Art and Physics Symposium

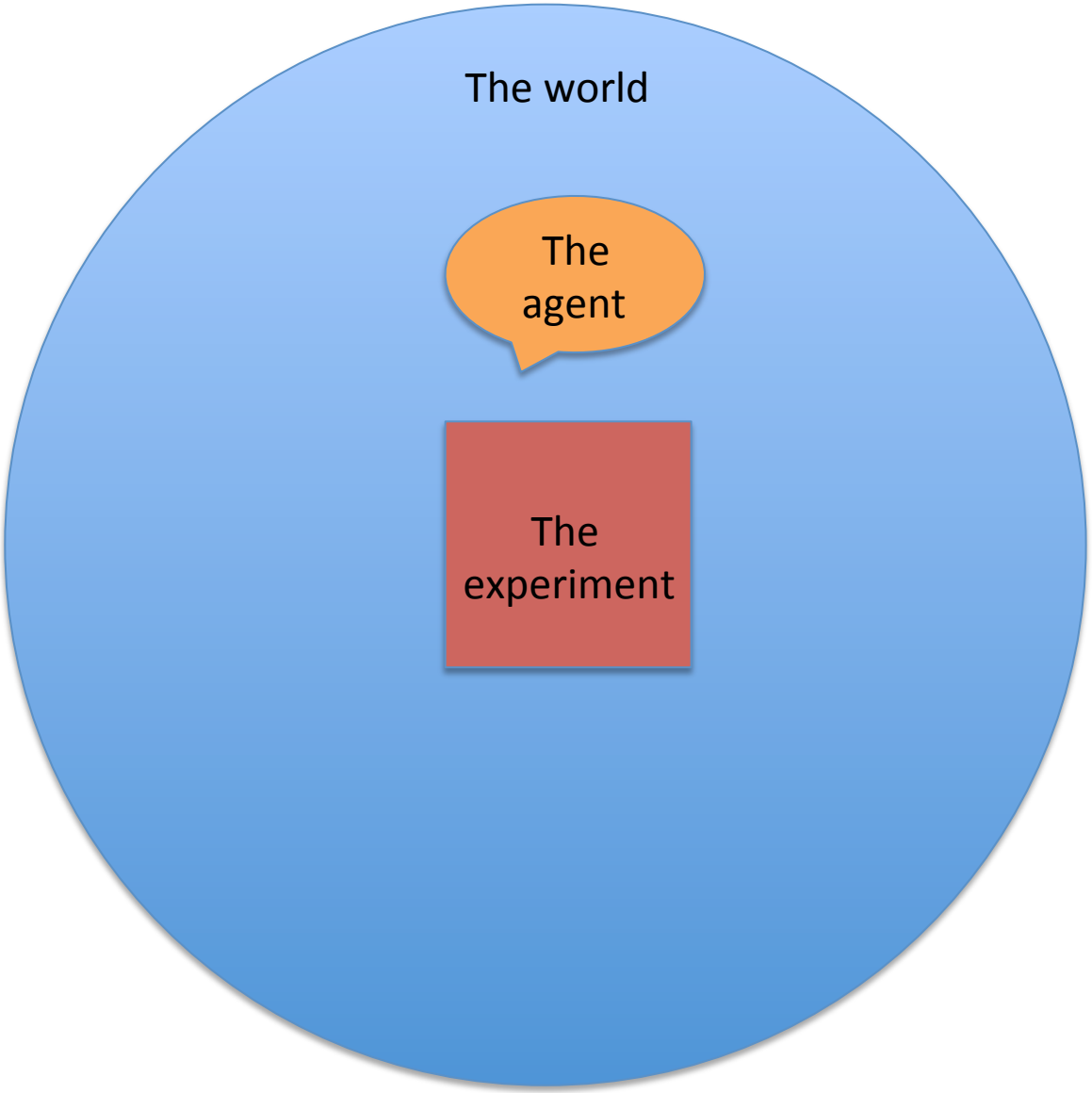
Quantum computing: Beyond intelligence

Gerard Milburn
The University of Queensland

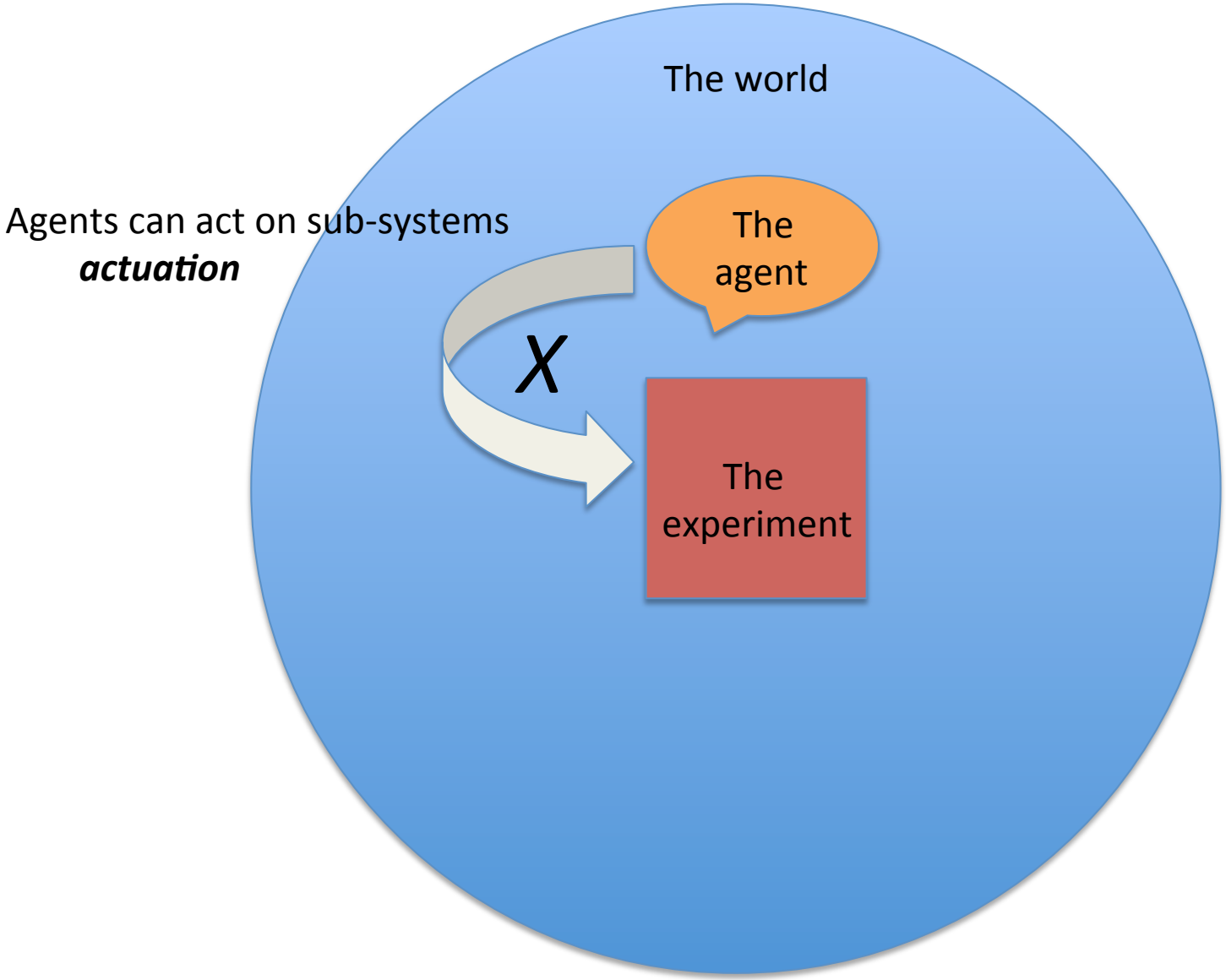
ARC CENTRE OF EXCELLENCE FOR
ENGINEERED QUANTUM SYSTEMS

Australian Government
Australian Research Council

The Scientific method as a learning algorithm



The Scientific method as a learning algorithm



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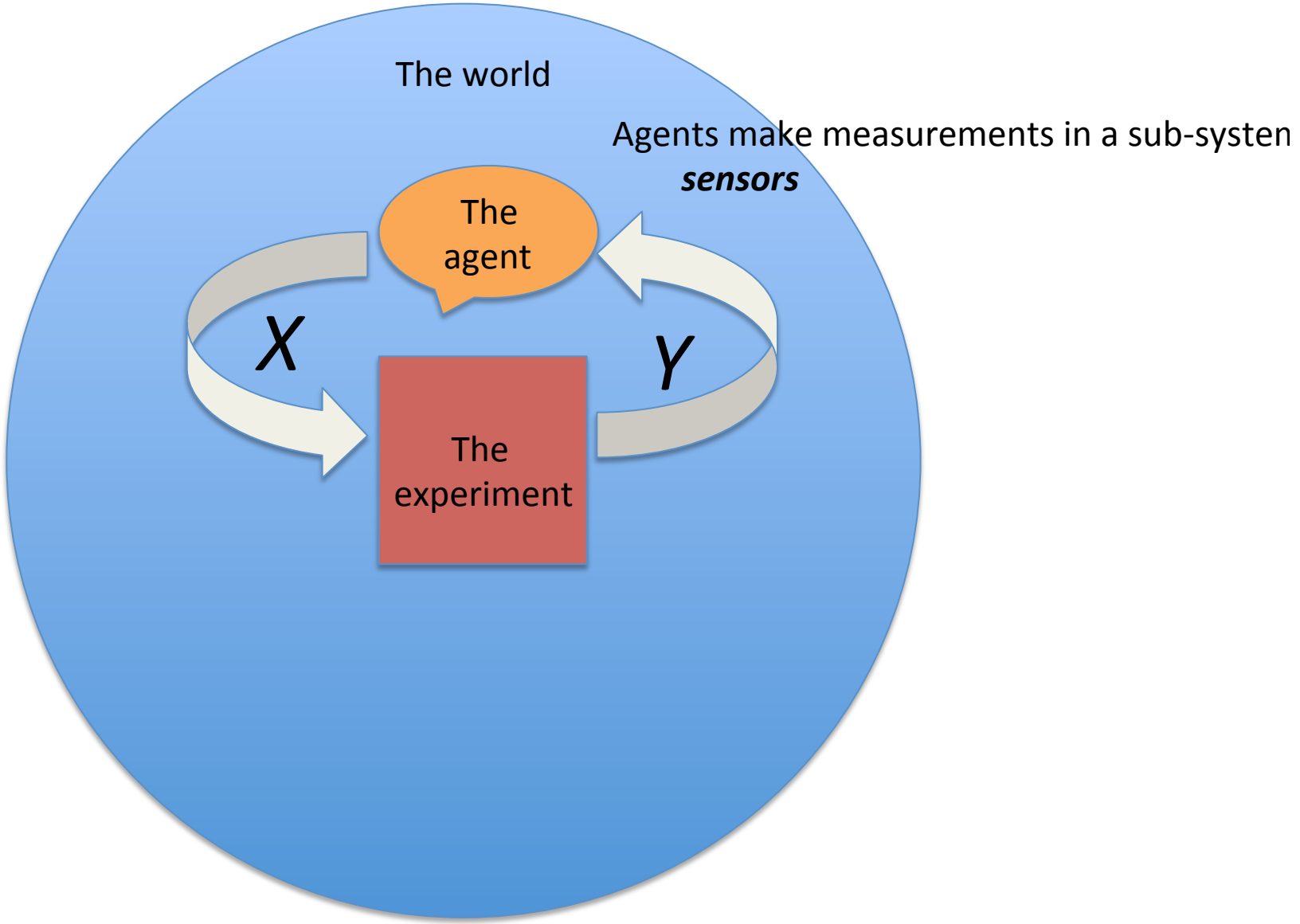

