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■ *Research Paper*

Seven and the Sausage Machine: Searching for Conclusions in Miller's 1956 Magical Paper

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This paper offers an analytical review of Miller's classic paper of 1956 on 'the magical number 7'. It takes account of that paper's contradictions as well as of its implicit conclusions. Miller's text is by no means clear in its logic or in its terms, and a review might be deemed helpful to those who are trying to understand it. The discussion begins with a brief historical overview. Miller's paper is then reviewed according to the order of the points made by Miller, thus facilitating a lucid comparative reading with that paper. Guidance on interpreting Miller's text is given throughout, leading to a number of technical conclusions. Finally, two general conclusions are offered, one which refers to the decision-making literature, and one which refers more synoptically to science itself.

Keywords psychology; George A. Miller; information theory; Kenneth E. Boulding; decision making

The limit is not information but our capacity to attend to it.

(Simon, 1997)

INTRODUCTION

Once in a while, a paper appears in this journal that references George Miller's (1956) classic paper *The magical number seven, plus or minus two: some limits on our capacity for processing information*. Some recent examples include Warfield (1999, 2003, 2004), Murthy (2000), Magliocca and Christakis (2001), Christakis (2004), Österlund and Lovén (2005), Bausch (2008) and Hogan (2008). Mode 1 of Soft Systems Methodology has also been praised for adhering to Miller's magical number (Checkland, 2000).

The purpose here is not to comment on how system theorists have appropriated Miller's thesis, much less on how psychological experiments have built upon it—good overviews, in this respect, are provided by Sperling (1988),

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Baddeley (1994) and Shiffrin and Nosofsky (1994). Instead, what is offered is an analytical review of Miller's paper, one that takes account of its contradictions as well as of its implicit conclusions. Miller's text is by no means clear in its logic or in its terms, and a review might be deemed helpful to those who are trying to understand it. The discussion begins with a brief historical overview. Miller's paper is then reviewed according to the order of the points set out by Miller, thus facilitating a lucid comparative reading with that paper. Guidance on interpreting Miller's text is given throughout, leading to a number of technical conclusions. Finally, two general conclusions are offered, one which refers to the decision-making literature, and one which refers more synoptically to science itself.

HISTORICAL CONTEXT

> My problem is that I have been persecuted by an integer. For seven years this number has followed me around, has intruded in my most private data, and has assaulted me from the pages of our most public journals.

So Miller began his 'magical' paper, first read as an Invited Address before the Eastern Psychological Association in Philadelphia on 15 April 1955. During the 7 years in question, 1948–1955, Miller had been a Research Associate at the Psychoacoustic Laboratory at Harvard University (1946–1948); an Assistant Professor of psychology (again at Harvard—1948–1951); an Associate Professor of psychology at the Massachusetts Institute of Technology (1951–1955) as well as group leader of the Psychology Group of the MIT Lincoln Laboratory. By the time the paper was published, he had returned to Harvard as a tenured Associate Professor of psychology.

In 1950, inspired by Shannon's (1948) information theory, he had spent his sabbatical at the Institute for Advanced Studies at Princeton in order to study mathematics, having introduced information theory to psychology the previous year (Miller and Frick, 1949). In 1951, he had published *Language and Communication*, a book that helped establish psycholinguistics as an independent field. This was but one of his 43 publications by the time his magical paper appeared.

The paper itself draws from the results of 14 experiments reported between 1949 and 1955. Some of the authors of those papers were colleagues of Miller such as Wendell Garner (also a fellow graduate student) and John Beebe-Center (a long-time Harvard psychologist who also studied sailboat hulls). The paper is known as a classic in cognitive science, a highly interdisciplinary field that is concerned with the manner in which the brain handles information. Miller is an acknowledged pioneer of this field. It is a field that deals extensively with laboratory experiments, but one that also sprung as a reaction against behaviourism. Indeed, Miller's career began in a Harvard basement office next to that of renowned experimental psychophysicist Stanley Smith Stevens, whilst B.F. Skinner's office was situated at the far end of the corridor. Sandwiched between the two, but closer to the former, one can only guess the influence of these spatial arrangements on the young Miller. Hirst (1988) provides a lucid and interesting history of Miller's career as well as that of the development of the field.

