KEYNOTE ADDRESS


# WSC 2067: WHAT ARE THE CHANCES?

**Barry L. Nelson**

**Walter P. Murphy Professor of Industrial Engineering and Management Sciences**

Northwestern | McCORMICK SCHOOL OF ENGINEERING

# I know what you're thinking…

We're in Las Vegas, we could've had Celine Dion!

# My WSC street cred

- Attended every WSC since 1983 (70%).
- Helped drive *Proceedings* to WSC ’83, wrecking the van in the hotel garage.
- Arrested at WSC ’84 for bringing “liquid refreshment” into the hotel for the TIMS College on Simulation Mixer.
- Worried Secret Service at WSC ‘89 by running at Sen. Richard Lugar on the Mall.
- Pasted 2470 running heads & page numbers on the WSC ‘91 *Proceedings* by hand (my arms & wrists still hurt).
- Broke WSC ’97 budget by forgetting **Correlation[number of tracks, attendance] > 0**.
- **So Ernie, what could possibly go wrong?**

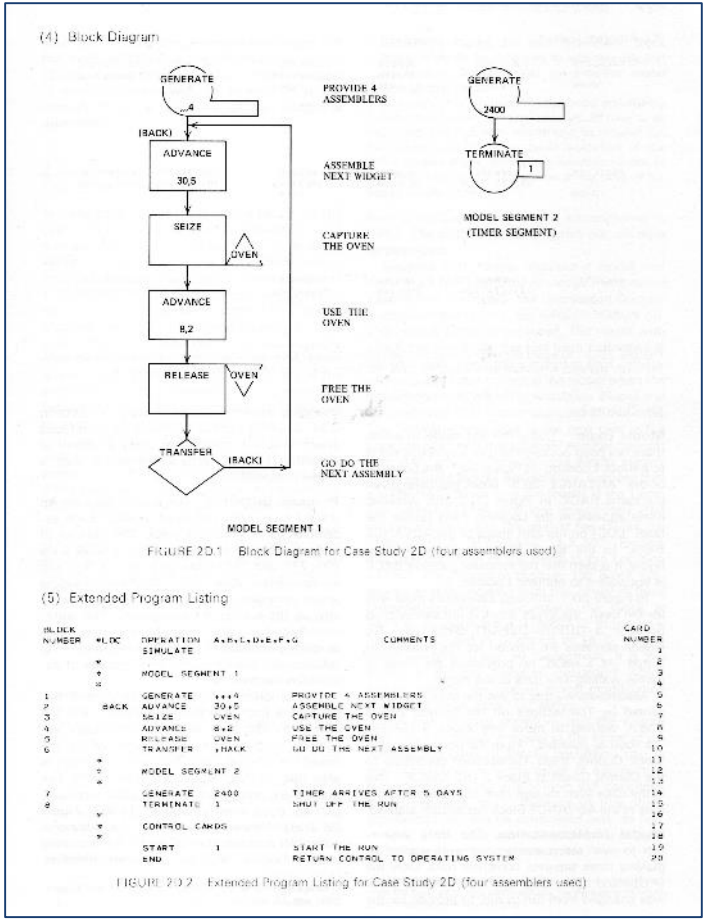
# In the beginning…

…there was the 1967 "Conference on the Applications of Simulation Using GPSS" which became the WSC we know today.

- This year we have a great **history track** that celebrates the mythology & legends of WSC.
- But let's take a moment to salute **GPSS:**
  - GPSS = *General Purpose Simulation System*
  - Came free with IBM mainframes.
  - Had an integer clock, a uniform distribution, you drew the network diagram by hand, and you ran it from cards.
  - But without GPSS we might be at a **machine learning** conference today.

# GPSS!

- Scanned from the famous textbook *Simulation Using GPSS*, Wiley, 1974.
  - Written by the famous Tom Schriber!



(4) Block Diagram



FIGURE 2D.1 Block Diagram for Case Study 2D (four assemblers used)

(5) Extended Program Listing

```
BLOCK                                                                  CARD
NUMBER   *LOC   OPERATION  A,B,C,D,E,F,G          COMMENTS            NUMBER
                SIMULATE                                                   1
                *                                                          2
                *  MODEL SEGMENT 1                                         3
                *                                                          4
1                GENERATE   4,,,,,,0             PROVIDE 4 ASSEMBLERS    5
2          BACK  ADVANCE    30,5                ASSEMBLE NEXT WIDGET    6
3                SEIZE      OVEN                CAPTURE THE OVEN        7
4                ADVANCE    8,2                 USE THE OVEN            8
5                RELEASE    OVEN                FREE THE OVEN           9
6                TRANSFER   ,BACK               GO DO THE NEXT ASSEMBLY 10
                *                                                         11
                *  MODEL SEGMENT 2                                        12
                *                                                         13
7                GENERATE   2400                TIMER ARRIVES AFTER 5 DAYS 14
8                TERMINATE  1                   SHUT OFF THE RUN        15
                *                                                         16
                *  CONTROL CARDS                                          17
                *                                                         18
                START      1                   START THE RUN           19
                END                            RETURN CONTROL TO OPERATING SYSTEM 20
```

