Teoria fisica che vai, Teoria informatica che trovi

Davide Rolino*, Lorenzo Siro Trezzini*

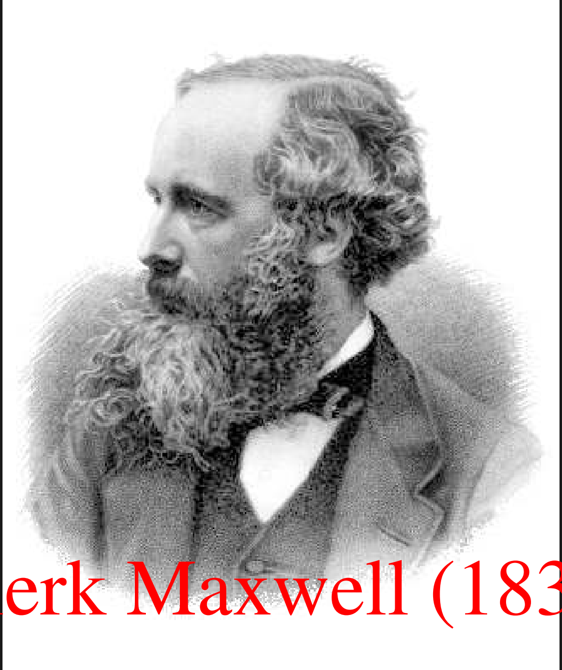
*Università degli Studi di Pavia, Dipartimento di Fisica, QUIT Group and INFN Gruppo IV, Sezione di Pavia

Incontri di fisica moderna

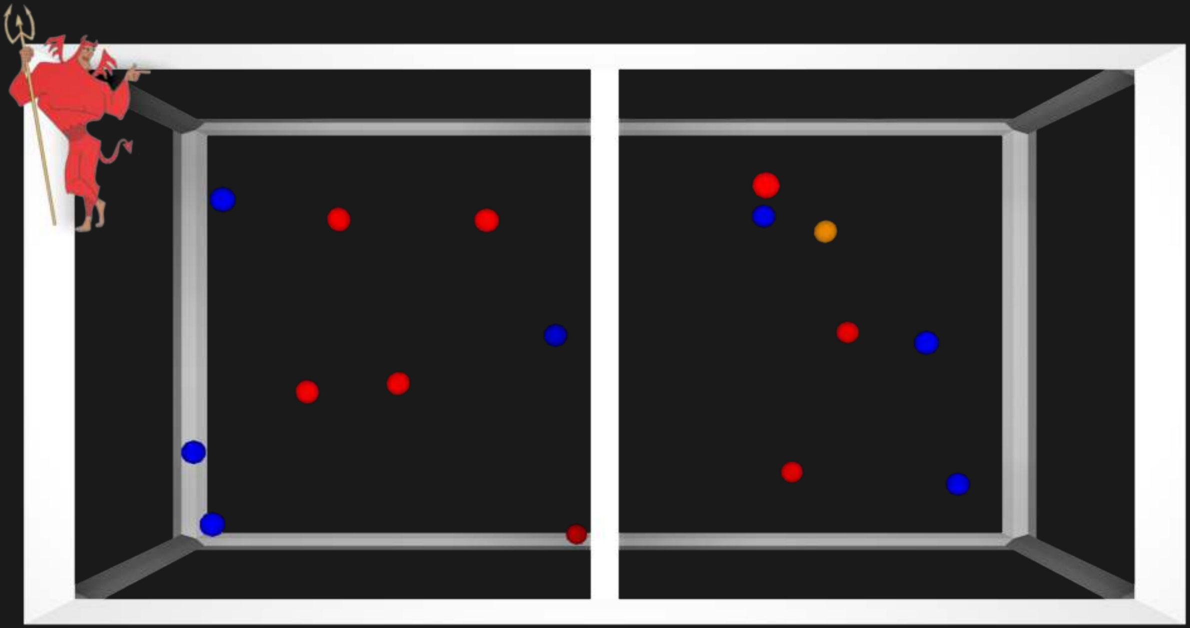
14/11/2023

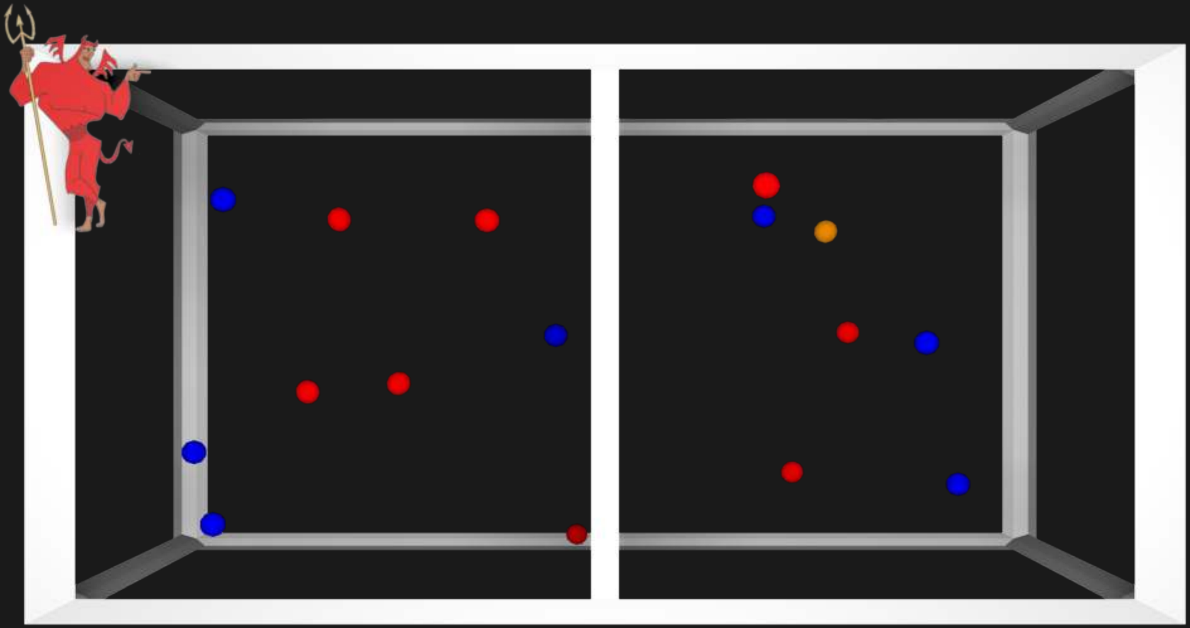

“La computer science studia i computer tanto quanto l’astrofisica studia i telescopi”

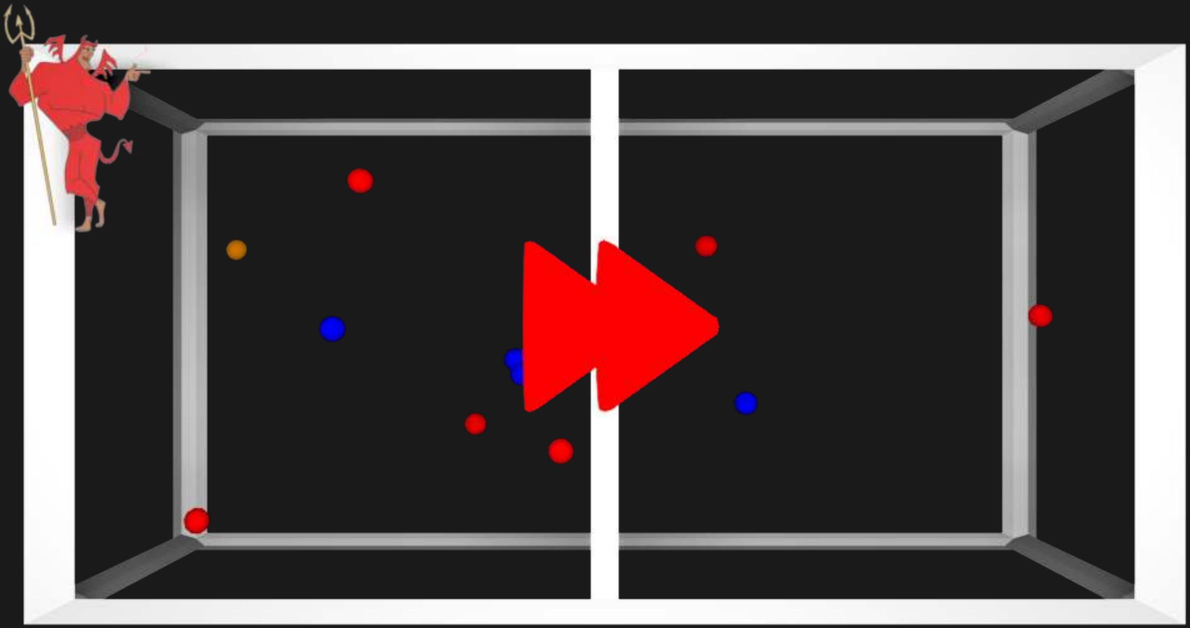
E. Dijkstra

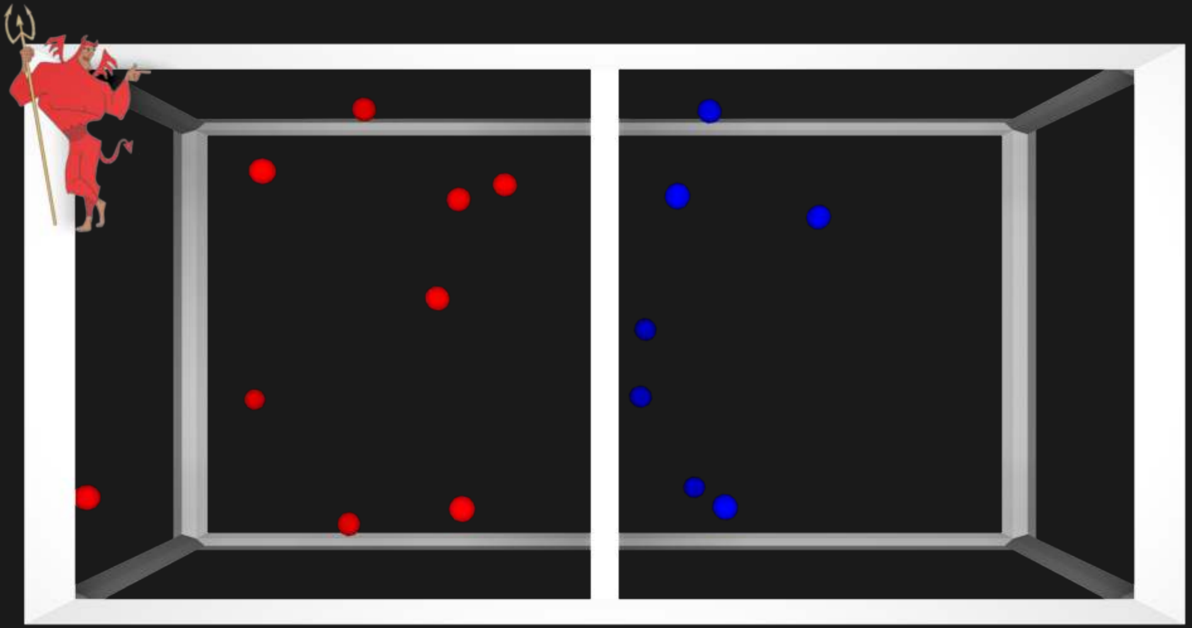


James Clerk Maxwell (1831 - 1879)









Termodinamica

Prima legge della termodinamica

Energia

Energia: permette ai sistemi fisici di agire

Prima legge: L’energia si conserva

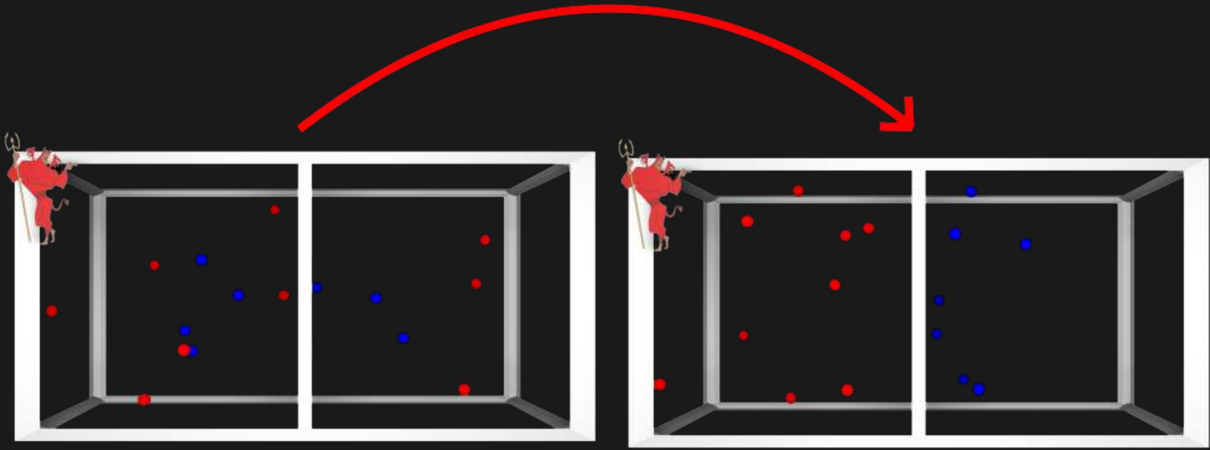
Seconda legge della termodinamica

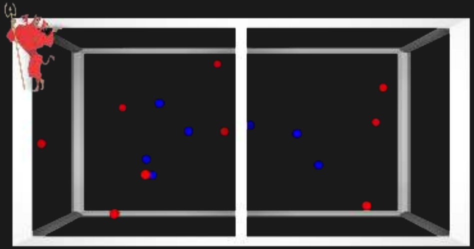
Entropia

Entropia: misura del disordine di un sistema

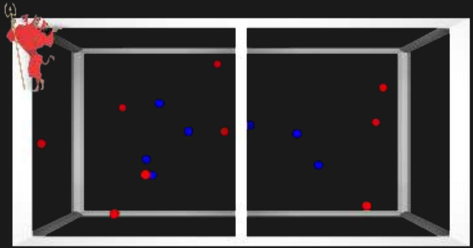
Misura di quanta energia termica di un sistema non è disponibile per essere convertita in lavoro

