



Applying the Experimental Paradigm to Software Engineering

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Current situation

- **16.3%** of software projects are **successful**

The project is completed on time and within budget, and has all the features and functions specified at the start

- **52.7%** of software projects cost more, take longer or do less

The project is completed and operational, but it cost more than budgeted (189% more), took longer than estimated and offers fewer features and functions than originally specified (42%)

- **3%** are **cancelled**

The project is called off at some point during development before the system is put into operation

Current situation

■ Knowledge

- Today the results of applying software development methods are **unpredictable**
- There is **no evidence** to support most of the beliefs on which software systems development is based

■ Practice

- Method selection for and decision making on software production is **based on suppositions and subjective opinions**
 - When, by chance (or thanks to practitioners' personal and non-transferable know-how), the right methods are used, the software construction projects run smoothly and output the desired product
 - When the wrong methods are applied, the project develops haphazardly and the output product tends to be of poor quality
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2. Scientific laws
3. Predicting & understanding

2. Experimental Software Engineering

1. Is the scientific method applicable to SE?
 2. Experiment & laboratory
 3. Designing experiments
 4. Challenges in applying the scientific method to SE
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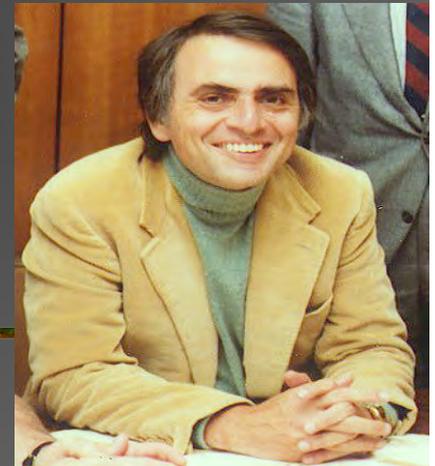


The Scientific Method

A process called science

- Science is a **process of understanding** the world
- *Science is a way of thinking much more than it is a body of knowledge*

Carl Sagan



Explaining the world

- Science looks for **explanations** about how a phenomenon works and why it works as we perceive it
 - These explanations are known as **laws or theories**
 - Nature generally acts regularly enough to be described by laws
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Scientific laws

- Are patterns of behaviour
 - Describe **cause-effect relationships**
 - Explain
 - **why** some events are related
 - **how** the mechanism linking the events behaves
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We only perceive nexus

- We cannot perceive laws directly through our senses
 - Anyone can see an apple fall, but Newton's inverse-square law of gravitation only becomes apparent through special systematic measurement



$$F_1 = F_2 = G \frac{m_1 \times m_2}{r^2}$$

- Two activities are necessary
 - Systematic **objective observation**
 - **Inference** of links between cause & effect

