Course Syllabus

ISYE 6644

Simulation and Modeling for Engineering and Science

Summer 2020

Professor: Dr. David Goldsman

Course Description

This course covers modeling of discrete-event dynamic systems and introduces simulation-based methods for using these models to solve engineering design and analysis problems.

Prerequisites

You will be expected to come in knowing a bit of basic calculus, probability, and statistics. But don't worry too much – we'll provide bootcamps on that material so as to make the class pretty much self-contained. In addition, this course will involve extensive computer programming, so it would be nice to have at least a little experience in something like Excel, just to bring back the programming memories.

Course Goals

- Learn how to develop simulation models and conduct simulation studies.
- Become familiar with the organization of simulation languages. In particular, we will do a great deal of modeling with Arena, a comprehensive simulation package with animation capabilities.
- Review statistical aspects including input analysis, random variate generation, output analysis, and variance reduction techniques.

Grading Policy

- There will be two midterms and one final exam. Test questions are typically multiple choice or T/F.
- There will be 11 Homework assignments (not as bad as it sounds). The HWs often have bonus questions, which you can do to earn a few extra points. Let r = the number of required questions, R = the # of required questions you answer correctly, and B = the number of bonus questions you answer correctly. Then your HW grade will be 100*(R+B)/r.
- You must achieve an overall weighted average of 60% to pass the course.
- Work hard and you will be rewarded – Grading is usually pretty generous.
- But let's be winners, not whiners. We are happy to discuss grades, but please make reasonable requests. 😊
- Breakdown
  - Homeworks 10%

- Midterm Quiz 1 30%
- Midterm Quiz 2 30%
- Final Quiz 3 30%

Total	100%

Homework and Quiz Due Dates

All homeworks and quizzes will be due at the times in the table at the end of this syllabus. These times are subject to change so please check back often. Please convert from Eastern Daylight Savings Time (EDST) to your local time zone using a Time Zone Converter.

Timing Policy

- The Modules follow a logical sequence, so they (mostly) need to be done in order.
- Homework Assignments should be completed by their due dates.
- Quizzes must be completed during the time allotted on the schedule.
- You will have access to the course content for the scheduled duration of the course.

Quiz Policy

- For Quiz *x* (*x* = 1,2,3), you are allowed to use *x* sheets of paper, either 8.5”x11” or A4, with handwritten notes (both sides of the sheet, 2*x* sides total).
- For all quizzes, you are allowed a blank sheet of paper for scratch work. (All OMS Analytics degree students will be proctored; you will have to show the front and back of the blank sheet while you are being proctored.)
- You are also allowed to bring any reasonable calculator.

Attendance Policy

- This is a fully online course.
- Login on a regular basis to complete your work, so that you do not have to spend a lot of time reviewing and refreshing yourself regarding the content.

Plagiarism Policy

- Plagiarism is considered a serious offense. You are not allowed to copy and paste or submit materials created or published by others, as if you created the materials. All materials submitted and posted must be your own.

Student Honor Code

All OMS Analytics degree students should abide by the Georgia Tech Student Honor Code.

- Review the Georgia Tech Student Honor Code: www.honor.gatech.edu.
- You are responsible for completing your own work.
- Any OMS Analytics degree student suspected of behavior in violation of the Georgia Tech Honor Code will be referred to Georgia Tech’s Office of Student Integrity.

Communication

- Feel totally free to contact your instructor, teaching assistants, and fellow learners via the Piazza discussion forums. Often, discussions with fellow learners are the sources of key pieces of learning and are often funny and entertaining. Some suggestions:

- Always be courteous and nice (see Netiquette below).
- Please make sure that your subject line PRECISELY states what problem you are asking about, as failure to do so causes everyone a great deal of time trying to figure out what you need. For instance, “Fall 2018 Practice Test 3, Question 5a”.
- Your problem may have already been addressed! So make sure that you sniff around the Piazza forum to see if that’s the case! That avoids repetitive and redundant repetition.
- Think about your problem a bit and give it the old college try before asking about it on Piazza. Don’t give up too early before you punt!

