RETROCAUSALITY AND RETRODICTION: LOOKING BACK TO GO FORWARDS

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Mapping the Irreverse

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Talk Outline

PART 1: RETROCAUSALITY

- A basic way to think about experimental results in physics
- Emergent patterns in experimental results
- Powerful patterns
- No-backwards-in-time signalling
- Backwards-in-time influence
- Where we are now

PART 2: RETRODICTION

~~• Old results from a new standpoint~~ we won’t get there.

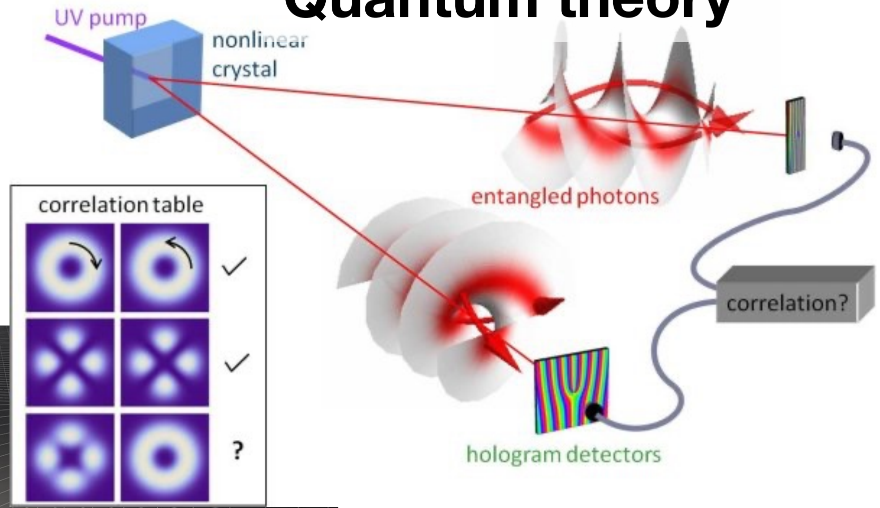
Disclaimers

- Many things I say in this talk will be *almost* true. My choice of words my often be non-optimal.
- A few subtleties will be glossed over.
- I will tell you things, and then correct them later.
- ~~It may help to try to abstract from things you already know, e.g., “this thing is like the shape of a ball”.~~ This talk will be full of metaphors.

Different theories for different (relative) scales

Classical Thermodynamics

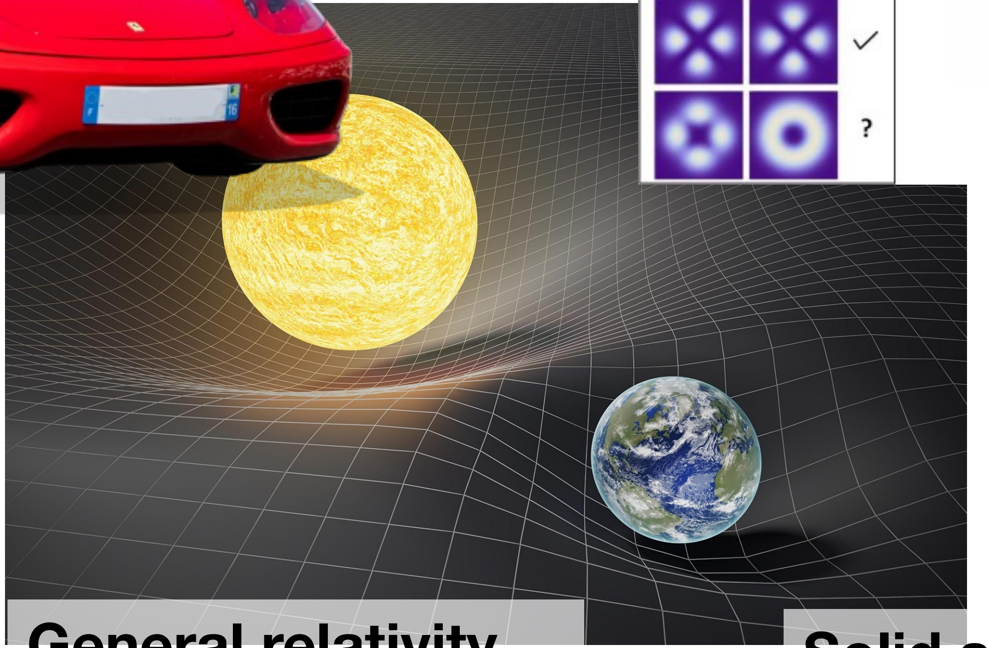
Classical mechanics



Quantum theory

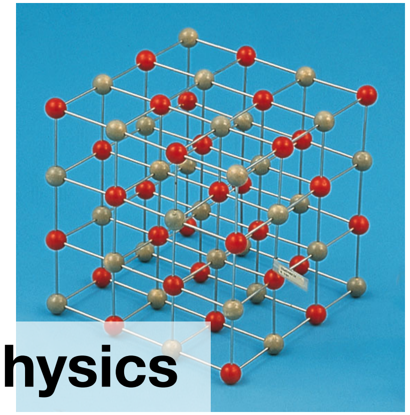
Image by: Sonja Franke-Arnold

Astrophysics



General relativity

NIST image on scitechdaily.com



Solid state physics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Black box scenario: a basic way to think about experimental results in physics

$$x, y, a, b \in \{0, 1\}$$

SCENARIO (2, 2, 2)
(parties, inputs, outputs)

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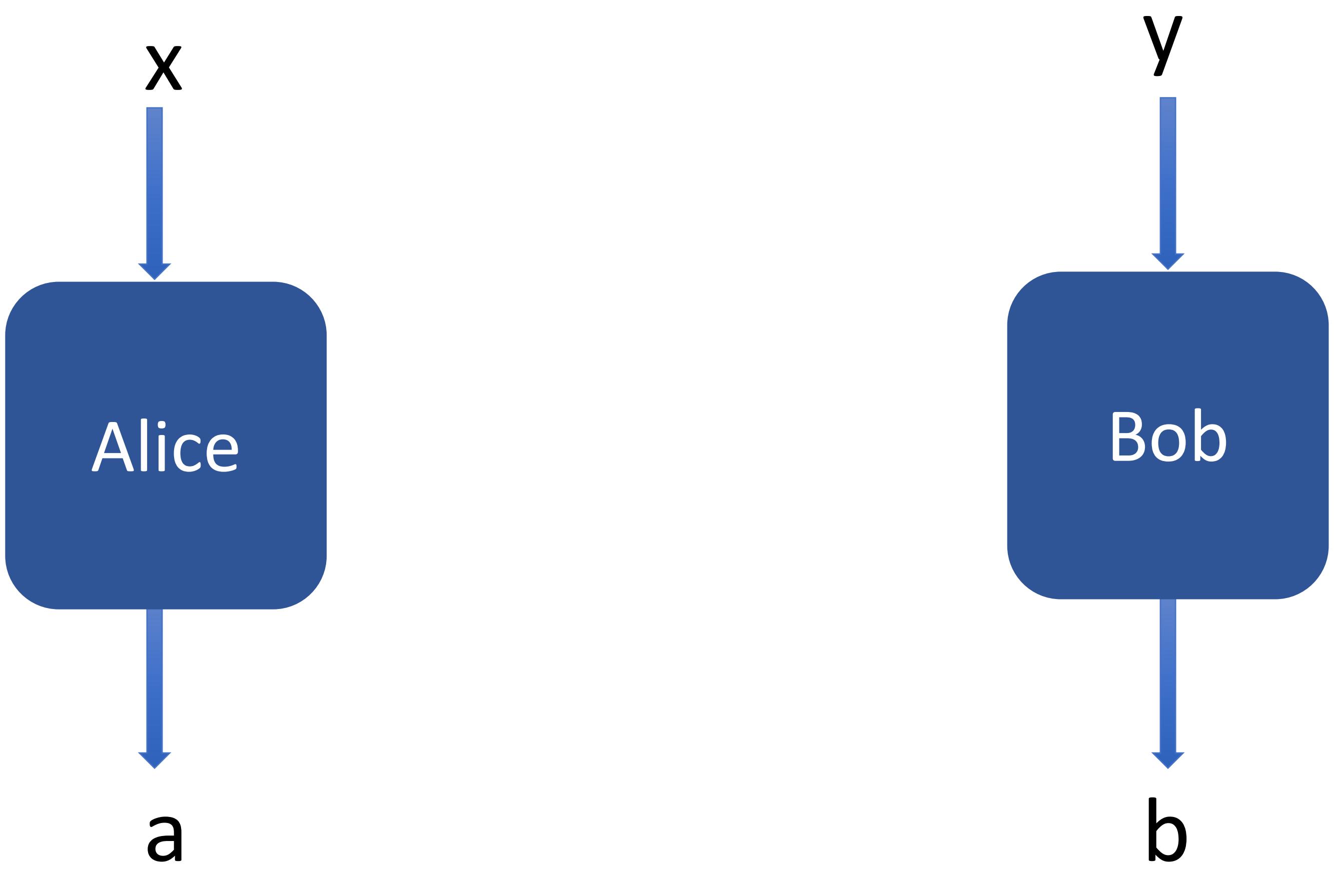

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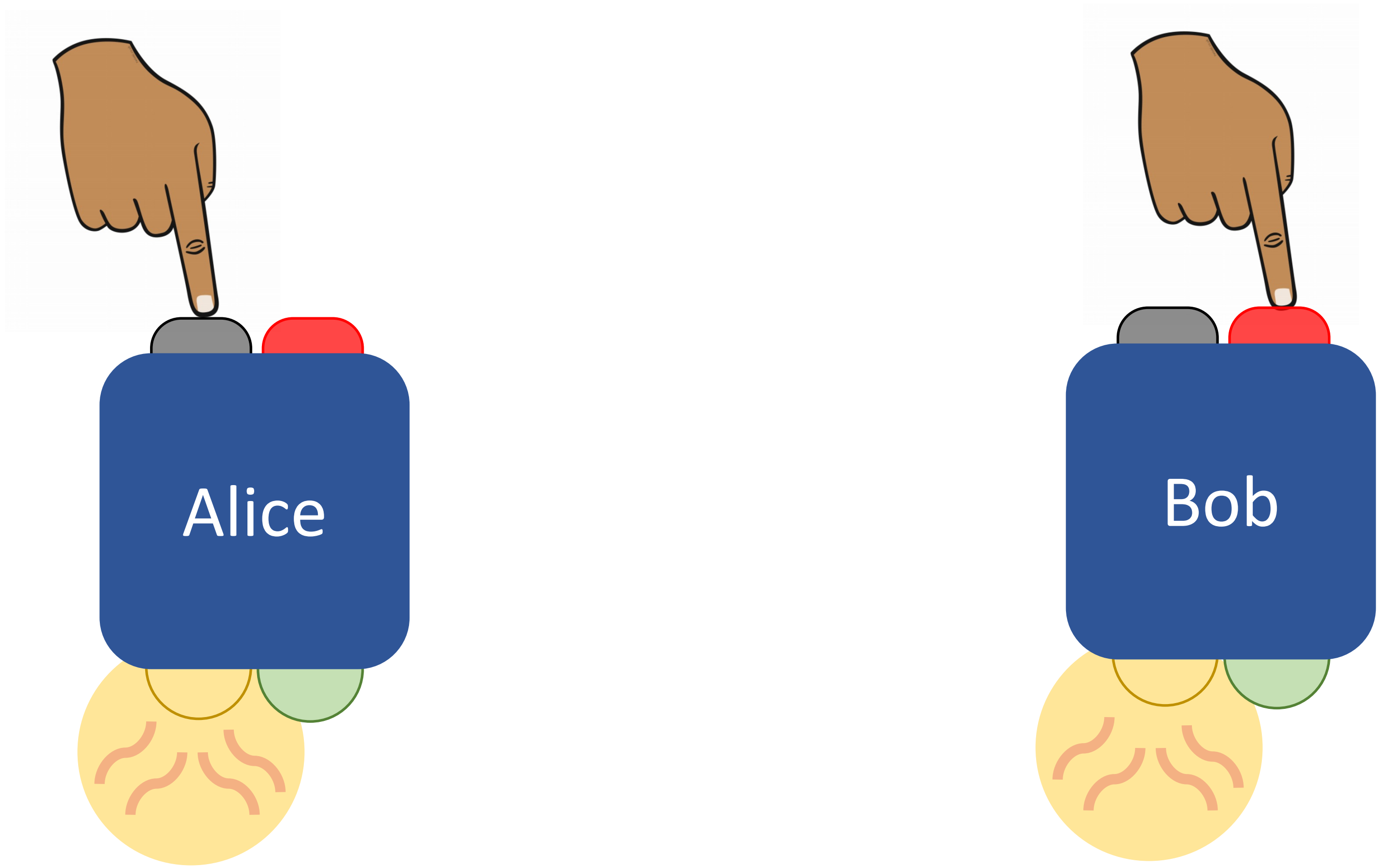


$$x, y, a, b \in \{0, 1\}$$

SCENARIO (2, 2, 2)
(parties, inputs, outputs)

Black box scenario

5. Black
4. Black
3. Red
2. Black
1. Red

5. Red
4. Black
3. Red
2. Red
1. Black

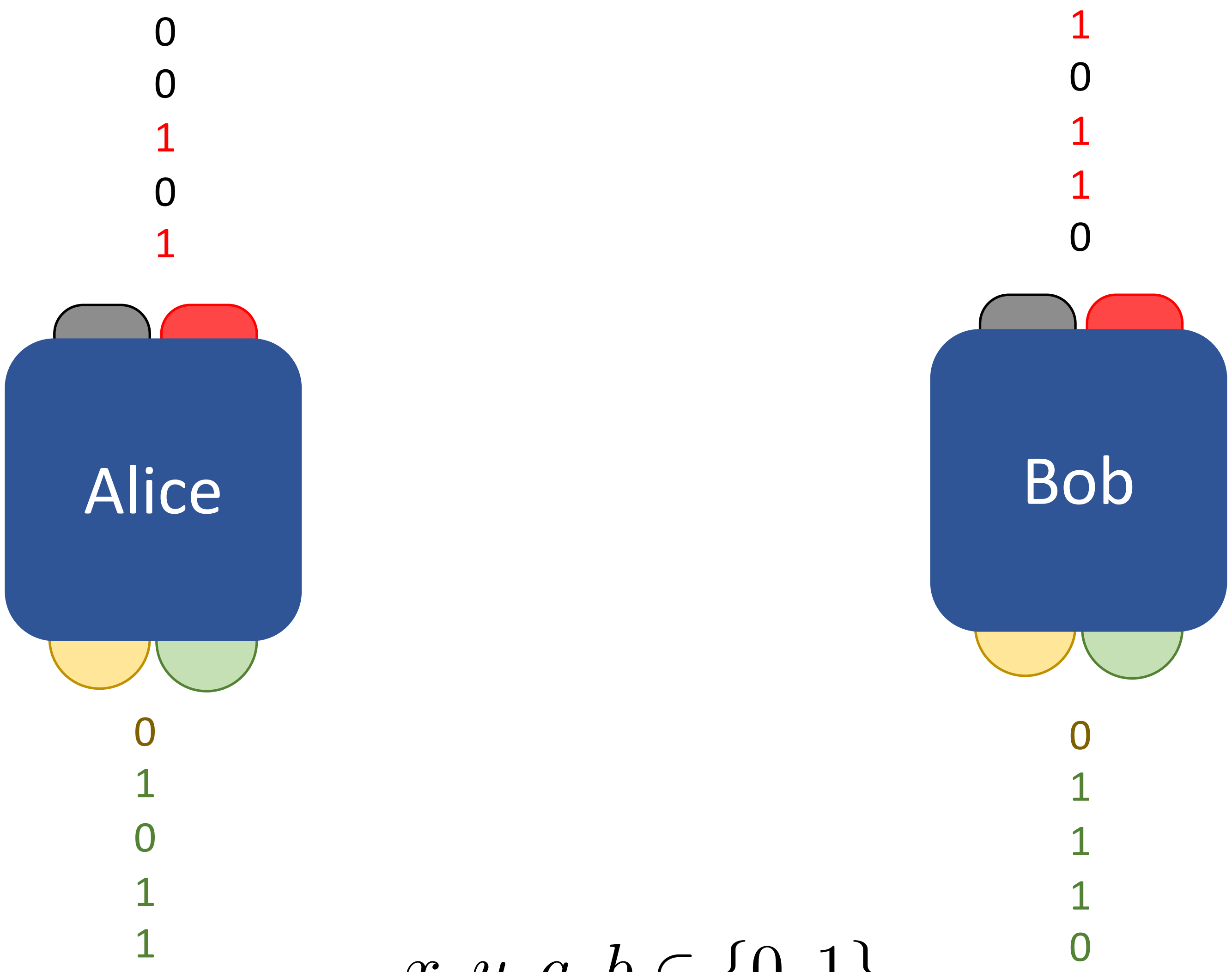
1. Yellow
2. Green
3. Green

1. Green
2. Yellow
3. Green

$$x, y, a, b \in \{0, 1\}$$

SCENARIO (2, 2, 2)
(parties, inputs, outputs)