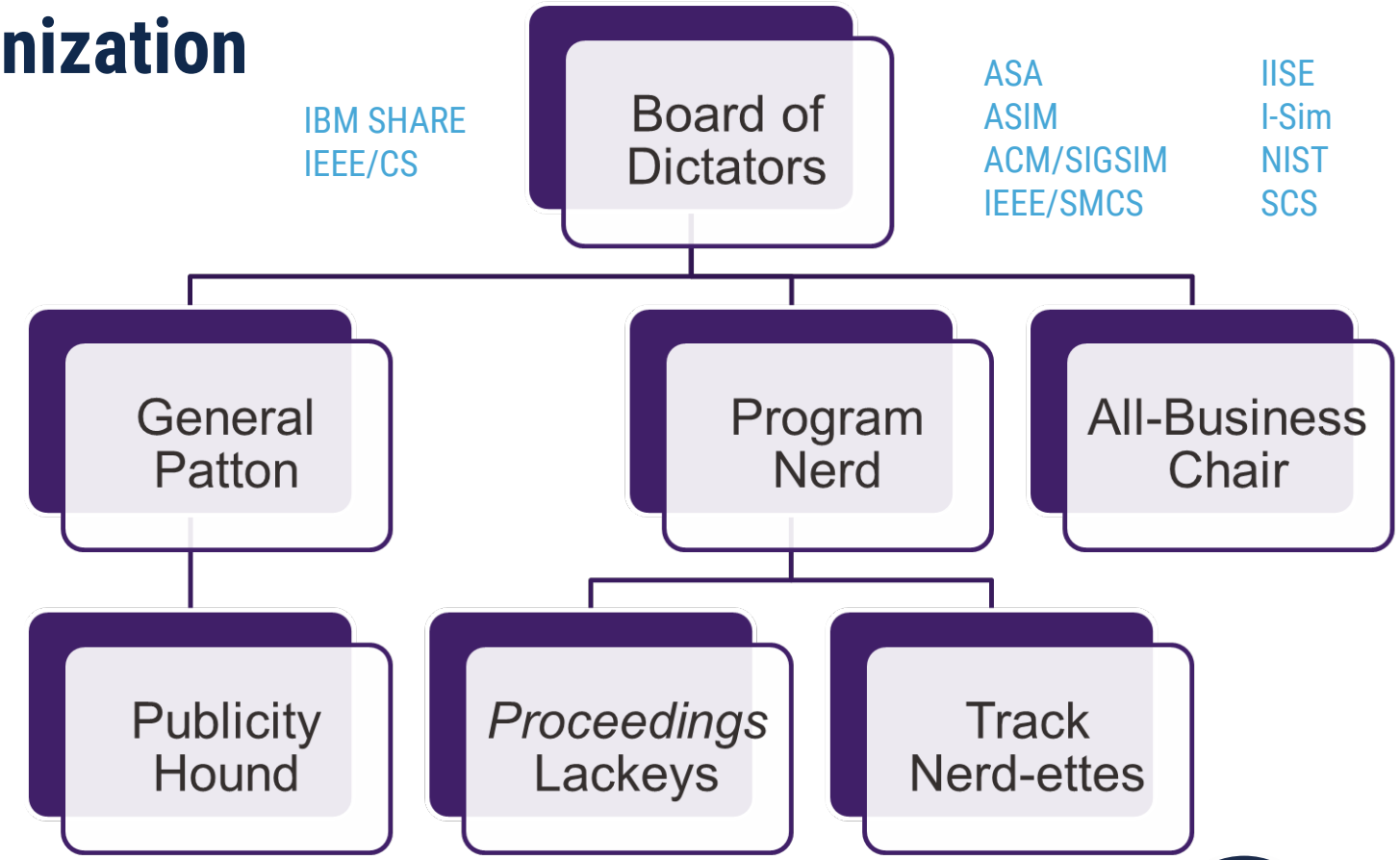
FIGURE 2D.2 Extended Program Listing for Case Study 2D (four assemblers used)

Case study 2D: One-line, one-server queueing system with feedback.