Netiquette

- Netiquette refers to etiquette that is used when communicating on the Internet. Review the Core Rules of Netiquette. When you are communicating via email, discussion forums or synchronously (in real-time), please use correct spelling, punctuation, and grammar consistent with the academic environment and scholarship[1].
- We expect all participants in Georgia Tech’s MS in Analytics program, (learners, faculty, teaching assistants, staff) to interact respectfully. Learners who do not adhere to this guideline may be removed from the course.

[1]Conner, P. (2006–2014). Ground Rules for Online Discussions, Retrieved 4/21/2014 from http://teaching.colostate.edu/tips/tip.cfm?tipid=128

Course Topics and Sample Pacing Schedule

The table below contains a course topic outline and homework due dates. [Note that some topics below are marked as OPTIONAL. You will not be given homework nor will you be tested on those topics; but we have nevertheless included this material in case you need additional review or would like to delve into a topic further.]

Weeks	**Course Topics**	**Release Dates**
Week 1	**Module 1: Whirlwind Tour of Simulation** • Lesson 1: Getting to Know You • Lesson 2: Syllabus • Lesson 3: Whirlwind Tour • Lesson 4: Whirlwind Tour – History • Lesson 5: What Can We Do For You • Lesson 6: Some Baby Examples • Lesson 7: More Baby Examples • Lesson 8: Generating Randomness • Lesson 9 **[OPTIONAL]**: Simulation Output Analysis	M May 11, 2020 at 8:00 am EDST

Week 1 Homework	Homework 1	F May 15 at 8:00 am EDST – F May 22 at 11:59 pm EDST
Week 2	**Module 2: Bootcamps** • Lesson 1 **[OPTIONAL]**: Calculus Primer • Lesson 2 **[OPTIONAL]**: Saved By Zero! Solving Equations • Lesson 3 **[OPTIONAL]**: Integration • Lesson 4 **[OPTIONAL]**:: Integration Computer Exercises • Lesson 5: Probability Basics • Lesson 6: Simulating Random Variables • Lesson 7: Great Expectations • Lesson 8: Functions of a Random Variable • Lesson 9: Jointly Distributed Random Variables • Lesson 10 **[OPTIONAL]**: Conditional Distributions / Expectation • Lesson 11: Covariance and Correlation • Lesson 12: Probability Distributions • Lesson 13: Limit Theorems • Lesson 14 **[OPTIONAL]**: Introduction to Estimation • Lesson 15 **[OPTIONAL]**: Maximum Likelihood Estimation • Lesson 16 **[OPTIONAL]**: Confidence Intervals	M May 18, 2020 at 8:00 am EDST
Week 2 Homework	Homework 2	F May 22 at 8:00 am EDST – F May 29 at 11:59 pm EDST
Week 3	**Module 3: Hand Simulations** • Lesson 1: Stepping Through Differential Equation • Lesson 2: Monte Carlo Integration • Lesson 3: Monte Carlo Integration Demo • Lesson 4: Making Some Pi • Lesson 5: A Single-Server Queue • Lesson 6: An (*s*,*S*) Inventory System • Lesson 7: An (*s*,*S*) Inventory System Demo • Lesson 8: Simulating Random Variables • Lesson 9: Simulating Random Variables Demo • Lesson 10: Spreadsheet Simulation **Module 4: General Simulation Principles** • Lesson 1: Steps in a Simulation Study • Lesson 2: Some Useful Definitions • Lesson 3: Time-Advance Mechanisms • Lesson 4: Two Modeling Approaches • Lesson 5: Simulation Languages	M May 25, 2020 (Memorial Day) at 8:00 am EDST

