THE STRUCTURE OF CAUSAL EVIDENCE IN DETERMINISTIC SETTINGS

CAUSALITY AND EVIDENCE IN THE SCIENCES
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Basic question: what kind of situations are scientists supposed to be looking for in the world in order to establish causal relations, i.e. relations that allow for prediction and control?

OVERVIEW

I. (In-)difference-making
II. Basic principles of eliminative inference
    a. Causal relevance: method of difference
    b. Causal irrelevance: strict method of agreement
    c. Functional dependence
    d. Role of enumerative induction
    e. Problem of eliminative induction
III. Examples from exp. physics and engineering
    a. Failure analysis
    b. Parameter variation
IV. Counterfactuals and Interventions

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I CAUSALITY IN EXP. PHYSICS AND ENGINEERING

- **Differences with respect to social sciences, medicine, etc.**
  - Determinism (forget quantum mechanics!)
  - Isolation of the phenomenon under laboratory conditions is usually possible
  - Good knowledge and control of (all?) potentially relevant boundary conditions

I STRUCTURE OF CAUSAL EVIDENCE IN DETERMINISTIC SETTINGS

- **Pairs of observations that differ in only one C of all circumstances that are potentially relevant to a phenomenon P.**
  - (i) the change in C prevents P from happening and one infers that C is causally *relevant* to P.
  - (ii) the change in C has no effect on P and one infers that C is causally *irrelevant* to P.
- **(generalization: systematic trial of all possible combinations in the parameter space)**

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II PRINCIPLES OF ELIMINATIVE INFERENCE

- **Phenomenon P is examined**
- **… under variable boundary conditions C1, C2, …, CN**
  - which are all potentially causally relevant
- **… with respect to background B**
  - consisting of boundary conditions that remain constant if causally relevant or are allowed to vary if causally irrelevant
  - (further complications result since the irrelevance of background conditions might be contextual)

- **Causal statements have the following structure:**
  - Boundary condition CX is causally relevant/irrelevant to phenomenon P with respect to background B.
  - Contextuality of causal statements!

II.A CAUSAL RELEVANCE

- **Method of Difference to determine causal relevance:**

Instance	Basic Boundary Conditions	Phenomenon
1	C1, …, CX, …, CN	P
2	C1, …, ¬CX, …, CN	¬P

CX is causally relevant for P with respect to B*.

- **i.e. a change in CX results in a change in P with respect to all backgrounds B*.**
- **where B* is comprised of B and all boundary conditions C1, …, CN except CX.**
- **Relevance with respect to B does not follow!**

II.B CAUSAL IRRELEVANCE

- **Strict Method of Agreement to determine causal irrelevance:**

Instance	Basic Boundary Conditions	Phenomenon
1	C1, …, CX, …, CN	P
2	C1, …, ¬CX, …, CN	P

CX is causally irrelevant for P with respect to B*.

- **Where B* is comprised of B and all boundary conditions C1, …, CN except CX.**
- **Irrelevance with respect to B does not follow!**

II.C FUNCTIONAL DEPENDENCE

- **Method of concomitant variations relies on a repeated application of the method of difference**
- **‚Derivation' under two assumptions:**
  - The quantitative boundary condition CX is considered as the combined contribution of small ΔCX.
  - Regarding the addition of causes, the effect of ΔCX shall depend smoothly on the value of CX.

II.D ROLE OF ENUMERATIVE INDUCTION

- **Enumerative induction should always be justified eliminatively, i.e. with respect to the relevance of boundary conditions.**
- **For example:**
  - Reproducibility: does not aim at the multiplication of instances but the verification that all relevant boundary conditions are sufficiently known and under control.
  - Error analysis: aims at estimating the influence of small, random changes of relevant but uncontrollable boundary conditions.