Seconda legge: L’entropia di un sistema isolato può solo aumentare o rimanere costante





Sistema all'equilibrio termico

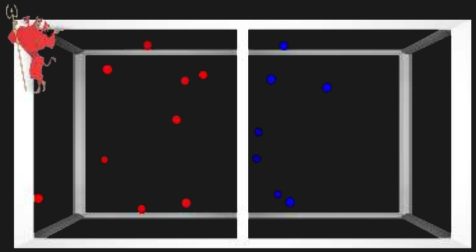


Sistema all'equilibrio termico

↓

Non è possibile estrarre lavoro

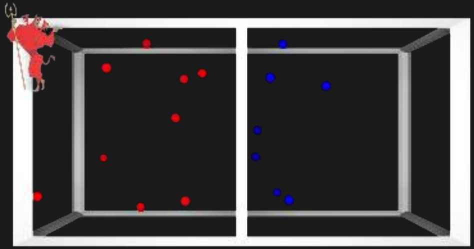
Sistema con ΔT



Sistema con ΔT

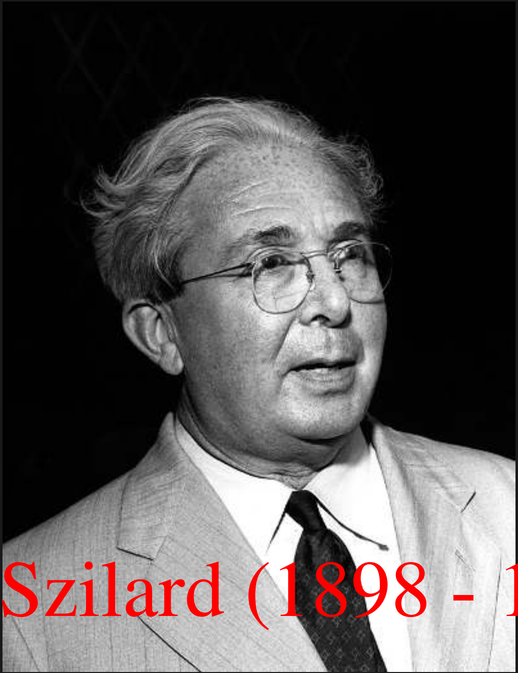
$\downarrow$

É possibile estrarre lavoro

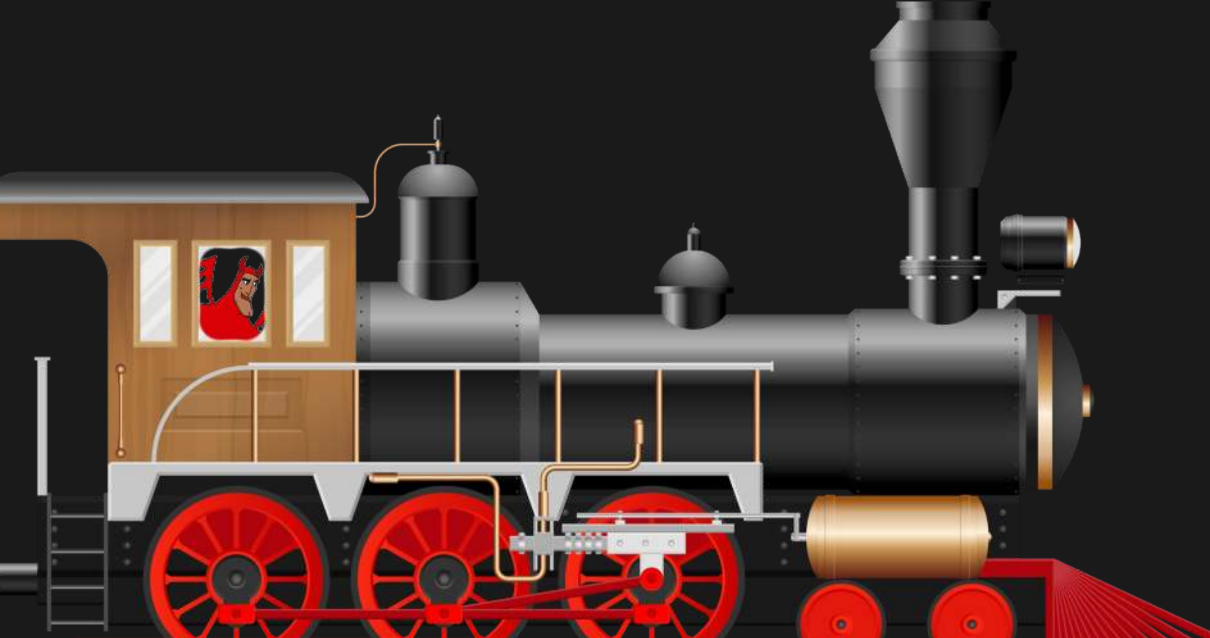


L’ENTROPIA É DIMINUITA!!!

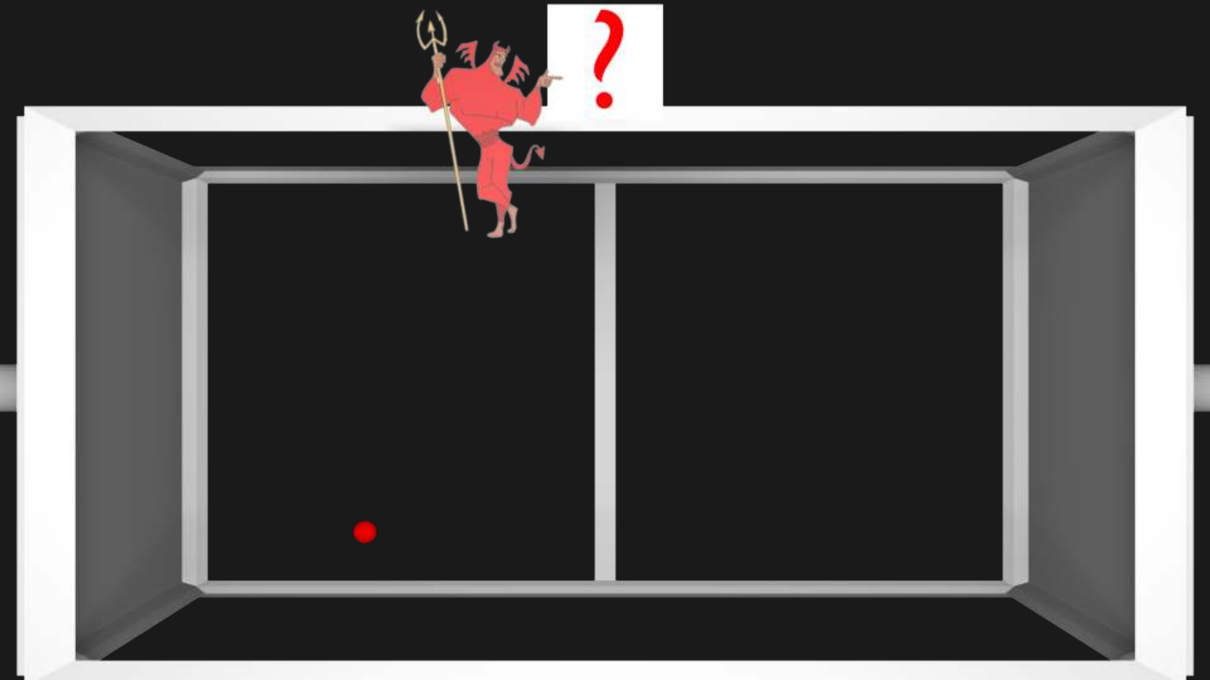
Informazione sulla posizione delle particelle

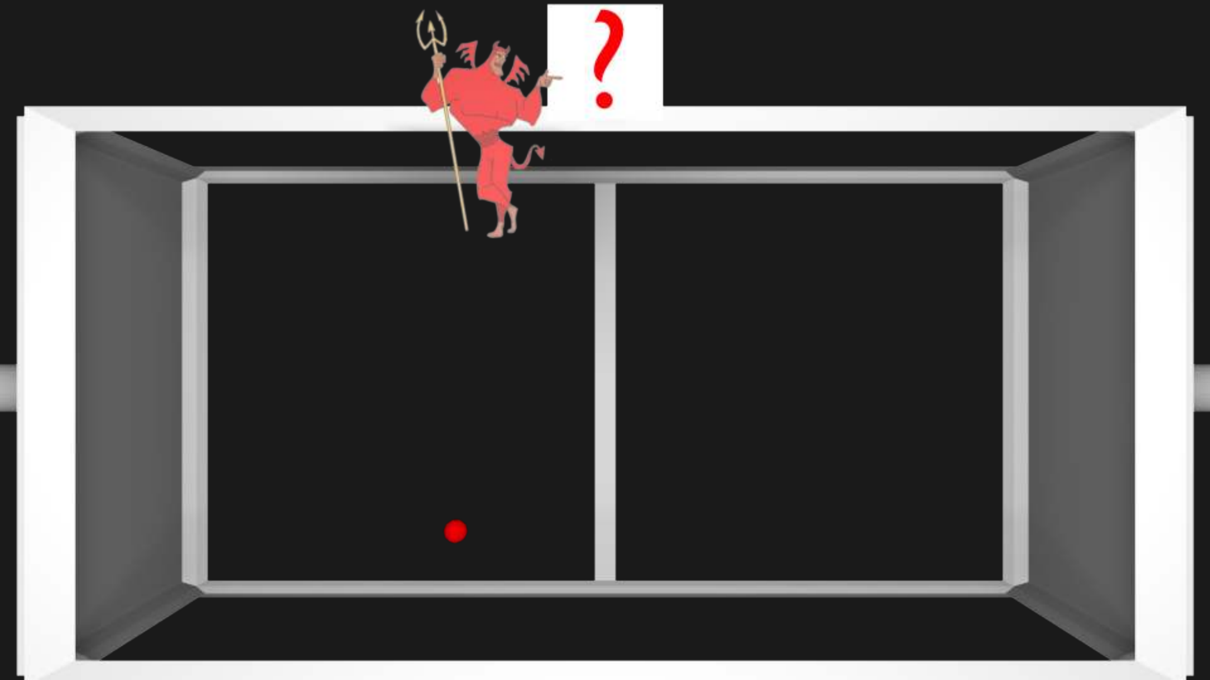


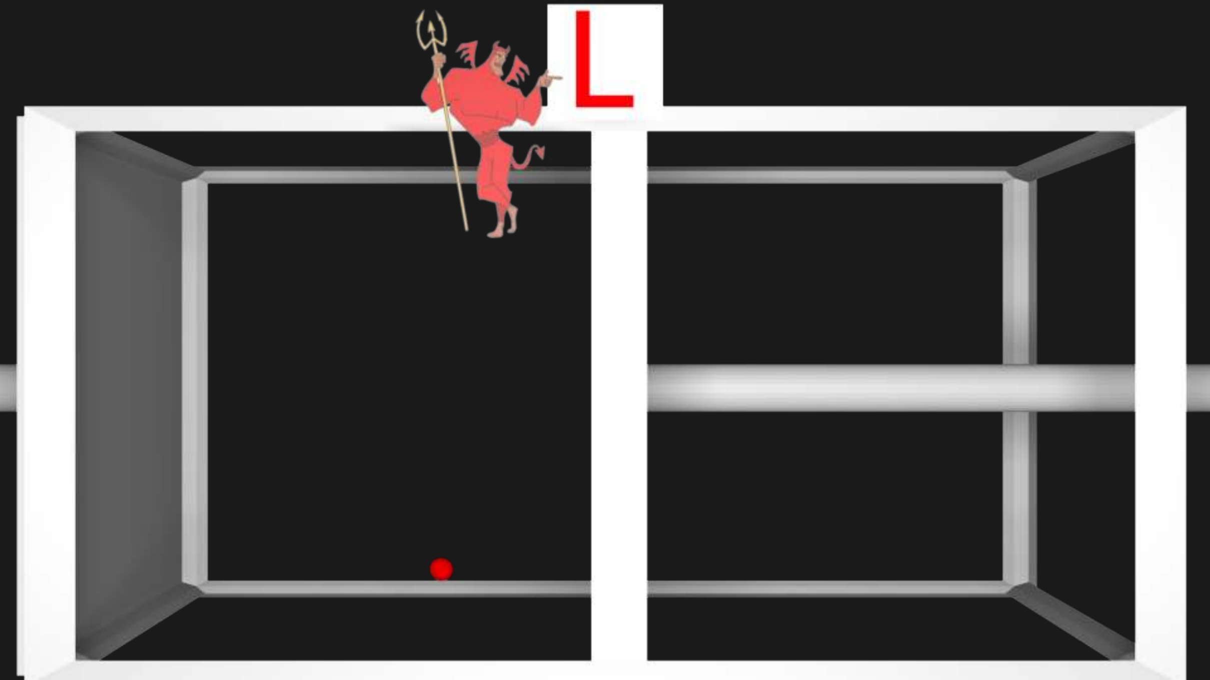
Leo Szilard (1898 - 1964)

