Engineering Systems Doctoral Seminar

ESD.83 – Fall 2009

Class 4
Lec #4
Faculty: Chris Magee and Joe Sussman
Guest: Professor John Little

MIT ESD
Massachusetts Institute of Technology
Engineering Systems Division

Session 4: Agenda

- Welcome and Overview of class 2 (5 min.)
- Dialogue with Professor Little (55min)
- Break (10 min.)
- Discussion of other papers (lead David Ramberg, 30 -40 min)
- Theme and topic integration (Magee)
  - What I learned while modeling vehicle crashes
  - Models taxonomy and uses
  - What I learned about modeling PD
  - Comparisons among some model types
  - Report from the Front
- Next Steps -preparation for week 5- (5 min.)

Quotes on Models

- “All models are wrong but some are useful” (attributed to George Box – date perhaps 1970s)
- The best theory is the one that is as simple as possible but not at all simpler (Einstein)

“Learnings” from Crash Modeling

- CLM entry into “crashworthiness”

NHTSA ESVs in early 1970s

- Research and build cars to meet a set of "stretch" crash standards.
- One mode (the "hardest" to meet) was to strike a rigid pole at 50 MPH.
- "Simple scaling of *physical/analog* model"

"Learnings" from Crash Modeling 2

- CLM entry into "crashworthiness"
  - **Simple quantitative models *can be predictive* (and useful)**
- Full-scale "design-oriented" models (1972-1990)
  - A full range of modeling approaches were developed in parallel "coopertition"
  - "lumped mass" semi-empirical models and non-linear elasto-plastic FEMs were the main candidates

Classification of Models

Physical or Iconic	Analog	**Mathematical or Symbolic**	Schematic

$$-x\cdot\frac{\mathrm{d}h}{\mathrm{d}t}=\frac{-h^{3}}{12\mu}\cdot\frac{\mathrm{d}p}{\mathrm{d}x}$$

$$E=\int_{a}^{b}\frac{1}{\sqrt{2\pi}\sigma}e^{-x^{2}\frac{1}{2\sigma^{2}}}f(x)dx$$

Definitions

- **Physical Model** – A construct that physically (but abstractly) represents the system
- **Analog Model –** A construct that functionally (but abstractly) represents the system
- **Schematic Model-** A human-designed way of assessing or understanding an important aspect of a system. Such models often attempt to abstractly represent several system functions and their interaction
- **Mathematical (or Symbolic) Model** – A construct that comprises a mathematical representation (abstraction) of a real system. Models are constructed by people, often for the purpose of system design.
- **Computational Simulation** – A mathematical model implemented in a digital computer

The main contenders for crash models

- Lumped mass= physical/empirical structural elements “hybridizied” with DE dynamics models
- Non-linear, elasto-plastic Finite element computer simulations

Crash Models

- Lumped mass= physical/empirical structural elements “hybridizied” with DE dynamics models
  - 1973: reasonably constructed model (iterate with experiment) ~10 % error in acceleration profile
- Non-linear, elasto-plastic Finite element computer simulations
  - 1973: first models were an order of magnitude (1000%) wrong and cost lots more to run

Crash Models 2

- Lumped mass= physical/empirical structural elements “hybridizied” with DE dynamics models
  - 1993: reasonably constructed model (iterate with experiment) ~10 % error **but still not useful in design**
- Non-linear, elasto-plastic Finite element computer simulations
  - 1993: models were **more accurate, reliable and cheaper than experimental prototypes**

"Learnings" from Crash Modeling 3

- CLM entry into "crashworthiness"
  - **Simple quantitative models can be predictive (and useful)**
- Full-scale "design-oriented" models (1972-1990)
  - **More complex models won this competition "hands-down"**
- Although FE models started "far behind", lumped mass models were never capable of "***serious***" prediction

Enablers of knowledge accumulation

- **Falsifiable theories** (**Richer levels of prediction increase falsifiability**);
- **Critical** vs. dogmatic **thinking;**
- The use of **mathematics** and other logic methodology in analysis of observations and creation of theory;
- **Iterative** theoretical and experimental cycles moving from “myths” to well-defined qualitative frameworks to more tightly defined quantitative theories;

Implementation of the successful crash modeling approach

- How might one suspect that the successful modeling technology was adopted?
- Does Turkle's work suggest any issues that might arise?