Black box scenario



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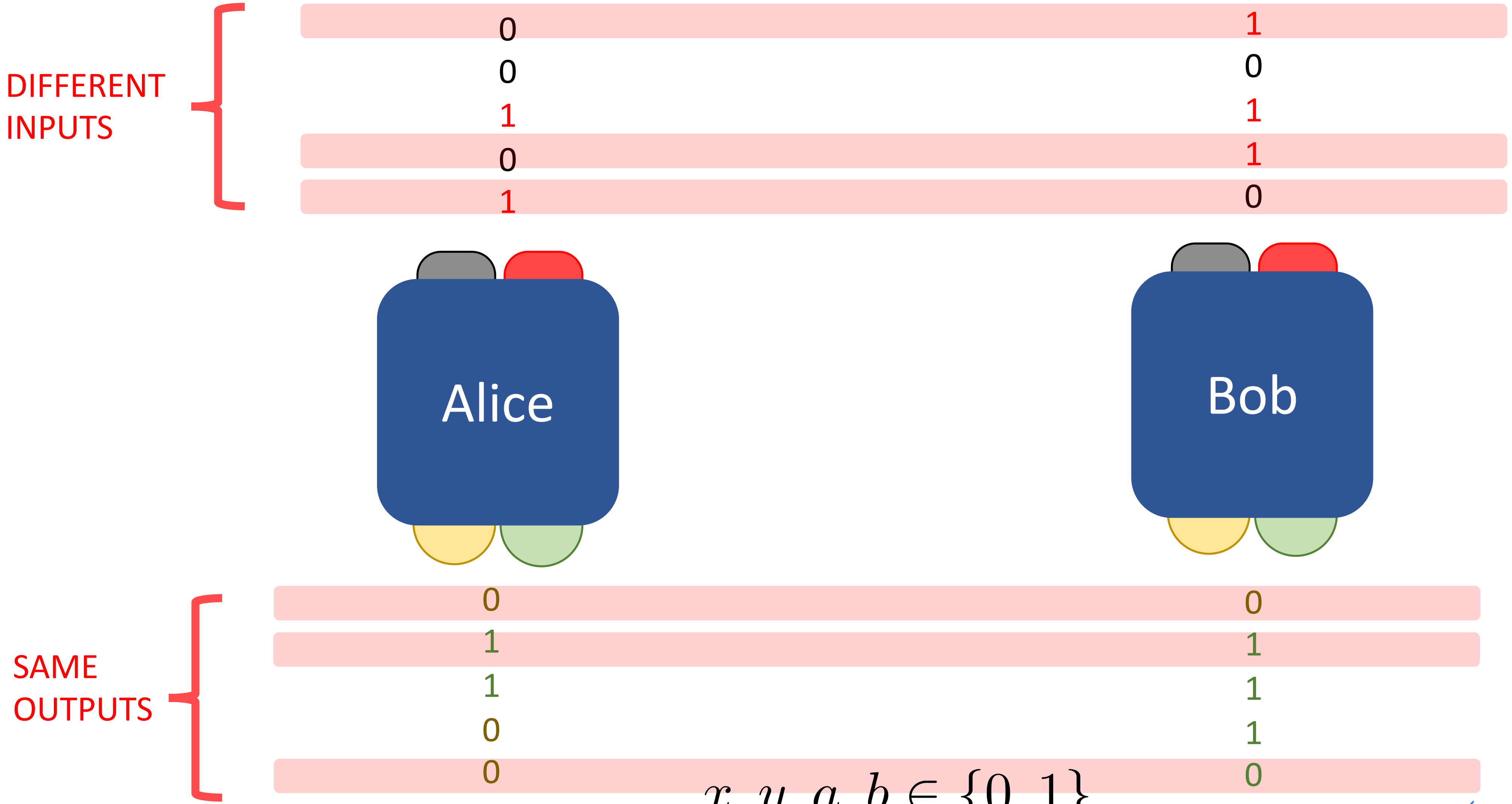

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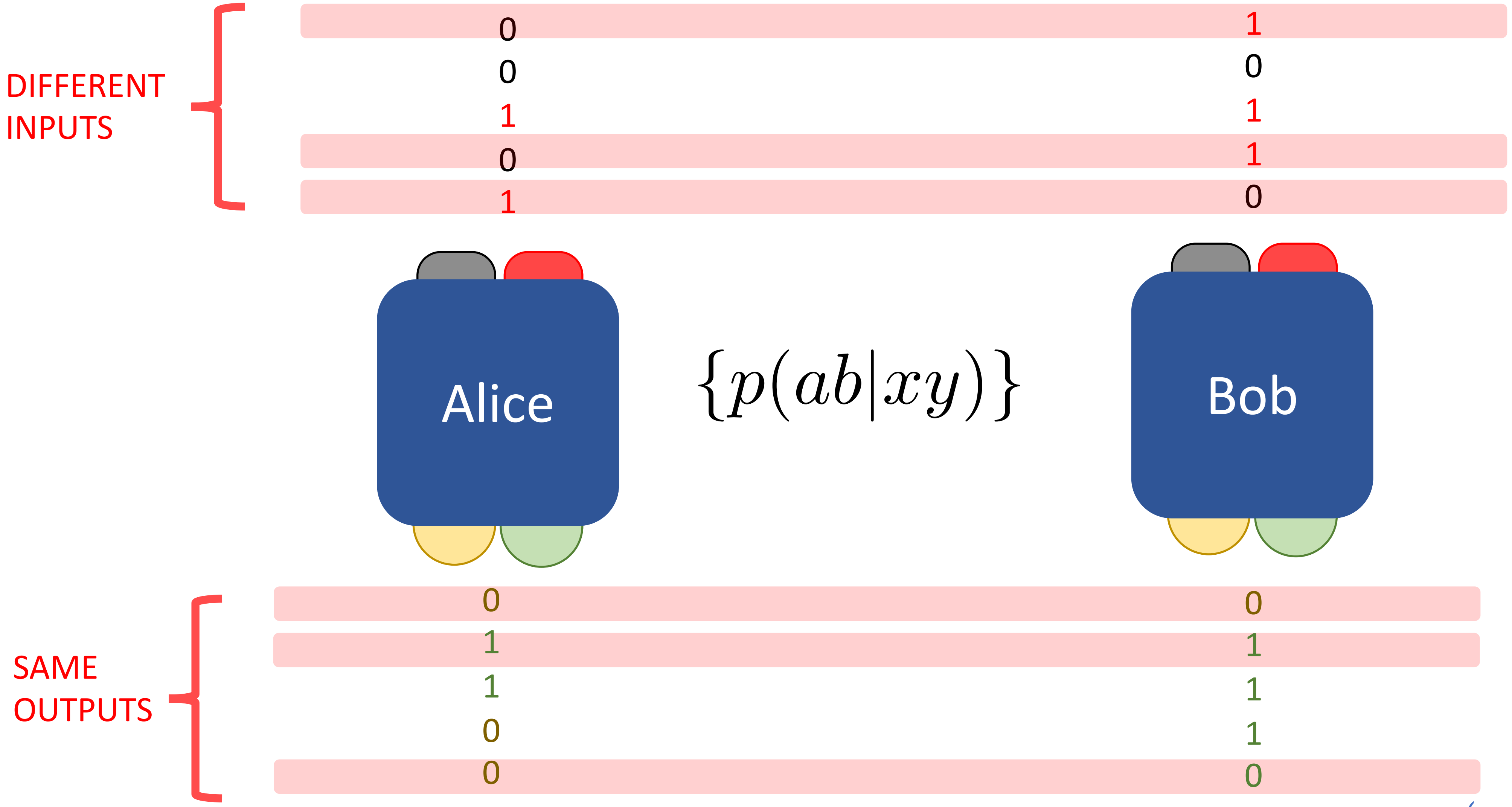

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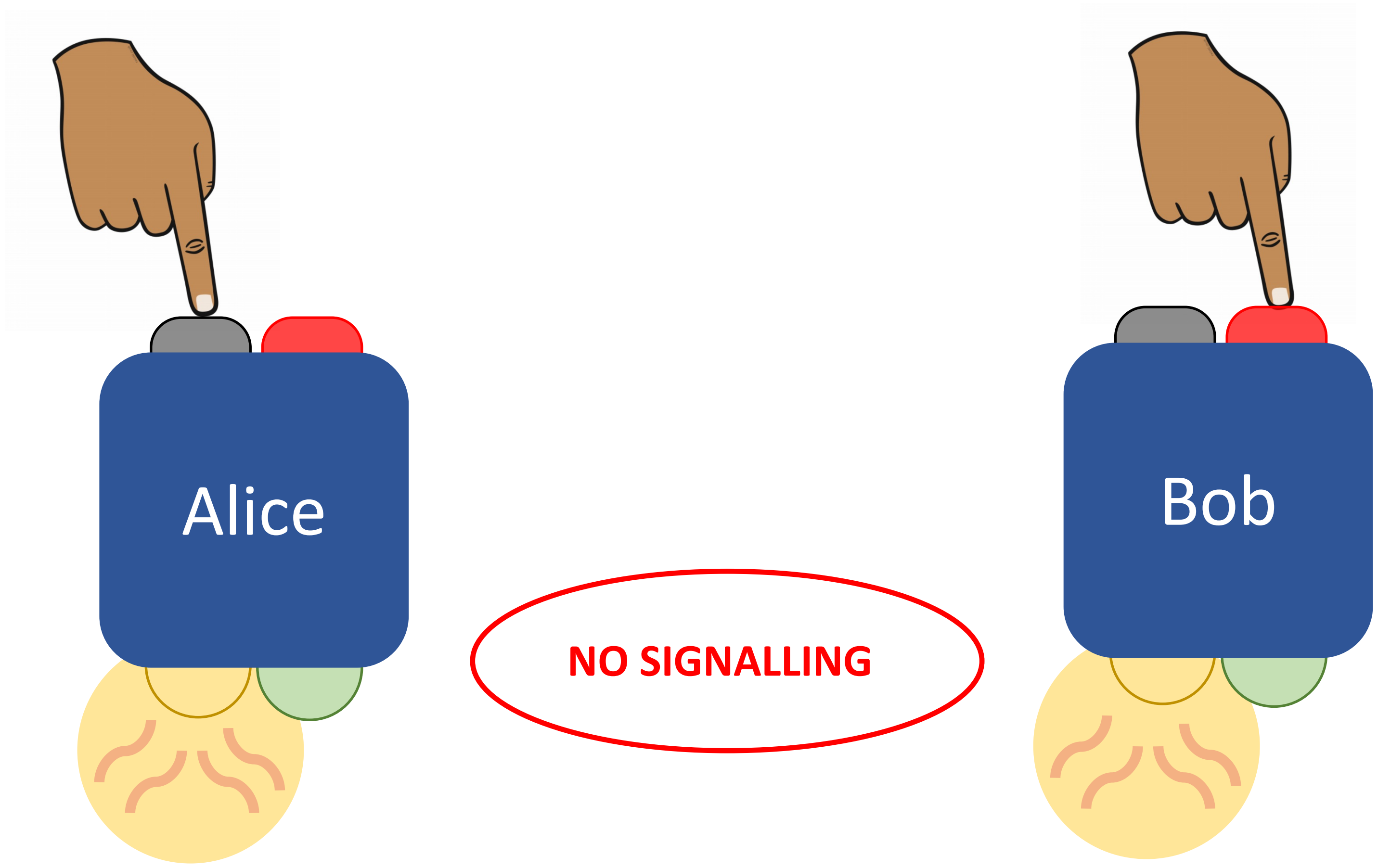

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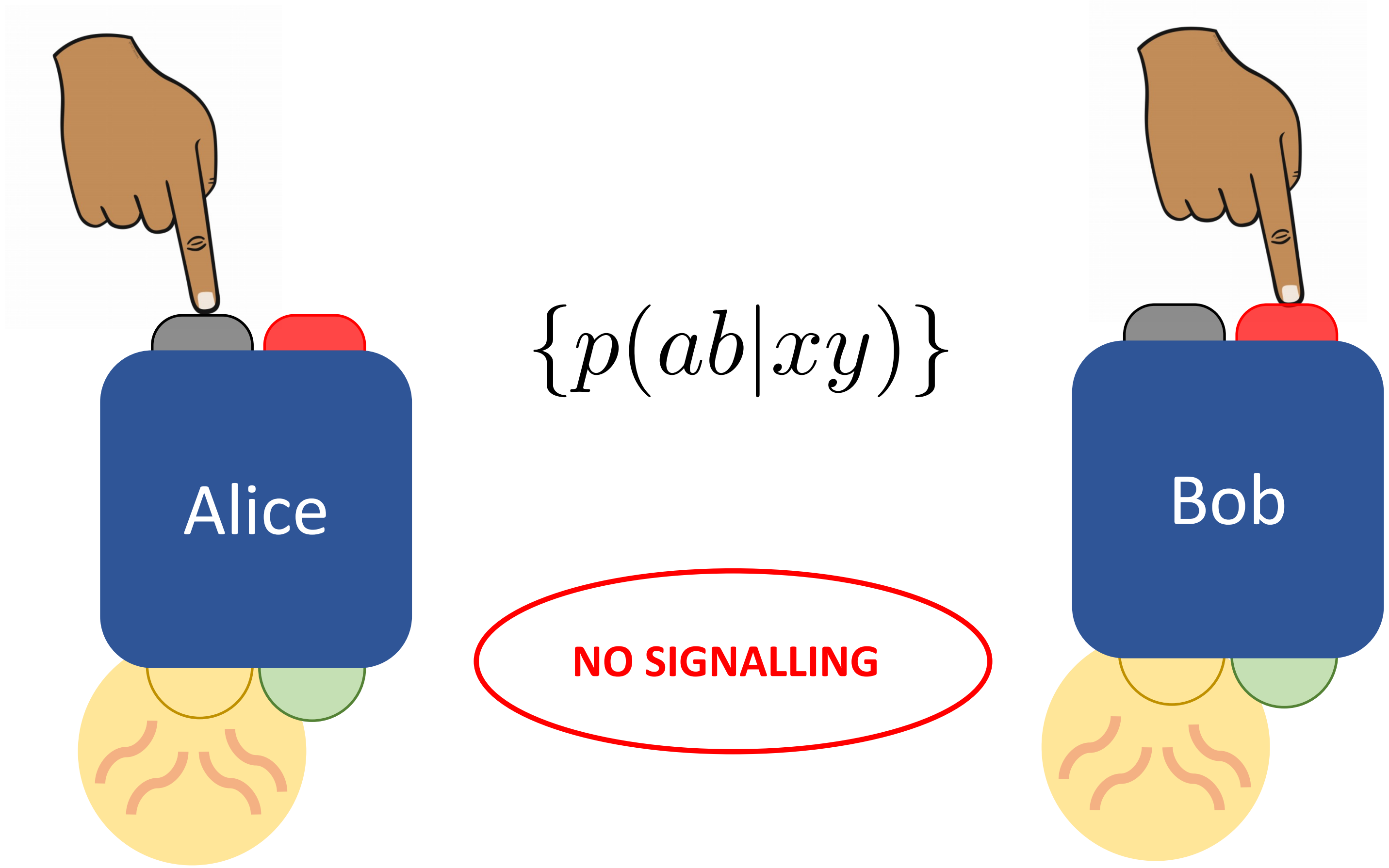