The scientific method

- Collection of empirical data
 - Systematic **observation** to appreciate nexus
 - Theoretical interpretation of data
 - Formation of hypotheses (right or wrong) about the **mechanism** relating the events
 - Collection of empirical data
 - Hypotheses to be **tested** against reality to find out whether or not they are true
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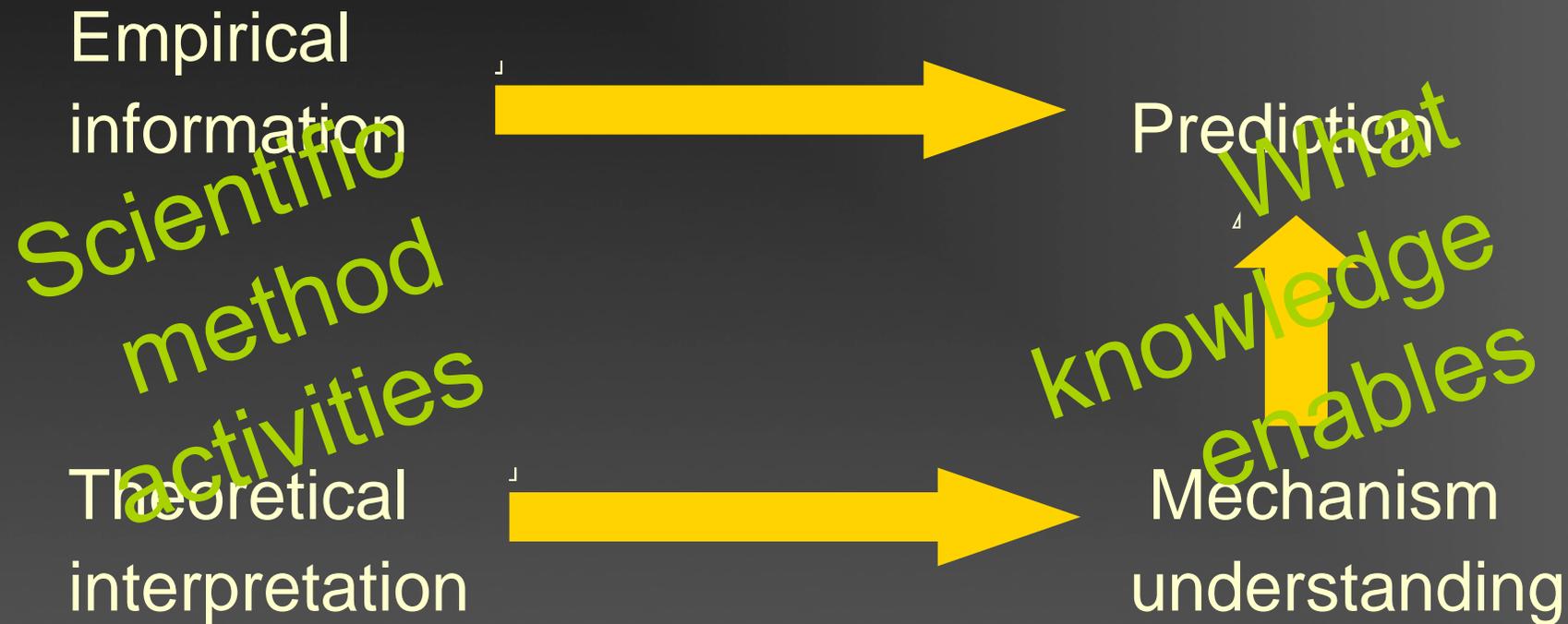
Building vs. understanding

- Humans are able to build interesting artefacts without scientific knowledge
 - The builders do not necessarily understand the mechanisms governing the observed behaviour
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Building without understanding



