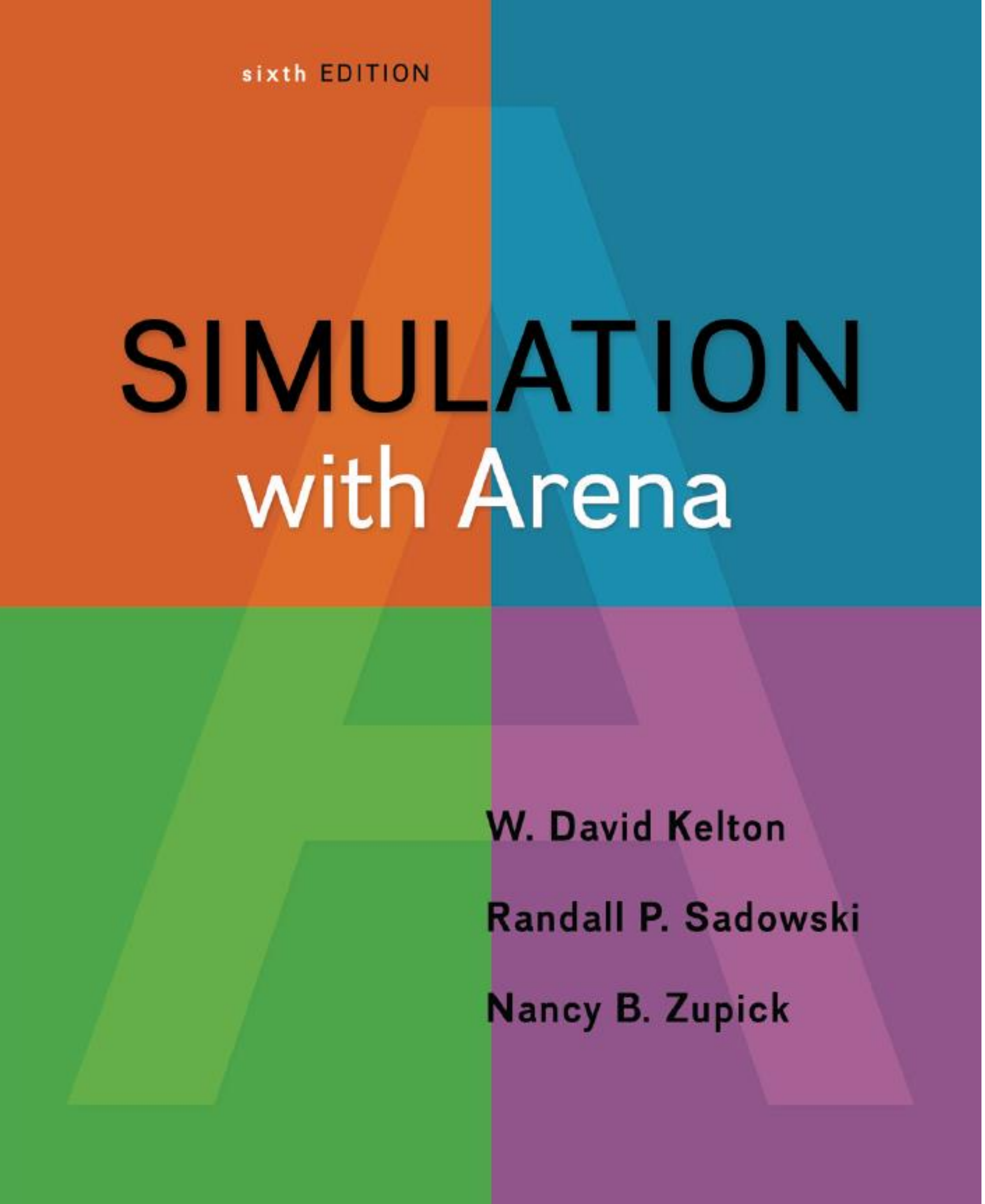


What is Simulation?