REVIEW OF MILLER'S PAPER

The first section of Miller's paper is taken up with explaining information theory—he had offered a more complete explanation a couple of years prior to his address to the Eastern Psychological Association (Miller, 1953). It serves as an introductory description of his analytical approach to the reported psychological experiments from which he draws. A description of information theory is beyond the remit of the present discussion. Miller's use of information theory, however, will be addressed after a review of the main body of his paper.

Seven and the Single Dimension

In the first part of his paper, Miller examines the experimental results of various psychologists researching the mind's ability to classify

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phenomena. Each one of these experiments involved alternative exposures to a single type of stimulus, the objective being to classify the alternatives according to some linear scale. For instance, sound would be classified on a scale of soft-to-loud, tones on a scale of low-to-high and taste intensity on a scale of salt concentration. Visual stimuli would be classified on a positional scale, or a scale that classified the stimulus' size. Colour would be classified on scales of hue and brightness. An experiment involving the placing of a vibrator in the chest region required classifications of intensities, durations and locations, all on linear scales. Another experiment required the categorization of curvature (length of an arc and of a chord), of length and of angle of inclination of lines.

Results from all these experiments averaged 6.5 manageable categories, with a lower limit of 3 (for curvature classifications) and an upper limit of 15 (for positions in an interval). What is notable is that all of the experiments cited concerned sensory faculties such as perception, touch, and hearing and, moreover, all stimuli were unidimensional. That is to say, taste was measured using only salt; the sound projected would be of the same timbre, the variation lying only in its intensity, and so on and so forth. In other words, the type of decision making required in these instances was limited to classifying simple, unitary sensory phenomena.

At this point, Miller tentatively concluded that there appears to be either a conditioned (i.e. learnt) or a neuro-biological limitation that maintains the classificatory abilities of human beings within a range of 3–15 categories. In his words, 'it seems safe to say that we possess a finite and rather small capacity for making such unidimensional judgments and that this capacity does not vary a great deal from one simple sensory attribute to another'. The key terms that delimit the significance of the results are *unidimensional*, and *simple sensory attribute*. In other words, the evidence concerns experiments that could be done on primates with a justifiable expectation of certain positive results. That the human range of 3–15 categories is in any way demeaning, or even a limit, is an open question, for the experiments cited are a far cry from the multidimensional simultaneity of complex decision making that underlies the day-to-day activities of human beings.

Miller, of course, recognized that human beings can accurately identify any one of several hundred variables (such as, for example, faces, words and objects). The question was why the laboratory results differed so much from such experience. He hypothesized that the difference lay in that such variables exhibit a great number of independent attributes, whereas the unidimensional stimuli of the laboratory each differed by just a single attribute (e.g. salt concentration, brightness and so forth). Objects, such as tables, come in different forms, as do words (think of accents), and, of course, faces. Does interaction with multiattribute variables stimulate a greater cognitive classification ability because of the greater number of independent attributes involved?

Multiple Dimensions

Miller begins cautiously, by examining a two-dimensional experiment: the location of a dot in a square. This requires vertical as well as horizontal classification, which are merely two judgments of the same interval type. A previous unidimensional experiment of classifying the location of a dot on a horizontal interval had yielded between nine and ten manageable categories. Based upon a novel statistical relation from information theory, regarding the amount of information required to make a decision between two equally likely alternatives, Miller hypothesized that the addition of a vertical scale for classifying the two-dimensional position of a dot in a square would, due to its being of the same interval type, yield between 90 and 91 manageable categories. This hypothesis assumes that (1) either the human brain deals no differently with horizontal or with vertical positioning or (2) that it can juxtapose the two in a linear, and proportionally additive fashion that respectively extends the amount of information involved in making the decision or (3) both. As it happened, the introduction of a vertical scale increased the number of manageable categories to only between 24 and 25. In other words, the experiment showed that the human

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brain can accurately identify only up to 24–25 positions in the square—a result far short of that expected. Similar results were reported with dual salt–sweet taste intensities, with dual loudness-pitch stimuli, and with dual hue-saturation colour experiments. In all these cases, the introduction of a second dimension increased the number of mentally manageable classificatory categories, but by an amount far less than a linearly additive expectation.