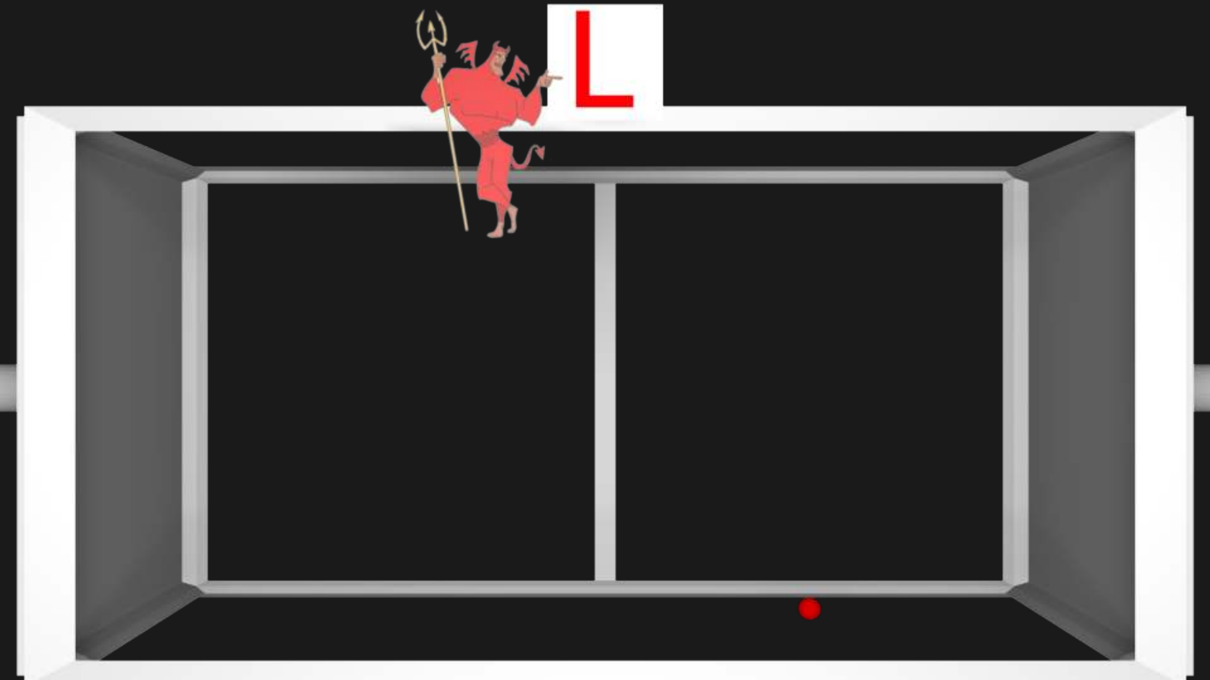


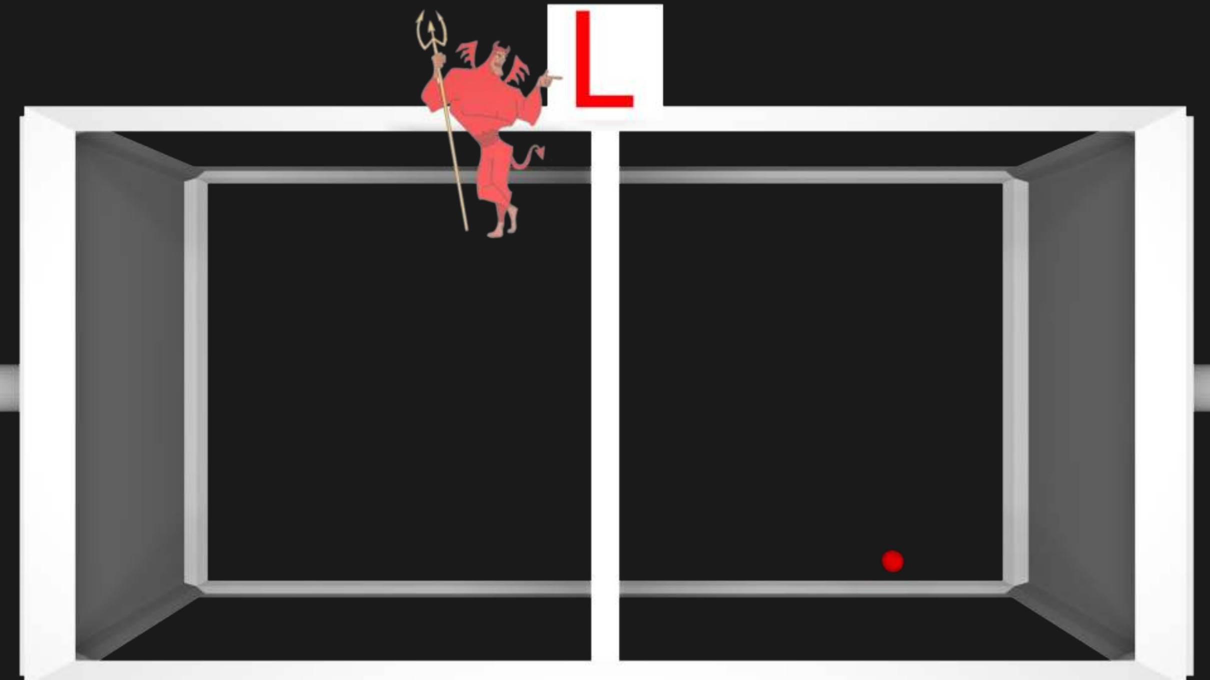
[1] L. Szilard, Zeitschrift für Physik **53**, 840 (1929)



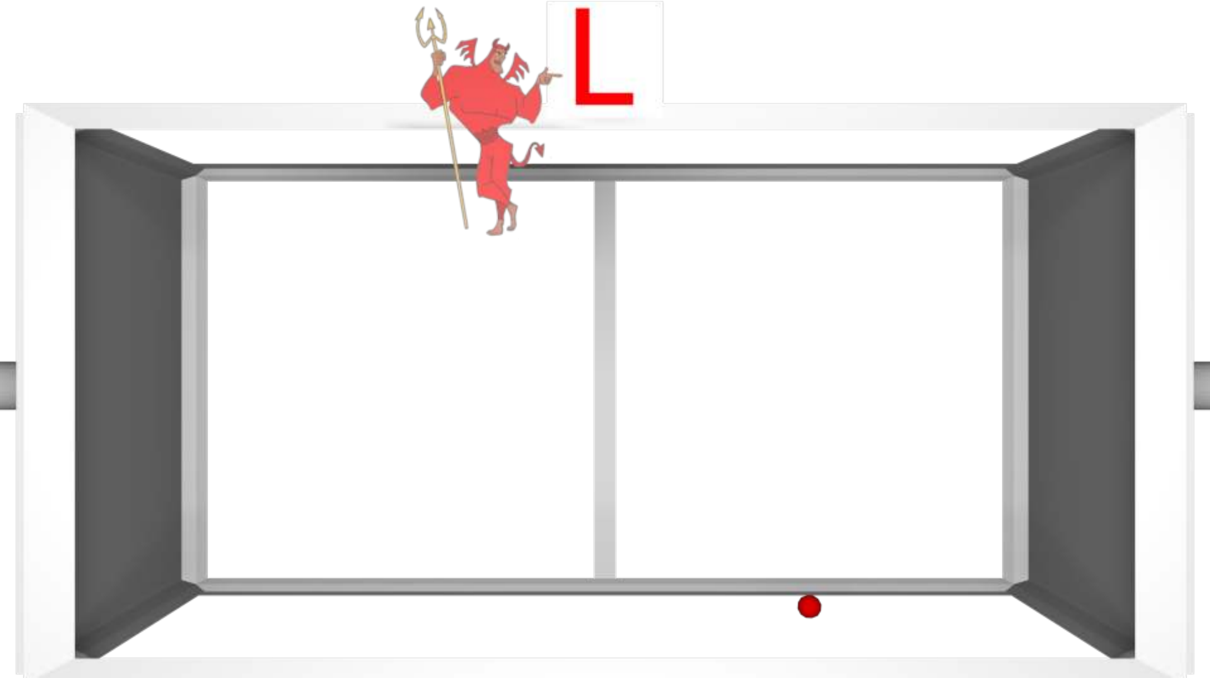


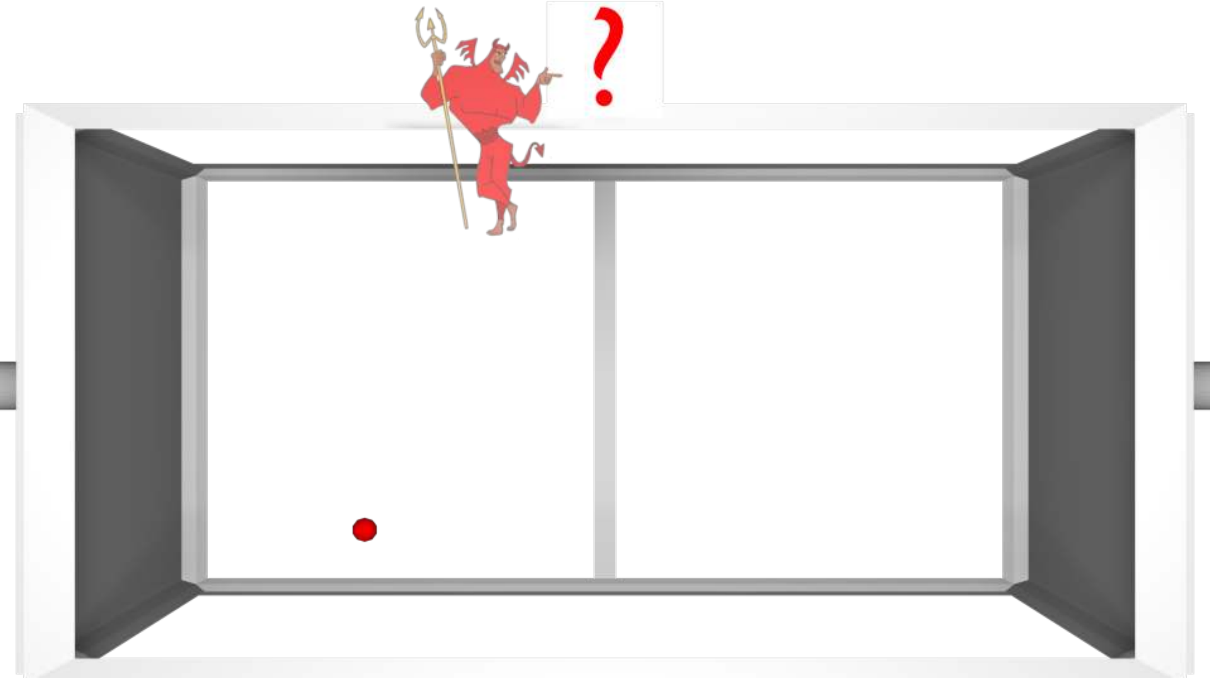

L


L


L

Hai chiuso il ciclo?

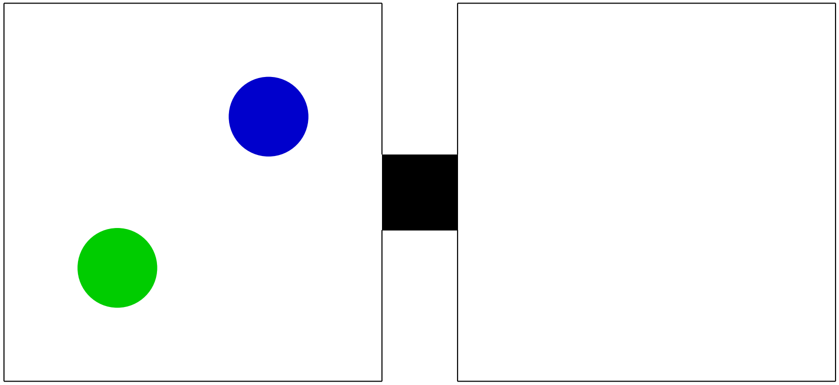

L

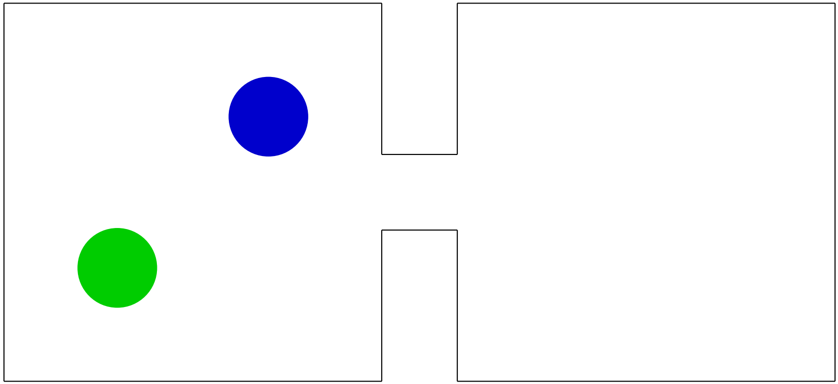


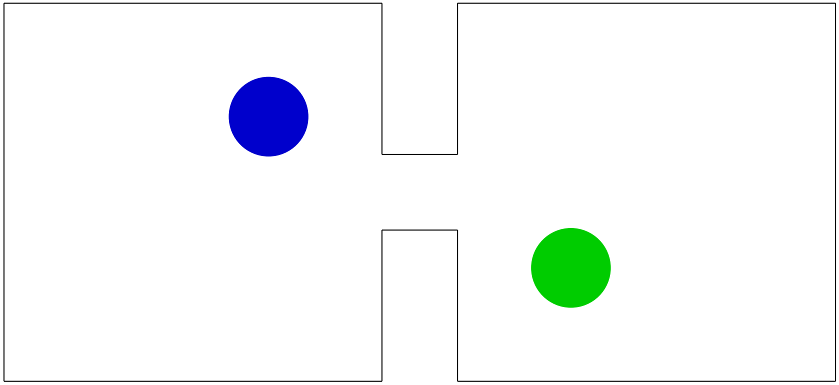
Rolf Landauer (1927 - 1999)