# Fun facts! (about the first conference)


- Registration was $30 in advance, $35 at the door.
- Cost for a hotel night was $18 (in New York!).
- 401 attendees.
- Conference had to borrow $700 to get off the ground.
- There were no *Proceedings*.
- All the organizers were **smart**, all the attendees were **good looking**, and all the talks were **above average**.
- **I believe we are still here because of great *organization*, great *talks*, great *cooperation* and great *relevance*.**

# Great organization



# Great talks

- “Only Wet Babies like Change”
  2003 keynote
- “The ‘Tell-Us-the-Answer-You-Want’ Problem”
  1983
- “Better Simulation with COBOL”
  **Fake news**
- “A Simulation of the Operations of an Illegal Numbers Game”
  1974
- “What to Simulate First: The Chicken or the Egg?”
  **Fake news**
- “Linda Arouses a Sleeping Barber”
  2002

# More great talks

- "Simulation, Drugs and Rock & Roll"
  **Fake news**
- "When is a Satellite not a Toaster?"
  1991
- "But, Mr. President - Is It ETHICAL?"
  1986
- "Lose all the Variance You Want without Being (data) Hungry"
  **Fake news**
- "The Daughter of Celia, the French Flag, and the Firing Squad"
  1973
- "Training Socialist Managers by Enterprise Simulation"
  1974

# Great cooperation

$$\mathrm{E}_{\psi}[g(X)] = \int g(x)\frac{\psi(x)}{\varphi(x)}\varphi(x)dx$$

50TH SUMMER OF LOVE SAN FRANCISCO 1967-2017

extendsim. Solves big tough problems

AnyLogic

Simio Forward Thinking

FlexSim problem solved.

**SAS® Simulation Studio**

```
>>> def car(env):
...     while True:
...         print('Start parking at %d' % env.now)
...         parking_duration = 5
...         yield env.timeout(parking_duration)
...
...         print('Start driving at %d' % env.now)
...         trip_duration = 2
...         yield env.timeout(trip_duration)
```

# With great RELEVANCE comes great responsibility

- WSC 2013 Titan's Talk: **"The Simulation Curmudgeon"**
  1. Why do we build simulation models as if they will never change?
  2. Why do we treat simulation like poor man's queueing theory?
  3. Why do we fit input distributions like it's 1922?
  4. Why can't I talk to my simulation?


- "'Some Tactical Problems in Digital Simulation' for the Next Ten Years," *Journal of Simulation* **10** (2016), 2-11.
  1. Simulation analytics
  2. Parallel simulation
  3. Simulation to support decisions


- "Technology Transfer of Simulation Analysis Methodology: One Man's Opinion," WSC 2016.

# The World has changed more than WSC has

- **Then…**


  - Batch runs on a single processor with limited memory and storage.
  - Simulation imitates queueing theory: long-run average performance of stationary systems for *design*.
  - Data gathered as needed.
  - Modeling & simulation viewed as a technical competency.

- **Now…**

  - Rent 1000s of processors; store and search vast quantities of results.
  - Support needed for real or near-real-time decisions, possibly made algorithmically, for *operations*.
  - Data gathered all the time.
  - "Analytics" viewed as a core competency.

## TAKEAWAY MESSAGE

**To remain relevant, we need better answers to harder problems in a more timely way.**

# Some challenges…

1) All models are wrong, but some models are wronger
2) Simulation: the glitter or the glue?
3) All the world's a database
4) Mutually assured relevance

## CHALLENGE #1

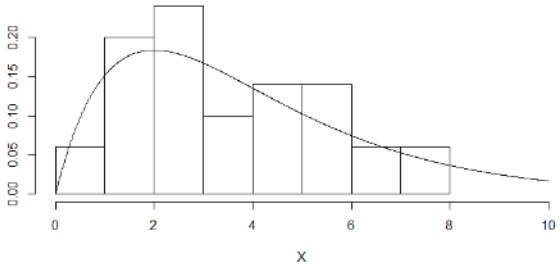
# All models are wrong, but some models are *wronger*

# George Box said…

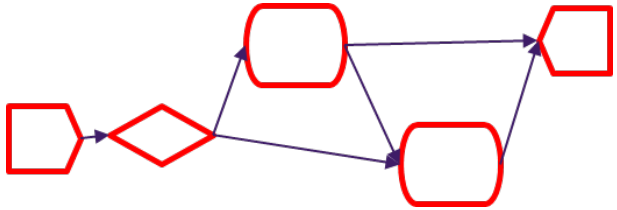
- "Remember that all models are wrong; the practical question is how wrong do they have to be to not be useful?"
  - From his book *Empirical Model-Building and Response Surfaces*
- We often quote this to justify what we do.
  - But did we take the wrong message from Box?
- **"… how wrong do they have to be to not be useful?"**
  - Box's statement is not a blanket license to use models.
  - "Better answers" requires a better idea about "how wrong."

# Simulation = Inputs + Logic

- The **inputs** are the lowest level of unexplained variation.
  - Modeled by distributions, often estimated from data.