Chapter 1

Last revision December 21, 2013

Simulation Is …

- *Simulation* – very broad term – methods and applications to imitate or mimic real systems, usually via computer
- Applies in many fields, industries
- Very popular, powerful
- Book covers simulation in general,
  Arena simulation software in particular
- This chapter – general ideas, terminology, examples of applications, good/bad things, kinds of simulation, software options, how/when simulation is used

Systems

- ***System*** **– facility or process, actual or planned**
  - Examples abound …
    - Manufacturing facility
    - Bank operation
    - Airport operations (passengers, security, planes, crews, baggage)
    - Transportation/logistics/distribution operation
    - Hospital facilities (emergency room, operating room, admissions)
    - Computer network
    - Freeway system
    - Business process (insurance office)
    - Criminal justice system
    - Chemical plant
    - Fast-food restaurant
    - Supermarket
    - Theme park
    - Emergency-response system
    - Shipping ports, berths
    - Military combat, logistics

Work With the System?

- **Study system – measure, improve, design, control**
  - Maybe just play with actual system
    - Advantage — unquestionably looking at the right thing
  - But often impossible in reality with actual system
    - System doesn't exist
    - Would be disruptive, expensive, dangerous

Models

- ***Model*** **– set of assumptions/approximations about how system works**
  - Study model instead of real system … usually much easier, faster, cheaper, safer
  - Can try wide-ranging ideas with model
    - Make your mistakes on the computer where they *don't* count, rather than for real where they *do* count
  - Often, just *building* model is instructive – regardless of results
  - Model *validity* (any kind of model … not just simulation)
    - Care in building to mimic reality faithfully
    - Level of detail
    - Get same conclusions from model as you would from system
    - More in Chapter 13

Types of Models

- ***Physical*** **(*iconic*) models**
  - Tabletop material-handling models
  - Mock-ups of fast-food restaurants
  - Flight simulators
- ***Logical*** **(*mathematical*) models**
  - Approximations, assumptions about system's operation
  - Often represented via computer program in appropriate software
  - Exercise program to try things, get results, learn about model behavior

Studying Logical Models

- **If model is simple enough, use traditional mathematical analysis … get exact results, lots of insight into model**
  - Queueing theory
  - Differential equations
  - Linear programming
- **But complex systems can seldom be *validly* represented by simple analytic model**
  - Danger of over-simplifying assumptions … model validity?
  - Type III error – working on the wrong problem
- **Often, complex system requires complex model, analytical methods don't apply … what to do?**

Computer Simulation

- **Methods for studying wide variety of models of systems**
  - Numerically evaluate on computer
  - Use software to imitate system's operations, characteristics, often over time
- **Can use to study simple models, but should not use if an analytical solution is available**
- **Real power of simulation – studying complex models**
- **Simulation can tolerate complex models since we don't even aspire to an analytical solution**

Popularity of Simulation

- **Has been consistently ranked as the most useful, popular tool in broader area of operations research / management science**
  - 1978: M.S. graduates of CWRU O.R. Department … after graduation
    1. Statistical analysis
    2. Forecasting
    3. Systems Analysis
    4. Information systems
    5. Simulation
  - 1979: Survey 137 large firms, which methods used?
    1. Statistical analysis (93% used it)
    2. Simulation (84%)
    3. Followed by LP, PERT/CPM, inventory theory, NLP, …

Popularity of Simulation (cont'd.)

- 1980: (A)IIE O.R. division members
  - First in utility and interest — simulation
  - First in familiarity — LP (simulation was second)
- 1983, 1989, 1993: Longitudinal study of corporate practice
  1. Statistical analysis
  2. Simulation
- 1989: Survey of surveys
  - Heavy use of simulation consistently reported
- 2012 (Powers thesis): Literally exponential growth in number of simulation papers

- **Since most of these surveys, hardware/software have improved, making simulation even more attractive**
  - Historical impediment to simulation – computer speed

Advantages of Simulation

- **Flexibility to model things as they are (even if messy and complicated)**
  - Avoid *looking where the light is* (a morality play):

You're walking along in the dark and see someone on hands and knees searching the ground under a street light.

You:	"What's wrong? Can I help you?"
Other person:	"I dropped my car keys and can't find them."
You:	"Oh, so you dropped them around here, huh?"
Other person:	"No, I dropped them over there." (Points into the darkness.)
You:	"Then why are you looking here?"
Other person:	"Because this is where the light is."

- **Allows uncertainty, nonstationarity in modeling**
  - The only thing that's for sure: nothing is for sure
  - Danger of ignoring system variability
  - Model validity

Advantages of Simulation (cont'd.)