II.E PROBLEM OF ELIMINATIVE INDUCTION

- **Four assumptions:**
  - Principle of causality (determinism): phenomenon must be completely determined by boundary conditions
  - Constancy of the background
  - Adequate language
  - Reproducibility of the context
- **Related assumptions: Selection Postulate (von Wright), Principle of Limited Variety (Keynes), Homogeneity Condition (Baumgartner & Grasshoff), Locality Condition**

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III.A DIAGNOSING FAILURE (BUCCIARELLI 2003)

- **Replication of the failure.**
- **The boundary conditions are changed systematically until the failure is eliminated.**
  - „Our traditional strategy recommends that we change but one condition at a time.“

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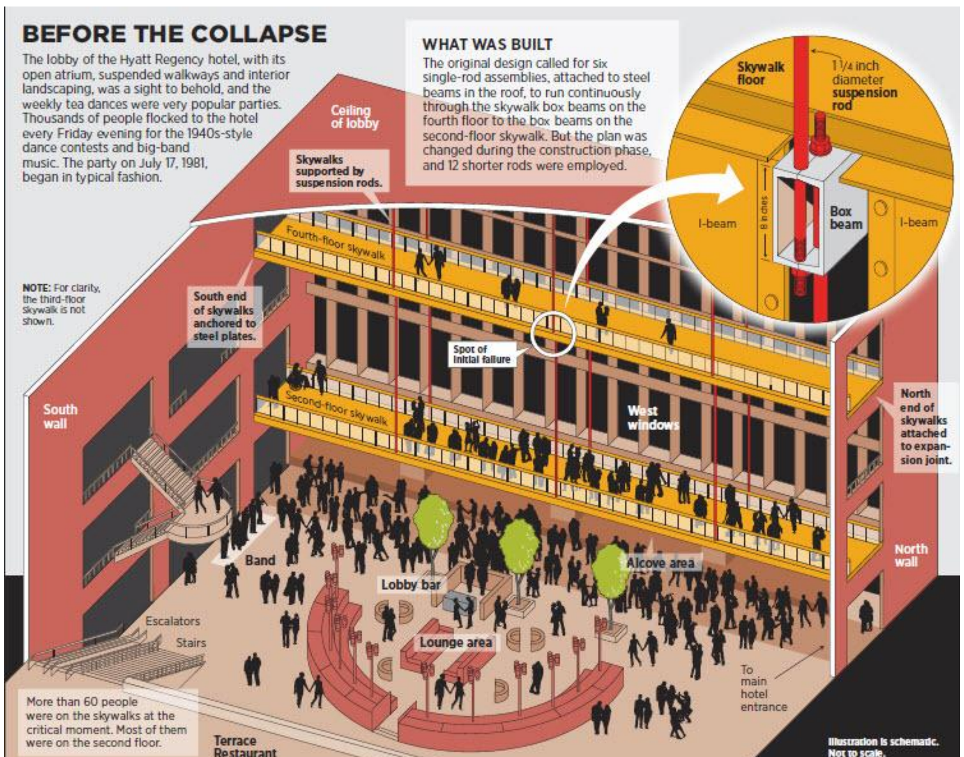
- **Sometimes the actual artifact is not accessible and a model must be used instead (e.g. mathematical model, scale model)**
  - characterized by the fact that it adequately represents those causal relations that are thought to be relevant in the desired context.
  - Sometimes the relation between model and reality is not trivial: laws of similitude, dimensional analysis.