Week 3 Homework	Homework 3	F May 29 at 8:00 am EDST – F June 5 at 11:59 pm EDST
Week 4	**Module 5: The Arena Simulation Language** • Lesson 1: Introduction • Lesson 2: Process-interaction • Lesson 3: Let's Meet Arena! • Lesson 4: The Arena Basic Template • Lesson 5: Create-Process-Dispose Modules • Lesson 6: The Process Module • Lesson 7: Resource, Schedule, and Queue Spreadsheets • Lesson 8: The Decide Module • Lesson 9: The Assign Module • Lesson 10: Attribute, Variable, and Entity Spreadsheets • Lesson 11: Arena Internal Variables • Lesson 12: Displaying Stuff	M June 1, 2020 at 8:00 am EDST
Week 4 Homework	Homework 4	F June 5 at 8:00 am EDST – F June 12 at 11:59 pm EDST
Midterm Exam 1	Midterm Exam 1 [Covers up to and including Week 3 material + maybe a tiny bit of Arena material from Week 4. See Topics Attachment.]	F June 5 at 8:00 am EDST – **Su June 14** at 11:59 pm EDST
Week 5	**Module 5 (cont.): More Arena** • Lesson 13: Batch, Separate and Control • Lesson 14: Run Setup and Control Lesson 15: Two-Channel Manufacturing Example • Lesson 16: Fake Customers • Lesson 17: The Advanced Process Template • Lesson 18: Resource Failures + Maintenance • Lesson 19: The Blocks Template • Lesson 20: The Joy of Sets • Lesson 21: Description of Call Center • Lesson 22: Call Center Demo • Lesson 23: An Inventory Model • Lesson 24: One Line vs Two Lines? • Lesson 25 **[OPTIONAL]**: A Re-entrant Queue • Lesson 26 **[OPTIONAL]**: SMARTS Files + Rockwell Demos • Lesson 27: A Manufacturing System Demo	M June 8, 2020 at 8:00 am EDST
Week 5 Homework	Homework 5	F June 12 at 8:00 am EDST – F June 19 at 11:59 pm EDST

Week 6	**Module 6: Random Number Generation** • Lesson 1: Introduction • Lesson 2: Some Lousy Generators • Lesson 3: Linear Congruential Generators • Lesson 4: Tausworthe Generators • Lesson 5: Generalization of LCGs • Lesson 6: Choosing a Generator – Some Theory • Lesson 7: Choosing a Generator – Statistics Test, Intro • Lesson 8: Choosing a Generator – Goodness of Fit Tests • Lesson 9: Choosing a Generator – Independence Tests, I • Lesson 10 **[OPTIONAL]**: Choosing a Generator – Independence Tests, II	M June 15, 2020 at 8:00 am EDST
Week 6 Homework	Homework 6	F June 19 at 8:00 am EDST – F June 26 at 11:59 pm EDST
Week 7	**Module 7: Random Variate Generation** • Lesson 1: Introduction • Lesson 2: Inverse Transform Method • Lesson 3.1: ITM – Continuous Examples • Lesson 3.2: ITM – Continuous Examples DEMO 1 • Lesson 3.3: ITM – Continuous Examples DEMO 2 • Lesson 4: ITM – Discrete Examples • Lesson 5 **[OPTIONAL]**: ITM – Empirical Distributions • Lesson 6.1: Convolution Method • Lesson 6.2: Convolution DEMO • Lesson 7: Acceptance-Rejection Method • Lesson 8 **[OPTIONAL]**: Proof of the A-R Method • Lesson 9.1: A-R Method – Continuous Examples • Lesson 9.2: A-R Method – Continuous Examples DEMO	M June 22, 2020 at 8:00 am EDST
Week 7 Homework	Homework 7	F June 26 at 8:00 am EDST – F July 3 at 11:59 pm EDST
Week 8	**Module 7 (cont.): More RV Generation** • Lesson 10: A-R Method - Poisson Distribution • Lesson 11 **[OPTIONAL]**: Composition • Lesson 12: Box-Muller Normal RVs • Lesson 13: Order Statistics Other Stuff • Lesson 14: Multivariate Normal Distribution • Lesson 15 **[OPTIONAL]**: Baby Stochastic Processes • Lesson 16.1: Nonhomogeneous Poisson Processes • Lesson 16.2: Nonhomogeneous Poisson Processes DEMO	M June 29, 2020 at 8:00 am EDST

