INTERDISCIPLINARY SCIENCE REVIEWS, Vol. 37 No. 3, September 2012, 237–53

Warren McCulloch and the British Cyberneticians

PHIL HUSBANDS and OWEN HOLLAND
Department of Informatics, University of Sussex

The relationships and interactions between Warren McCulloch and a number of British cyberneticians are traced. He interacted regularly with most of the main figures on the British cybernetics scene, forming close friendships and collaborations with several, as well as mentoring others. Many of these interactions stemmed from a 1949 visit to London, during which he gave the opening talk at the inaugural meeting of the Ratio Club, a gathering of brilliant, mainly young, British scientists working in areas related to cybernetics.

KEYWORDS Warren McCulloch, British cybernetics, Ratio Club, Macy meetings

Introduction

The famous photograph reproduced in Figure 1, showing McCulloch (1898–1969) and Norbert Wiener (1894–1964) with British Cyberneticians Ross Ashby (1903–1972) and Grey Walter (1910–1977), first appeared in de Latil (1953) with the caption 'The four pioneers of Cybernetics get together in Paris', and encapsulates a view of the development of cybernetics that has slowly become more accepted: that there were important British contributions from the outset (Cordeschi 2002, Holland 2003, Boden 2006, Husbands *et al*. 2008, Pickering 2010). Warren McCulloch embraced these influences and had significant contact with a number of British cyberneticians, forming friendships and collaborations with several, as well as mentoring others. This study traces some of these relationships, attempting to shed light on their influences on both McCulloch and the British scientists involved, and showing that, in some cases, McCulloch's influence was indirect, for instance by enabling visits or collaborations that were to prove pivotal, but nonetheless important. This is the first explicit exploration of this topic and it makes use of original, primary source research, building on the authors' detailed work on the Ratio Club (Husbands and Holland 2008, Holland and Husbands 2011).

Much has been written about how in the USA many key ideas underpinning the development of cybernetics began to take form in the late 1930s and early 1940s (Heims 1991, Cordeschi 2002, Abraham 2002, Boden 2006, Husbands *et al*. 2008). Perhaps less well known is the parallel and, at

DOI 10.1179/030801881 2Z.00000000019

FIGURE 1 Left to right, W. Ross Ashby, Warren McCulloch, Grey Walter and Norbert Wiener at the 1951 Congress on Cybernetics held in Paris. From de Latil 1953, reproduced with permission.

first, largely independent development of similar ideas in Britain (Asaro 2008, Husbands and Holland 2008, Pickering 2010). Alan Turing (1912–1954) and Kenneth Craik (1914–1945) were particularly important figures in the British scene during this period and their ideas soon crossed the Atlantic, helping to shape the American cybernetic movement as it matured. As we shall see, both had a direct influence on McCulloch.

The Second World War was to prove a major catalyst for advances in mechanistic ways of thinking about natural intelligence as well as in the development of practical computers. In Britain there was very little actual biological research carried out as part of the war effort, so most biologists were drafted into the main thrust of scientific research on communications and radar (Pringle 1975). This was to have the extremely important effect of exposing these biologists to electronics and communication theory. This mixing of disciplines led to a two way flow of ideas that was to prove highly significant in advancing formal understanding of the nervous system as well as in developments in machine intelligence (MacKay 1991).

In the years immediately after the war fascination with these areas continued to grow in Britain, culminating in the establishment of the Ratio

Club (Husbands and Holland 2008). The club was founded and organized by John Bates (1918–1993), a neurologist at the National Hospital for Nervous Diseases in London. The other twenty carefully selected, highly talented members were a mixed group of mainly young neurophysiologists, engineers and mathematicians, with the centre of gravity firmly towards the brain sciences. The inaugural meeting of the club was held to coincide with McCulloch's visit to London in 1949 so that he could give the opening talk. The focus of the Ratio Club was very much in tune with McCulloch's preoccupations, indeed arguably to a greater degree than the more intellectually sprawling cybernetics group that was coalescing in the USA around the Macy meetings. McCulloch formed a close association with the club and developed lasting friendships with several members as well as being involved in extended correspondence and collaborations with others.

Because the club immediately expanded McCulloch's interactions with British scientists of a kindred spirit, 1949 was a watershed year in his relationship with the British cyberneticians. Hence, this study is divided into a discussion of pre- and post-1949 influences and interactions. It is worth noting that McCulloch was very proud of his British — or more specifically, Scottish — roots (Cowan 2003, Andrew 2012). It is probably no coincidence that a good number of the British cyberneticians he promoted and/or collaborated with were Scottish, or had been brought up in Scotland, including: Craik, Turner McLardy, Donald MacKay, Alex Andrew and Jack Cowan.

Influences and interaction, pre-1949

By the late 1930s, Alan Turing's work in mathematics was well known in American academic circles and his celebrated 1936 paper (Turing 1936) on one of Hilbert's open problems in mathematics, the *Entscheidungsproblem*, which asked if it was possible to define a formal procedure that could be used to decide whether any given mathematical assertion was provable, was to have lasting impact on the development of cybernetics and computing (Hodges 1983, Boden 2006). Turing's startlingly original approach to the problem was to define a kind of simple abstract machine as a very general way of constructing a formal procedure in mathematics; thus he was able to show that it followed that the answer to the problem was no. The concept of the Turing machine, as it became known, now serves as the foundation of modern theories of computation and computability. In the paper, Turing, a research fellow at Cambridge University at the time, explicitly drew a parallel between the operation of such a machine and human thought processes, as well as defining the properties of universal Turing machines on which the modern notion of a general purpose programmable computer rests. Turing's work was a major influence on McCulloch and Pitts' seminal research on artificial neural networks (McCulloch and Pitts 1943) and the last part of that paper was aimed at proving that a McCulloch-Pitts net was equivalent to a Turing machine. McCulloch and Pitts concluded that this afforded 'a psychological justification of the Turing definition of computability'. During the discussion session following a lecture given by von Neumann in 1948, McCulloch stressed the importance of Turing to his and Pitts' work: 'I started at entirely the wrong angle . . . and it was not until I saw Turing's [1936] paper that I began to get going the right way around, and with Pitts' help formulated the required logical calculus. What we thought we were doing (and I think we succeeded fairly well) was treating the brain as a Turing machine' (in Von Neumann 1961, p. 319). It seems highly likely that Turing would have been aware of McCulloch and Pitts' work by the time he started research on his own brand of binary neural networks in 1947, but surprisingly he makes no reference to it in his report on the topic (Turing 1948). As Copeland and Proudfoot (1996) have noted, it remains an open question to what extent, if at all, the work of McCulloch and Pitts influenced Turing's ideas on neural networks. However, McCulloch was certainly aware of Turing's increasing interest in machine intelligence and cybernetics after the war and sought him out on his trip to England in 1949, as described later.

