# Computational indeterminism in complex models of social systems

Krzysztof Kułakowski

Faculty of Physics and Applied Computer Science

AGH

If men define situations as real, they are real in their consequences.

*[William I. Thomas, Dorothy S. Thomas, 1928]*

# outline

1. Sociophysics : on the edge of social sciences
2. Determinism and causal complexity
3. Cellular automaton as an allegory of a deterministic world
4. Mind – hidden variables
5. Consequences: modelling, everyday decisions

**Determinism** : theory that all events, including moral choices, are completely determined by previously existing causes.

*[Encycl. Britannica]*

# XVII ISA WORLD CONGRESS OF SOCIOLOGY

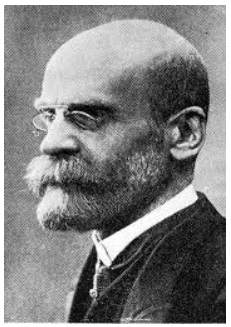
SOCIOLOGY ON THE MOVE
LA SOCIOLOGIE EN MOUVEMENT
LA SOCIOLOGÍA EN MARCHA
11-17 JULY, 2010
GOTHENBURG, SWEDEN

Michel Wieviorka, ISA President
Hans Joas, ISA Vice-President, Programme
Ulla Bjornberg, Chair, Local Organizing Committee

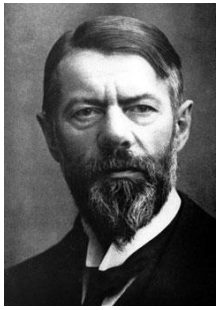
**Sociology on the move**

Determinism is dead in the social sciences. Despite a strong interest in social structures, social mechanisms, forms of reproduction, we are all aware that human beings are not completely dominated by them. The world changes, and this change to a large extent depends on human action and imagination.

statistical physics



empiricistic sociology: facts



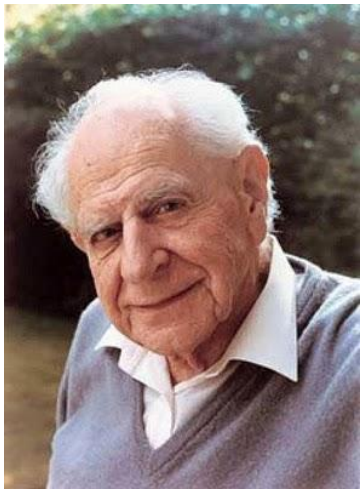
interpretative sociology: minds

?

agent simulations

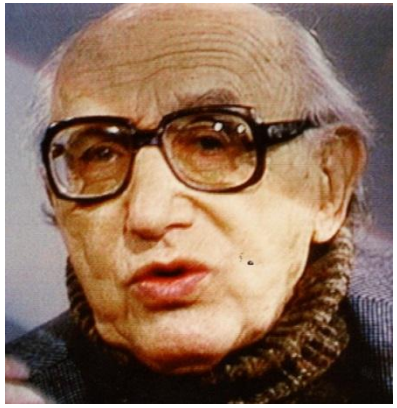
interactions -> phase transitions
non-equilibrium processes

*[W. Weidlich, G. Haag, Concepts and Models of Quantitative Sociology, Springer Verlag 1983; C. Castellano ea, Statistical physics of social dynamics , Review of Modern Physics, 2009; Statistical Physics and Social Sciences, special issue of the Journal of Statistical Physics, 2013]*



empiricistic sociology

interpretative sociology



To-day, things may begin to be different, owing to our slowly increasing knowledge of society, i.e. owing to the study of the unintended repercussions of our plans and actions; and one day, men may even become the conscious creators of an open society, and thereby of a greater part of their own fate.

*[Karl Popper, Open Society and Its Enemies, 1945, Ch. 14]*

It would be less difficult (…) if our language and thought were not so thoroughly permeated with words and concepts like 'casual necessity', 'determinism', 'scientific law', and others of the same sort.

*[Norbert Elias on the need of reorientation of scientific language, What is Sociology? 1970]*

The entities which obey the laws of science X
are treated as elementary in science Y.

| Y | X |
|---|---|
| solid state or many-body physics | elementary particle physics |
| chemistry | many-body physics |
| molecular biology | chemistry |
| cell biology | molecular biology |
| * | * |
| * | * |
| * | * |
| psychology | physiology |
| social sciences | psychology |

But this hierarchy does not imply that science Y is „just applied science X".
At each stage entirely new laws, concepts, and generalizations are necessary…

*[P. W. Anderson, More is different, Science, 1972]*

## Criteria of experimental recognition of causes and effects

1. The cause and effect must be contiguous in space and time.

2. The cause must be prior to the effect.

3. There must be a constant union betwixt the cause and effect. 'Tis chiefly this quality, that constitutes the relation.