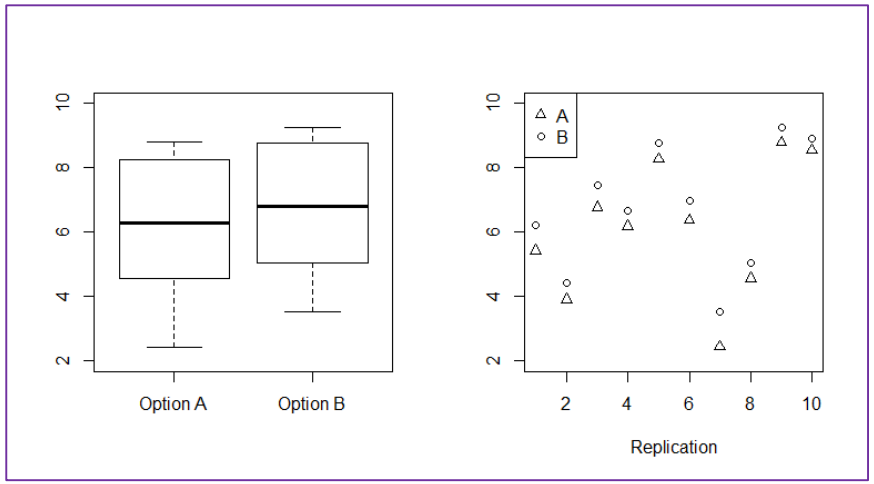


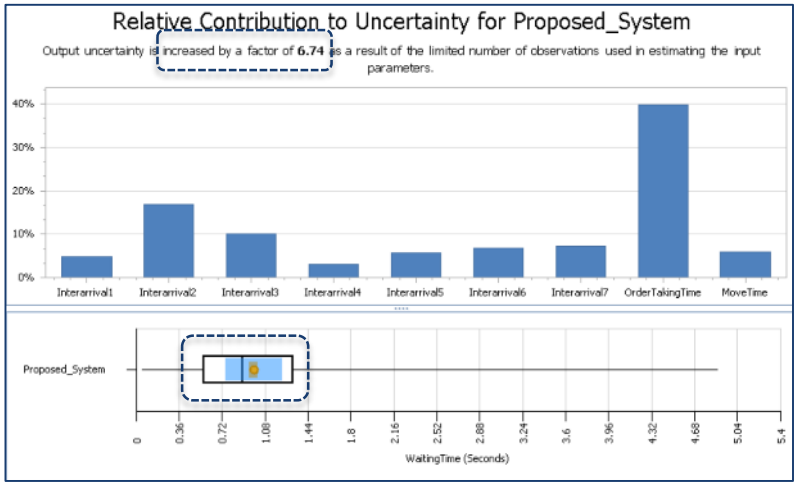

- Everything else is **logic**: the "art" part that is true-enough or not, right level or wrong level.
  - Tocher (1963) *The Art of Simulation.*



# Thinking about "how wrong"

- **Old Idea:** Common random numbers and estimating *differences*.
- **New Idea:** Model risk & inference to the *resolution of the model*.



# Old school simulation modeling

# Inputs & Logic revisited

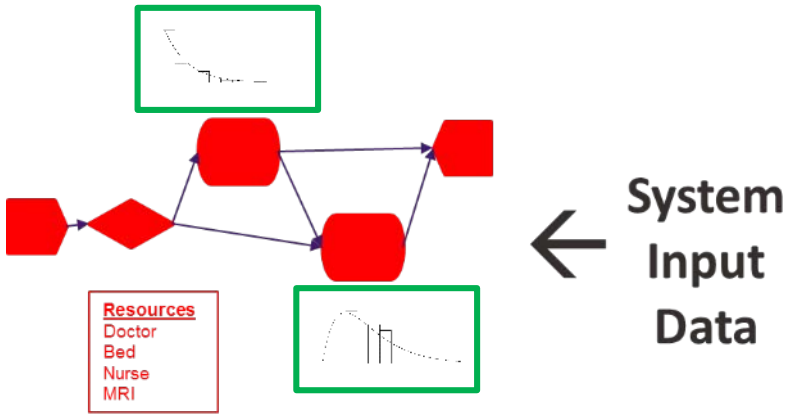
- **The Sloan Valve video is really just a big dataset.**
- Instead of (younger) me with a notepad, the "logic" could be **"learned"** from dissecting the video.
  - Fixed objects, dynamic objects, what follows what and with what regularity.
  - Analysis of hours of video would reveal inconsistencies, worker differences, rare events, etc. that I would never observe.
  - When "logic" is like a statistical model, then I can infer "how wrong!"
- **Did I just throw us under the machine learning bus?**

# Is simulation just "machine learning?"

- **Question**: What is the essential difference?

$$\text{minimize} \sum \{\boldsymbol{\beta}^T \boldsymbol{f}(\boldsymbol{x}_i) - y_i\}^2$$

- **Answer**: The meaning of $\boldsymbol{x}$.
  - We observe at most **one** $\boldsymbol{x}$.
  - We need to **model** what happens at *new* $\boldsymbol{x}$'s.



