Communication and Knowledge. (pp. 121-141). Springer. ISBN 978-94-007-6973-1

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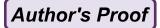
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Copyright Year	2014	
Copyright Holder	Springer Science+Business Media B.V.	
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Abstract	biological, social and philoso these conceptions are discuss including those of Shannon/V examined. The value of atternanalogies, is explained. With and biology gaining the statu- look for links, relationships,	in five different realms – technological, physical, phical – is briefly examined. The 'gaps' between sed, and unifying frameworks of diverse nature, Viener, Landauer, Stonier, Bates and Floridi, are apting to bridge the gaps, while avoiding shallow information physics gaining general acceptance, as of an information science, it seems rational to analogies and even helpful metaphors between ation sciences. Prospects for doing so, involving mergence, are suggested.

Chapter 6	1	
Mind the Gap: Transitions Between Concepts	2	
of Information in Varied Domains	3	
Lyn Robinson and David Bawden	4	
for the numerous possible applications of this general field.	5 6 7	
	8 9	
Shannon and Wiener and I Have found it confusing to try To measure sagacity And channel capacity By $\sum p_i \log p$. (Anonymous, Behavioural Science, 1962, 7(July issue), p. 395)	10 11 12 13 14 15	
Life, language, human beings, society, culture – all owe their existence to the intrinsic ability of matter and energy to process information. (Seth Lloyd)	16 17 18	
6.1 Introduction	19	
'Information' is a notoriously slippery and multifaceted concept. Not only has the		
word had many different meanings over the years – its entry in the full Oxford		
English Dictionary of 2010, which shows its usage over time, runs to nearly 10,000		
words – but it is used with different connotations in various domains. For overviews of the mutability and diversity of the information concept, see Belkin (1978),		

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Machlup and Mansfield (1983), Qvortrup (1993), Bawden (2001), Capurro and 25 Hjørland (2003), Gleick (2011), Ma (2012), and Bawden and Robinson (2012).



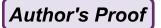
In this chapter, we will focus on usage in different domains and disciplines. As 27 Capurro and Hjørland (2003, p. 356 and 396) say: "almost every scientific discipline 28 uses the concept of information within its own context and with regard to specific 29 phenomena ..., There are many concepts of information, and they are embedded 30 in more or less explicit theoretical structures". Our concern will be to examine 31 these different concepts of information, and in particular the 'gaps' between them. 32 By 'gap', we mean the discontinuities in understanding which make it difficult to 33 understand whether the 'information' being spoken of in different contexts is in any 34 way 'the same thing', or at least 'the same sort of thing'; and if not, in what way - if 35 any – the different meanings of information relate to one another. Given the current 36 enthusiasm for 'information physics', exemplified by writings of Zurek, Vedral, 37 Lloyd and others cited in Sect. 6.2.2, we place particular stress on the information 38 concept in the physical sciences. We have also tried to emphasise the historical 39 perspective of these ideas.

We will focus particularly on the implications of these considerations for the 41 idea of information in the field of library/information science. Perhaps because 42 information is at its centre, there has been particular debate about the issue in this 43 discipline; see Belkin and Robertson (1976) for an early account and Cornelius 44 (2002), Bates (2005) and the reviews cited above, for overviews of the on-going 45 debate. A Delphi study carried out by Zins (2007) presents many definitions of 46 information for information science, typically relating information to data and/or 47 knowledge.

Indeed, it is the relationship between these concepts that is a constant concern, 49 perhaps even an obsession, within the information sciences. This has led to two 50 main classes of model (Bawden and Robinson 2012; Ma 2012). The first, based in 51 Karl Popper's 'objective epistemology' uses 'knowledge' to denote Popper's 'World 52 2', the subjective knowledge within an individual person's mind. 'Information' is 53 used to denote communicable knowledge, recorded, or directly exchanged between 54 people; this is Popper's 'World 3' of objective knowledge, necessarily encoded in 55 a 'World '1 document, or physical communication. Information, in this model, is 56 'knowledge in transit'. The second regards information and knowledge as the same 57 kind of entity, with knowledge viewed as 'refined' information, set into some form 58 of larger structure. This is typically presented as a linear progression, or a pyramid, 59 from 'data', or 'capta' - data in which we are interested - through 'information' to 60 'knowledge', perhaps with 'wisdom' or 'action' at the far end of the spectrum or 61 the apex of the pyramid; see, for example, Checkland and Holwell (1998), Frické 62 (2009), Rowley (2011), and Ma (2012).

The debate on the nature of information within the information sciences, somewhat limited in scope, has been widened by some wider visions, such as those of 65 Buckland and of Bates, which will be discussed below. The purpose of this chapter is 66 to attempt to widen perspectives still further; to attempt, in effect, to begin to answer 67 John Wheeler's question 'What makes meaning?', by considering conceptions of 68 meaning-free and meaningful information, and the relations between them.

We begin with a brief consideration of the way in which information is viewed 70 in several diverse domains.



Information in Various Domains

We will examine the concept of information in five domains, in each of which 73 information has come to be regarded, at least by some, as a central concept: 74 technological, physical, biological, social and philosophical. For reasons of space, 75 the discussion must be cursory, and the reader is referred for more extensive 76 treatments (at an accessible level in the case of the scientific perspective) to Gleick 77 (2011), Greene (2011), Deutsch (2011), Floridi (2010a), Davies and Gregersen 78 (2010), Vedral (2010, 2012), Lloyd (2006, 2010), von Baeyer (2004), Smolin (2000) 79 and Leff and Rex (1990, 2002). 80

Information and Communication Technology

We begin with technology rather than the sciences, since the closest approach 82 yet available to a universal formal account of information is 'information theory', 83 originated by Claude Shannon, and properly referred to as the Shannon-Weaver- 84 Hartley theory in recognition of those who added to it and gave it its current form. 85 Gleick (2011) gives a detailed account of these developments, which all occurred 86 in Bell Laboratories, and which focused on communication network engineering 87 issues.

