Observation and Interaction

(and Determinism and Free Will)

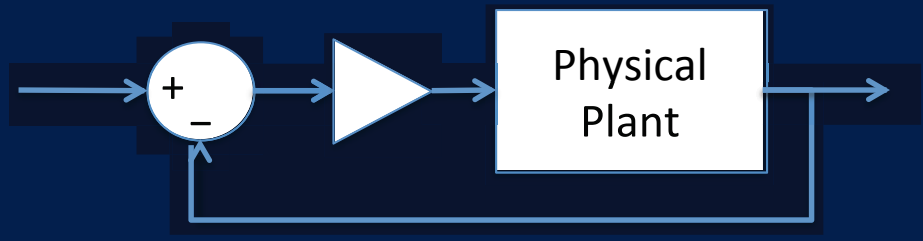
Edward A. Lee

UC Berkeley

Language and Automata Theory and Applications (LATA), St. Petersburg, Russia, March 26, 2019

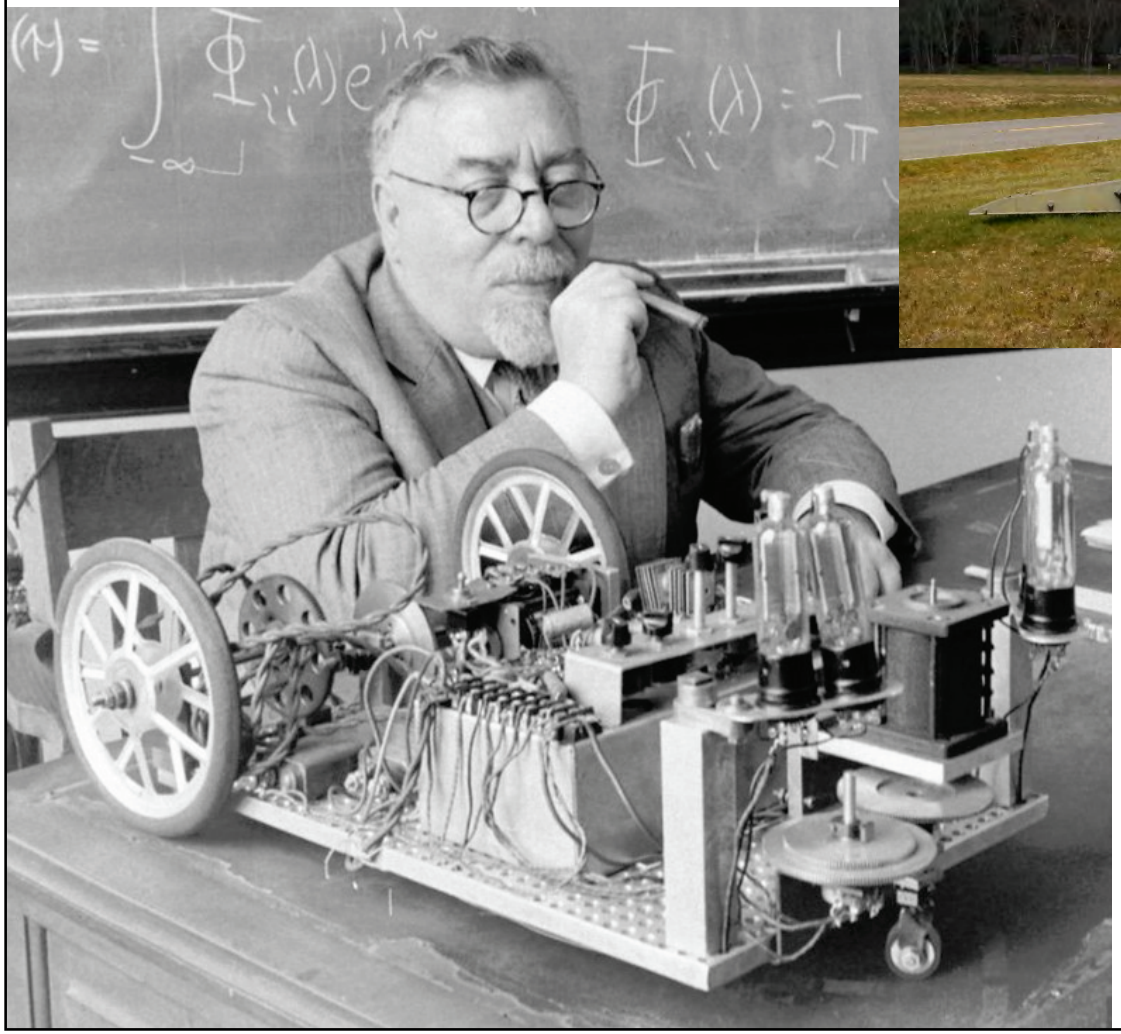
University of California at Berkeley

Feedback



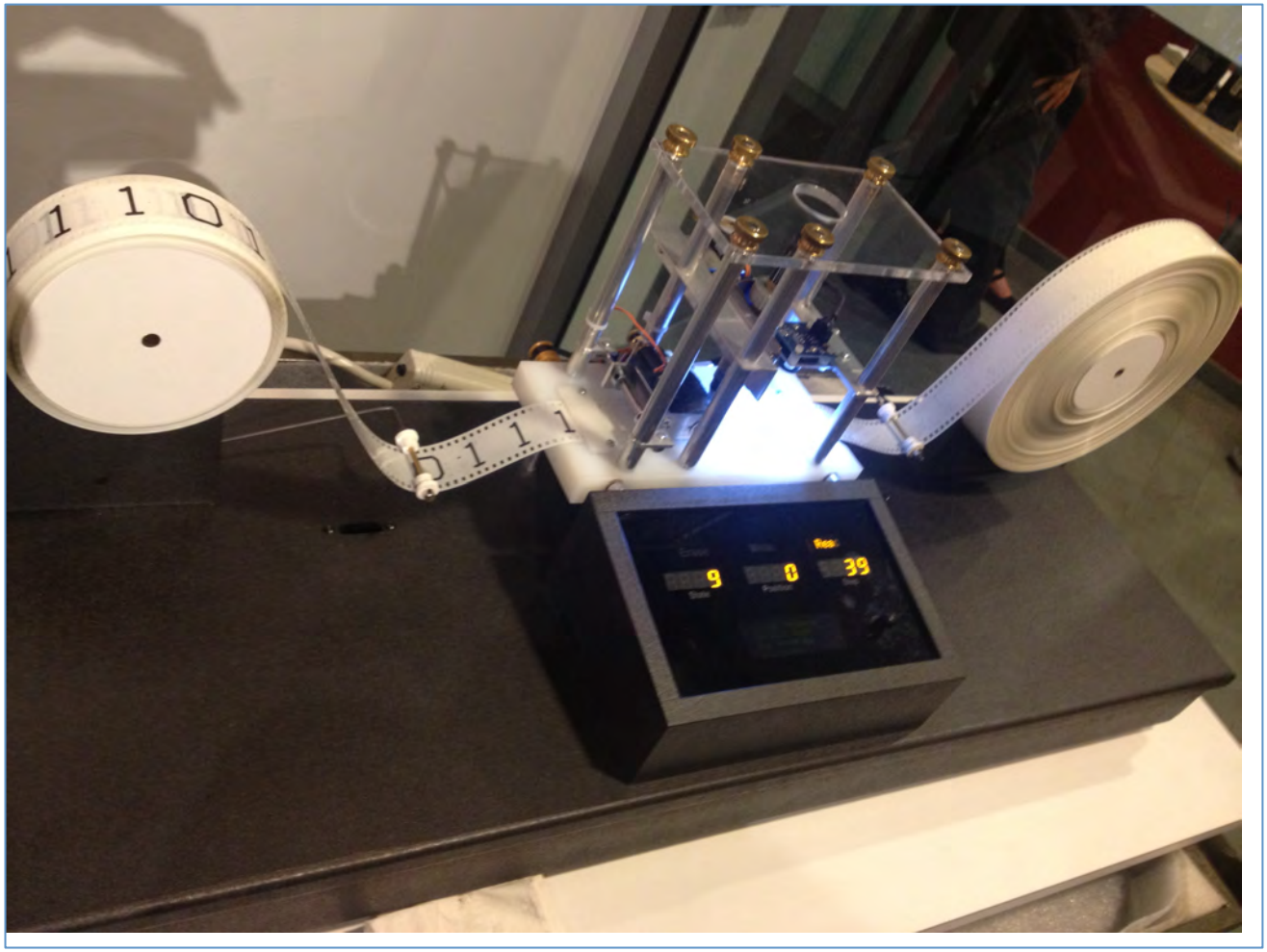
Harold Black

Feedback



Norbert Wiener

In Contrast:
Turing Machines Lack Interaction



Machine designed by Mike Davey to resemble as closely as possible Turing's 1936 description.
[Photo by GabrielF, CC BY-SA 3.0, via Wikimedia Commons]

In This Talk…

I will leverage the results of four Turing-Award winners:

Robin Milner

Judea Pearl

Shafi Goldwasser

Silvio Micali

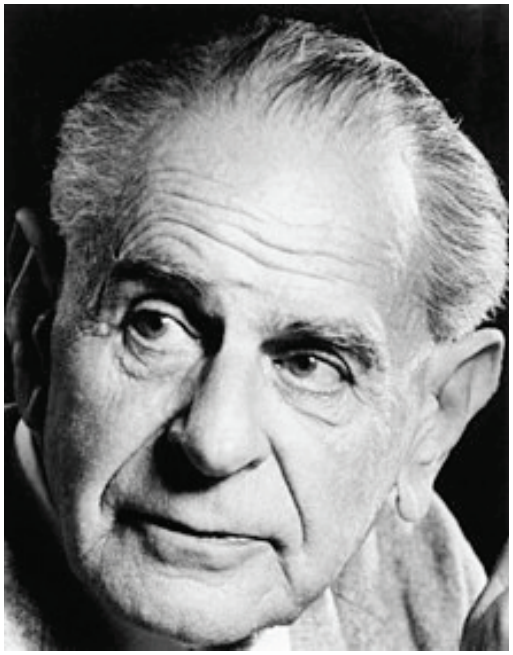
First Person vs. Third Person
Subjective vs. Objective

Interaction is about first-person involvement, “I” not “them” or “those.”