“Learnings” from Crash Modeling 4

- CLM entry into “crashworthiness”
  - **Simple quantitative models can be predictive (and useful)**
- Full-scale “design-oriented” models (1972-1990)
  - **More complex models won this competition “hands-down”**
- The organizational implementation of a highly accurate modeling approach **was as challenging as the development.**

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Modeling Product Development

- IN the late 1990s, SD models (fairly elaborate) were built and exercised to educate PD managers about what is going on in PD
- “Progress and utility”
- Would have my experience been any different with an agent based model?

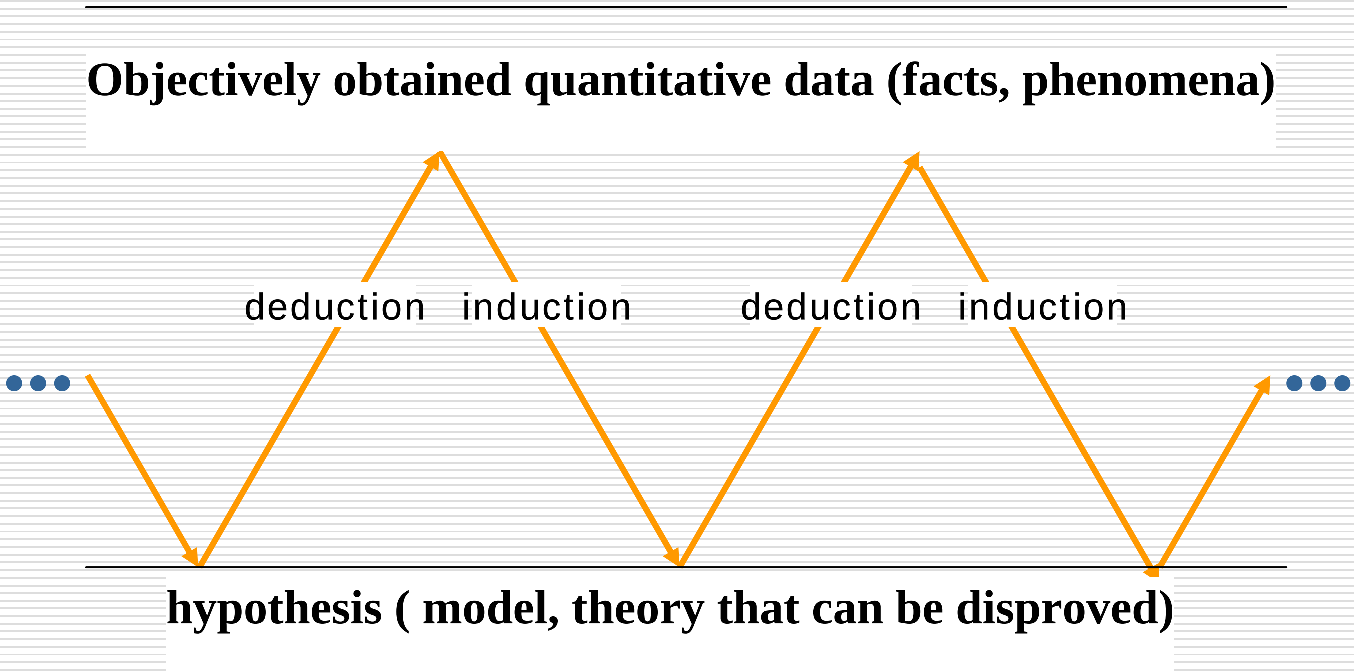
The Importance of appreciating "Enduring Dilemmas"

- Enduring dilemmas involve pairs of incompatible factors which are simultaneously necessary. In practical problems, there are **always** such dilemmas and effective solutions must be structured to honor **both** poles in each dilemma.
- In modeling, one such dilemma involves simplicity vs completeness

Comparisons among Model Types 2

- What would it take to make SD models predictive?
- What would it take to make ABMs predictive?