# Is simulation just "machine learning?"

- **Question**: What is the essential difference?

$$\text{minimize} \sum \{\boldsymbol{\beta}^T \boldsymbol{f}(\boldsymbol{x}_i) - y_i\}^2$$

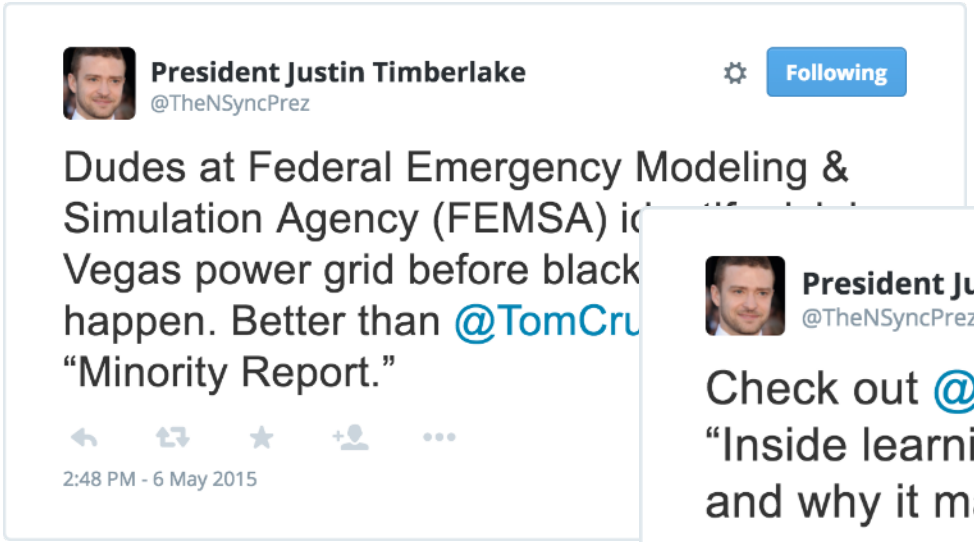
- **Answer**: The meaning of $\boldsymbol{x}$.
  - We observe at most **one** $\boldsymbol{x}$.
  - We need to **model** what happens at *new* $\boldsymbol{x}$'s.

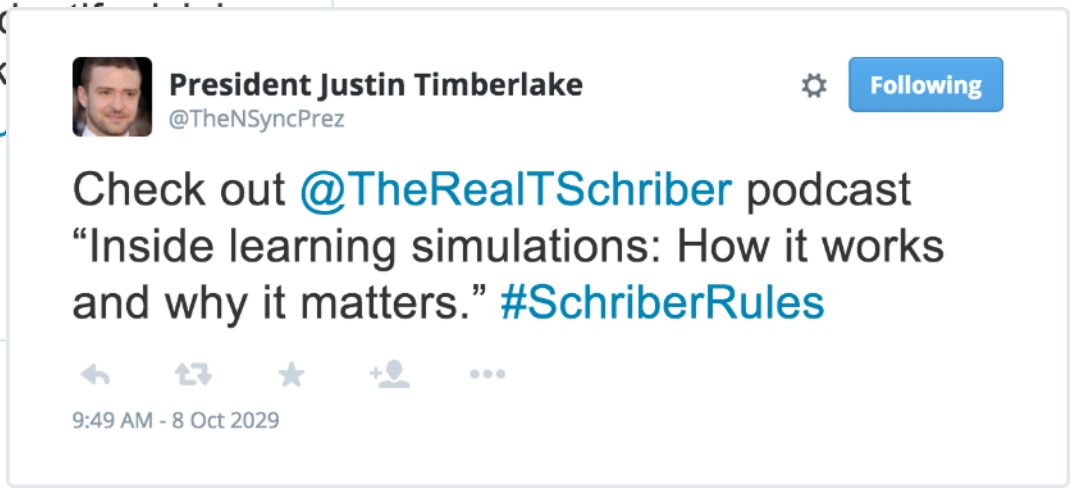
$$\text{minimize} \sum \left\{ \text{Resources: Doctor, Bed, Nurse, MRI} - \text{Dynamic System Data} \right\}^2$$

# "Learning" our simulations

- Statistical models can be learned from data.
  - Push as much of the simulation model **as sensible** to being an "input."
- But we are interested in more than the *observable* I-O relationship.
  - Embedded in the data is a *control* $\boldsymbol{x}$ that we want to *change*.
- The "art" part is what a *change in* $\boldsymbol{x}$ will do to the I-O relationship.
- **Our value add**:
  - Modeling focused on the impact of *changes*.
  - Fully recognizing uncertainty to generate robust, defensible solutions.