Following this, Miller searched around for a truly multidimensional experiment with multi-attribute variables. He found only one, an auditory study that could set tones according to six different acoustic variables, providing 15 625 possible tones as stimuli. Each of the six dimensions was rated separately by each listener. Under these conditions, 147 categories could be mentally managed. So, an increase in the number of attributes appeared to increase the number of mentally manageable classificatory categories.

Based on the data, Miller concluded the following: as the number of independent attributes increases, the mind's capacity for classification increases, but at a diminishing rate. There is, in other words, an asymptotic relationship between the number of inputs and the mind's capacity to classify them, with the latter extending to some limit. Miller did not have a reasonable amount of experimental data that could shed some light as to the asymptotic limit of this relationship. He noted that it would be of significant interest to discover whether this limit depends upon the attributes or whether it depends upon the mind's inherent capacity to classify them. He did add, however, that, with the introduction of new attributes, the asymptotic increase in mental classification capacity means that classificatory accuracy decreases for any particular attribute. The message seems to be, in his words, that human beings 'can make relatively crude judgments of several things simultaneously'. Miller hypothesized that this result fits evolutionary theory: organisms that know a little about lots of things, instead of a lot about a small number of things, can respond to the widest range of stimuli in a dynamic environment, rendering them more adaptive and, therefore, giving them relatively higher chances of survival.

In brief, the experiments considered by Miller seemed to be showing that accuracy of judgment per variable decreases as more attributes are introduced. Miller was at pains to point out that the experiments did not demonstrate that people can judge only one attribute at a time. What they indicated was that people are less accurate per attribute if they have to judge more than one attribute simultaneously. Finding the limit of this relationship is a significant research question to this day.

The Unidimensional Enigma

While Miller spelt out these results about multi-dimensionality, he was less clear on what the initial unidimensional experiments actually showed. He provided three interpretations, which in the context of the paper as a whole, are as follows:

(1) A human being can process, or classify, about seven different unidimensional sensory inputs without risking their confusion. This implies that if more than about seven inputs are presented, the human being begins to confuse them and thus classify them erroneously.
(2) Irrespective of the number of unidimensional sensory inputs, a human being can accurately assign them to about seven classes.
(3) 'If we know that there were N alternative stimuli, then his judgment enables us to narrow down the particular stimulus to one out of $N/6$ (*sic*)'.

Of these, the third is the most cryptic, but consider them in order.

The first interpretation says that, in the context of accurately classifying inputs, there is a maximum number that may be simultaneously given, beyond which the human being begins to get confused. This interpretation clearly sets a limit on the number of inputs given, if the objective is to obtain an accurate classificatory response. What is missing from this interpretation is whether, and how, the number of available classifications influences the manageable number of simultaneous unidimensional inputs.

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The second interpretation says that, no matter the number of unidimensional inputs simultaneously presented, the human being can accurately assign them to about seven classes. Quantity of given input, in other words, in no way influences accuracy of classification. Where the number seven was first attributed to the quantity of the given input, it is now attributed to the quantity of available classes. As a result, where, before, classificatory accuracy was a function of the quantity of inputs, now it is a function of the number of classes. Furthermore, classificatory accuracy seems to depend on the given inputs being classifiable into one of only these seven classes.

There seems to be a contradiction here. In the first case, classificatory accuracy depends on the number of inputs simultaneously given. In the second case, this number is irrelevant, with classificatory accuracy depending on the existence of seven classes. Does classificatory accuracy depend on a limited number of simultaneous inputs, or does it depend on having seven classes at hand? Is the magical number attributable to inputs or to classes? Miller does not offer a clear answer regarding classificatory accuracy, although he offers a tentative conclusion regarding immediate memory (which is discussed below).

