Engineering Systems Doctoral Seminar

ESD.83 – Fall 2009

Class 2

Lec #2

Faculty: Chris Magee and Joe Sussman

Guest: Professor David Kaiser (STS) and Senior Lecturer (Physics)

Session 2: Agenda

- Welcome and Overview of class 2 (5 min.)
- Dialogue with Professor Kaiser (55min)
- Discussion of other papers (lead Tommy Rand- Nash, 30 -40 min)
- Break (10 min.)
- Theme and topic integration (Magee)
  - Cumulative knowledge in engineering and science
  - Attributes for enabling knowledge accumulation
  - Report from the Front
- Next Steps -preparation for week 3- (5 min.)

“Calling Card”- Personal Experience

- Ph.D + 4 Years in Ford ***Fundamental Research***
- 10 years in applied research, **engineering** and management **+MBA**
- 15-20 years in vehicle systems engineering and higher **management**
- 35 years total at Ford Motor Company
- Last ~8 years at MIT as ***Professor of Practice*** in Engineering Systems and Mechanical Engineering

Cumulative Aspects of Science and Engineering/Technology

- The science (research) process with science (knowledge) as the output
  - **What characteristics indicate and/or enable accumulation of knowledge?**
  - Laws, principles and theories in the natural sciences
  - On the "validity of knowledge"
    Falsifiability
  - The induction problem
- The engineering process with technology as the output
  - What enables technology to be cumulative?

Physical Laws from Wikipedia

- A **physical law** or **scientific law** is a scientific generalization based on empirical observations of physical behavior (i.e. the **law of nature** [1]). Laws of nature are observable. Scientific laws are empirical, describing the observable laws. Empirical laws are typically conclusions based on repeated scientific experiments and simple observations, over many years, and which have become accepted universally within the scientific community. The production of a summary description of our environment in the form of such laws is a fundamental aim of science. (WOULD FEYNMAN AGREE?)
- Conservative estimates indicate that there are 18 basic physical laws in the universe: [1]

Scientific Laws

- **Fluid mechanics**
- Archimedes' principle
- **Force, mass, and inertia**
- Kepler's three laws of planetary motion
- Newton's three laws of motion
- Euler's laws of rigid body motion
- Newton's law of universal gravitation
- **Heat, energy, and temperature**
- Newton's law of cooling
- Boyle's law
- Law of conservation of energy
- Joule's first and second law
- The four laws of thermodynamics
- **Quantum mechanics**
- Heisenberg's uncertainty principle
- Others, such as Roger Penrose with his 2004 book *The Road to Reality* (subtitled "A Complete Guide to the Laws of the Universe") argues that there are a large number of established laws of science. Some laws, such as Descartes' *first law of nature*, have become obsolete.

Falsifiability

- Popper on pages 47-48 gives a 7 point summary of what distinguishes scientific and non-scientific knowledge- he gives an overall statement as *“the criterion of a scientific status of a theory is its falsifiability or refutability or testability”*
- Confirmation is easy if one is looking for it. If there is little or no falsifiability, the theory is pseudo-science.
- Popper makes the point that “pseudo-science” can contribute – it should not be considered necessarily inferior. So why might we care about his “demarcation line”?

Accumulation of Knowledge

- How does falsifiability relate to knowledge accumulation?
- All useful theories contain strong prohibitions (Popper). Prohibitions mean we know a lot about where not to look for new knowledge. We can also use predictions to learn new knowledge when they "seem" not to work (Feynman page 13)
- Theories that are not falsifiable cannot be built upon because in a sense they explain everything already.
- Without falsifiable theories and hard testing, one can end up with "theory du jour".
- Thus, I think that Popper's "demarcation line" is a key characteristic of cumulative science