SCENARIO (2, 2, 2)
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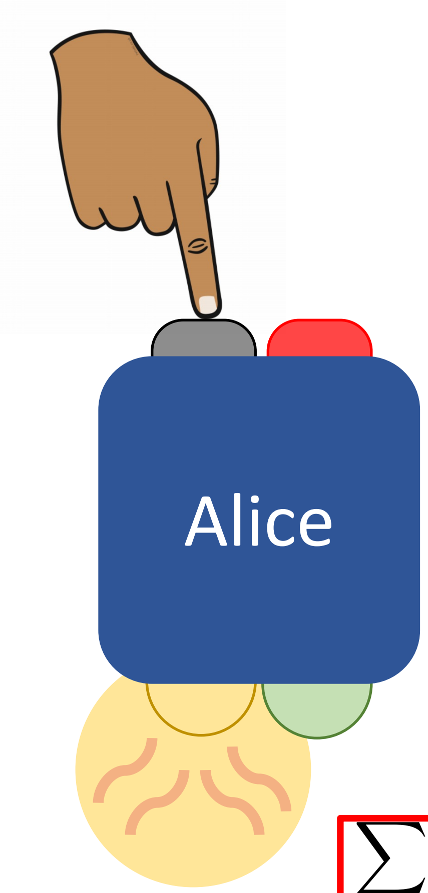
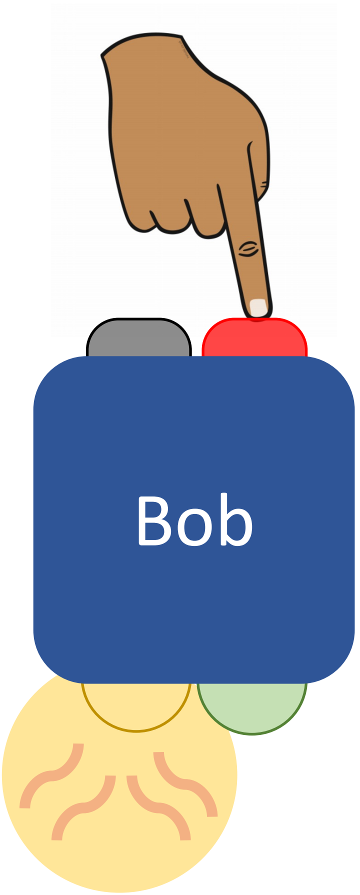
Black box scenario



$$\{p(ab|xy)\}$$



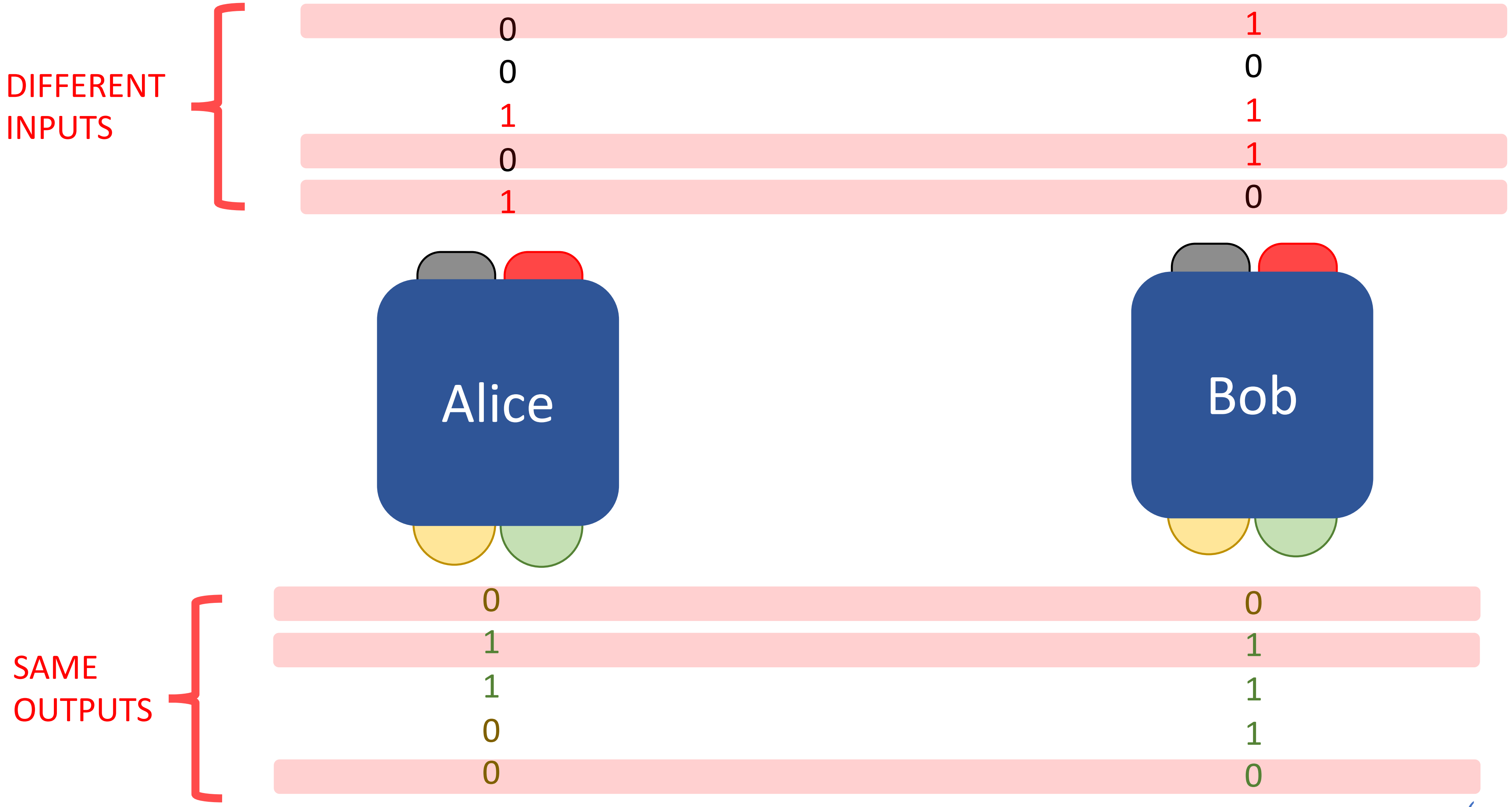
$$\sum_a p(ab|xy) = p(b|xy) := p(b|y)$$

$$\sum_b p(ab|xy) = p(a|xy) := p(a|x)$$

SCENARIO (2, 2, 2)
(parties, inputs, outputs)

Some experimental results can be explained by a theory patterns

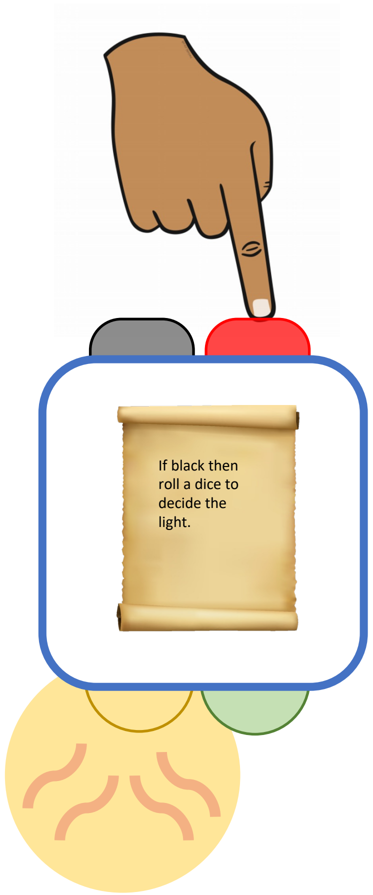
Some ~~experimental results~~ can be explained by a theory



SCENARIO (2, 2, 2)
(parties, inputs, outputs)

In local (classical) physics we have a very good explanation of what happens inside the box. We have equations that can characterise the patterns and model the physical systems producing them.

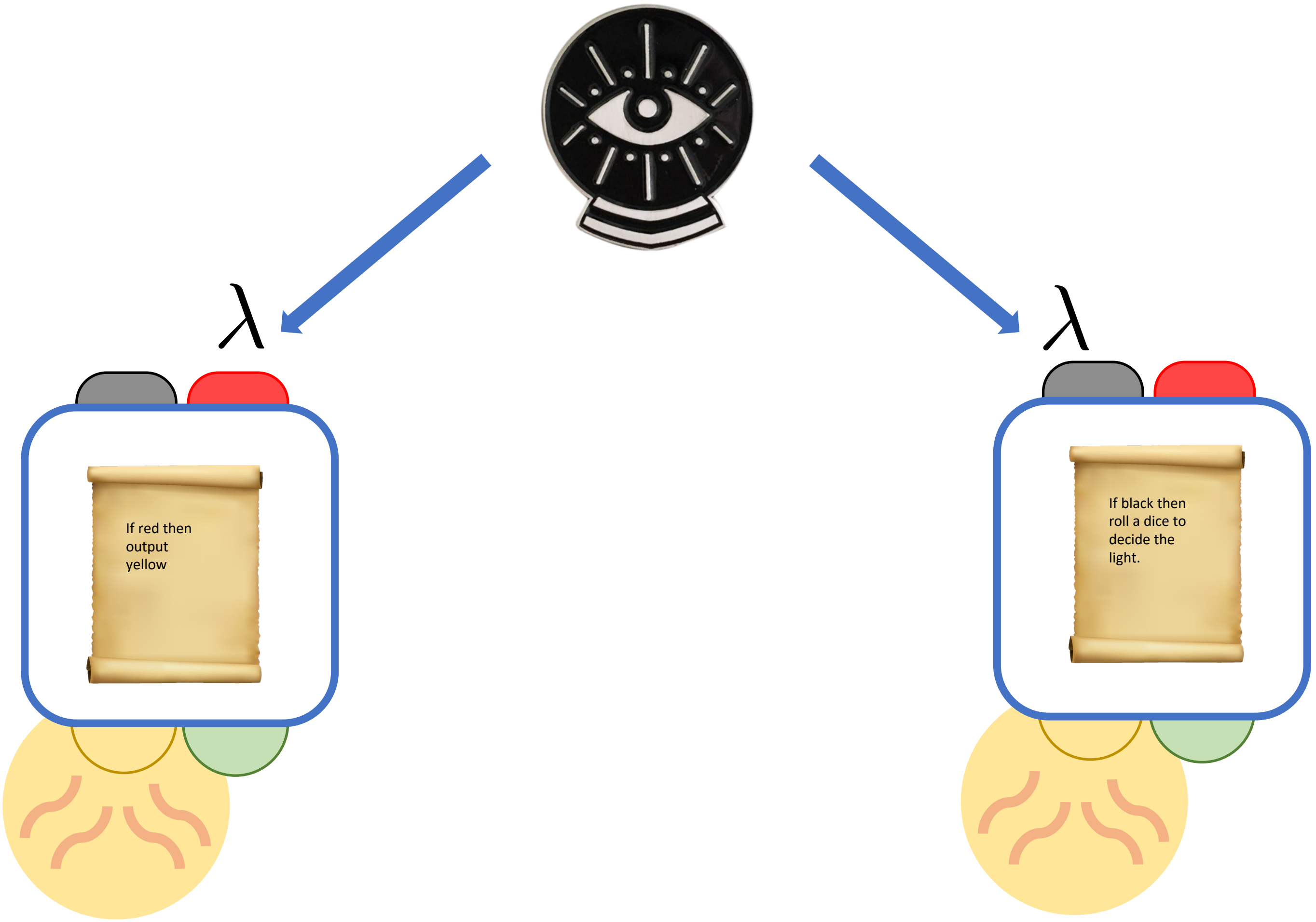
Local (classical) physics



NO SIGNALLING

SCENARIO (2, 2, 2)
(parties, inputs, outputs)

Local (classical) physics

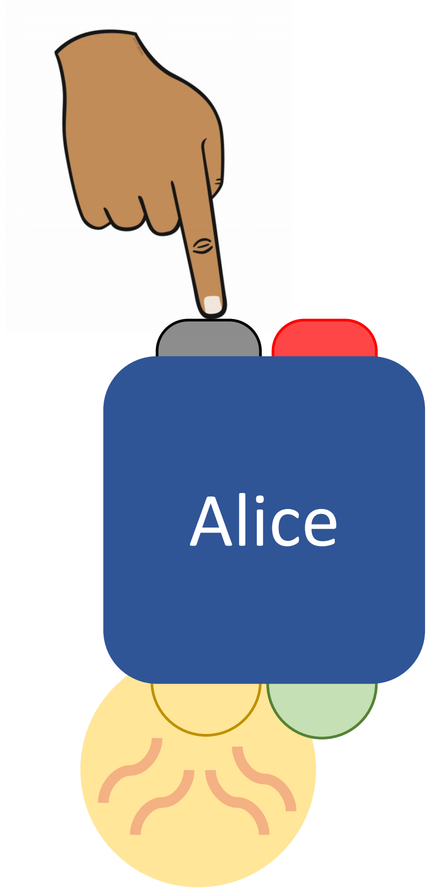


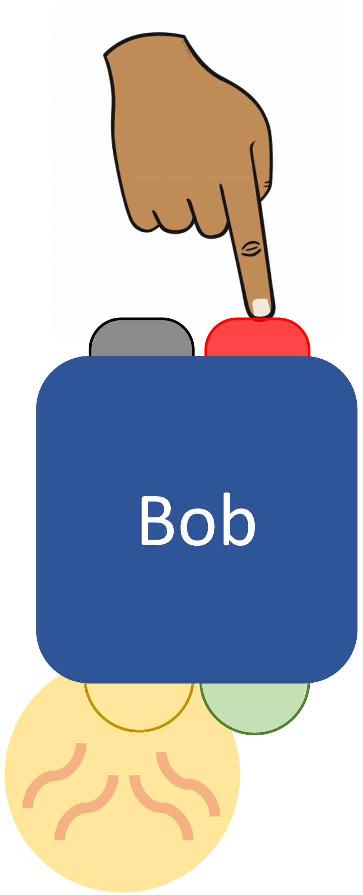
$$p(ab|xy) = \sum_{\lambda} \pi_{\lambda}\, p(a|x,\lambda)p(b|y,\lambda)$$

NO SIGNALLING

SCENARIO (2, 2, 2)
(parties, inputs, outputs)

Black box scenario





SCENARIO (2, 2, 2)
(parties, inputs, outputs)

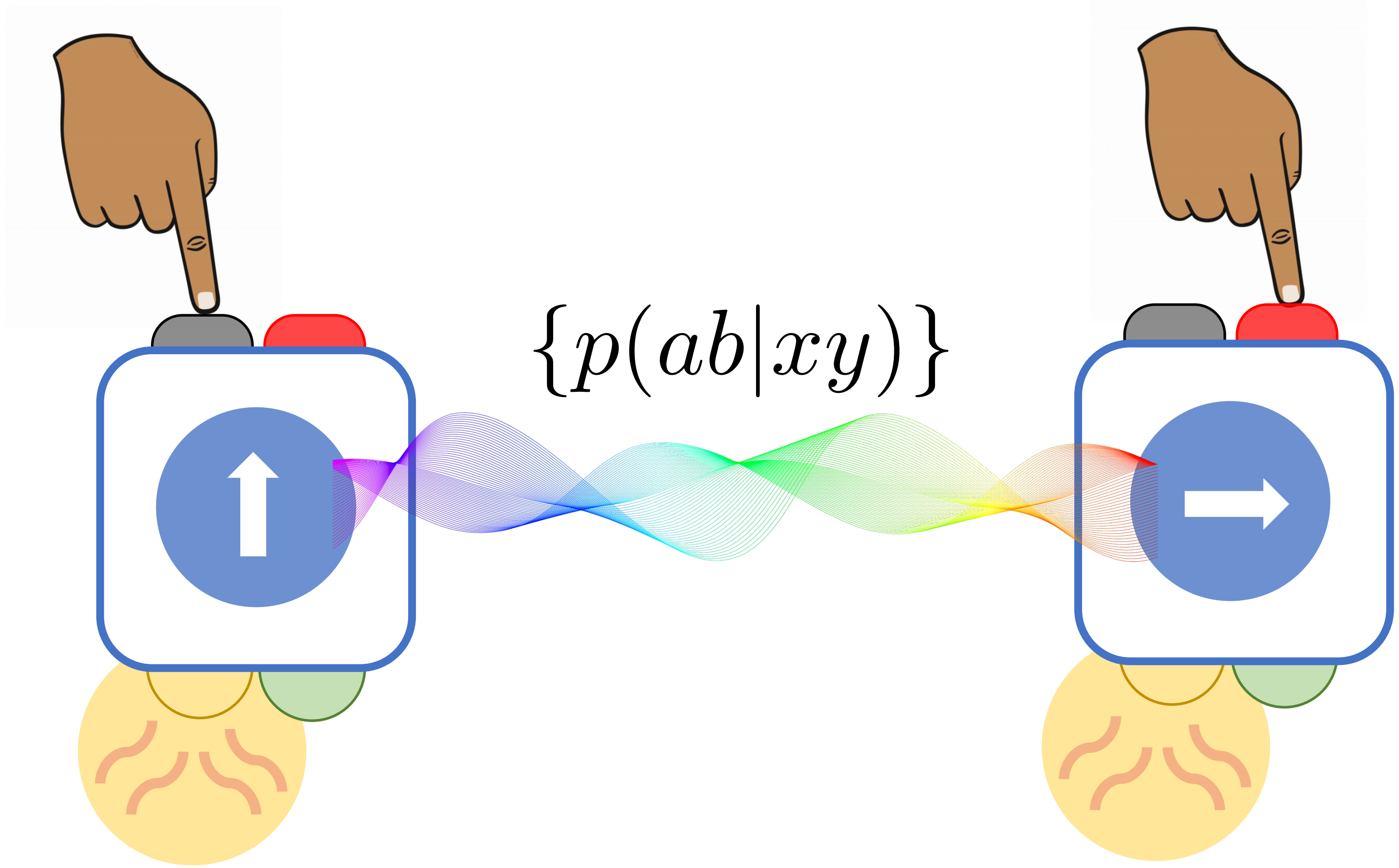
In quantum physics we have a very good explanation of what happens inside the box. We have equations that can characterise the patterns and model the physical systems producing them. These patterns are all the classical ones **and** some more.

Patterns produced by quantum things can be distinctly different to patterns produced by classical things.

In quantum physics we have a very good explanation of what happens inside the box. We have equations that can characterise the patterns and model the physical systems producing them. These patterns are all the classical ones **and** some more.