The third interpretation has been given in Miller's own words. As can be seen, the number 6 features prominently instead of the usual 7. This probably reflects the result of the first experiment discussed by Miller, the one that yielded an average of 6.5 manageable categories—although Miller is not clear whether such an inference is to be made. In the context of the entire paper, this number should probably be 7. In the interest of maintaining a degree of coherence, therefore, the number 7 will be used in the ensuing discussion.

The third interpretation, then, begins by referring to the '*N* alternative stimuli'. Given that, at this point in the paper, multidimensional stimuli have yet to be addressed, the '*N*' can only refer to the number of inputs presented at any one iteration of the experiment (as opposed to '*N*' possibly referring to the number of attributes characteristic of the inputs, as in multidimensional experiments). This third interpretation also refers to the human being's 'judgment'. Up to this point in Miller's paper, the only thing discussed that comes anywhere near being understood as a 'judgment' is the classificatory attempt of the mind. Finally, we are referred to '$N/7$' ('$N/6$' in the citation). The only thing to which this can conceivably refer is the number of classes—since Miller has already mentioned the 'stimuli'. So we can paraphrase as follows: if we know that there were N inputs, then a human being's classification enables us to narrow down the particular input to one out of $N/7$ classes. Let us maintain the paraphrase and try this out with a few numbers:

- If we know that there was one input, then a human being's classification enables us to narrow down the particular input to one out of 1/7 classes.
- If we know that there were seven inputs, then a human being's classification enables us to narrow down the particular input to one out of one class.
- If we know that there were 21 inputs, then a human being's classification enables us to narrow down the particular input to one out of three classes.
- If we know that there were 42 inputs, then a human being's classification enables us to narrow down the particular input to one out of seven classes.
- If we know that there were 70 inputs, then a human being's classification enables us to narrow down the particular input to one out of 10 classes.

It is obvious that, no matter what numbers are used, the phrase is ambiguous. At most we can infer the following: the third interpretation is saying that, as we increase the number of inputs, the number of classes increases. This, however, contradicts the second interpretation that set a limit on the manageable number of classes. And by allowing an undetermined N increase in the number of inputs, the third interpretation contradicts the first.

As a result we are faced with some questions. Does classificatory accuracy depend on the number of inputs (interpretation 1)? Does classificatory accuracy depend on a given number of

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classes, probably with all inputs classifiable only within these classes (interpretation 2)? Or does classificatory accuracy evolve as the number of inputs changes (interpretation 3)? The third question would only make sense in the context of the multidimensional experiments, but even then the $N/7$ function yields a linear, not an asymptotic, relationship. Only the first interpretation comes anywhere near the spirit and content of Miller's argument. As a result, we can conclude only the following: in unidimensional situations, and unrestricted by time, the human being can accurately process only about seven different and simultaneous sensory inputs—a conclusion noted earlier as being far too delimiting to inform the multidimensional simultaneity of complex decision making evident in human experience.

Chunks of Sevens

Overall then, Miller's thesis is as follows. First, the human being can accurately process only about seven unidimensional inputs. This, as noted, is a trivial result in the face of human experience. Second, as the number of simultaneous attributes per input is increased, the human being's classification of these inputs becomes less accurate.

The second point confirms what we know from experience: as the number of attributes we have to deal with increases, our capacity for accurately dealing with them decreases. Perhaps because of this relevance to experience, Miller wondered how human beings can (and do) increase the number of unidimensional inputs they can accurately classify at any one time. He noted that there are three techniques available that allow us to get around the 7 ± 2 limit. The first technique concerns making relative judgments instead of absolute judgments. In this case, for instance, instead of attempting to classify an input accurately on a scale, one merely compares it to any one of the other inputs in order to conclude whether the input in question is greater, smaller, brighter etc. Miller did not elaborate on how exactly this technique expands the range of the mind's capacity. The second technique concerns increasing the number of dimensions along which inputs can differ. This refers to the multidimensional experiments already discussed. The third technique concerns arranging the classification task so that the subject can make a sequence of several absolute judgments in a row. Miller discussed this alternative.