Predicting vs. understanding



Predicting without understanding

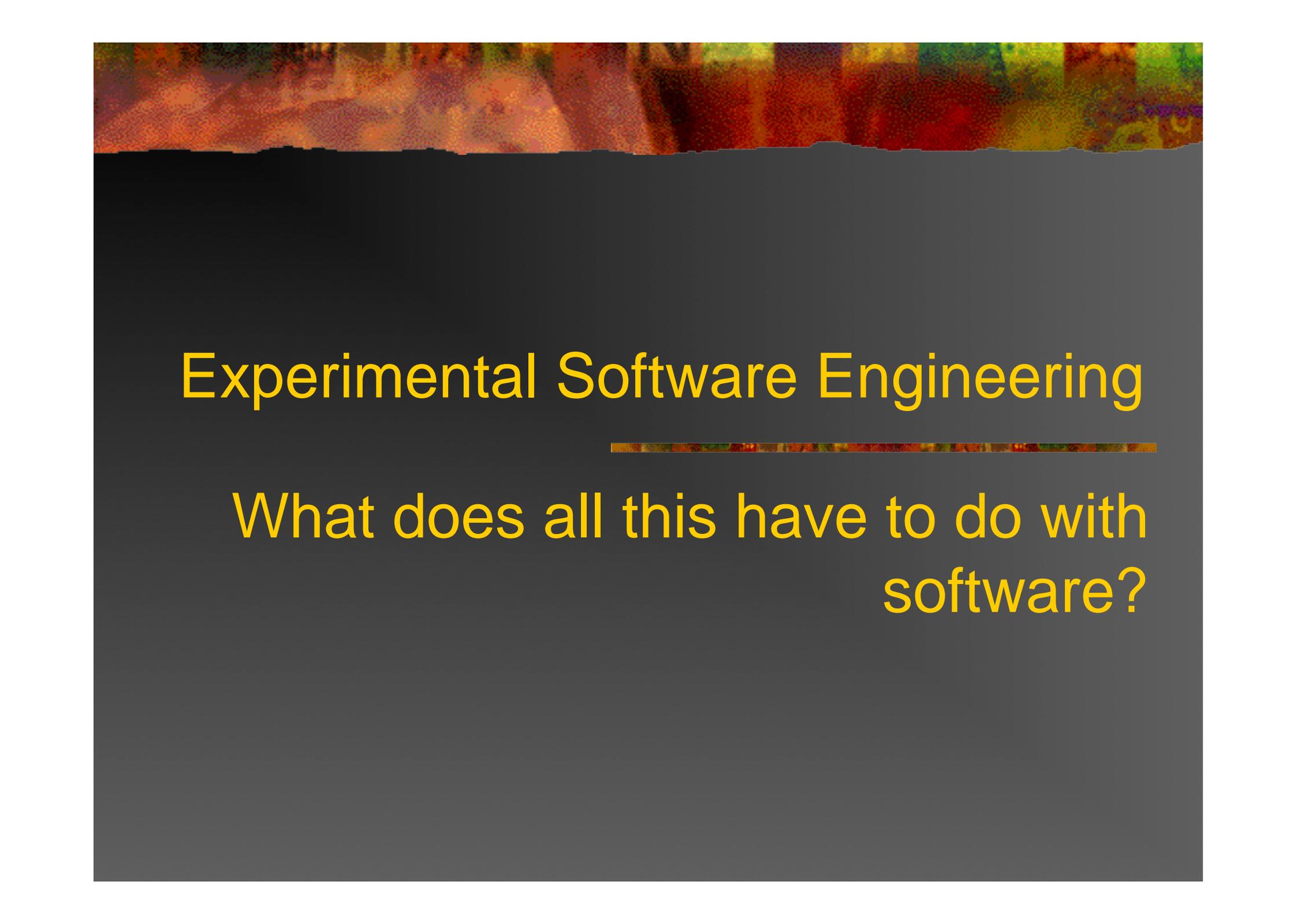


Data ⁴ ↔ theory

- Without an inferential leap to theory, the accumulation of data will never lead to an understanding of the mechanism
 - In the absence of empirical data, theories move in the realm of speculation
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Scientific research method

- A rigorous process for properly developing and evaluating explanations for observable phenomena based on reliable empirical evidence and neutral, unbiased independent verification
 - Not based on arguments from authority or popular preferences
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Experimental Software Engineering

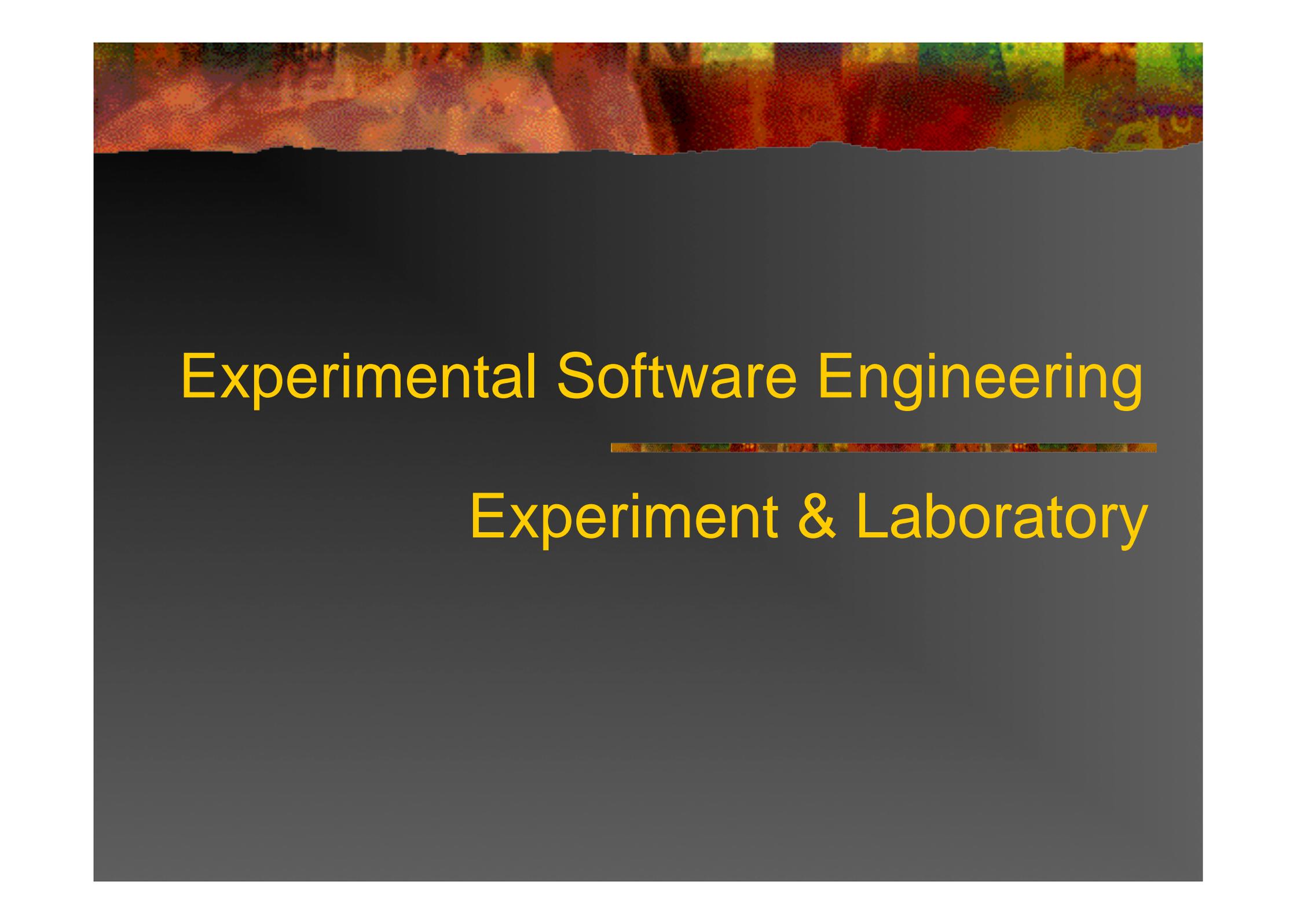
What does all this have to do with
software?