The initial steps were taken by Harry Nyquist (1924), who showed how to 89 estimate the amount of information that could be transmitted in a channel of 90 given bandwidth – in his case, the telegraph. His ideas were developed by Ralph 91 Hartley (1928), who established a quantitative measure of information, so as to 92 compare the transmission capacities of different systems. Hartley (1928, 535) 93 emphasised that this measure was "based on physical as contrasted with psycho-94 logical considerations". The meaning of the messages was not to be considered; 95 information was regarded as being communicated successfully when the receiver 96 could distinguish between sets of symbols sent by the originator. His measure of 97 information, understood in this way, was the logarithm of the number of possible 98 symbol sequences. For a single selection, the associated information, H, is the 99 logarithm of the number of symbols

 $H = \log s$

This in turn was generalised in (1948) by Claude Shannon into a fuller theory 101 of communication, which was later republished in book form (Shannon and Weaver 102 1949). This volume included a contribution by Warren Weaver that expounded the 103 ideas in a non-mathematical and more wide-ranging manner. Weaver's presentation 104 arguably had greater influence in promoting information theory than any of its 105 originators' writings. 106

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Following Nyquist and Hartley, Shannon defined the fundamental problem of 107 communication as the accurate reproduction at one point of a message selected from 108 another point. Meaning was to be ignored; as Weaver noted, "these semantic aspects 109 of communication are irrelevant to the engineering problem" (Shannon and Weaver 110 1949, 3). The message in each case is one selected from the set of possible messages, 111 and the system must cope with any selection. If the number of possible messages is 112 finite, then the information associated with any message is a function of the number 113 of possible messages.

Shannon derived his well-known formula for H, the measure of information

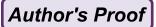
$$H = -K \sum p_i \log p_i$$

where p_i is the probability of each symbol, and K is a constant defining the units. 116 The minus sign is included to make the quantity of information, H, positive; this is 117 necessary as a probability will be a positive number less than 1, and the log of such 118 a number is negative.

Shannon pointed out that formulae of the general form $H = -\sum p_i \log p_i$ 120 appear very often in information theory as measures of information, choice, and 121 uncertainty; the three concepts seem almost synonymous for his purposes. Shannon 122 then gave the name 'entropy' to his quantity H, since the form of its equation was 123 that of entropy as defined in thermodynamics. It is usually said that the idea of 124 using this name was suggested to him by John von Neumann. The original source 125 for this story seems to be Myron Tribus who, citing a private discussion between 126 himself and Shannon in Cambridge, Massachusetts, on March 30th 1961, gives the 127 following account:

When Shannon discovered this function he was faced with the need to name it, for it occurred quite often in the theory of communication he was developing. He considered naming it 'information' but felt that this word had unfortunate popular interpretations that would interfere with his intended uses of it in his new theory. He was inclined towards naming it 'uncertainty', and discussed the matter with John Von Neumann. Von Neumann suggested that the function ought to be called 'entropy' since it was already in use in some treatises on statistical thermodynamics. Von Neumann, Shannon reports, suggested that there were two good reasons for calling the function 'entropy'. 'It is already in use under that name', he is reported to have said, 'and besides, it will give you a great edge in debates because nobody really knows what entropy is anyway'. Shannon called his function 'entropy' and used it as a measure of 'uncertainty', interchanging between the two words in his writings without discrimination. (Tribus 1964, p 354)

Whatever the truth of this, Shannon's equating of information to entropy was 141 controversial from the first. Specialists in thermodynamics, in particular, suggested that 'uncertainty', 'spread', or 'dispersion' were better terms, without the implica- 143 tions of 'entropy' (see, for example, Denbigh 1981). A particularly caustic view 144 is expressed by Müller (2007, 124, 126): "No doubt Shannon and von Neumann 145 thought that this was funny joke, but it is not – it merely exposes Shannon and von 146 Neumann as intellectual snobs If von Neumann had a problem with entropy, he 147 had no right to compound that problem for others ... by suggesting that entropy 148



has anything to do with information ... [Entropy] is nothing by itself. It has to 149 be seen and discussed in conjunction with temperature and heat, and energy and 150 work. And, if there is to be an extrapolation of entropy to a foreign field, it must be 151 accompanied by the appropriate extrapolations of temperature and heat and work". 152 This reminds us that, when we see later that there have been criticisms of the use 153 of objective measures of information in the library/information sciences, these have 154 been matched by criticisms regarding the arguably uncritical use of information 155 concepts in the sciences.

Shannon's was not the only attempt to derive a mathematical theory of in- 157 formation, based on ideas of probability and uncertainty. The British statistician 158 R.A. Fisher derived such a measure, as did the American mathematician Norbert 159 Wiener, the originator of cybernetics. The latter seems to have been irritated that 160 the credit for the development was given mainly to Shannon; less than 10 years later, he was referring to "the Shannon-Wiener definition of quantity of information" and insisting that "it belongs to the two of us equally" (Wiener 1956, 63) His mathematical formalism was the same as Shannon's but, significantly, he treated 164 information as the negative of physical entropy, associating it with structure and 165 order, the opposite of Shannon's equating of information with entropy and disorder: 166

The notion of the amount of information attaches itself very naturally to a classical notion in statistical mechanics: that of entropy. Just as the amount of information in a system is a measure of its degree of organization, so the entropy of a system is a measure of its degree of disorganization; and the one is simply the negative of the other (Wiener 1948, 18).