Eliminating first-person involvement has long been a goal in science.
The mantra:

“Objective is better than subjective.”

“Let the data speak for itself.”



Karl Popper

Zero-Knowledge Proofs as a First-Person Phenomenon

How to Explain Zero-Knowledge Protocols to Your Children

QUISQUATER Jean-Jacques[1], *Myriam, Muriel, Michaël*
GUILLOU Louis[2], *Marie Annick, Gaïd, Anna, Gwenolé, Soazig*

in collaboration with *Tom BERSON*[3] for the English version

[1] Philips Research Laboratory, Avenue Van Becelaere, 2, B–1170 Brussels, Belgium.
[2] CCETT/EPT, BP 59, F–35512 Cesson Sévigné, France.
[3] Anagram Laboratories, P.O. Box 791, Palo Alto CA 94301, USA.

The Strange Cave of Ali Baba

◇ Know, oh my children, that very long ago, in the Eastern city of Baghdad, there lived an old man named Ali Baba. Every day Ali Baba would go to the bazaar to buy or sell things. This is a story which is partly about Ali Baba, and partly also about a cave, a

Shafi Goldwasser

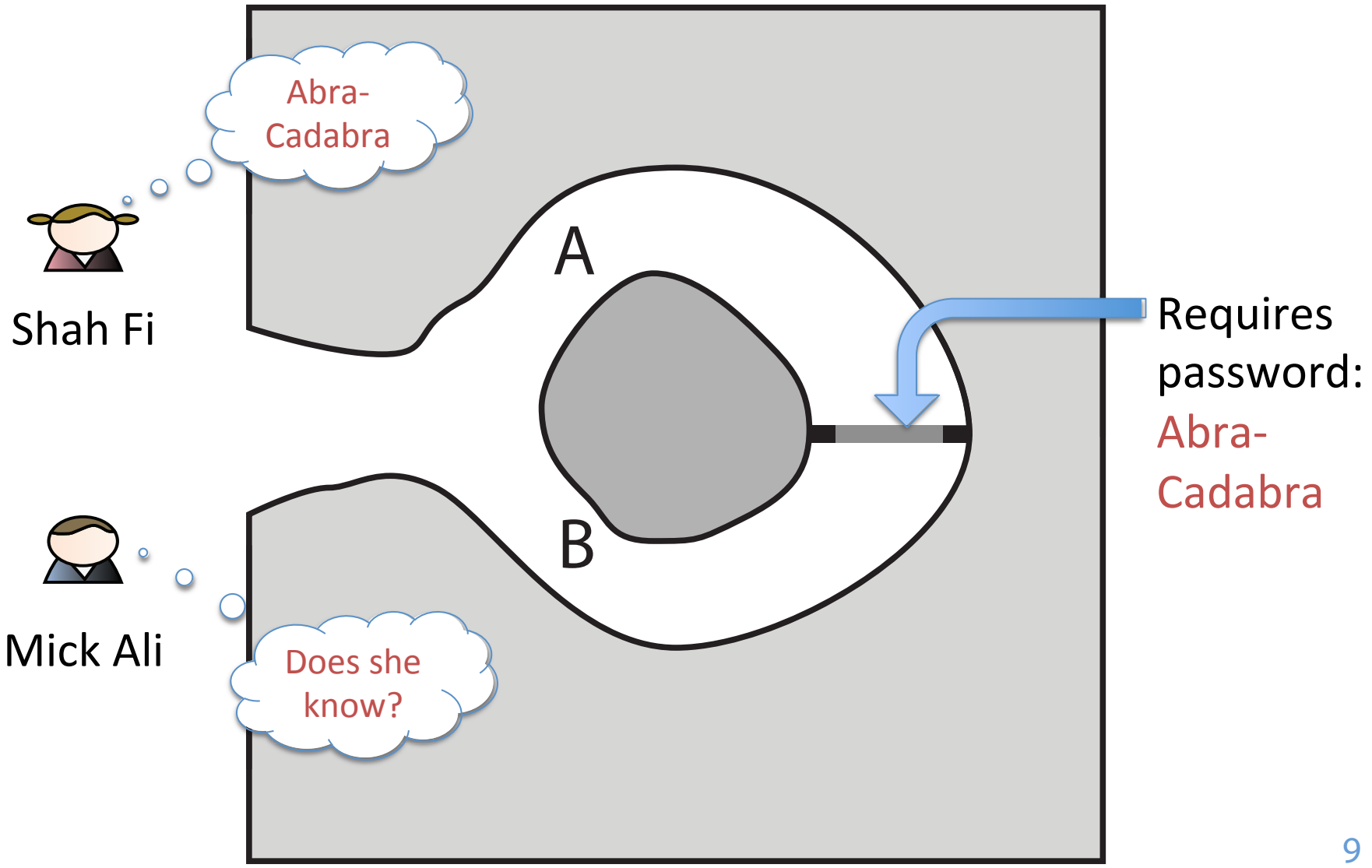
Silvio Micali

The Challenge

How can one person prove to another that they know a secret, while revealing nothing about the secret, and *without giving that other person the ability to prove to anyone else that they know the secret*?

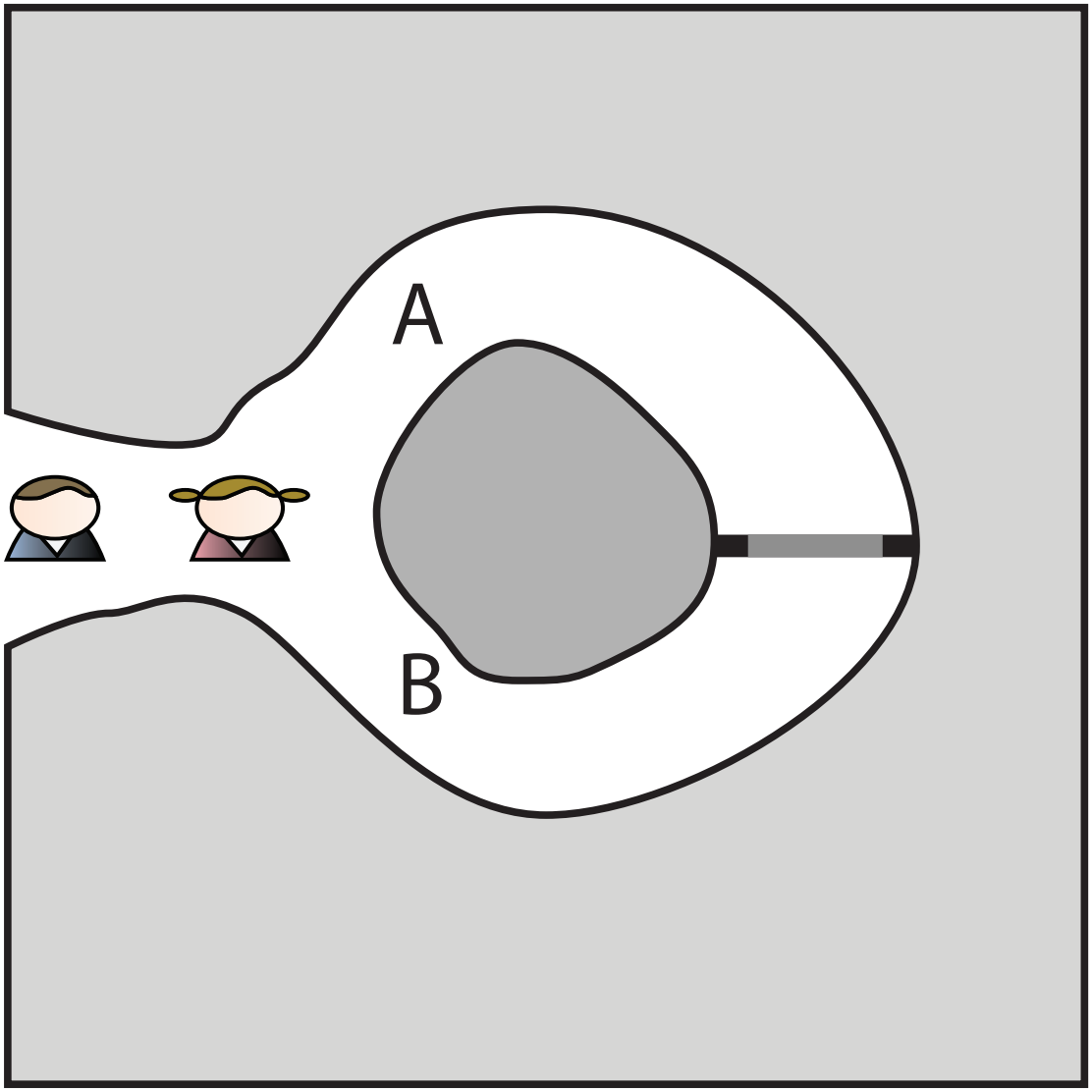
We want absolutely minimal information transfer!