	• Lesson 17.1 [OPTIONAL]: Time Series • Lesson 17.2 [OPTIONAL]: Time Series DEMO • Lesson 18 [OPTIONAL]: Queueing • Lesson 19.1: Brownian Motion • Lesson 19.2: Brownian Motion DEMO	
Week 8 Homework	Homework 8	F July 3 at 8:00 am EDST – F July 10 at 11:59 pm EDST
Midterm Exam 2	**Midterm Exam 2 [Covers up to and including Week 7 material and even a little bit of Week 8, with emphasis on more-recent stuff. See Topics Attachment.]**	F July 3 at 8:00 am EDST – **Su July 12** at 11:59 pm EDST
Week 9	**Module 8: Input Analysis** • Lesson 1: Introduction • Lesson 2: Identifying Distributions • Lesson 3: Unbiased Point Estimation • Lesson 4: Mean Squared Error • Lesson 5: Maximum Likelihood Estimators • Lesson 6: MLE Examples • Lesson 7: Invariance Property of MLEs • Lesson 8 [OPTIONAL]: The Method of Moments • Lesson 9: Goodness of Fit Tests • Lesson 10: Exponential Example • Lesson 11: Weibull Example • Lesson 12: Still More Goodness-of-Fit Tests • Lesson 13: Problem Children • Lesson 14: Demo Time	M July 6, 2020 at 8:00 am EDST
Week 9 Homework	Homework 9	F July 10 at 8:00 am EDST – F July 17 at 11:59 pm EDST
Week 10	**Module 9: Output Analysis** • Lesson 1: Introduction • Lesson 2 [OPTIONAL]: Mathematical Interlude • Lesson 3: Finite-Horizon Analysis • Lesson 4: Finite-Horizon Extensions • Lesson 5: Simulation Initialization Issues • Lesson 6: Steady-State Analysis • Lesson 7 [OPTIONAL]: Properties of Batch Means • Lesson 8: Other Steady-State Methods **Module 10: Comparing Systems** • Lesson 1: Introduction • Lesson 2: Confidence Interval for the Mean	M July 13, 2020 at 8:00 am EDST

	• Lesson 3: CIs for the Difference in Two Means • Lesson 4: Paired CI for the Difference in Two Means • Lesson 5: CIs for the Mean Difference in Simulations	
Week 10 HW	Homework 10	F July 17 at 8:00 am EDST – F July 24 at 11:59 pm EDST
Week 11	**Module 10 (cont'd): Comparing Systems** • Lesson 6: Common Random Numbers • Lesson 7: Antithetic Random Numbers • Lesson 8 **[OPTIONAL]**: Control Variates • Lesson 9: Ranking and Selection Methods • Lesson 10: Normal Means Selection • Lesson 11: Single-Stage Normal Means Procedure • Lesson 12 **[OPTIONAL]**: Normal Means Extensions • Lesson 13: Bernoulli Probability Selection • Lesson 14 **[OPTIONAL]**: Bernoulli Extensions • Lesson 15: Multinomial Cell Selection • Lesson 16 **[OPTIONAL]**: Multinomial Procedure + Extensions • Lesson 17: Summary	M July 20, 2020 at 8:00 am EDST
Week 11 HW	No Homework (though some sample problems will be handed out)	
Final Exam	**Final Exam [Covers everything, with emphasis on more-recent stuff. See Topics Attachment.]**	F July 24 at 8:00 am EDST – **F July 31** at 11:59 pm EDST

Course Materials

- All content and course materials can be accessed online.
- There is no required textbook for this course, though students are encouraged to find copies of the following references:
  - Law, A. M., Simulation Modeling and Analysis, 5th edition, McGraw-Hill Education, New York, 2015. [This textbook is most for the "theory" aspects of the course.]
  - Kelton, W. D., Sadowski, R. P., and Zupick, N. B., Simulation with Arena, 6th edition, McGraw-Hill, New York, 2015. [This book covers the Arena simulation language.]

