Summer School
Quantum Technologies

Consiglio Nazionale delle Ricerche
UNIVERSITÀ DI PAVIA
QST
QUANTUM FLAGSHIP

In Viaggio verso il Quantum Machine Learning

Da Turing al Computer Quantistico

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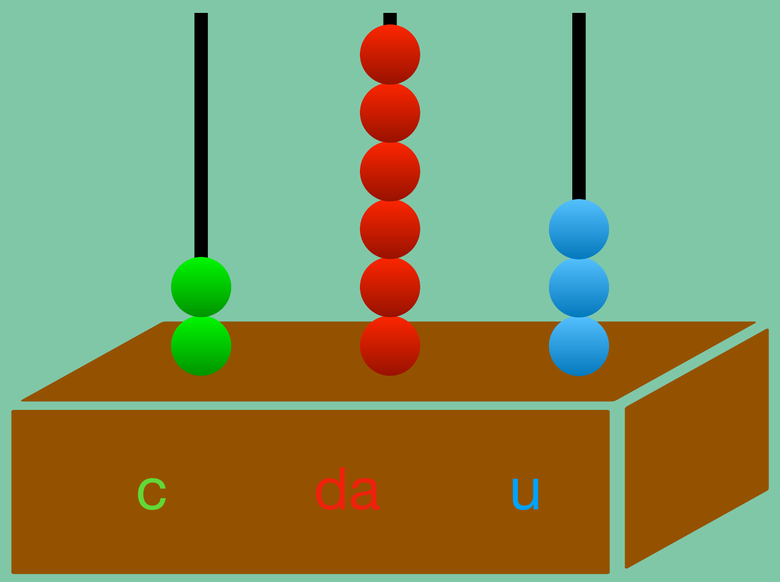
05/09/2023

A cosa serve
Quantum Machine Learning?

CODICE

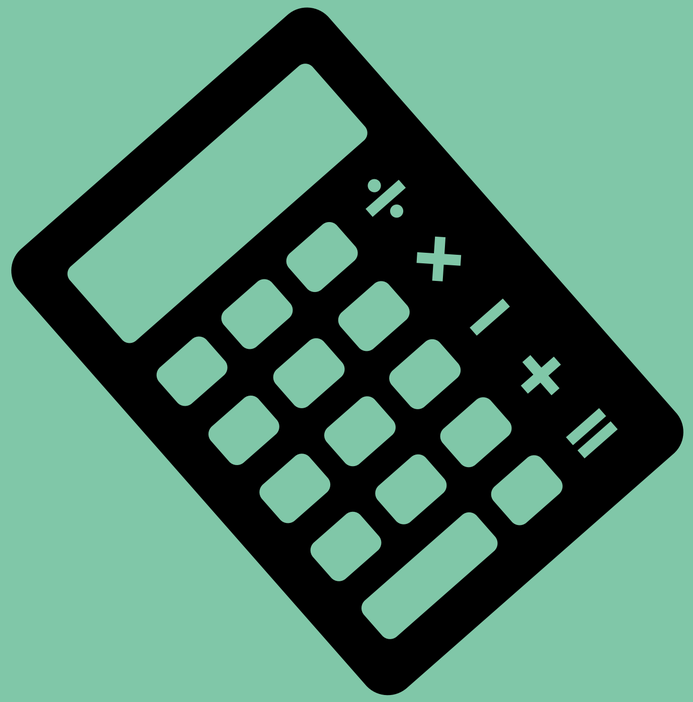
Conti facili e conti difficili

Come impariamo a fare i conti?



Conti facili e conti difficili

Come impariamo a fare i conti?