Ali Baba's Cave

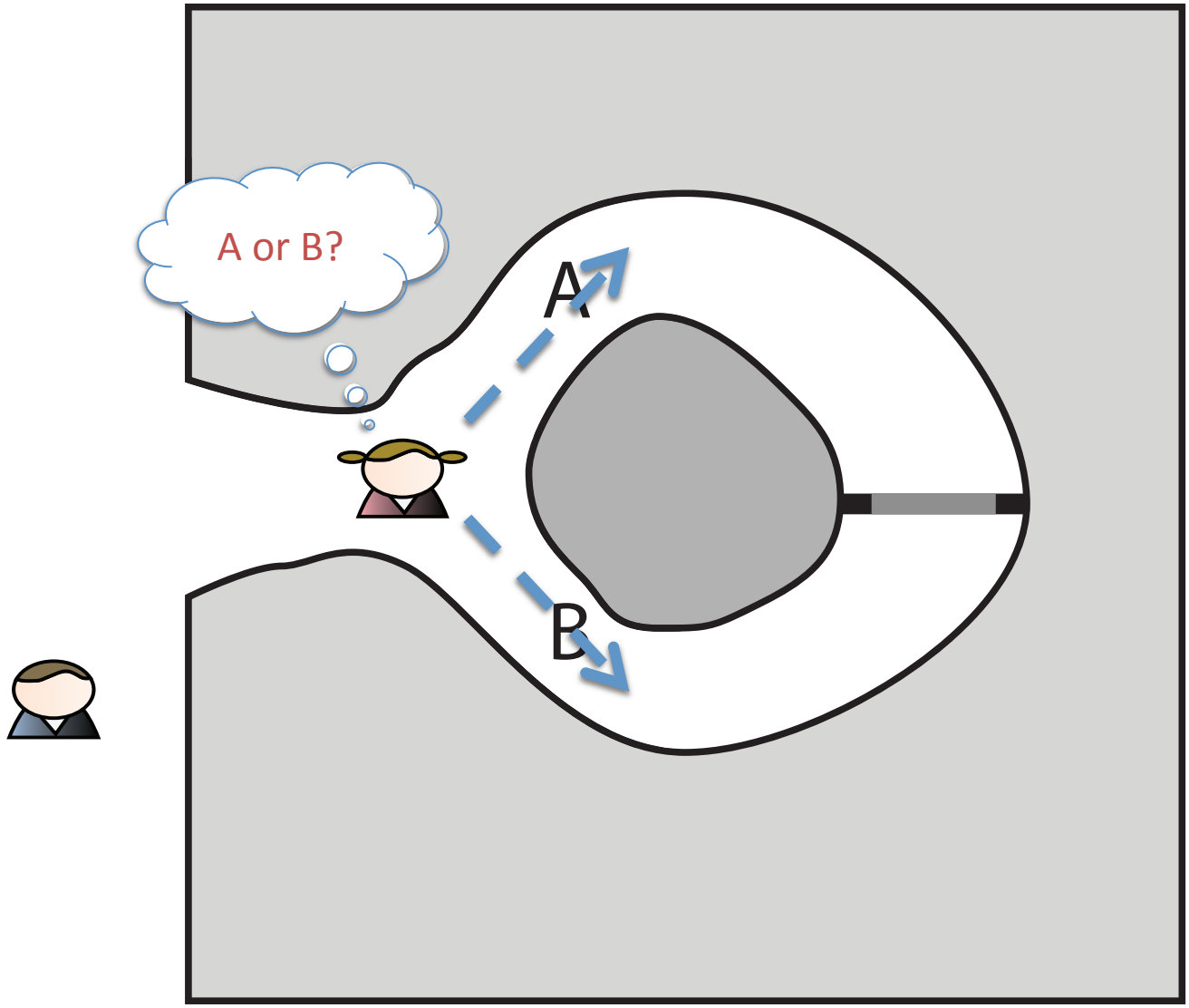


One Possible Proof

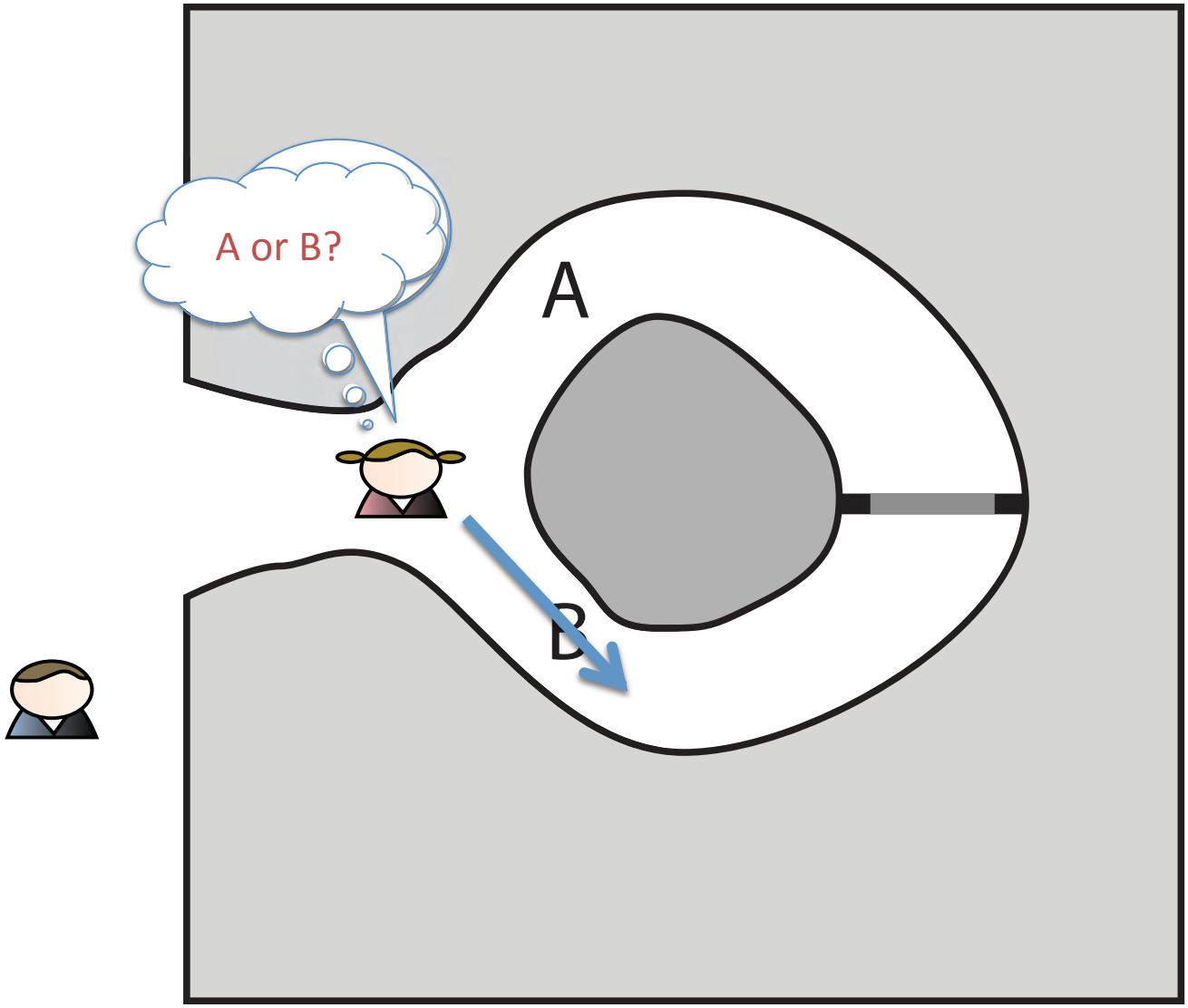
Knowledge becomes available to any third-person observer.



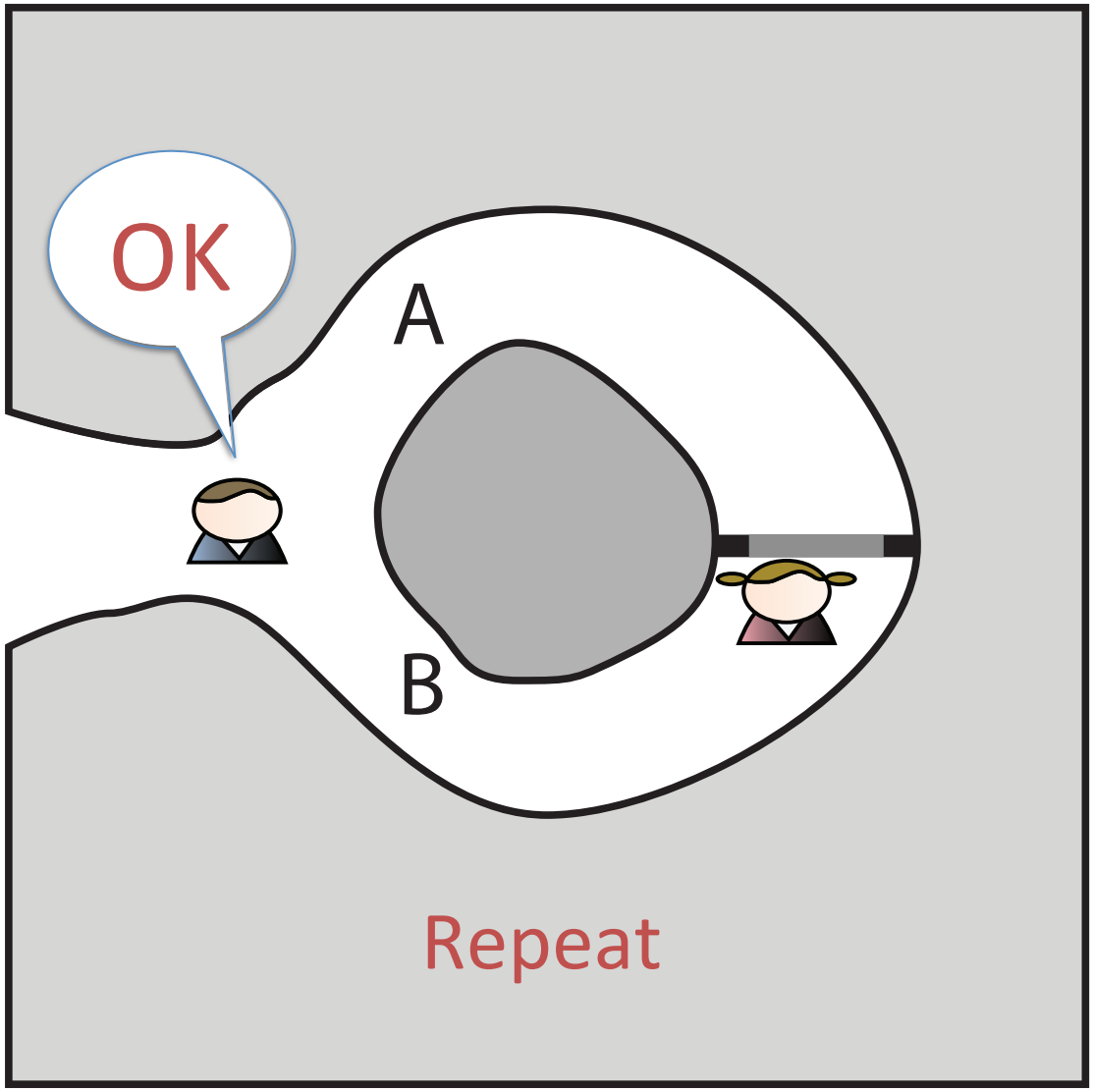
Zero Knowledge Proof



Zero Knowledge Proof



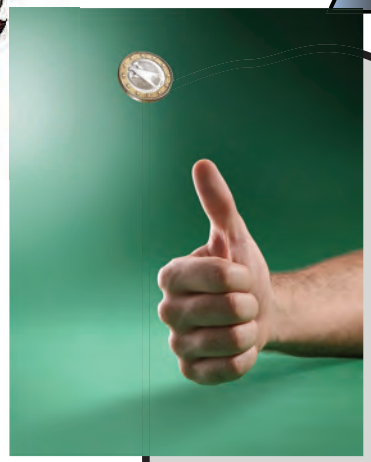
Zero Knowledge Proof



Essential Features

- Residual uncertainty
- Randomness
- First person
- Free will

First Person, Free Will, and Randomness



Knowledge becomes available to any third-person observer.