At the same time as Turing was opening up new worlds, in another part of Cambridge Kenneth Craik was developing revolutionary ideas about the study of the mind. A few year later his landmark book, which was to have a galvanising effect on the development of British, and indeed American, cybernetics, emerged from the midst of war-time interdisciplinary problem solving. Craik's slim volume, *The Nature of Explanation* (Craik 1943), laid out his mechanistic view of the nature of intelligence and the need to understand it in terms of the empirical observation of underlying mechanisms.

Kenneth Craik was a Scottish psychologist who many colleagues openly referred to as a genius (Bartlett 1945). His story is made particularly poignant by his tragic and sudden demise at the age of 31 on the last day of the war in Europe.

After studying Philosophy at Edinburgh University, in 1936 he began a PhD in psychology and physiology at Cambridge University. Here he came under the influence of pioneering head of psychology Sir Frederick Bartlett (1886–1969). His classic 1943 book was published in the middle of his war work on factors affecting the efficient operation and servicing of artillery machinery. Noting that 'one of the most fundamental properties of thought is its power of predicting events' (Craik 1943, p. 50), Craik suggests that such predictive power is 'not unique to minds'. Indeed, although the 'flexibility and versatility' of human thought is unparalleled, he saw no reason why, at least in principle, such essential properties as recognition and memory could not be emulated by a man-made device. He went even further by claiming that the human mind is a kind of machine that constructs small-scale models of reality that it uses to anticipate events.

Craik's switch from studying philosophy to psychology and physiology was motivated by his advocacy of an 'experimental philosophy' in which the study of psychological and physiological mechanisms was seen as fundamental to the philosophy of mind. Craik believed this subject was hindered by a fundamentally flawed methodology based on 'introspective analyses of particular instances of perception. . . . You cannot wring the truth out of a particular observation of a particular event' (Craik 1943).

McCulloch's own vision of an 'experimental epistemology', also arrived at from a dissatisfaction with the philosophical study of the mind (McCulloch 1965, 1974), and the lack of engagement with underlying neural mechanisms in mainstream psychology and psychiatry, resonated strongly with Craik's views. Hence Craik's little book became an important source of inspiration for McCulloch and he viewed it as one of the foundation stones of cybernetics [see Collins's paper in this issue for an extensive discussion of Craik's influence on McCulloch (Collins 2012)].

W. Grey Walter was a near contemporary of Craik's, having just left Cambridge University as Craik arrived. Before establishing himself as a leading neurologist and electroencephalography (EEG) researcher he had, like several others of those who would later form the Ratio Club, studied under Lord Adrian (1889–1977), the charismatic Nobel prize winning head of physiology at Cambridge. He first met McCulloch and Wiener and other members of the cybernetics group during a visit to the USA in 1946. Although approving of the general thrust of their ideas, in a 1947 letter to Lord Adrian, Walter refers to them as 'thinking on very much the same lines as Kenneth Craik did, but with much less sparkle and humour' (Walter 1947). Walter would later find world-wide fame for his pioneering cybernetic 'tortoises', probably the first ever autonomous mobile robots (Walter 1950), which were built specifically to demonstrate models of neural mechanisms driving embodied behaviour. He would often meet up with McCulloch when they became two of the leading figures in the burgeoning 1950s international cybernetics scene. They respected each other's opinions, enjoyed socialising together (they were both showmen with non-conventional and open-minded attitudes to life) and corresponded regularly from 1947–60. Although they did not collaborate on specific research projects, their central research interests being in slightly different areas, it is hard to imagine that they did not have a general intellectual influence on each other.

Travel restrictions during and just after the Second World War meant that for several years British scientists, particularly junior ones, rarely visited the USA and McCulloch had few opportunities to meet with the coming generation of UK researchers. As restrictions loosened and Britain began to rebuild, John Westcott (1920–) took early advantage of the opportunities that followed by gaining a scholarship to spend a year at MIT from 1947–48 as a guest of the institute while working with Wiener. After war work on radar, which had introduced him to the nascent cybernetic fields of information and control theory, to which he would later make significant contributions, Westcott had returned to Imperial College, London to undertake a PhD under the supervision of Colin Cherry. Towards the end of his stay, during an east to west coast road trip with other graduate students, he arranged to call on McCulloch and Pitts in Chicago and spent an enjoyable few hours discussing research with them (Westcott 2002). Not long after his return to London, where he found himself in demand to give talks on what the newly named field of cybernetics was all about, he was reacquainted with McCulloch during the latter's 1949 trip to Britain.

Influences and interactions, 1949 onwards

The 1949 visit

In 1949, McCulloch travelled to England to attend the Anglo-American Symposium on Psychosurgery, Neurophysiology, and Physical Treatments in Psychiatry, held at the Royal Society of Medicine, London on the 12th and 13th of September. The American contingent at the meeting included McCulloch and Walter Freeman II, the renowned lobotomy enthusiast, while their English counterparts included the Nobel laureate neurophysiologist Sir Henry Dale (1875–1968), who became friends with McCulloch, and F. L. Golla (1878–1968), a leading neuropsychiatrist and then director of the Burden Neurological Institute in Bristol. McCulloch gave a paper entitled 'Physiological Processes Underlying Psychoneuroses' (McCulloch 1949). As the title suggests, his talk tackled head-on the schism between the dominant introspective psychological and mechanistic neurophysiological approaches to 'the understanding of disease called mental'. The official discussants of the paper generally made very positive comments except for Golla who was sceptical about whether a mechanistic approach to neuroses was a real possibility. He made a slightly rambling point about the effects of alcohol on the masses at pub closing time, concluding that 'Professor McCulloch might be asking too much, it might be that they [the drinkers] would ultimately have to correlate the mechanistic account with introspection to make it intelligible. As living beings they could do something which no mechanical thing could ever do — they could objectify themselves' (Golla in McCulloch 1949, p. 80). McCulloch's reply gives us a glimpse of the extent of his optimism for the cybernetic approach. He stated that 'since he had shown that machines can and do have ideas and purposes it did not seem to him to be any great matter to design a machine that objectified itself, which is to have reflective knowledge of its own thinking' (*ibid* p. 82). In answer to a question from Derek Richter about the relationship between (brain) alpha rhythms and psychomotor behaviours, McCulloch referred the audience to the 'brilliant' work of Craik, remarking that 'The man, Craik, who held most promise for the world in this direction unfortunately was dead and his work was so buried in Governmental reports that except for his little book it was not accessible' (*ibid* p. 83). He went on to declare that 'there was but one thing he would like to persuade his audience to do, namely to collect Craik's work and get it published soon' (*ibid* p. 83), revealing the roots of his project that eventually resulted in Craik's (1966) *The Nature of Psychology*.