Technology/Software Requirements

- Internet connection (DSL, LAN, or cable connection desirable)
- R statistical software (free download; see cran.r-project.org)

- Arena simulation software (free student download; see www.arenasimulation.com/academic/students)
- Adobe Acrobat PDF reader (free download; see https://get.adobe.com/reader/)

Test Topix for ISyE 6644 Online Masters in Analytics, Fall 2019

- I've tried my best to make this list as complete as possible, but I may have missed a topic or two. That being said, you are responsible for everything that we do in class or homework.
- As GT students, you are expected to formulate problems and solution strategies which are more than mere rote regurgitation of material you learned in class. Thus, you shouldn't be surprised if some questions cover natural extensions of material from class.
- I'll supply all necessary tables, e.g., N(0,1), t, and χ^2, but you can feel free to use your own.

TEST 1 TOPIX

1. Intro Material

a. Definition of simulation
b. Advantages and disadvantages of simulation
c. History of simulation
d. Typical questions and applications

2. Calculus, Probability, and Statistics Review

a. **Calculus [not really responsible for this material, except I might make you search for a zero]**
    i. Basic definitions
    ii. Derivatives
    iii. Solving for zeros
    iv. Integration
    v. Numerical integration
b. Probability Preliminaries
    i. Conditional probability
    ii. Independent events
    iii. Definition of random variable
    iv. Discrete RV's and probability mass function
    v. Continuous RV's and probability density function
    vi. Cumulative distribution function

c. Simulating RV's (first pass)
    i. Discrete uniform distribution
    ii. General discrete distribution
    iii. Inverse Transform Theorem for continuous RV's
    iv. Exponential (and other) continuous distributions via IVT.
    v. Generating U(0,1)'s via desert island algorithm, including walk-through of pseudo-code.
d. Expected Values
    i. Definition
    ii. Discrete and continuous examples of expected value
    iii. Law of the Unconscious Statistician
    iv. Moments, central moments, variance, standard deviation
    v. Discrete and continuous examples of LOTUS
    vi. Moment generating function
    vii. Examples and properties of mgf's
e. Functions of a RV
    i. Discrete examples
    ii. Continuous examples
    iii. IVT methods (again) with examples
    iv. Relationship with LOTUS
f. Jointly distributed RV's
    i. Definition of joint cdf
    ii. Marginal cdf's
    iii. Joint and marginal pmf's
    iv. Joint and marginal pdf's
    v. Examples for discrete and continuous cases
    vi. Independent RV's
    vii. Conditional pmf's and pdf's
    viii. **Conditional expectation [this won't be on the test]**
    ix. **Double expectation E(E(Y|X)) = EY, including examples [this won't be on the test]**
g. Covariance and correlation
    i. Definitions
    ii. Relationship between independence and correlation
    iii. Examples
    iv. Miscellaneous properties (e.g., Var(X+Y), bounds on correlation, etc.)
h. Probability distributions
    i. Discrete distributions
        1. Bernoulli
        2. Binomial
        3. Geometric

4. Poisson (including discussion on Poisson processes)

ii. Continuous distributions

1. Uniform
2. Exponential (including memoryless property)
3. Erlang, Gamma distributions
4. Triangular
5. Normal (including Standard Normal)
6. Other sampling distributions (including chi-square, t, F, and various relationships with each other)

i. Limit theorems

i. Linear combinations of independent normal (including distribution of sample mean)

ii. Convergence in distribution

iii. Law of Large Numbers

iv. Central Limit Theorem for independent and identically distributed data.

v. Examples

j. Statistics Tidbits **[this material will eventually be covered in modules 8, 9, 10, so it's in fair territory to have it on the final! ☺]**

i. Properties of sample mean and sample variance

ii. Confidence intervals for the mean and variance

3. Hand Simulations

a. Monte Carlo integration

b. Determining π via simulation (dart tossing on a circle and sphere)

c. Single-server queue (including FIFO and LIFO service disciplines)

d. (s,S) inventory system

e. Simulating RV's (repeats some material from the Prob/Stats review)

f. Spreadsheet simulation (e.g., stock portfolio in Excel)