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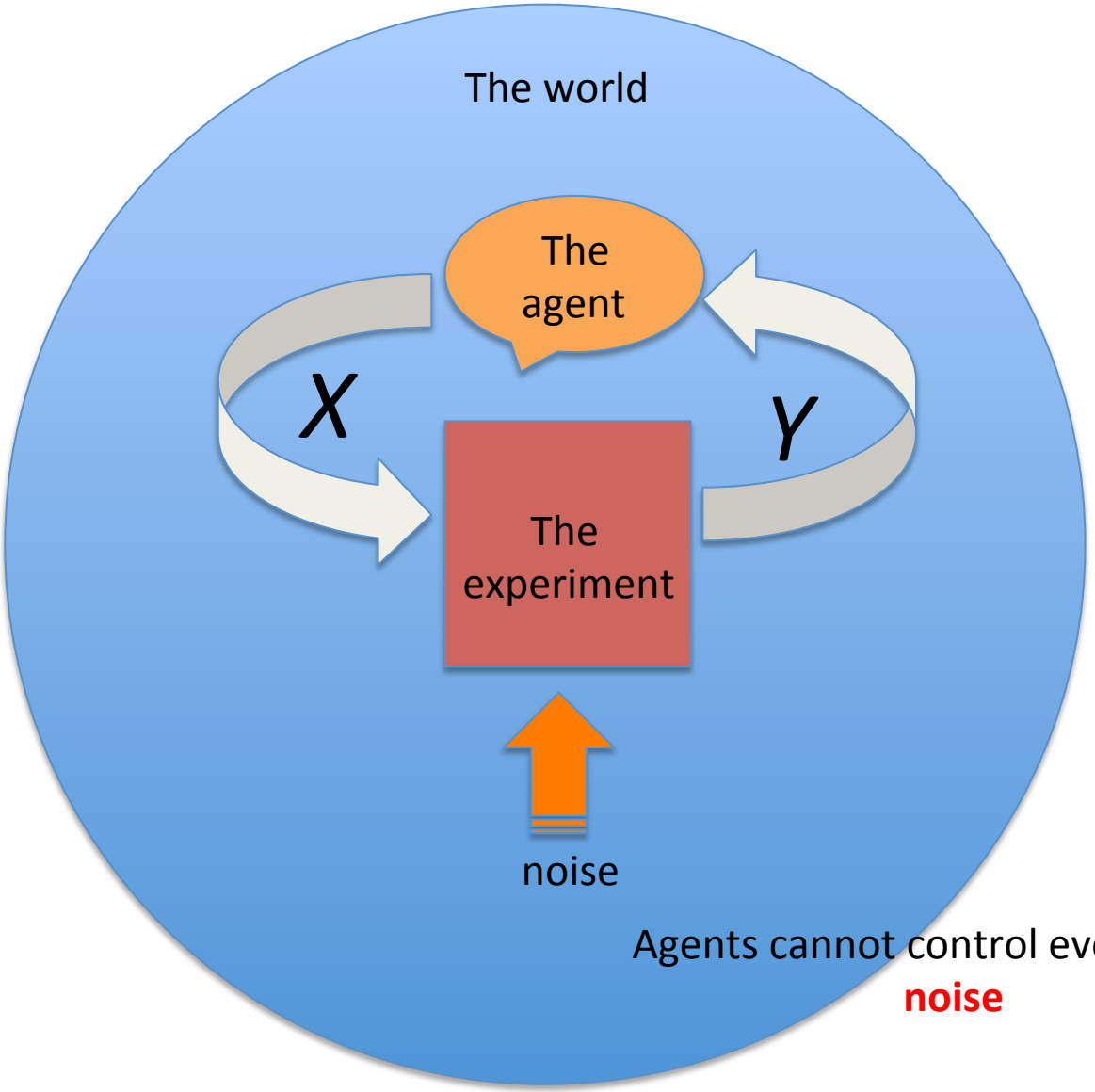
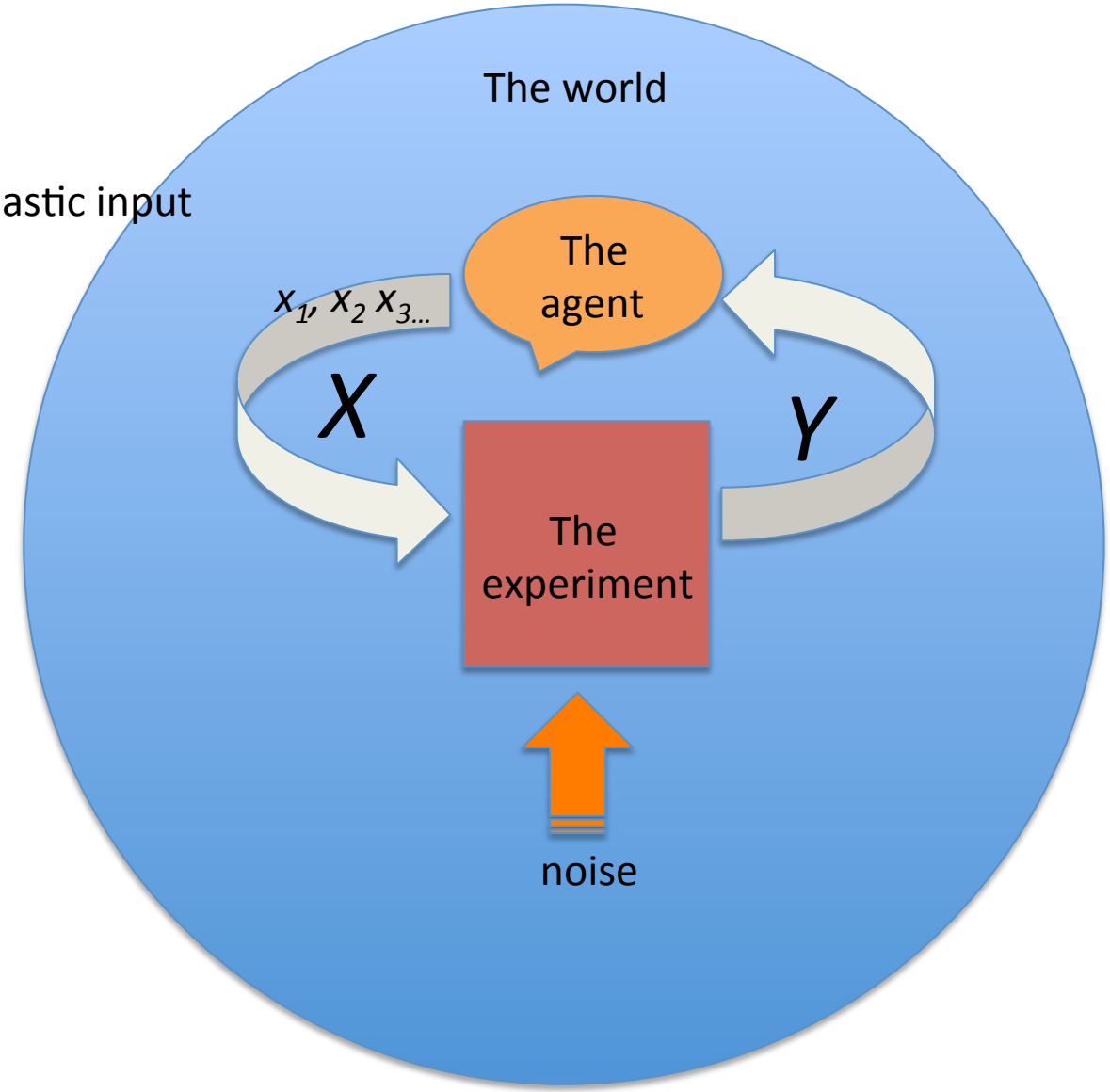


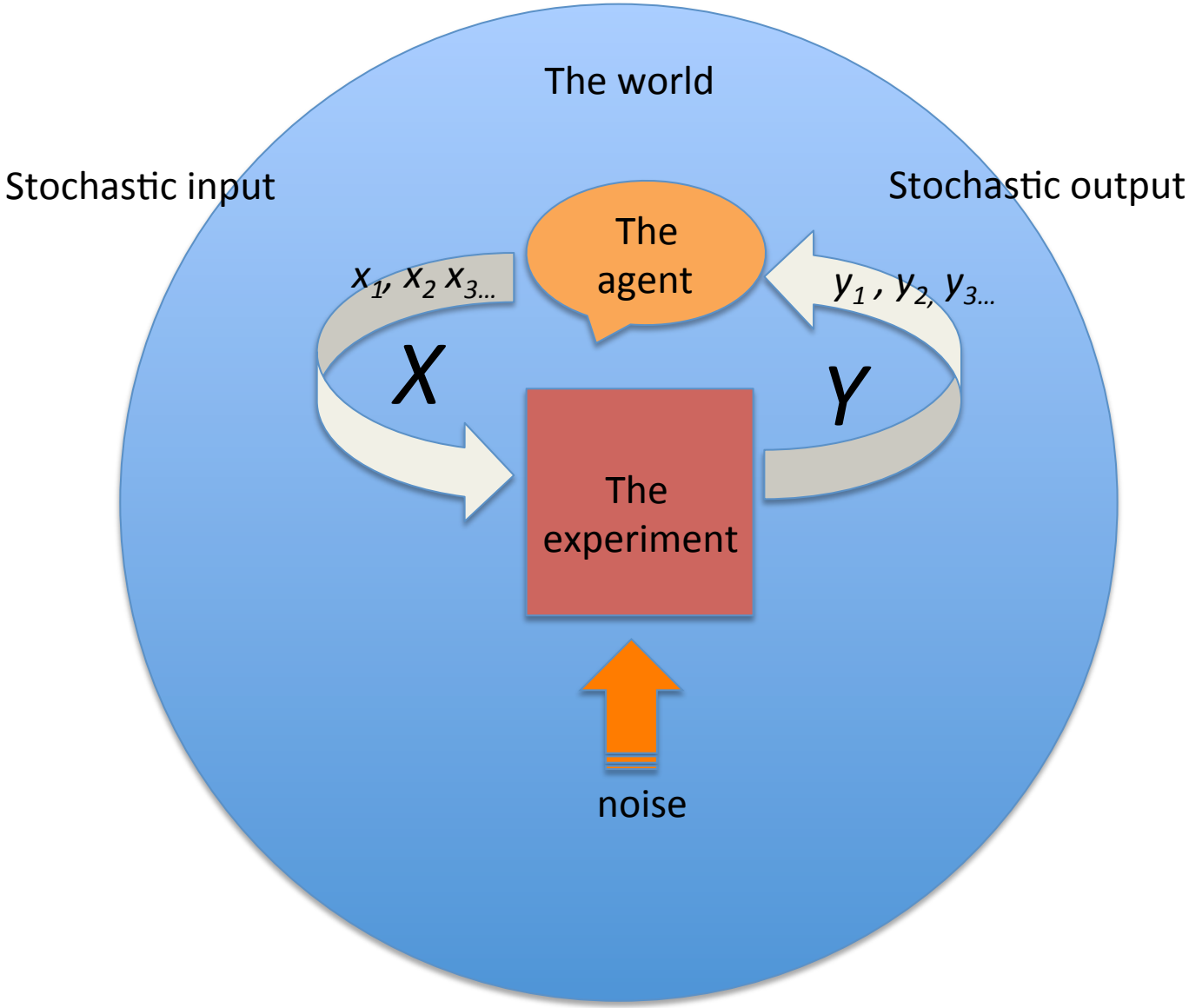
Agents cannot control everything

noise

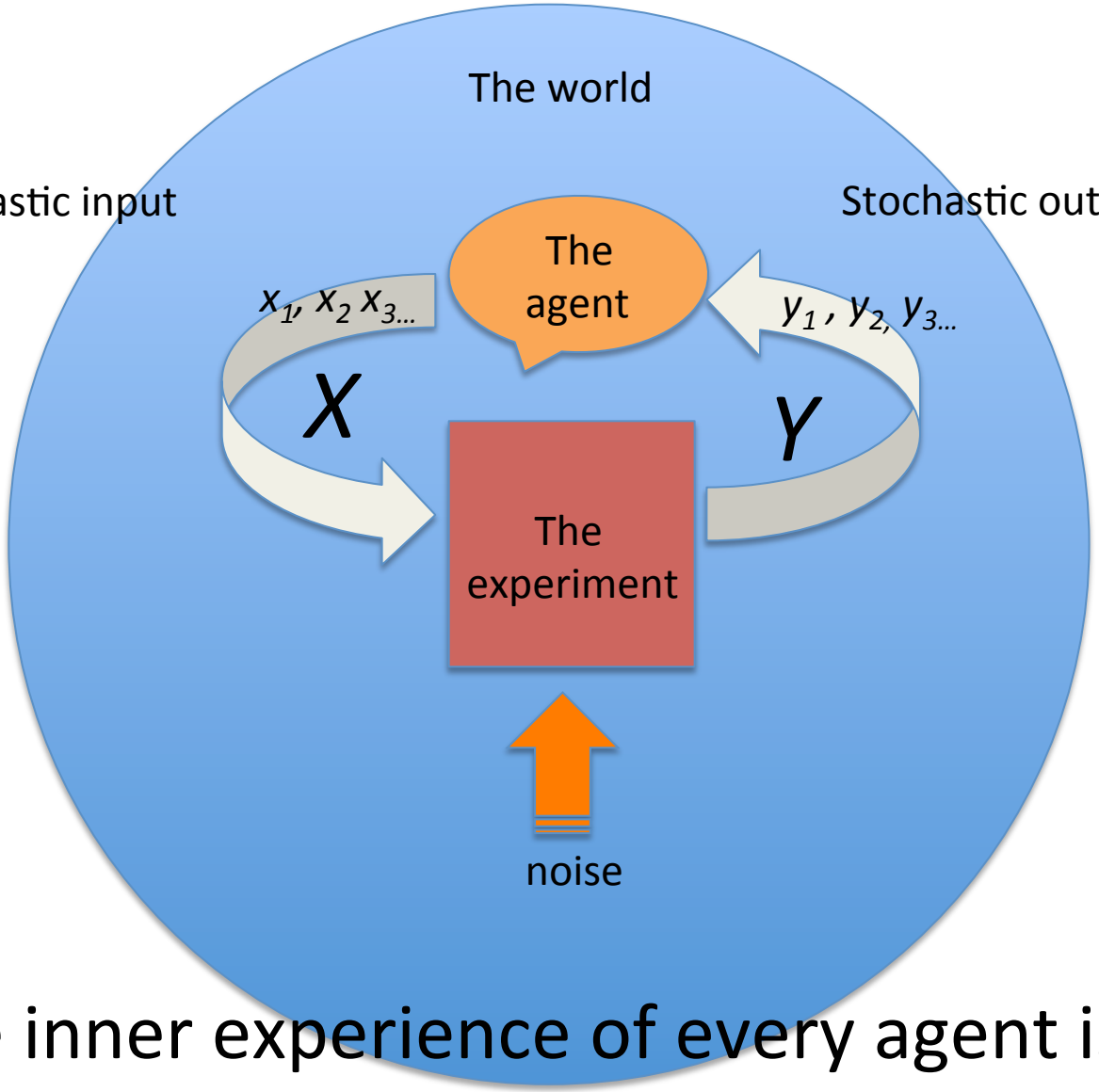
The Scientific method as a learning algorithm