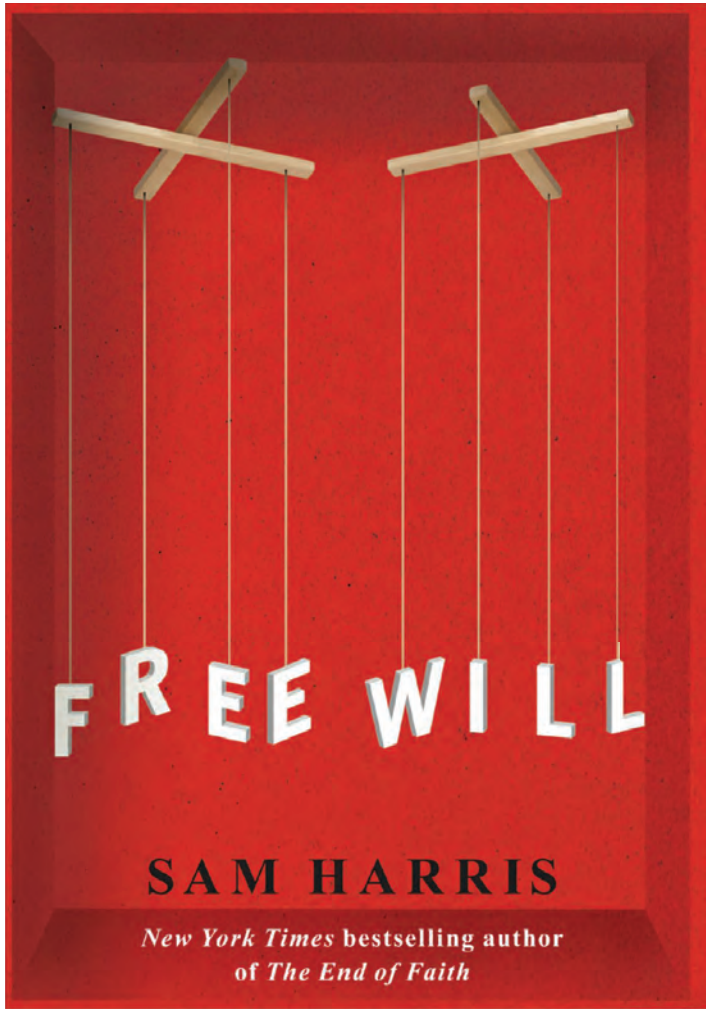
[CC BY SA 2.0, ICMA Photos]

A Scandal in Philosophy

‘The Berkeley philosopher John Searle has dubbed the free will problem “a scandal in philosophy” on which we have made little progress since antiquity.’

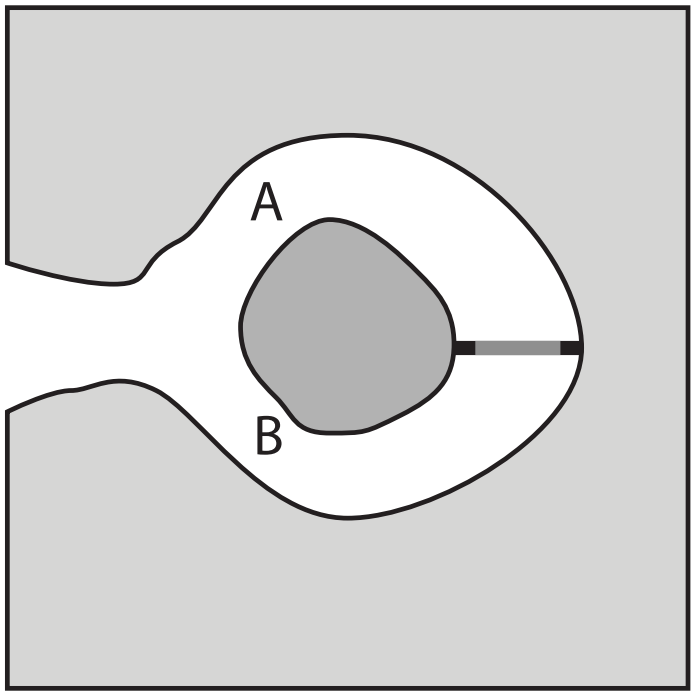
[Doyle, 2012]

Sam Harris: Free will does not and cannot exist in any material system.



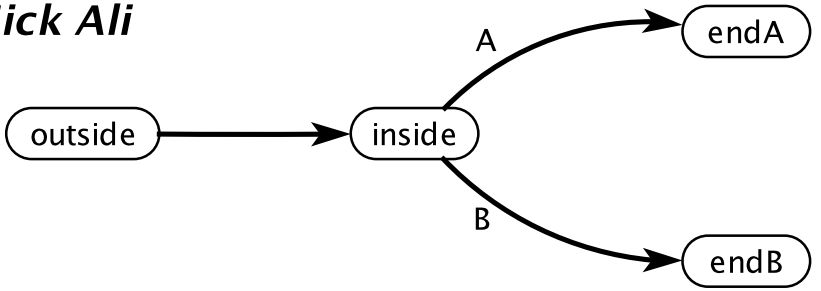
Modeling the Cave With Automata

Shah Fi

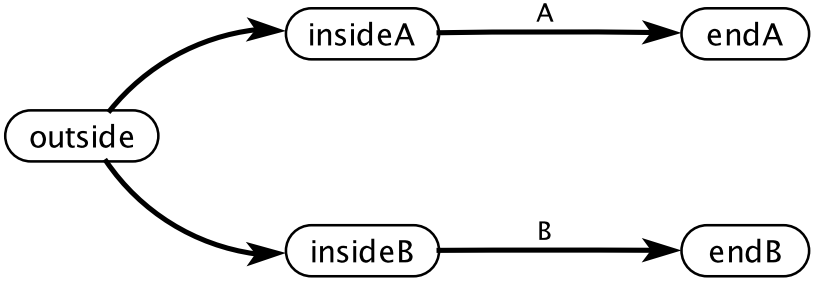


Mick Ali

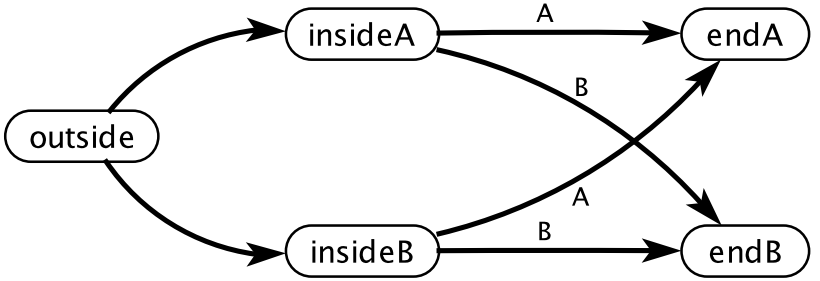
Mick Ali



Shah Fi (Without Password)



Shah Fi (With Password)

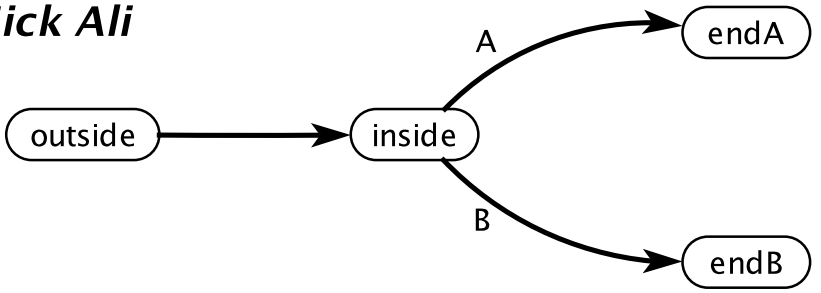


Language Equivalence

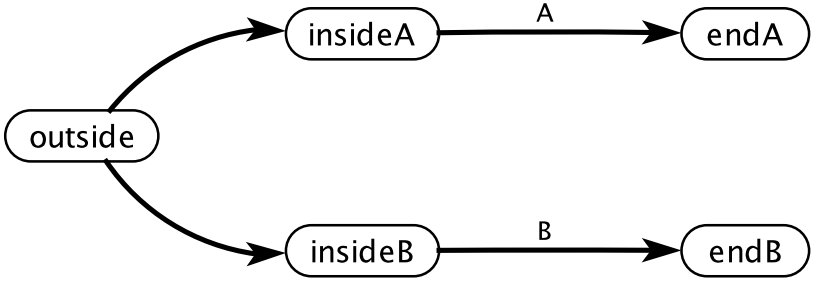
The essential difference between these is whether alternatives resolve early or late.

No passive observer can tell the difference.

