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Error detecting and error correcting codes

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The theory of the representation of information in binary form such that at the receiving end any number of errors up to a given level can be detected and/or corrected without further information is presented. The paper gives explicit solutions for the cases of single error detection, single error correction, and single error correction plus double error detection. It also indicates the nature of the general case, and supplies a few relevant observations on the problem. [The *SCI*® indicates that this paper has been cited in over 135 publications since 1961.]

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"During World War II, I was involved in the computation of atomic bomb design simulations. The experience convinced me that there were situations for which there was no alternative to extensive numerical computations. When I went to Bell Laboratories in 1946 I continued to use both analog and digital computers and this experience reinforced the belief in the necessity for doing large-scale computations.

"Bell Laboratories had built a number of relay computers based on the ideas of George Stibitz, and for a time Model 5 was available for use. It has error detection built into it, in exactly the same way that the then current central offices had error detection. I became very interested in error detection as a means for getting the right answers, and more importantly as a means for maintenance of machines.

"The coming electronic computers were obviously going to do many more operations per second. Since the stored program concept was bound to develop it became doubly apparent that the level of reliability that electronic computers would require greatly exceeded anything that had ever been built—a single error would vitiate an entire computation rather than, as in the central office, merely make a local error. It was further evident from work on guided missiles that 'jamming' would also bring about the problem of signaling through a high level of noise.

"I was therefore led to study carefully the general theory of error detection using parity checks, especially their strengths and weaknesses as revealed by past experience and by mathematical models.

"The next obvious step, error correction, was not that large (by hindsight). That it could be done was obvious from the idea of triplication of computers and the additional cross-comparison circuits that took a majority vote. But since error detection via parity checks was so superior to duplication of computers, it was natural to search for better error correction methods. The actual work was accomplished in about three months, but for patent reasons was held up for over two years. During this time, management leaned on me to write it up carefully and clearly.

"The paper has been highly cited because (1) it laid out the fundamentals of an important field, (2) it was written clearly and at an elementary level, (3) while it cleared up the simplest cases it left room for further research, and (4) in a real sense there is no complete solution to the basic problem of the design of suitable high order error correcting codes, hence there developed an extensive literature on the topic and the paper was cited frequently. It is also true that the technology has come along that makes extensive use of error correction in many ways, from the design of computers to signaling from the distant planets. I had seen accurately the main needs for error correction and the simple fact that it is often easier to build a bit more circuitry than it is to try to do it perfectly in the first place—a concept that was not popular in the days when the codes were developed.

"I have received many honors in the course of a long career, and most of them cite the error correcting codes as part of the reason for the awards. A more recent reference is *The Theory of Error Correcting Codes*."[1]

1. **MacWilliams F J & Sloane N J A.** *The theory of error correcting codes.* Amsterdam: North-Holland, 1977. 2 vols.