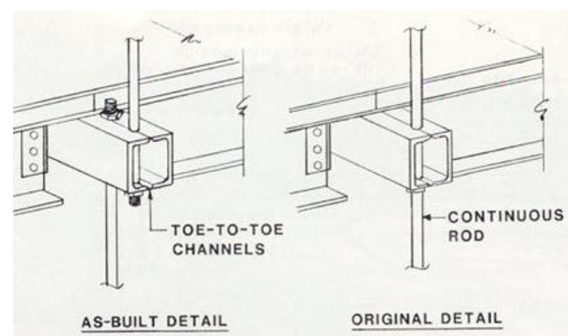
III.A DIAGNOSING FAILURE

- **Hyatt Regency Walkway Collapse (Kansas City; July 17, 1981)**



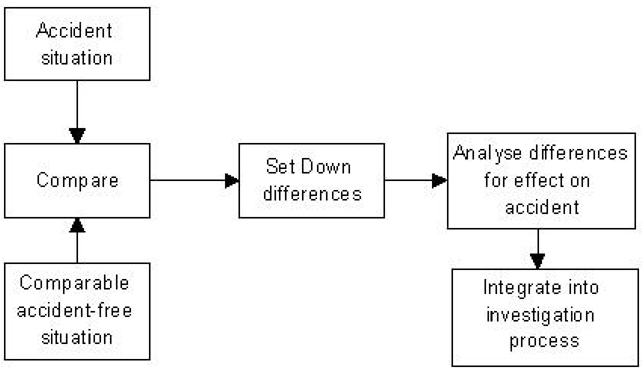

third floor


fourth floor

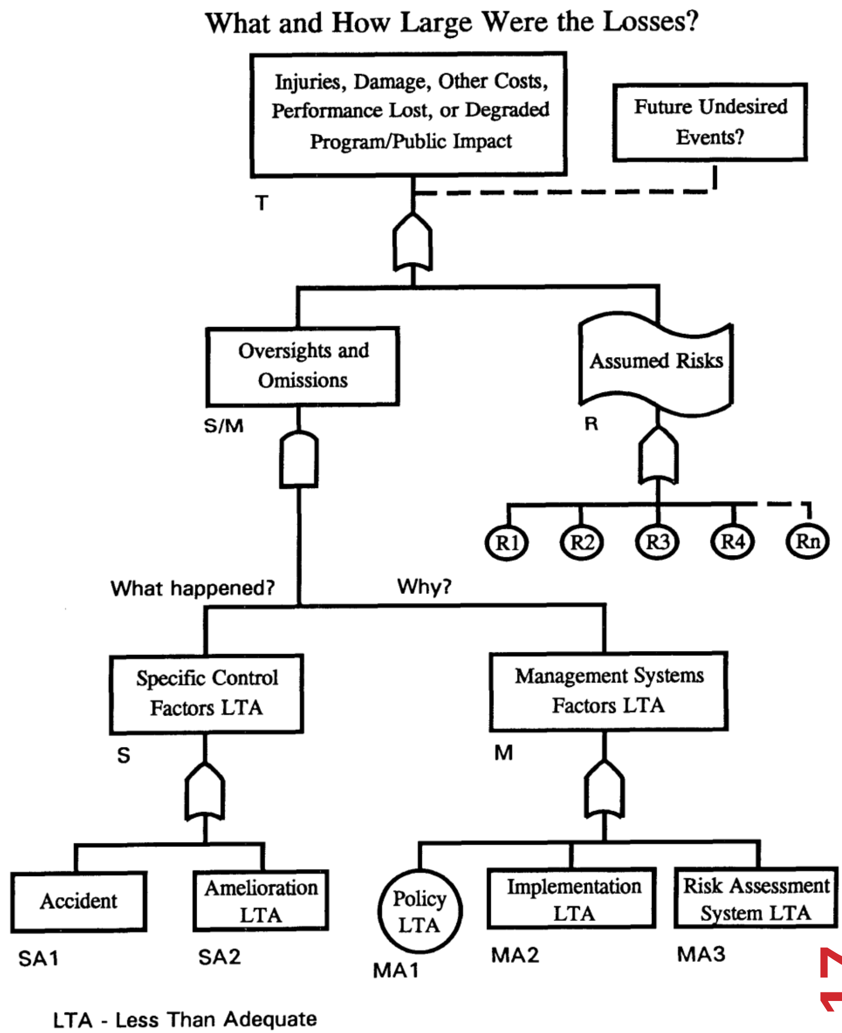


III.A DIAGNOSING FAILURE

- Failure Analysis, Risk analysis, Quality control
- Change Analysis
  (e.g. RAND):



- MORT Analysis
  (Management Oversight Risk Tree, US Atomic Energy Commision)



III.B ARTIFACT DESIGN (VINCENTI 1990)