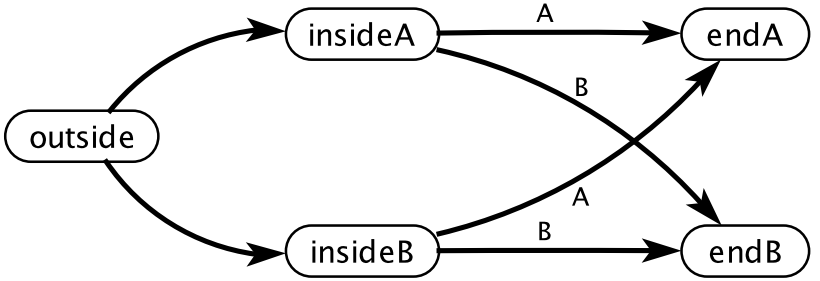
Mick Ali



Shah Fi (Without Password)



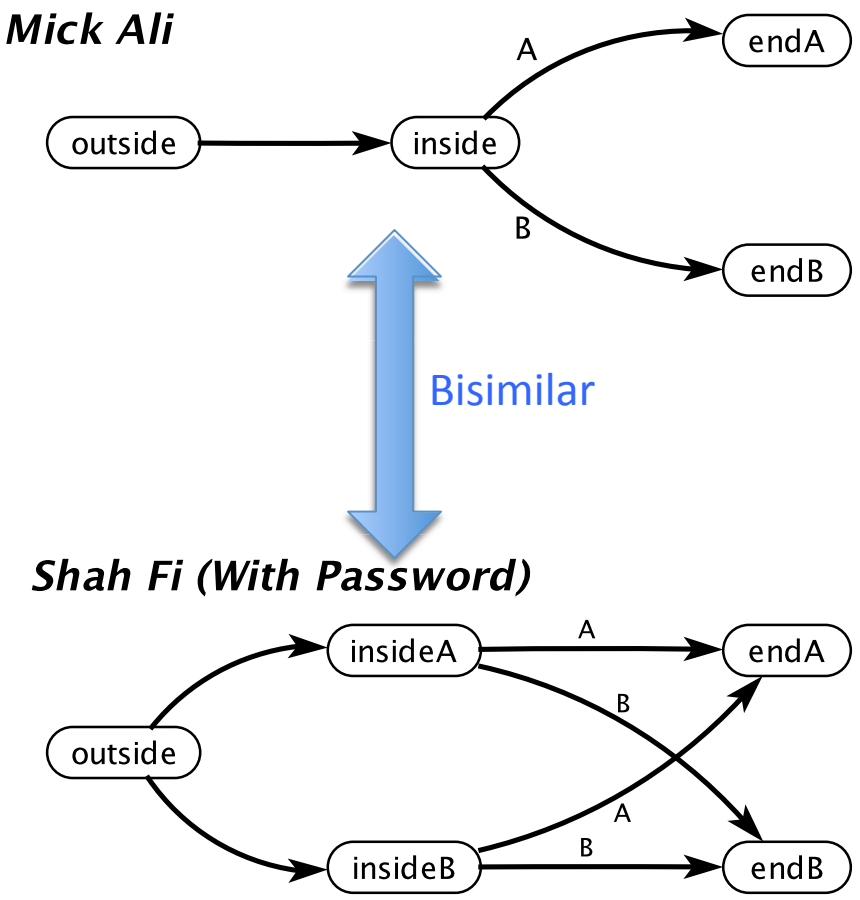
Shah Fi (With Password)



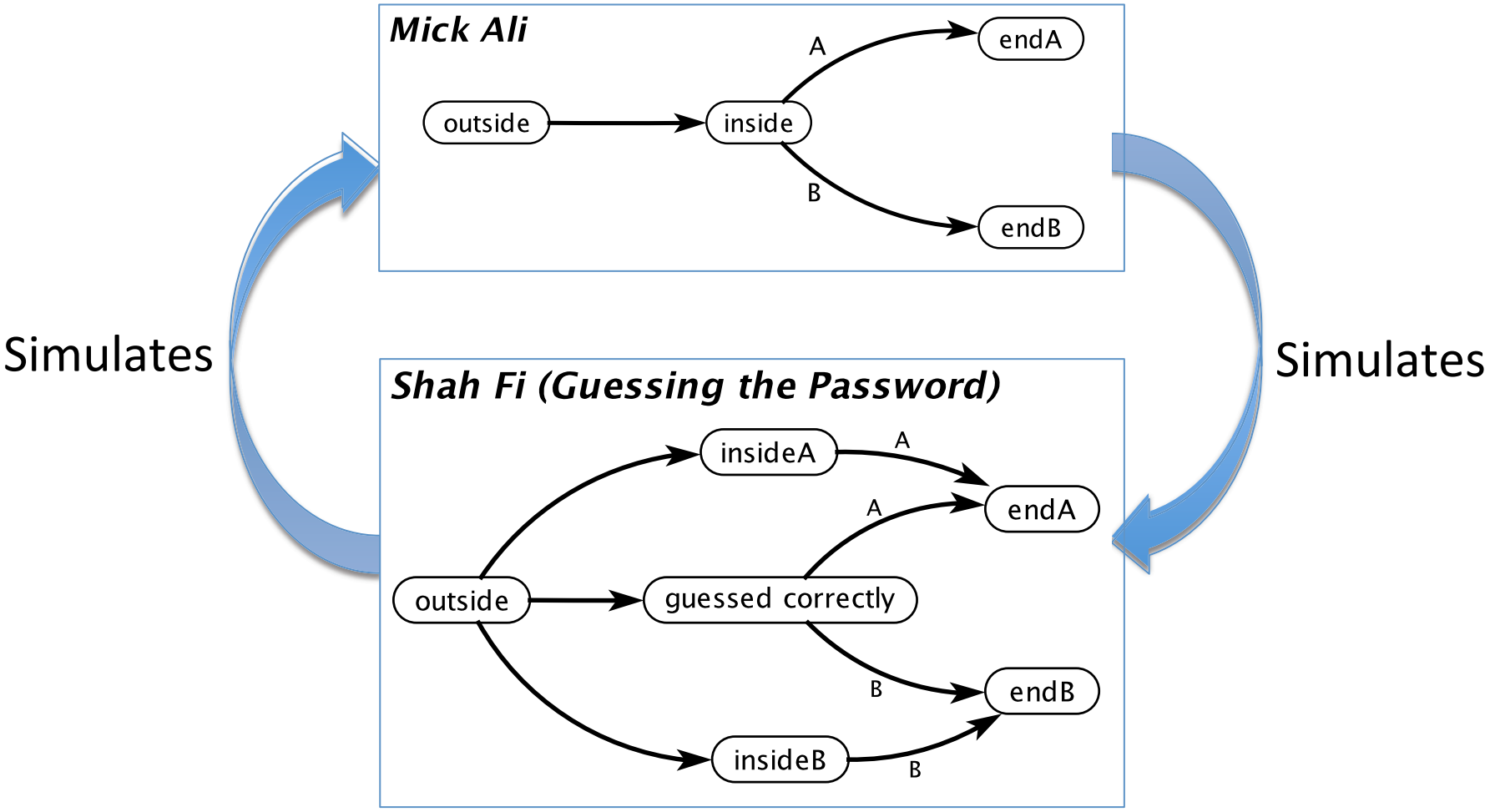
Shah and Mick Bisimulate

Bisimulation is interactive.

Constructing a bisimulation relation gives certainty, but it requires knowledge of the internal structure of the state machines.



Simulation relations, in contrast, have one-way information flow



Resolution of Alternatives: Determinism

As a property of the physical world:

- Everything that happens is inevitable, preordained by some earlier state of the universe, and then following from the laws of physics.

As a property of a model:

- A model is deterministic if given an initial *state* of the model, and given all the *inputs* that are provided to the model, the model defines exactly one possible *behavior*.

Determinism

Both definitions are about resolution of alternatives.

Questions:

- *How* are alternatives resolved?
- *Why* do alternatives resolve the way they do?
- *When* do alternative resolve?

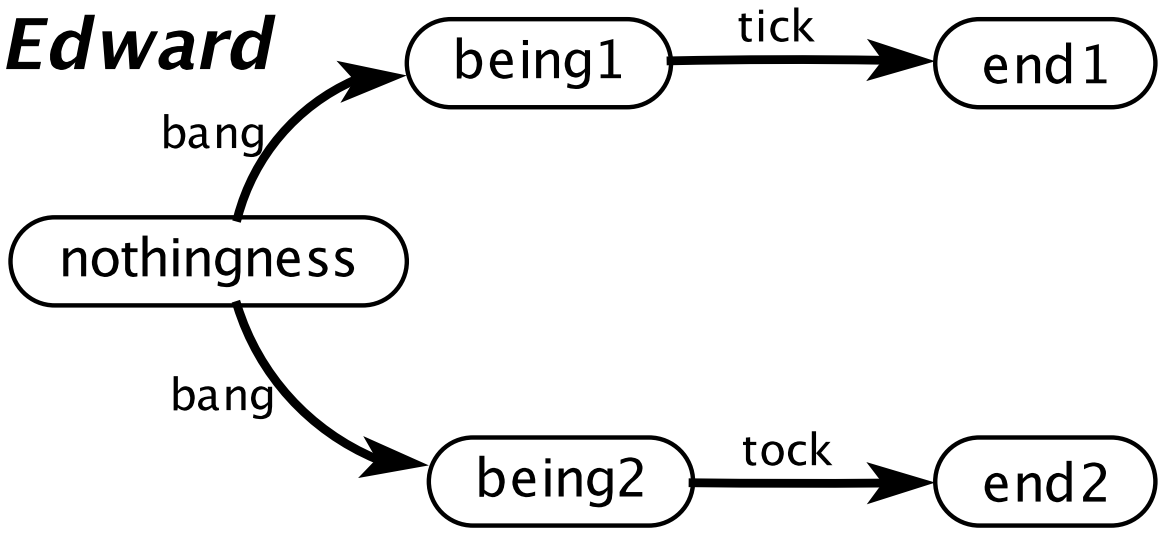
A Tiny Universe

Consider a tiny universe that comes into existence with a finite number of beings, and for each being, one of two things happens later:

tick or *tock*.