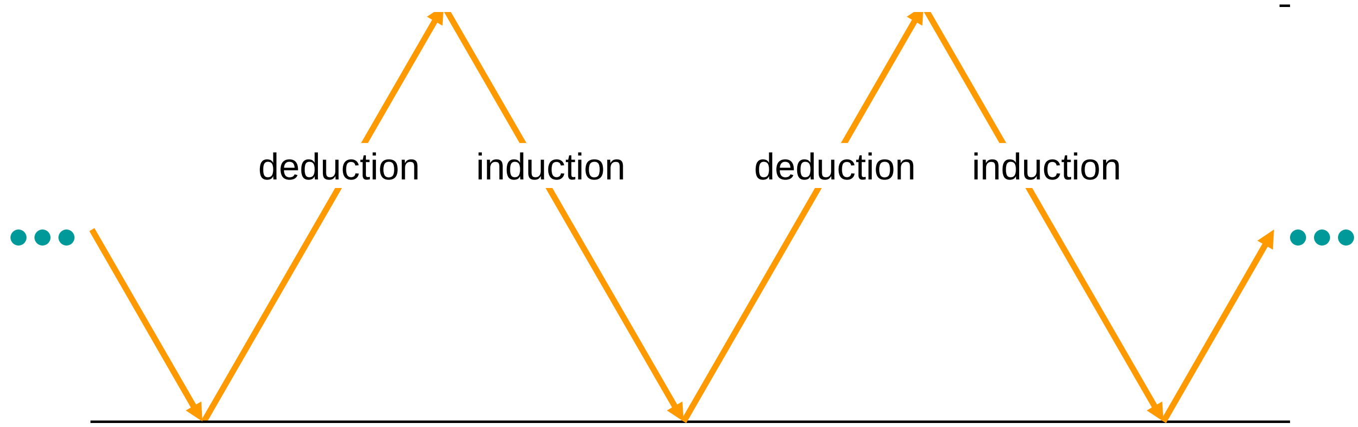
"Problem of Induction"

- No logical basis exists for establishing "*that those instances of which we have no experience, resemble those, of which we have experience*" *(*Hume in Popper)
- How do successful conjectures arise?
- What about generalizations?

- Is it a "wild guess" that happens to be right (as one might take away from Popper)?

The Iterative Learning Process

Objectively obtained quantitative data (facts, phenomena)



hypothesis (model, theory that can be disproved)

A falsified theory serves as a stronger basis for “guessing” a better theory. There are leaps but not without “some prior giant shoulders” (or “multitudes of shoulders in an extensive pyramid”) to stand on. Feynman emphasizes that existing theories allow one to make informed mathematical guesses but that experiment is the final arbiter.