The Scientific method as a learning algorithm



The Scientific method as a learning algorithm



The inner experience of every agent is *unique.*

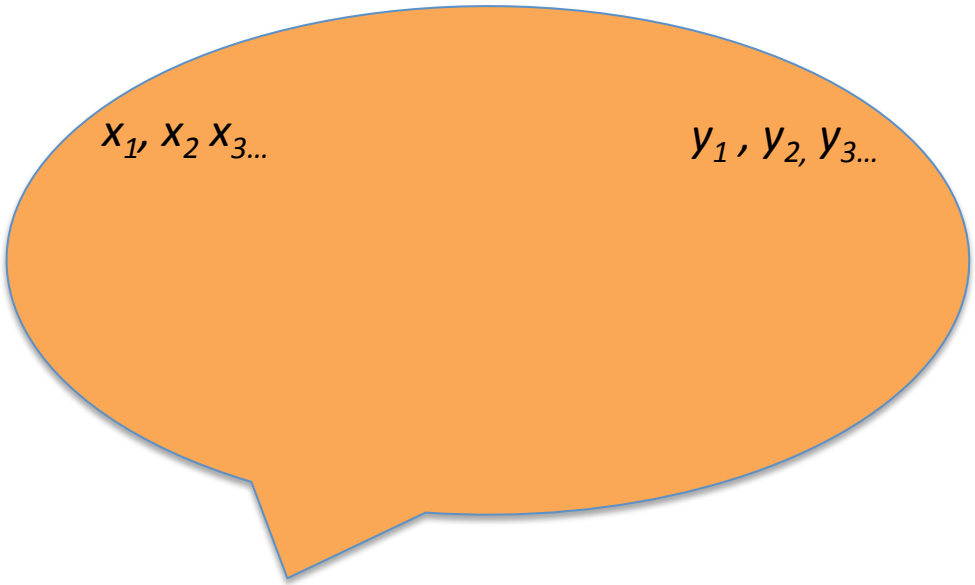
The Scientific method as a learning algorithm

"So the world acts on us like a teaching machine, reinforcing our good ideas with moments of satisfaction....we learn to abandon certainty ... we learn to do experiments, not worrying about the artificiality of our arrangements. Our understandings accumulate. It is all unplanned and unpredictable, but it leads to reliable knowledge, and gives us joy along the way.

Weinberg, "To explain the world: the discovery of modern science", 2015

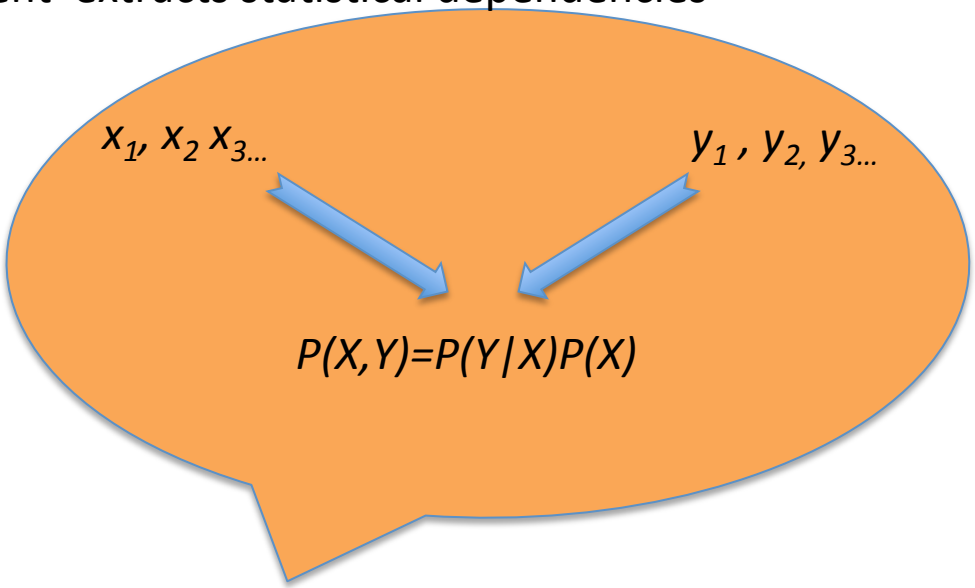
The Scientific method as a learning algorithm

The agent has a record of the stochastic process

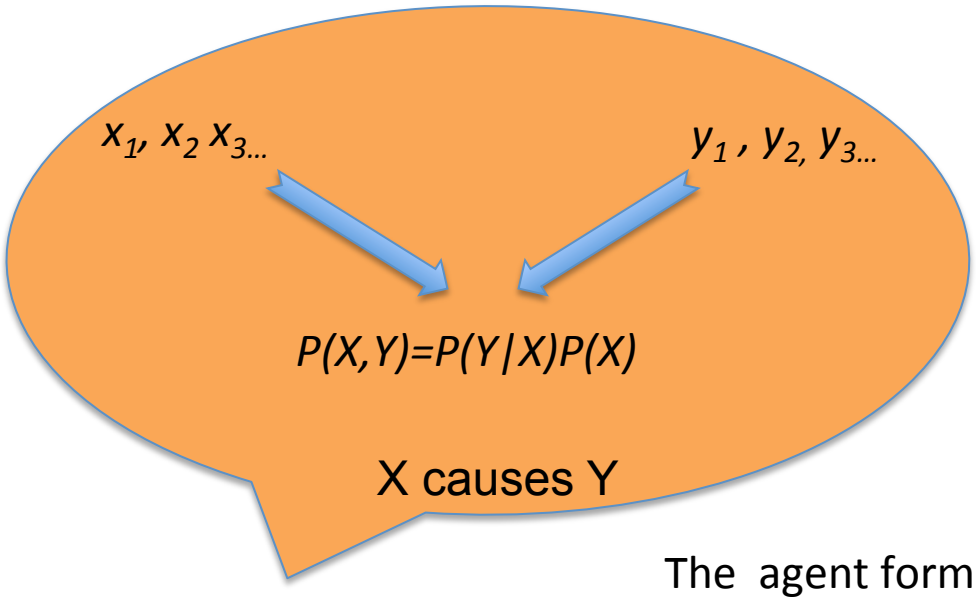


The Scientific method as a learning algorithm

The agent extracts statistical dependencies

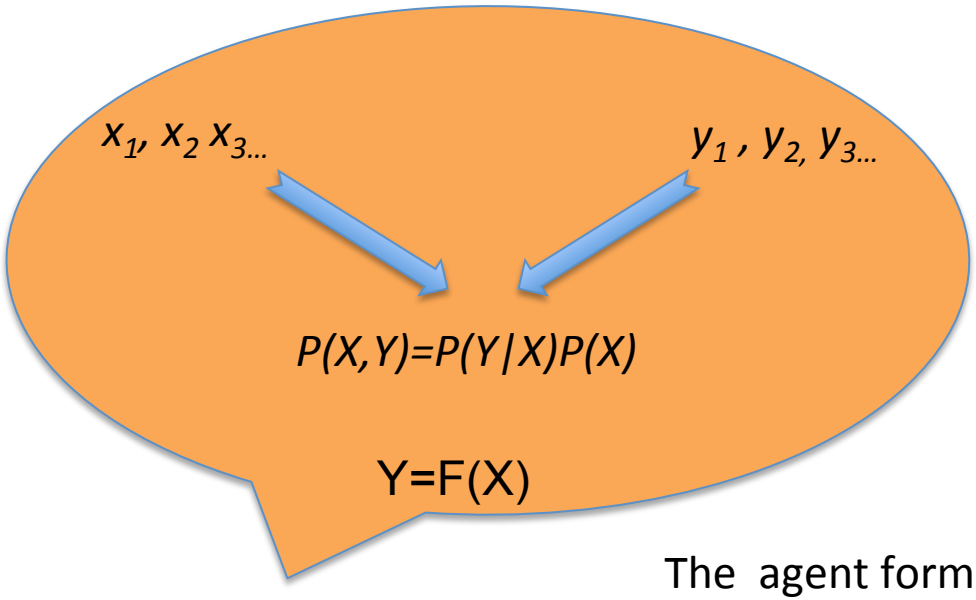


The Scientific method as a learning algorithm



The agent forms an hypothesis

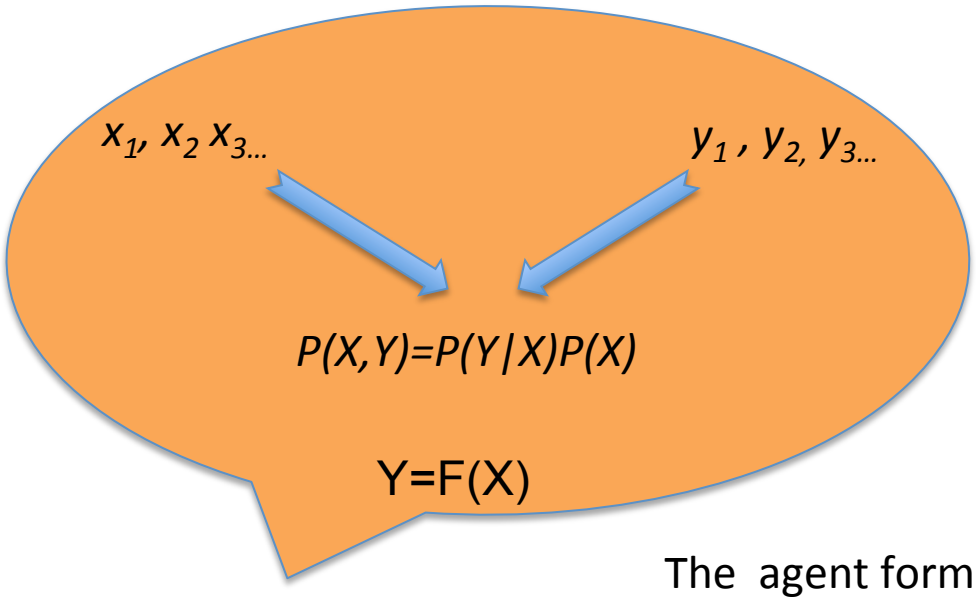
The Scientific method as a learning algorithm



The agent forms an hypothesis

The Scientific method as a learning algorithm

How complex is the data analysis?
What is the probability that the hypothesis is correct?



The agent forms an hypothesis

The Scientific method as a learning algorithm

How complex is the data analysis?

Size of the problem: *N*

How many computational steps are required to form an hypothesis with bounded error probability

p_{error} *less than some maximum error*

The Scientific method as a learning algorithm

How complex is the data analysis?