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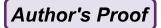
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Shannon's information is, in effect, the opposite of Wiener's, which has caused 171 confusion ever since for those who seek to understand the meaning of the mathematics, as Qvortrup (1993) makes plain.

In Shannon's sense, information, like physical entropy, is associated with lack 174 of order. A set of index cards, ordered alphabetically, has low entropy, and little 175 information; if we know the order of the alphabet, we know all there is to know 176 about the ordering of the cards, and we can explain it to someone very briefly. If they 177 are disordered, however, they contain, in Shannon's sense, much more information, 178 since we would need a much more lengthy statement to describe their arrangement. 179

By contrast, there is a long-standing idea that information should be associated 180 with order and pattern, rather than its opposite; in essence, this view follows 181 Wiener's conception. Even Warren Weaver, arguing in support of Shannon, wrote 182 that "the concept of information developed in this theory at first seems disappointing 183 and bizarre – disappointing because it has nothing to do with meaning, and bizarre 184 in these statistical terms the two words information and uncertainty find 185 themselves to be partners" (Shannon and Weaver 1949, 116). Leon Brillouin, 186 who pioneered the introduction of Shannon's ideas into the sciences, in effect 187 took Wiener's stance, renaming Shannon's entropy formulation as 'negentropy' (Brillouin 1962). As we shall see later, Tom Stonier took the same approach, proposing a framework for a unified understanding of information in various domains.

Marcia Bates (2005) noted that the idea of 'information as pattern / organisation' was 'endemic' during the 1970s, and identified Parker (1974, 10) as the first to 192 state explicitly in a library/information context that "information is the pattern or 193



organization of matter and energy". While this concept has gained some popularity, 194 it is by no means universally accepted: Birger Hjørland (2008) speaks for those who 195 doubt it, saying that such patterns are nothing more than patterns until they inform 196 somebody about something. Reading (2011) exemplifies those who take a middle 197 course, positing that such patterns are information, but 'meaningless information', 198 in contrast to the 'meaningful information' encountered in social, and, arguably, in 199 biological, systems.

We now consider how these ideas were applied to bring information as an entity 201 into the physical sciences.

6.2.2 Information Physics

The idea of information as a feature of the physical world arose through studies of 204 the thermodynamic property known as entropy. Usually understood as a measure 205 of the disorder of a physical system, entropy has also come to be associated with 206 the extent of our knowledge of it; the more disordered a system, the less detailed 207 knowledge we have of where its components are, or what they are doing. This idea 208 was formalised by Zurek (1989), though it builds on earlier insights of scientists 209 such as Ludwig Boltzmann and Leo Szilard who introduced information as a 210 fundamental concept in science, though it was not named by them as such.

Boltzmann related the entropy of gases to their degree of disorder, measured in 212 probability terms, showing that entropy was related to the probability of collisions 213 between gas particles with different velocities. Hence it could be equated to the 214 probability distribution of the states of a system, expressed by the formula

$$S = k \log W$$

where k is Boltzmann's constant, and W is a measure of the number of states of a 216 system; i.e. the ways that molecules can be arranged, given a known total energy. 217 This equation is certainly reminiscent of later information theory formalisms, but - 218 although it is carved on his tombstone in the Vienna cemetery (actually using an Ω 219 symbol instead of the more modern W) - Boltzmann never wrote it in this form, 220 which is due to Max Planck (Atkins 2007). To suggest, as does von Baeyer (2003, 221 98), that "by identifying entropy with missing information, Boltzmann hurled the 222 concept of information into the realm of physics" seems to be anachronistic, as well 223 as over-dramatic.

Szilard (1929) analysed the well-worked thermodynamic problem of 'Maxwell's 225 Demon' (Leff and Rex 1990, 2002), in what was subsequently assessed as "the 226 earliest known paper in the field of information theory" (Hargatti 2006, 46), though 227 information is again not specifically mentioned. As Szilard himself later recalled:

... I wrote a little paper which was on a rather closely related subject [to a paper on the second law of thermodynamics]. It dealt with the problem of what is essential in the operations of the so-called Maxwell's Demon, who guesses right and then does 203

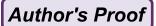
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something, and by guessing right and doing something he can violate the second law of thermodynamics. This paper was a radical departure in thinking, because I said that the essential thing here is that the demon utilizes information – to be precise, information which is not really in his possession until he guesses it. I said that there is a relationship between information and entropy, and I computed what that relationship was. No one paid any attention to this paper until, after the war, information theory became fashionable. Then the paper was rediscovered. Now this old paper, to which for over 35 years nobody paid any attention, is a cornerstone of modern information theory (Weart and Szilard 1978, 11).

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True information physics began decades later when the ideas of information 240 theory were introduced into science, by pioneers such as Leon Brillouin (1962). In 241 essence, this amounted to recognising a formal mathematical link between entropy and information, when information is defined in the way required by Shannon's 243 theory (although it should be noted that it was Wiener's interpretation that was 244 generally adopted) or, indeed, by other formalisms for defining information in 245 objective and quantitative terms, such as Fisher information (Frieden 1999), a 246 quantitative measure of information used most often in statistical analysis.

Subsequent analysis of the relation between information and physical entropy 248 led Landauer (1991) to propose his well-known aphorism 'information is physical'. 249 Information must always be instantiated in some physical system; that is to say, in 250 some kind of document, in the broadest sense. Information is subject to physical 251 laws, and these laws can, in turn, be cast in information terms. The physical nature 252 of information, and, in particular, its relation to entropy, continues to arouse debate; 253 for early discussions, see Avramescu (1980) and Shaw and Davis (1983), and for 254 recent contributions, see Duncan and Semura (2007) and Karnani, Pääkkönen, and 255 Annila (2009).