J. S. Bell, Physics Physique Fizika **1**, 195 (1964)

Black box scenario: quantum inside



$$\{p(ab|xy)\}$$

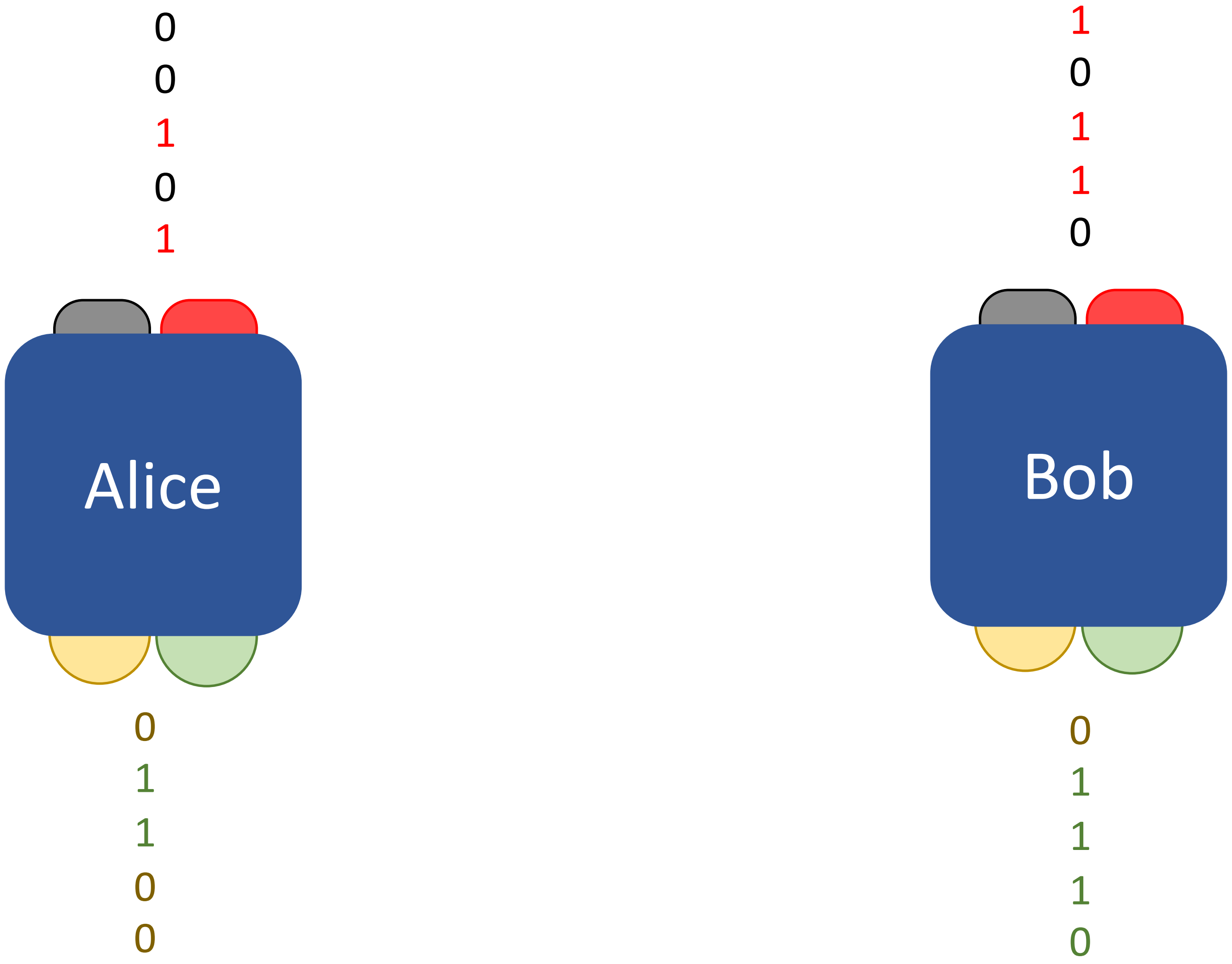
NO SIGNALLING

SCENARIO (2, 2, 2)
(parties, inputs, outputs)

Some patterns … are just patterns.

There is no explanation for what is going on inside the box. We don’t have a model or a mechanism for *how* these patterns are generated. We are able to write down characterisations of these patterns.

Some patterns are just that



SCENARIO (2, 2, 2)
(parties, inputs, outputs)

Given some patterns, can I tell if they were produced by something classical or something quantum?

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In general no.

Just by looking at patterns should it be, in principle, possible to tell if they were produced by something in quantum theory?

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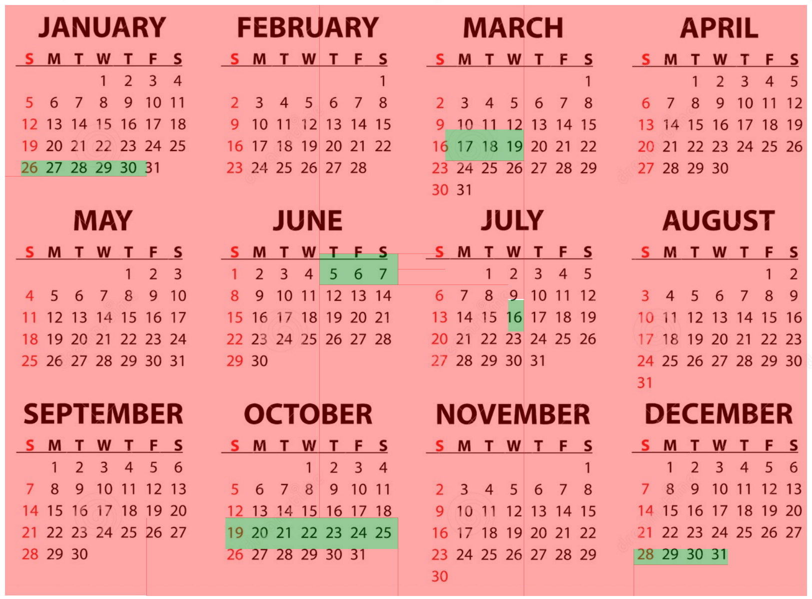
We have no idea.

Some patterns are extremely powerful

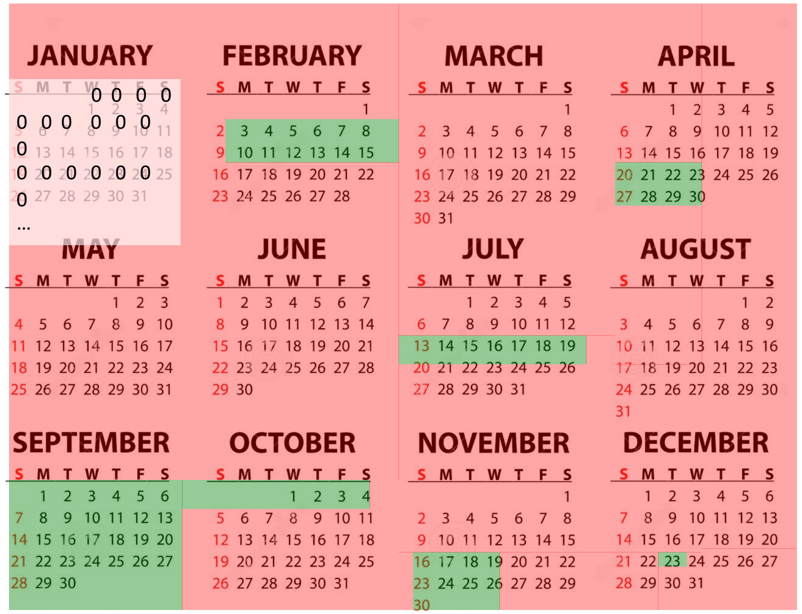
G. Brassard, H. Buhrman, N. Linden, A. A. Methot, A. Tapp and F. Unger, Phys. Rev. Lett., **96** 250401, (2006).

The calendar problem

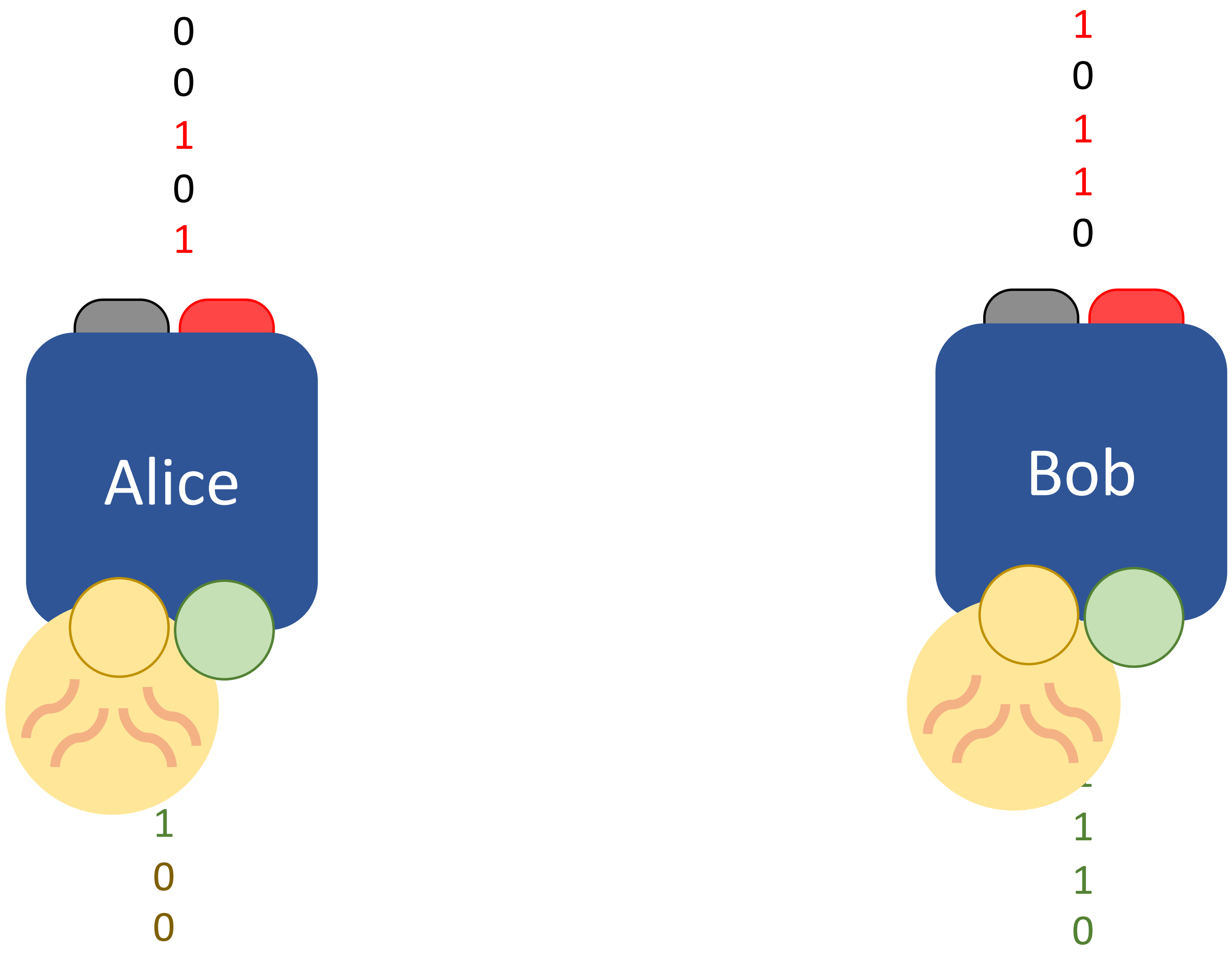
Alice



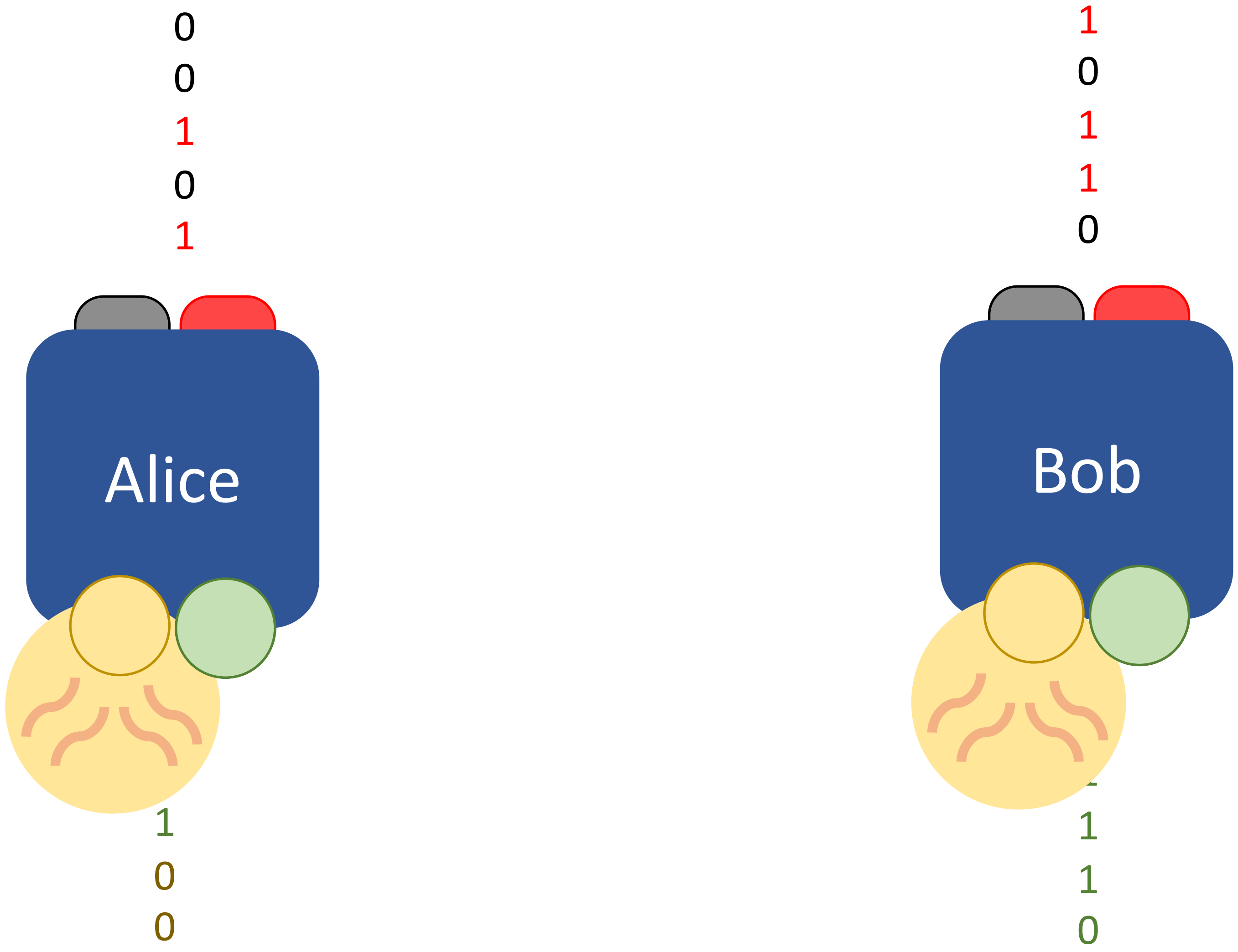
Bob



- **Q:** is the number of days that we are *both* free even or odd?