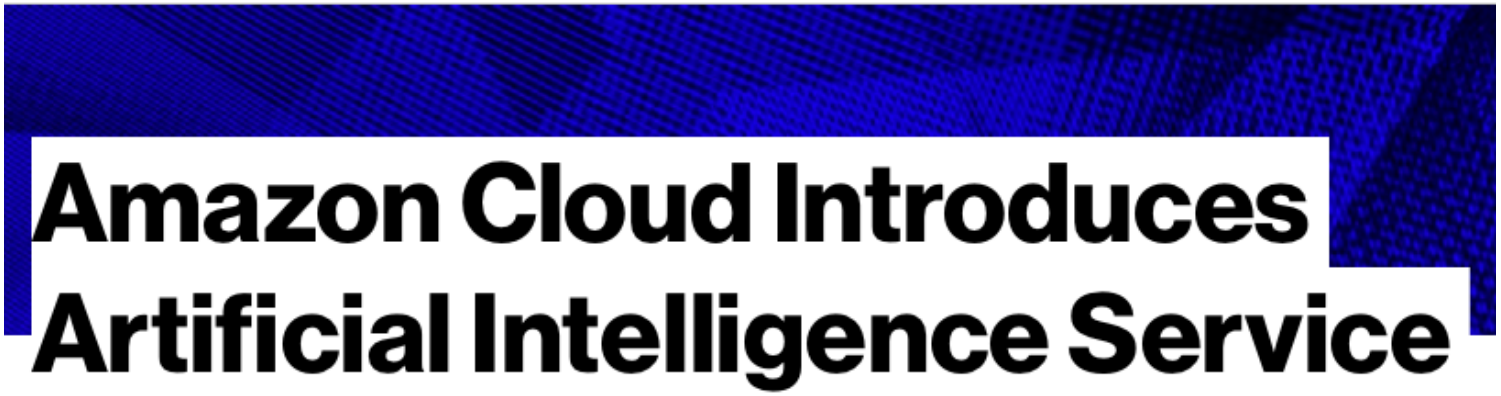
Size of the problem: *N*

How many computational steps are required to form an hypothesis with bounded error probability

p_{error} *less than some maximum error*

If number of steps to reach this error is
NOT exponential in N, the agent can learn.

April, 2015.



The new product is “a fully managed machine-learning service for developers with no experience,”

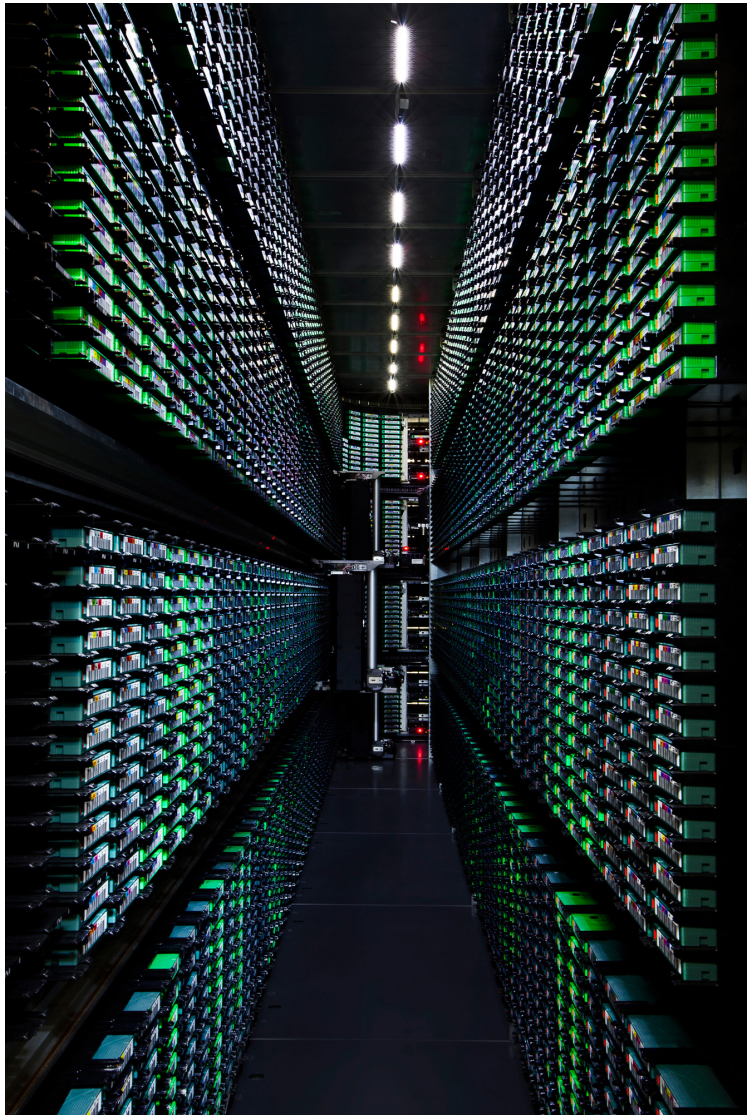
“Anything you can fit into a spreadsheet file you can feed into a machine-learning service,”

The agent?

The agent.

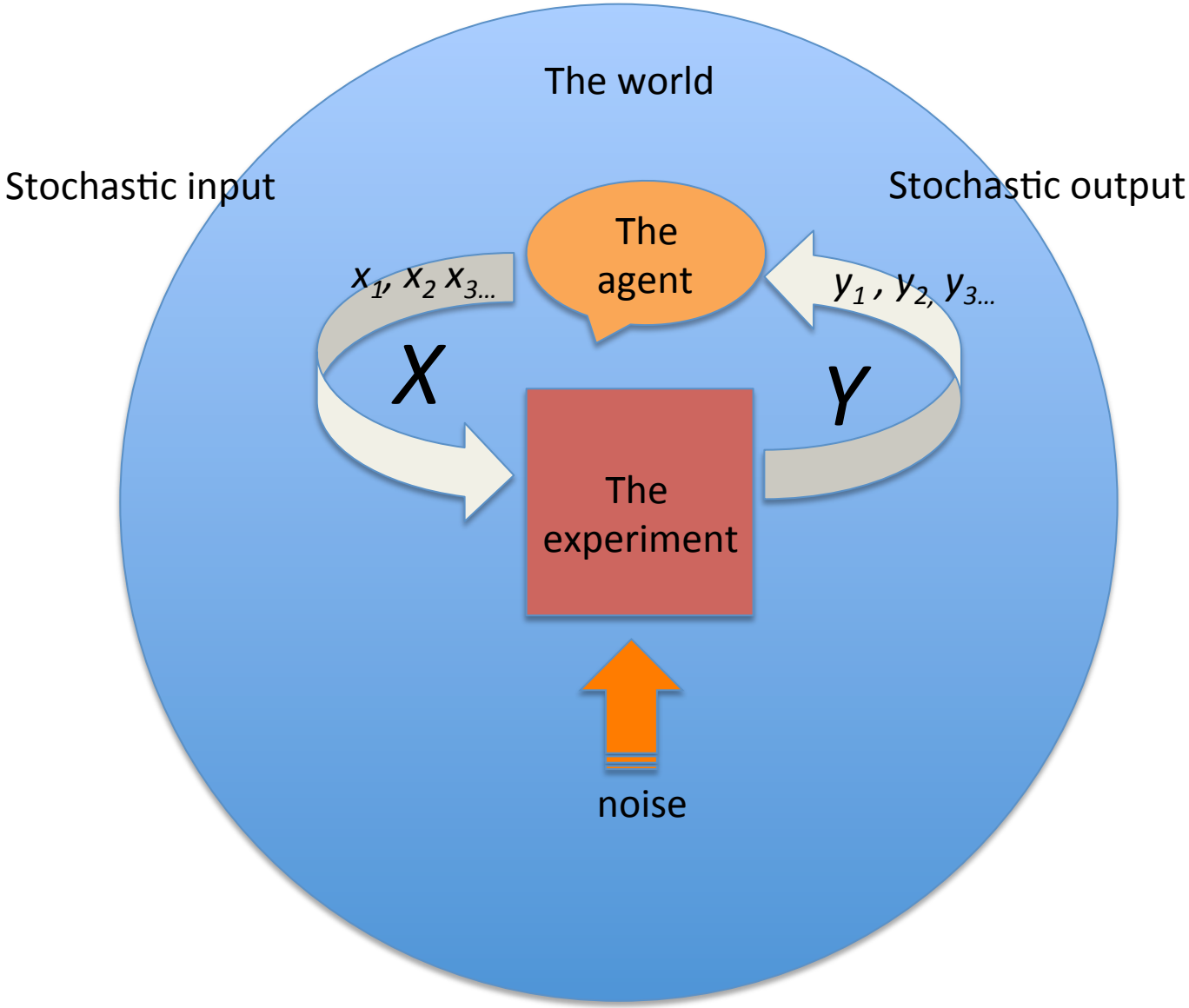
Amazon Echo.

The agent.



Inside a
Google server facility.

The Scientific method as a learning algorithm



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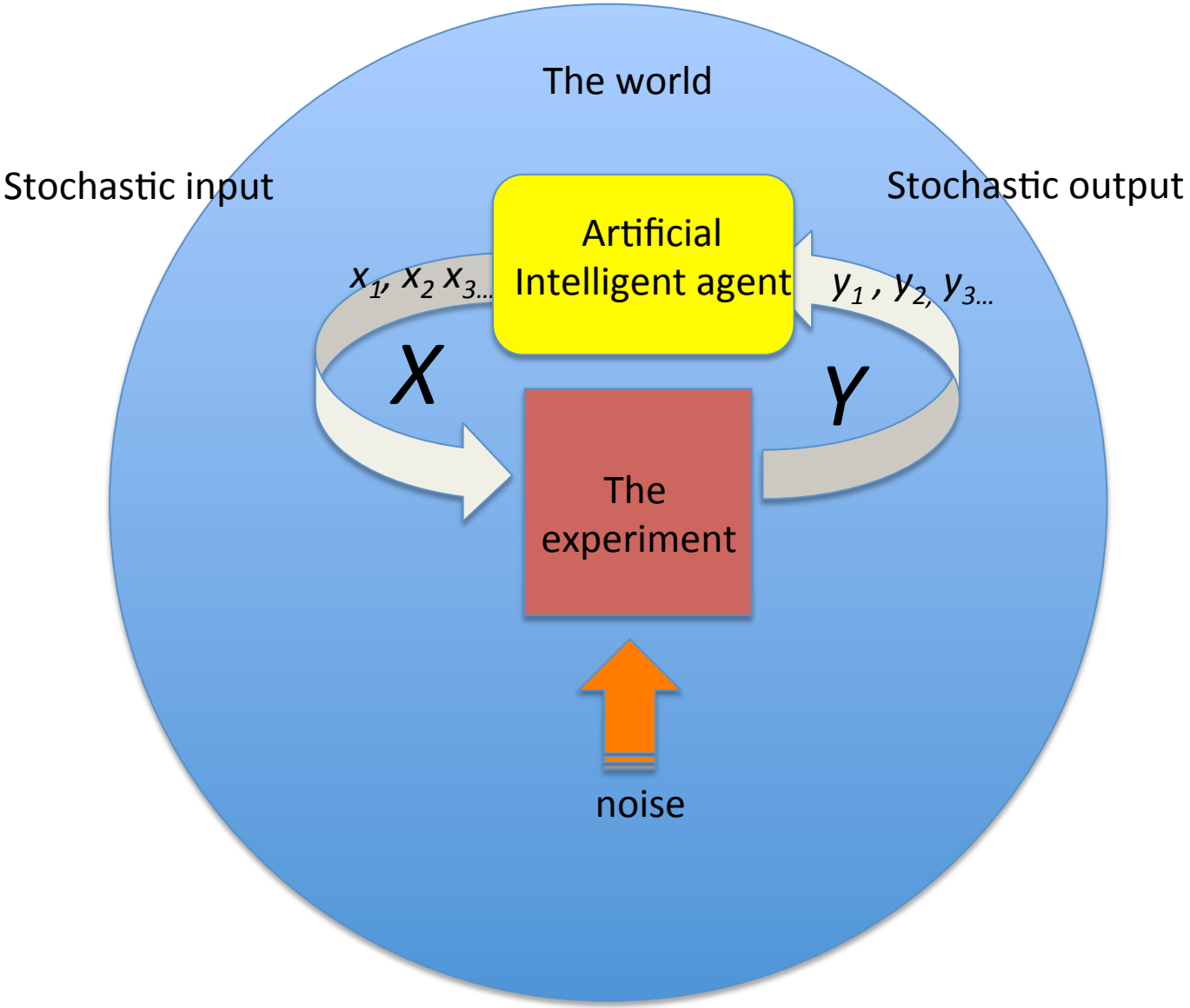


