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# A BRIEF HISTORY OF SIMULATION

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## ABSTRACT

We survey the history of simulation up to 1981, with special emphasis on some of the critical advances in the field and some of the individuals who played leading roles in those advances.

## 1 INTRODUCTION

A history of simulation can be written from many perspectives—for example, uses of simulation (analysis, training, research); types of simulation models (discrete-event, continuous, combined discrete-continuous); simulation programming languages or environments (GPSS, SIMSCRIPT, SIMULA, SLAM, Arena, AutoMod, Simio); and application domains or communities of interest (communications, manufacturing, military, transportation). Examples of the various perspectives and combinations can be readily found in the published histories; see Nance (1996), Nance and Sargent (2002), and Hollocks (2006). We offer this brief treatment from a very informal perspective; the objective is to highlight people, places, and events that have marked the development of discrete-event and Monte Carlo simulation. Within this informal perspective, and sometimes anecdotal description, lies a secondary objective: to motivate others to document their historical contributions or knowledge so that a comprehensive history can be captured for posterity in places like the Simulation Archive at North Carolina State University `<www.lib.ncsu.edu/specialcollections/manuscripts/simulation>`.

## 2 THE PRECOMPUTER ERA: FROM BUFFON TO WORLD WAR II (1777–1945)

The Monte Carlo method is generally considered to have originated with the Buffon "needle experiment" in 1777. The experiment is to "throw" needles onto a plane with equally spaced parallel lines in order to estimate the value of $\pi$. The reader interested in the details may consult `<web.mit.edu/urban_or_book/www/book/chapter3/3.3.1.html>`. Since Buffon's published solution contained an error that was corrected by Laplace in 1812, the terminology Buffon-Laplace needle problem is also used; see `<mathworld.wolfram.com/Buffon-LaplaceNeedleProblem.html>`.

About a century after Laplace's contribution is the perhaps surprising role played by simulation in one of the most important applied statistics developments. William Sealy Gosset, trained in mathematics and chemistry, became a brewer with Arthur Guiness, Son & Co. Ltd., in 1899 at the age of 23. Guiness allowed Gosset to publish certain major statistical results, provided he used a pseudonym and no proprietary data was used. These results were published under the pseudonym "Student" beginning in 1908 with a paper formulating what is now known as Student's $t$-distribution. Because Gosset had incomplete analytical results, he used a crude form of manual simulation to verify his conjecture about the exact form of the probability density function for Student's $t$-distribution. This inaugural application of simulation to the field of industrial process control is a remarkable example of the synergy of simulation-based experimentation and analytic techniques in the discovery of the exact solution of what is arguably a classical industrial-engineering problem.

## 3 THE FORMATIVE PERIOD (1945–1970)

In the mid-1940s two major developments set the stage for the rapid growth of the field of simulation:

- The construction of the first general-purpose electronic computers such as the ENIAC (Burks and Burks 1981); and

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- The work of Stanislaw Ulam, John von Neumann, and others to use the Monte Carlo method on electronic computers in order to solve certain problems in neutron diffusion that arose in the design of the hydrogen bomb and that were (and still are) analytically intractable (Cooper 1988).

Ulam's fondness for card games and his attempts to find a easier way to estimate the probabilities of certain events in those card games apparently led him to the idea that a "Monte Carlo" approach to the problems of mathematical physics might be effective. The increasing availability of general-purpose electronic computers in the 1950s set the stage for the rapid proliferation of simulation techniques and applications in other disciplines.

Keith Douglas Tocher, a professor of operational research at the University of Southampton, developed the General Simulation Program (GSP), the first general-purpose simulator, as a tool for systematically building a simulation of an industrial plant that comprises a set of machines, each cycling through states such as busy, idle, unavailable, and failed. Obviously, the machine states and the times of the next machine actions collectively define the state of the plant (see Tocher and Owen 1960). Tocher's preeminent contributions to simulation include the three-phase method for timing executives, the first textbook in simulation, *The Art of Simulation* (1963), and the wheel chart or activity-cycle diagram (ACD) in 1964. The ACD became a cornerstone of simulation teaching in the UK and the core of research in program generators during the 1970s. It is especially noteworthy that Tocher conceived and implemented an approach to combined simulation (discrete-event and continuous model execution) well before its appearance in a US simulation language (Tocher and Splaine 1966). We are indebted to Hollocks (2006) for detailing the contributions of Tocher that led to the establishment of the K.D. Tocher Award by the Operational Research Society (UK) in 2008.