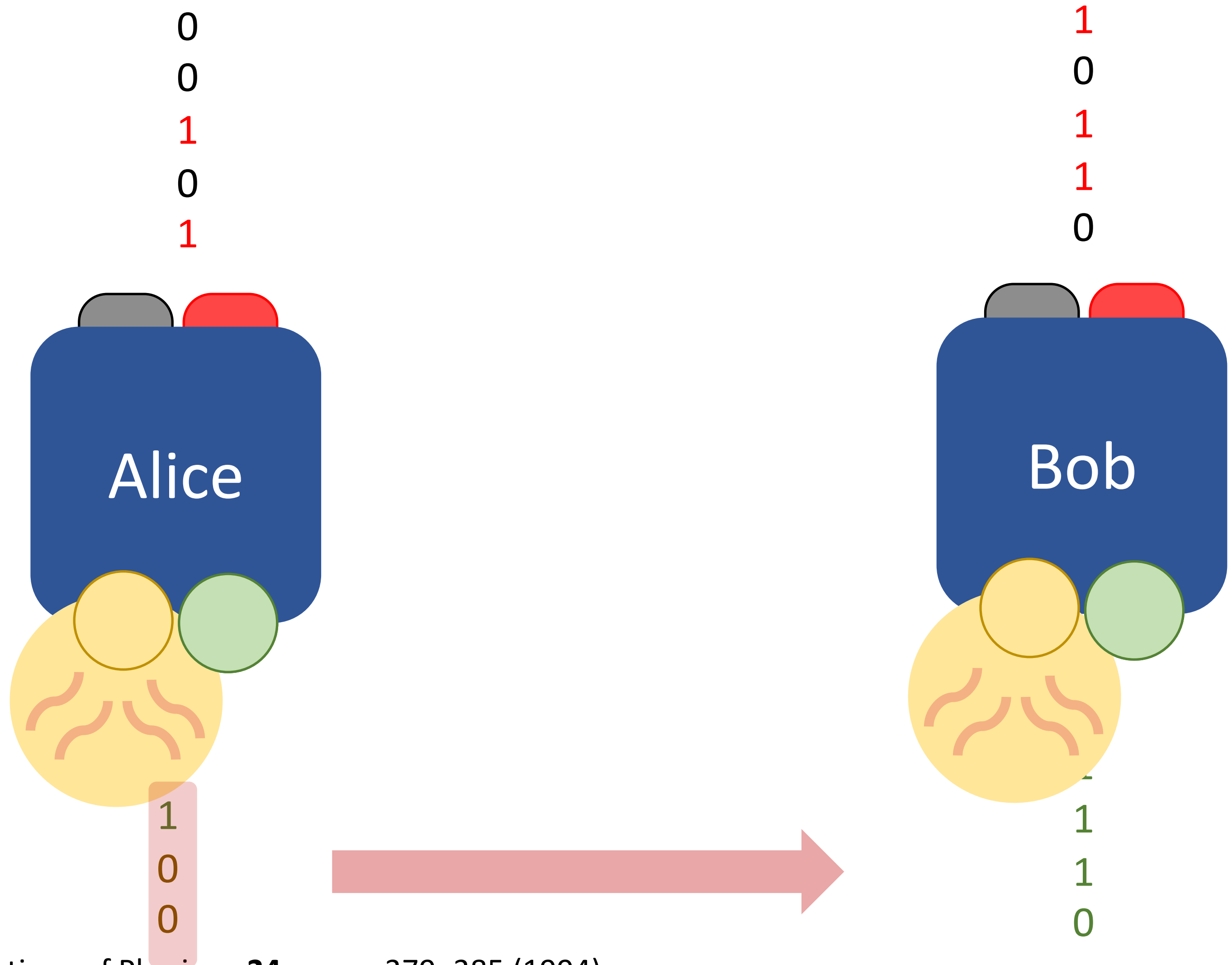

0
0
1
0
1
Alice
1
0
0
1
0
1
1
0
Bob
1
1
0

An extremely powerful pattern



S. Popescu and D. Rohrlich , Foundations of Physics v **24**, pages 379–385 (1994)

An extremely powerful pattern



S. Popescu and D. Rohrlich , Foundations of Physics v **24**, pages 379–385 (1994)

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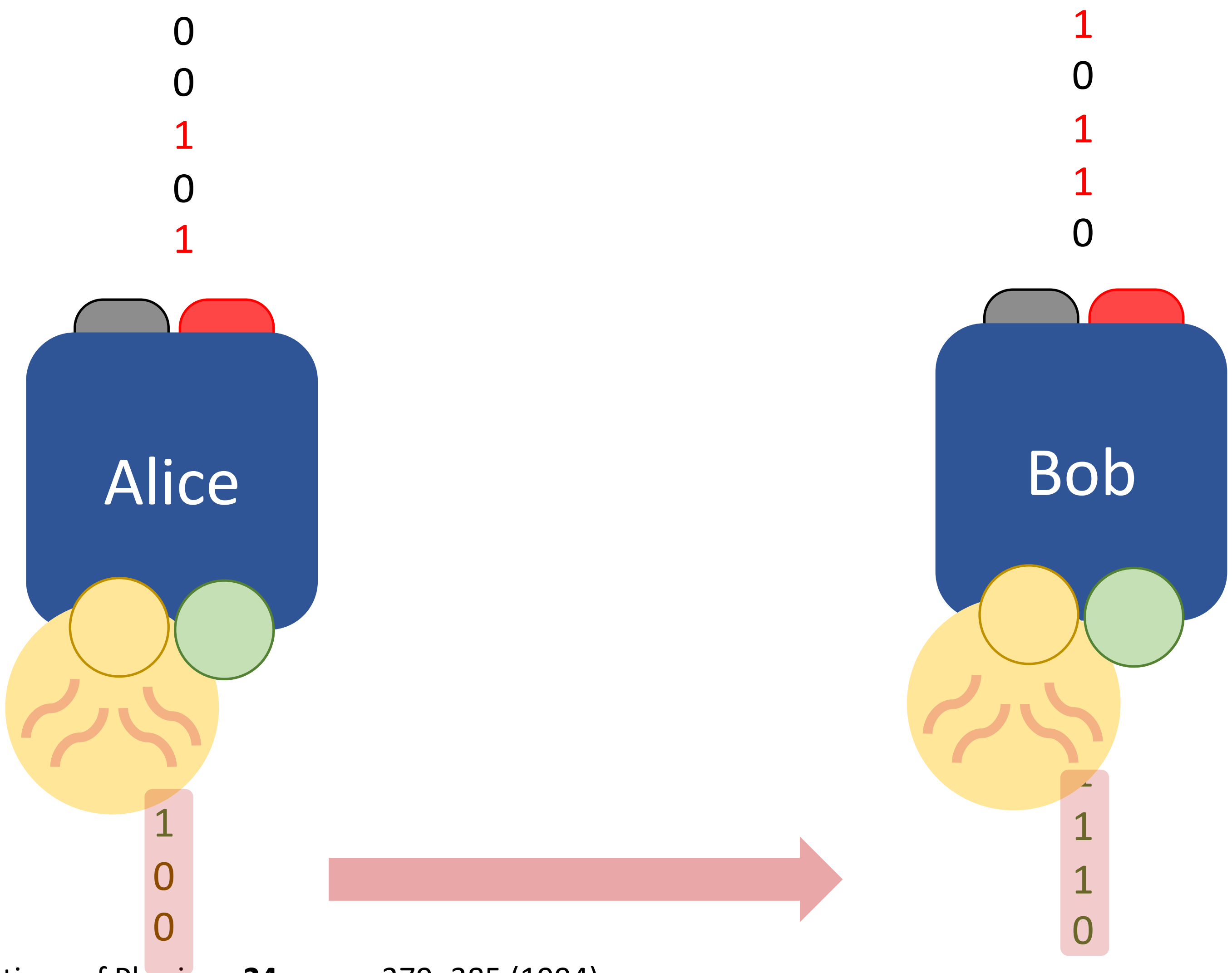


EVEN → NO. DAYS EVEN
ODD → NO. DAYS ODD.

S. Popescu and D. Rohrlich , Foundations of Physics v **24**, pages 379–385 (1994)

Calendar problem

- **Classically**: Bob needs to communicate with Alice 365 times (bits) to answer the question
- **Quantum**: does no better for this problem.
- **Other patterns:** there exist patterns which solve this problem in 1 bit – we call this *trivial communication complexity.*

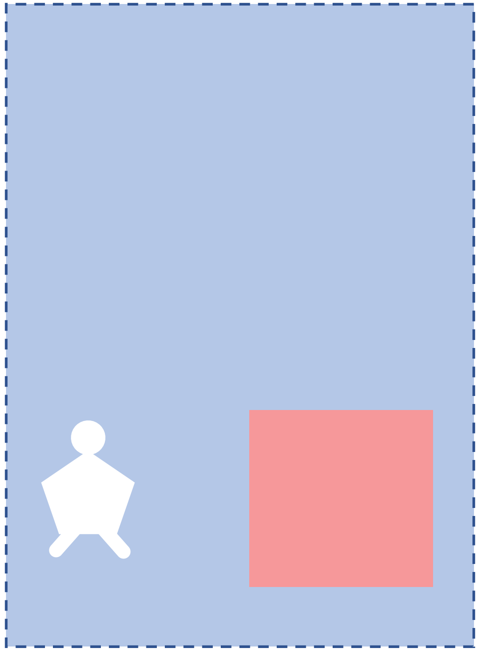
→ Patterns that we observe in Nature (our world) encode some kind of redundancy.

W. van Dam, "Nonlocality & communication complexity", D.Phil. Thesis, University of Oxford, Chap. 9 (2000).

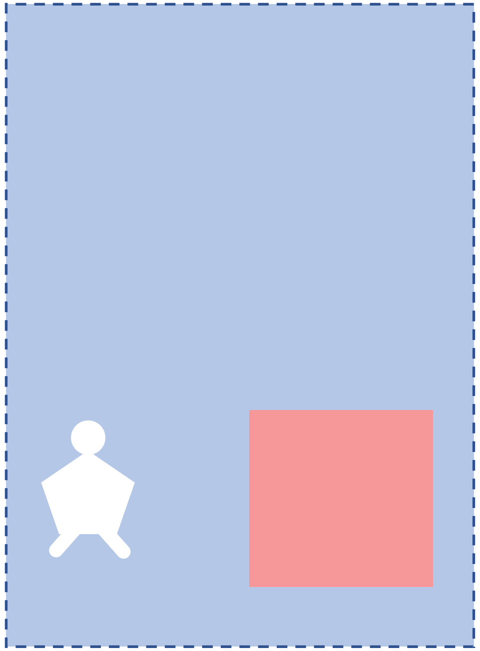
Story so far

- Thinking about the world in terms of patterns (correlations) has many advantages. One of these is that it is **device independent.**
- The restriction we considered on the patters was “no signaling” (no communication).
- Patterns obtained from quantum objects in experiments can be distinctly different to those in classical objects experiments.

Black box scenario: add agents and labs



Add structure: two step procedure



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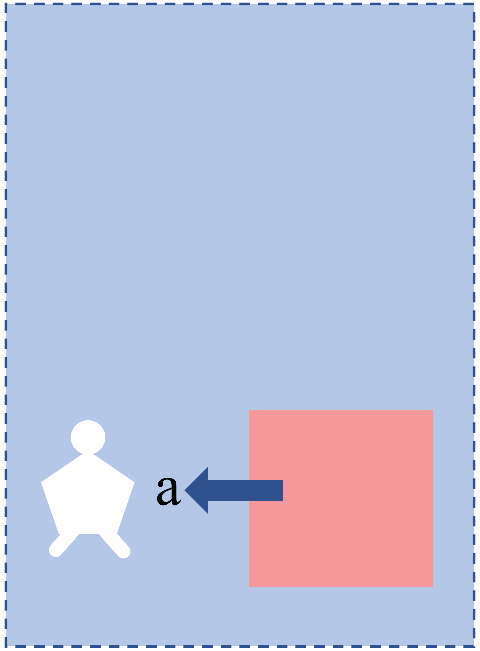

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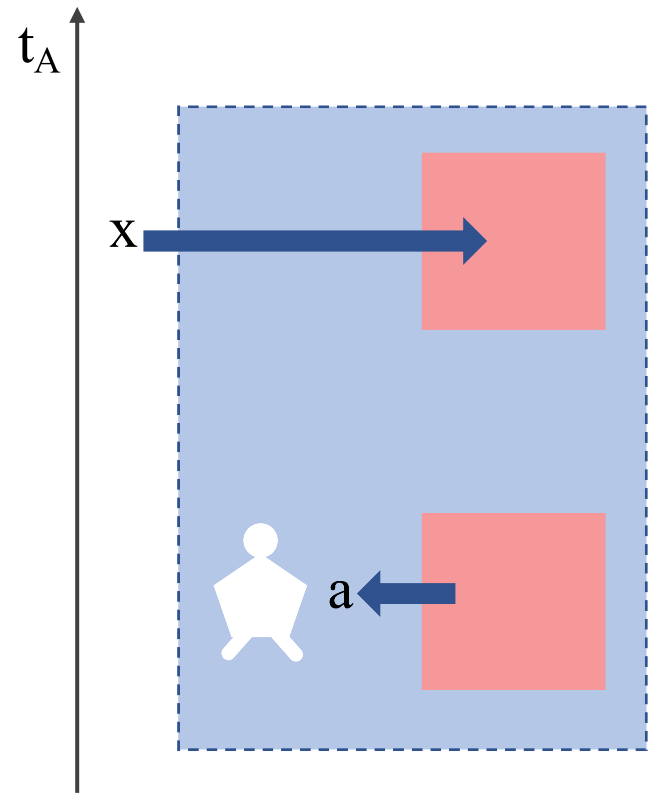
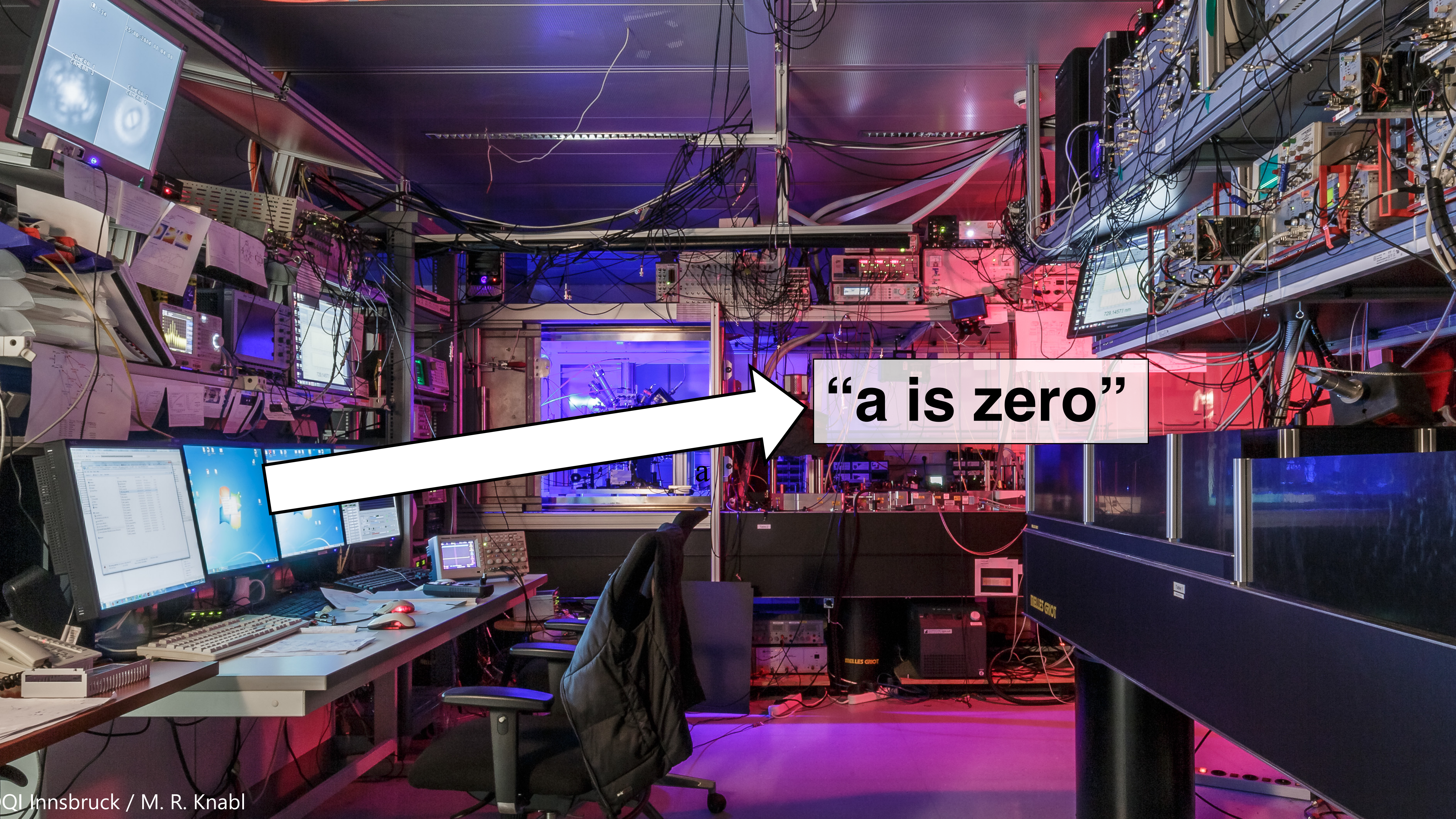
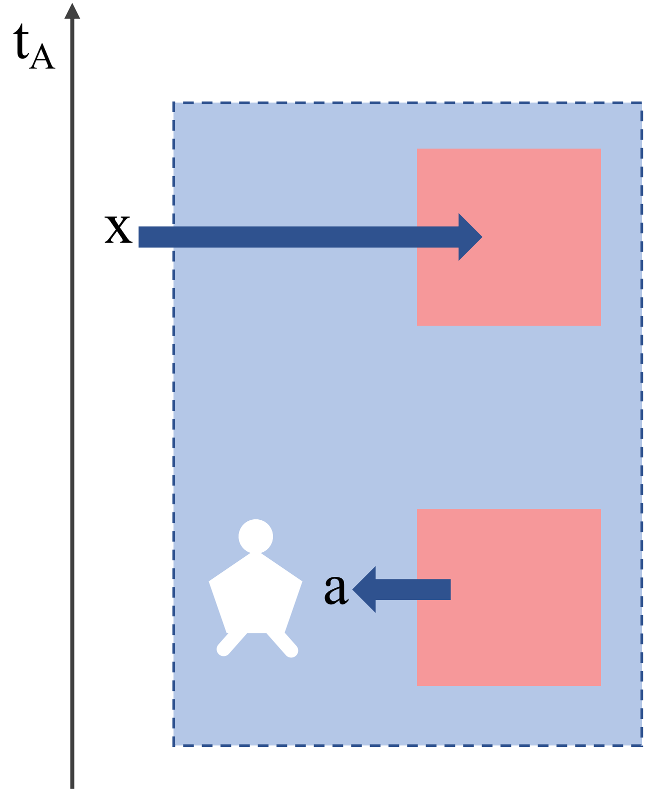



"a is zero"
a
©IQOQI Innsbruck / M. R. Knabl


NOW DO THAT OTHER
EXPERIMENT AT THE
BACK OF THE ROOM!