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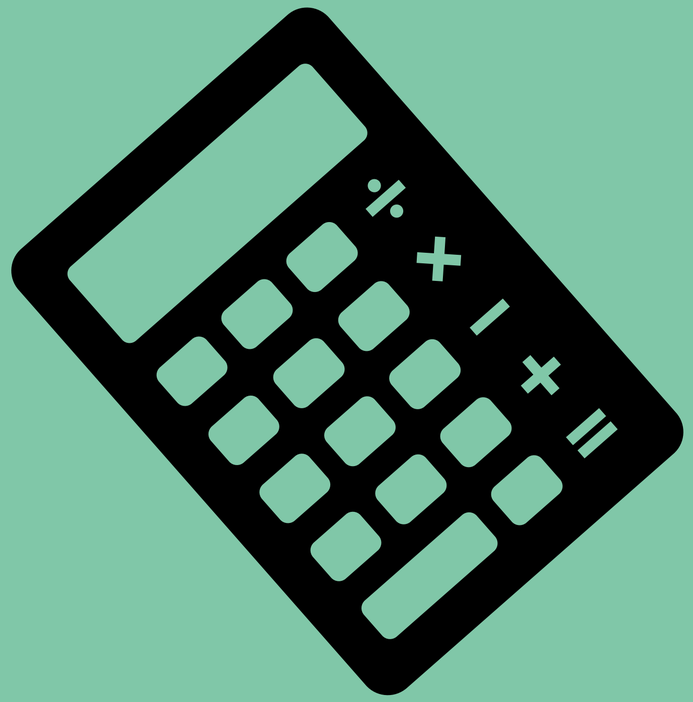