The role of mathematics in science

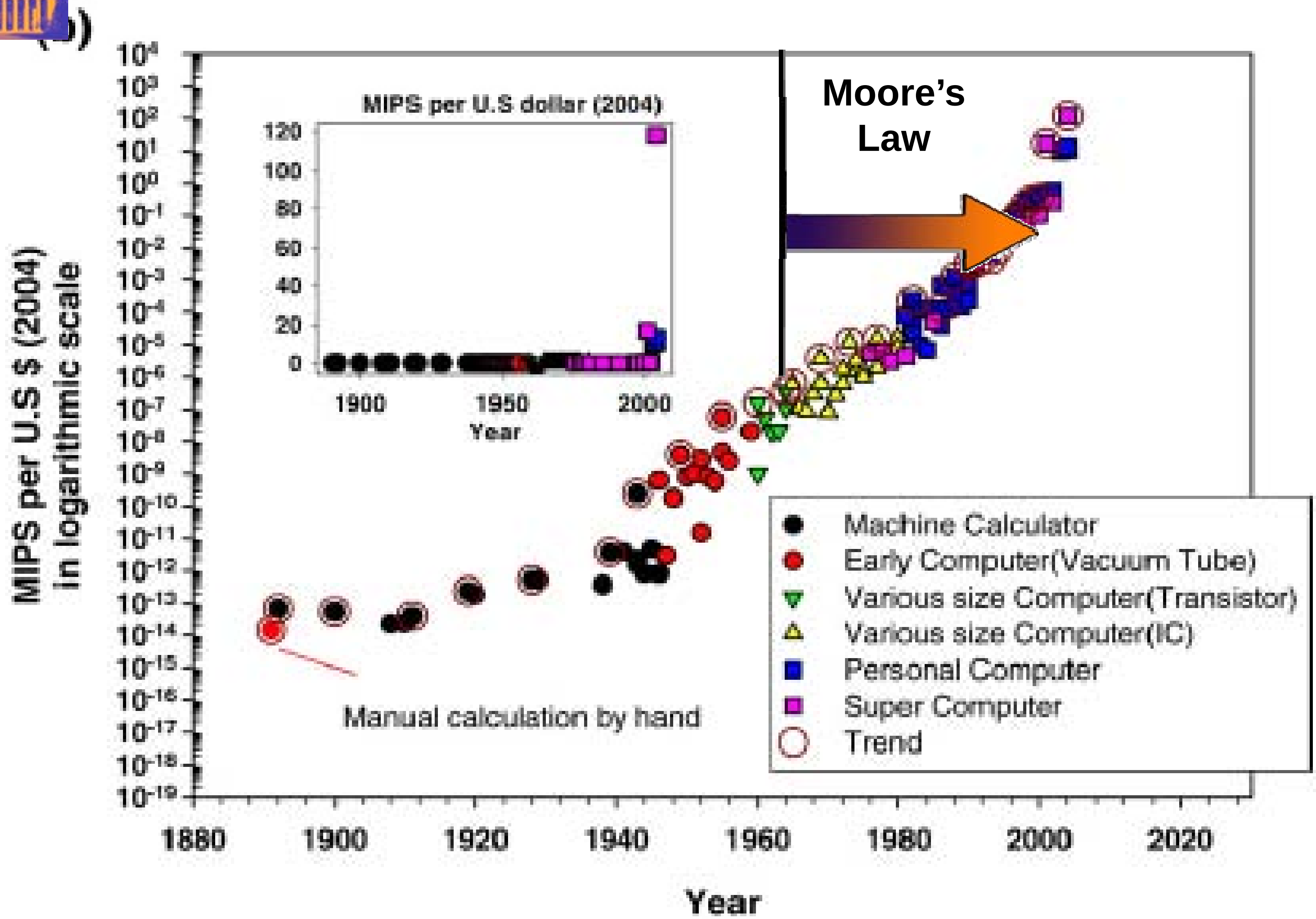
- Feynman, Einstein and many others have commented upon the “mysterious” power of mathematics to describe reality.
- How does the role of mathematics relate to our theme today(accumulation of knowledge)?
- In my opinion, there is a strong link because mathematical formulations are naturally much more testable/falsifiable.
- However, **in new fields the first conjectures are always non-mathematical** and we cannot count on mathematics having a strong role in all fields

What characteristics indicate and/or enable accumulation of knowledge?

- **Falsifiable theories** (science vs. pseudo-science);
- **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;

Cumulative knowledge 2

- Do you believe that technology (the output of the engineering process) is cumulative?
- How might one measure or determine empirically that technology is or is not cumulative?



(b)
MIPS per U.S $ (2004)
in logarithmic scale
MIPS per U.S dollar (2004)
Year
Moore's
Law
Manual calculation by hand
Machine Calculator
Early Computer(Vacuum Tube)
Various size Computer(Transistor)
Various size Computer(IC)
Personal Computer
Super Computer
Trend
Year

Technical capability time dependence

- TC = f(K) where K accumulates over time as TC advances
  - $dTC/dt = \alpha f(K) = \alpha TC$
  - $TC = \exp(\alpha t)$; EXPONENTIAL ..

- **Most importantly**, **exponentials** (even if not forever) **directly indicate accumulation** and every case (~50) shows exponentials .