NOW ADJUST ALL THE KNOBS ON THE OTHER EXPERIMENT AT THE BACK OF THE ROOM!
QI Innsbruck / M. R. Knabl

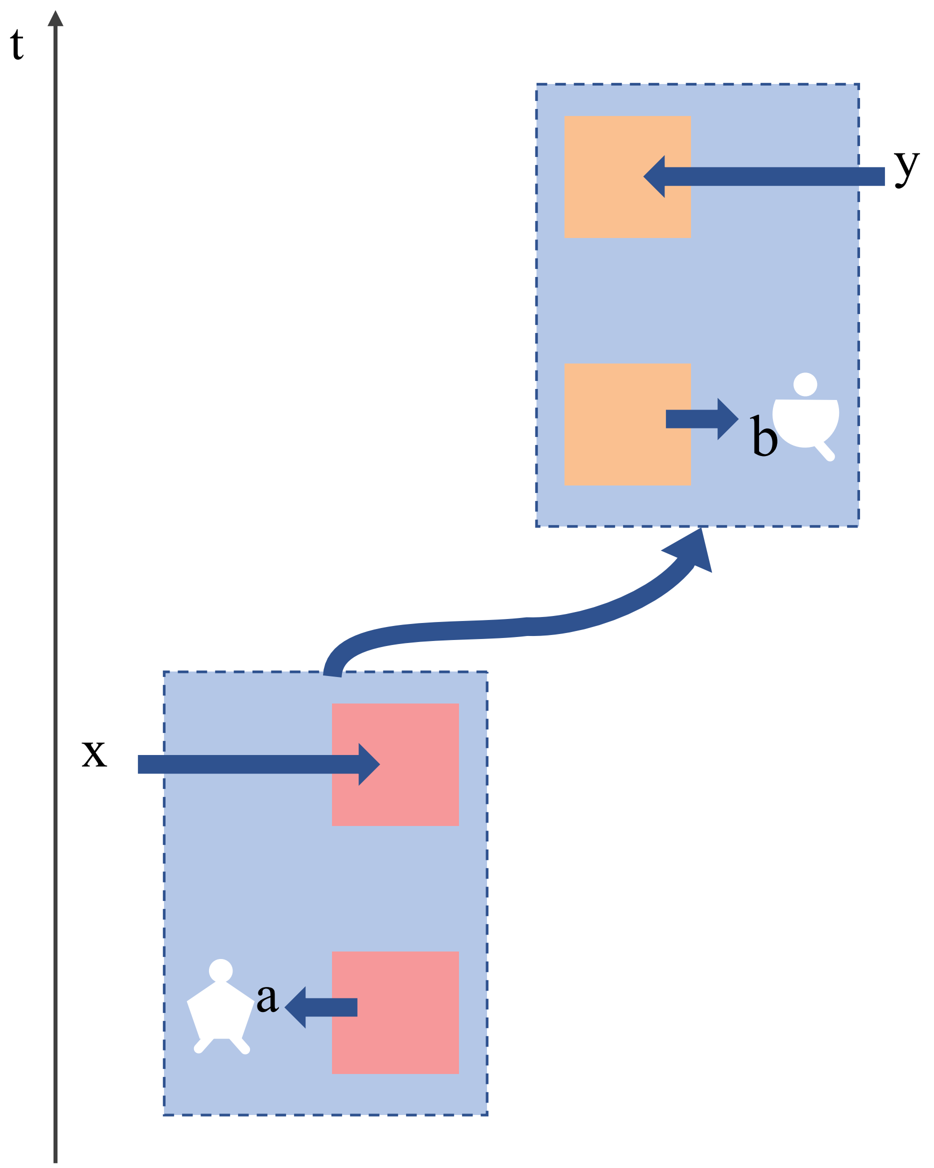
No-backwards-in-time-signalling



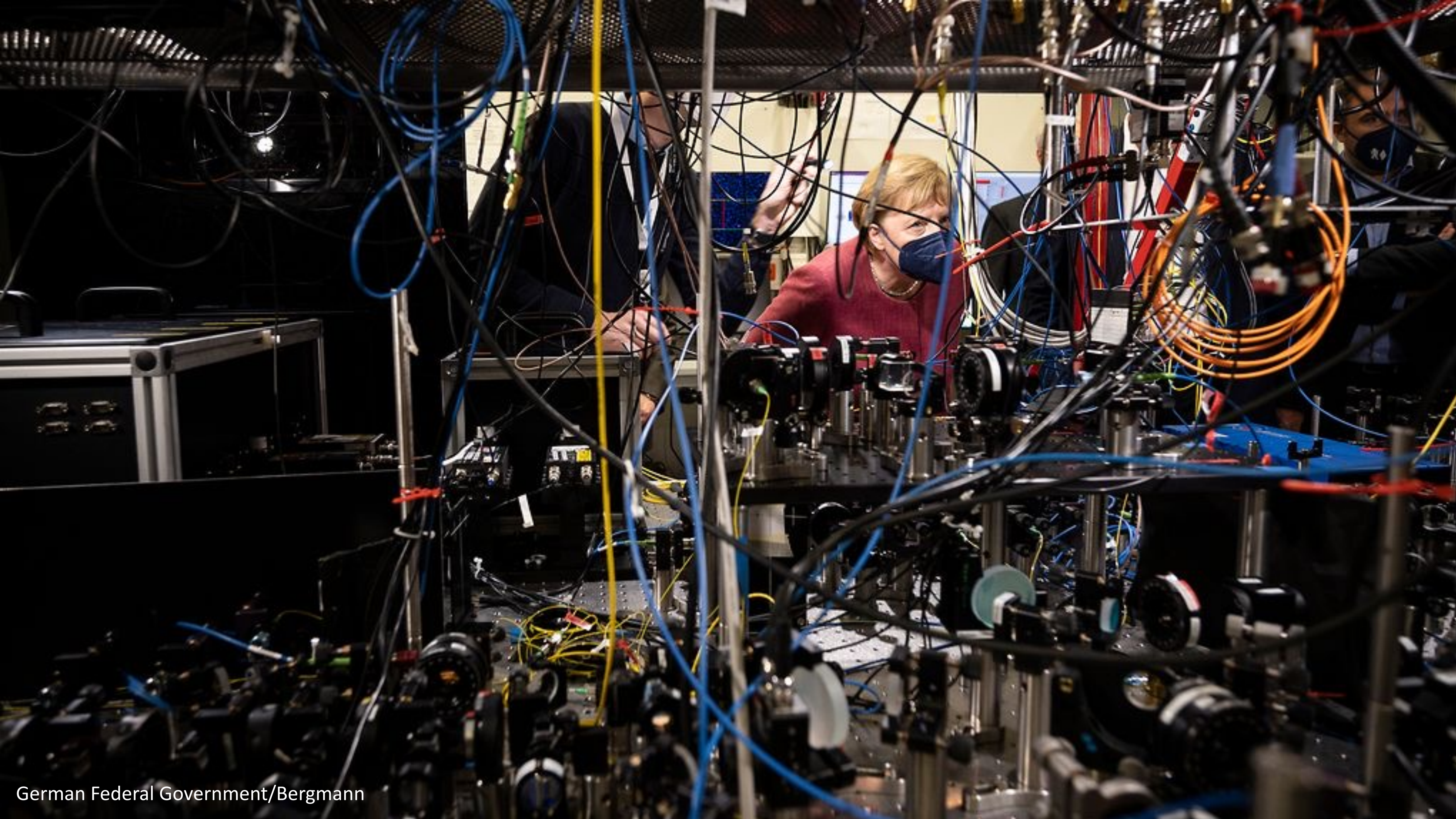
The outcome **a,** that Alice gets, does not depend on the future input **x.**

$$p(a|x) = p(a)$$

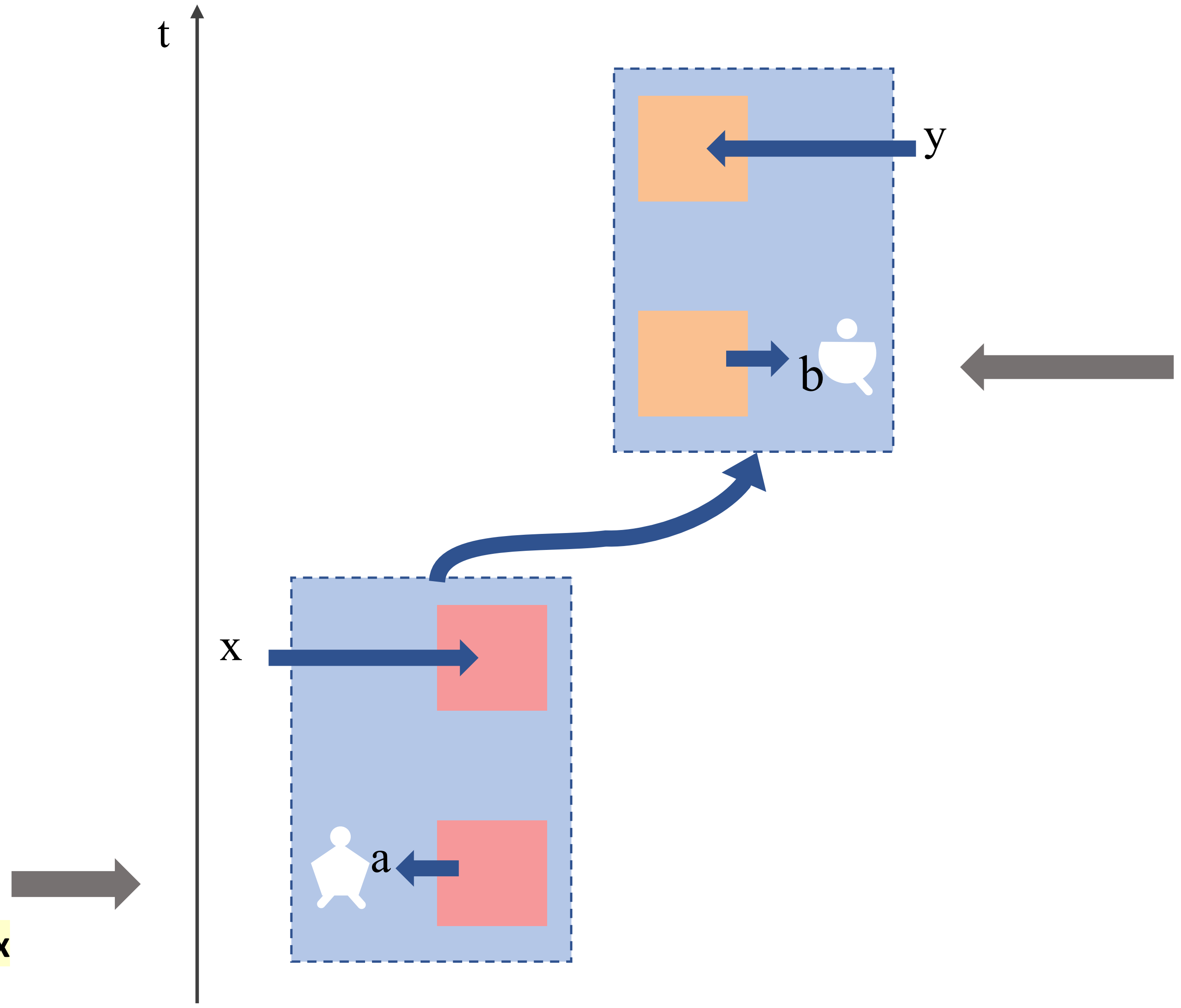
a does not depend on **x**



A → B


German Federal Government/Bergmann

$$\{ \, p(ab|xy) \, \}$$



$A \rightarrow B$

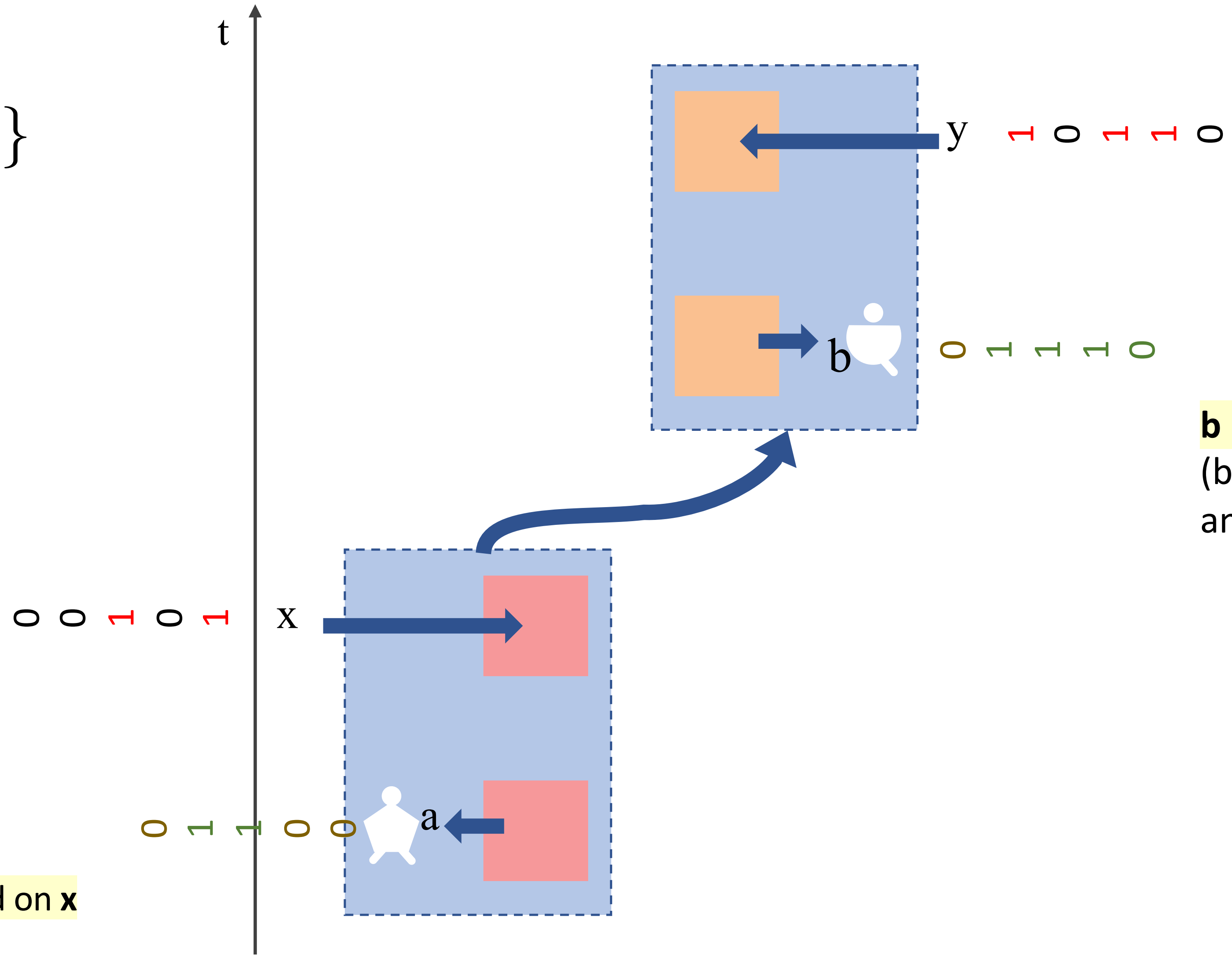
b does not depend on **y** (but it can depend on a and **x**)

Bob's local probability **can** depend on Alice *p(b|a,x)*

Alice's local probability **cannot** depend on her future operation $p(a|x) = p(a)$.

a does not depend on **x** (and **b** and **y**)

$$\{\, p(ab|xy) \,\}$$

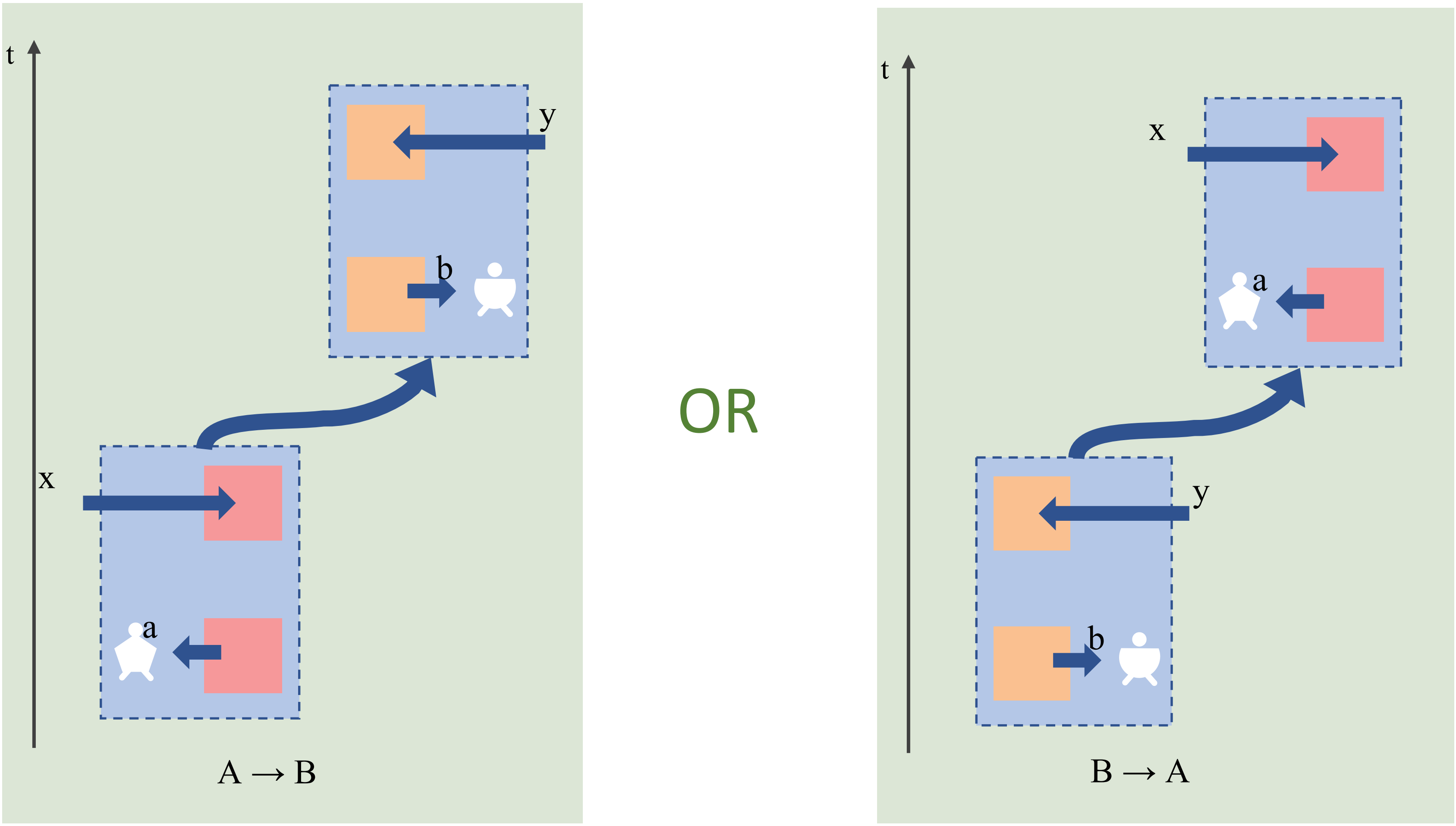


b does not depend on **y**
(but it can depend on a and **x**)

a does not depend on **x**
(and **b** and **y**)