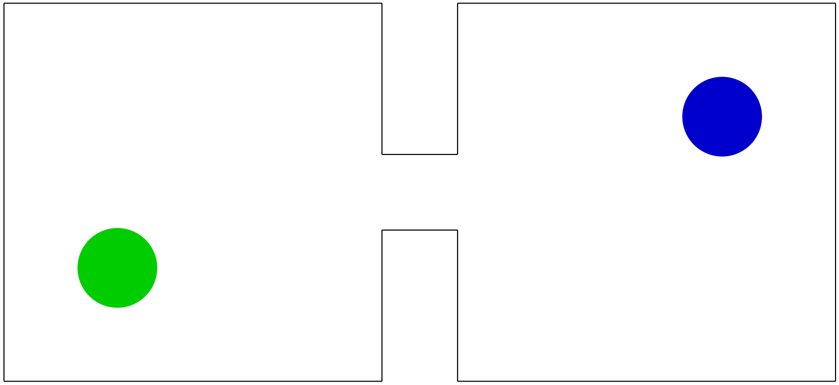
$$S = k \ln(W)$$

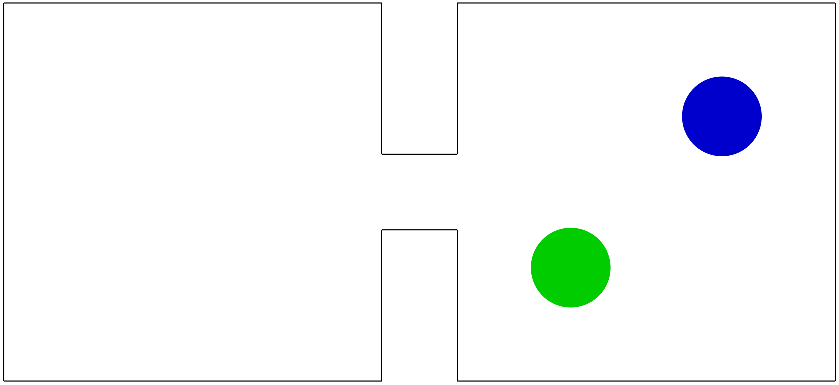
- $k = 1.38 \cdot 10^{-23}\ \mathrm{J/K}$
- $W = \frac{\text{stati interesse}}{\text{stati possibili}}$



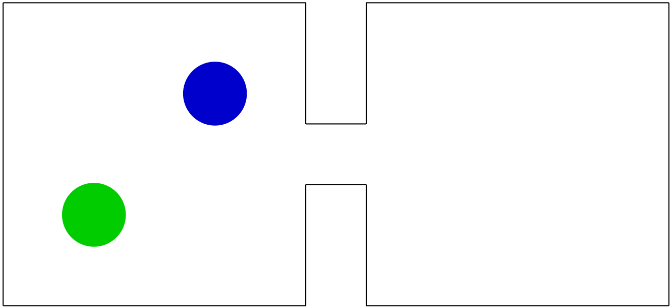




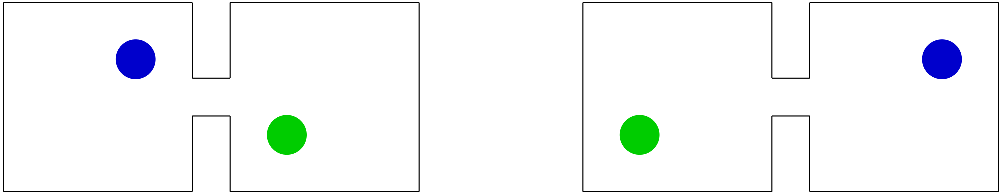




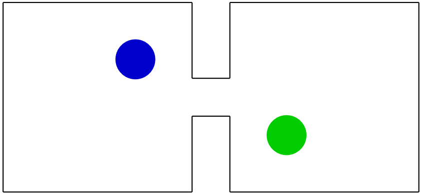
Domanda: Se lascio evolvere il sistema qual è la configurazione assumerà?

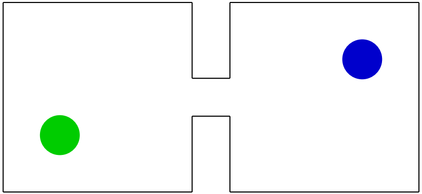


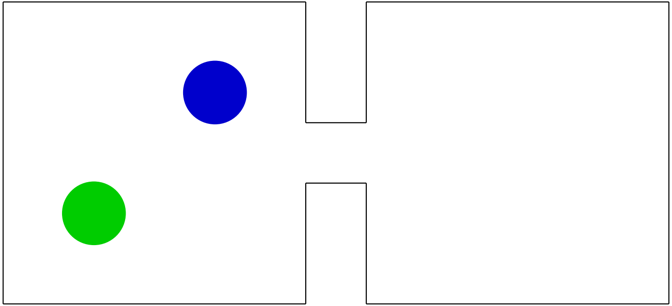
$$W = \frac{1}{4}$$



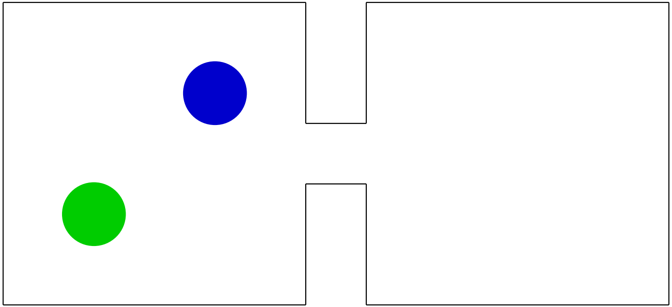
$$W = \frac{2}{4} = \frac{1}{2}$$



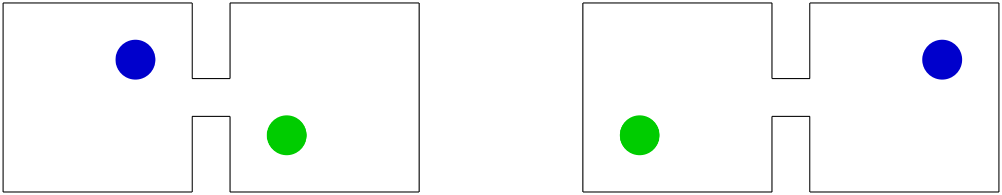




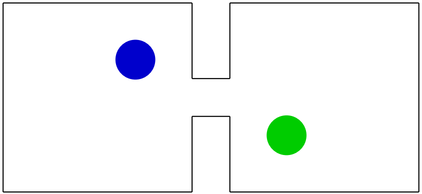
$$W = \frac{1}{4}$$

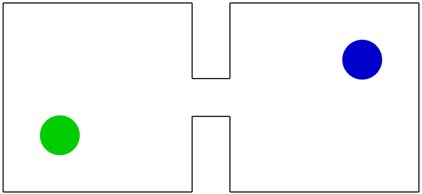


$$W = \frac{1}{4} \qquad S = k \ln\left(\frac{1}{4}\right)$$



$$W = \frac{1}{2}$$





$$W = \frac{1}{2}$$

$$S = k \ln(\frac{1}{2})$$

MAGGIORE ENTROPIA

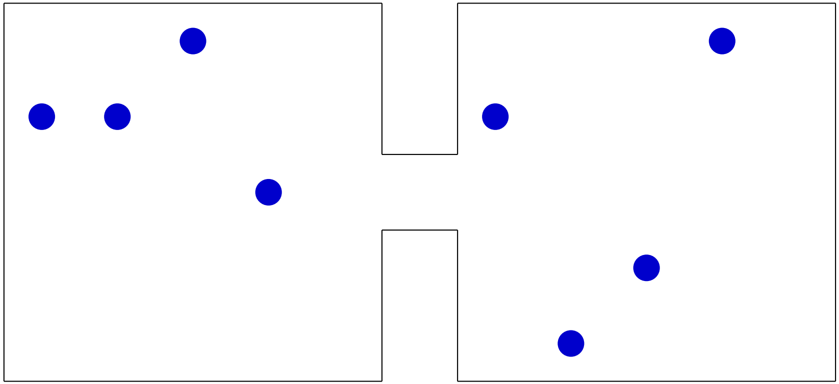
$$\Downarrow$$

MAGGIORE DISORDINE

STATI AD ENTROPIA MAGGIORE

$$\Downarrow$$

STATI PIÚ PROBABILI



Entropia

↓

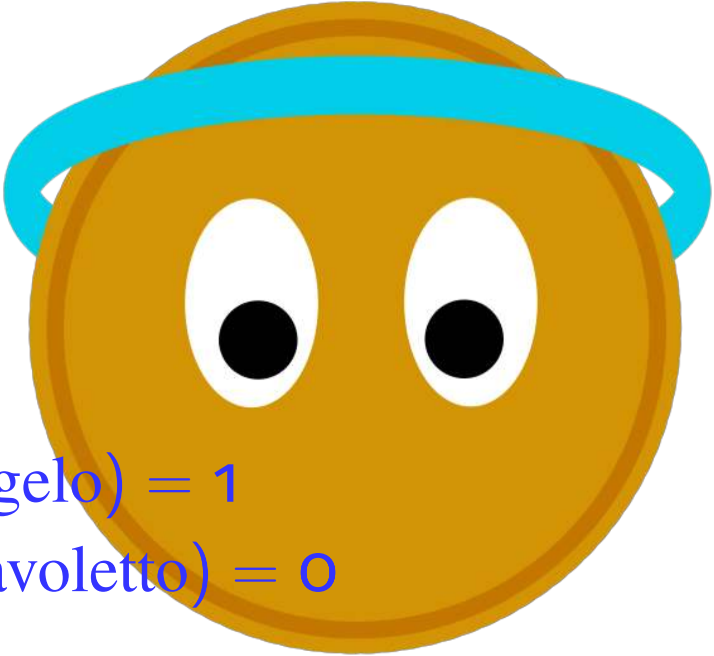
Quantità di informazione che possiamo raccogliere su una variabile random

Entropia di Shannon[1]

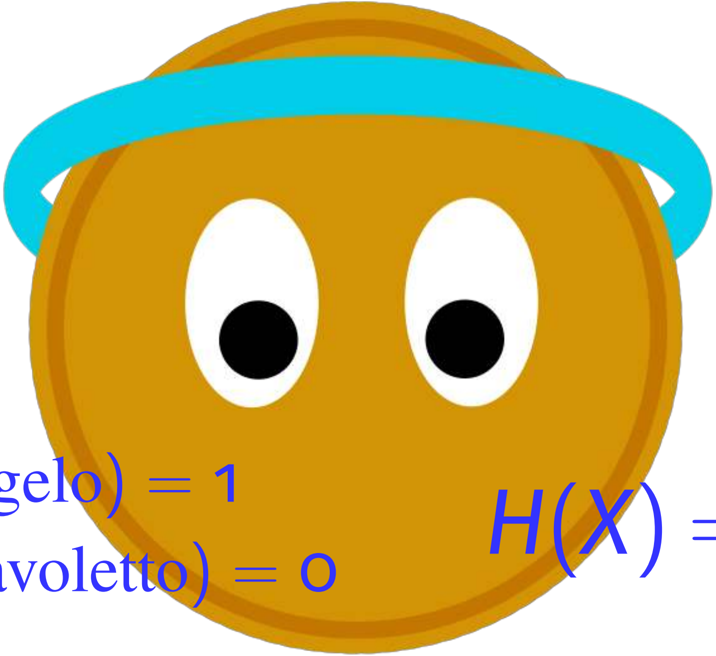
[1] C. E. Shannon, The Bell System Technical Journal **27**, Conference Name: The Bell System Technical Journal, 379 (1948).

$$H(X) = -\sum_i p_i \log_2(p_i)$$

$$0 \log_2(0) = 0$$

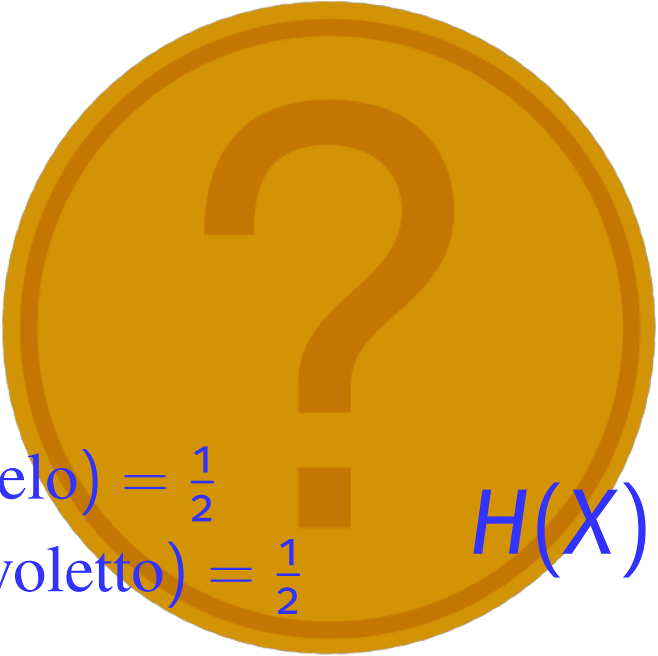
$$\begin{cases} p(\text{angelo}) = 1 \\ p(\text{diavoletto}) = 0 \end{cases}$$



$$\begin{cases} p(\text{angelo}) = 1 \\ p(\text{diavoletto}) = 0 \end{cases}$$

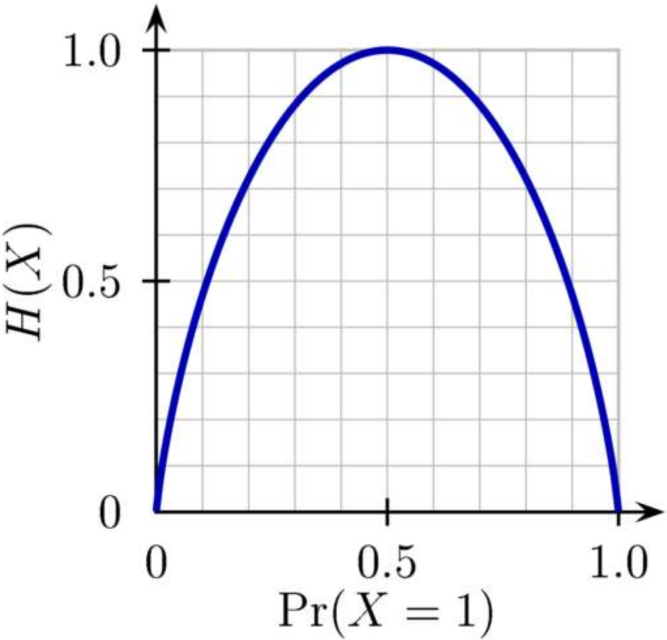
$$H(X) = 0$$

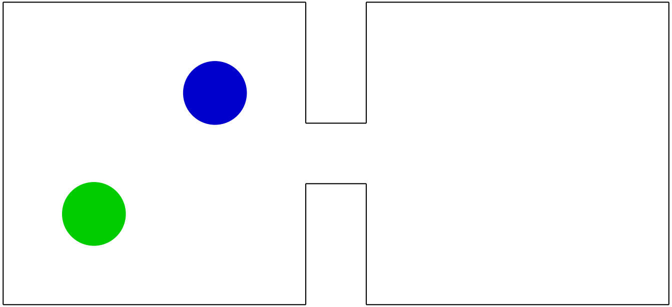
$$\begin{cases} p(\text{angelo}) = \frac{1}{2} \\ p(\text{diavoletto}) = \frac{1}{2} \end{cases}$$