The idea of information as a fundamental physical entity has received increasing 257 attention in recent decades, inspired particularly by an association of information 258 with complexity; see Zurek (1990) for papers from a seminal meeting which 259 effectively launched this approach. Information has been proposed as a fundamental 260 aspect of the physical universe, on a par with – or even more fundamental than – 261 matter and energy. The American physicist John Wheeler is generally recognised 262 as the originator of this approach, stemming from his focus on the foundations 263 of physics, leading him to formulate what he termed his 'Really Big Questions', 264 such as 'How come existence?' and 'Why the quantum?'. Two of his questions 265 involved information and meaning. In asking 'It from bit?', Wheeler queried 266 whether information was a concept playing a significant role at the foundations of 267 physics; whether it was a fundamental physical entity, equivalent to, say, energy. 268 Indeed, he divided his own intellectual career into three phases: from a starting 269 belief that 'Everything is particles', he moved through a view that 'Everything is 270 fields', to finally conclude that 'Everything is information', focusing on the idea 271 that logic and information form the bedrock of physical theory (MacPherson 2008). 272 In asking 'What makes meaning?', he invoked the idea of a 'participatory universe', 273 in which conscious beings may play an active role in determining the nature of the 274 physical universe. Wheeler's views are surveyed, critiqued, and extended in papers 275 in Barrow et al. (2004).

Other well-known contributors to the information physics approach are: Lee 277 Smolin (2000), who has suggested that the idea of space itself may be replaceable 278 by a 'network of relations' or a 'web of information'; Seth Lloyd (2006, 2010), 279 who argues that 'the universe computes' (specifically in the form of a quantum 280 computer); and David Deutsch, who proposes that information flow determines the 281 nature of everything that is. "The physical world is a multiverse", writes Deutsch 282 (2011, 304), "and its structure is determined by how information flows in it. In 283 many regions of the multiverse, information flows in quasi-autonomous streams 284 called histories, one of which we call our universe". 'Information flow', in this 285 account, may be (simplistically) regarded as what changes occur in what order. 286 Finally, having mentioned the multiverse, we should note that the increasingly 287 influential 'many worlds' interpretation of quantum mechanics is inextricably linked 288 with information concepts (Byrne 2010; Saunders et al. 2010; Wallace 2012).

'Information', in the physical realm is invariably defined in an objective, 290 meaning-free way. However, there has been a realisation that information content, as 291 assessed by any of the formalisms, with randomness giving the highest information 292 content by Shannon's measure, is not an intuitively sensible measure. Interest has 293 focused on ideas of complexity, and on the idea that it is from an interaction of 294 order and randomness that complex systems, embodying 'interesting' information, 295 emerge. This has led to alternative measures of complexity and order (Lloyd 2001, 296 2006; Gell-Mann and Lloyd 1998). Examples, with very informal explanations are: 297 algorithmic information content (related to the length of the shortest algorithm 298 which recreates the state; ordered systems need only short algorithms); logical 299 depth (related to the running time of the simplest algorithm which recreates the 300 state); and thermodynamic depth (related to the number of possible ways that a 301 system may arrive at its present state; 'deep' systems are hard to create). These 302 offer the promise of quantifying physical information in ways which, by contrast 303 with the Shannon formalism, account for emergent properties, and to 'interesting' informational structures, of potential relevance to biological and social domains, 305 as well as providing powerful tools for explaining the physical world; for popular 306 accounts see Gell-Mann (1995) and Barrow (2007).

At about the same time, in the 1940s, as the groundwork for an information 308 perspective on the physical sciences was being developed, the same was happening 309 in biology, and it is to that domain we now turn.

6.2.3 Information Biology

In biology, the discovery of the genetic code and the statement of the so-called 312 'central dogma' of molecular biology – that information flows from DNA to 313 proteins – have led to the ideas that information is a fundamental biological property, 314 and that the ability to process information may be a characteristic of living things 315 as fundamental as, or more fundamental than, metabolism, reproduction, and other 316 signifiers of life. Dartnell (2007) describes this as the Darwinian definition: life as 317

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6 Mind the Gap: Transitions Between Concepts of Information in Varied Domains

information transmission. For this reason, it is sometimes stated that biology is now 318 an information science; see, for example, Baltimore (2002), Maynard Smith (2010), 319 and Terzis and Arp (2011).

Concepts of information in the biology domain are varied, and we make no 321 attempt to summarise a complex area. Information may manifest in many contexts: 322 the transmission of genetic information through the DNA code, the transmission of 323 neural information, and the many and varied forms of communication and signalling 324 between living things being just three examples. One vexed, and undecided, 325 question is at what stage 'meaning' can be said to appear; some authors argue 326 that it is sensible to speak of the meaning of a segment of DNA, while others 327 allege that meaning is an accompaniment of consciousness. And there are those 328 who suggest that consciousness itself is explicable in information terms; see, for 329 instance, Tonioni's (2008) ideas of consciousness as integrated information.

The analysis of living systems in information terms has been typically associated 331 with a reductionist approach, with enthusiastic adoption of Shannon's 'meaning- 332 free' formulae to assess the information content of living things; see, for example 333 Gatlin (1972). An idea similar to Wiener's conception of information as an opposite 334 of entropy had been proposed at an early stage by the German physicist Erwin 335 Schrödinger (1944), one of the pioneers of quantum mechanics, who had suggested 336 that living organisms fed upon such negative entropy. Later, the idea of information 337 as the opposite of entropy was popularised, under the name of 'negentropy', by Brillouin (1962), and was adopted by researchers in several areas of biology, 339 including ecology; for examples, see Patter (1961), Kier (1980), and Jaffe (1984).