McCulloch's host for his trip to London was Turner McLardy (1913–1988), a neuropsychiatrist at the Maudsley Hospital, who was a prominent discussant at the meeting. A few weeks earlier, McLardy had been contacted by John Bates with an invitation to join a select dining club to discuss cybernetics and related research. On learning from Walter and McLardy about McCulloch's imminent visit, Bates decided to time the inaugural meeting around the Royal Society of Medicine symposium so that McCulloch could attend. Bates met McCulloch at an EEG conference in Paris at the end of August and the invitation was accepted. And so it was that on the 13 September, after lunch and discussions with Westcott and Donald MacKay (1922–1987) — a philosophically inclined physicist with a strong interest in applying the knowledge of control and information theories he had gained during the war to understanding nervous systems — McCulloch found himself addressing the inaugural meeting of what was to soon become the Ratio Club.

The Ratio Club

The genesis and spirit of the club are very well captured in the following excerpt from an invitation letter from Bates to Grey Walter (Bates 1949a):
'I have been having a lot of "Cybernetic" discussions during the past few weeks here and in Cambridge during a Symposium on Animal Behaviour Mechanisms, and it is quite clear that there is a need for the creation of an environment in which these subjects can be discussed freely. It seems that the essentials are a closed and limited membership and a post-prandial situation, in fact a dining-club in which conventional scientific criteria are eschewed.
I know personally about 15 people who had Wiener's ideas before Wiener's book appeared and who are more or less concerned with them in their present work and who I think would come. The idea would be to hire a room where we could start with a simple meal and thence turn in our easy chairs

towards a blackboard where someone would open a discussion'. Bates then went on to suggest various names for membership.

Walter replied with an enthusiastic acceptance and suggested a few more names. Over the next few weeks the list grew to comprise the following initial membership:

W. Ross Ashby, a psychiatrist who went on to be regarded as one of the most influential pioneers of cybernetics and systems science. At the inception of the club he was director of research at Barnwood House Hospital, Gloucester.

Horace Barlow (1921–), FRS, a great-grandson of Charles Darwin, who became an enormously influential neuroscientist and was one of the pioneers of using information theory to understand neural mechanisms. When the club started he was a PhD student in Lord Adrian's lab.

John Bates, who had a distinguished reputation for his work on the human EEG in relation to voluntary movement.

George Dawson (1911–1983), a clinical neurologist at the National Hospital who was a world leader in using EEG recordings in a clinical setting.

Thomas Gold (1920–2004) FRS, who was later recognised as one of the great astrophysicists of the twentieth century. Eschewing disciplinary boundaries, at the time of the Ratio Club he was working in Cambridge University Zoology Department on a radical positive feedback theory of hearing.

W. E. Hick (1912–1974), an important pioneer of information theoretic thinking in psychology. During the Ratio years he worked in the Psychology laboratory at Cambridge University.

Victor Little (1920–1976), a physicist at Bedford College, London.

Donald MacKay, the youngest member of the club, who, as well as emerging as a very highly regarded pioneer of early machine intelligence and of neuropsychology, became the leading scientific apologist for Christianity of his day. At the birth of the club he was working on a PhD at King's College London.

Turner McLardy, who became prominent in a number of areas of neuropsychiatry.

Pat Merton (1921–2000), FRS, a neurophysiologist at the National Hospital who went on to do very highly regarded pioneering work on control theoretic understandings of the action of muscles, and in magnetic stimulation of the cortex.

John Pringle (1912–1982), FRS, a researcher in the Cambridge Zoology department who became one of the leading invertebrate neurobiologists of his day.

Harold Shipton (1920–2007), an electronics wizard who worked with Grey Walter on the development of EEG technology at the Burden Neurological Institute.

D. A. Sholl (1903–1960), from the Anatomy department of University College, London, who later did classic research on classifying neuron morphologies and growth patterns.

Eliot Slater (1904–1983), a colleague of Bates' who went on to become one of the most eminent British psychiatrists of the twentieth century.

Albert Uttley (1906–1985), an important pioneer of machine intelligence and artificial neural networks. At the birth of the club he worked at the military Telecommunications Research Establishment (TRE), Malvern.

Grey Walter who, as well as his cybernetics contributions, made many major discoveries related to his EEG research, including theta and delta brain waves and, with Shipton, developed the first EEG brain topography machine.

John Westcott, FRS, who did pioneering work on control under noisy conditions as well as on applying control theory to economics.

Alan Turing, FRS, who at the time was working at Manchester University, and fellow mathematician **Philip Woodward** (1919–), who was working at the Telecommunications Research Establishment (TRE) and made important contributions to information theory and Bayesian approaches, joined immediately after the first meeting. At the same time leading Cambridge neurobiologist **William Rushton** (1901–1980), FRS, who became one of the great figures in twentieth century vision science, was added to the list. A year later leading mathematician **I. J. Good** (1916–2009), who had worked as the main statistician with Turing at code-cracking centre Bletchley Park during the war, and at the time was still employed by British intelligence, became the 21st and final member. Had he survived, there is no doubt Craik would have been a leading member of the club. In fact, there was a proposal to call it the Craik Club in his honour (Husbands and Holland 2008).

