



Electrical & Computer  
**ENGINEERING**

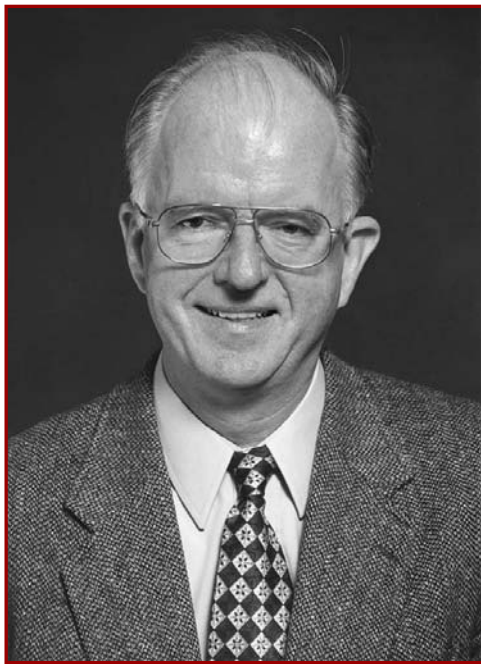
**SEMINAR**  
DISTINGUISHED LECTURER SERIES

**THURSDAY**  
**SEPTEMBER 30, 2004**

Scaife Hall Auditorium  
Room 125

**4:00 PM**  
Refreshments—3:30 PM

# DESIGNING AND TESTING QUANTUM CIRCUITS



## John P. Hayes

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John P. Hayes is the Claude E. Shannon Professor of Engineering Science at the University of Michigan, where he teaches and conducts research in the areas of CAD, embedded systems and quantum computing. He received the B.E. degree from the National University of Ireland, and the M.S. and Ph.D. degrees from the University of Illinois. At Illinois he participated in the design of the ILLIAC III computer. He spent ten years with the University of Southern California before moving to the University of Michigan in 1982.

Hayes was the founding director of Michigan's Advanced Computer Architecture Laboratory (ACAL). He is the author of numerous technical papers, several patents and five books, including *Computer Architecture and Organization*, (3rd ed., McGraw-Hill, 1998). Hayes is a Fellow of IEEE and ACM. He received the University of Michigan's Distinguished Faculty Achievement Award in 1999 and the Humboldt Foundation's Research Award in 2004.

Quantum computation is a fairly recent approach to information processing, which is based on quantum mechanics rather than classical physics. Information is represented by quantum bits (qubits) that correspond to quantum states such as photon polarization. Because of the superposition property of quantum states,  $n$  qubits can store up to  $2^n$  binary words simultaneously, implying a type of massive parallelism. Qubits also allow powerful forms of interaction such as interference and entanglement, which have no counterparts in classical computer science.

Quantum computers can solve some important and hitherto intractable problems, such as prime factorization of large numbers. Novel forms of highly secure communication are also possible. In practice, however, quantum computing devices and circuits are extremely difficult to design and build, since they are nanoscale in size and operate at very low energy levels. Consequently, they have many more failure modes than classical (non-quantum) circuits. For example, quantum signal states are inherently unstable and tend to decay rapidly due to interaction with the environment (decoherence). Quantum gate operations are defined by continuous parameters that allow small errors to arise and propagate to other gates. Furthermore, state measurement is probabilistic and the measurement process itself affects the state being measured; destructive testing is therefore the norm.

This talk will review the history and development of quantum circuits, with emphasis on their testing and fault-tolerance requirements. It will be seen that quantum circuits are highly testable for classical faults. However, they are also subject to various complex, non-classical failure modes, which are not well understood. Some methods for error correction and recovery that have been developed specifically for quantum circuits will be reviewed.

*For more information:*

<http://www.ece.cmu.edu/seminar>

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