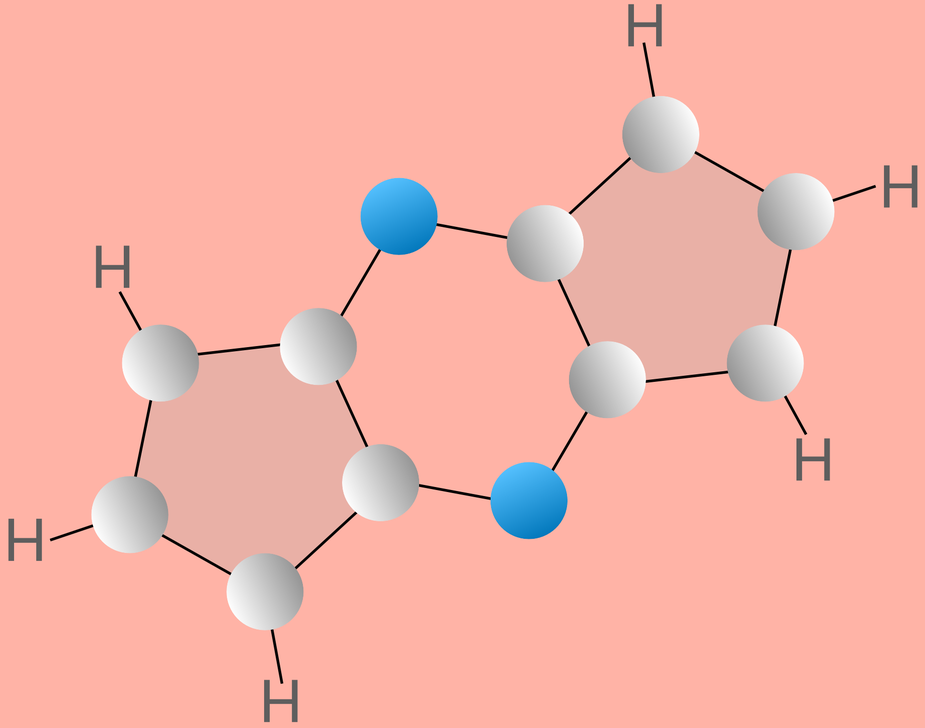
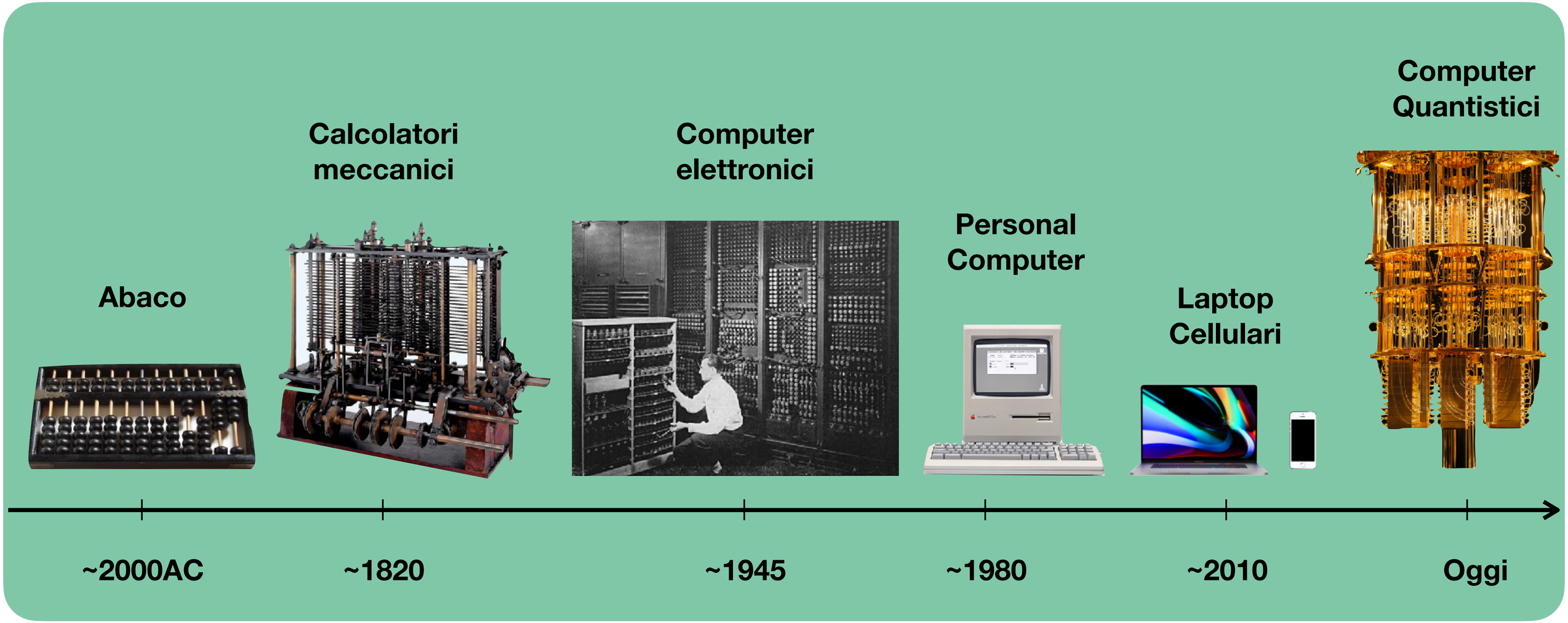