The 'had Wiener's ideas before Wiener's book appeared' remark in Bates' letter of course refers to the publication of Wiener's (1948) landmark *Cybernetics* a few months earlier, no doubt a contributory spur to the formation of the club, but is a reminder that this was no amateur cybernetics appreciation society; many members had already been active for years in developing the new ways of thinking about behaviour-generating mechanisms and information processing in brains and machines that were now being pulled together under the term coined by Wiener. The club was very active between September 1949 and July 1953 with only a few meeting after that until the final one in November 1958. It had a significant impact on several members' work and subsequent careers and helped to enable cybernetic thinking to spread in British science. It was undoubtedly the most intellectually powerful grouping of British scientists interested in cybernetics and it is not surprising that McCulloch was attracted to it. For much more extensive details of the club, including discussion of some of the considerable achievements of its members and topics covered at meetings, see Husbands and Holland (2008 and 2011).

The first meeting, like most subsequent ones, was held in a basement room under a nurses' home at the National Hospital. After sherries, McCulloch gave his presentation, *Finality and Form in Nervous Activity*, a popular talk that he had first given in 1946 — perhaps not the best choice for such a demanding audience. Correspondence between members reveals almost unanimous disappointment in the talk. Bates gave a rather condescending reaction to it in a letter to Grey Walter: 'I had led myself to expect too much of McCulloch and I was a little disappointed; partly for the reason that I find all Americans less clever than they appear to think themselves; partly because I discovered by hearing him talk on 6 occasions and by drinking with him in private on several more, that he had chunks of his purple stuff stored parrot-wise. By and large however, I found him good value' (Bates 1949b).

Walter wrote to Bates apologizing for not being present at the meeting owing to the birth of a son. He went on to tell Bates that he has had 'an amusing time' with McCulloch who had travelled on to Bristol to visit him at the Burden Institute. In reference to Bates' view on McCulloch's talk, he comments '. . . his reasoning has reached a plateau . . . flowers that bloom on this alp are worth gathering but one should keep one's eyes on the heights' (Walter 1949).

After Bristol, McCulloch travelled to Manchester University to visit Turing. Although there is no record of what was discussed, their meeting does not seem to have gone well as Turing later remarked that he found McCulloch 'a charlatan' (Hodges 1983, p. 411), perhaps for the same reason that the Ratio members disliked his talk.

If McCulloch had instead given the much more interesting and well-received presentation he'd delivered the previous day at the Royal Society of Medicine symposium, the reaction would have been very different. But despite his wife Rook's regular advice to the contrary (Andrew 2010), he couldn't resist trying to impress by spouting great reams of 'the purple stuff'. However, many members had a high regard for his research and they obviously came to appreciate his style as the whole meeting of 2 July 1953 was given over to a discussion of his work, with McCulloch giving a presentation to open the debate. He also attended meetings whenever they coincided with his visits to England and members often visited him in the USA (Husbands and Holland 2008). He developed collaborations and extended correspondence with several members and mentions the club fondly in some of his autobiographical writings (McCulloch 1974).

There is insufficient room to cover all his interactions with Ratio members, so just a few highlights are mentioned here. McCulloch formed a friendship with Turner McLardy with whom he enjoyed discussing neuropsychology. They frequently visited each other and had an extensive written correspondence from 1949–64. In the picaresque *Where is Fancy Bred*, McCulloch (1961) recalls, during a 1958 trip to England, joining McLardy to study the brains of some of his patients and marvelling at 'the strange two-dimensional braiding of the fine axons . . . that pass from the granular layer to the pyramidal cells of the hippocampus' and then spending much time discussing with him 'the third problem of learning machines — call it insight if you will' (how brains/machines are able to make use of sudden long-shot insights in problem solving — still a very live topic today), approaching it in relation to possible hippocampal functions.

Ashby first wrote to McCulloch in 1946. Although Ashby's letter appears to no longer exist, we can gather from McCulloch's reply (McCulloch 1946) that Ashby enclosed a copy of one of his early papers on adaptation, which McCulloch thanked him for and promised to share with others 'interested in the mathematical formulation of learning, particularly Professor Rashevsky'. McCulloch offers a constructive criticism of Ashby's ideas giving his view that 'the theory should not be phrased in terms of any sort of equilibrium . . . I look for the final answer to be in terms of a reorganization enforced by the continuous activity reverberating by a variable path . . .[with] activity brought to an abrupt end by negative feedback around the appetitive loop . . .' Given the dates and McCulloch's reference to 'equilibrium' and (elsewhere in the letter) Ashby's 'theory of breaks', it is very likely the paper in question is Ashby (1945). McCulloch raises two interesting issues: equilibrium and feedback. For some years Ashby (Ashby 1940, 45) had been developing theories of adaptation in organisms in which he attempted to formalise the somewhat woolly notion of adaptation in terms of equilibrium in dynamical systems. Ashby's theories of adaptation were based on dynamical systems models which acted as abstract models of organisms interacting with their environment. He was careful to point out that 'stable equilibrium does not mean immobility. A body, e.g. a pendulum swinging, may vary considerably and yet be in stable equilibrium the whole time . . . the concept of equilibrium is essentially a dynamic one' (Ashby 1940, p. 479). His idea was that adaptation could be modelled in terms of the stability of a dynamical system in which there is a tendency for key variables (e.g. body temperature, blood sugar level) to remain within certain limits; if they went outside the limits adaptive forces acted to pull them back in. McCulloch seems to be of the view that biological adaptation must be thought of in terms of continuous activity and reorganization rather than equilibrium. Mathematically speaking, it could be argued that the generality of Ashby's framework does in fact encompass this view, with the tendency towards (dynamic) equilibrium powering the reorganization. However, this reading is much clearer in the later, more developed version of the theory (Ashby 1952a) which suggests that Ashby may have taken note of McCulloch and other critics. Ashby's methodology employed sets of coupled differential equations (Ashby 1940, 45). The generality of the cross coupling between equations meant that implicit feedback loops were possible, and indeed Ashby had long been aware of the importance of circular patterns of connectivity (Ashby 1940). However, he did not refer explicitly to feedback mechanisms and although Ashby's journal from this period does not mention McCulloch's letter, it is interesting to note that as the more mature, and widely influential, theory of ultra-stable systems was developed over the next few years, he did incorporate negative feedback as an important explicit element (Ashby 1952a).