However, such approaches, with their generally reductionist overtones, have not 341 been particularly fruitful, leading some biologists to favour an approach focusing 342 more on the emergence of complexity and, in various senses, meaning; see, for 343 example, Hazen, Griffin, Carothers and Szostak (2007). Several authors have 344 considered the ways in which information may both influence and be influenced 345 by evolutionary processes relating this to the evolution of exosomatic meaningful 346 information in the human realm; see, for example, Goonatilake (1994), Madden 347 (2004), Auletta (2011), and Reading (2011).

Meaningful information, though not yet accepted as a central concept in biology, 349 is certainly so in the realm of human, social, communicable information, to which 350 we now turn.

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Social Information

The social, or human, conception of information is, of course, prominent in 353 library/information science. As such, it is likely to be most familiar to this book's 354 readers, and, accordingly, this section is relatively short. But information is also 355 a significant concept in other human-centred disciplines, including psychology, 356 semiotics, communication studies, and sociology. While the exact conceptions, and 357 to a degree the terminology differ, all take a subjective and context-dependent 358

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view of information; one which is associated with knowledge and meaning. 359 Information is regarded as something which is always and inevitably associated 360 with human beings being informed about, and therefore knowing, something, and 361 that information having a meaning to them. There are, of course, a variety of ways 362 in which human-centred information may be conceptualised; some of these are 363 discussed later in this chapter.

There have been attempts to bridge the gap between this conception of information and the scientific and technical perspective. A variety of means have been 366 adopted to try to extend the kind of information theory pioneered by Shannon 367 and by Wiener to deal with meaningful semantic information, and to develop 368 mathematical models for information flow: see Dretske (1981) and Barwise and 369 Seligman (1997) as examples, and see Cornelius (2002) and Floridi (2011a) for 370 reviews. Some authors, such as Qvortrup (1993), have argued that the information 371 theory formalisms in themselves are not as objective, external, and impersonal as 372 suggested, but this view has not been generally accepted.

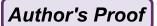
The 'negentropy' concept has been applied, some would argue unwisely, to 374 such areas as economics, sociology, psychology and theology. Müller (2007, 73), 375 a scientist in the field of chemical thermodynamics, warns against "a lack of 376 intellectual thoroughness in such extrapolations. Each one ought to be examined 377 properly for mere shallow analogies". The same is surely true for applications in the 378 library/information sciences.

Finally, in this brief survey of information concepts in different domains, we 380 consider philosophy. Although the sub-discipline of epistemology has studied the 381 nature of knowledge for many centuries, information per se has not until recently 382 been of major concern to philosophers.

Philosophy of Information

Before Luciano Floridi proposed his 'philosophy of information' in the late 1990s 385 (as he recounts in Floridi 2010b), relatively few philosophers took any interest in information, at least in a way likely to be of value for library/information science; see 387 Furner (2010) for an insightful overview. Knowledge, of course, is another matter; 388 that has been studied for many centuries, as the subject matter of epistemology. The 389 usual view in that context is that knowledge is to be understood as 'justified, true 390 belief'; that is to say, for something to count as knowledge, it must be believed by 391 someone, for rational reasons, and it must be true. Information fits into epistemology 392 in the form of testimony. This is a kind of evidence in which philosophers are 393 becoming increasingly interested; see, for example, Audi (1997) and Adler (2010).

Apart from this, there have been a number of developments in philosophical 395 thought which provide ways of viewing the relations between information and 396 knowledge which offer different insights to the Popperian Three Worlds 'objective 397 knowledge' model and the data-information-knowledge hierarchy, both of which 398 have already been mentioned. One is the work of philosophers such as Dretske 399



(1981), who have attempted to extend Shannon theory into the area of semantic 400 information. Another, and certainly the most ambitious to date, is that within 401 Floridi's 'philosophy of information', which will be discussed in detail later. We 402 may also mention three other interesting ideas: David Deutsch's (2011) concept of 403 'explanatory knowledge', which comprises our best rational explanations for the 404 way the world is, with the understanding that such knowledge is inevitably fallible 405 and imperfect, and our task is to improve it, not to justify it; Jonathan Kvanvig's 406 (2003) idea of knowledge as 'understanding', which allows for contradictions 407 and inconsistencies; and Michael Polanyi's (1962) ideas of 'personal knowledge' (somewhat similar to Popper's World 2), which have been further developed within 409 the context of library/information science; see, for example, Day (2005).

This concludes our cursory examination of information in different domains, and 411 we now move to look specifically at the gaps between them.

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Identifying the Gaps 6.3

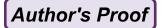
We have noted the various ways in which the information concept can be used in 414 five domains, and some of the attempts made to transfer concepts and formalisms 415 between domains. We could add others, not least library/information science, but 416 five is more than sufficient.

In principle, we could seek to describe the gap between the information concept 418 between each pair of domains, but a simpler and more sensible alternative is to 419 hand. Consideration of the ways in which information is understood in the various 420 domains leads us to two alternatives, both of which have been espoused in the 421 literature.

The first is to consider a binary divide, between those domains in which 423 information is treated as something objective, quantitative, and mainly associated 424 with data, and those in which it is treated as subjective, qualitative, and mainly 425 associated with knowledge, meaning, and understanding. The former include 426 physics and technology; the latter include the social realm. The biological treatment 427 of information is ambiguous, lying somewhere between the two, though tending to 428 the former the more information-centred the biological approach is, especially in the 429 more reductive areas of genetics, genomics, and bioinformatics. The philosophical 430 treatment depends on the philosopher; as we have seen, different philosophers and 431 schools of philosophy take radically different views of the concept of information.