Cumulative knowledge 2a

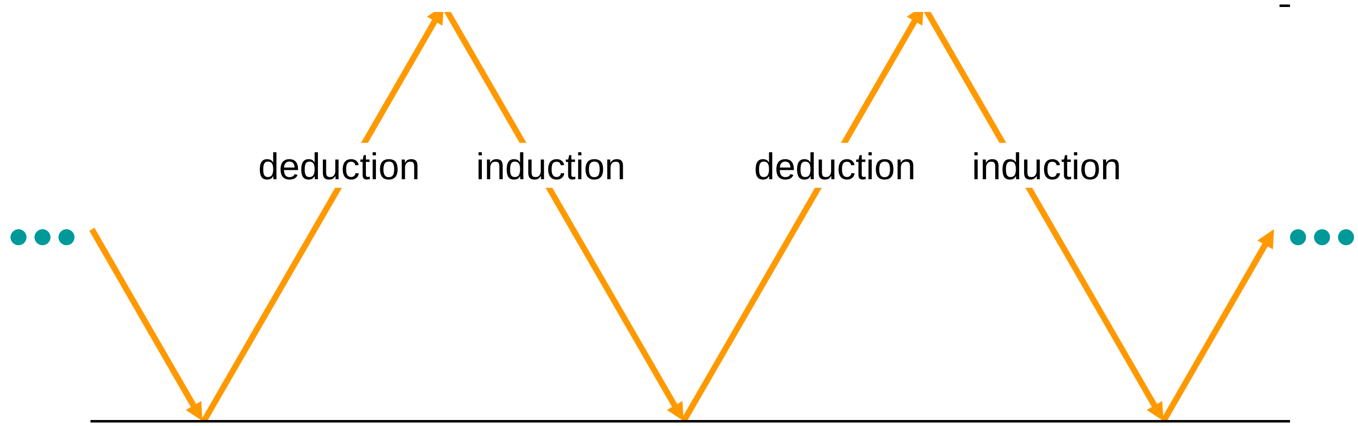
- Do you believe that technology is cumulative?
- How might one measure or determine empirically that technology is or is not cumulative?
- What mechanisms might apply?
- Partial or full "transference" between technological areas: "technology (science) can reap tremendous benefits when practitioners (researchers) move from familiar subjects to new challenges" –(Kaiser) , existing capability used in next advance, engineering principles growth, **the accumulation of scientific knowledge**, etc.

Cumulative knowledge 3

- Do you believe that scientific knowledge is cumulative- that is that current new knowledge builds upon (all) knowledge that came previously?
- What are possible mechanisms for accumulation?
- **Is cumulative knowledge apparent in socio-technical systems**?
- What is needed to accelerate the cumulative process in socio-technical systems?

The Iterative Learning Process

Objectively obtained quantitative data (facts, phenomena)



hypothesis (model, theory that can be disproved)

As this process matures,
what new can the models accomplish?

The major accomplishment will be the rapid facilitation of a transition to engineering (vs. craft approaches) for the design of complex social/ technological systems. This accompanies the transition from pseudo- science to science

Report from the Front

- "News article" from *Wired* (based upon a longer review article in *Nature)*
- Is the topic of interest to those of us who are highly interested in complex techno-social systems?
- Topic = "Scientists seek Warning Signs for Catastrophic Tipping Points"
- Is it of *general* interest?

Report from the Front 2

- "News article" from *Wired* (based upon a longer review article in *Nature)*
- Is there (yet) a *scientific* theory in prediction of "Catastrophic Tipping Points"?
- Do you think it is fundamental to distinguish between natural and social/ human complexity when trying to make predictions of tipping points?