4. The same cause always produces the same effect, and the same effect never arises but from the same cause...

5. …where several different objects produce the same effect, it must be by means of some quality, which we discover to be common amongst them…

6. The difference in the effects of two resembling objects must proceed from that particular, in which they differ. (…)

7. The absence or presence of one part of the cause is here suppos'd to be always attended with the absence or presence of a proportionable part of the effect. (…)

8. …an object, which exists for any time in its full perfection without any effect, is not the sole cause of that effect, but requires to be assisted by some other principle, which may forward its influence and operation…

*[David Hume, A Treatise of Human Nature, 1739, sect.XV]*

# Causal complexity - examples

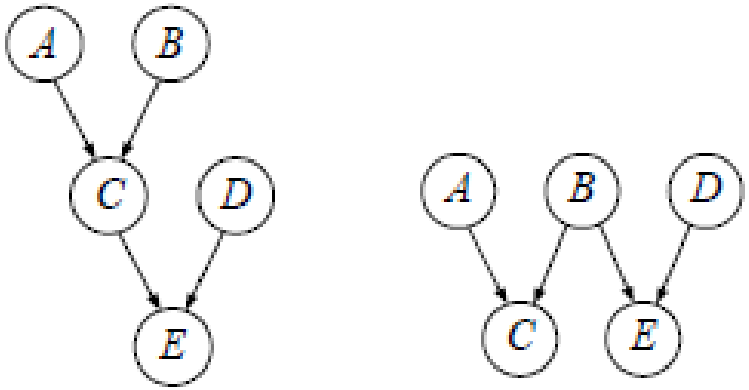
$$X_1 \cup X_2 \cup X_3 \Rightarrow Y$$

$$X_1 \cap X_2 \cap X_3 \Rightarrow Y$$

context $\quad X_1 \Rightarrow (X_2 \Rightarrow Y)$

INUS* $\quad (X_1 \cap X_2) \cup (X_3 \cap X_4) \Rightarrow Y$

*[B. F. Braumoeller, Causal complexity and the study of politics, Political Analysis ,2003]*



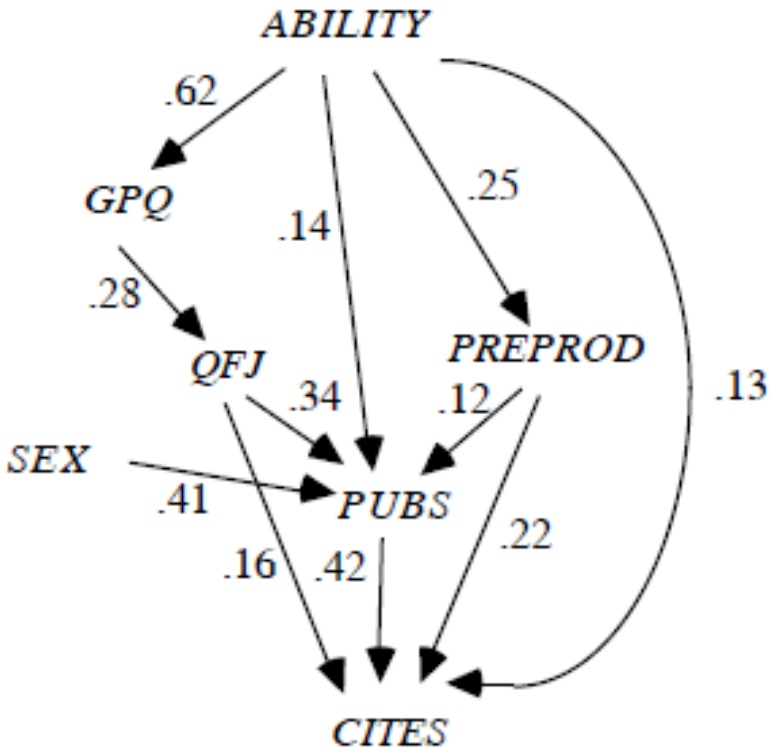

*[M. Baumgartner, Inferring causal complexity, Sociological Methods Research, 2009]*

* insufficient but necessary part of a condition which is itself unnecessary but sufficient for the result

# Causal complexity – structural equations - an example

Why some academic psychologists publish more than the others ?