Come si simula una molecola?



La computazione nel tempo



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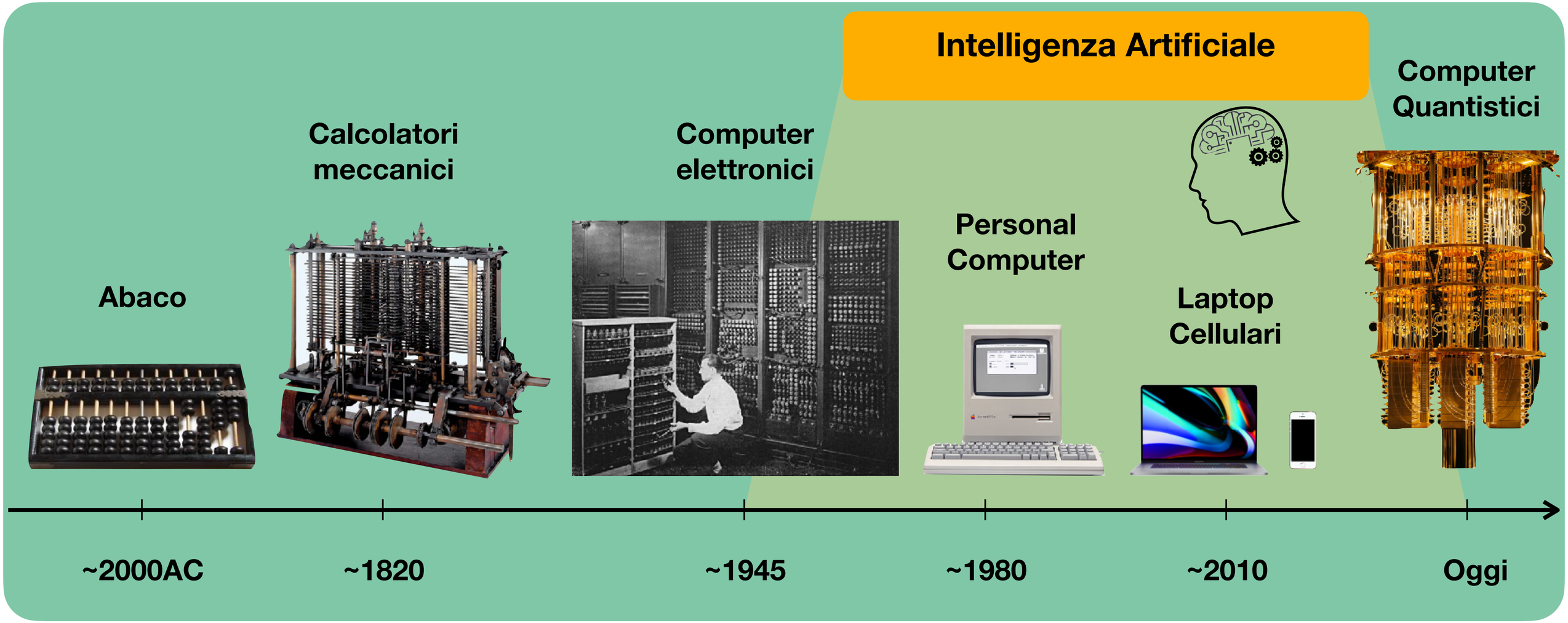
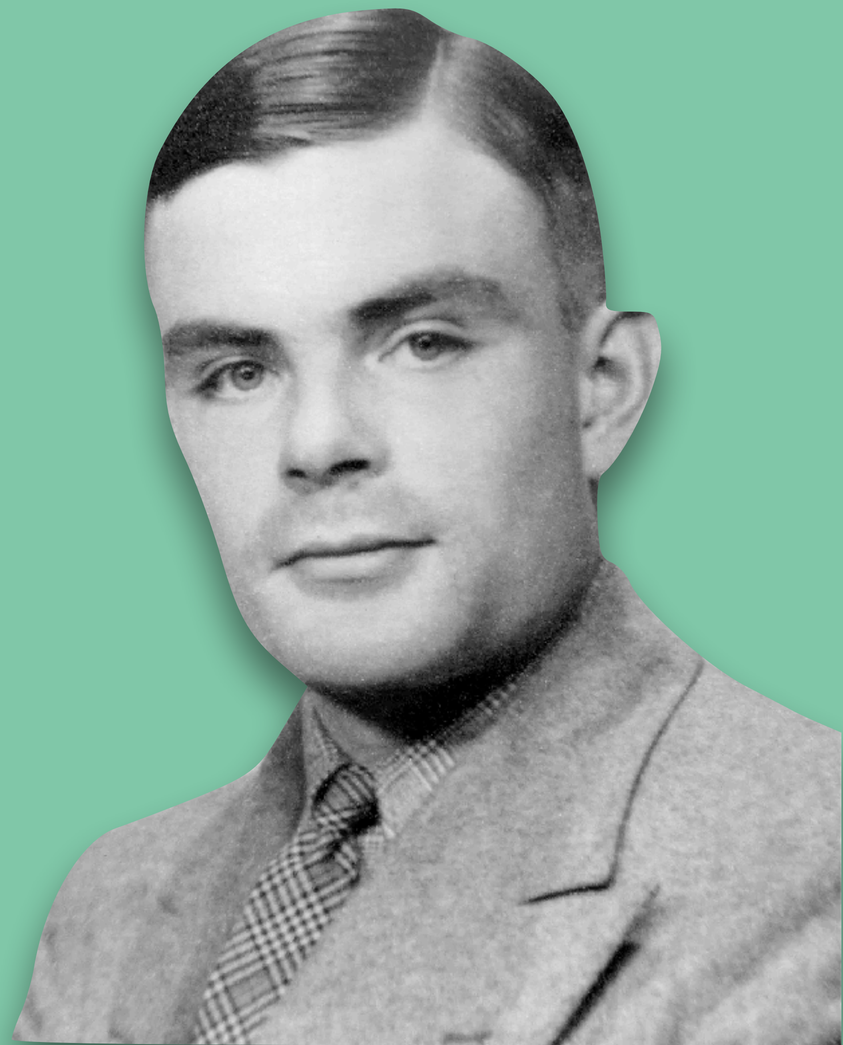