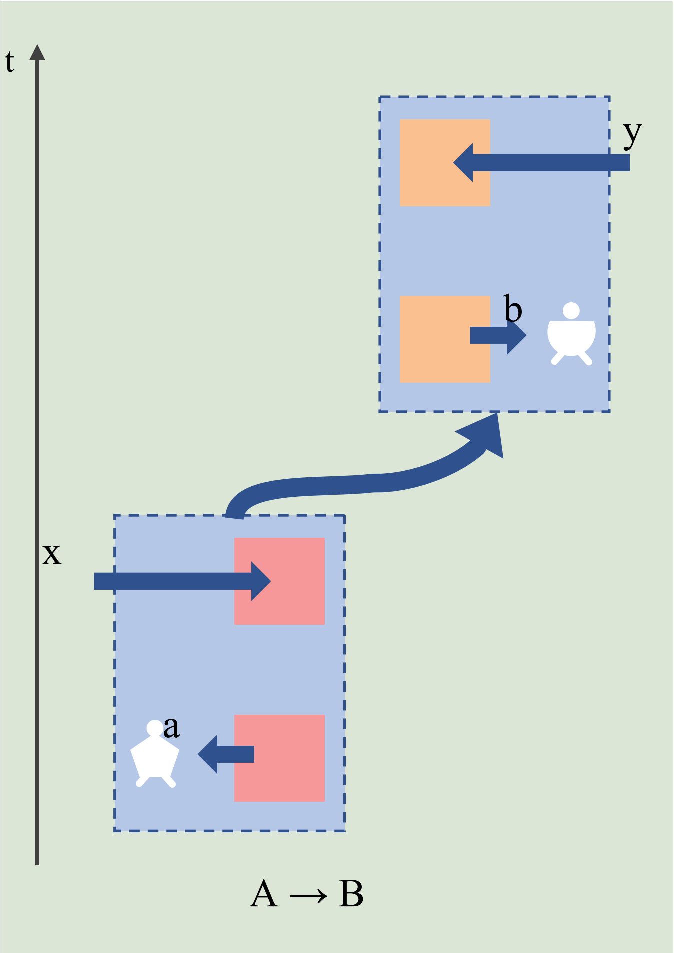
$A \to B$

We consider all the patterns compatible with this restriction

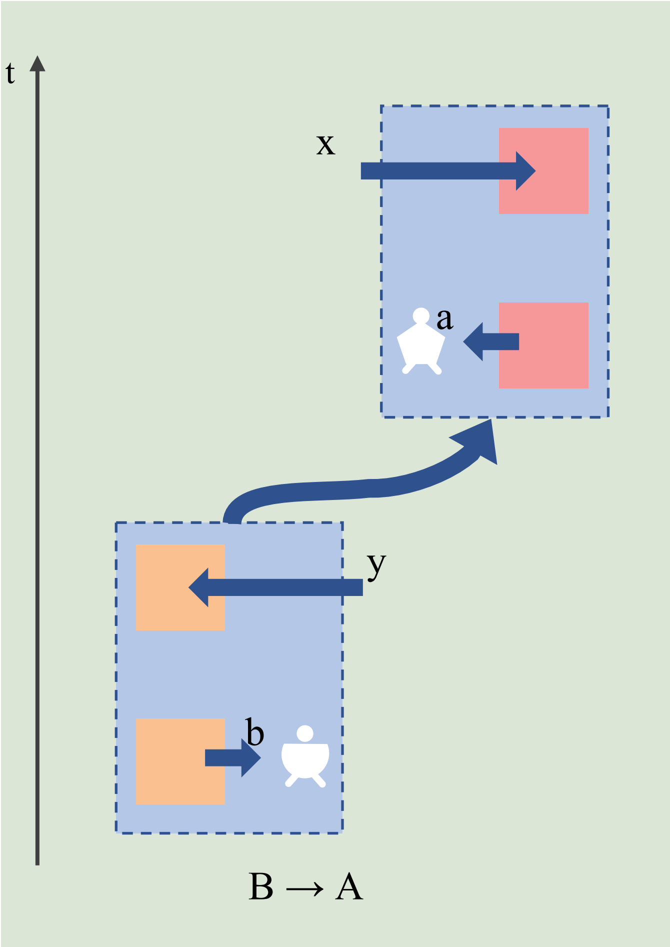


a does not depend on **x**
b does not depend on **y**

Sequential order



OR

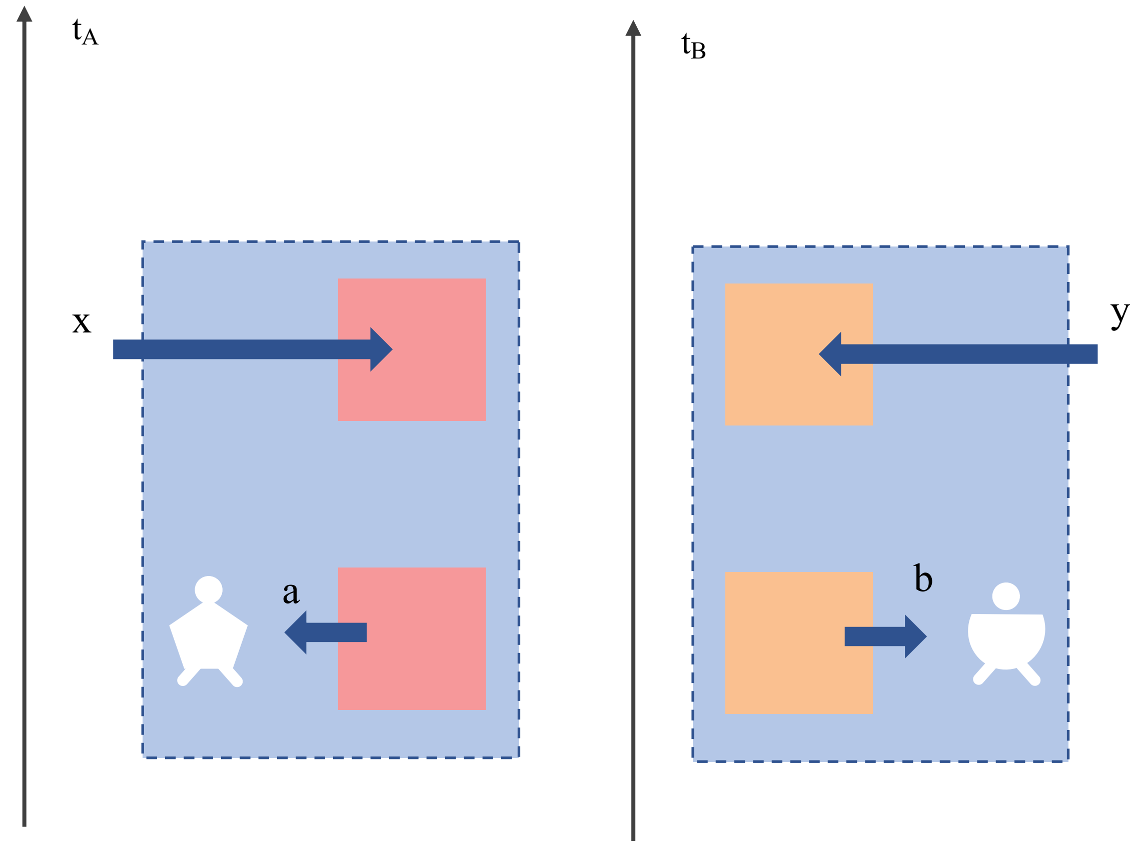


Some fraction of the time A→ B

Some fraction of the time B→ A

Indefinite order (parallel)

a does not depend on **x**
b does not depend on **y**



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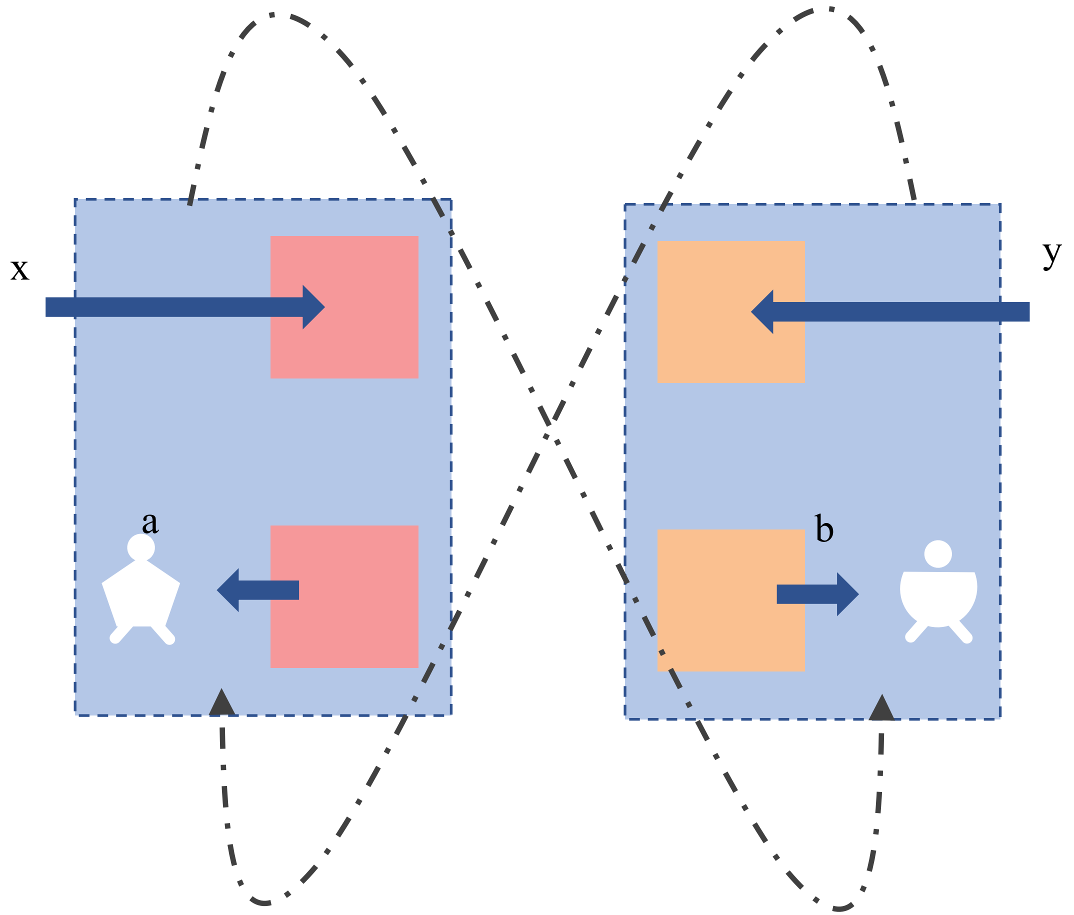

Indefinite order (parallel)

a does not depend on **x**
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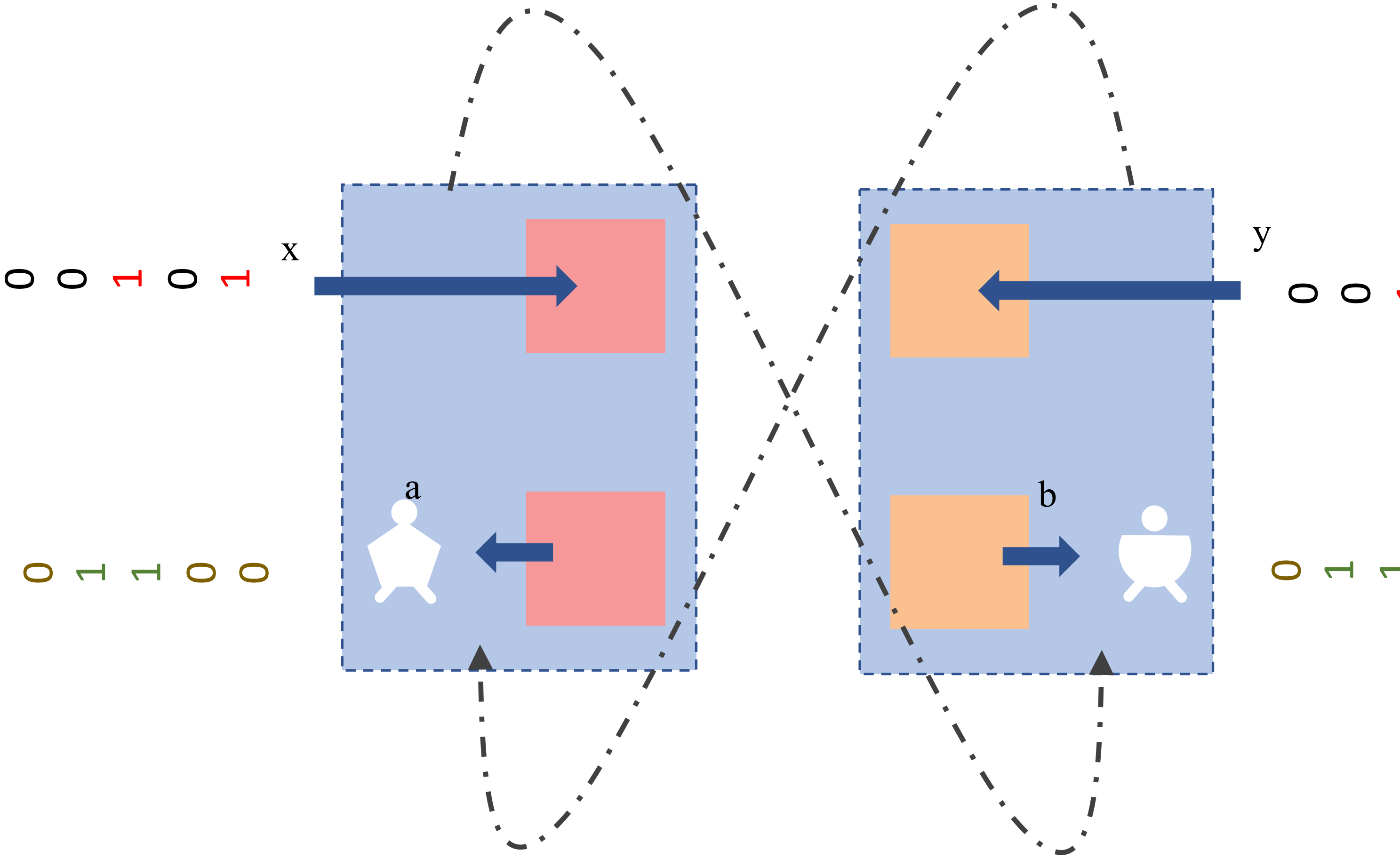
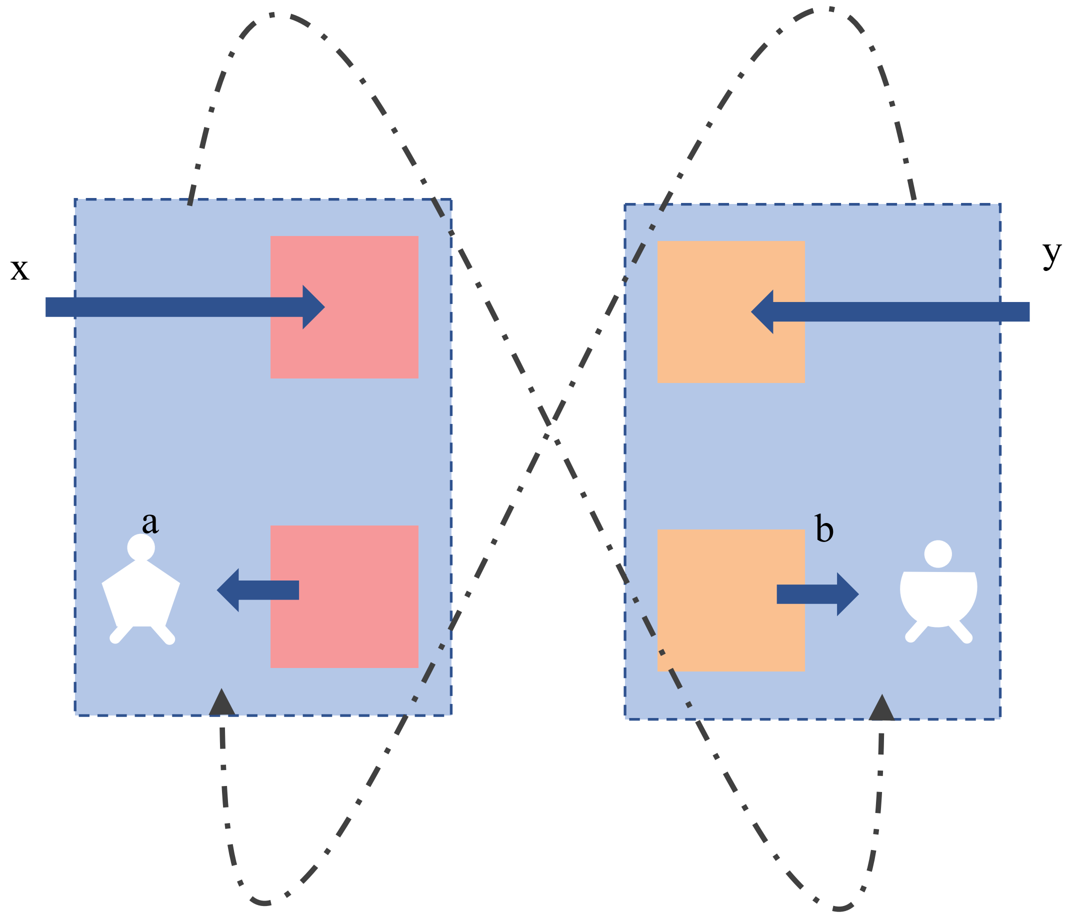


Backwards-in-time influence without backwards in time signalling

- **Monday:** the results of Alice and Bob's measurements depend on the external inputs x and y that they receive on **Tuesday.**
- However, this dependence can only be observed on **Wednesday** when Alice and Bob emerge from their labs and compare their results to check their correlations.