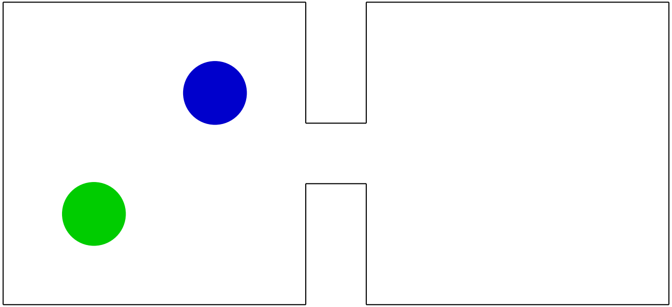
$$\begin{cases} p(\text{angelo}) = \frac{1}{2} \\ p(\text{diavoletto}) = \frac{1}{2} \end{cases}$$

$$H(X) = 1$$

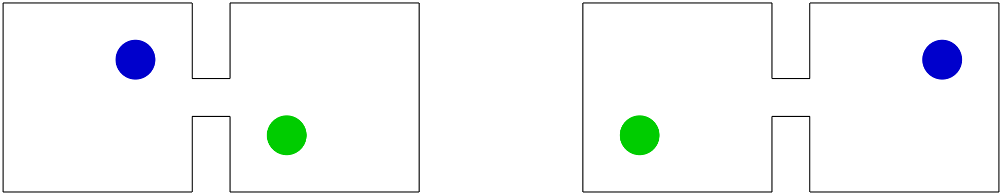

1.0
0.5
0
H(X)
0
0.5
1.0
Pr(X = 1)



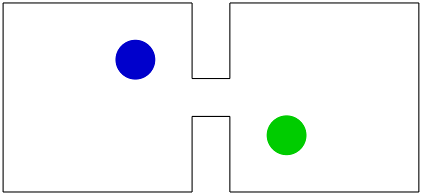
$$p = 1$$



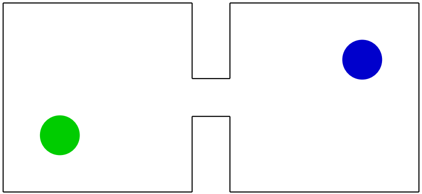
$p = 1$ $H = 0$



$$p = \frac{1}{2}$$

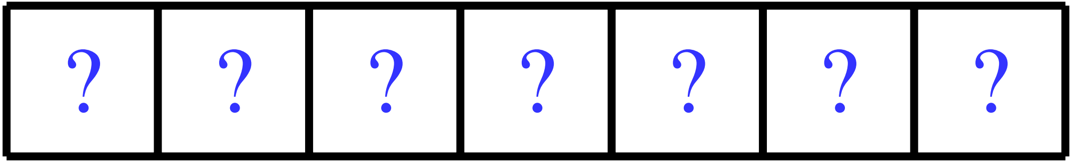


$$p = \frac{1}{2}$$



$$H = 1$$

SISTEMI TENDONO AD EVOLVERE IN STATI RIGUARDO A CUI ABBIAMO MENO INFORMAZIONE



L	?	?	?	?	?	?

L	R	?	?	?	?	?

L	R	R	?	?	?	?

L	R	R	L	?	?	?

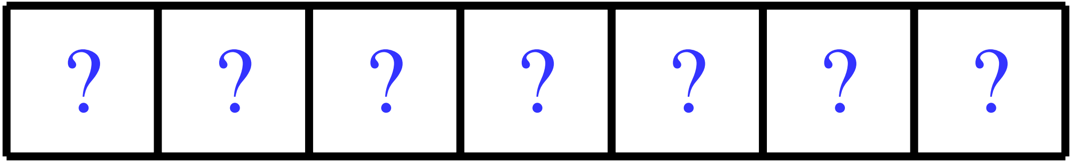
L	R	R	L	L	?	?

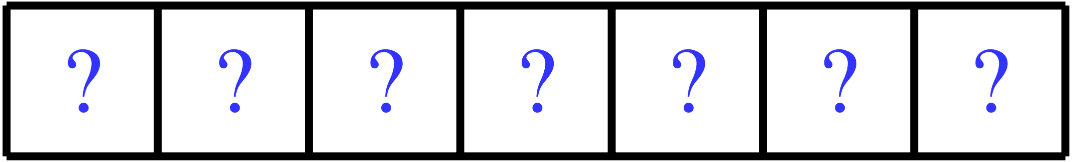
L	R	R	L	L	R	?

L	R	R	L	L	R	L

L	R	R	L	L	R	L

$$H(X) > 0$$



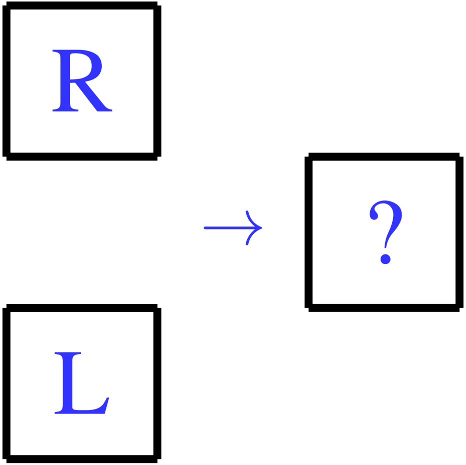


$$H(X) = 0$$

Cancellazione

Cancellazione

Cancellazione



$$\Delta H(X) < 0$$

Principio di Landauer: Per modificare lo stato logico di un computer, è necessario modificare lo stato fisico su cui tale stato è codificato[1][2]

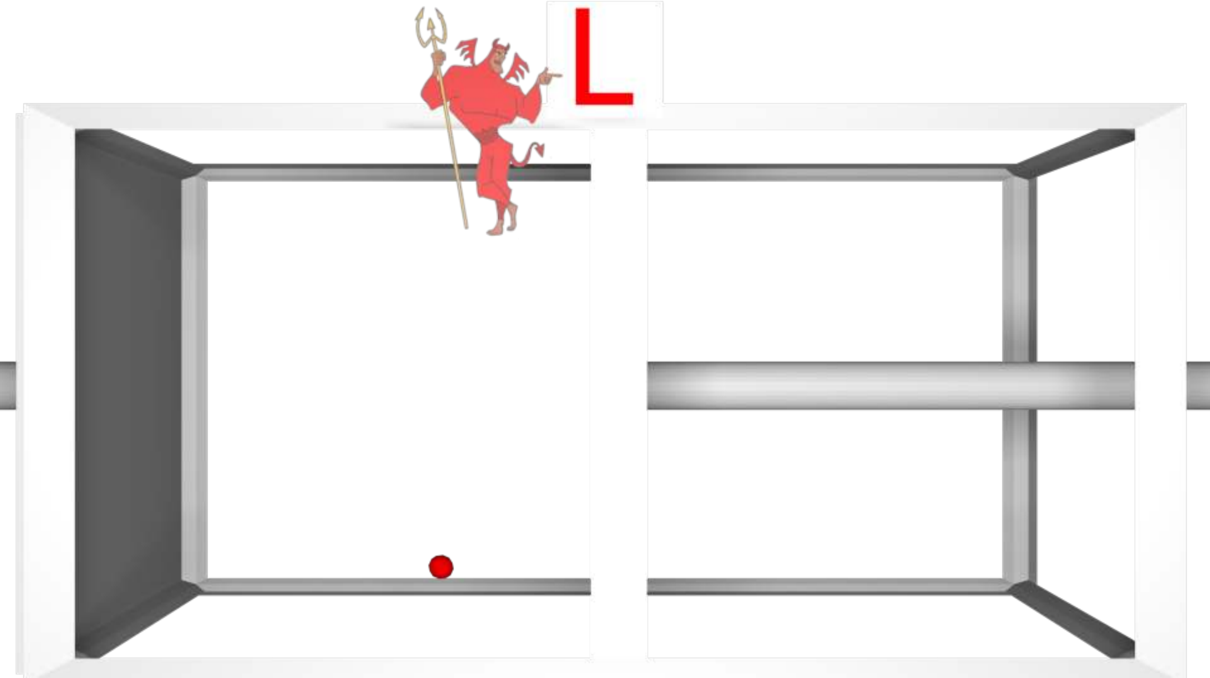
---

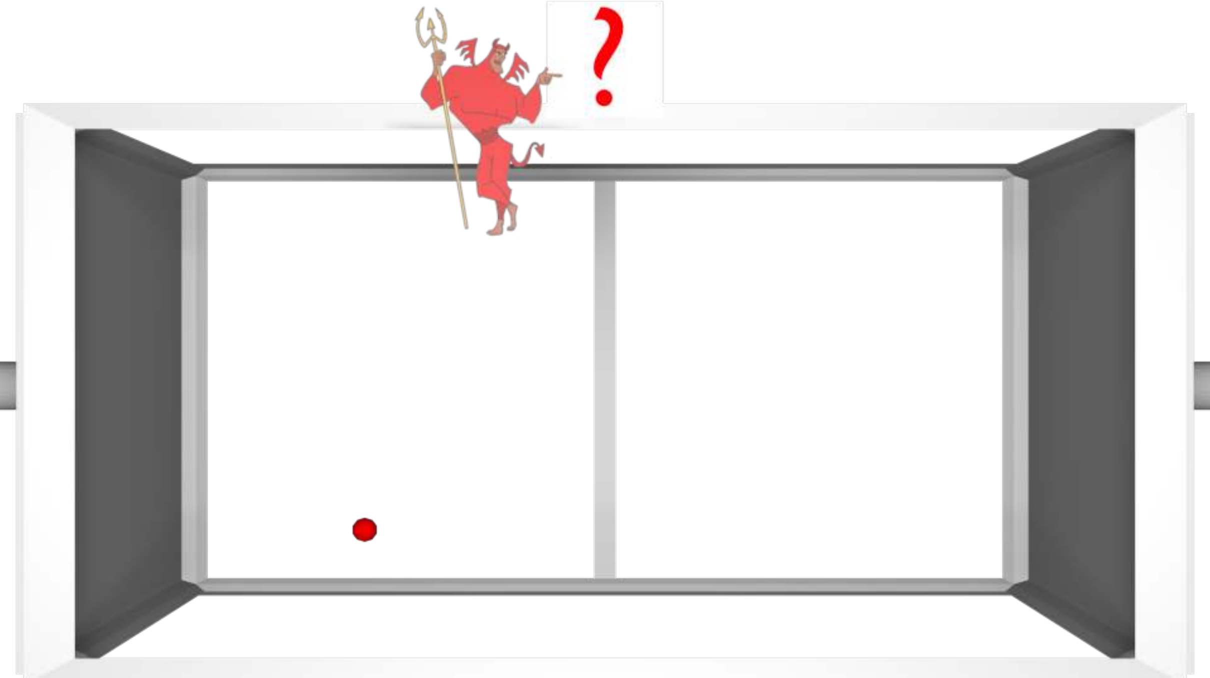
[1] R. Landauer, IBM Journal of Research and Development **5**, 183 (1961).

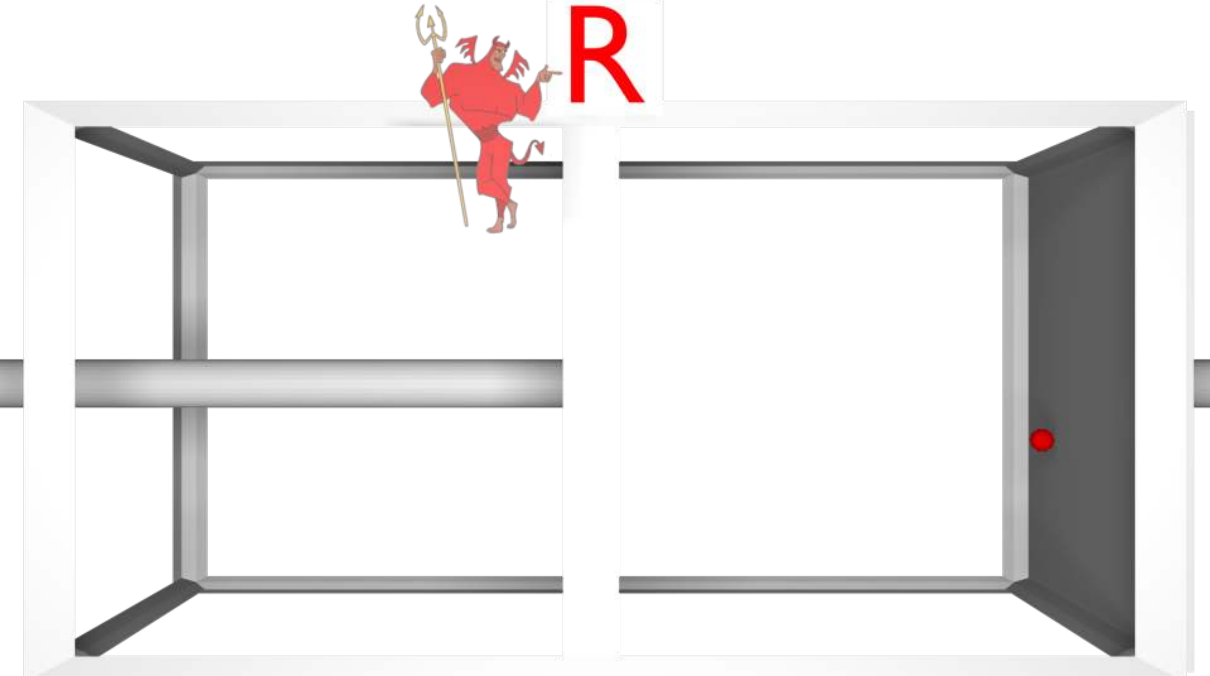
[2] C. H. Bennett, Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics, Quantum Information and Computation **34**, 501 (2003).