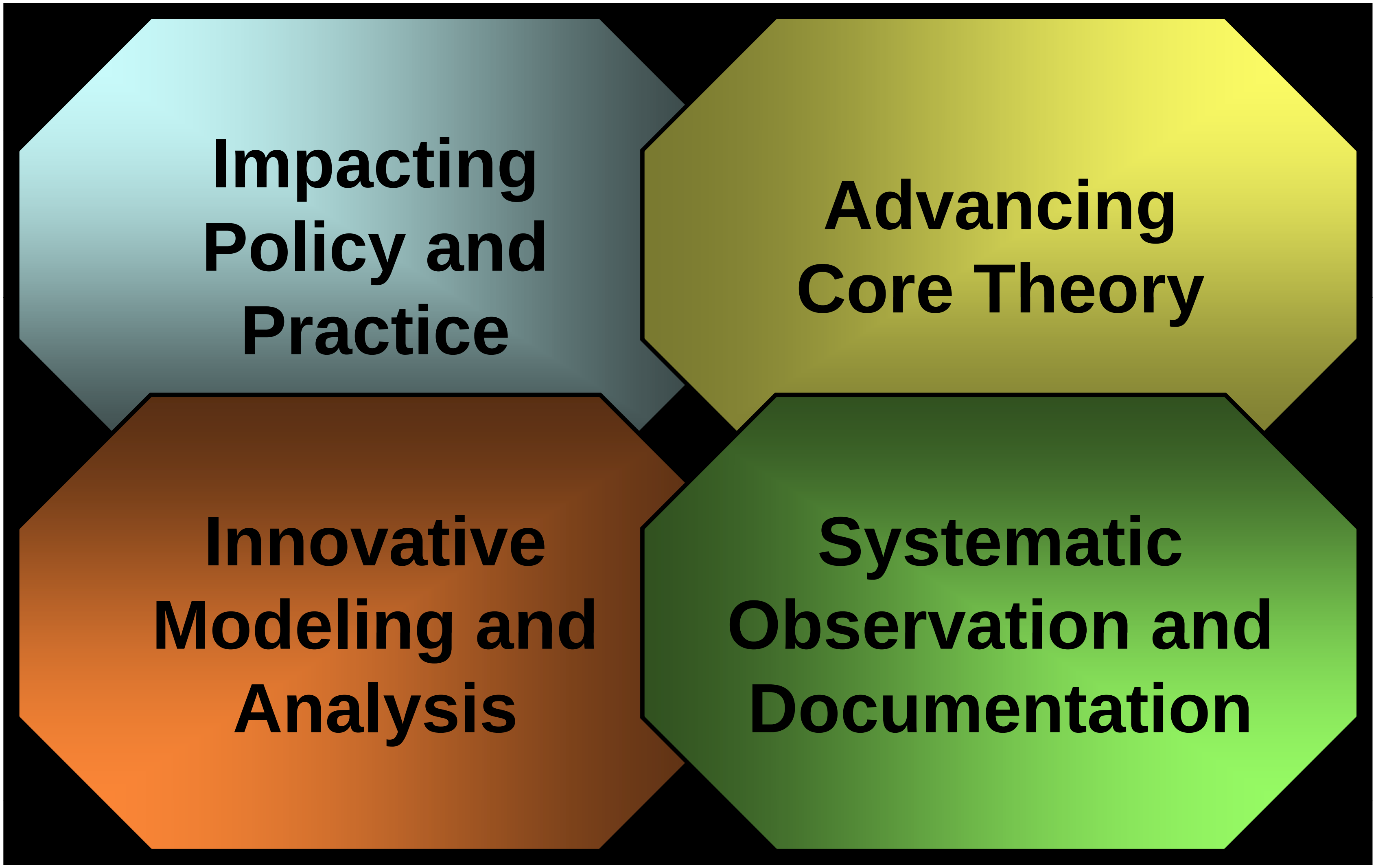
Further topical readings

1. Class 5 readings and other classes
2. Feynman –the rest of *CPL* esp. Chapter 7
3. M. Polyani- *Personal Knowledge* (etc.)
4. W. Vincenti, *What engineers know and how they know it*
5. Popper- *LSD* and the rest of *CAR*
6. Petroski- *The evolution of useful things*
7. T. Kuhn – *The Structure of Scientific Revolutions*

Cumulative Knowledge

- Do you believe that scientific knowledge is cumulative- that is that current new knowledge builds upon (all) knowledge that came previously?

Strategies for Advancing Engineering Systems as a Field



Some quotes

- The most incomprehensible thing about the universe is that it is comprehensible. -- Albert Einstein
- Nature uses only the longest threads to weave her patterns, so each small piece of the fabric reveals the organization of the entire tapestry – Feynman
- How can it be that mathematics, being after all a product of human thought which is independent of experience, is so admirably appropriate to the objects of reality? -- Albert Einstein

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