The second alternative is slightly more complex, and envisages a three-way 433 demarcation, with the biological treatment of information occupying a distinct 434 position between the other two extremes, physical and social.

Whichever of these alternatives is preferred, the basic question is the same: 436 to what extent, if at all, are objective, quantitative, and 'meaning-free' notions 437 of information 'the same as', emergent into, or at least in some way related to, 438 subjective, qualitative, and 'meaningful' notions. This, we suggest, is in essence the 439 same question as Wheeler framed when he asked 'What makes meaning?'.



Bridging the Gaps

There have been a number of contributions to the literature suggesting, in general 442 terms, that 'gap bridging' may be feasible and desirable, without giving any very 443 definite suggestions as to how this may be done. One of the authors of this chapter 444 has put forward a proposal of this vague nature, suggesting that information in 445 human, biological, and physical realms is related through emergent properties in 446 complex systems (Bawden 2007a, b). In this view, physical information is associated 447 with pattern, biological information with meaning, and social information with 448 understanding.

In an influential paper from (1991), Buckland distinguished three uses of the term 450 'information':

- Information-as-thing, where the information is associated with a document;
- Information-as-process, where the information is that which changes a person's 453 knowledge state;
- Information-as-knowledge, where the information is equated with the knowledge 455 which it imparts.

From the information-as-thing viewpoint, information is regarded as physical 457 and objective, or at least as being 'contained within' physical documents and 458 essentially equivalent to them. The other two meanings treat information as 459 abstract and intangible. Buckland gives arguments in favour of the information- 460 as-thing approach, as being very directly relevant to information science, since 461 it deals primarily with information in the form of documents. Information-as- 462 process underlies theories of information behaviour which have a focus on the 463 experience of individuals, such as those of Dervin and Kuhlthau (Bawden and 464 Robinson 2012). Information-as-knowledge invokes the idea, well-trodden in the 465 library/information area, as noted above, that information and knowledge are closely 466 related. The exact relation, however, is not an obvious one. How is knowledge to be 467 understood here? As a 'refined', summarised, and evaluated form of information?; 468 as a structured and contextualised form of information?; or information embedded 469 within an individual's knowledge structure? These, and other, ideas all have their 470 supporters.

We will now look at three approaches to this kind of gap bridging which offer 472 more concrete proposals: those of Tom Stonier, Marcia Bates, and Luciano Floridi. 473

Stonier, in a series of three books, advanced a model of information as an abstract 474 force promoting organisation in systems of all kinds: physical, biological, mental, 475 and social, including recorded information (Stonier 1990, 1992, 1997). This is a 476 model envisaging the bridging of two distinct gaps, in the terms discussed above. 477 Stonier regards information, in its most fundamental form, as a physical entity 478 analogous to energy; whereas energy, in his view, is defined as the capacity to 479 perform work, information is the capacity to organise a system, or to maintain it in 480 a state of organisation. He regards a high-information state as one that is organised 481 and of low physical entropy. This, he points out is the opposite of Shannon's relation 482

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6 Mind the Gap: Transitions Between Concepts of Information in Varied Domains

between information and entropy, which Stonier regards as an unfortunate metaphor. 483 He links this concept of information to biological and human information, or as 484 he prefers intelligence, and to meaning, through an evolutionary process. Salthe 485 (2011) presents a somewhat similar viewpoint linking thermodynamic entropy and 486 Shannon information through to meaning and semiotics.

Bates, has advanced a similar all-encompassing model, which she characterises 488 as 'evolutionary' (Bates 2005, 2006). It relies on identifying and interrelating a 489 number of 'information-like' entities:

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- Information 1 the pattern of organization of matter and energy
- Information 2 some pattern of organization of matter and energy given meaning 492 by a living being
- Data 1 that portion of the entire information environment available to a sensing organism that is taken in, or processed, by that organism
- Data 2 information selected or generated by human beings for social purposes 496
- Knowledge information given meaning and integrated with other contents of 497 understanding

This model, while all-encompassing and one of the more ambitious attempts at 499 integrating information in all its contexts, remains at a conceptual and qualitative 500 level, and introduces a potentially confusing multiplicity of forms of information 501 and similar entities. In particular, the distinction between Information 1 and 502 Information 2, without any clear indication of their relation, seems to perpetuate 503 a gap, rather than bridge one. Bates describes her approach as evolutionary, and 504 relates it to the approaches of Goonatilake (1991) and Madden (2004), mentioned 505 earlier, though these latter start with information in the biological realm, rather than 506 the, arguably more basic, physical world. She argues that the different forms of 507 information are emergent, as animals - not just humans - can recognise patterns 508 of physical information in their environment. Animals can assign meaning to such 509 recognition, though not in a conscious act of labelling; this is reserved for the human 510 realm. In contrast to Stonier, she argues that information is the order in the system, 511 rather than its capacity to create order (both of which, we may remind ourselves, are 512 the opposite of the Shannon conception). For Bates, knowing the degree of order of 513 a system tells us how much information it contains; for Stonier, knowing how much 514 information is in it tells us how it may be ordered.