Per ridurre l’entropia di un sistema bisogna compiere lavoro

Ecco che ti ho chiuso il ciclo!


L




R

Fisica

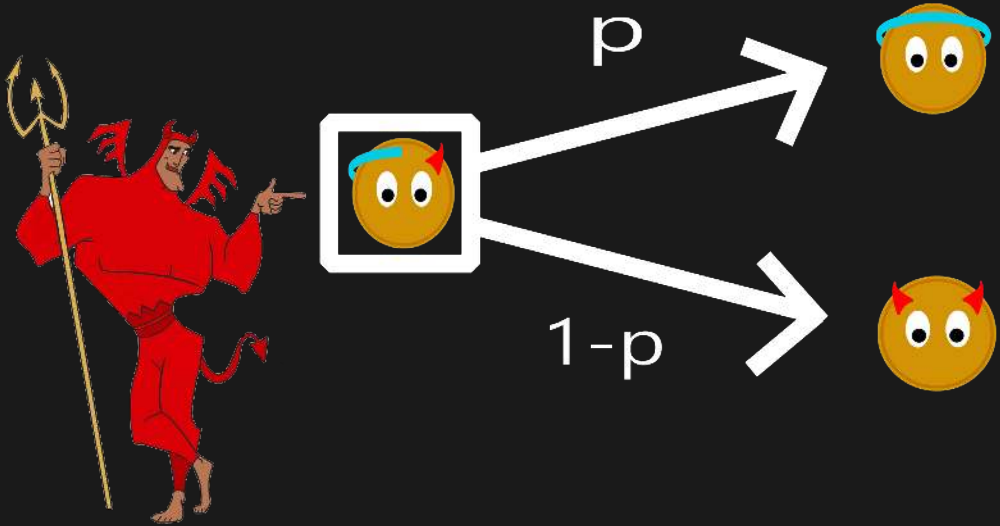
$\Updownarrow$

Informazione

E se cambio la fisica?

Stati determinati

 $= p$  $+ (1 - p)$ 

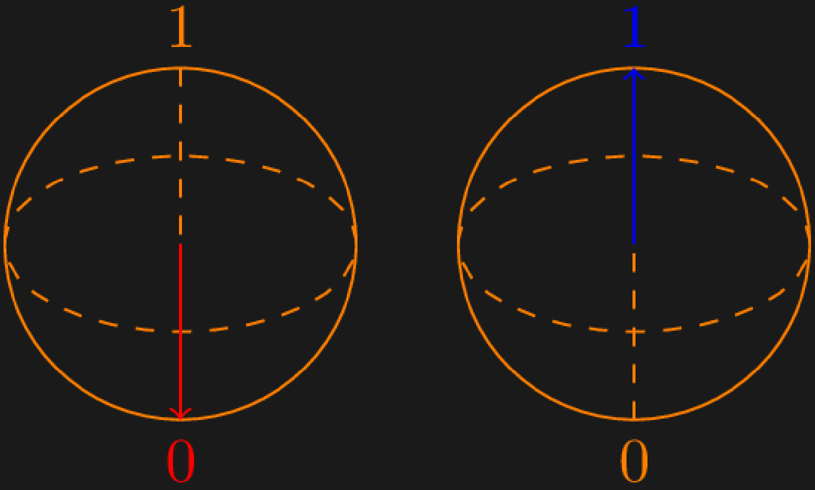


p
1-p

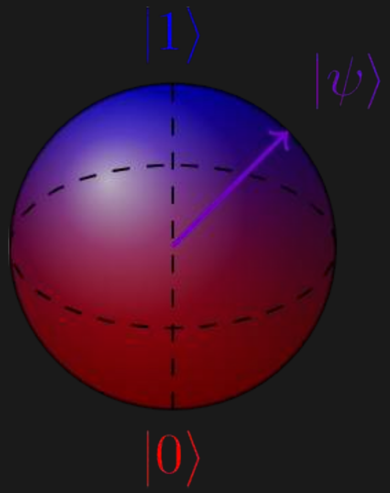
$$p, 1 - p \in \mathbb{R}$$

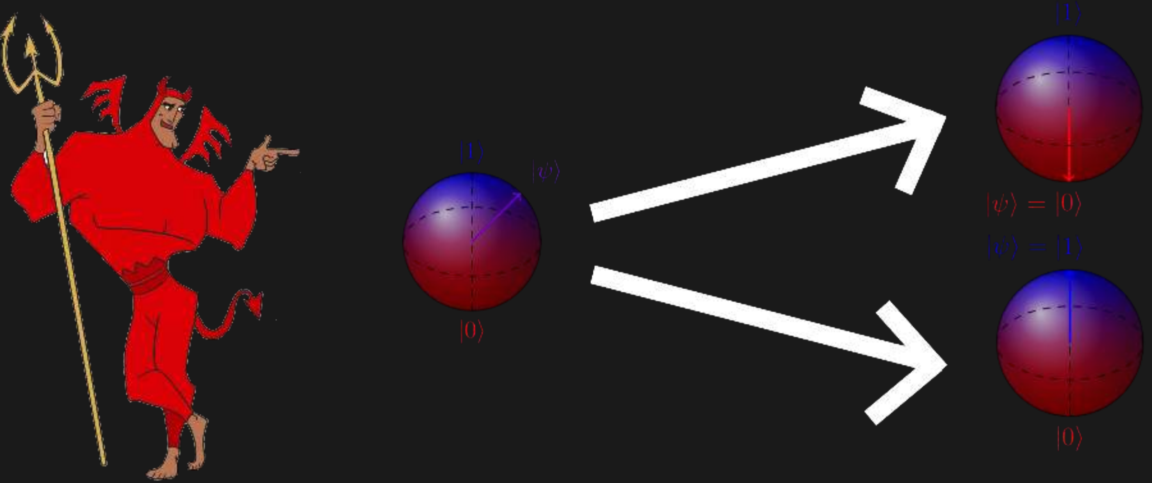
$$p, 1 - p \in \mathbb{R}$$

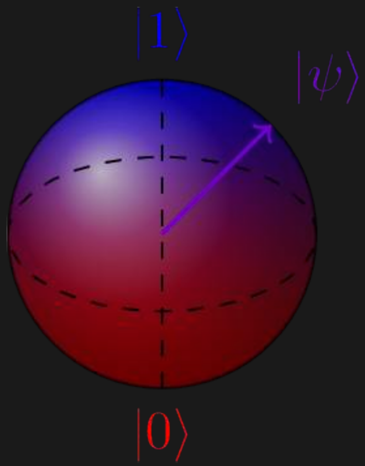
$$\downarrow$$

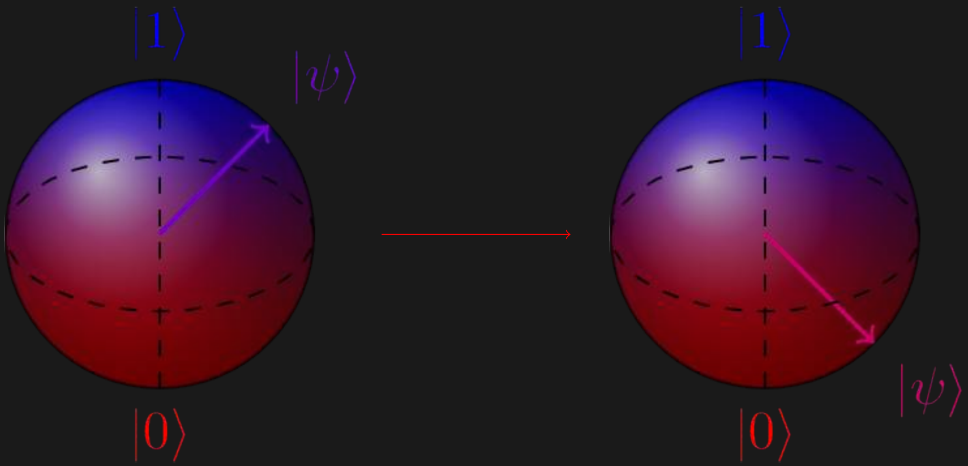
Infiniti bit per codificare numero reale!


1
0
1
0

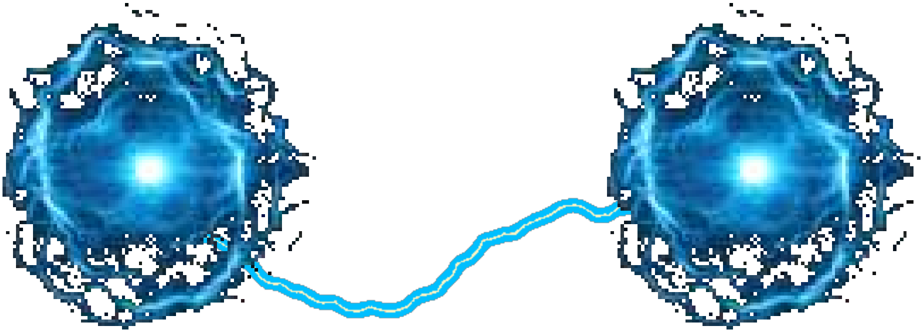

$|1\rangle$
$|\psi\rangle$
$|0\rangle$


$|1\rangle$
$|\psi\rangle$
$|0\rangle$
$|1\rangle$
$|\psi\rangle = |0\rangle$
$|\psi\rangle = |1\rangle$
$|0\rangle$

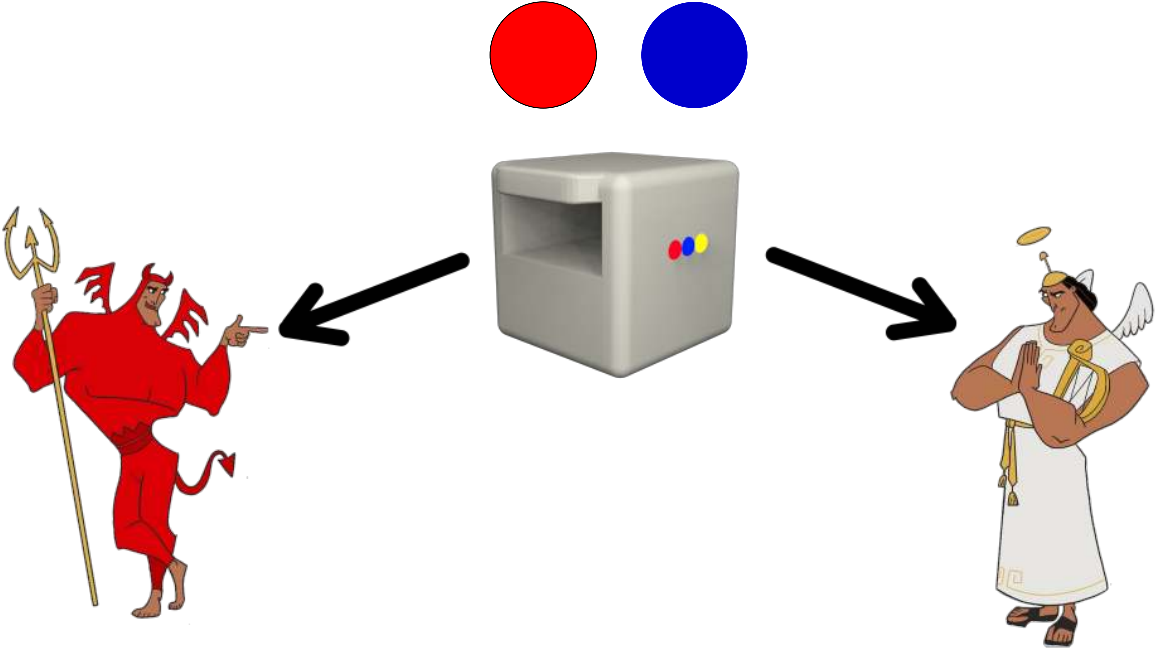

$|1\rangle$
$|\psi\rangle$
$|0\rangle$



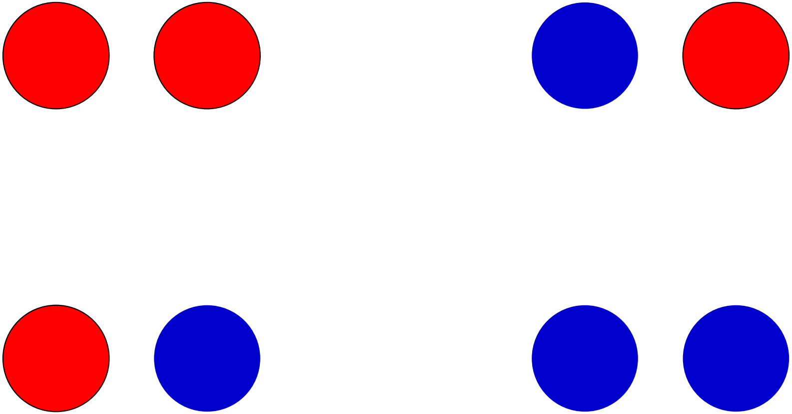
$|1\rangle$
$|\psi\rangle$
$|0\rangle$
$|1\rangle$
$|\psi\rangle$
$|0\rangle$



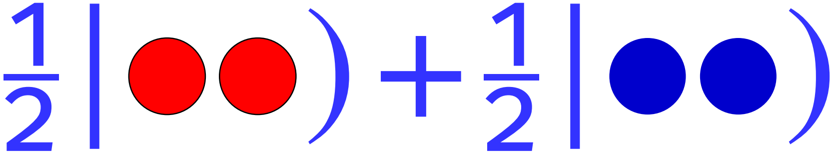
Correlazione



$$|\textcolor{red}{\bullet}\rangle\left(\frac{1}{2}|\textcolor{red}{\bullet}\rangle+\frac{1}{2}|\textcolor{blue}{\bullet}\rangle\right)$$



$$\left(\frac{1}{2}\left|{\color{red}\bullet}\right) + \frac{1}{2}\left|{\color{blue}\bullet}\right)\right)\left(\frac{1}{2}\left|{\color{red}\bullet}\right) + \frac{1}{2}\left|{\color{blue}\bullet}\right)\right)$$