Backwards-in-time influence without backwards in time signalling

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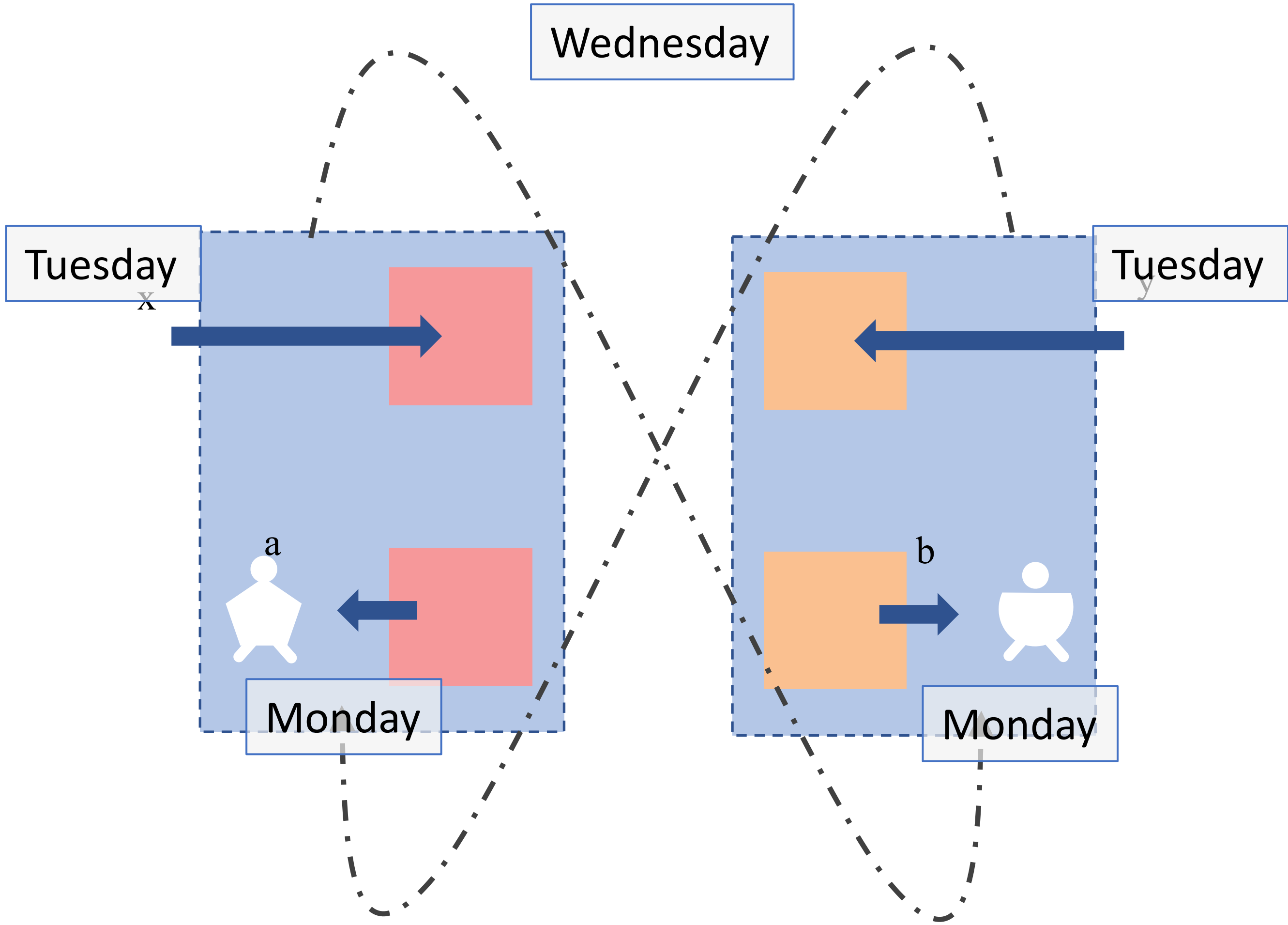
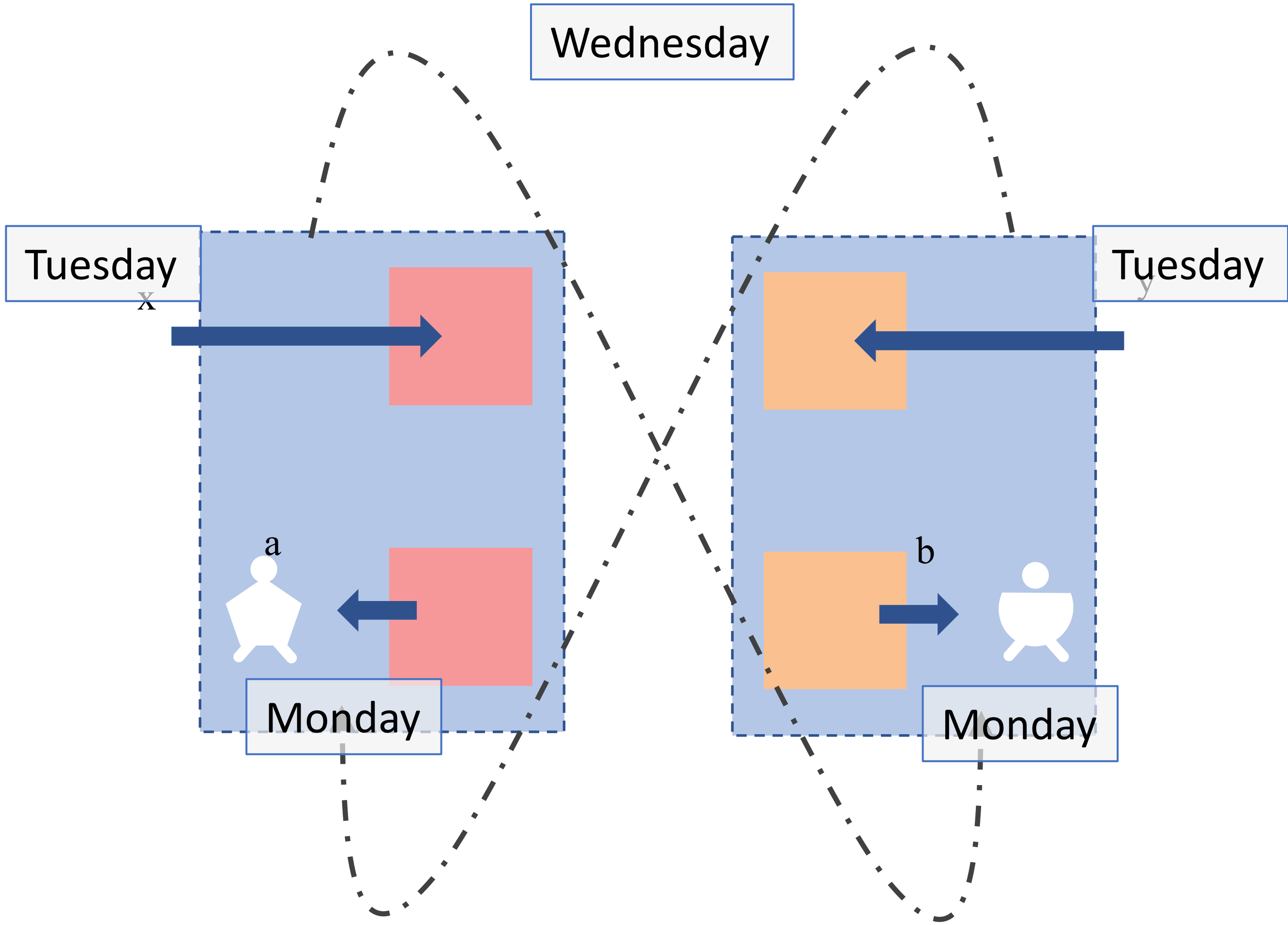
- However, this dependence can only be observed on **Wednesday** when Alice and Bob emerge from their labs and com-pare their results to check their correlations.



Backwards-in-time influence without backwards in time signalling

- The outcome **a** is independent of **x** (and **y**).
- The outcome **b** is independent of **y** (and **x**).
- The outcomes **a together with b** depend on both **x** and **y.** Only when they come together on Wednesday and look across their results, do see this structure.



Does this type of situation occur in our world? Are we receiving backwards-in-time influence without backwards in time signalling?

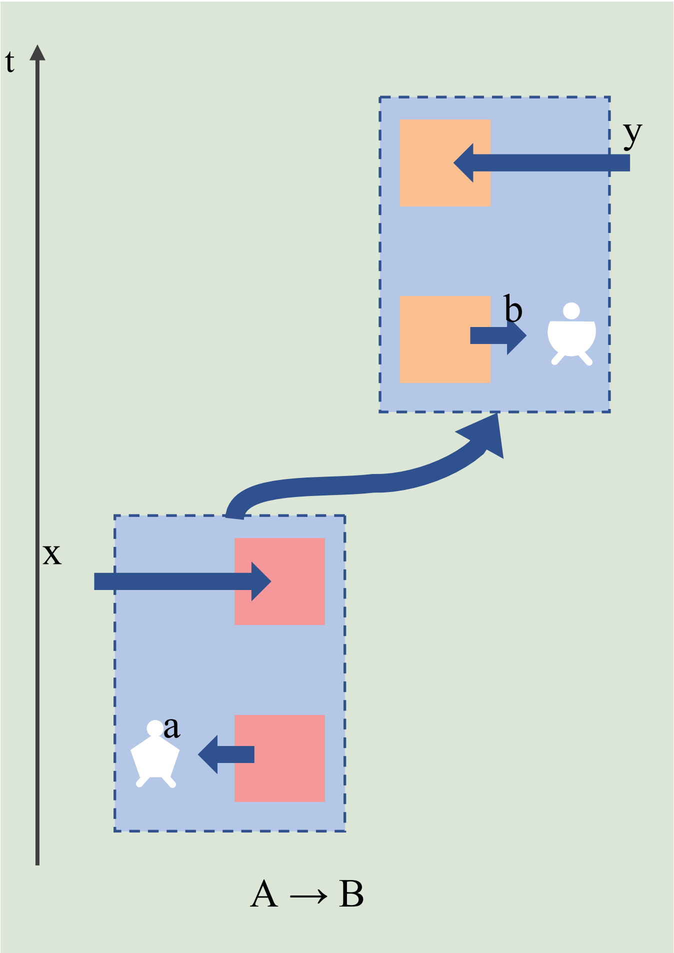
Does this type of situation occur in our world? Are we receiving backwards-in-time influence without backwards in time signalling? No.

Does this type of situation occur in our world? Are we receiving backwards-in-time influence without backwards in time signalling? **No.**

All patterns produced in quantum theory in this paradigm are compatible with sometimes A→ B, sometimes B → A.

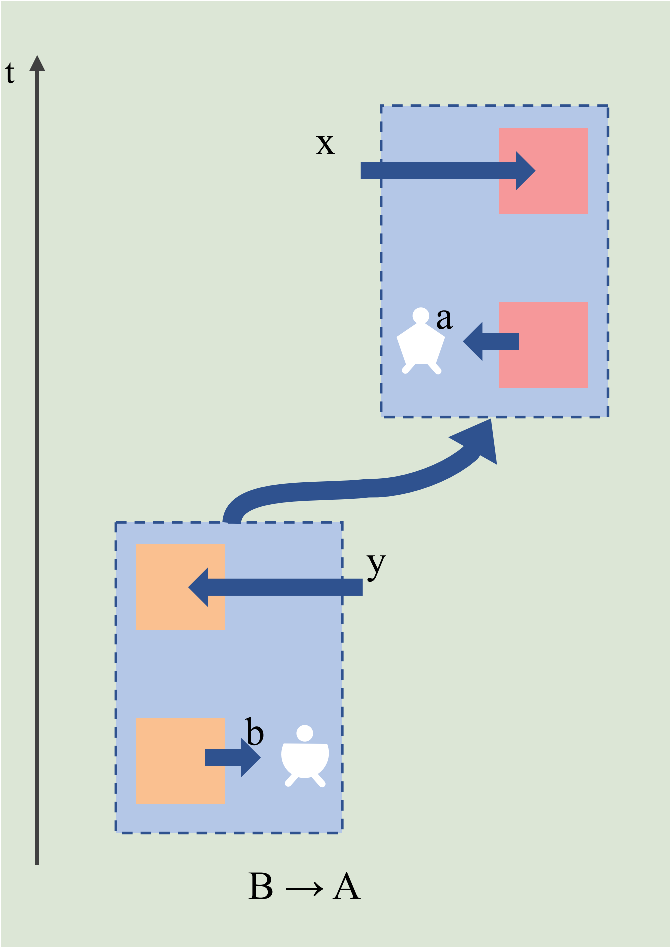
YG, R Silva, A J. Short, P Skrzypczyk, N Brunner and S Popescu. Quantum **3**, 211, (2019).

Sequential order



Some fraction of the time A→ B

OR



Some fraction of the time B→ A

Does this type of situation occur in our world? Are we receiving backwards-in-time influence without backwards in time signalling? **No.**

We can come up with patterns that do this though. These patterns don’t seem to belong to our world.

Where does this leave us?

- Assume a local time for Alice and Bob in their labs respectively, **and** that there is no-backwards-in-time signalling, **then** in the quantum world there is no backwards in time influence.
- It is theoretically possible to have situations in which the future affects the past, but in such a way that the effect can only be discovered later, thereby avoiding paradoxes such as killing one's own grandfather.
- Thinking about correlations with certain restrictions can help elucidate more about the world we live in. So far a complete characterization of the limits has not been found.

THANK YOU FOR YOUR ATTENTION

Assuming that the above can happen, that an x_a exists for each a such that $p(a, b^*|x_a, y') = 0$, then from the classicality conditions (44) it would follow that for all a,

$$p(a, b^*|x^*, y^*) = p(a, b^*|x_a, y^*) + p(a, b^*|x^*, y'). \quad (55)$$

From the NBTS condition of Alice, it holds that

$$\sum_a p(a, b^*|x^*, y^*) = \sum_a p(a, b^*|x^*, y'). \quad (56)$$

Substituting (55) into this NBTS condition, this would therefore imply that

$$\sum_a p(a, b^*|x_a, y^*) = 0 \quad (57)$$

which in turn would imply that $p(a, b^*|x_a, y^*) = 0$ for all a. This however cannot occur, since for the choice $a = a^*$ it would imply that $p(a^*, b^*|x_{a^*}, y^*) = 0$, however by assumption of case (ii), $p(a^*, b^*|x, y^*) \geq \epsilon$ for all x. This contra-

that $p(a^*, b_x|x, y) \geq \epsilon$ for all y. Subsequently $\mathbf{p}$ can be decomposed as $\mathbf{p} = \epsilon\mathbf{p}_c + (1-\epsilon)\mathbf{p}'$ if $\epsilon < 1$ or $\mathbf{p} = \mathbf{p}_c$ if $\epsilon = 1$, where now $\mathbf{p}_c$ is a vertex from the family (46) with $\alpha = a^*$ and $\beta_x = b_x$, and $\mathbf{p}'$ has at least one more vanishing probability compared to $\mathbf{p}$.

In conclusion, given any distribution $\mathbf{p} = \{p(a, b|x, y)\}_{a,b,x,y}$ that satisfies the NBTS, normalisation and classicality conditions, by iterating the above procedure, a sequence of decompositions are generated,

$$\begin{aligned}\mathbf{p} &= \epsilon^{(1)}\mathbf{p}_c^{(1)} + (1-\epsilon^{(1)})\mathbf{p}^{(1)} \\ &= \epsilon^{(1)}\mathbf{p}_c^{(1)} + (1-\epsilon^{(1)})[\epsilon^{(2)}\mathbf{p}_c^{(2)} + (1-\epsilon^{(2)})\mathbf{p}^{(2)}] \\ &\vdots \\ &= \epsilon^{(1)}\mathbf{p}_c^{(1)} + (1-\epsilon^{(1)})\epsilon^{(2)}\mathbf{p}_c^{(2)} + \ldots + \prod_{i=1}^{k}(1-\epsilon^{(i)})\mathbf{p}^{(k)} \\ &\vdots \end{aligned} \quad (59)$$

Potential paradoxes

$$a \oplus b = x \oplus y \oplus 1$$