4. General Simulation Principles

a. Steps in a simulation study

b. List of various simulation definitions (e.g., event, system state, simulation clock, etc.)

c. Event-Scheduling vs. Process Interaction modeling approaches

d. How are events processed?

e. Future events list + extended example

f. Simulation languages – what to look for

Plus, the first few Arena mini-topix below…

TEST 2 TOPIX

Everything from Test 1 + the following (with less emphasis placed on the Test 1 material)…

5. **Arena**
    a. Layout of Arena screen (panels, modules, etc.)
    b. Basic Process template: CREATE-PROCESS-DISPOSE modules
    c. SEIZE-DELAY-RELEASE inside of the PROCESS module.
    d. Resource, Schedule, Queue, Entity, and other spreadsheets
    e. ASSIGN module
    f. DECIDE module – probabilistic and conditional routing
    g. Simple examples, e.g. (partial list),
        i. Single-server queue
        ii. Parallel servers
        iii. Schedules for servers
        iv. Multiple arrival streams
    h. Displays, graphics, etc.
    i. BATCH and SEPARATE modules
    j. Run set-up and control
    k. More-sophisticated queueing networks (e.g., two-channel manufacturing example, call center example)
        i. Advanced Process modules (e.g., SEIZE, DELAY, RELEASE modules)
        ii. Some primitive blocks (e.g., QUEUE)
        iii. Use of “pretend” customers
        iv. Nonhomogeneous Poisson arrivals
        v. Use of resource sets, including how to prioritize servers
        vi. Use of submodels
    l. Inventory processes
    m. **Crazy examples such as re-entrant queues [this won’t be on the test]**
    n. SMARTS files and other Rockwell examples
    o. Manufacturing systems **(you’re only responsible for the basics)**
        i. Advanced Transfer modules
        ii. Sequences of customer visitation locations
        iii. **Advanced sets of sequences [this won’t be on the test]**

6. **Uniform Random Number Generation**
    a. Overview – desirable properties of a pseudo-random number generator
    b. Some generators we won’t use, e.g.,
        i. PRN’s from tables
        ii. Midsquare
    c. Linear congruential generators
        i. Cycling
        ii. 16807 desert island generator (again)

iii. RANDU (a bad generator)
d. Tausworthe generator
e. Combined generators
i. L'Ecuyer's generator of cycle length 2^{191}
ii. Mersenne Twister
f. Some theoretical considerations, e.g., from Knuth's book
g. Statistical tests for randomness
i. Goodness-of-fit test – Chi-squared
ii. Runs tests for independence
1. Runs up and down
2. Runs above and below the mean
3. **Autocorrelation test [this won't be on the test]**

7. Random Variate Generation
a. Inverse Transform Theorem (yet again)
i. Proof
ii. Discrete example adaptations
iii. Continuous examples
1. East ones such as Exponential, Weibull, etc.
2. Slightly harder examples such as Triangle distribution
3. Normal distribution, both exact and approximate methods
iv. Special case methods, e.g., Geometric
v. **Empirical distributions [this won't be on the test]**
b. Convolution method
i. Binomial
ii. Triangle
iii. Erlang
iv. CLT
1. Desert island sum of Uniforms to generate Normal
2. Normal approximation to Poisson (including continuity correction)
v. Cauchy
1. Cauchy's add up to another Cauchy
2. IVT method
3. Ratio of two Normals
c. Acceptance-Rejection methods
i. Trivial Uniform example
ii. Some discussion on general method
iii. **Proof of the general method [don't expect to see this on the test, unless I'm in a really bad mood!]**
iv. Examples involving polynomial and half-normal p.d.f.'s
v. Poisson distribution

d. **Composition [this won't be on the test]**

Plus, maybe a couple of topix below, such as Box-Muller (which we've actually seen before)…