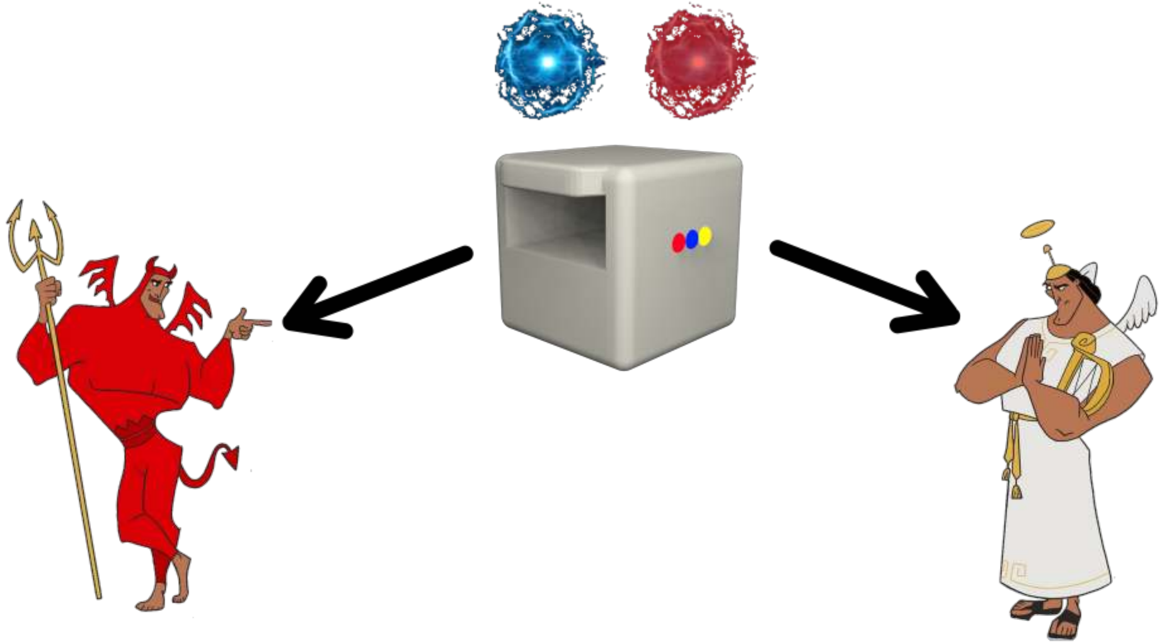
$$\frac{1}{2}\left|{\color{red}\bullet}{\color{blue}\bullet}\right) + \frac{1}{2}\left|{\color{blue}\bullet}{\color{red}\bullet}\right)$$

Entanglement

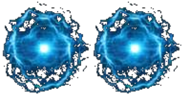
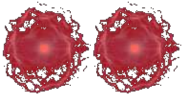
Entanglement

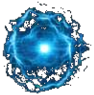
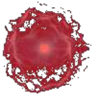
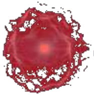
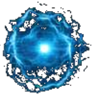
$\Downarrow$

Correlazioni quantistiche



$\left(\frac{1}{2}\Big|$  $\Big\rangle + \frac{1}{2}\Big|$  $\Big\rangle\right)\left(\frac{1}{2}\Big|$  $\Big\rangle + \frac{1}{2}\Big|$  $\Big\rangle\right)$

$\frac{1}{2}|$  $) + \frac{1}{2}|$  $)$

$\frac{1}{2}|$   $\rangle + \frac{1}{2}|$   $\rangle$

Quantistiche > Classiche

Esperimenti di Bell[1][2]

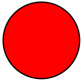
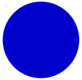
[1] J. S. Bell, Physics Physique Fizika **1**, Publisher: American Physical Society, 195 (1964).

[2] S. J. Freedman and J. F. Clauser, Physical Review Letters **28**, Publisher: American Physical Society, 938 (1972).

$$\frac{1}{2}\left|{\color{red}\bullet\bullet}\right) + \frac{1}{2}\left|{\color{blue}\bullet\bullet}\right)$$

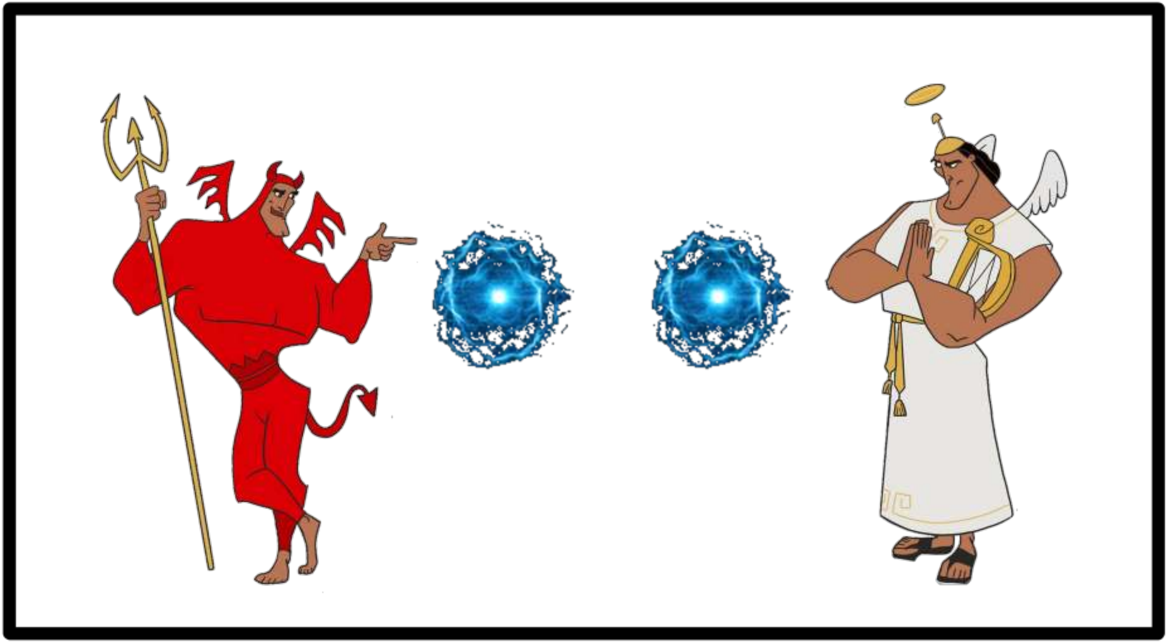
$$\frac{1}{2}|{\color{red}\bullet\bullet}) + \frac{1}{2}|{\color{blue}\bullet\bullet})$$

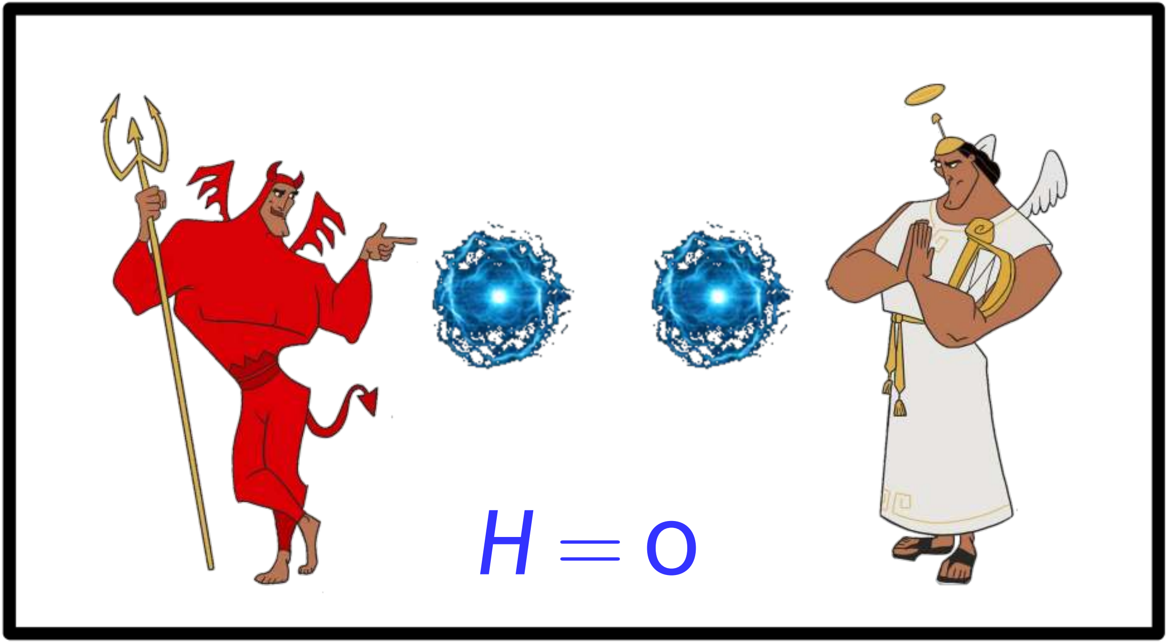
$$H > 0$$

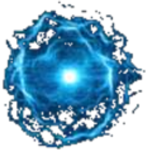
$\frac{1}{2}|$  $) + \frac{1}{2}|$  $)$

$$\frac{1}{2}\left|\textcolor{red}{\bullet}\right) + \frac{1}{2}\left|\textcolor{blue}{\bullet}\right)$$

$$H > 0$$

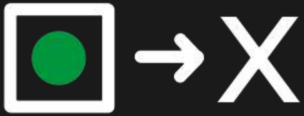



H = O



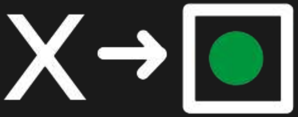
$H > O$

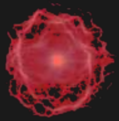
L’insieme è più della somma delle sue parti