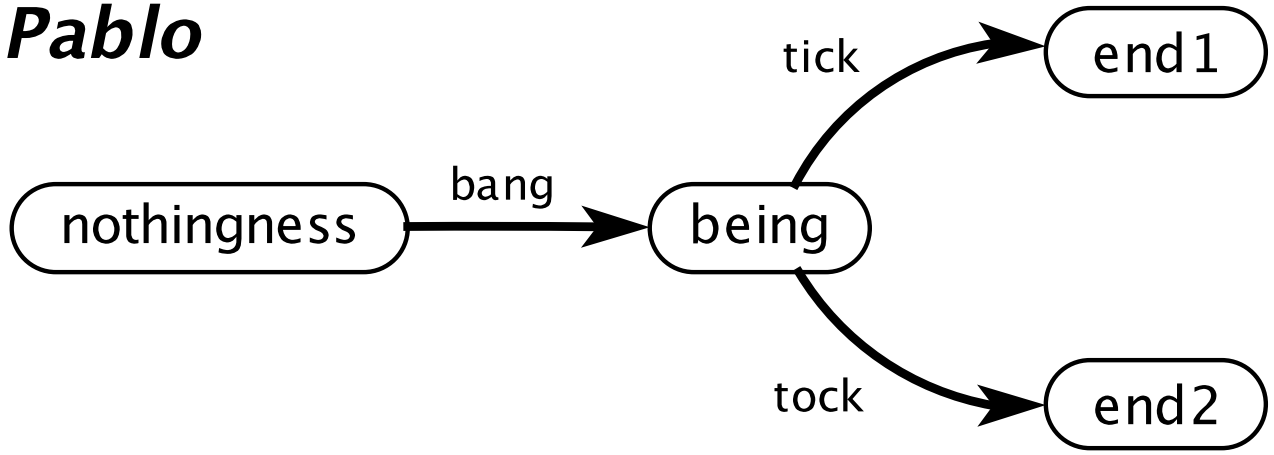
A Deterministic Tiny Universe

In a deterministic tiny universe, the choice between *tick* and *tock* is resolved at the time of the "little bang."



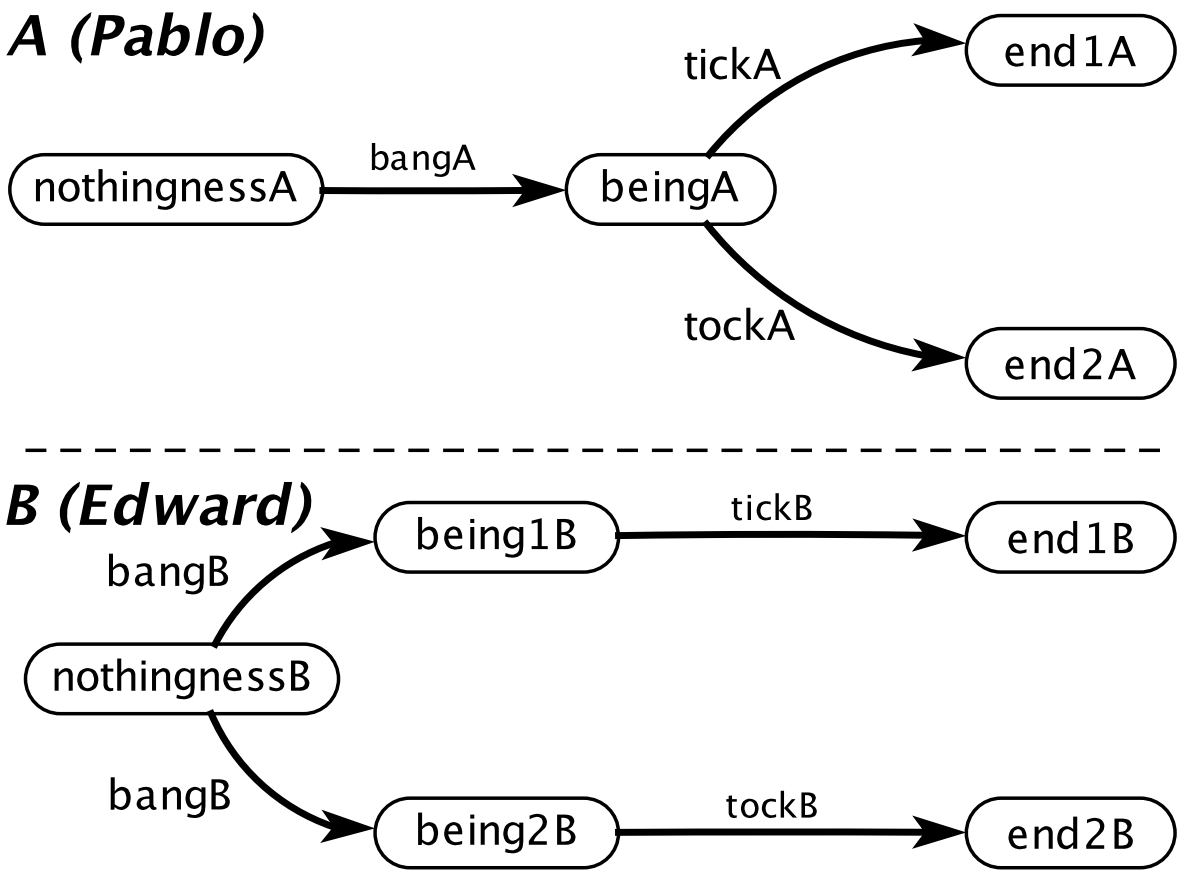
A Nondeterministic Tiny Universe

In a nondeterministic tiny universe, the choice between *tick* and *tock* is resolved later.



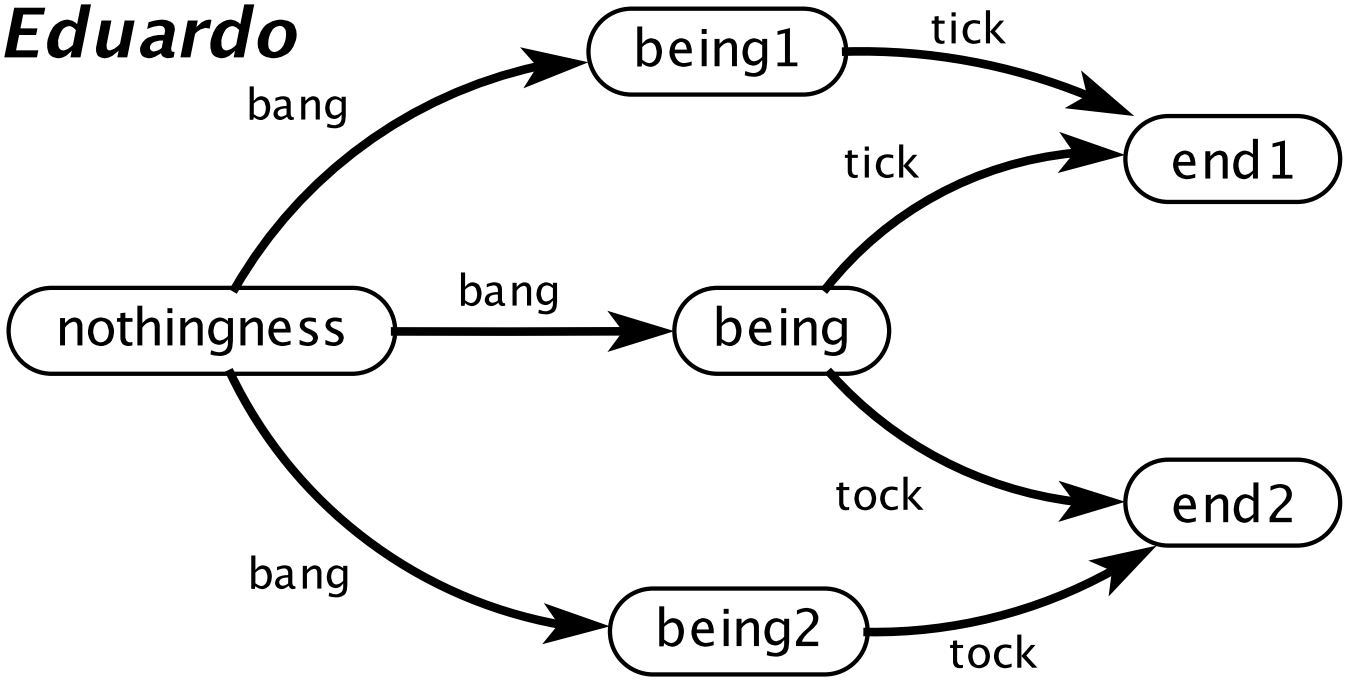
Modeling in a Tiny Universe

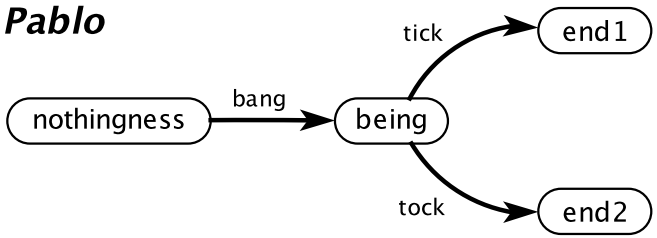
Pablo simulates Edward, but not vice versa.



A tiny universe where actions may be predetermined or not.

Eduardo simulates Pablo and vice versa, but they are not bisimilar.



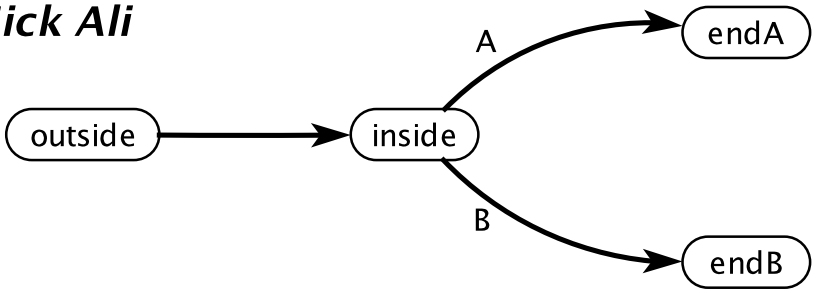


Determinism and Free Will

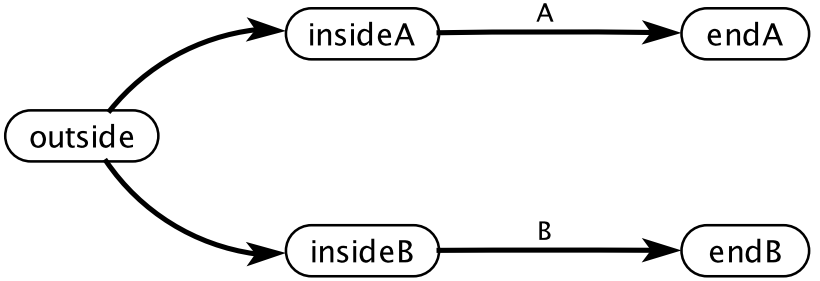
Mick requires late resolution of alternatives (after Shah has resolved hers).