Alan Turing

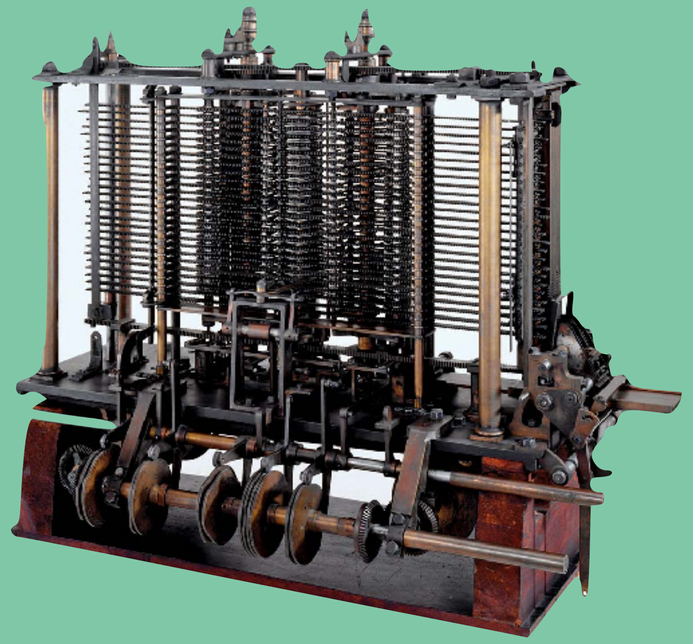
(1912-1954)

Padre dell'Informatica
e dell'Intelligenza Artificiale



Computazione astratta

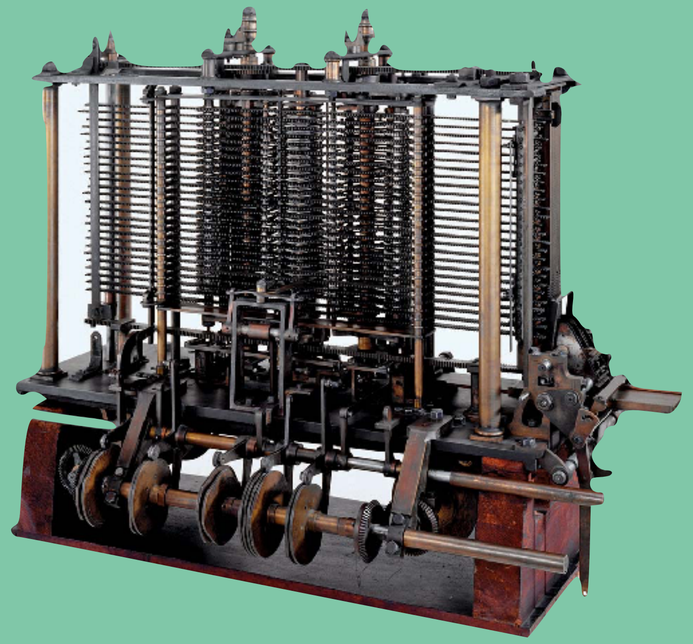
Calcolo meccanico



Calcolo astratto

Computazione astratta

Calcolo meccanico



Calcolo astratto

Calcolo → Computazione → Algoritmo

Le macchine pensano veramente?

MIND

A QUARTERLY REVIEW

OF

PSYCHOLOGY AND PHILOSOPHY

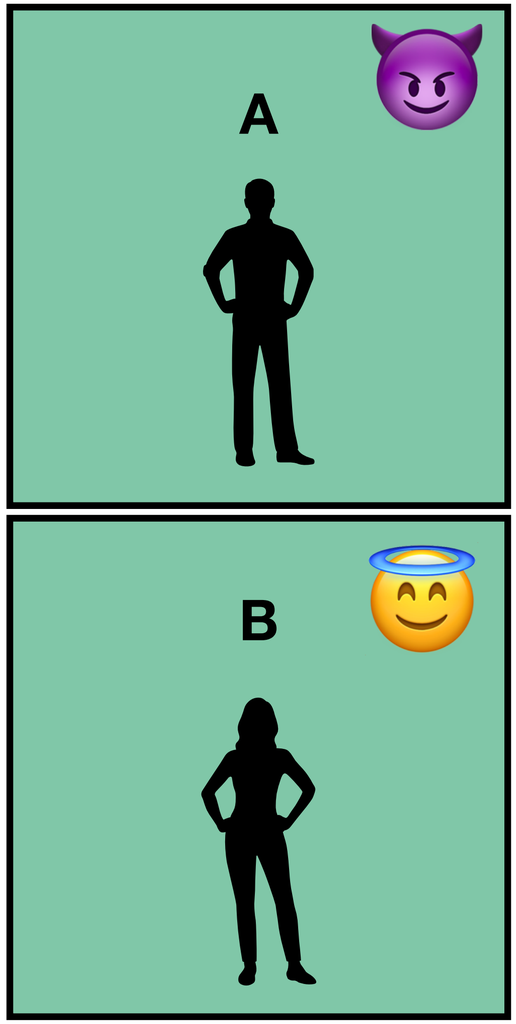
I.—COMPUTING MACHINERY AND INTELLIGENCE

By A. M. Turing

1. *The Imitation Game.*

I propose to consider the question, 'Can machines think?'