He noted that this is analogical to mnemonic processes. Music theory, for example, teaches us to remember *every good boy deserves food* for the notes that fall on each of the five lines of the treble staff. In this case, instead of having to remember five letters/notes, we remember one phrase, and thus reduce the amount of input we have to deal with at any one time. Whether this mnemonic is actually useful to music students is not relevant for the present purposes. Here we are merely concerned with the amount of information we have to process at any one time, and there is clearly a reduction in the quantity of this information—a reduction from five letters/notes to one simple and easily remembered phrase. The role of the mnemonic is as an *aide-memoire*.

Miller then made a connection. On the one hand, the case of the span of absolute judgment revealed an ability to distinguish about seven categories. On the other hand, Miller wrote, 'everybody knows' (!) that the finite span of immediate memory is about seven variables. *Ergo*, there is nothing more natural than to conclude that both spans are merely different aspects of a single underlying process. The difference is one of dimensionality. For, in the music example, we have reduced the number of inputs from five individual bits to one chunk, or one grouping of items. In other words, the experiments were showing that the span of immediate memory depends upon the number of chunks or groupings we make of raw data, not on the quantity of this data itself. If the span of immediate memory is seven variables (as 'everybody knows'), these variables can be groupings, each of which can contain any number of individual bits of input of the same type. Miller called the process of grouping *recoding*. He argued that by recoding inputs, in other words by grouping them, we can increase the amount of inputs we can deal with at any one time. He did not explicitly infer from the available experimental data, however, whether the grouping span of immediate memory is around seven. He only said that 'everybody knows' this.

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In brief, absolute judgment is limited to seven individual inputs, and immediate memory is limited to seven groupings. In the case of the latter, each group is constituted by an unstipulated number of inputs of the same type. We do not know, in other words, what limit of individual bits in each group can actually be recalled. At best we can say that Miller's thesis indicates that we can deal with seven units of data at any one time, be they seven individual pieces of data (for the case of absolute judgments) or seven groups of data (for the case of immediate memory). Miller was cautious, and concluded that whether this number is actually seven or not is still an open question.

TENTATIVE CONCLUSIONS

Indeed, caution is required in drawing conclusions about the mind's classificatory and computational abilities, or even about decision making, from Miller's influential paper. The reasons are as follows:

- Only the mind's classificatory abilities are addressed, and these within a highly delimited range of classification types, resulting in a restricted view of the mind's processing capabilities.
- The thesis mainly concerns the classification of unidimensional phenomena. Those multidimensional phenomena that are considered are characterized by up to only six attributes.
- All phenomena considered are simple, sensory phenomena, a significant delimitation in that it reduces the relevance of the thesis to stimulus–response mechanisms.
- The thesis is based on controlled laboratory work. In order to draw any conclusions regarding the mind's capabilities in the flux of the reality of the world, that is, in the flux of real-world decision making, experiments richer in detail are required.

Perhaps a more significant reason to be cautious lies in the mathematics upon which Miller relied for his thesis. The statistical relation that Miller used, regarding the amount of information required to make a decision, is based on the information theory developed by Shannon (1948)—a theory to which Miller was no stranger (Frick and Miller, 1951; Miller, 1953), and one which he himself introduced to psychology a year after Shannon's paper (Miller and Frick, 1949). Sperling (1988) notes that it was, for Miller, the only systematic framework available for dealing with information. He adds that, although it is relevant for absolute judgments, it is not so useful in the case of immediate recall—Baddeley (1994) offers an empirically-based view to the contrary. Besides this, however, Miller noted that the statistical computations are useful only for judgments between two equally likely alternatives. What about the case of two or more unequally likely alternatives? Or, more generally, what about the case of existential experience wherein human beings are not often faced with neat 50–50 alternatives? Shannon does discuss the mathematical case of multiple, unequally likely alternatives. But his mathematical edifice cannot account for the all-too-human evidence that we sometimes choose the least probable alternative, or even the one that promises the least success. In a word, Shannon's thesis cannot account for the motivation behind human choices.

