# NANO, QUANTUM AND MOLECULAR COMPUTING: IMPLICATIONS TO HIGH LEVEL DESIGN AND VALIDATION

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Chapter 4

# OBTAINING QUADRILLION-TRANSISTOR LOGIC SYSTEMS DESPITE IMPERFECT MANUFACTURE, HARDWARE FAILURE, AND INCOMPLETE SYSTEM SPECIFICATION


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**Abstract** New approaches to manufacturing low-level logic—switches, wires, gates—are under development that are stark departures from current techniques, and may drastically advance logic system manufacture. At some point in the future, possibly within 20 years, logic designers may have access to a billion times more switches than they do now. It is sometimes useful to allow larger milestones such as this to determine some of the directions of contemporary research. What questions must be answered so that we sooner and more gracefully reach this milestone at which logic systems contain a billion times more components? Some problems include how to design, implement, maintain, and control such large systems so that the increase in complexity yields a similar increase in performance. When logic systems contain $10^{17}$ switches or components, it will be prohibitively difficult or expensive to manufacture them perfectly. Also, the handling and correction of operating errors will consume a lot of system resources. We believe these tendencies can be minimized by the introduction of a low-cost redundancy so that, in essence, if one switch or transistor fails, the one next to it can take over for it. This reduces effective hardware size by a factor in exchange for a way both to use imperfect manufacturing techniques, and, through similar means, maintain the system during its life cycle. It may also be possible to use similar basic principles for a more complex problem, designing a system that can catch and compensate for operating errors, but with low enough cost in time and resources to allow incorporation into all large systems. We suggest that such a system will be a distributed, parallel system or mode of operation in which systems failure detection is a hierarchical set of increasingly simple, local tasks run while the system is running. Work toward answering these questions appears to also yield some useful ways to approach a more general question, of constructing systems when their structure and function cannot be completely predetermined.

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## 4.1 Four Areas for New Research

Hardware and logic designs have come a long way. The transistors used in a modern single-chip CPU are several hundred million times smaller than the original transistor built in 1947. If a contemporary CPU were built with the original transistor technology, it would take up a space of roughly one square kilometer. Current ways to produce logic designs pack many more transistors into hardware than their predecessors ten years ago, and ten to twenty years from now there may be ways to produce hardware devices with a billion times more transistors or switches. Note that such an increase in fabrication density does not lie on most current technology road maps, such as ITRS. This prediction is instead based on the expectation that researchers will uncover fundamentally different technologies that cause a sudden jump in device density. At the end of the curve following Moore's Law, we may find that process technology begins a completely new curve.

There has been and continues to be strong economic incentive for miniaturization of logic designs and electronics. Although for some products this has been used to simply reduce the footprint, designers have also been freed to create larger and more complex designs as transistor density has increased.

How complex will designs be with a billion times more capacity available? And what of the fact that some of the work to uncover replacements for the field effect transistor is being done in scientific disciplines in which three dimensional structures are not at all unusual– ten to twenty years from now there could be ways to produce three dimensional hardware for logic designs.

Technical breakthroughs over the next ten to twenty years could come gradually, but may instead exhibit sudden leaps in progress as problems are solved, discoveries are made. The path will depend on many variables: the nature and timing of future breakthroughs, whether they combine to form a complete production method, and how rapidly these new ideas are put into practice. In addition to having much larger switch counts and much smaller package sizes