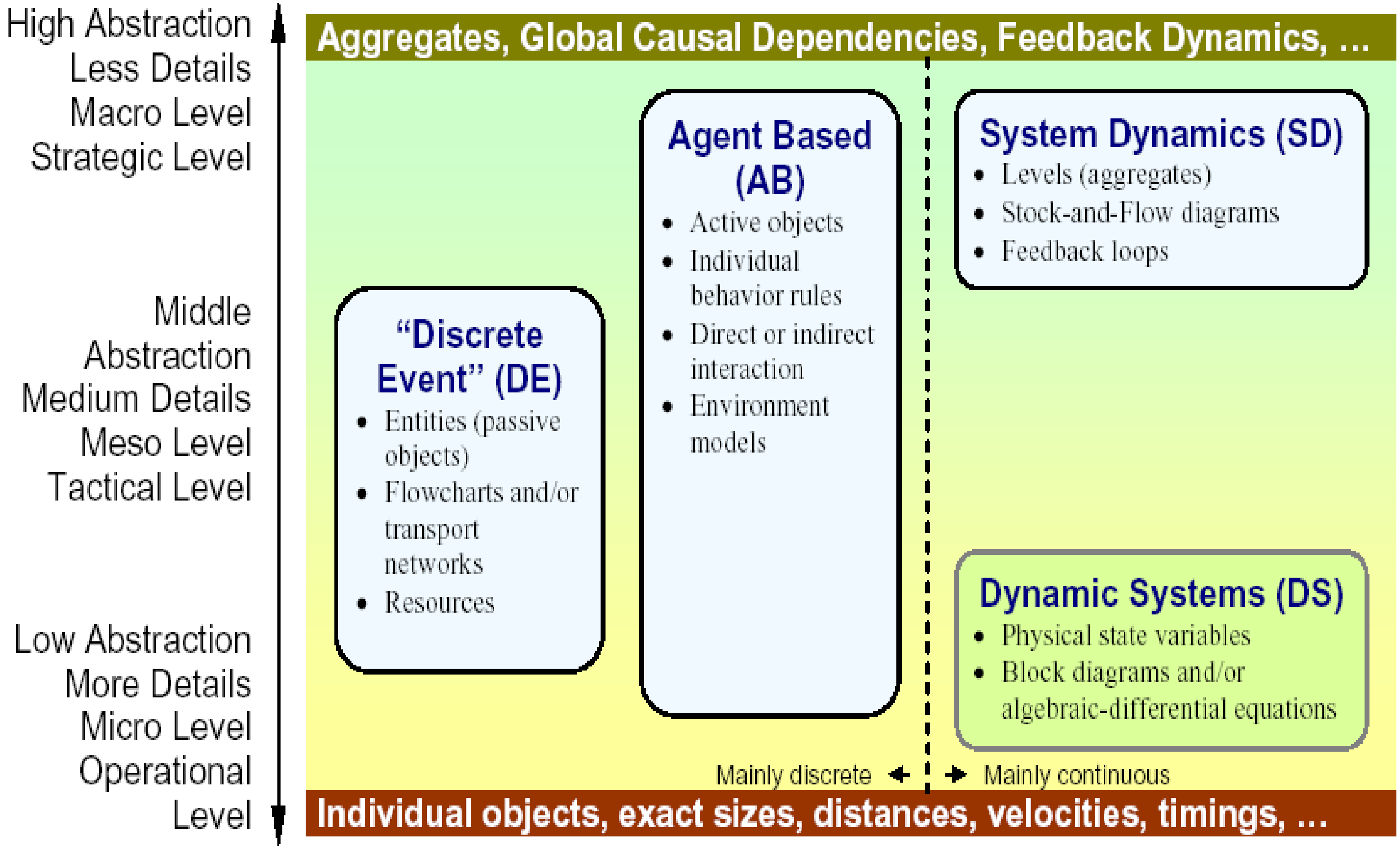
- **Advances in computing/cost ratios**
  - Estimated that 75% of computing power is used for various kinds of simulations
  - Dedicated machines (e.g., real-time shop-floor control)
- **Advances in simulation software**
  - Far easier to use (GUIs)
  - No longer as restrictive in modeling constructs (hierarchical, down to C)
  - Statistical design & analysis capabilities