Mick requires free will to achieve zero-knowledge proof.

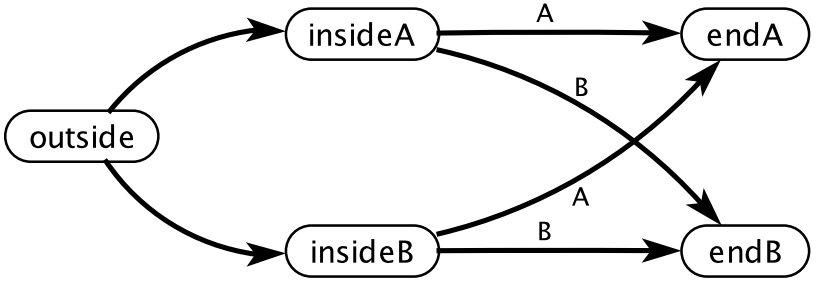
Mick Ali



Shah Fi (Without Password)

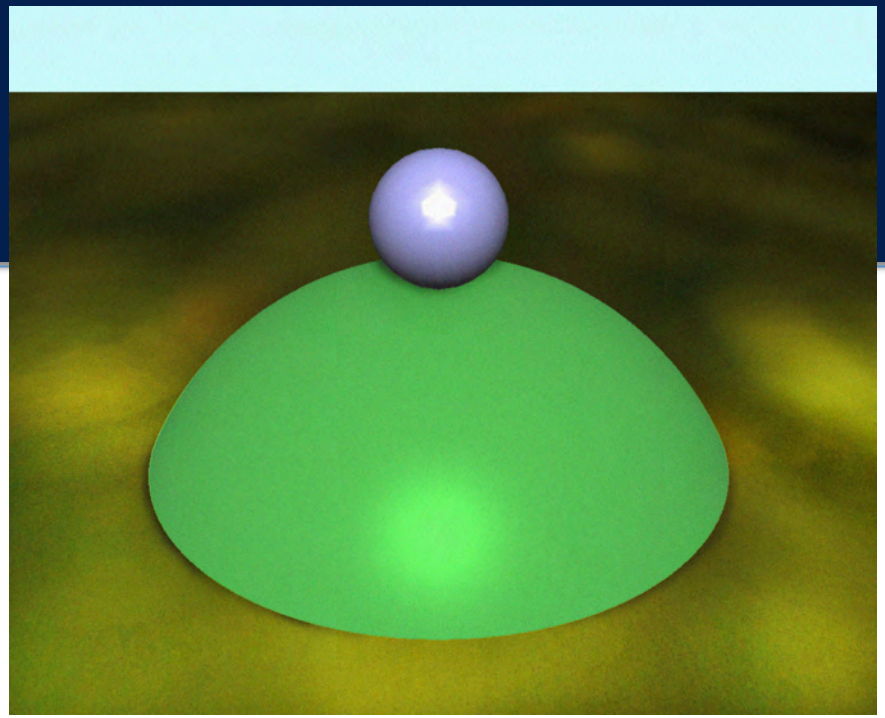


Shah Fi (With Password)



Is the physical world deterministic?

Physical Nondetermism



Naïve assumption: Newtonian mechanics is deterministic.

Pierre-Simon Laplace

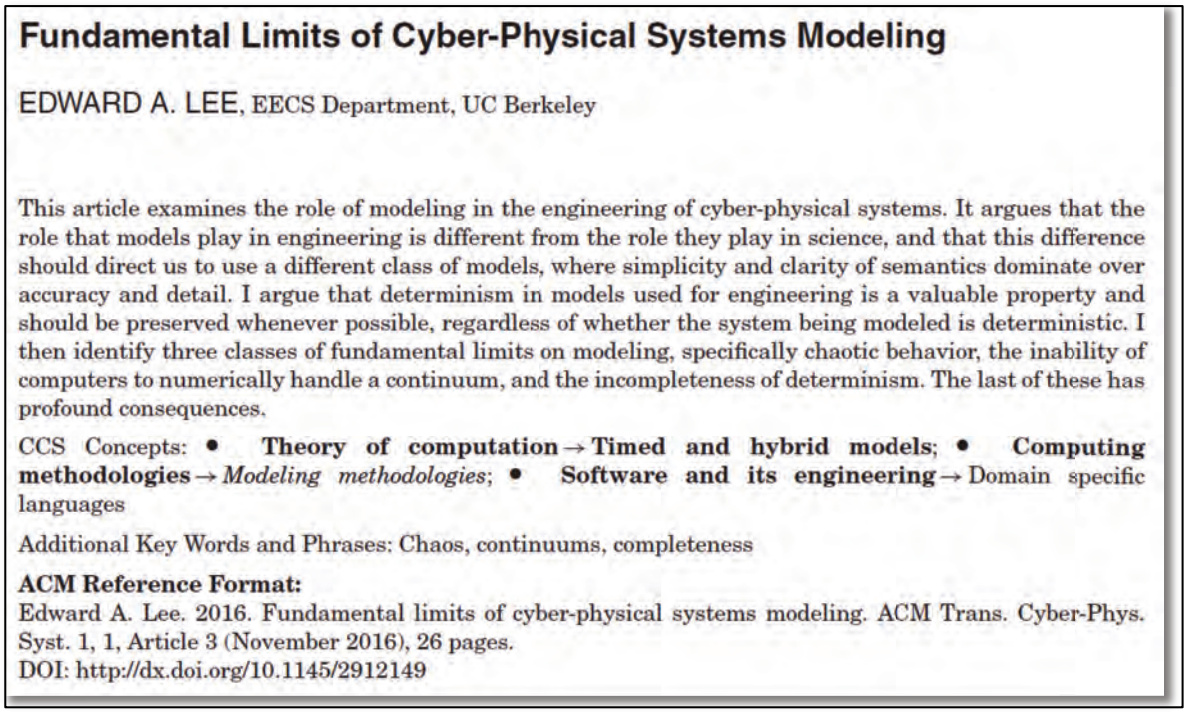
Metastable system that obeys all of Newton's laws but is nondeterministic.

[Norton, 2007]

Incompleteness of Determinism

Any set of deterministic models rich enough to encompass Newton's laws plus discrete events is incomplete.

Lee, *Fundamental Limits of Cyber-Physical Systems Modeling*, ACM Tr. on CPS, Vol. 1, No. 1, November 2016



Fundamental Limits of Cyber-Physical Systems Modeling

EDWARD A. LEE, EECS Department, UC Berkeley

This article examines the role of modeling in the engineering of cyber-physical systems. It argues that the role that models play in engineering is different from the role they play in science, and that this difference should direct us to use a different class of models, where simplicity and clarity of semantics dominate over accuracy and detail. I argue that determinism in models used for engineering is a valuable property and should be preserved whenever possible, regardless of whether the system being modeled is deterministic. I then identify three classes of fundamental limits on modeling, specifically chaotic behavior, the inability of computers to numerically handle a continuum, and the incompleteness of determinism. The last of these has profound consequences.

CCS Concepts: • **Theory of computation** → **Timed and hybrid models**; • **Computing methodologies** → *Modeling methodologies*; • **Software and its engineering** → Domain specific languages

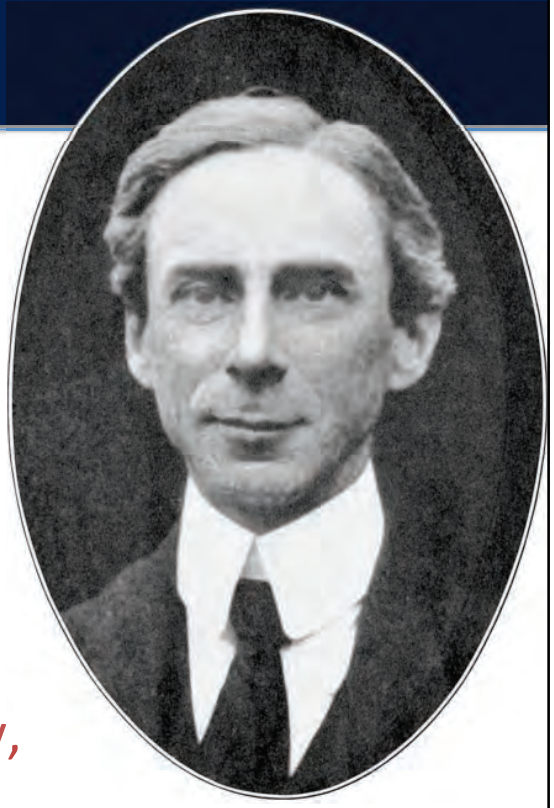
Additional Key Words and Phrases: Chaos, continuums, completeness

ACM Reference Format:
Edward A. Lee. 2016. Fundamental limits of cyber-physical systems modeling. ACM Trans. Cyber-Phys. Syst. 1, 1, Article 3 (November 2016), 26 pages.
DOI: http://dx.doi.org/10.1145/2912149

Causality or Causation

Every effect is produced, as a consequence of some law of nature, by a cause.