In his journal entry on the opening Ratio Club meeting, Ashby notes that 'McCulloch spoke for an hour. But don't think we have much to learn from him, though he undoubtedly has brains' (Ashby 1949). He also refers to McCulloch's visit to the Burden Neurological Institute in Bristol on the 16 September; Ashby had come across from his nearby place of work to demonstrate his newly built Homeostat which demonstrated his theories of adaptation and which was soon to become one of the most famous cybernetic artefacts of the time. He writes that McCulloch 'was interested but gave little away. He admitted however that he had seen nothing like it either in England or America'. Ashby was notoriously socially awkward and at the time very focused on his own work, so he may not have been the best judge of McCulloch's degree of enthusiasm. However, McCulloch *was* interested in Ashby's work and helped to raise his profile by promoting him in the USA through an invitation to one of the Macy meetings on cybernetics (see next section), passing preprints and proofs of his articles and books around the cybernetics group (McCulloch 1952) and writing favourably about his research (e.g. McCulloch 1961, 1974), including a high profile, insightful, very positive review of Ashby's 1952 book *Design for a Brain* (McCulloch 1953), demonstrating a close appreciation of the work. Ashby and McCulloch corresponded fairly regularly and visited each other's labs on several occasions.

Donald MacKay and McCulloch formed a close friendship that lasted from their first meeting at lunch before the inaugural Ratio gathering until the latter's death in 1969. They corresponded very regularly over this period and visited each other's labs and family homes whenever travel permitted (R. MacKay 2012). McCulloch invited MacKay to spend the year of 1951 with him at his lab at the University of Illinois, Chicago, to, among other things, test the Pitts-McCulloch theory of neural mechanisms underlying recognition of shapes and musical chords (Pitts and McCulloch 1947). Their theory required various 'scanning' mechanisms whereby alpha activity and certain sets of neurons acted to scan areas of the cortex. This was partly required because information in the model was represented in terms of binary digits, quantized with respect to time as in a serially operated digital computer.

MacKay set to work to test this part of the theory but, as McCulloch reported at the final Macy meeting, his results refuted the details of the proposed mechanism (Heims 1993, p. 241). McCulloch was happy to conclude from this that their work had indeed developed into scientific epistemology whereby hypotheses can be properly tested. This collaboration resulted in an important paper (MacKay and McCulloch 1952) that more generally sought to shed light on a hot topic of the day: which of two competing theories of information transmission in the nervous system was more likely — binary modulation (binary coding as in digital computers, based on neurons firing or not) or interval (pulse position) modulation mechanisms (signal coded in terms of relative position in time of pulses in a train of neural spikes/pulses)? They attacked this problem by comparing how efficiently a typical synapse could convey information in the two models. They built a simple mathematical model of synaptic information transmission incorporating the most accurate available measurements/estimates of crucial parameters such as synaptic delays, maximum neural firing frequencies, minimum intervals between successive spikes and so on. They concluded that the view that binary coding would be more effective 'is unsupported by considerations of efficiency' and that pulse interval modulation would be more efficient under conditions which seemed to match those of the nervous system. However, they cautioned that 'much more likely is it that the statistically determined scurry of activity therein depends in one way or another on all the information-bearing parameters of an impulse [including] presence or absence . . . precise timing and even its amplitude, particularly on the effective amplitude as modified by threshold control, proximity effects and the like' (MacKay and McCulloch 1953, p. 134). Although this issue is not yet fully resolved, and evidence of further coding schemes has been discovered, MacKay and McCulloch's view of multiple schemes (at least for different contexts and/or neuron types) was supported by later empirical findings as modern neuroscience developed (Purves 1997).

A major part of McCulloch's initial interest in MacKay's work rested on MacKay's theory of information (MacKay 1950) which attempted to include a role for meaning, something missing from the Shannon version (Shannon and Weaver 1949), which can be shown to be a special case of the MacKay formulation. MacKay's theory used the idea of an information space with dimensions corresponding to features, or basic characteristics, of the domain in question. Through the use of appropriate metrics, meaning could be represented in terms of the length and orientation of vectors within such a space (MacKay 1950, 1969). McCulloch saw MacKay's more complex formulation of information as more appropriate than Shannon's for many biological questions, because, among other things, it took into account changes in uncertainty through repeated observations (McCulloch 1974). It is therefore slightly ironic that MacKay's time in McCulloch's laboratory was an important impetus in him switching from information theory and computation to brain science: 'a year among neurophysiologists in the United States (1951) completed the transition process; and, for good or ill, most of my remaining half-baked ideas in the field of 'pure' information theory were left to grow cold' (MacKay 1969, p. 6).

At the time many mutual acquaintances remarked on the unlikely nature of the McCulloch–MacKay friendship: MacKay was extremely straight-laced and religious, coming from a strict Calvinist background, whereas McCulloch was famously free-spirited (Barlow 2002). Jack Cowan remembers that on one visit to McCulloch's farm in Old Lyme, MacKay had to avert his gaze from the frolicking skinny dippers in the pond because of the ungodly nature of the spectacle (Cowan 2003). It was almost too much for MacKay when on the same visit McCulloch tried to introduce him to alcohol. Despite their different temperaments, they got along extremely well and both had a philosophically oriented attitude towards science, born out of an early interest in theology (McCulloch was fond of likening MacKay to the eleventh-century Scottish philosopher Duns Scotus (Andrew 2012)). It is sometimes forgotten that McCulloch originally began training for the Quaker ministry so he probably understood and respected Donald's deep religiosity better than most. McCulloch and Pitts even went on a trip with MacKay to Wick, near the wild far north east tip of Scotland, to visit his parents (Andrew 2012).

Macy meetings

McCulloch invited several members of the Ratio Club to participate in the famous Macy meetings on cybernetics of which he was chair. This undoubtedly helped to spread knowledge of British cybernetics research in the USA and contributed to the growing international reputations of the Ratio members involved.

The first of the Ratio group to be invited as a guest was Turner McLardy, who attended the seventh conference held in March 1950. In the event, McLardy was not invited to give a talk, unlike subsequent visitors from the Ratio Club.

Donald MacKay was the next Ratio Club guest, at the eighth conference held in March 1951. Although a 'note by the editors' which introduces the conference transcript (von Foerster 1952) suggests that information theory was to be a major theme of the meeting, it is only MacKay's paper (MacKay 1952a) that deals explicitly with the topic. The discussion following MacKay's presentation was lively and involved several members of the group.