Experimental SE

- Generates **scientific statements about building software** through experimentation
 - This knowledge should help to identify the applicability conditions, strengths and weaknesses of the different software development technologies
 - All engineering disciplines have taken a similar step
 - Achieve predictable results moving from beliefs, speculations and lucky guesses to scientific knowledge
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Gaining SE knowledge with experiments

- Identify and understand
 - the **variables** that play a role in software development
 - the **connections** between variables
 - Learn **cause-effect relationships** between the development process and the resulting products
 - Establish laws and theories about software construction that **explain** development behaviour
-

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Experimental Software Engineering

Experiment & Laboratory

Experiment

- Experiments
 - Model **key characteristics** of a reality in a **controlled** environment by **manipulating them iteratively** to investigate the **impact** of such variations and get a better understanding of a phenomenon
 - Are a formal, rigorous and controlled investigation in which the variables under study are given different values to find out what effect each value has
 - The properties of a complex system are explained by analysing the behaviour of its parts
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SE experiment

- Development decomposed into its parts
 - Manipulated variables
 - Techniques (design, testing, etc.),
 - Developers (experience, knowledge, etc.)
 - Variables that can be assigned during development
 - Investigated impacts
 - Effectiveness, efficiency, productivity, quality
 - Examples of instances
 - number of detected defects, number of code lines, etc.
 - Interesting characteristics obtained as a result of development
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The laboratory

- Laboratory
 - Simplified and controllable reality where the phenomenon under study can be manipulated and studied
 - Chemistry laboratory
 - Flasks and pipettes where temperatures and pressures are controlled
 - Real world: real substances with temperature and pressures
 - Economics laboratory
 - Sets of individuals playing games to earn toy benefits
 - Real-world: markets (composed of thousands of agents) where real rewards are pursued
 - What is a SE laboratory like??
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SE laboratory

- Students
 - rather than professionals
 - Toy software
 - rather than real systems
 - Exercises
 - rather than real projects
 - Academic workshops or industrial tutorials
 - rather than real knowledge & experience in industry
 - Phases, techniques
 - rather than whole projects
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Weakness

- How representative is any lab finding of reality?
 - Different levels of experimental studies
 - In vitro experiments
 - In vivo experiments (from mice to monkeys)
 - Field experiments (from volunteers to clinical trials)
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External validity

- Is concerned with the extent to which the results can be **generalized**
 - **from** the unique and idiosyncratic experimental settings, procedures and participants
 - **to** other populations and conditions
 - **Generalizability** of experimental results to
 - the target population of the study
 - the universe of other populations
-

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Experimental Software Engineering

Designing Experiments

Cause-effect relationships

- The independent variable
 - is the variable that is thought to be the cause
 - must meet two requirements
 - be changeable
 - the change must be controllable