# Tweets from our future: 2029



## CHALLENGE #2

# Simulation: the glitter or the glue?

# Think BIG

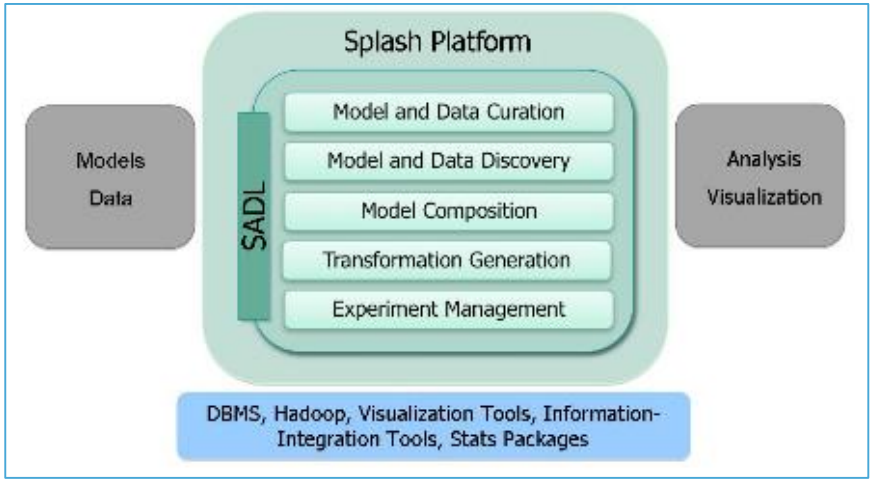
- Many of society's most important challenges — healthcare, global terrorism, income inequality, world food supply, power distribution, unfiltered tweets — are **systems-of-systems problems**.
  - What is our role in solving these "harder" problems?
- Strategies that seem doomed to fail:
  - One big, fully detailed model of *everything*.
  - A simple, stylized model that provides "insight."
- "**Models of models**" seem to be required.
  - Should simulation be the glitter or the glue?

# An argument for glue…

- We naturally account for **time**.
- Level of detail can be **variable** and **our choice**.
- **Uncertainty** matters; if it can be modeled then we can include it.
- We do **realizations**, and realizations **parallelize**.
- We have a history of **combined** discrete-event, continuous-state, agent-based, and hybrid modeling.
- **Simulation is arguably the least restrictive modeling & analysis paradigm.**

# Cool proof-of-concept: IBM Splash

- "The **Splash** project provides a prototype platform for combining existing heterogeneous simulation models and datasets to create composite simulation models of complex systems, thereby facilitating cross-disciplinary modeling, simulation, and optimization."
- The Splash philosophy is to **take the world as it is** (i.e., lots of individual models) and to solve the **assembly problem**.



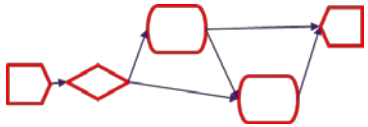

Haas et al. "Splash: Simulation Optimization in Complex Systems of Systems," Fiftieth Annual Allerton Conference, UIUC, 2012

# Why are we "not yet ready for prime time"

- We are not good at **policy optimization** or **system control.**
- We typically think in terms of a **single-resolution** model and **one time scale**, that tries to **get everything right**.
- **Computation** does matter ("computationally tractable").
- Our dominant model-building paradigm **does not easily scale up** to large, data-driven, parametric, multi-resolution models.
  - Watch closely as the keynote speaker now commits professional suicide.

# Drag & drop ‘til you drag & drop

- Drag and drop with embedded animation has been good to us, but going forward it is a **bottleneck**.
  - Glitter!

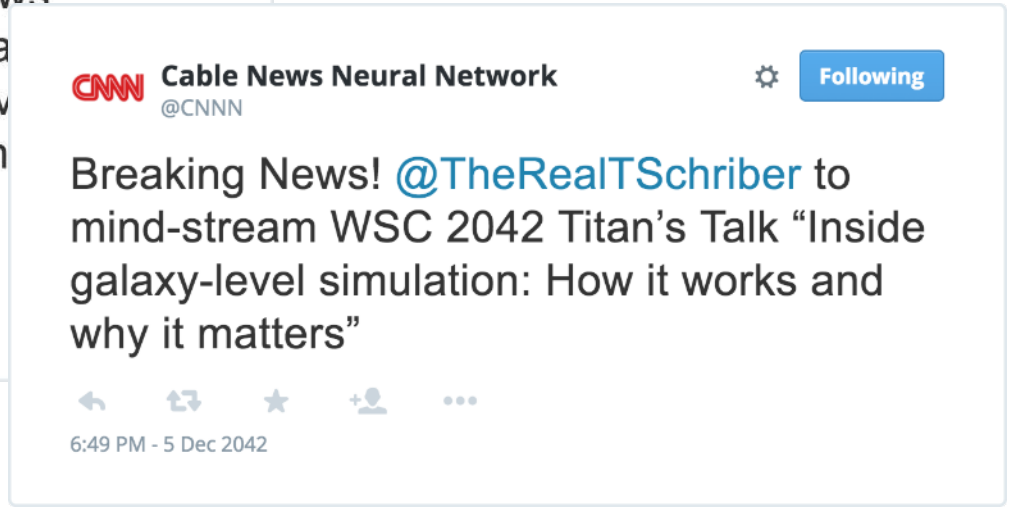


- **Models connected to the real world**
  - Call out to the world & “symbiotic simulation”
- **Aggregate & disaggregate time, space and data**
  - Input and output to multiple models
  - “Believe your limit theorems” — PW Glynn
- **Retain as much I/O data as possible**