The Bad News

- **Don’t get exact answers, only approximations, estimates**
  - Also true of many other modern methods
  - Can bound errors by machine roundoff
- **Get random output (*RIRO*) from stochastic simulations**
  - Statistical design, analysis of simulation experiments
  - Exploit: noise control, replicability, sequential sampling, variance-reduction techniques
  - Catch: “standard” statistical methods seldom work

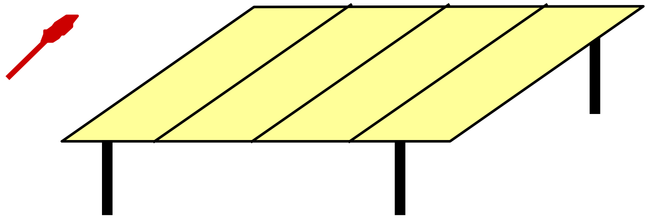
Different Kinds of Simulation

- **Static vs. *Dynamic***
  - Does time have a role in model?
- **Continuous-change vs. *Discrete-change***
  - Can "state" change continuously, or only at discrete points in time?
- **Deterministic vs. *Stochastic***
  - Is everything for sure or is there uncertainty?
- **Most operational models:**
  - *Dynamic*, *Discrete-change*, *Stochastic*
    - But Chapter 2 discusses one static model
    - And Chapter 11 discusses continuous and combined discrete-continuous models



approaches (paradigms) in simulation modeling on abstraction level scale (source: Borshev and Filippov (2004))

Simulation by Hand: The Buffon Needle Problem



- **Estimate π (George Louis Leclerc, c. 1733)**
- **Toss needle of length *l* onto table with stripes *d* (>*l*) apart**
- ***P* (needle crosses a line) =** $\dfrac{2l}{\pi d}$
- **Repeat; tally $\hat{p}$ = proportion of times a line is crossed**
- **Estimate π by** $\dfrac{2l}{\hat{p}d}$

Just for fun:
http://www.mste.uiuc.edu/reese/buffon/bufjava.html
http://www.angelfire.com/wa/hurben/buff.html

Why Toss Needles?

- **Buffon needle problem seems silly now, but has important simulation features:**
  - Experiment to *estimate* something hard to compute exactly (in 1733)
  - *Randomness*, so estimate will not be exact; estimate the error in the estimate
  - *Replication* (the more the better) to reduce error
  - *Sequential sampling* to control error — keep tossing until probable error in estimate is “small enough”
  - *Variance reduction* (*Buffon Cross*)