The Iterative Learning Process



A falsified theory/model serves as a stronger basis for “guessing” a better theory/model. **A model that makes no predictions cannot be falsified and therefore cannot be improved**

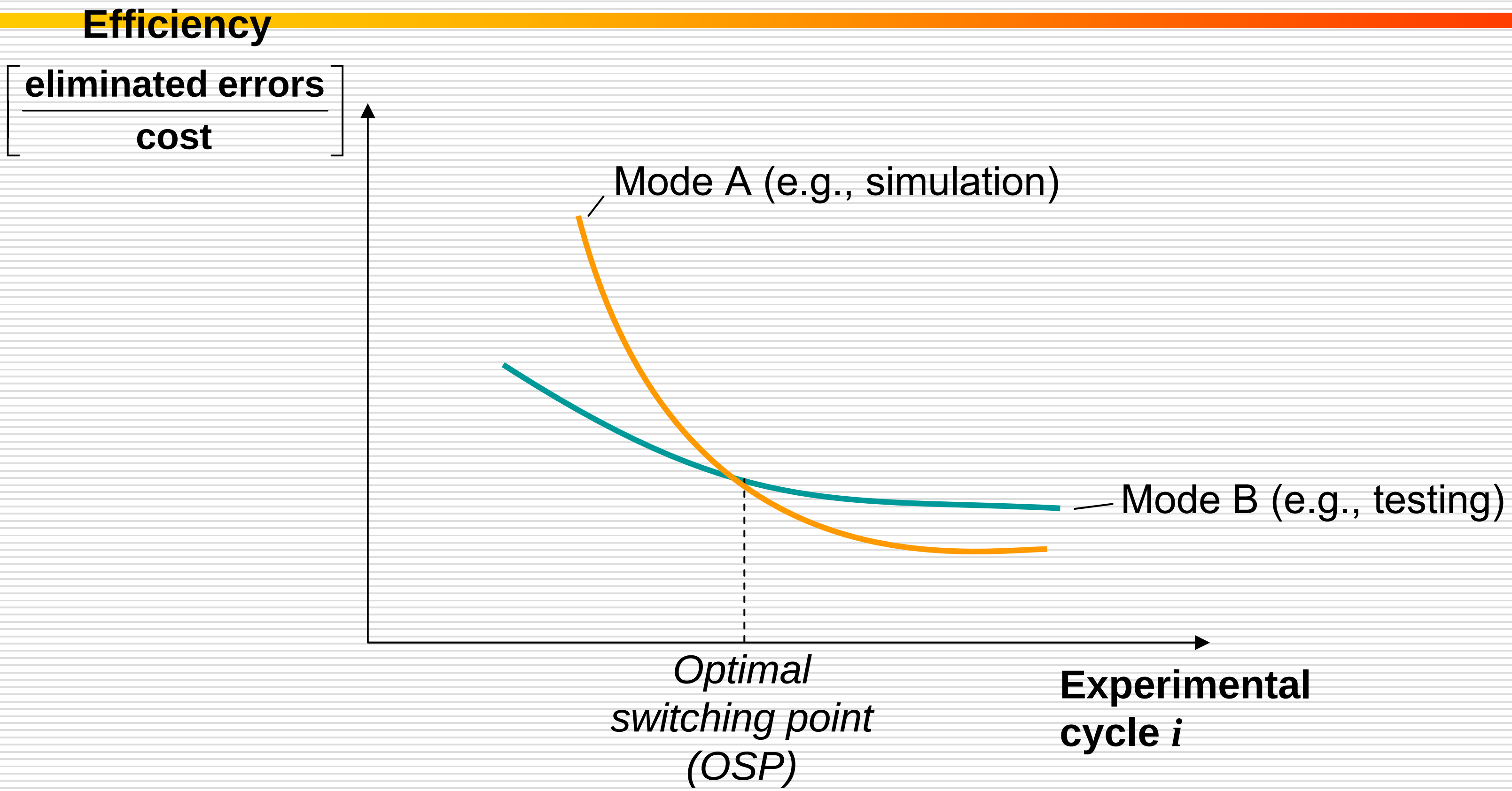
Quotes on Models 2

- "All models are wrong but some are more useful than others" (attributed to George Box –date perhaps 1970s)
- All models are wrong **but some are capable of being fundamentally improved by testing against reality** while others are not (Chris Magee, 2009)

Report from the Front

- What relevance did the article have to today's topic?
- According to Krugman, what lesson learned about models came from the recent economic "meltdown"?