Boulding (1956: pp. 153–155), writing in the same year as Miller, takes this issue one step further in his *The Image*. On the one hand, he hails 'the development of a mathematical concept of information' as being of equal importance to 'the development of mass and energy in physics', for 'it has opened up the possibility of a new and more quantitative approach to the whole problem of organization.' He continues, however, by asking whether the information concept of Shannon is anything more than a mere statistic, no more insightful than, say, a standard deviation—'a convenient statistic for use in certain problems in solving the communication of messages over limited channels'. Boulding questions whether the theory can get beyond the pings of a message and explain its more impalpable dimensions such as its semantic qualities. Since such qualities bear significantly upon a unit of information, is it ever possible to abstract and mathematize what is essential to a message?

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It is worth noting that Boulding chose to question the scope of relevance of the mathematics of information theory whilst writing an epistemological thesis. For him, information, communication, judgments, memory and any approach to understanding the mind or consciousness, must take into account the epistemological angle, that is, the manner in which we learn, know and understand. There is something simplistic about experiments such as those described by Miller, and about information theory as a whole, that Boulding (1956: p. 28) wants to warn against, and it comes early on in his thesis:

> [The mind is not] simply a sausage machine grinding out [responses] from the messages received. It is much more realistic to suppose that between the incoming and outgoing messages lies the great intervening variable of [subjective knowledge]. The outgoing messages are the result of [subjective knowledge], not the result of the incoming messages. The incoming messages only modify the outgoing messages as they succeed in modifying [subjective knowledge].[1]

For Boulding, in other words, two issues crucial to the communication of information—semantics and subjectivity—are ignored by information theory as well as by Miller's thesis. Whether semantics and subjectivity actually enhance the mind's computational and classificatory ability is not addressed. It is quite obvious, however, that Miller's thesis is incomplete, and he confesses as much at the end of his paper.

Notwithstanding this, as well as the earlier caveats, what general conclusion can one draw from Miller's paper as it stands? This is relevant not merely as an intellectual exercise. As a standalone paper, there must be some conclusion forthcoming, and yet Miller only offers a somewhat hasty summary instead. In the late 1980s, Sperling (1988) noted that, for 20 years, the paper was 'the single most often cited paper in cognitive psychology'. By the mid-1990s, it was 'clearly the most widely cited article in the history of the *Psychological Review*' (Kintsch and Cacioppo, 1994). Even if, as we saw earlier, ambiguity and contradiction lie at its heart, surely there must be something worth salvaging.

One general conclusion lends itself in terms of decision making. There are two reasons for this. First, not only each experiment to which he refers, but also the entire paper, concerned as it is with the number of variables the mind can deal with, is one about making decisions, be they classificatory or purely computational. Second, Miller's paper appeared at a time when the limiting capacity of the mind was very much an issue with decision theorists (Dale, 1953; Dahl and Lindblom, 1953; Simon, 1955, 1956, 1957; Cyert *et al*., 1956; Lindblom, 1958, 1959; Brown, 2004; Klaes and Sent, 2005). In terms of decision making, then, a conclusion to draw from Miller's paper is this: when faced with making a decision, we can only reasonable rely on limited information, not because the information might not be there but because, even if it is there, we can only deal with a small subset of it.

This conclusion may offer nothing that we do not already intuitively know, or at least feel. But it is an unforgiving verdict, for it implies that, faced with a decision-making situation where all pertinent information is given, the decision maker is condemned to make a decision *as if* not all the information was given. Over the years, responses to this verdict have ranged from combative to ones of acceptance, though never ones of resignation. In the 1960s, for instance, the field of information systems was in combative spirit and sought to provide omniscience to decision makers through the design of ever more sophisticated decision support systems (Diebold, 1953; Leavitt and Whisler, 1958; Burlingame, 1961; Evans and Hague, 1962; Chambers, 1964; Dean, 1968; Jones, 1970; Applegate *et al*., 1988). Indeed, management science offered up a distinctive decision support system in the shape of the computer-based system dynamics approach (Forrester, 1958, 1961) which allowed decision makers to learn about counterintuitive consequences stemming from decisions.

