1.1 The Goal of Modeling

At the outset it seems necessary to clarify the frequently used terms analysis, simulation and modeling. By tracing the literature one often has the impression that authors use these terms in a fairly arbitrary manner. A while ago I picked up a heavy dictionary and, among many others, I have found the following interpretations to be quite appropriate:

Analysis
- separation of a whole into its component parts, possibly with comment and judgement
- examination of a complex, its elements, and their relations in order to learn about

Simulation
- imitative representation of the functioning of one system or process by means of the functioning of another
- examination of a problem not subject to experimentation

Modeling
- to produce a representation or simulation of a problem or process
- to make a description or analogy used to help visualize something that cannot be directly observed

Therefore, as difficult as it might be to decide in an individual case, analysis is at least intended to mean “exact analysis” and simulation must mean “approximate simulation” by inference. Modeling is obviously a necessity for analysis and simulation.

With a model one can analyse some phenomena, provided that the effects one wants to extract are built in the model, possibly in a very complex manner. A model for the purpose of pure simulation (like a curve fitting model) is usually much more simple than a model for analysis. Many effects can be treated in a very heuristic manner for the purpose of simulation, just reflecting the underlying physics in a qualitative way.

An excellent example to highlight these aspects can be found in the application of a Monte Carlo method. “Modeling” with a Monte Carlo method is equivalent to “producing an imitative representation of the functioning of a system”. But the
The purpose of a Monte Carlo model is strictly analysis and not just simulation, because the underlying basis is "a separation of a whole into its component parts". However, one has to keep foremost in mind the limitations of any model in order not to interpret too naively results which are just obtained by improper application of a model.

I feel obliged to explicitly state my personal opinion about the quality of the results which can be obtained by contemporary device modeling. The development of devices involves several iterations of trial and error in fabrication until a specified goal in terms of design conditions is reached. The application of device models can now, and sometimes fairly substantially, decrease the number of trial and error steps during the development. A serious speculation about the average savings in development effort could be on the order of forty percent. Obviously, this number depends strongly on the individual conditions of a specific project. The total elimination of trial and error in device development is not possible nowadays, because the uncertainties of several parameters of the available models, although they are already very sophisticated, are still too large. I absolutely expect not being wrong in claiming that device modeling will become more and more important in the near future. This assumption is also supported by the fact that computer resources are going to be cheaper compared to drastically increasing costs for experimental investigations. Hence, many more engineers will have to face the problem of numerical device modeling in order to stay competitive.

It remains to say that the main power of higher dimensional device model lies in their capability to provide insight into the functioning of devices by means of distributions of the various physical quantities in the interior of a device. However, many device engineers are not at all used to interpreting those results; they prefer global quantities like current-voltage characteristics. A properly tuned higher dimensional device model is certainly able to predict global device parameters with a desired accuracy, but much simpler and cheaper (in terms of computer resources) models will often be able to deliver global results with equally good reliability. For miniaturized devices, however, higher dimensional models are often the only existing and imaginable tool for the accurate prediction of device performance.

### 1.2 The History of Numerical Device Modeling

Fully numerical modeling of a semiconductor device based on partial differential equations [1.87] which describe all different regions of a device in one unified manner was first suggested by Gummel [1.29] in 1964 for the one dimensional bipolar transistor. This approach was further developed and applied to pn-junction theory by DeMari [1.18], [1.19] and to IMPATT diodes by Scharfetter and Gummel [1.75]. A two dimensional solution of Poisson's equation with application to a MOS structure was first published by Loeb et al. [1.49] and Schroeder and Muller [1.76] in 1968. Kennedy and O'Brien [1.39] investigated in 1969 the junction field effect transistor by means of a two dimensional numerical solution of Poisson's equation and one continuity equation. At the same time Slotboom [1.82] presented a two dimensional analysis of the bipolar transistor solving Poisson's equation and both continuity equations. Since then two dimensional modeling has