The Scientific method as a learning algorithm

SCIENCE VOL 324 3 APRIL 2009

Distilling Free-Form Natural Laws from Experimental Data

Michael Schmidt[1] and Hod Lipson[2,3]*

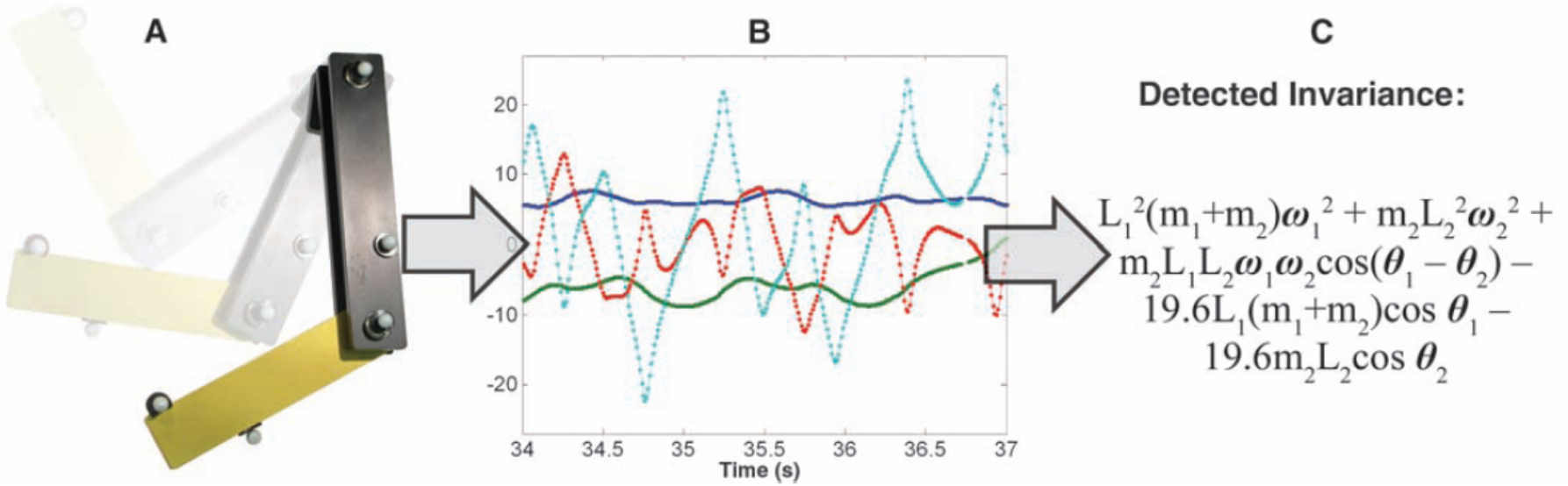
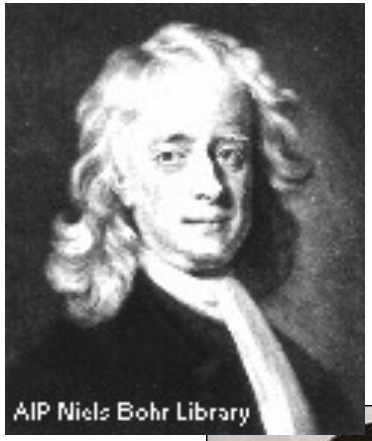


Fig. 1. Mining physical systems. We captured the angles and angular velocities of a chaotic double-pendulum (**A**) over time using motion tracking (**B**), then we automatically searched for equations that describe a single natural law relating these variables. Without any prior knowledge about physics or geometry, the algorithm found the conservation law (**C**), which turns out to be the double pendulum's Hamiltonian. Actual pendulum, data, and results are shown.

The world of classical physics

Maxwell



Newton

Einstein

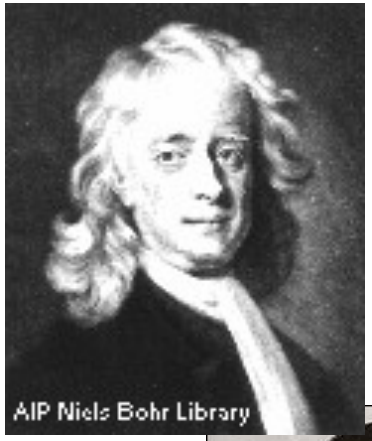
The world of classical physics

Physical systems have objective properties,
even if unknown.

Correlations in measurement results are explained
by relations between objective properties.

The world of classical physics

Maxwell

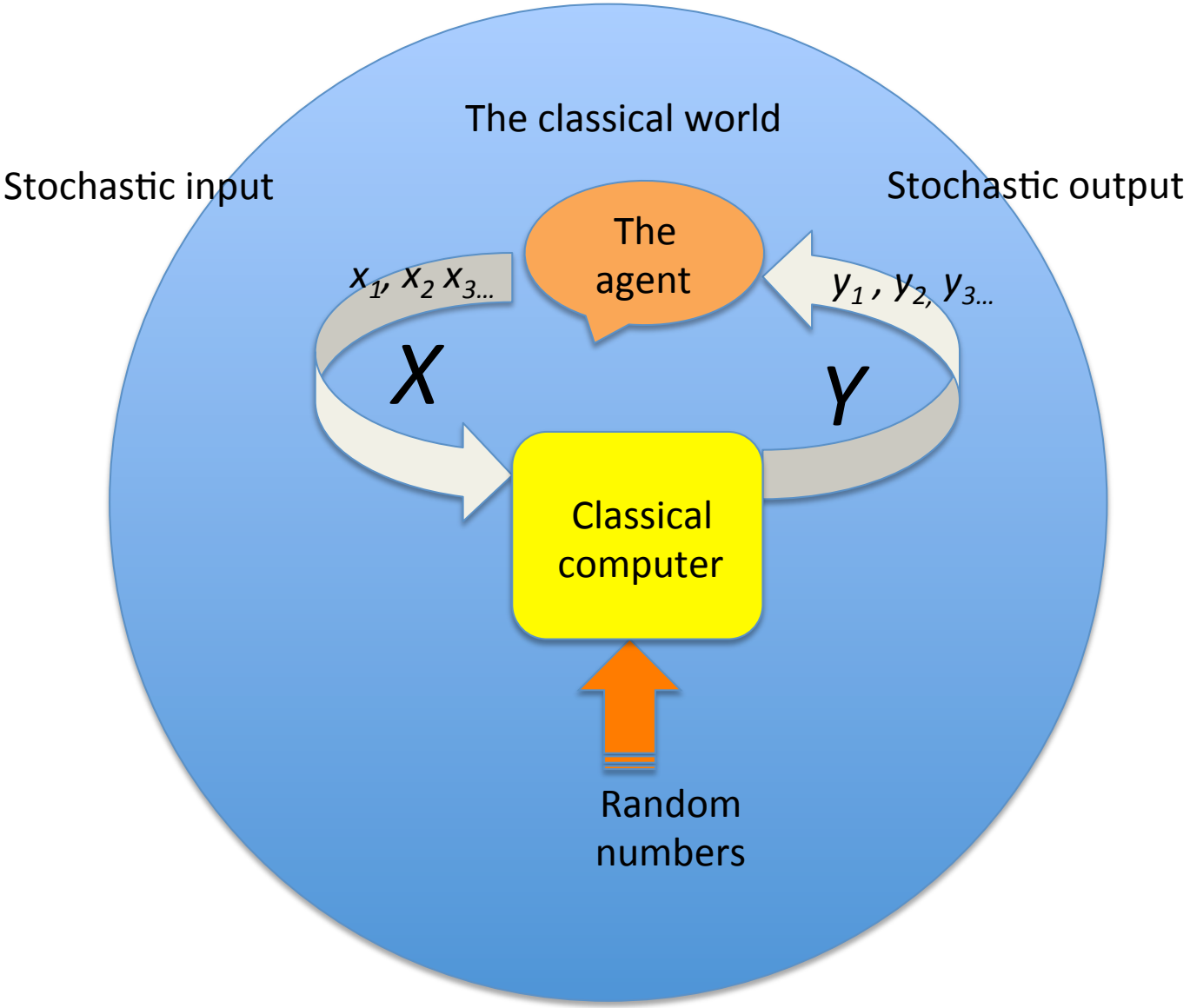


Newton

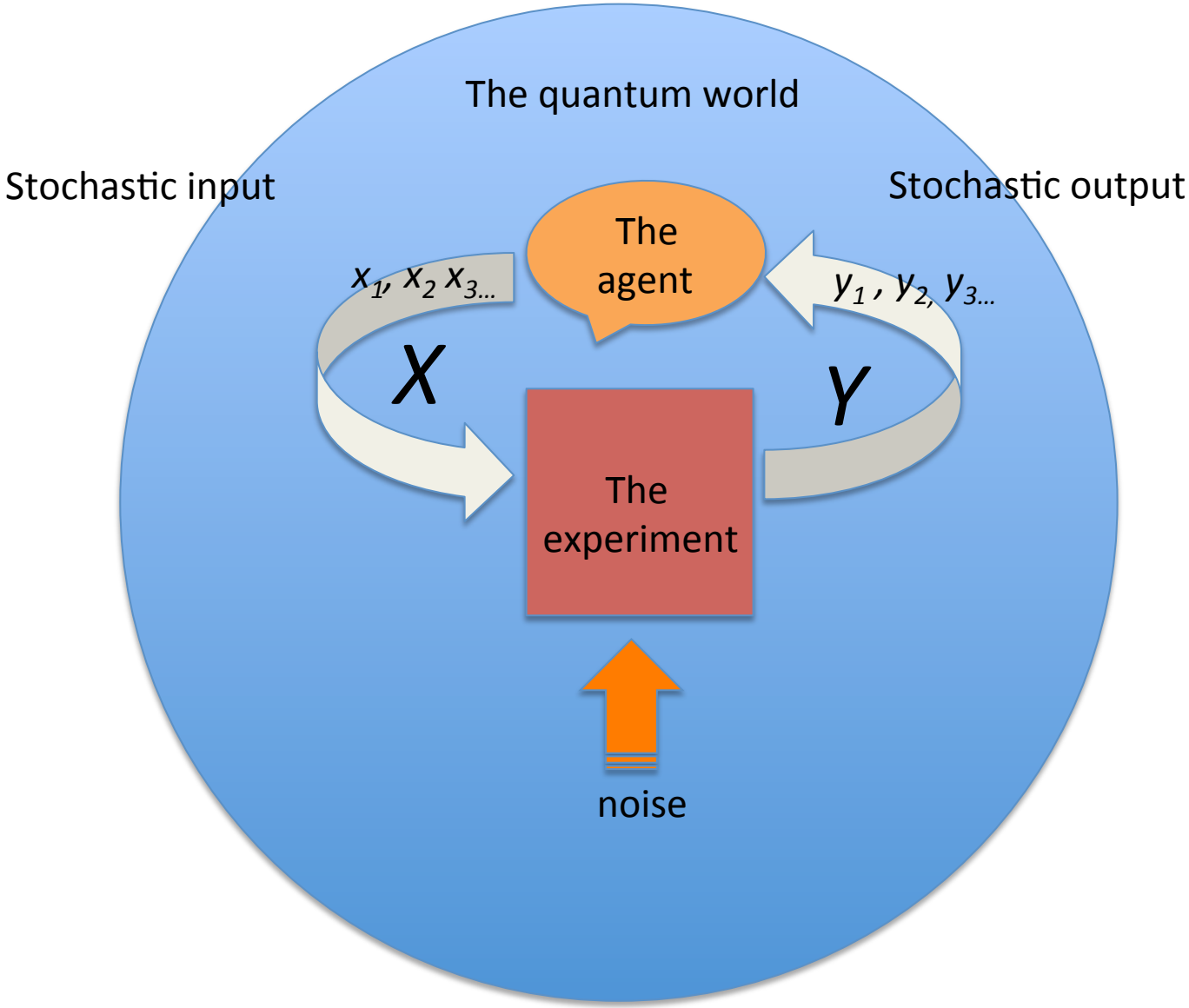
Einstein

Is learnable !

The simulation of the classical world.



The Scientific method as a learning algorithm



The quantum world

Bohr

Heisenberg

Schroedinger

The quantum world

THE QUANTUM PRINCIPLE.

The physical universe is irreducibly random.

Given complete knowledge of the state of a physical system, there is at least one measurement the results of which are completely random.

The quantum world

CERTAINTY WITHIN UNCERTAINTY

Given complete knowledge of a physical state there is at least one measurement the results of which are completely certain.

The quantum world

The only objective facts are the results of measurements.

Correlations between measurement results are explained by ....