- **More data-driven input and structure**
  - Relationships that build the models, not just models that build the relationships
- **Models easily created, updated & explored**
  - Easy to change; easy to vary
  - Reference models rather than analysis models

- But **Python** is not the answer either.

# Tweets from our future: 2042

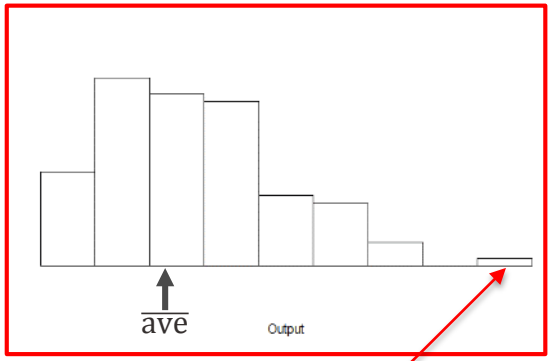



## CHALLENGE #3

# All the world's a database

# What's wrong with this? A thought experiment

- Think about something *important* that you would simulate.
  - Big is bad; small is good.
- You run some number of replications of one scenario.
- You look at the average and a histogram of performance.
- What is the first question that comes into your mind when you see **this**?




- "Why did that happen?"
  - Do we actually ask this question?
  - Would we know how to find the answer?

# Why the world loves "the machine"

- *Conditional statements* are useful for making money:
  - **Unconditional**: Customers spend $87.12 on average

    vs.

    **Conditional**: A university professor from the Midwest spends $1.35 on average
- "Big Data" is less about *quantity* and more about *coverage* of a space of *covariates*.
- Unconditional has been ok because **design** is more forgiving than **operations**.
  - For macro changes the "main effects" matter, but control is about "dynamics."
- If we want to be taken **seriously** in the future, then we have to take our **simulation-generated data seriously** too.

# Taking simulation data seriously

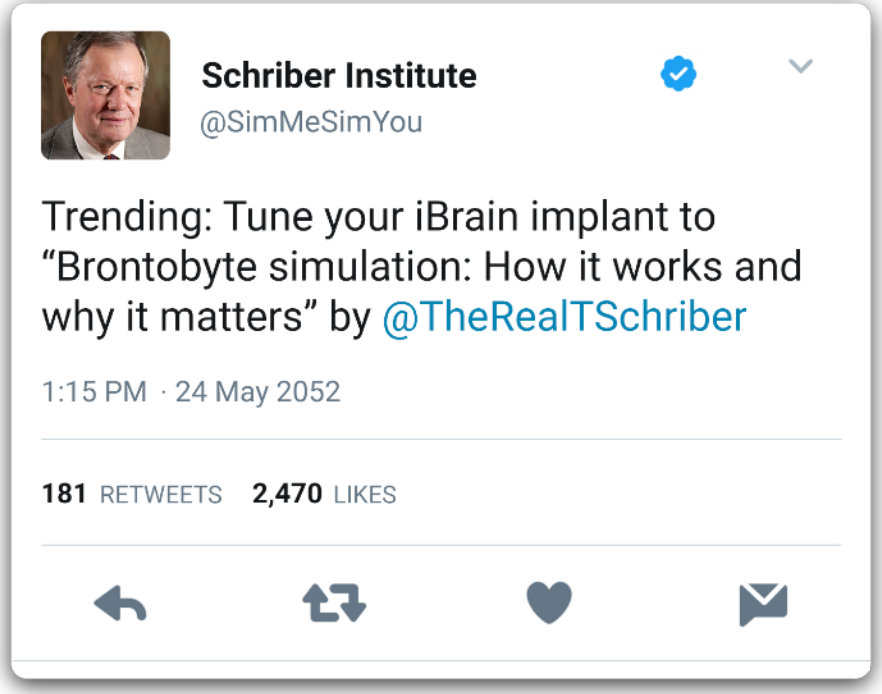
- Last year Titan Susan Sanchez talked about **data farming**:
  - Experiments to explore **huge** factor spaces of complex systems.
  - Recognizes our differences from "field data" analytics:
    - We can **design** the experiment to **grow** the data.
    - High-performance computing ≠ Infinite computing.
    - And we can go back for more.