[1]Readers of Boulding's *The Image* will know that the citation has substituted 'subjective knowledge' for 'the image'. This stems from Boulding's own definition of 'the image' (1956) when he writes: what I have been talking about is knowledge. Knowledge, perhaps, is not a good word for this. Perhaps one would rather say my Image of the world. Knowledge has an implication of validity, of truth. What I am talking about is what I believe to be true: my subjective knowledge. It is this Image that largely governs my behavior.

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Soon, however, a more sober appreciation of the features and faults of information systems had set in (Anshen, 1960; Brabb and Hutchins, 1963; Dearden, 1964, 1965, 1966, 1967; Taylor and Dean, 1966; Rhind, 1968), leading some to reduce the 'systems men' to technical prowess with an artefact—the computer—that was increasingly perceived as a 'poisoned chalice or a golden shackle' (Haigh, 2001). The 1970s saw a backlash against the inability of, what was essentially, an algorithmic approach to deal with the perceived increasing complexity of real-world issues that impacted decision makers (Dearden, 1972; Halbrecht *et al*., 1972; Woolsey, 1972; Argyris, 1973a, b; Lee, 1973; Rittel and Webber, 1973; Simon, 1973; Friedmann and Hudson, 1974; Nelson, 1974). This instigated a period of self-reflection (Henry, 1975; Ackoff, 1977, 1979; Dando and Bennett, 1981; Rosenhead and Thunhurst, 1982) infused with an unprecedented interdisciplinary search for decision-making approaches that could support, as opposed to somehow cure, the inability of the decision-making mind to maximize. From this period emerged a softer operational research (Rosenhead, 1989), complete with a set of 'problem structuring methods' inspired by theories such as incrementalism (Braybrooke and Lindblom, 1963) and mixed-scanning (Etzioni, 1967, 1968), and a softer, if not more critical, systems thinking (Flood and Jackson, 1991a, b). By the middle of the first decade of the 21st Century, this general choice to adhere to and work with, as opposed to cure, what Simon had called 'bounded rationality' led to calls for training in 'making decisions in the absence of clear facts' (Bennis and O'Toole, 2005; Georgiou, 2006, 2008)—*absence*, as opposed to procurement, being the key term. Simon (1997: p. 226) may have suggested training in 'selectively extracting from [information] just the parts we want,' but Ackoff (1967) had already noted that there is no definite answer to the question of what information a decision maker might want. Absence and indefiniteness are pervasive in real-world decision making; and Miller, in drawing from limited experiments where the complexities of the real-world are significantly controlled, offered up a verdict that rings true to this day.

There is another conclusion that may be drawn, simpler and perhaps obliging. The contemporary 'information age' popularly believes that the information explosion has instigated a period of unprecedented progress. If 'information' is taken as an epistemological variable, progress taken as referring to the advancement of 'knowledge' and knowledge taken as a synonym of 'science', then the popularized belief is misguided. With the advent of the Internet, an argument could be put that information has indeed exploded. It has, however, exploded onto a dynamic platform that can seemingly accommodate increasing quantities. As such, the explosion has yet to reach a steady state, and is unpredictable in its development. These two factors contribute to its structural disorder. In other words, the information age is in a period of high information entropy. And where there is entropy, there is no progress but decay. As Simon (1997: pp. 226–227) noted: 'Science does not advance by piling up information—it organizes information and compresses it.' No matter how empirically inconclusive, Miller's paper was about the organization of information and the search for the compressing limits required of this information for mental assimilation. As such, the persecuting integer to which Miller referred in opening the paper was, if nothing else, the whisper of science.

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