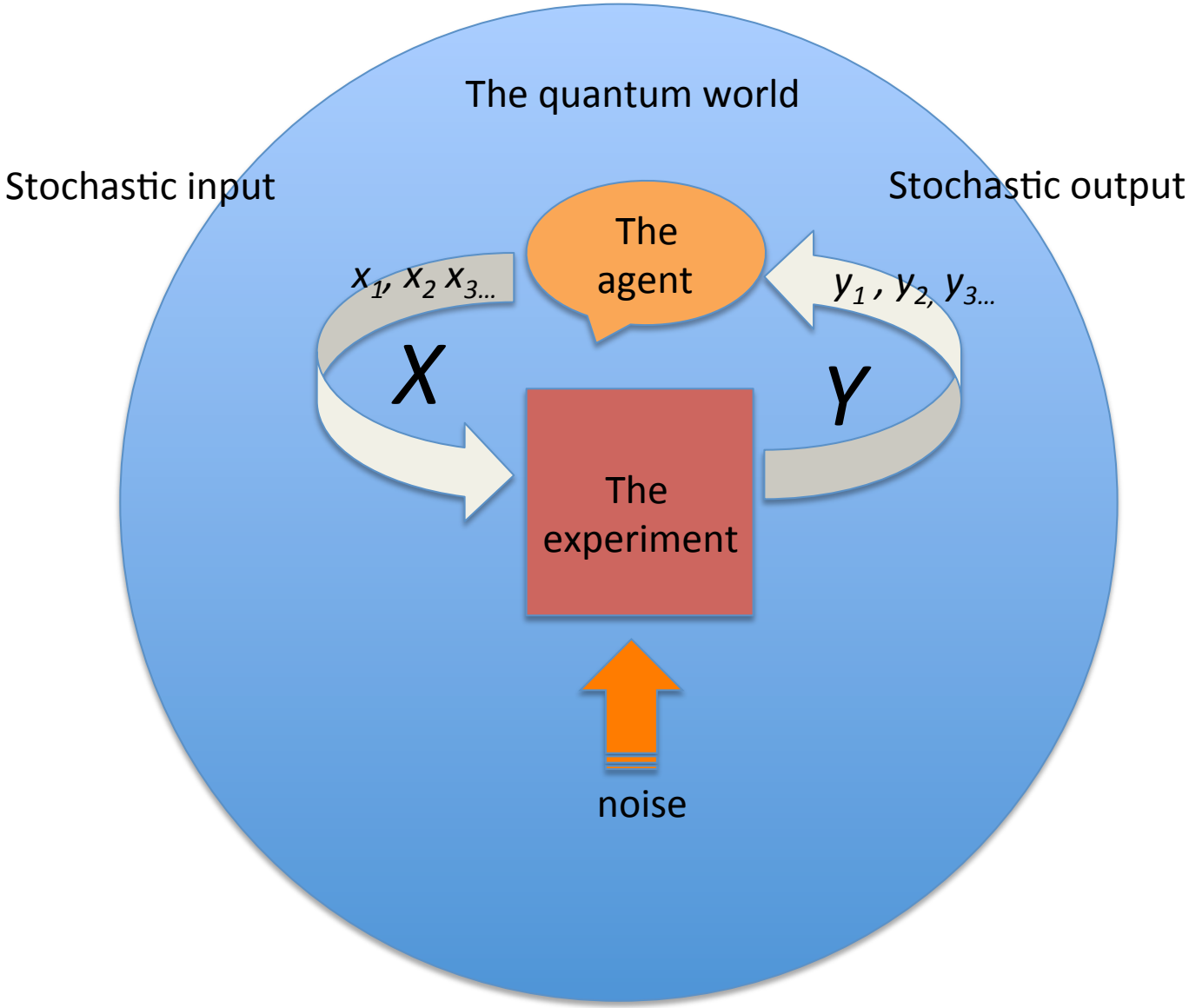
The quantum world

The only objective facts are the results of measurements.

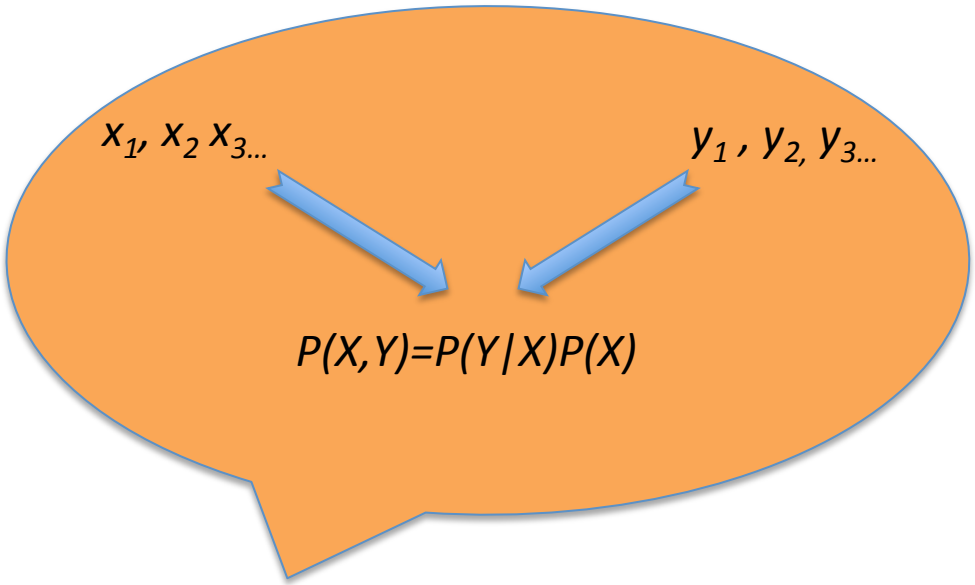
Correlations between measurement results are explained by a new probability calculus

… agrees with experiment better than any other theory.

The Scientific method as a learning algorithm



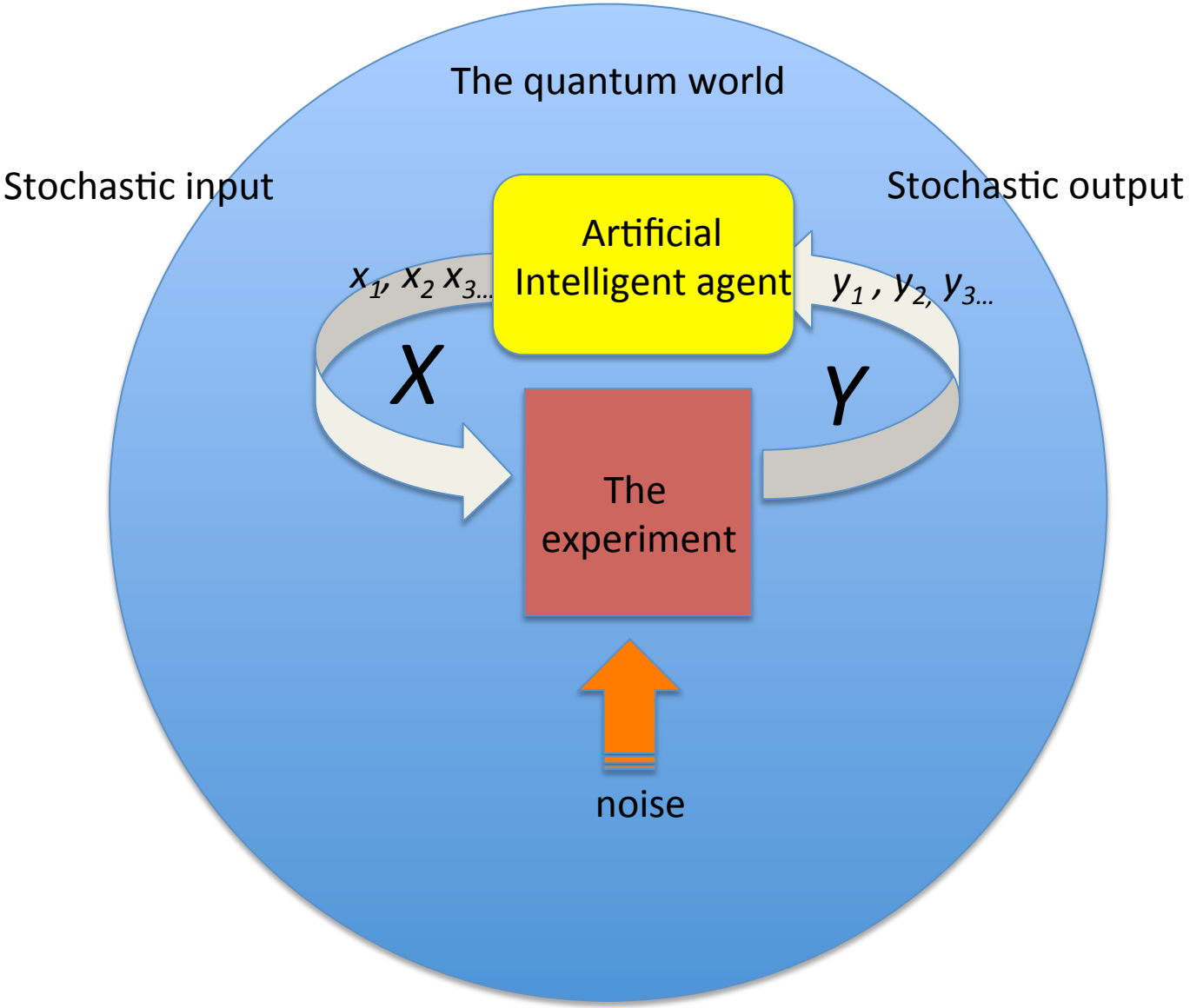
The statistic of results in a quantum world.



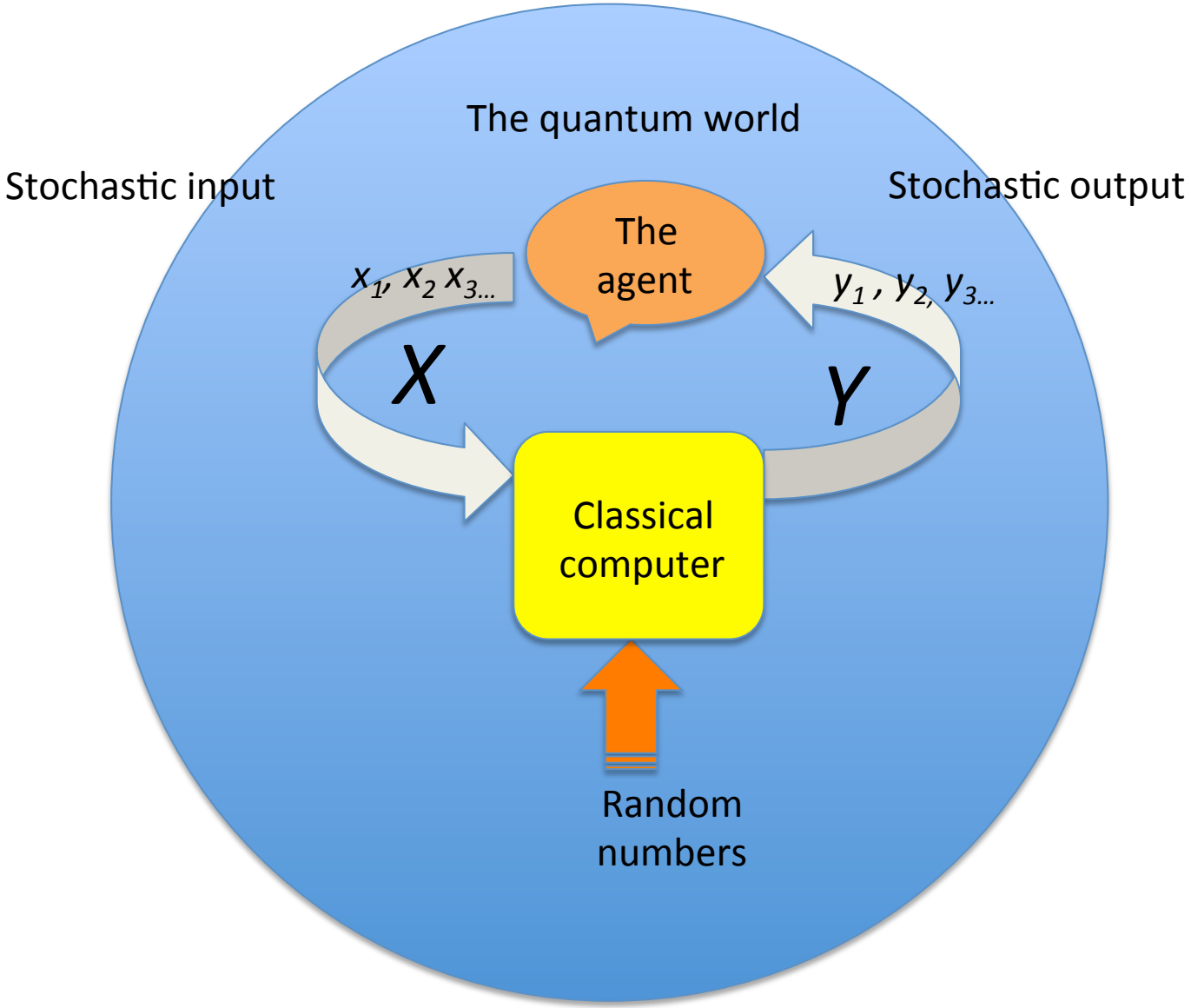
The theory predicts (incredibly well) the observed relations

and that is all we can say.