TEST 3 (FINAL) TOPIX

Everything in the freaking course, including the following new stuff (with less emphasis placed on the Test 1 and 2 material)…

e. Special-case techniques
   i. Box-Muller method for Normal distribution
   ii. Extensions of B-M, e.g., Cauchy, Chi-squared.
   iii. Generating min's and max's of iid RV's, e.g., min of iid Exponentials.

f. Multivariate Normal
   i. Definition in 2 and then >2 dimensions
   ii. Cholesky decomposition method for generating realizations (exact expression in 2 dimensions, algorithm for >2 dimensions)

g. Stochastic processes
   i. **Markov chains [this won't be on the test]**
   ii. Poisson processes
   iii. Nonhomogeneous Poisson processes (via thinning method)
   iv. **Time series [this won't be on the test, except stuff you can do from scratch]**
      1. MA(1)
      2. AR(1)
      3. EAR(1)
      4. ARTOP
   v. **M/M/1 queue waiting times [this won't be on the test, unless you can do it from scratch]**
   vi. Brownian motion
      1. Definition and history
      2. Elementary properties, including covariance structure
      3. General CLT
      4. How to generate
      5. Geometric BM and financial applications

8. Input Analysis

a. General discussion
   i. Careful about GIGO with respect to simulation input
   ii. What makes a good distribution

iii. Identification of obvious distributions

b. Estimation review
    i. Unbiased estimators
        1. Definition
        2. Sample mean
        3. Sample variance
        4. Other examples such as Unif(0,θ)
    ii. Mean squared error
    iii. Maximum likelihood estimators
        1. Definition
        2. Examples such as Exponential
        3. Two-dimensional examples such as Normal with unknown mean and variance
        4. Other tougher examples such as Unif(0,θ) and Gamma
        5. Invariance Property + examples
    iv. Method of Moments [this won't be on the test (sorry, MoM!)]

c. Goodness-of-fit tests for input distributions
    i. Chi-squared for Exponential
    ii. Chi-squared for Weibull, including search techniques such as bisection and Newton
    iii. Kolmogorov-Smirnov
    iv. More goodness-of-fit tests

d. Problem Children
    i. Little or no data
    ii. Data from an unusual distribution
    iii. Nonstationary data
    iv. Multivariate / correlated data

e. Arena Input Analyzer demo

9. Output Analysis

a. Introduction
    i. The need for output analysis in a proper statistical study
    ii. Simulation data isn't iid normal, and this is a problem
    iii. Types of output analysis – finite-horizon (terminating) and steady-state

b. A mathematical interlude related to the fact that the variance of the sample mean isn't $Var(X_i)/n$, and its consequences **[I might ask you to calculate the variance of the sample mean for a specific process, but nothing else.]**

c. Finite-horizon (terminating) simulations
    i. Examples
    ii. Confidence intervals for mean performance via the method of Independent Replications

d. Initialization problems
e. Steady-state analysis for a single system
    i. Examples
    ii. Confidence intervals for the steady-state mean via the method of Batch Means
    iii. **Properties of Batch Means [this won't be on the test]**
    iv. Overlapping Batch Means
    v. Other methods

10. Comparing Systems

a. Classical confidence interval for the mean of one normal population
b. Classical confidence interval to compare the means of two normal systems
    i. Variance completely unknown
    ii. Paired-t CI
    iii. Use in simulation scenarios
c. Variance reduction techniques
    i. Common random numbers
    ii. Antithetic random numbers **[no theory related to this will be on the test]**
    iii. **Control variates [this won't be on the test]**
d. Ranking and selection methods to compare means of >2 systems
    i. Definition of problem
    ii. Relevance to simulation
    iii. Indifference-zone approach
    iv. Normal means selection problem
        - Bechhofer's single-stage procedure
        - **Extensions [this won't be on the test]**
    v. Bernoulli parameter selection problem
        - Sobel and Huyett single-stage procedure
        - **Extensions [this won't be on the test]**
    vi. Multinomial cell selection problem
        - Multinomial review and motivation
        - Bechhofer, Elmaghraby, and Morse single-stage procedure
        - **Extensions [this won't be on the test]**