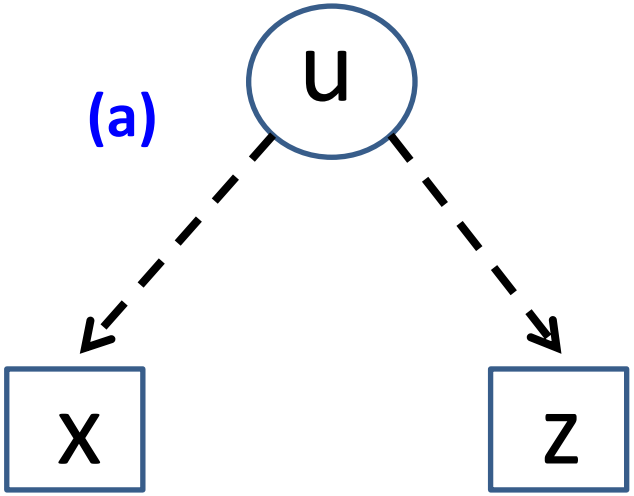
GPQ – program quality
QFJ – quality of 1st job
PREPROD – publications during studies
PUBS – publications after studies
CITES – number of citations

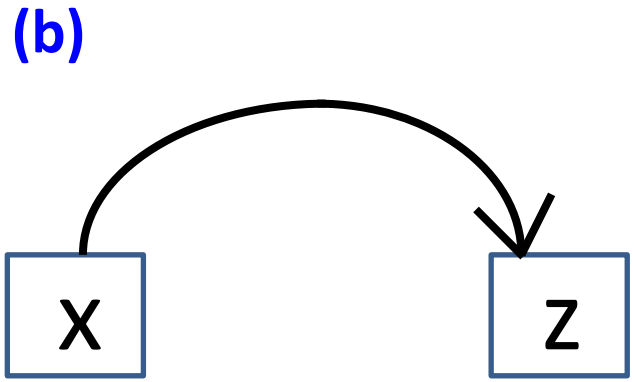



*[P. Spirtes, C. Glymour, R. Scheines, Causation, Prediction, and Search, MIT, 2000]*

# Structural equations

x, z – measured
u – hidden



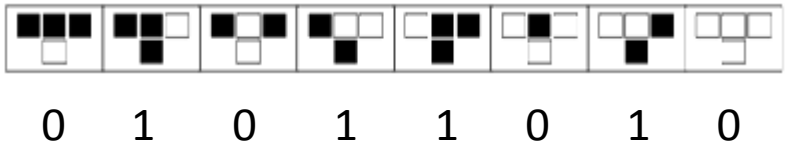

We cannot distinguish (a) and (b) by measurements of x and z
With a condition $x = c$, we can.

*[J. Pearl, Causality. Models, Reasoning, and Inference, Cambridge UP, 2000]*

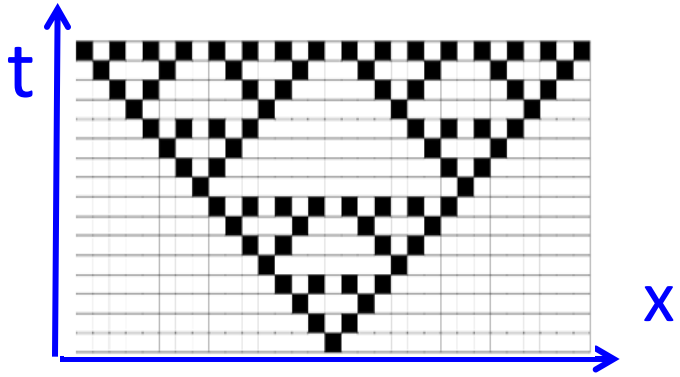
## An allegory of deterministic world – cellular automaton

- lattice of cells
- a set of states of a unit cell
- the rule which determines the cell state at time *t+1*,
  based on the state of the cell and its neighbourhood at time *t*

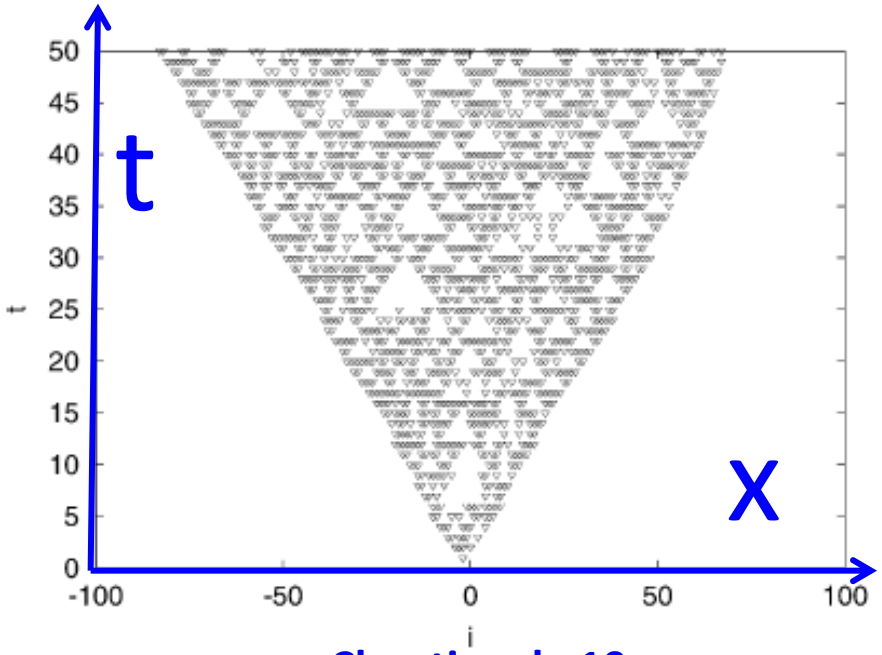
## Examples of elementary cellular automata