The Scientific method as a learning algorithm



The simulation of the quantum world.



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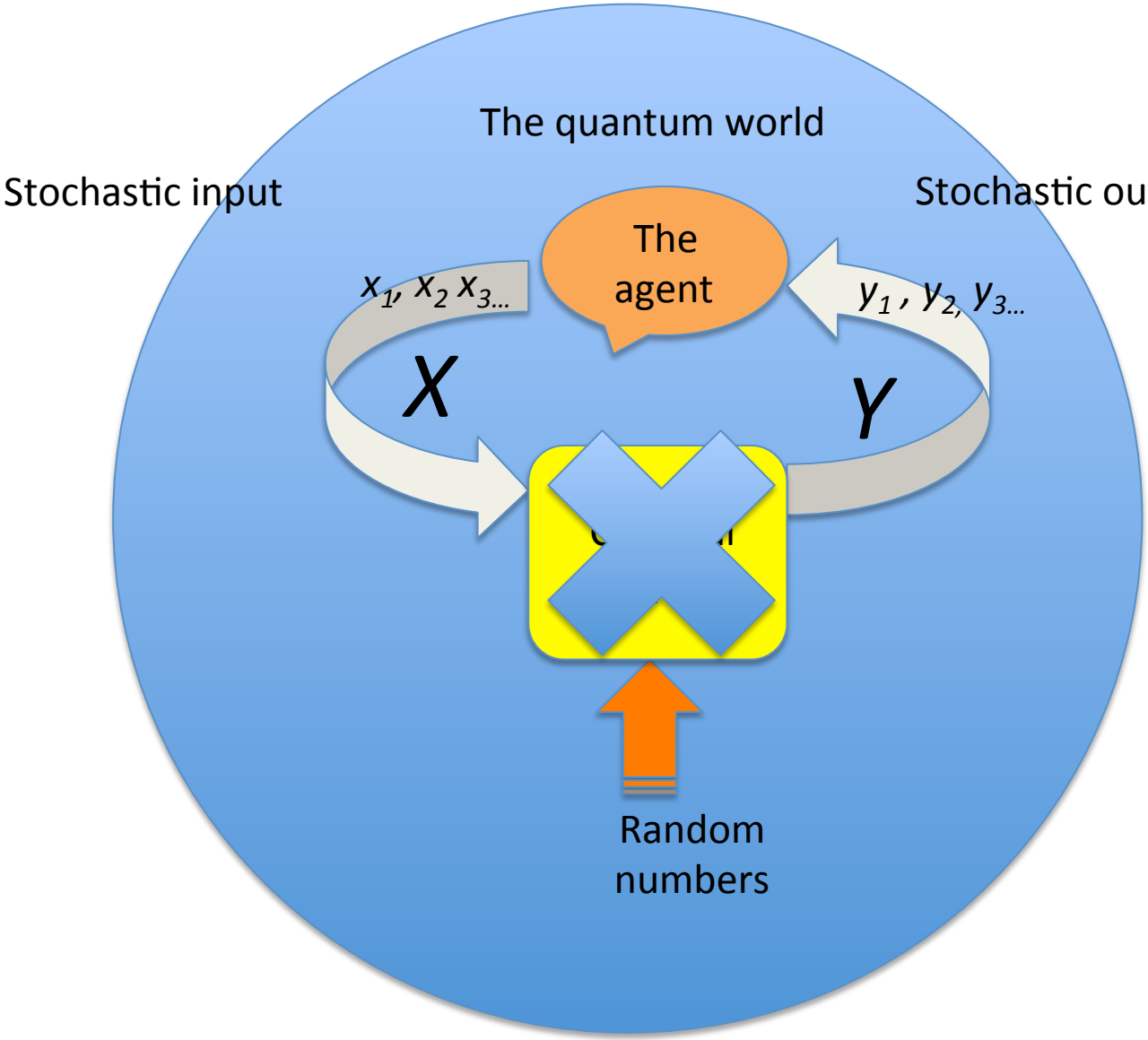
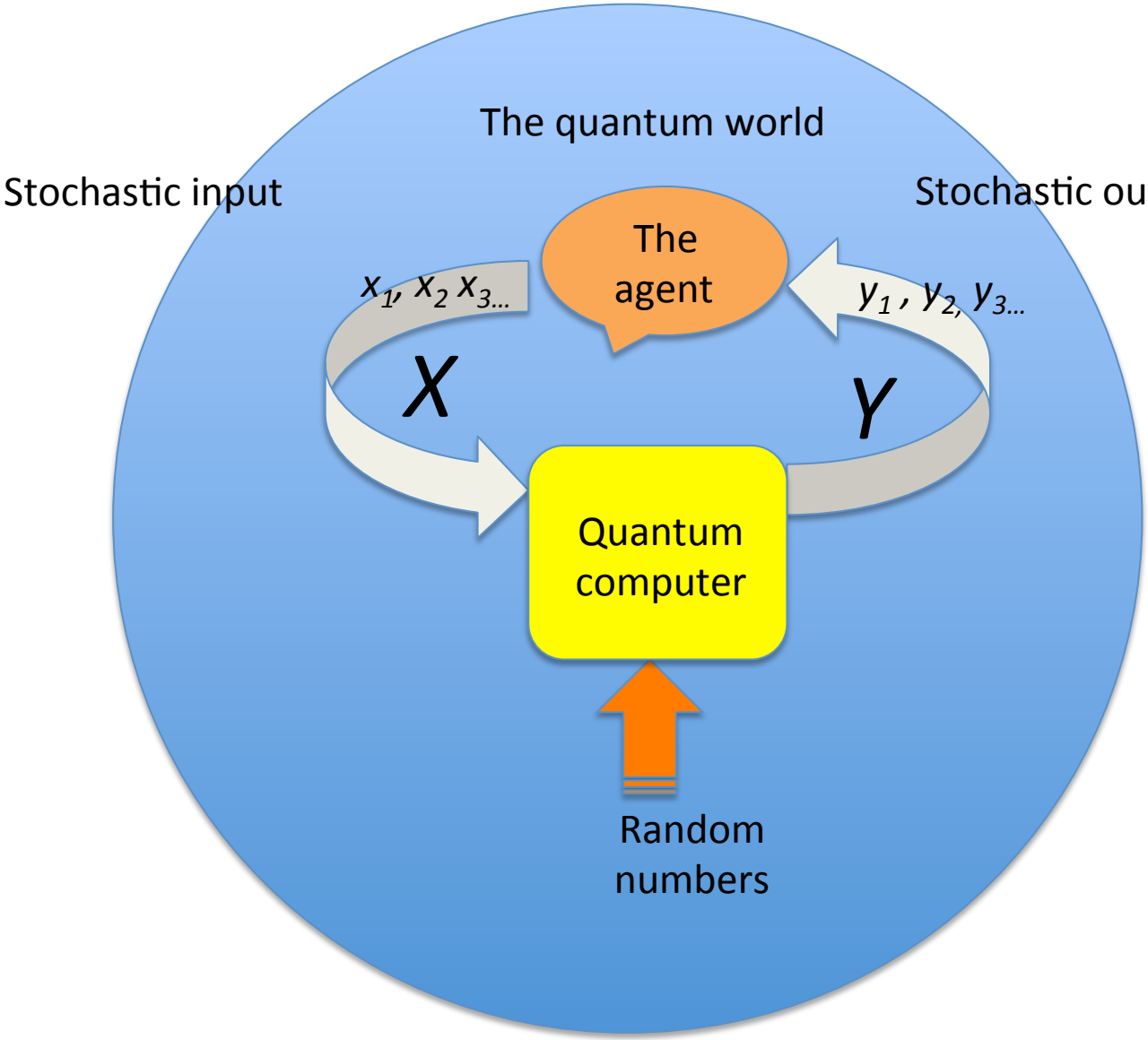


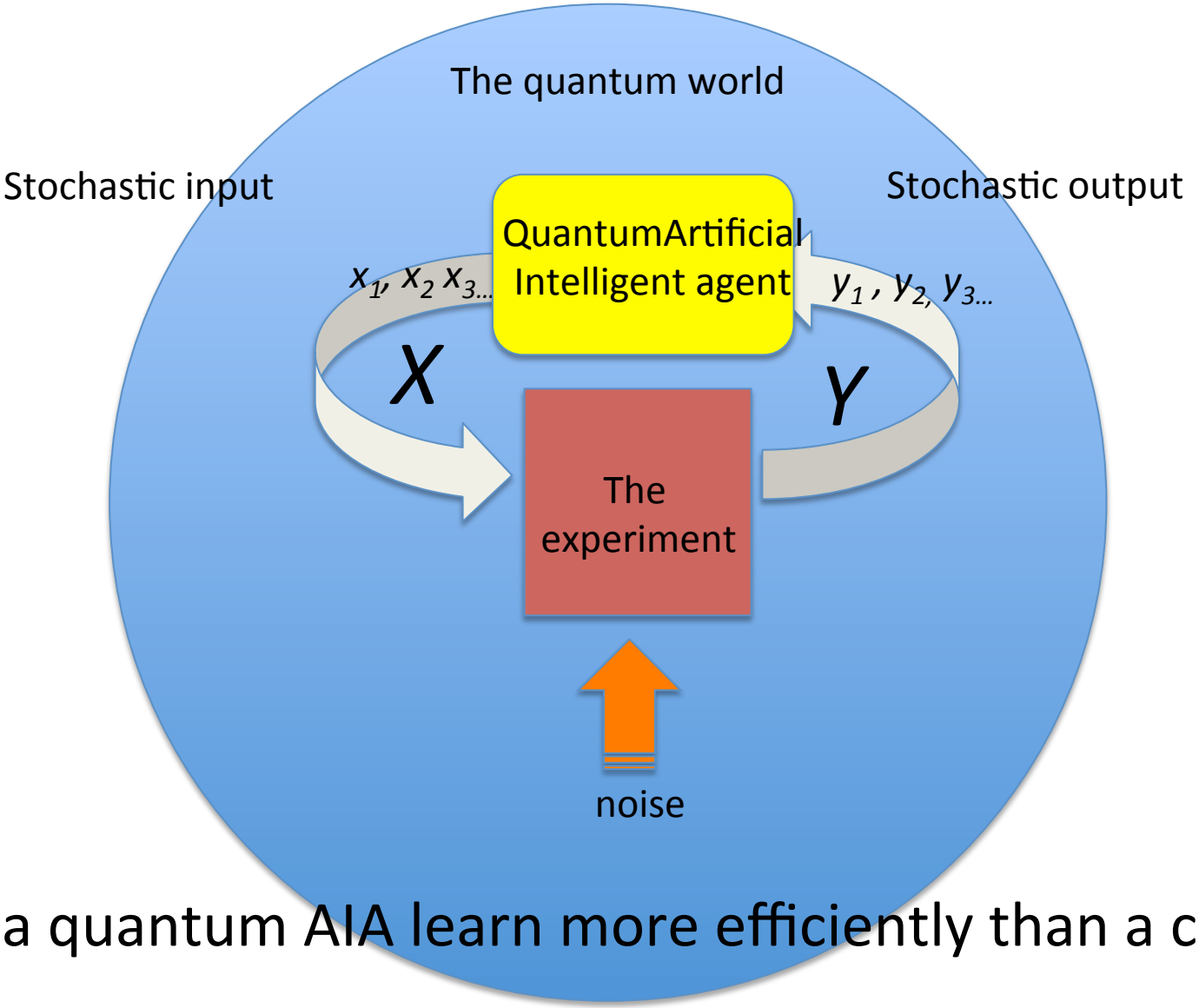
A Classical computer cannot Efficiently simulate quantum experiments.

The simulation of the quantum world.



A quantum computer can efficiently simulate quantum experiments.