# Making simulation runs you don't "need"

- **Proposition:** One purpose of a simulation is to fill a database with detailed, relevant, dynamic observations of systems that do not yet exist to be mined for insight & solutions as needed.
- **Translation:** Simulation everywhere, all the time.

- Same decision made repeatedly in evolving conditions.
  - Forecast-driven designs
- Very expensive simulations covering a big factor space.
  - Low-discrepancy/low-uncertainty designs
- Want to decide if real-world experiments are worthwhile.
  - Designs that mimic real experiments.
- Detect trouble before it happens.
  - Designs that seeks danger close to where we are now

# Tweets from our future: 2052

## CHALLENGE #4

# Mutually assured relevance

$$\mathrm{E}_{\psi}[g(X)] = \int g(x)\frac{\psi(x)}{\varphi(x)}\varphi(x)dx$$

```
>>> def car(env):
...     while True:
...         print('Start parking at %d' % env.now)
...         parking_duration = 5
...         yield env.timeout(parking_duration)
...
...         print('Start driving at %d' % env.now)
...         trip_duration = 2
...         yield env.timeout(trip_duration)
```

# Benchmarks

- **Optimization** and **Statistics** are two communities that are very similar to us.
- Yet the connections seem better for them.
- Why?

# Statistics

- The competitive advantage comes from providing deeper and more-robust insight than others can provide.

- Not concerned with the **creation of data.**
- Vendors compete with free options that have extensive and continually evolving public libraries to provide better answers.

- Implications
  - Need to implement near the cutting edge.
  - Worth employing methodologists; worth it to methodologists to work with data & software.
  - Intensive computation is OK.




# Optimization

- A universally agreed upon definition of **"the problem"** allows the model to be separated from the solver.

- Implications
  - Competition is on better solvers for harder problems.
  - Connection to latest OR & CS research is a competitive advantage.
  - Intensive computation is expected.

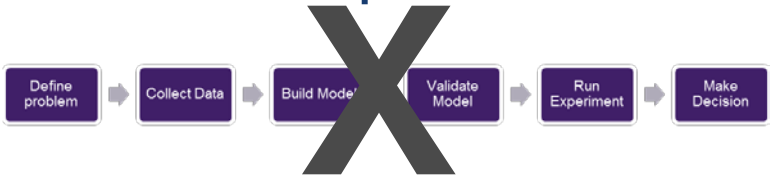
Optimize $f(x)$
such that $x \in C$


GUROBI
OPTIMIZATION

IBM
CPLEX

# What about the good guys (simulation)?

- The focus has been on generating the **right data** (including animation) not analysis of a common model.
- **Researchers** pretend that…




- **Users** understand modeling takes time, but can be impatient if the simulation itself does.
- It is a competitive advantage for **vendors** to differentiate based on better modeling.

# It takes a SimCity

- **"Better answers to harder problems in a more timely way" won't happen separately in each group.**
  - **Researchers**: Machine learning research involves real (i.e., hard) data sets, but we don't often work with real simulations.
  - **Vendors**: R, Python, etc. succeed because "better answer" has become more important than "easy to use."
  - **Users**: Ad hoc modeling & simulation methods really can produce misleading results that underachieve your objectives.
- **The good news is that all the key players are at WSC, every year.**

# Tweets from our future: 2067


# So what are the chances?

- "To a large degree, it [simulation] developed as a **counter element** in the emerging computer culture — a tool for support in an area that aimed toward the practical rather than the theoretical, and toward the complex rather than the simple."
  - Julian Reitman, 25th Anniversary Panel Discussion, WSC 1992.
- Computing, data & acceptance of scientific management work in our favor.
  - Provide robust, credible solutions that comprehensively hedge risks.
  - Be the foundation for modeling the most difficult societal problems.
  - Produce data analytics before there are data.
  - Deliver theory in support of practice, and practice in support of theory.
- **We do all that and our chances are pretty good.**

# THANK YOU

# ACKNOWLEDGEMENTS


**SLAVE LABOR**

Yujing Lin • Linda Pei • Mark Semelhago • Eunhye Song

**SAGE WISDOM**

Paul Fishwick (modeling guru) • Robert Sargent (history spoilers)
Dave Goldsman (joke tester) • Russell Barton (ego deflator)

**TEST MARKETS**

2017 INFORMS Simulation Society Workshop:
“Toward an Ecosystem of Models and Data”

2017 BIRS Workshop: “Future Research Directions in
Digital Simulation Methodology for the Next 10 Years”

Supply Chain Optimization Tech Talk @ Amazon

**INSPIRATION**

Peter Glynn • Peter Haas • Jeff Hong • Leon McGinnis
Shane Henderson • Henry Lam • Susan Sanchez
And the many who have given their time and talents to WSC