"All philosophers, of every school, imagine that causation is one of the fundamental axioms or postulates of science, yet, oddly enough, in advanced sciences such as gravitational astronomy, the word 'cause' never occurs …The law of causality, I believe, like much that passes muster among philosophers, is a relic of a bygone age, surviving, like the monarchy, only because it is erroneously supposed to do no harm." (Russell, 1913)

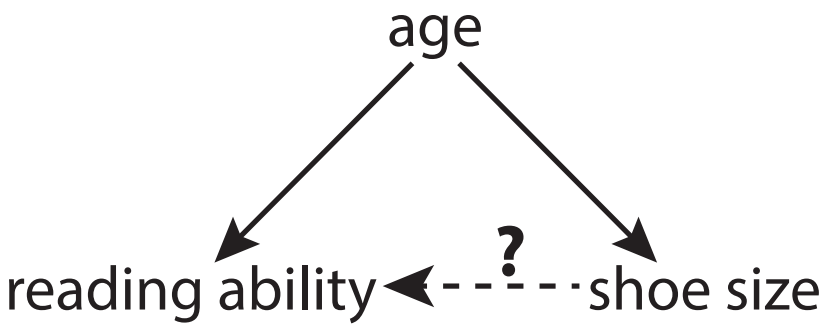


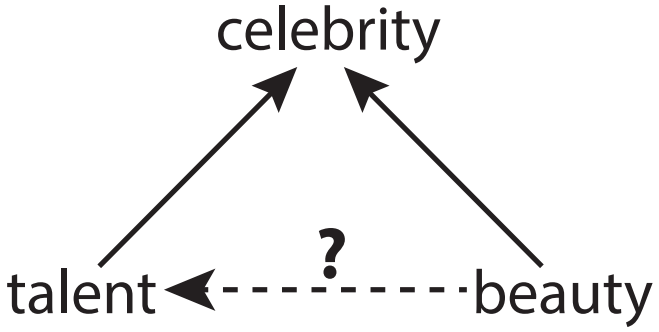
Bertrand Russell

Causal Reasoning

You cannot reason about causality by objective observation alone.

Judea Pearl

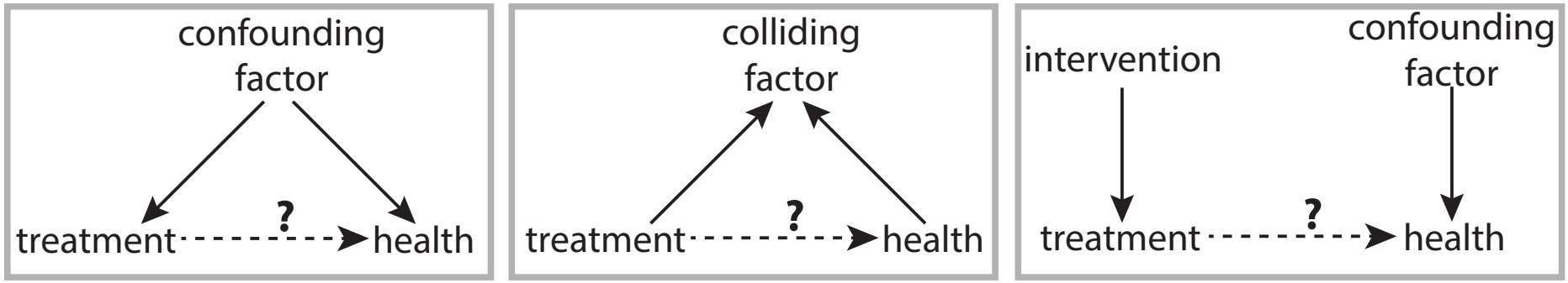




[Pearl and Mackenzie, 2018]

Randomized Controlled Trials

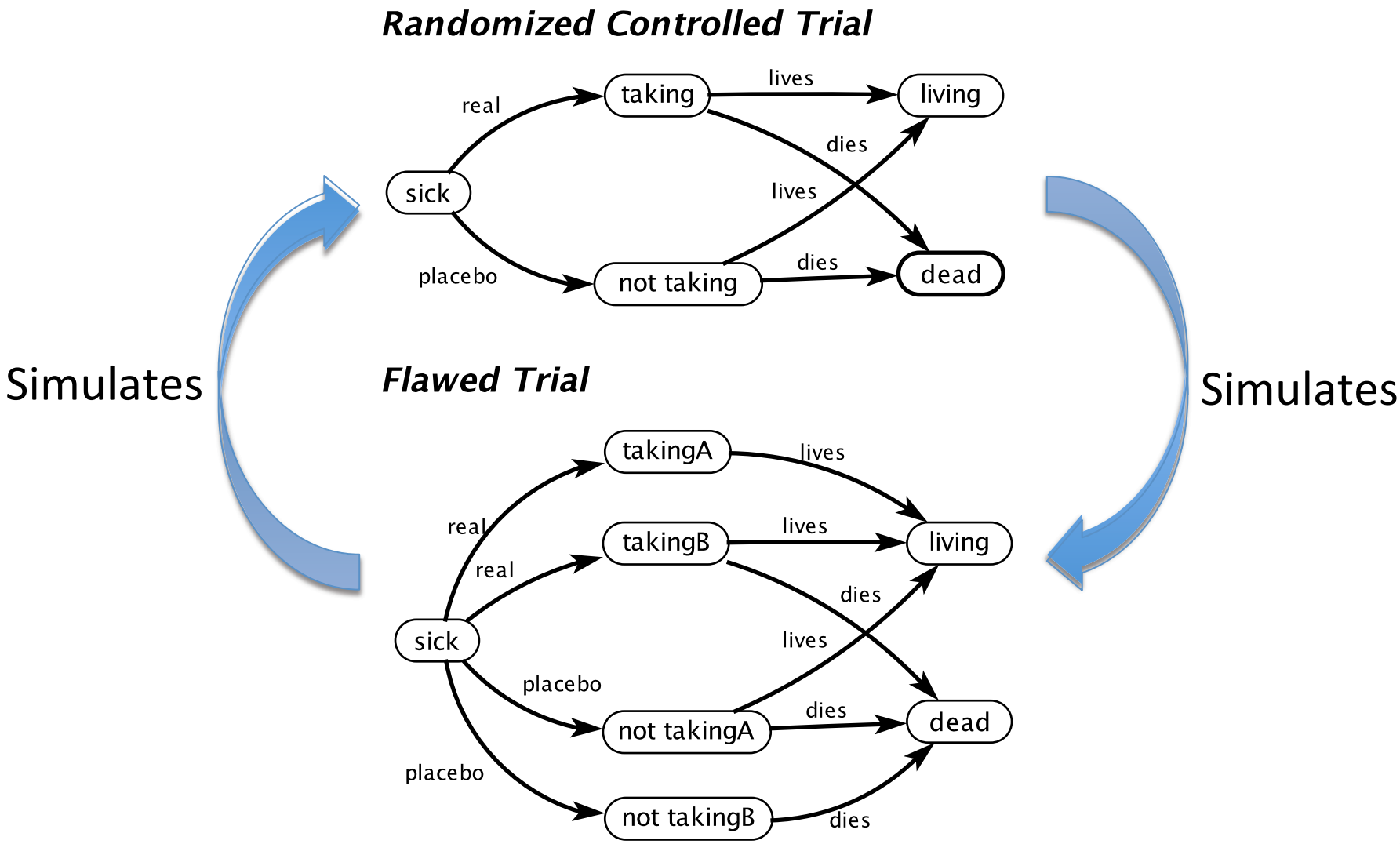
Interaction enables reasoning about causality.



Intervention is analogous to Mick calling out *A* or *B.*

But the purpose is to broadcast the result!

Mutual Simulation is Not Enough



Interaction vs. Observation

- Machines that look identical to an observer are not identical if you can interact with them.
- Interaction can do things that are not possible without interaction (zero knowledge proofs).
- Reasoning about causality requires interaction and subjective judgment.

First person is fundamentally different from third person!

Lessons from Physics
The Quantum Observer Problem

- Pure observation is impossible, at least under the Copenhagen interpretation.
- But the Copenhagen interpretation ignores the backwards direction, the effect on the observer.

Lessons from Psychology: Embodied Cognition

"The mind simply does not exist as something decoupled from the body and the environment in which it resides."

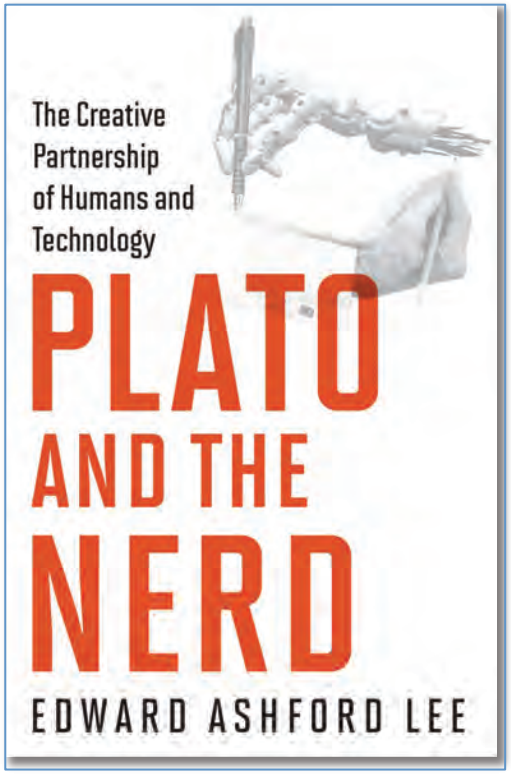
[Thelen, E., 2000: Grounded in the world]

AI will arise from cyber-physical systems and cyber-human systems, not pure cyber ones.

Esther Thelen (1941—2004)
Developmental psychologist,
Indiana University, pioneer of embodied cognition.

Conclusions

Interaction is more powerful than observation.



MIT Press, 2017

Subjectivity rules!

Спасибо

MIT Press, 2020

References

- Doyle, B., 2011: *Free Will: The Scandal in Philosophy*. I-Phi Press, Cambridge, MA.
- Harris, S., 2012: *Free Will*, Simon & Schuster.
- Lee, E. A., 2016: *Fundamental Limits of Cyber-Physical Systems Modeling*, ACM Tr. on CPS, Vol. 1, No. 1, Nov.
- Norton, J. D. (2007). Causation as Folk Science. In Causation, Physics, and the Constitution of Reality Oxford, Clarendon Press.
- Pearl, J. and D. Mackenzie (2018). The Book of Why: The New Science of Cause and Effect. New York, Basic Books.
- Russell, B. (1913). "On the Notion of Cause." Proceedings of the Aristotelian Society **13**: 1-26.
- Quisquater, J.-J., Myriam, Mureil, Michaël, L. C. Guillou, M. Annick, Gaïd, Anna, Gwenolé, Soazig, and T. A. Berson, 1989: How to explain zero-knowledge protocols to your children. In Brassard, G., ed., Advances in Cryptology (CRYPTO), Springer, vol. 435, pp. 628–631.
- Thelen, E. (2000). "Grounded in the World: Developmental Origins of the Embodied Mind " Infancy **1**(1): 3-28.