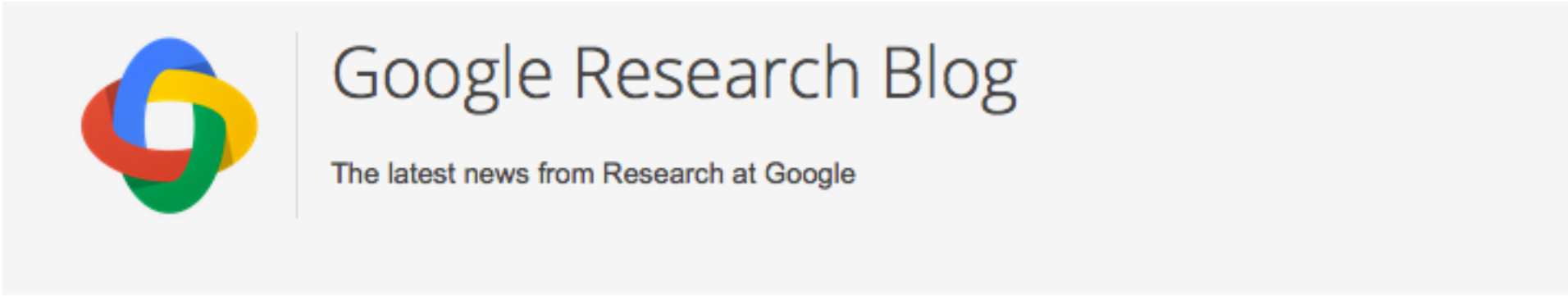
The Scientific method as a learning algorithm



Can a quantum AIA learn more efficiently than a classical AIA?

Can a quantum AIA learn more efficiently than a classical AIA?

Google has a hunch …



Launching the Quantum Artificial Intelligence Lab

Google's First Quantum Computer Will Build on D-Wave's A... http://spectru

Google's First Quantum Computer Will Build on D-Wave's Approach

By Jeremy Hsu
Posted 12 Sep 2014 | 21:00 GMT

Can a quantum AIA learn more efficiently than a classical AIA?

PHYSICAL REVIEW X **4,** 031002 (2014)

Quantum Speedup for Active Learning Agents

Giuseppe Davide Paparo,[1] Vedran Dunjko,[2,3,4] Adi Makmal,[2,3] Miguel Angel Martin-Delgado,[1] and Hans J. Briegel[2,3]

Artificial agents, freedom and creativity.

On creative machines and the physical origins of freedom

Hans J. Briegel[1,2]

SCIENTIFIC REPORTS | 2 : 522 | DOI: 10.1038/srep00522 2012

[1]Institut für Theoretische Physik, Universität Innsbruck, Technikerstraße 25, A-6020 Innsbruck, Austria, [2]Institut für Quantenoptik und Quanteninformation der Österreichischen Akademie der Wissenschaften, Innsbruck, Austria.

Artificial agents, freedom and creativity.

Briegel, Sci Rep. (2012).

A model of an artificial agent that exhibits a
notion of freedom in dealing with its environment.

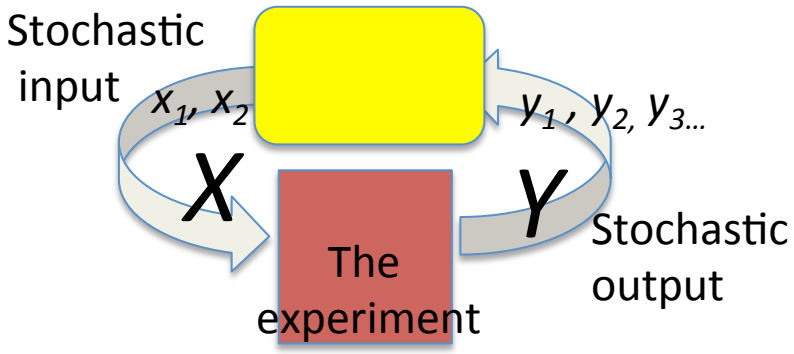
Demonstrates,

1. a notion of freedom exists for entities that operate, without exception and at all scales, under the laws of physics.

2. free behavior as an emergent property of biological systems of sufficient complexity that have evolved a specific form of memory.

Artificial agents, freedom and creativity.

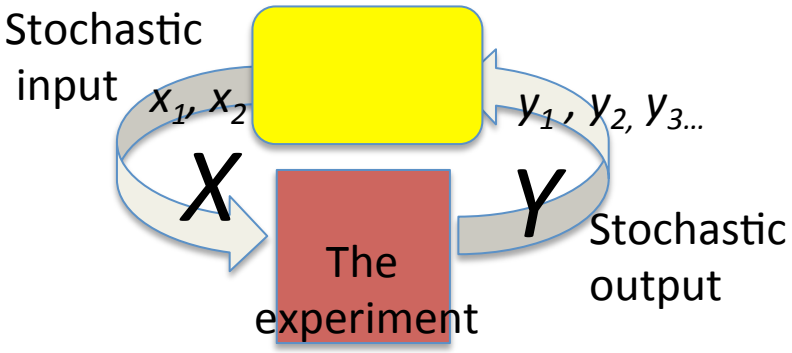
Projective simulation (Briegel).

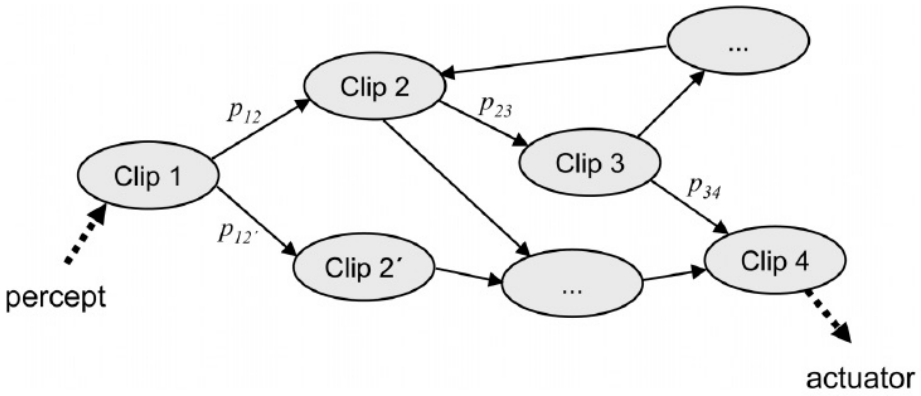


1. Memory to store the stochastic records (episodes) of actuator/sensor strings.
2. Sequences (clips) of episodes can be recalled and processed separately from the world
3. A stochastic processing on a network of clips
4. Decay rate for the memory … forgetting …

Artificial agents, freedom and creativity.

Projective simulation (Briegel).

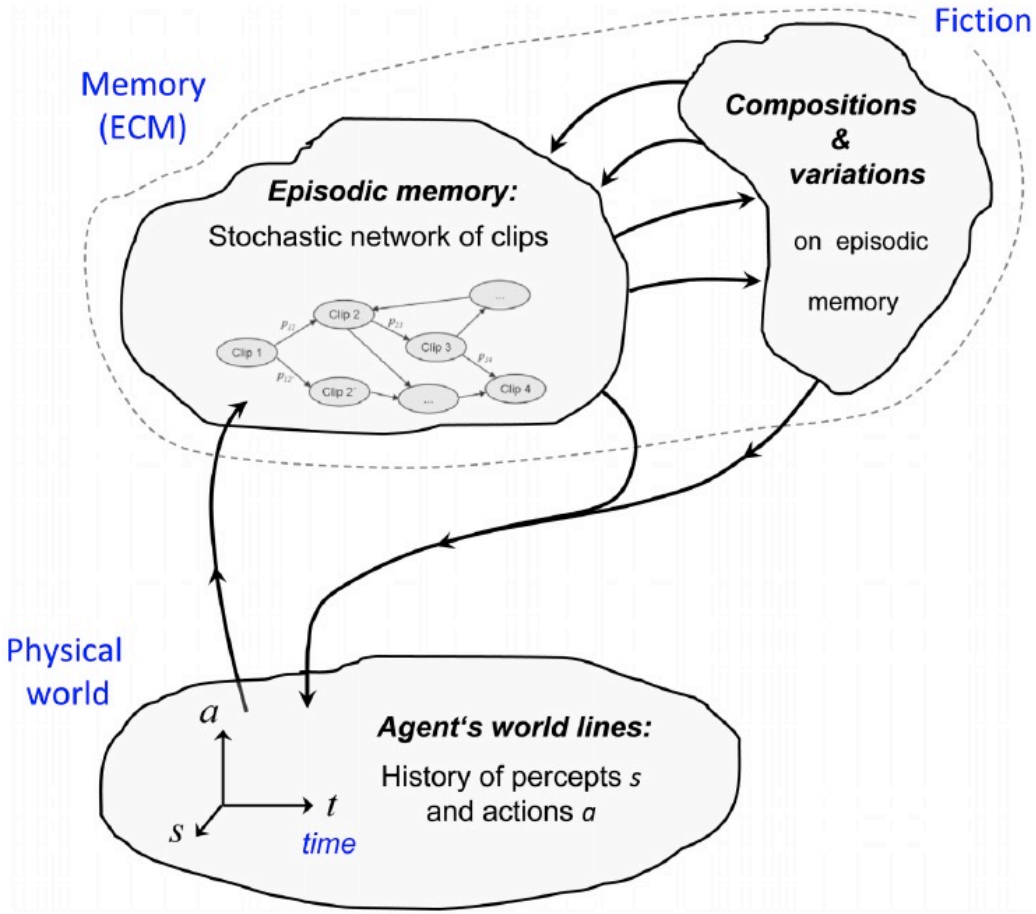




1. Memory stores stochastic records (episodes) sensor/actuator strings.
2. Sequences of episodes (clips) processed separately from the world
3. A stochastic processing on a network of clips
4. Decay rate for the memory … forgetting …
5. Reinforcement learning on clip links.

Artificial agents, freedom and creativity.

Projective simulation (Briegel).



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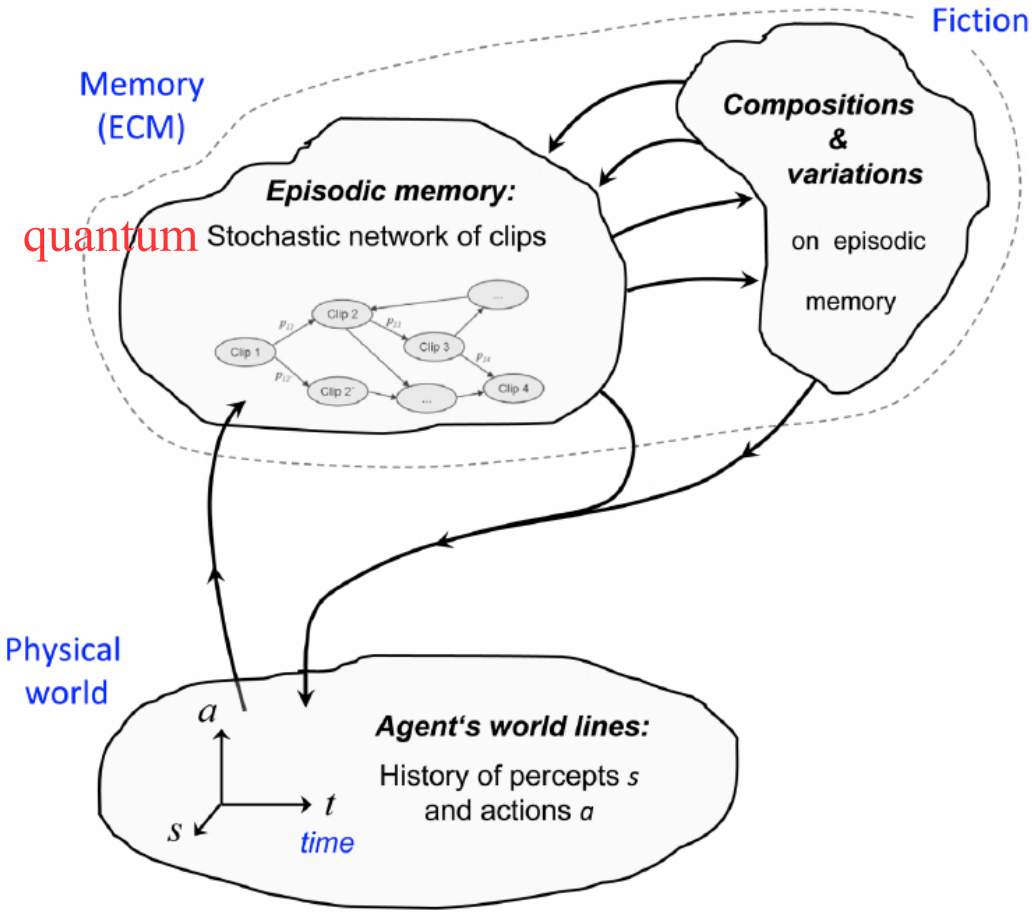

Artificial agents, freedom and creativity.

Q-AI agents learn faster.

Q-AI agents … may be more creative .

Q-AI agents … may be more free

Q-AI agents … at home in a quantum world.