0 1 0 1 1 0 1 0



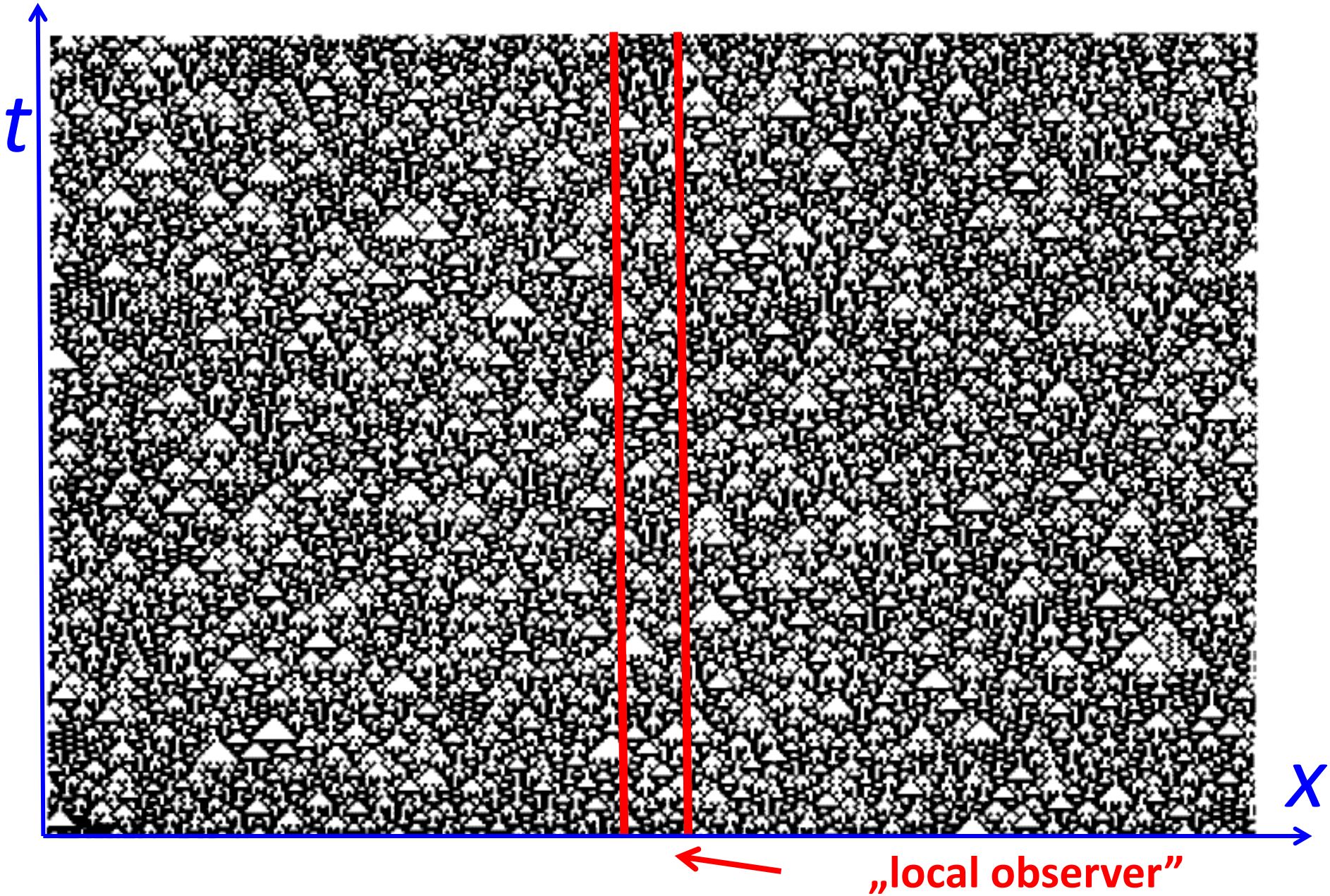

**XOR = rule 90**




**Chaotic rule 10**
**– damage spreading**

*[G. Bofetta et al., Predictability – a way to characterize complexity, Phys. Reports 2002]*