X

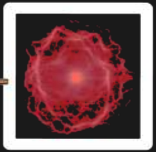

X

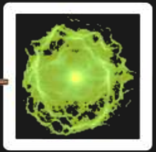
X → □


X



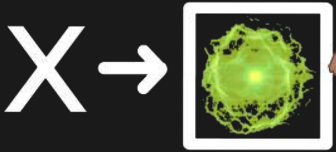


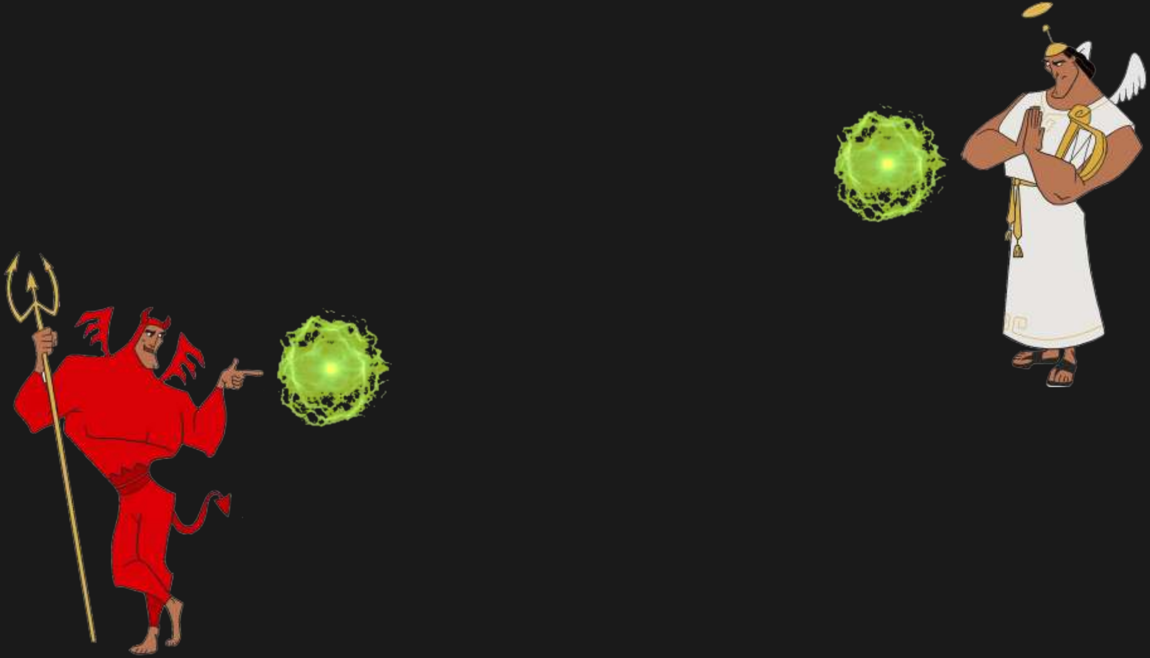



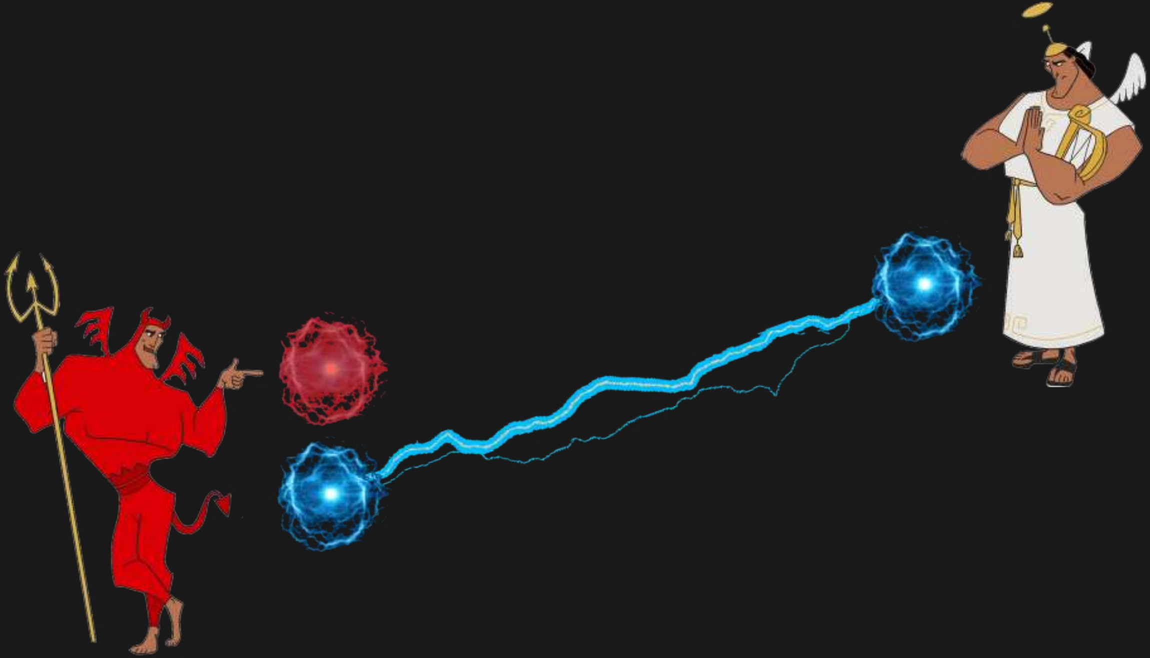
→ X

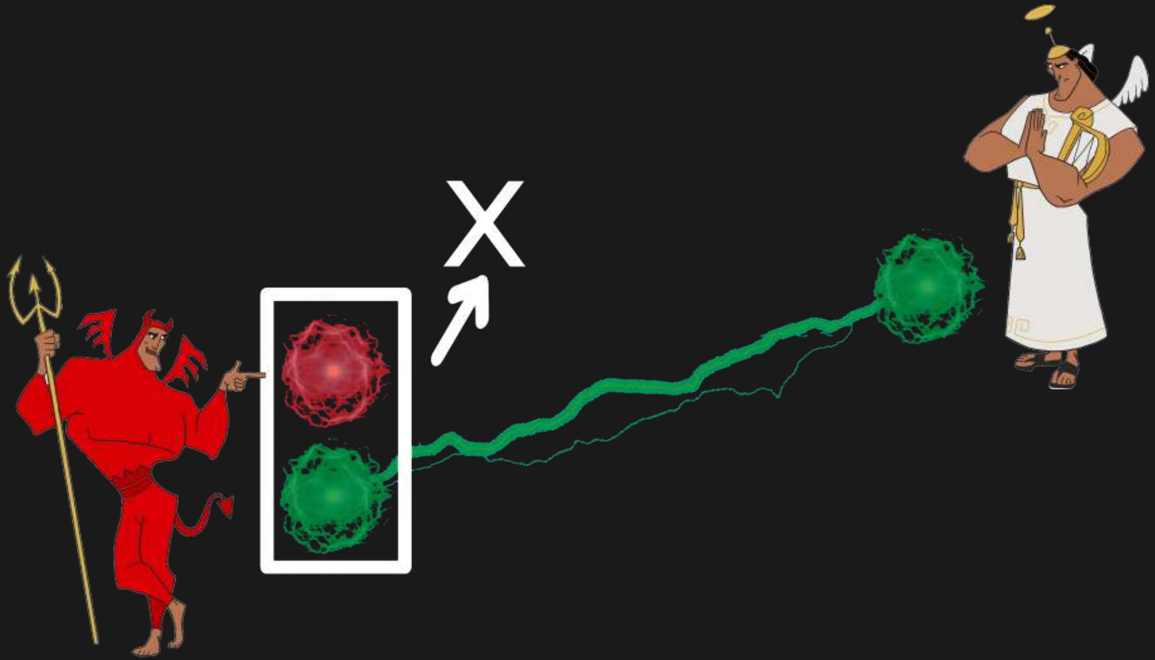

X

X → □


X

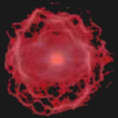





X

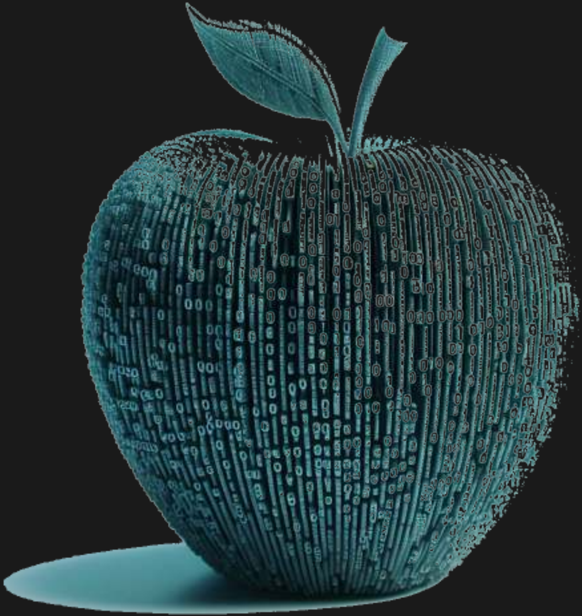

X


X



Experimental Realization of Teleporting an Unknown Pure Quantum State via Dual Classical and Einstein-Podolsky-Rosen Channels

D. Boschi, S. Branca, F. De Martini, L. Hardy, and S. Popescu
Phys. Rev. Lett. **80**, 1121 – Published 9 February 1998



FRAMEWORK DELLE TEORIE OPERAZIONALI[1]

[1] G. M. D'Ariano, G. Chiribella, and P. Perinotti, ***Quantum Theory from First Principles: An Informational Approach***, 1st ed. (Cambridge University Press, Nov. 2016).

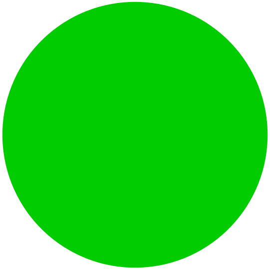
Approccio informazionale

e minimale

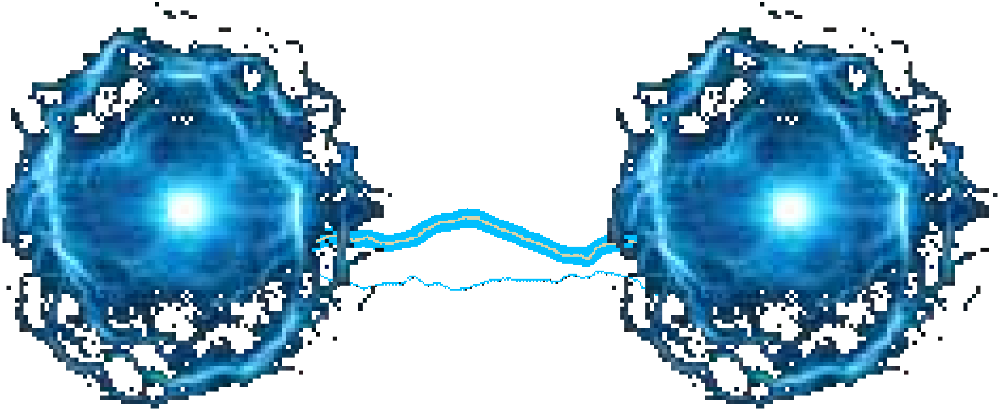
Sistemi fisici

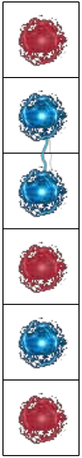
Sistemi fisici

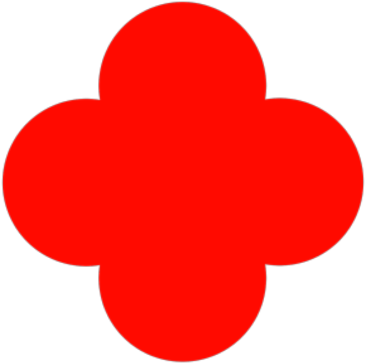
Celle di memoria

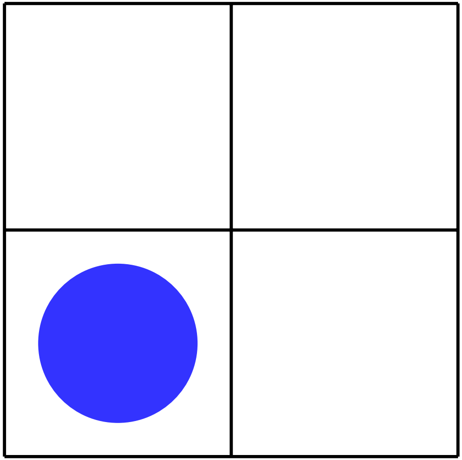


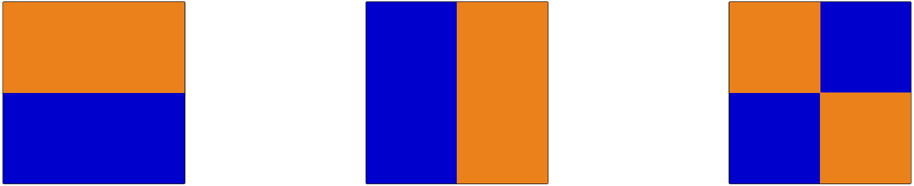
0
1
1
0
1
0

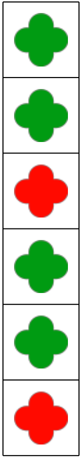










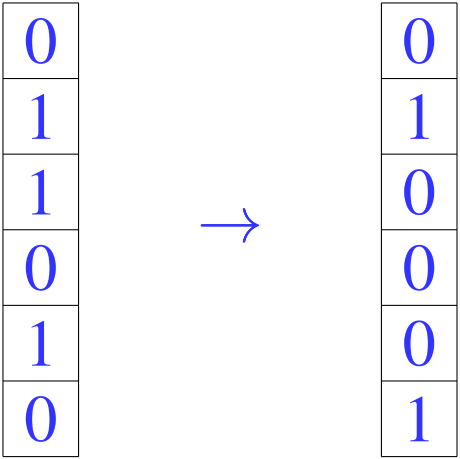


Evolvere i sistemi

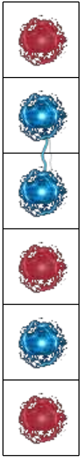
Evolvere i sistemi

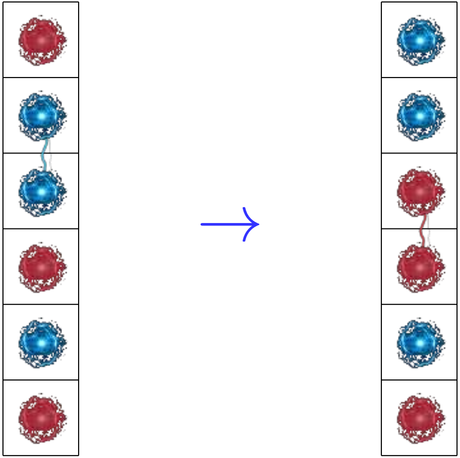
Algoritmi

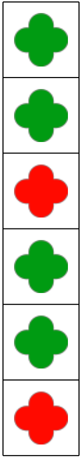
0
1
1
0
1
0

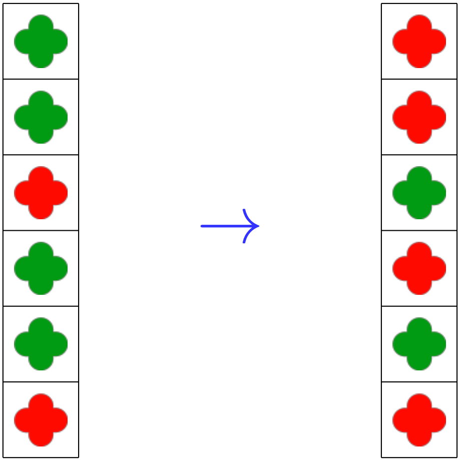


0
1
1
0
1
0
0
1
0
0
0
1

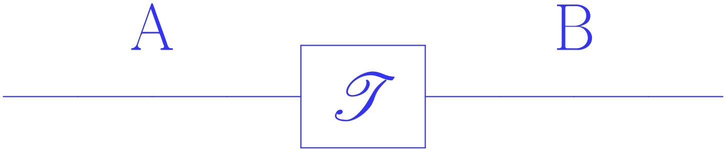


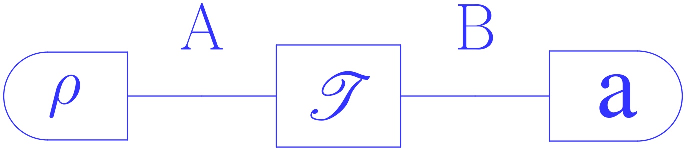




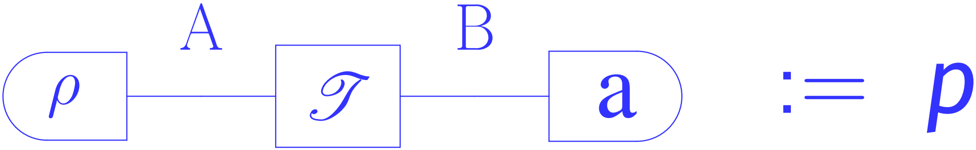


A


A
B


A
B
ρ
$\mathscr{T}$
$\mathbf{a}$

Probabilità


ρ
A
𝒯
B
a
:= p

Published: March 1994

Quantum nonlocality as an axiom

Sandu Popescu & Daniel Rohrlich

Foundations of Physics **24**, 379–385 (1994)

Evidence for the epistemic view of quantum states: A toy theory

Robert W. Spekkens

Phys. Rev. A **75**, 032110 – Published 19 March 2007

International Journal of Modern Physics A | Vol. 29, No. 17, 1430025 (2014) | Reviews

The Feynman problem and fermionic entanglement: Fermionic theory versus qubit theory

Giacomo Mauro D'Ariano, Franco Manessi, Paolo Perinotti, and Alessandro Tosini

https://doi.org/10.1142/S0217751X14300257

Classicality without local discriminability: Decoupling entanglement and complementarity

Giacomo Mauro D'Ariano, Marco Erba, and Paolo Perinotti

Phys. Rev. A **102**, 052216 – Published 11 November 2020

Capire meglio il mondo che ci circonda

Cosa vuole dire essere quantistico?

Com’è fatta una teoria dell’informazione compatibile con gli esperimenti?

INFORMATICA CHE VAI

INFORMATICA CHE VAI, FISICA CHE TROVI