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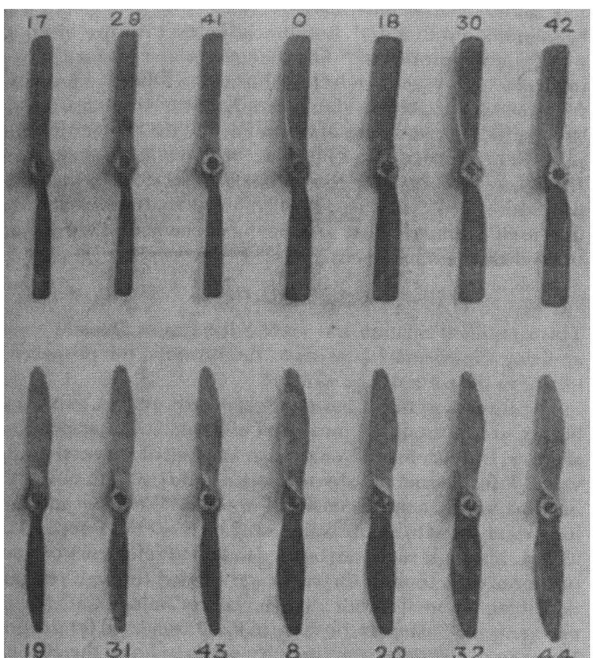
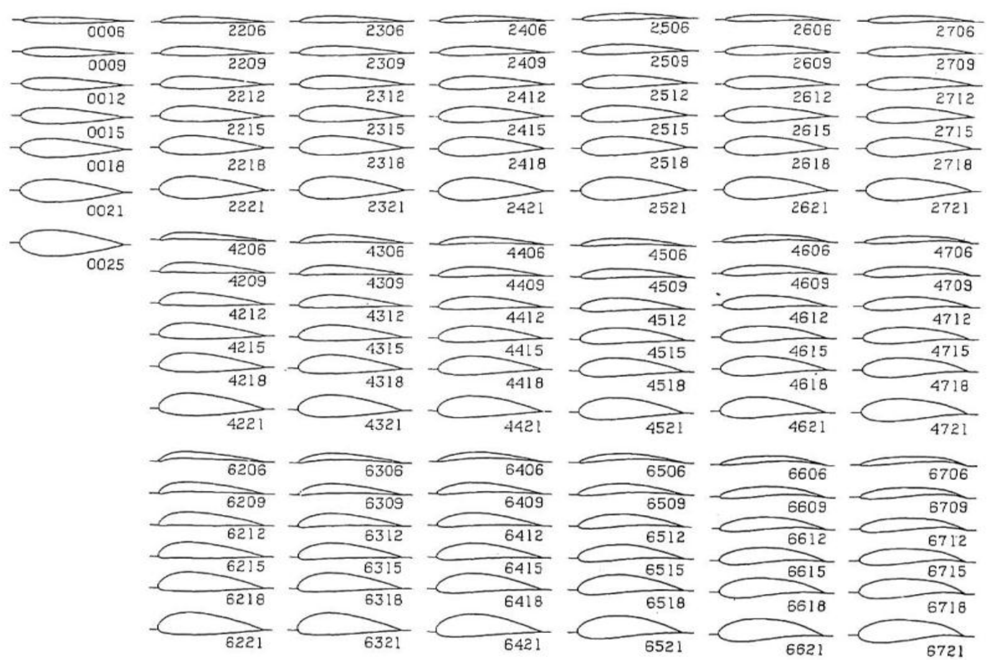
- **Parameter variation** **(„so much taken for granted by engineers that they rarely call it by name“)**
  - In absence of theory





III.B EVOLUTION OF ARTEFACTS (VINCENTI 1990)

- **The development of artifacts often follows basic evolutionary principles**
  - Start with a (more or less) functioning artifact
  - Mutation (Parameter Variation)
    - Small changes are more effective than large ones
  - Selection (Optimization)
    - If the changes lead to improvement (wrt a certain context), then they will persist and other variants eventually vanish.

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IV.A COUNTERFACTUALS

- **Counterfactual approach:**
  - "C caused E *if and only if* there was a sequence of events X1, X2, …, Xn such that: if C had not occurred, than X1 would not have occurred; if X1 had not occurred, then X2 would not have occurred, … if Xn had not occurred, then E would not have occurred." (Lewis 1973)
- **On the basis of evidence <E>, the truth/falsity of the counterfactual statements can be evaluated in terms of comparisons with actual events/situations which differ only regarding irrelevant circumstances.**

IV.B INTERVENTIONS

- **Interventionist approach:**
  - "An intervention I on X with respect to Y (for the purpose of determining whether X causes Y) is an exogenous causal process that completely determines the value of X in such a way that if any change occurs in the value of Y it occurs only in virtue of Y's relationship to X and not in any other way." (Woodward 2003, 91)
- **I.e. interventions generate situations giving evidence of the form <E>.**
- **However, type of evidence <E> can be acquired also by pure observation.**

V CONCLUSIONS

- **Ideally, causal evidence in deterministic settings has the following structure:**
  - Pairs of observations that differ in only one C of all circumstances that are potentially relevant to a phenomenon P.
- **This is the type of evidence required by eliminative induction.**
- **It is the basic type of causal evidence in experimental physics and the engineering sciences:**
  - experimental method, failure analysis, parameter variation
- **Evidence of this type can shed light on the evaluation of counterfactual statements and the role of interventions.**