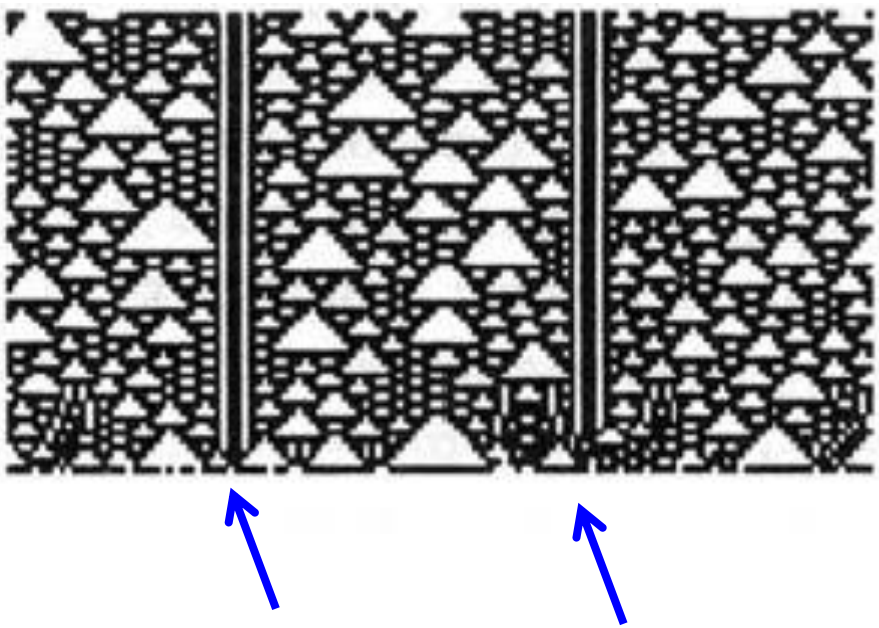
# the same XOR, random initial state



# Chaotic automata: damage spreading

Are consequences of a local change spatially limited?

An example:  one-dimensional automaton



blocking configurations

boundaries of damage spreading

*[N.H. Packard, S. Wolfram, Two-dimensional cellular automata, J Stat Phys, 1985]*

In a fully deterministic world ruled by cellular automata:

- the evolution is computationally irreducible; the only method of prediction is to perform the whole simulation;

- the evolution can be chaotic, i.e. susceptible to small local changes;

- a check if a given automaton is chaotic, is computationally undecidable.

As a rule, we know neither the neighbourhood size , nor the rule.
All we know is the result of a local observation.

***Any hypothesis as „s(x,t)=0 => s(y,t+1)=1”***

***- cannot be deduced from observations,***

***- can fail when confronted with new observations.***

To use the idea of cause and effect, we need a reproducible measurement,
and therefore the system should be isolated.