Geoffrey Gordon joined the Advanced Systems Development Division of IBM in 1960 as Manager of Simulation Development; and during the period 1960–1961, he introduced the General Purpose System Simulator, which was later renamed the General Purpose Simulation System (GPSS). GPSS was designed to facilitate rapid simulation modeling of complex teleprocessing systems involving, for example, urban traffic control, telephone call interception and switching, airline reservation processing, and steel-mill operations. Gordon focused on a block diagram interface because he feared that programming might be too great a challenge for engineers. The ease of use and the software marketing policies of IBM at the time established GPSS as the most popular instructional simulation language in the US. An in-depth description of the history of GPSS is provided in Gordon (1981).

Based on FORTRAN, the initial version of SIMSCRIPT in 1963 was intended for users that were not computer experts and utilized a set of forms for model definition, model initialization, and report generation. The second generation SIMSCRIPT 1.5 unchained the translation from FORTRAN and served as a concept and idea generator for SIMSCRIPT II, the most ambitious language undertaking at that time. SIMSCRIPT II as published was a "layered" language, defined on five levels. Written in SIMSCRIPT II, the language was intended to have seven levels, the highest being a language writing "language" (Markowitz 1979, p. 29). Comprehensive descriptions of SIMSCRIPT are provided in Markowitz (1979) and Nance (1996).

A major contributor to the development and implementation of SIMSCRIPT II was Philip Kiviat, who had come from Cornell University to U.S. Steel in 1961 where he developed GASP (General Activity Simulation Program). Kiviat joined the RAND Corporation in 1963 and became a major driver in SIMSCRIPT II. Succeeding versions of GASP were developed by Alan Pritsker. The role of organizations (places) is emphasized by noting that Pritsker worked at RAND in the summer of 1969 on a version of GASP based on JOSS. Professor Richard Conway of Cornell also had a working relationship with RAND during this period.

Along with RAND, IBM, Cornell, and U.S. Steel, the Royal Norwegian Computing Center was a hotbed of simulation language development. Kristen Nygaard and Ole-Johan Dahl initiated work on SIMULA in 1961. With strong support from Univac, the two with capable programming staff created SIMULA I as an extension of ALGOL 60. The resulting evolution produced arguably the most influential programming language in computing history. A comprehensive description of the evolution of SIMULA is provided by Nygaard and Dahl (1981).

The 1967 forerunner of the Winter Simulation Conference (WSC) was the Conference on Applications of Simulation Using the General Purpose Simulation System, which in subsequent years was expanded to include papers on any simulation language or any aspect of simulation applications. WSC is now the premier international forum for disseminating recent advances in the field of system simulation.

Meanwhile, on the theory side of things, R. W. Conway, B. M. Johnson, and W. L. Maxwell of Cornell University laid out the central problems of digital simulation in two seminal papers, Conway et al. (1959) and Conway (1963). These groundbreaking authors stated that simulation problems fall into two broad categories—the *construction* of a simulation and the *use* of simulation.

The problems of simulation model construction include:

- Modular design of simulation programs for easy revision;
- Management of computer memory;

- Control of error arising from the discretization of all continuous quantities that is inherent in digital simulation;
- Design and implementation of an efficient time-advance mechanism; and
- Management of files containing the simulation's entities.

Although many of the above problems have been largely resolved, the design and implementation of an efficient time-advance procedure for handling certain types of events is still—even to this day—an active area of research and development.