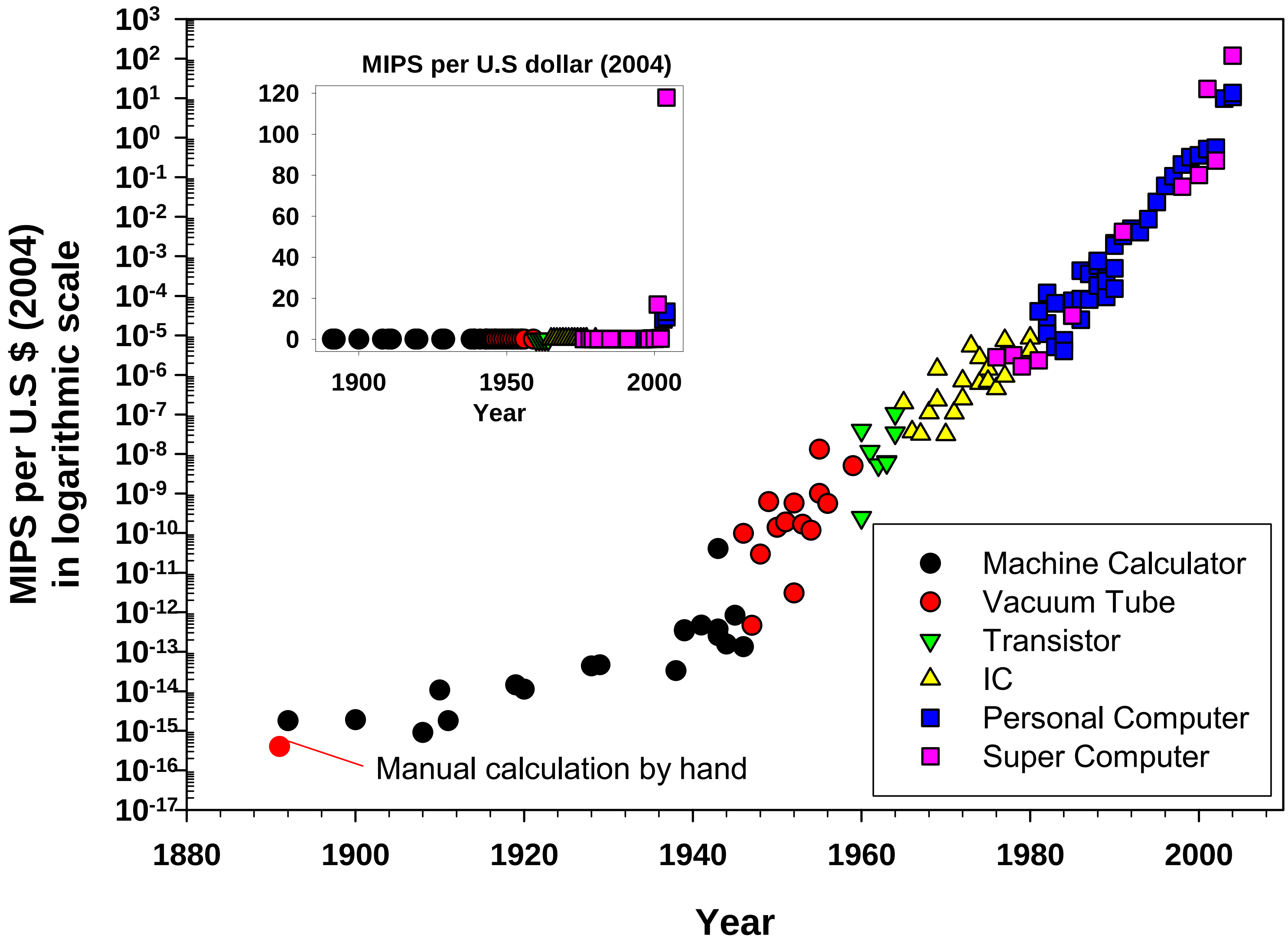
Switching between different modes as experimentation efficiencies decrease at different rates



Why might the efficiency decrease with time for any mode?

Why might different modes have different slopes?