Floridi (2010a, 2011b) has presented a General Definition of Information (GDI) 516 as part of his Philosophy of Information, analysing the ways in which information 517 may be understood, and opting to regard it from the semantic viewpoint, as "well-518 formed, meaningful and truthful data". Data is understood here as simply a lack 519 of uniformity; a noticeable difference or distinction in something. To count as 520 information, individual data elements must be compiled into a collection which must 521 be well-formed (put together correctly according to relevant syntax), meaningful 522 (complying with relevant semantics), and truthful; the latter requires a detailed 523 analysis of the nature of true information, as distinct from misinformation, pseudo- 524 information and false information. Although Floridi takes account of Shannon's 525 formalism in the development of his conception of information, and argues that it 526

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"provides the necessary ground to understand other kinds of information" (Floridi 527 2010a, 78), he moves beyond it in discussing human, semantic information. His 528 analysis also includes biological information in detail; noting that it is complex 529 and multifaceted, he treats, for example, genetic and neural information separately. 530 Meaningful information and knowledge are part of the same conceptual family. 531 Information is converted to knowledge by being inter-related, a process that may 532 be expressed through network theory. Informally, "what [knowledge] enjoys and 533 [information] lacks ... is the web of mutual relations that allow one part of it 534 to account for another. Shatter that, and you are left with a pile of truths or a 535 random list of bits of information that cannot help to make sense of the reality 536 that they seek to address" (Floridi 2011b, 288). Furthermore, information that is 537 meaningful must also be relevant in order to qualify as knowledge, and this aspect 538 may be formally modelled, as also the distinction between 'knowing', 'believing', 539 and 'being informed'.

This is therefore a formalism – the only one of its kind thus far – which 541 begins with a treatment of information in Shannon's objective sense, and goes on, 542 apparently seamlessly, to include subjectivity, meaning, and relevance. It provides 543 a formal framework for understanding a variety of forms of information, and, while 544 in itself an exercise in philosophical analysis, it may serve as a basis for other forms 545 of consideration of information in various domains. It also, happily, includes and 546 systematises library/information science's pragmatic approaches to the information- 547 knowledge relation, discussed earlier.

While undoubtedly valuable as a framework for understanding, Floridi's concep- 549 tualisation does not of itself answer our basic question: which, if any, conceptions, 550 and laws and principles, of information in one domain can be meaningfully applied 551 in another? We will go on to consider this, but first we must ask: why bother?

Why Attempt to Bridge the Gaps? 6.5

The question then inevitably arises as to whether these various ideas of information 554 have any relevance for the library/information sciences, whether it just happens that 555 the English word 'information' is used to mean quite different things in different 556 contexts, or whether any connections which there may be are so vague and limited 557 as to be of little interest or value.

We believe that this is a question well worth investigating, and not just for the 559 sake of having a neat and all-encompassing framework. If the gaps between different 560 understandings of information can be bridged in some way, then there is a possibility 561 for helpful interactions and synergies between the different conceptualisations. 562 In particular, if it is correct that the principles of physics and of biology can 563 be, to a significant extent, cast in information terms, then there should be the 564 possibility, at the least, for analogies helpful to human-centred disciplines, including 565 library/information science to be identified. This need not be in any sense a 566 reductionist enterprise, attempting to 'explain away' social and human factors in 567

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physical and biological terms. Nor need it be just one way. If it is true, as some 568 authors suggest, that there are some general principles, involving information, 569 complexity, meaning, and similar entities and concepts, which operate very widely, 570 beyond the scope of individual disciplines, then it is not beyond the bounds of 571 possibility that insights from the library/information sciences could 'feed back' 572 to inform physical and biological conceptions. No such examples have yet been 573 reported, though one might envisages them coming from areas such as infometrics, 574 information behaviour, and information organisation. This kind of feedback is, of 575 course, in the opposite direction to the common reductive approach, by which 576 physics informs chemistry, which informs biology, which in turn informs the social 577 sciences. If it ever proved fruitful, it would have the potential to change the standing 578 of the library/information sciences within the academic spectrum, giving it a place 579 as a more fundamental discipline.

Let us, at the risk of seriously annoying those readers who will think this 581 approach too naïve to be worth dignifying in print, give some examples of physical 582 laws which could have 'information analogies' for a popular account of these laws, 583 see Pickover (2008).

To begin with perhaps the simplest possible example, Ohm's law states that 585 the strength of an electric current, I, is proportional to the applied voltage, V, and 586 inversely proportional to the resistance, R, of the material carrying the current; in 587 appropriate units, I = V/R. We can easily envisage an information analogy, with 588 information flow equating to current, the strength of the need for information equating to voltage, and a measure of difficulty of obtaining the necessary information 590 equating to resistance. So, if we consider the situation of a doctor treating a seriously 591 ill patient, and needing to know the appropriate drug treatment, we have a high value 592 of V. If the doctor has in their pocket a mobile device giving immediate access to 593 well-structure drug information, then we might say that R was low.

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Too simple? How about Poiseille's Law, which governs the rate of flow, Q, of a 595 fluid with viscosity μ through a pipe of length L and internal radius r, when there is 596 a pressure difference P. The formula, assuming that the flow is smooth, without any 597 turbulence, and that the density of the fluid never changes, is $Q = \pi r^4 \Delta P/8 \mu L$. Again, we may amuse ourselves looking for information equivalents: the length of 599 the pipe equates to the number of steps in a communication chain; its internal radius 600 equates the amount of information which can be transferred; the viscosity equates 601 to the difficulty in understanding the information; and so on. This is not such an odd 602 idea: Qvortrup (1993) reminds us that Shannon's theories are firmly based on the 603 metaphor of information as water flowing through a pipe.