The next Ratio guest, in 1952, was Ross Ashby, who gave two talks. In the first he described his view of the concept of homeostasis, and the physical model — the Homeostat — he had built to investigate it (Ashby 1952b). Although he described the talk as 'highly successful' in his journal (Ashby 1952c), it is clear from the transcript that he was under sustained critical pressure from Wiesner, Pitts, and particularly Bigelow for most of the time. Much of this was concerned with the clarification of his terminology, the implementation of randomness in the Homeostat, and what relationship there might be between the behaviour of the Homeostat and the behaviour of natural organisms in their environments, especially regarding learning. Ashby was agile in defending his position, and the battle was quite equal for much of the talk, but there was growing negativity from Bigelow in particular, who remarked at one point of the Homeostat, 'It may be a beautiful replica of something, but heaven only knows what'. McCulloch, and occasionally the impressively even-handed Pitts, offered supporting comments, but it is clear by the end of the transcript that the group have raised several points on which Ashby has been unable to offer satisfaction.

That the onslaught continued in Ashby's second talk, based on his 1952 paper 'Can a mechanical chess-player outplay its designer?' (Ashby 1952d), is revealed, not in the transcript, but in a memoir by Heinz von Foerster (2002) who described how Bigelow continually interrupted almost every sentence Ashby tried to speak. Von Foerster recalled that 'since I was the editor, I did not want to allow this, because what could I do about this stupid business once it was in the transcript? And I found it disgraceful that this appalling attack on dear Ross Ashby should be permitted' (trans. O. H.). He appealed to McCulloch, as chairman, to stop the interruptions and leave questions until the end. McCulloch complied, as did Bigelow.

The discussion after the talk, however, was dominated by critical comments from Bigelow and Wiesner, who made 12 of the 14 contributions. As with some of their comments during and after Ashby's Homeostat talk, they were particularly opposed to Ashby's treatment and use of randomness, raising a similar point to one that Pitts had made during the first talk concerning the relevance of the random number generated resistor values in the Homeostat. Pitts had commented, '. . .any particular sequence of numbers is on the same plane as any other, and the fact that it was got out of a table of random numbers instead of being some other sequence of values makes. . .no difference'. To that, Ashby had more or less agreed, saying, 'It is quite possible that the regular arrangements might be better, but I have dealt with random numbers almost deliberately, to show that it can be done the random way'. Discussing the second talk, Wiesner objected to Ashby's use of 'something like Brownian movement' to generate new moves, observing that 'If you have a stack of cards and you shuffle through them to find something, without knowing anything about the order, it doesn't matter if you do it in a systematic way, if there are a fair number of operations to perform, or do it randomly, provided you examine each thing only once. If you inject the Brownian motion, you run the possibility of sometimes taking longer because you do certain operations more often'.

Although Ashby resisted their attacks at the time, he later examined some of Bigelow's concerns in a long journal entry (Ashby 1952e) and concluded: 'I now see that my emphasis on randomness in "Can a mechanical. . ." was misplaced'. However, by then, his paper on the mechanical chess player was in press (Ashby 1952d). The validity of the Macy group criticisms were confirmed when the published paper elicited a comment (from Ashby's Ratio Club colleague Hick) in the subsequent issue of the journal making exactly the same objections (Hick 1953).

As well as correcting Ashby's ideas about the utility of randomness, the Macy visit arranged by McCulloch may have had an enormous influence on Ashby's later career, as it marked his first encounter with Heinz von Foerster. In 1960, as Ashby's career in the UK ran into difficulties, it was von Foerster who invited him to take up a professorship at the Biological Computing Laboratory at Illinois, where he worked very productively for the rest of his career.

The last member of the Ratio Club to attend a Macy meeting was Grey Walter, in 1953. This was the last of the conferences; however, the transcript was never published because '. . .it became evident to the Editors that the presentations repeatedly interrupted by discussion would not produce an effective publication' (introduction to von Foerster 1955). Instead, the speakers were invited to submit papers based on their presentations, and Grey Walter was one of only three to do so (Walter 1955). It is a typical Grey Walter effort, filled with amusing and slightly old fashioned wordplay rather like some of McCulloch's less formal pieces. The fact that they got on extremely well is clear from the very familiar tone of Walter's letters to McCulloch. On his quite formal reply to the Macy invitation (Walter 1953a), Walter has scrawled 'What role would you like me to play; if a speaking one what character? physiologist, model maker, engineer — or just my usual universal ham act?' In his letter thanking McCulloch after the conference (Walter 1953b), he is even more unbuttoned: 'My dear Warren. I'm still woolgathering after a protracted stop in Gander — surely the hairiest arsehole in creation — but hasten to tell you how much I enjoyed the conference, the chance to meet you and your gang, and the terrific stimulation I always get from your milieu. . . . They certainly are an improbable crew, but my god you rode'em, Warren, like a rooster — ladies being absent, no obscenity intended'.

The second generation

McCulloch's support for bright young British cyberneticians continued with the second generation of researchers. In the early 1950s, after a degree in physics, Alex Andrew became a PhD student in the Physiology Department at Glasgow University working on applications of electronics to understanding the nervous system. Here he encountered McCulloch who gave two talks on cybernetics at the university (Andrew 2011a). McCulloch invited Andrew to work with him at MIT and so he spent the whole of 1954 and half of 1955 there. He pursued a project on vision in the frog under the supervision of Jerry Lettvin and Pat Wall. Interesting results were obtained at the time, and the work paved the way for the later study that resulted in Lettvin and coworkers' (1959) landmark paper, in which Andrew's prior work is acknowledged. Andrew's time at MIT gave him a lot of new experiences and broadened his outlook, encouraging him to engage more with physiology (Andrew 2012). Lettvin's influence was more direct than McCulloch's, but the opportunity McCulloch had organised was important in the subsequent development of Andrew's career. He remained friends with McCulloch and they would visit each other regularly, although a 1958 trip to London when McCulloch stayed with Andrew turned out to be 'rather a disaster as Warren was in a bad state for a lot of the time' due to drink. Andrew went on to a very successful industrial and then academic career in cybernetics and systems science.

After undergraduate studies in Edinburgh, and a period of industrial research, Jack Cowan began a PhD with Denis Gabor at Imperial College, London in 1957 (Cowan 2008). Here he won a fellowship to spend four years at MIT. On arriving in autumn 1958, he joined Walter Rosenblith's Communications Biophysics lab. Cowan's interests did not quite fit with Rosenblith's group and so, in early 1960, after learning about the exciting research going on in McCulloch's group, he asked to transfer. McCulloch gladly accepted him and he never looked back. He acknowledges McCulloch and Pitts, along with Shannon and Wiener, as major influences on his subsequent career (Cowan 2008). In particular, under McCulloch's influence he 'moved from thinking about automata towards starting to think about the nervous system'. Cowan went on to make many important contributions to machine learning, neural networks and computational neuroscience. In 1967 he took over from Nicolas Rashevsky as Chair of the Committee on Mathematical Biology at the University of Chicago where he has remained ever since.