Test di Turing



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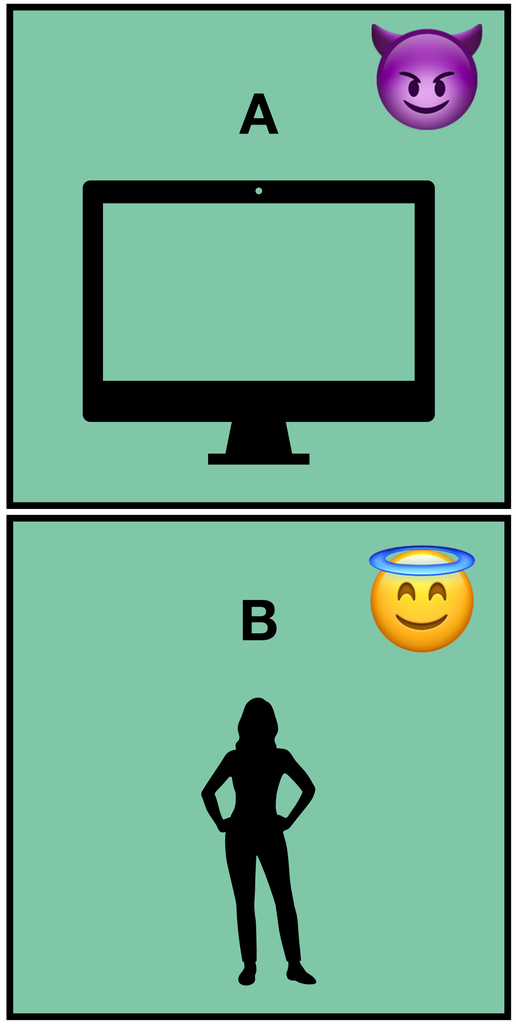

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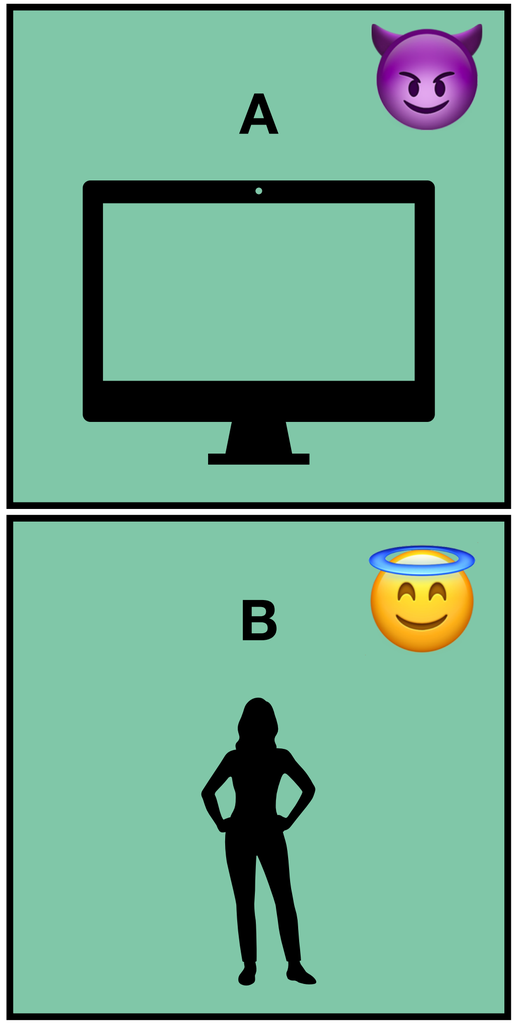