Using Computers to Simulate

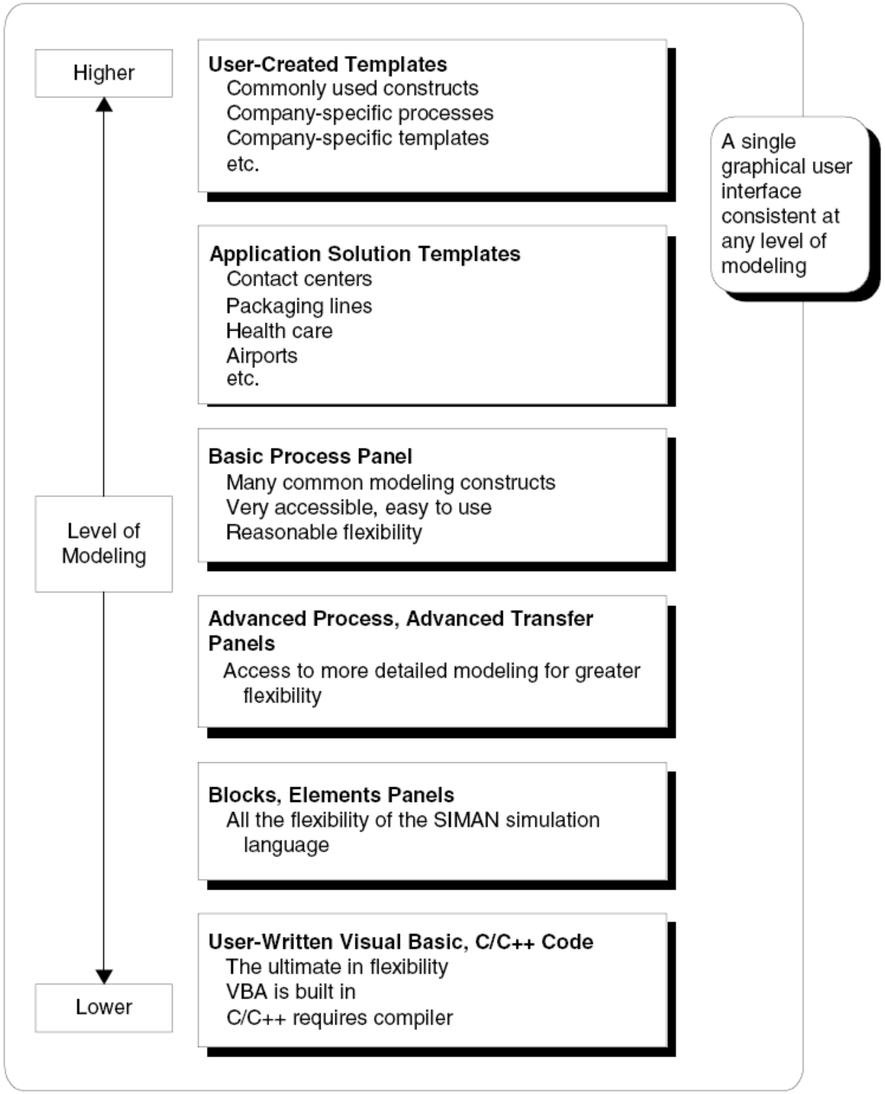
- **General-purpose languages (C, C++, C#, Java, Matlab, FORTRAN, others)**
  - Tedious, low-level, error-prone
  - But, almost complete flexibility
- **Support packages for general-purpose languages**
  - Subroutines for list processing, bookkeeping, time advance
  - Widely distributed, widely modified
- **Spreadsheets**
  - Usually static models (only *very* simple dynamic models)
  - Financial scenarios, distribution sampling, SQC
  - Examples in Chapter 2 (one static, one dynamic)
  - Add-ins are available (@RISK, Crystal Ball)

Using Computers to Simulate (cont'd.)

- **Simulation languages**
  - GPSS, SLX, SIMAN (on which Arena is based, included in Arena)
  - Popular, some still in use
  - Learning curve for features, effective use, syntax
- **High-level simulators**
  - Very easy, graphical interface
  - Domain-restricted (manufacturing, communications)
  - Limited flexibility — model validity?

Where Arena Fits In

- **Hierarchical structure**
  - Multiple levels of modeling
  - Mix different modeling levels together in same model
  - Often, start high then go lower as needed
- **Get ease-of-use advantage of simulators without sacrificing modeling flexibility**



When Simulations are Used

- **Use of simulation has evolved with hardware, software**
- **Early years (1950s – 1960s)**
  - Very expensive, specialized tool
  - Required big computers, special training
  - Mostly in FORTRAN (or even Assembler)
  - Processing cost as high as $1000/hour for a sub-PC level machine

When Simulations are Used (cont'd.)

- **Formative years (1970s – early 1980s)**
  - Computers got faster, cheaper
  - Value of simulation more widely recognized
  - Simulation software improved, but still languages to be learned, typed, batch processed
  - Often used to clean up "disasters" in auto, aerospace industries
    - Car plant; heavy demand for certain model
    - Line underperforming
    - Simulated, problem identified
    - But demand had dried up — simulation was too late

When Simulations are Used (cont'd.)

- **Recent past (late 1980s – mid 2000s)**
  - Microcomputer power
  - Software expanded into GUIs, animation
  - Wider acceptance across more areas
    - Traditional manufacturing applications
    - Services
    - Health care
    - "Business processes"
  - Still mostly in large firms
  - Simulation is often part of "specs"

When Simulations are Used (cont'd.)

- **Present**
  - Proliferating into smaller firms
  - Becoming a standard tool
  - Being used earlier in design phase
  - Real-time control
  - 3D graphics, business dashboards
- **Future**
  - Integration with other applications for visualization, analysis
  - Networked sharing of data in real time
  - Internet-enabled distributed model building, execution
  - Specialized vertical "templates" for specific industries, firms
  - Better model re-usability, operational decision making
  - Automated statistical design, analysis