 - The dependent variable is
 - the effect brought about by this cause
 - is not manipulated
 - measured to see how it is affected by the manipulation of the independent variable
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Extraneous variables

- If extraneous variables also vary systematically with the independent variables
 - then conclusions regarding causality are not valid
 - the observations are “confounded”
 - Experiment **design involves controlling** the influence of extraneous variables on the dependent variables
 - Good design avoids confounding variables
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Control strategies

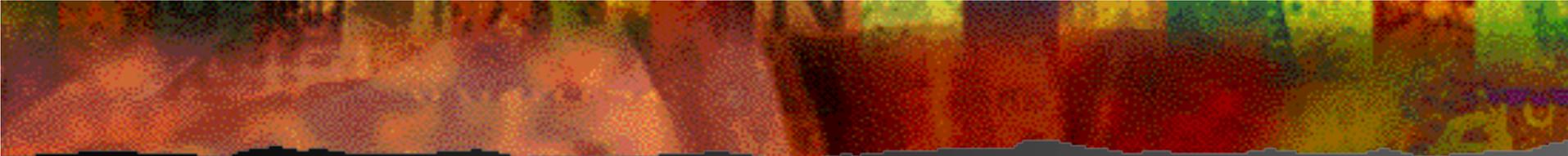
- Control neutralizes variation of extraneous variables
 - Control strategies
 - Constancy
 - Keeping extraneous variables constant
 - Blocking
 - Neutralizing known extraneous variables
 - Purposely assigning every value of the blocked variable to every group
 - Randomization
 - Neutralizing unknown extraneous variables
 - Random assignment of subjects to experiment conditions
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Experiment design

- The validity of the design of experiments is a fundamental part of the scientific method
 - The design of a controlled experiment is **a set of strategies aiming to control**
 - Without a valid design, valid conclusions cannot be drawn
 - Statistics cannot fix a badly designed experiment
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Internal validity

- Is concerned with whether we can **accurately infer** that
 - the independent variable **caused** the **effect** on the dependent variable
 - **Certainty** with which we can establish the cause of the variations in results
 - Were there any extraneous variables that could have caused the observed effect?
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Experimental Software Engineering

Current Status

Journals, conferences, books

- A specialized journal
 - Empirical Software Engineering Journal
 - A specialized conference
 - Empirical SE and Measurement Conference
 - A couple of books
 - *Experimentation in SE: An Introduction*
Wohlin, Runeson, Höst, Ohlsson, Regnell, Wesslén
Springer 2012
 - *Basics of SE Experimentation*
Juristo & Moreno
Springer 2001
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ESE: Origins

- The **first experiments** were run in the early 1980s by Victor Basili's group at the University of Maryland with NASA's Software Engineering Laboratory
 - The use of experiments to examine the applicability of SE technologies has gradually gained in importance as a research methodology
 - Empirical studies have finally become recognized as an important component of the SE discipline
 - Fraction of empirical studies is rising in the last 3-4 years
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ESE: Evolution

- 1993-2003: Leading SE journals
 - TSE, TOSEM, JSS, EMSE, IST, IEEE Software, IEEE Computer, SP&E
 - 78 experiments
 - 1977-2006: ICSE
 - 3.2% had some type of empirical evaluation. Of such
 - 0.9% case studies; 0% experiments; 0.7% quasi-experiments
 - 0% the contribution was pure empirical
 - 2012: ICSE
 - 71% had an empirical evaluation
 - 20% the contribution was pure empirical
 - experiments, case studies & qualitative
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SE Experimental paradigm is still immature

- SE experiments are mostly exploratory
 - They produce objective observation but cannot yet be explained
 - The scientific method's inference step is not being exercised
 - Finding (statistical) patterns is not enough
 - Mechanisms have to be found that explain the patterns
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SE Experimental paradigm is still immature

- SE experiments have flaws
 - Lack of thoroughly thought-out designs to rule out extraneous variables in each experiment
 - Proper analysis techniques are not always used
 - Lack of replications
 - Lack of field experiments
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It is not Just Import the Paradigm

- ESE lays the foundations for carrying out experimental research into SE
 - It is not enough just to apply experimental design and statistical data analysis to take experimental research in SE forward
 - A discipline's specific experimental methodology cannot be imported directly from others
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THE ROLE OF SCIENTIFIC METHOD IN SOFTWARE DEVELOPMENT

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