McCulloch was a strong supporter of Stafford Beer and Gordon Pask who both became prominent cyberneticians in the 1960s. Beer, who was largely self-taught, was a pioneer of applying cybernetics thinking to industrial management. He practiced this within British industry and through a consultancy company he set up. Referring to Beer's efforts, McCulloch noted that in the late 1950s 'in English medicine cybernetics is still a dirty word, but in their industry it has been washed in the holy water of filthy lucre' (McCulloch 1961, p. 222). Gordon Pask was an eccentric maverick who, after study at Cambridge and London universities, made important contributions to cybernetics and psychology, doing pioneering work on educational technology (Bird and DiPaolo 2008). He worked closely with Beer and the two became great friends with McCulloch who approvingly declared them 'not guilty of the solemnity of the square hat' (McCulloch 1974).

Conclusions

Jack Cowan has described McCulloch as 'liking everyone and always seeing the best in them, particularly the Brits. He always went out of his way to help . .' (Cowan 2003). As Heims (1991) has noted, his open, generous spirit and enjoyment of friendships led him to do much to encourage and support others, particularly young scientist at the start of their careers. This was certainly true of his interactions with British cyberneticians. Perhaps this urge to nurture and network was in part a replacement for his thwarted dream of establishing an international interdisciplinary research centre dedicated to cybernetics (Andrew 2011b).

Acknowledgements

Thanks to Tara Abraham and an anonymous reviewer for helpful comments on an earlier draft. Many thanks to Alex Andrew, Robert MacKay, Jack Cowan, Horace Barlow, Philip Woodward, John Westcott, John and Mick Ashby and Igor Alexander for providing invaluable documents and/or discussions.

References

Abraham, T. H. 2002 (Physio)logical circuits: The intellectual origins of the McCulloch-Pitts neural networks. *Journal of the History of the Behavioral Sciences* 38: 3–25.

Andrew, A. M. 2011a. Some reminiscences of cybernetics and systems. *International Journal of General Systems* 40(2): 131–144.

Andrew, A. M. 2011b. A little known origin of cybernetics and some implications. *Kybernetes* 40(9): 1235–1242.

Andrew, A. M. 2012. Email interview with PH, Feb. 2012.

Asaro, P. 2008. From Mechanisms of Adaptation to Intelligence Amplifiers: The Philosophy of W. Ross Ashby, in Husbands et al., eds. 2008, 149–184.

Ashby, W. R. 1940. Adaptiveness and equilibrium. *Journal of Mental Science* (now *The British Journal of Psychiatry*) 86: 478–483.

Ashby, W. R. 1945. The physical origin of adaptation by trial and error. *The Journal of General Psychology* 32: 13–25.

Ashby, W. R. 1949. W. Ross Ashby Digital Archive, http://www.rossashby.info/ Journals Volume 12 p. 2624

Ashby, W. R. 1952a. *Design for a Brain*. Chapman and Hall.

Ashby, W. R. 1952b. Homeostasis, in H. von Foerster, ed. 1952, 73–108.

Ashby, W. R. 1952c. W. Ross Ashby Digital Archive (http://www.rossashby.info/) Journals Volume 15 p3732.

Ashby, W. R. 1952d. Can a mechanical chess-player outplay its designer? *The British Journal for the Philosophy of Science* 3(9): 44–57.

Ashby, W. R. 1952e. W. Ross Ashby Digital Archive (http://www.rossashby.info/) Journals Volume 15 pp. 3744–3751, 2 April 1952.

Barlow, H. B. 2002. Interview with PH and OH, 19 June 2002, Cambridge.

Barlow, H. B. 2008. An interview with Horace Barlow in P. Husbands *et al*., eds., 2008, 409–430.

Bartlett, F. C. 1945. Dr K. J. W. Craik [obituary], *Nature* 155: 720.

Bates, J. 1949a. Letter to Grey Walter, 27th July 1949, *Unpublished papers and records for the Ratio Club*. J.A.V. Bates Archive, The Wellcome Library for the History and Understanding of Medicine, London.

Bates, J. 1949b. Letter to Grey Walter, 4th October 1949. *Unpublished papers and records for the Ratio Club*. J.A.V. Bates Archive, The Wellcome Library for the History and Understanding of Medicine, London.

Bird, J. and DiPaolo, E. 2008. Gordon Pask and his maverick machines, in Husbands *et al*., eds. 2008, 185–212.

Boden, M. A. 2006. *Mind as Machine: A History of Cognitive Science*. Oxford: Oxford University Press.

Collins, A. 2012. An asymmetric relationship: The spirit of Kenneth Craik and the work of Warren McCulloch. *Interdisciplinary Science Reviews* 37(3): 254–268.

Copeland, B. J. and Proudfoot, D. 1996. On Alan Turing's Anticipation of Connectionism. *Synthese* 108(3): 361–377.

Cordeschi, R. 2002. *The Discovery of the Artificial: Behavior, Mind and Machines Before and Beyond Cybernetics*. Dordrecht: Kluwer Academic Publishers.

Cowan, J. 2003. Jack Cowan interview with PH and OH, Chicago, April 16.

Cowan, J. 2008. An interview with Jack Cowan, in Husbands et al., eds. 2008, 430–446.

Craik, K. J. W. 1943. *The Nature of Explanation*, Cambridge University Press.

Craik, K. J. W. 1966. *The Nature of Psychology*, Cambridge University Press.

De Latil, P. 1953. *La Pensée Artificielle* Paris: Librairie Gallimard.

Heims, S. 1991. *Constructing a Social Science for Postwar America: The Cybernetics Group, 1946–1953*. Cambridge, MA:MIT Press.

Hick, W. E. 1953. The Mechanical Chess-Player. *The British Journal for the Philosophy of Science* 3(12): 353–355.

Hodges, A. 1983. *Alan Turing: The enigma of intelligence*, London: Counterpoint.