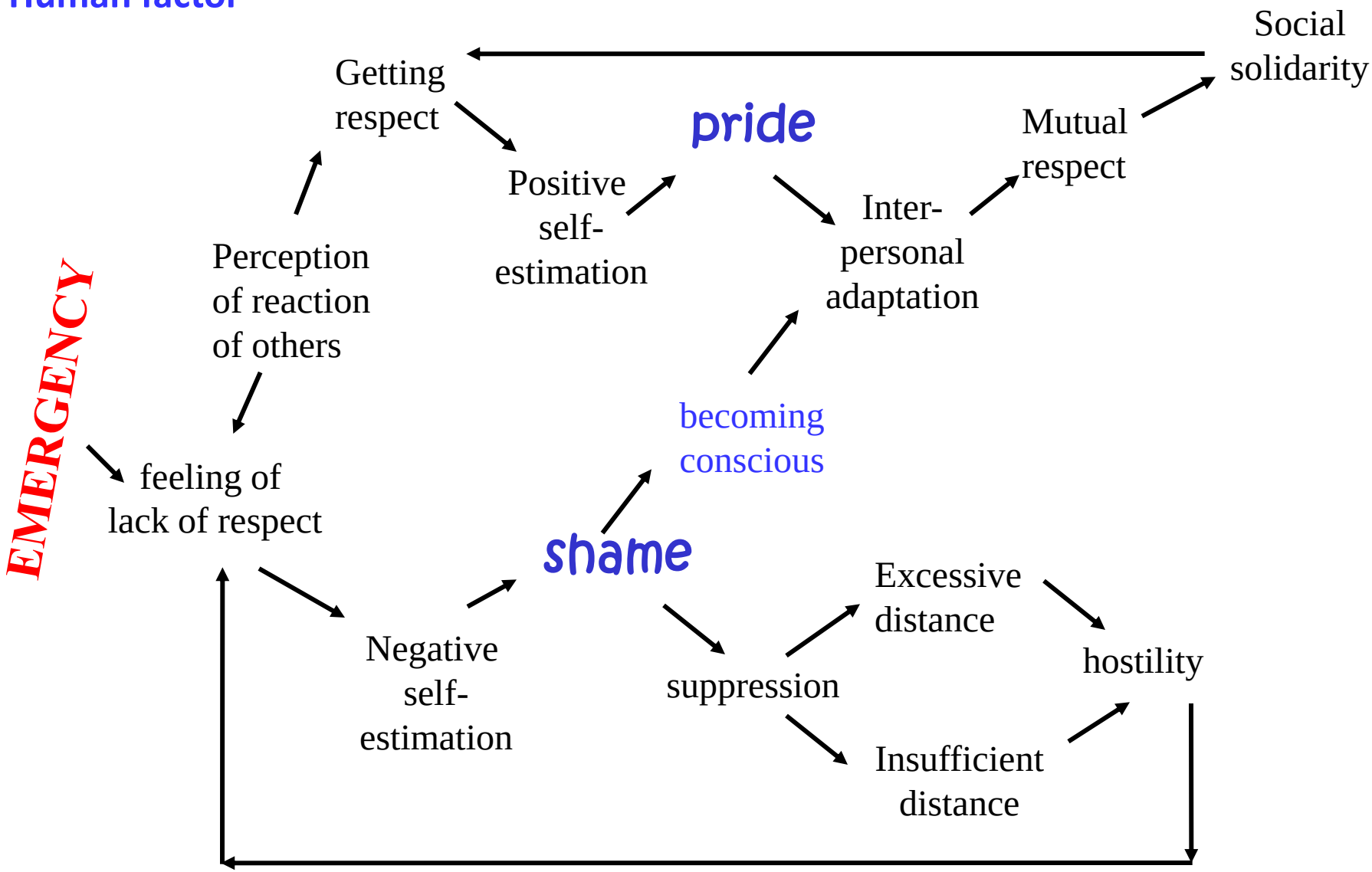
*[S. Wolfram, Undecidability and intractability in theoretical physics, PRL, 1985;*
*K. Culik II, Sheng Yu, Undecidability of CA classification scheme, Complex Systems, 1988]*

Indie, 1930

Tybet, 2008


Sydney, 2010


Baltimore, 2013




**Scheff model of adaptation and solidarity**

(J.H.Turner, J.E.Stets, *The Sociology of Emotions*, CUP 2005)

## Summary (not the end yet…)

To predict the future in a fully deterministic world we need to know:

- a deterministic rule of the evolution
- knowledge about an initial state
- an isolated system

In social sciences:

- results cannot be repeated
- the system cannot be isolated

In the interpretative sociology:

- only indirect measurements are possible
- it is impossible to determine a cause of a given effect.

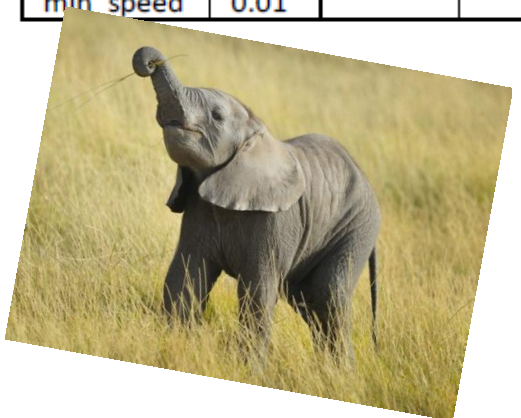
# Consequences for modelling: multiplying of hidden variables makes no sense