Another example is the use of the various scientific diffusion laws, which offer 605 clear analogies with information dissemination. Avramescu (1980) gave an early 606 example of this, using laws for the diffusion of heat in solids, equating temperature 607 to the extent of interest in the information; Liu and Rousseau (2012) review 608 this and other examples. Le Coadic (1987) mentions this, and similar attempts 609 to use diffusion and transfer models drawn for both the physical and biological 610 sciences, while cautioning against the uncritical use of such analogies. However, 611 provided they are treated with due caution, such analogies with physical laws, 612



even if it be accepted that there is no underlying common 'meta-law', may be of 613 value as aids to teaching and learning, and to the early stages of the planning of 614 research.

We must also mention quantum mechanics, the most fundamental scientific 616 advance of the last century, of which both the mathematical formalism (directly) and 617 concepts (by analogy) have been applied in a library/information science context; 618 see, for example, Piwowarski et al. (2010, 2012), and Budd (2012).

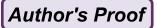
It may be objected that this is too simplistic an approach. Physical laws are 620 physical laws, and are too specific to their context to be adapted for human 621 information, and do not take account of its dynamic nature, nor of the ability of 622 humans to be more than passive recipients.

What, then, about a more general principle? In the physical sciences, the principle 624 of least action occupies a central place, as does Zipf's principle of least effort in the 625 social, including library/information, sciences. Is it unreasonable to ask if there may 626 be a reason for this, which would involve some common aspects of information in 627 the two realms?

Or perhaps we should look rather at statistical regularities, whether these be 629 called laws or not, and consider whether there may be some underlying reasons, 630 if similar regularities are found in different realms. One example may be the fractal, 631 or self-similar, nature of many physical systems, which, it is hypothesised, may also 632 be found in technical and social information; see, for example, Ottaviani (1994) and 633 Berners-Lee and Kagal (2008). Similarly the power law relationships underlying 634 the main bibliometric laws (Egghe 2005) have their equivalents in power laws in the 635 physical and biological sciences.

The important question is not which of these ideas or approaches is 'right'. It 637 is simply whether it is rational and appropriate to look at ideas of information 638 in different domains, seeking for causal links, emergent properties, analogies, or 639 perhaps just helpful metaphors. It is by no means certain that this is so. We 640 have seen that some scientists, such as Müller, object to the use of information 641 concepts in thermodynamics. And, conversely, many in the library/information 642 sciences are concerned about the application of the term 'information' to objective, 643 meaningless patterns. Le Coadic (1987), Cole (1994), Hjørland (2007, 2008), and 644 Ma (2012), for example, argue in various ways against any equating of the idea 645 of information as an objective and measurable 'thing' to the kind of information 646 of interest in library and information science; this kind of information, such 647 commentators argue, is subjective in nature, having meaning for a person in a 648 particular context, and cannot be reduced to a single objective, still less quantifiable, 649 definition. However, this perhaps overlooks some recent trends in the physical and 650 biological sciences themselves: not merely the increased focus on information noted 651 above, but a tendency towards conceptualisations involving non-linearity, systems 652 thinking, complexity, and reflexivity. All these tend to make current scientific 653 thinking a more amenable source of analogy for the library/information sciences, 654 than heretofore.

It may also be objected that the physical, and to a degree the biological, sciences 656 are necessarily mathematical in nature, whereas the library/information sciences 657



are largely qualitative. While qualitative analysis is certainly necessary, and indeed 658 arguably the best way of achieving understanding in this field (Bawden 2012), this 659 is no reason not to seek for mathematical formalisms to increase and deepen such 660 understanding. Over 30 years ago, Brookes (1980) argued that information science 661 needed a different kind of mathematics; perhaps the library/information sciences 662 still do.

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Our view is that the questions are so intriguing that it is worth the attempt to 664 bridge these gaps. And we believe that the valuable insights already gained from the 665 kinds of approaches discussed above justifies this position. Wheeler's Big Questions 666 have not been answered yet, and it may be that studies of the relation between 667 information as understood in the library/information sciences, and as understood 668 in other domains, may contribute to their solution.

6.6 **Conclusions** 670

We are faced with two kinds of gaps: the gaps between the concepts of information 671 in different domains; and the gap between those who believe that it is worth trying 672 to bridge such gaps and those who believe that such attempts are, for the most part 673 at least, doomed to fail. 674

The authors of this chapter consider themselves in the first group. But we wish 675 to be realistic about what can be attempted: as Jonathan Furner (2010, 174) puts it, 676 "the outlook for those who would hold out for a 'one size fits all' transdisciplinary 677 definition of information is not promising". We should not look for, nor expect to 678 find, direct and simplistic equivalences; rather we can hope to uncover more subtle 679 linkages, perhaps to be found through the use of concepts such as complexity and 680 emergence.

We would also do well to note Bates' (2005) reminder that there are swings 682 of fashion in this area, as in many other academic areas. The recent favouring 683 of subjective and qualitative conceptions of information is perhaps a reaction to 684 the strong objectivity of information science in preceding decades, which was 685 itself a reaction to the perceived limitations of traditional subjectivist methods of 686 library/information science (Bates 2005). Perhaps the time has come for something 687 of a swing back, to allow a merging of views, and a place for different viewpoints 688 in a holistic framework. A bridging of gaps, in fact. A number of authors have 689 advocated this, though so far it has not happened.

At a time when other disciplines, particularly in the physical and biological 691 sciences, are embracing information as a vital concept, it seems unwise for the 692 library/information sciences to ignore potentially valuable insights, though we 693 certainly wish to avoid the shallow analogies mentioned above.

Mind the gaps, certainly, but be aware of the insights that may be found within 695 them. 696

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- AQ2. Please update Budd (2012).
- AQ3. Please provide page range for MacPherson (2008).