Holland, O. and Husbands, P. 2011. The Origins of British Cybernetics: The Ratio Club. *Kybernetes* 40(1/2): 110–123.

Husbands, P., Holland, O. and Wheeler, M., eds. 2008. *The Mechanical Mind in History*, MIT Press.

Husbands, P. and Holland, O. 2008. The Ratio Club: A Hub of British Cybernetics. In P. Husbands *et al*., eds., 2008, 91–148.

Lettvin, J. Y., Maturana, H. R., McCulloch, W. S. and Pitts, W. H. 1959. What the frog's eye tells the frog's brain. *Proceedings of the I.R.E.* 4**7**: 1940–1959.

MacKay, D. M. 1950. Quantal Aspects of Scientific Information. *Philosophical Magazine* 41: 289–311.

MacKay, D. M. 1952a. In search of basic symbols. In H. von Foerster, ed. 1952, 181–221.

MacKay, D. M. 1969. *Information, Mechanism and Meaning*. Cambridge, MA: MIT Press.

MacKay, D. M. 1991. *Behind the Eye*, Oxford: Blackwells.

MacKay, D. M. and McCulloch, W. S. 1952. The limiting information capacity of a neuronal link. *Bulletin of Mathematical Biophysics* 14: 127–135.

MacKay, R. 2012. personal communication.

McCulloch, W. S. 1946. Letter to W. Ross Ashby, November 25. W. Ross Ashby Archive, British Library, London. Also at W. Ross Ashby digital archive www.rossashby.info.

McCulloch, W. S. 1949. Physiological Processes Underlying Psychoneuroses. *Proc. Roy. Soc. Med., Section of Psychiatry, vol. XLII, supplement, Anglo-American Symposium on Psychosurgery, Neurophysiology, and Physical Treatments in Psychiatry* 71–84 (including discussion).

McCulloch, W. S. 1952. Letter to W. Ross Ashby, January 14 (second letter of two with same date). W. Ross Ashby Archive, British Library, London.

McCulloch, W. S. 1953. Review of Design for a Brain by W.R. Ashby. *Scientific American* 188(5): 96–98.

McCulloch, W. S. 1961. Where is Fancy Bred? Reprinted as chapter 13 in W. S. McCulloch, *Embodiments of Mind*, MIT Press, 216–229.

McCulloch, W. S. 1965. A Historical Introduction to the Postulational Foundation of Experimental Epistemology, chapter 19 in W.S. McCulloch, *Embodiments of Mind*, MIT Press, 359–372.

McCulloch, W. S. 1974. Recollection of the Many Sources of Cybernetics, ASC FORUM Volume VI, Number 2.

McCulloch, W. S. and Pitts, W. 1943. A logical calculus of the ideas immanent in nervous activity. *Bulletin of Mathematical Biophysics* 5: 115–133.

Pias, C., ed. 2003. *Cybernetics–Kybernetik: The Macy Conferences 1946–1953 Volume 2 Essays and documents*. Zuerich-Berlin: Diaphenes.

Pickering, A. 2010. *The Cybernetic Brain*, Chicago: University of Chicago Press.

Pitts, W., and McCulloch, W. S. 1947. How we know universals: The perception of auditory and visual forms. *Bulletin of Mathematical Biophysics* 9: 127–147.

Pringle, J. W. S. 1975. Effects of World War II on the Development of Knowledge in the Biological Sciences [and Discussion] *Proc. R. Soc. Lond. A* 342(1631): 537–548.

Purves, D. 1997. *Neuroscience*. New York: Sinauer.

Shannon, C. and Weaver, W. 1949. *The Mathematical Theory of Communication*. University of Illinois Press.

Turing, A. M. 1936. On computable numbers, with an application to the Entscheidungsproblem, *Proc. London Math. Soc.* 42(2): 230–265.

Turing, A. M. 1948. Intelligent Machinery. National Physical Laboratory Report. Reprinted in Meltzer, B. and Michie, D., eds. *Machine Intelligence 5*, Edinburgh: Edinburgh University Press, 3–23, 1969.

von Foerster, H., ed. 1952. *Cybernetics: Circular causal and feedback mechanisms in biological and social systems: Transactions of the Eighth Conference March 15–16, 1951*. Josiah Macy Jr Foundation, New York.

von Foerster, H., ed. 1955. *Cybernetics: Circular causal and feedback mechanisms in biological and social systems: Transactions of the Tenth Conference April 22, 23 and 24, 1953*. Josiah Macy Jr Foundation, New York.

von Foerster, H. 2002. Erinnerungen an die Macy-Konferenzen und die Gruendung des Biological Computer Laboratory, Reprinted in Pias (2003), 43–64.

Von Neumann, J. 1961. *Collected Works*. Vol.5. A. Taub (Ed.), Oxford:Pergamon Press.

Walter, W. G. 1947. Letter from Grey Walter to Professor Adrian, 12 June 1947. *Burden Neurological Institute Papers*, Science Museum, London.

Walter, W. G. 1949. Letter to John Bates, 29th September 1949. *Unpublished papers and records for the Ratio Club*. J.A.V. Bates Archive, The Wellcome Library for the History and Understanding of Medicine, London.

Walter, W. G. 1950. An imitation of life. *Scientific American* 182(5): 42–45.

Walter, W. G. 1953a. Letter from Grey Walter to Warren McCulloch, 13 February 1953, in Pias (2003) p. 423.

Walter, W. G. 1953b. Letter from Grey Walter to Warren McCulloch, 29April 1953, in Pias (2003) p. 427.

Walter, W. G. 1955. Studies on activity of the brain, In von Foerster, ed. 1955.

Westcott, J. 2002. Interview with PH and OH, Imperial College, London, 15 March 2002.

Wiener, N. 1948. *Cybernetics, or control and communication in the Animal and the Machine*. Cambridge, MA: MIT Press.

Notes on contributors

Phil Husbands is Professor of Computer Science and Artificial intelligence and co-director of the Centre for Computational Neuroscience and Robotics at the University of Sussex. His research interests include biologically inspired approaches to robotics, computational neuroscience, evolutionary systems, and the history and philosophy of AI and cybernetics. philh@sussex.ac.uk

Owen Holland is Emeritus Professor of Cognitive Robotics at the University of Sussex and a member of the Sackler Centre for Consciousness Science. His research interests include machine consciousness, anthropomimetic robotics, swarm intelligence and the history of cybernetics. owen.holland@gmail.com