**Table 1.** Optimal parameter settings found

| Global parameters (not tuned) | | Initial variable settings (not tuned) | | Global parameters (tuned) | | Initial variables (tuned) | |
|---|---|---|---|---|---|---|---|
| #agents | 35 | $\varepsilon_{intention}$ | 0.5 | $\tau_{distance}$ | 190 | $q_{belief(nomove)}$ | 0.005 |
| max_x | 600 | $\delta_{intention}$ | 0.5 | sight_reach | 200 | | |
| max_y | 800 | $\eta_{intention}$ | 0.5 | max_speed (per agent) | see Fig.3 | | |
| $\Delta t$ | 0.5 | $\beta_{intention}$ | 0.5 | | | | |
| $\mu_{\delta belief}$ | 0.5 | $\varepsilon_{belief}$ | 0.5 | | | | |
| $\mu_{\eta belief}$ | 0.5 | $\delta_{belief}$ | 0.5 | | | | |
| $\mu_{\beta belief}$ | 0.5 | $\eta_{belief}$ | 0.5 | | | | |
| $\zeta_{belief}$ | 0.5 | $\beta_{belief}$ | 0.5 | | | | |
| $\sigma$ | 100 | $\varepsilon_{emotion}$ | 0.5 | | | | |
| $\omega_{OIA1}$ | 0.3 | $\delta_{emotion}$ | 0.5 | | | | |
| $\omega_{OEA2}$ | 0.3 | $\eta_{emotion}$ | 0.5 | | | | |
| $\omega_{OBA2}$ | 0.3 | $\beta_{emotion}$ | 0.5 | | | | |
| $\omega_{OEA1}$ | 0.5 | | | | | | |
| $\omega_{OBA1}$ | 0.5 | | | | | | |
| all $q_{belief(X)}$ | 0 | | | | | | |
| impact of event on $q_{belief(X)}$ | 1 | | | | | | |
| min_speed | 0.01 | | | | | | |

| | |
|---|---|
| fear of agent $A$ | $q_{fearA}(t)$ |
| emotion for option $O$ of agent $A$ | $q_{emotion(O)A}(t)$ |
| intention indication for option $O$ of agent $A$ | $q_{intention(O)A}(t)$ |
| belief in $X$ of agent $A$ | $q_{belief(X)A}(t)$ |

| | |
|---|---|
| $\mu_{\delta beliefA}, \mu_{\eta beliefA}, \mu_{\beta beliefA}$ | adaptation speed for $\delta$, $\eta$, $\beta$ for beliefs |
| $\sigma_A$, $\tau_A$ | steepness and threshold values for adaptation |
| $\zeta_A$ | optimistic/pessimistic bias upon fear |
| $\nu_A$ | weight of fear against beliefs |
| $\omega_{X,fear,A}$ | weight of information $X$ for fear |
| $\omega_{OEA1}$ | weight of the group impact on the emotion of $A$ for $O$ |
| $\omega_{OBA1}$ | weight for the own belief impact on the emotion of $A$ for $O$ |
| $\omega_{OIA1}$ | weight for the group impact on the intention of $A$ for $O$ |
| $\omega_{OEA2}$ | weight for own emotion impact on the intention of $A$ for $O$ |
| $\omega_{OBA2}$ | weight for the own belief impact on the intention of $A$ for $O$ |



**With *four parameters* I *can fit* an *elephant*,**
**and with *five* I *can make him wiggle his trunk.***
*[John von Neumann]*

# Consequences for theory of rational choice

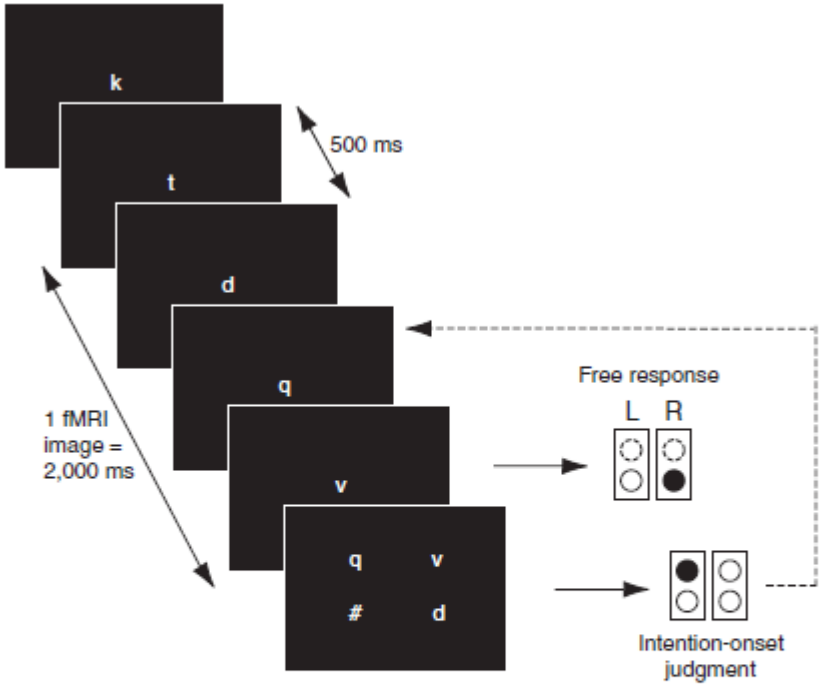
If we cannot build the relation ***cause=> effect***,
how can we infer about the future from the past?