Computational speed per dollar – before and after Moore's Law



Mathematical Models are broadening in scope and are Becoming Easier to Use

- A wide range of models are available
  - Finite Element Analysis
  - Computational fluid dynamics
  - Electronics simulations
  - Kinematics
  - Discrete event simulation
  - Process-based cost models, value models
  - Reliability and robustness models
- Sophisticated visualization & animation make results easier to communicate
- Many tedious tasks are becoming automated (e.g., mesh generation and refinement)

Mathematical Models are Becoming Better Interconnected

- Product Data Management Solutions
- Distributed Object-based Modeling Environment
  - Enables a decentralized design simulation marketplace
  - Intends to do for models what HTML does for text

Image removed due to copyright restrictions.

Nicola Senin, David R. Wallace, Nicholas Borland, 2003, Distributed Object-Based Modeling in Design Simulation Marketplace, *ASME J. of Mech. Design*.

An in- class quiz- “Conflicting Signals”

- Team 112z in the ZAP Company is developing a new product/system that is very critical to ZAP’s future success. Team 112z has also received pressure to stay on time and within the development budget. One part of the system (subsystem 2) was delayed relative to other parts of the design because of need for extra “human interface prototypes” before specifications were set. Subsystem 2 is now beginning to catch up to other subsystem design work but a dispute has arisen about action to take in response to a potential problem. As the leader of team 112z you are required to make the decision.
- FACTS
- A pre-existing analytical tool indicates that the recently completed subsystem 2 design will NOT meet an important requirement (low by 15%). The analytical tool is relatively new because the requirement is technically difficult to predict and one parameter (Alpha) which has significant impact on the requirement had to be determined as part of a verification program. In-depth studies of 5 previous subsystem 2 designs as parts of other ZAP Company projects had established that **one specific parameter value (alpha =120) fit all previous results within 5%.** The predictions from the tool were also consistent with other usual system behaviors relevant to this requirement.
- The engineers responsible for Subsystem 2 design had concerns about the validity of the analytical tool. They decided to build an “approximate” prototype using previously built versions of all other subsystems incorporating a “rough” version of what might represent subsystem 2 when it could actually be built. This prototype exceeded the requirement by 25%. These engineers noted that the analysis could be consistent with this test if a value of the parameter was chosen that is well within known physical bounds (Alpha = 135). They argued that this “slightly different” alpha for this program was more reasonable given the experimental results and the technical difficulty and newness of the analytical tool. Therefore, they recommended alternative b below. The analytical group favored alternative a.

Decision required

- For this quiz, you are required to decide among ONLY the two alternatives below with NO further information gathering.
  - a.) redesign subsystem 2 immediately to meet the requirement before building prototypes (delay of 1 month).
  - b.) recalibrate the model by using the higher alpha for this project and proceed acknowledging little risk.
- Class debate/consensus
- If further information gathering were possible, what are the most important questions to explore?

Why Models Can Go Wrong

- Right model → Inaccurate answer
  - Rounding error
  - Truncation error
  - Ill conditioning
- Right model → Misleading answer
  - Chaotic systems
- Right model → No answer whatsoever
  - Failure to converge
  - Algorithmic complexity
- Not-so right model → Inaccurate answer
  - Unmodeled effects
  - Bugs in coding the model

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These may be the biggest problems of all

Errors in Scientific Software

- Experiment T1
  - Statically measured errors in code
  - Cases drawn from many industries
  - ~10 serious faults per 1000 lines of commercially available code
- Experiment T2
  - Several independent implementations of the same code on the same input data
  - One application studied in depth (seismic data processing)
  - Agreement of 1 or 2 significant figures on average

Hatton, Les, 1997, "The T Experiments: Errors in Scientific Software", *IEEE Computational Science and Engineering*.

Uses of Models in Engineering

- Engineers seek to answer these questions:
  - Will the system, as designed, work?
  - Which of two system designs is the better?
  - Do I adequately understand the system?

Hazelrigg, 1999, “On the Role and Use of Models in Engineering Design”, *ASME J. of Mechanical Design.*

Definitions

- **Accuracy** – The ability of a model to faithfully represent the real world
- **Resolution** – The ability of a model to distinguish properly between alternative cases
- **Validation** – The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model. (AIAA, 1998)
- **Verification** – The process of determining that a model implementation accurately represents the developer’s conceptual description of the model and the solution to the model. (AIAA, 1998)

Models for Decision Support

- What are the critical elements to making informed engineering decisions?

- Are there engineering decisions that can be made with confidence despite large uncertainties?

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