The main problems in using simulation include the *strategic* problem of designing a simulation experiment and the following *tactical* problems on how to run the simulations specified in the experimental design:

- The start-up problem, i.e., determining when a simulation is in equilibrium (steady state) so that any transients caused by the simulation's initial condition have died out;
- Estimating the precision (variance) of simulation-based estimators of steady-state performance; and
- Performing precise comparisons of alternative system simulations. In other words, which is the best of a competing set of alternative systems or system configurations?

For the start-up problem, Conway (1963) proposed the first widely used rule for truncating (deleting) simulation-generated observations that are contaminated by initialization bias. For the variance-estimation problem, Conway proposed the method of batch means, which is still widely used in practice and is the basis for a great deal of ongoing research. For the comparison problem, Conway (1963) rejected traditional ANOVA methods and proposed the use of statistical ranking-and-selection procedures, which are now widely used in practice and are the basis for much ongoing research. The short story is that Conway showed remarkable insight into the problems and solution strategies that would shape the next fifty years of simulation methodology.

## 4 THE EXPANSION PERIOD (1970–1981)

During this period, those in the field of simulation developed enhanced modeling tools and analytical tools. In terms of discrete-event computer simulation modeling languages, we immediately think of, for instance, Pritkser and Hurst's development of GASP IV; Kiviat, Villanueva, and Markowitz's development of SIMSCRIPT II.5; Pritsker and Pegden's development of SLAM; Pegden's development of SIMAN; Nance's conical methodology for object-oriented model development; Schruben's event graphs; the development of specialty simulation products for niche markets; and Sargent's contributions to formal verification and validation. Some advances with respect to analytical work include, for instance, contributions to variate generation; contributions to output analysis; developments in input modeling; and the study of modern optimization techniques.

## 5 CONCLUSION

In this brief history of simulation from 1777 to 1981, we have attempted to provide a perspective on the critical advances in the field and some of the individuals who played leading roles in those advances.

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## REFERENCES

Burks, A. W., and A. R. Burks. 1981. The ENIAC: First general-purpose electronic computer. *IEEE Annals of the History of Computing* 3 (4): 310–399.

Conway, R. W., B. M. Johnson, and W. L. Maxwell. 1959. Some problems of digital systems simulation. *Management Science* 6 (1): 92–110.

Conway, R. W. 1963. Some tactical problems in digital simulation. *Management Science* 10 (1): 47–61.

Cooper, N. C., ed. 1988. *From cardinals to chaos: Reflections on the life and legacy of Stanislaw Ulam*. Cambridge: Cambridge University Press.

Gordon, G. 1981. The development of the General Purpose Simulation System. In *History of programming languages*, ed. R. L. Wexelblatt, 403–437. New York: Academic Press.

Hollocks, B. W. 2008. Intelligence, innovation and integrity—KD Tocher and the dawn of simulation. *Journal of Simulation* 2 (3): 128–137.

Markowitz, H. M. 1979. SIMSCRIPT: Past, present, and some thoughts about the future. In *Current Issues in Computer Simulation*, ed. N. R. Adam and A. Dogramaci, 27–60. New York: Academic Press.

Nance, R. E. 1996. A history of discrete event simulation programming languages. In *History of programming languages II,* ed. T. J. Bergin and R. J. Gibson, 369–427. New York: ACM Press; Reading, MA: Addison-Wesley.

Nance, R. E., and R. G. Sargent. 2002. Perspectives on the evolution of simulation. *Operations Research* 50(1): 161–172.

Nygaard, K., and O.-J. Dahl. 1981. The development of the SIMULA languages. In *History of programming languages*, ed. R. L. Wexelblatt, 439–491. New York: Academic Press.

Tocher, K. D., and D. G. Owen. 1960. The automatic programming of simulations. In *Proceedings of the Second International Conference on Operational Research,* ed. J. Banbury and J. Maitland, 50–68. London: The English Universities Press Ltd.

Tocher, K. D., and M. Splaine. 1966. Computer control of the Bessemer process. *Journal of the Iron and Steel Institute* 204 (February): 81–86.

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