Two ways of deciding how to behave:

- *rational deliberation*: we can systematically assess the situation, gather information, list and evaluate the possible consequences of of different actions… (This way) need not to assume perfect rationality. It only requires conscious deliberation…

- *heuristic route*: following behavioral rules that prescribe a particular course of action for the situation. These guides to behavior include habits, roles, and, of course, norms. (…) These processes lie beyond awareness and probably occur in split seconds.

*[C. Bicchieri, The Grammar of Society, Cambridge UP 2006]*



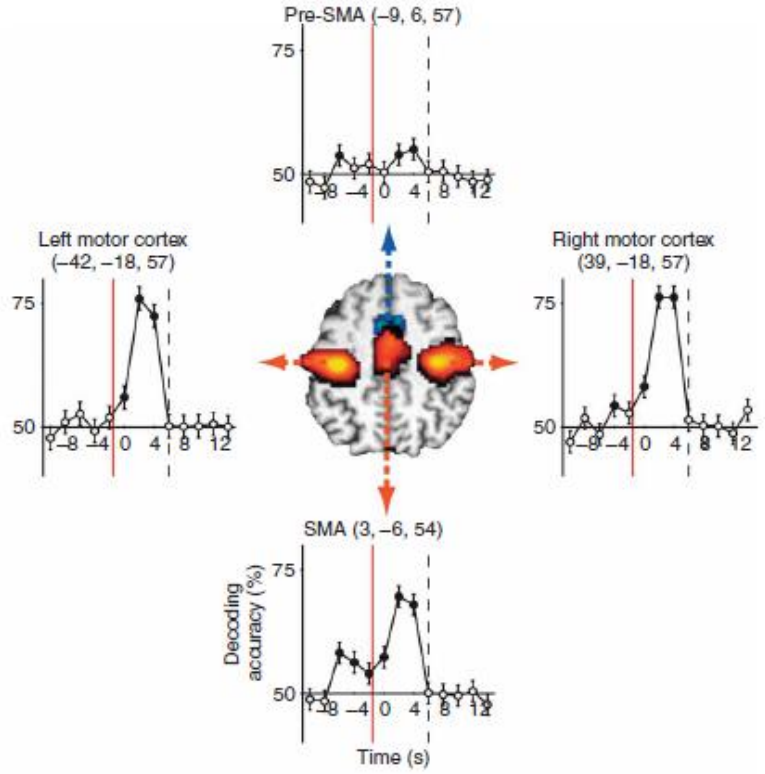




**Figure 1** Measuring the onset time of conscious motor intentions. Subjects viewed a letter stream that was updated every 500 ms (shown here only for a few frames). At some point they spontaneously made the decision to press either the left or right button using their corresponding index finger (free response). Subsequently, they were presented with a response-mapping screen that instructed subjects as to which second button to press to report the time at which they consciously made the motor decision (**Supplementary Methods**).

**…the outcome of a decision can be encoded in brain activity of prefrontal and parietal cortex up to 10 s before it enters awareness.**

*[Chun Siong Soon, M. Brass, H.-J.Heinze, J.-D. Haynes, Unconscious determinants of free decisions in the human brain, Nature Neuroscience 11 (2008) 543.*

hard
incompatibilism?

| **Determinism** | **true** | **false** | **true** | **false** | **true** | **false** | **?** | **?** | **?** |
|---|---|---|---|---|---|---|---|---|---|
| the sort of **Free will** required for moral responsibility | **false** | **true** | **true** | **false** | **?** | **?** | **false** | **true** | **?** |

classical
hard
determinism

classical
libertarianism

possible
compatibilism

*[G. Strawson, Freedom and Belief, Oxford UP, 1986;*
*D. Pereboom, Living Without Free Will, Cambridge UP, 2001]*

Such a stone, being conscious merely of its own endeavour and not at all indifferent, would believe itself to be completely free, and would think that it continued in motion solely because of its own wish.

*[Spinoza]*

Honestly, I cannot understand what people mean when they talk about the freedom of the human will. I have a feeling, for instance, that I will something or other; but what relation this has with freedom I cannot understand at all. I feel that I will to light my pipe and I do it; but how can I connect this up with the idea of freedom? What is behind the act of willing to light the pipe? Another act of willing?

Schopenhauer once said: Man can do what he will but he cannot will what he wills.

*[Albert Einstein]*


There once was a man who said, "Damn!
It is borne in upon me that I am
An engine that moves
In predestinate grooves,
I'm not even a bus, I'm a tram.

*[Maurice Evan Hare]*