The Center for Bits and Atoms
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# Avogadro-Scale Engineering

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Current fabrication technologies, from chip fabs to organic synthesis, are many orders of magnitude removed from the fundamental limits governing the rate and accuracy at which molecules may be ordered, severely bounding the complexity of accessible technology. In addition, current design methodologies give very few guiding principles for optimal designs at the highest complexity levels or on how one might arrive at such optimal designs in tractable times. We believe that this is so, not because current technologies and design principles have not gotten there yet, but because they are based on approaches that do not get there.

Only a few generations of technologists have been fortunate enough to be present at the dawn of a new technological age, be it the Iron Age, the Industrial Age or the Information Age. The first annual conference on Avogadro-Scale Engineering is aimed at exploring and establishing a new technical frontier: the engineering of systems at the limits of complexity, complexity per unit cost, complexity per unit volume and complexity per unit time-energy allowed by physical law. In order to establish a benchmark, Avogadro-Scale Engineering has the goal of designing and building systems which exceed the complexity metrics for current fabrication and molecular synthetic technologies by several orders of magnitude.

The Avogadro Scale Engineering program envisions several general categories of inquiry:

- The first, called **Form**, is aimed at developing technologies which are suitable for fabrication at several orders of magnitude higher yield per unit cost than what is currently or anticipated to be possible. Of particular interest are technologies for using logic to fabricate structures capable of executing logic (e.g., fabrication technologies which could yield > $10^{15}$ transistor-equivalent devices at a cost of less than $10^{-8}$ cents per device) and technologies for fabricating chemistry (e.g., chemical processes with repetitive yields greater than $10^{4}$).

- The second, called **Function**, is aimed at delineating the optimal architectures or generalized automated approaches for finding optimal architectures in tractable times for a given fabricated complexity (e.g., What is the optimal architecture parameterized in generalized flops for a fabrication process which can yield $10^{15}$ devices?). Key to this area is the idea of automated architecture discovery requiring specification solely of initial and final states (prescriptive architecture) rather than the currently-standard descriptive architecture in which each element of a design must be specified.

- Of particular interest is the elucidation of general principles governing Avogadro-Scale Engineering. Resources including quantum phase space, error-correcting fabrication, fault-tolerant hardware, fault-tolerant software, and nonlinear functional approximation can offer an exponential increase in complexity for a linear increase in physical degrees of freedom. The ASE program seeks to elucidate the full list of such exponential complexity-enabling resources and establish theorems and design rules which govern the allocation of these resources optimized against a particular parameter (e.g., device performance or fabricational energy-time). This third category of inquiry which includes questions of fundamental limits and uncertainty relations we have termed **Foundations**.

- The final area, **Formats**, is aimed at creating appropriate description languages (e.g., an Atomic Mark-Up Language), and design tools which can describe both logical and physical forms in a statistical-mechanical limit and which can directly drive fabrication machinery.

At this meeting the state of the art in each of these areas will be presented, with time for both demonstrations and discussion. Then, working groups for each will be charged with summarizing the key enabling insights, outstanding open questions, and resources required to tackle them (intellectual, physical, organizational, and financial).

It is far too early to tell if or how successful Avogadro-Scale Engineering will be. If it succeeds, we should be able to point to general principles which emerged from the program which were responsible for pushing technology significantly off of its current course, and that were able to bring technology provably close to the limits of physical law (e.g. complexity per unit energy-time). At that point we might be justified in calling this The Age of Complexity. We begin today.

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