The Role of Analytical Models in the Engineering and Science of Computer Systems

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ABSTRACT

2021 is the 50th anniversary of SIGMETRICS, the ACM Special Interest Group on Performance Evaluation. For this occasion, I wrote a review[1] of the role played by analytical modeling — a major topic in SIGMETRICS — in the engineering and science of computer systems. This talk is a summary of that review.

(1) Why an Analytical Model?
A common motivation in constructing an analytical model is to engineer a computer system: to predict the throughput for a workload, to determine how failures affect response time, to evaluate the performance implication for different design choices, etc.

(2) Assumptions
The derivations in an analytical model are often based on strong assumptions, and this is often considered a weakness of the approach. Nonetheless, the conclusions from these models are often robust with respect to violation of the assumptions.

(3) Average Value Approximations (AVA)
The derivations may also make approximations that are hard to justify theoretically. For example, average values are often used in place of random variables (I call this *Average Value Approximation*, or AVA). However, the final arbiter for whether the assumptions and approximations are acceptable lies not in theory, but in the experimental validation of the model.

(4) Bottleneck Analysis
One broadly applicable technique in modeling is bottleneck analysis. It is powerful in that it requires very little information about the details in a system, but it is also weak in that it offers only performance bounds. Even so, these may suffice for some purposes, like comparing scalability limits, say.

(5) Parameter Space
A crucial advantage that analytical models have over simulation models lies in the global view of the parameter space in the analysis. One can often use the equations to identify important (and unimportant) regions of the space, reduce the number of parameters, etc.

(6) Decomposition and Decoupling
A computer system can have many components that interact in complicated ways, but this complex interaction can be decomposed into separate smaller models. Such a decomposition then provides a way to study the separate impact of hardware and software on a workload, the interaction between resource and data contention, etc.

(7) Analytic Validation
Since an analytical model is an approximation of the real system, we must verify not just the accuracy of its numerical predictions, but also check that crucial properties revealed by the model (are not just artefacts of the model, but) are in fact properties of the real system. This is the concept of *analytic validation.*

(8) Analysis with an Analytical Model
Besides the engineering motivation for an analytical model, there is also a role that such models can play in developing a *science* for the behavior of these engineered systems.

The talk presents some examples from recent literature on hardware, networking and datacenters, etc. to illustrate the use of analytical models in designing, controlling and studying systems, large and small. More examples can be found in the textbook[2] that I use for teaching analytical modeling. The range of examples is wide, as wide as the broad perspective that we want our students to have.

CCS CONCEPTS

• **General and reference → Performance**; • **Information systems → Database performance evaluation**; • **Networks → Network performance modeling**; • **Software and its engineering → Software performance**; • **Computing methodologies** → *Modeling and simulation.*

KEYWORDS

performance; analytical model; approximations; assumptions; analysis; validation

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[1] https://arxiv.org/abs/2005.13144

[2] Y.C. Tay. *Analytical Performance Modeling for Computer Systems.* Morgan & Claypool Publishers, Third Edition (2018).

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