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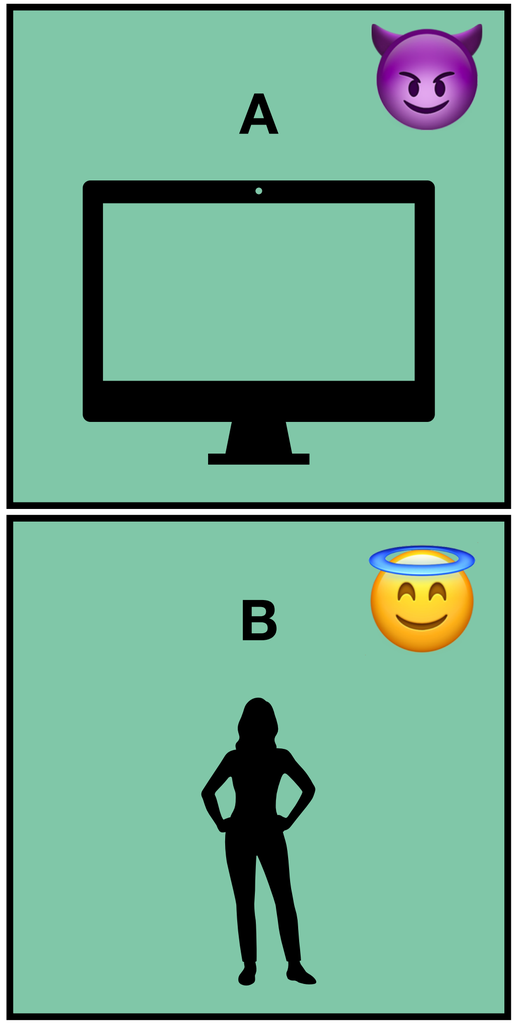
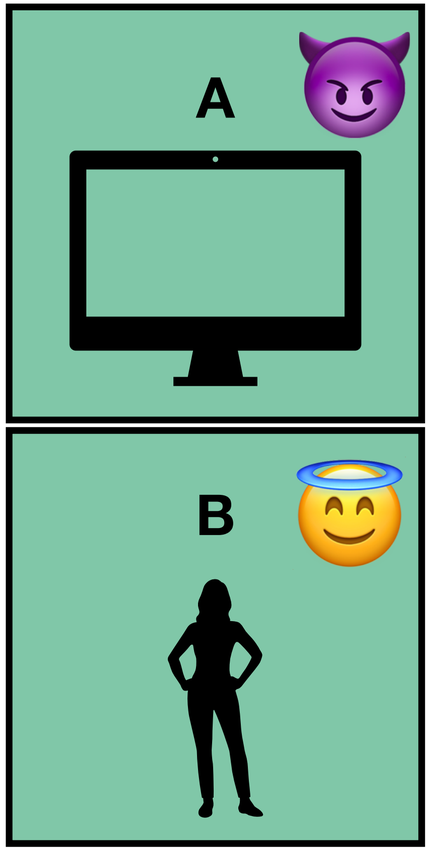
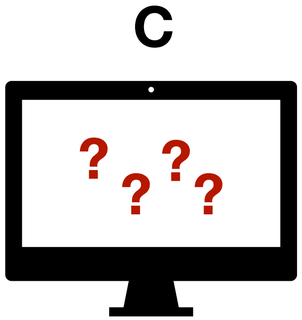


```
  Welcome to
                    EEEEEE  LL      IIII   ZZZZZZ   AAAAA
                    EE      LL       II       ZZ   AA   AA
                    EEEEE   LL       II     ZZZ    AAAAAAA
                    EE      LL       II    ZZ      AA   AA
                    EEEEEE  LLLLLL  IIII ZZZZZZ    AA   AA

  Eliza is a mock Rogerian psychotherapist.
  The original program was described by Joseph Weizenbaum in 1966.
  This implementation by Norbert Landsteiner 2005.


ELIZA: Is something troubling you ?
YOU:   Men are all alike.
ELIZA: What is the connection, do you suppose ?
YOU:   They're always bugging us about something or other.
ELIZA: Can you think of a specific example ?
YOU:   Well, my boyfriend made me come here.
ELIZA: Is it important to you that your boyfriend made you come here ?
YOU:   He says I'm depressed much of the time.
ELIZA: I am sorry to hear that you are depressed.
YOU:   It's true. I am unhappy.
ELIZA: Can you explain what made you unhappy ?
YOU:
```

reCAPTCHA

Test di Turing inverso

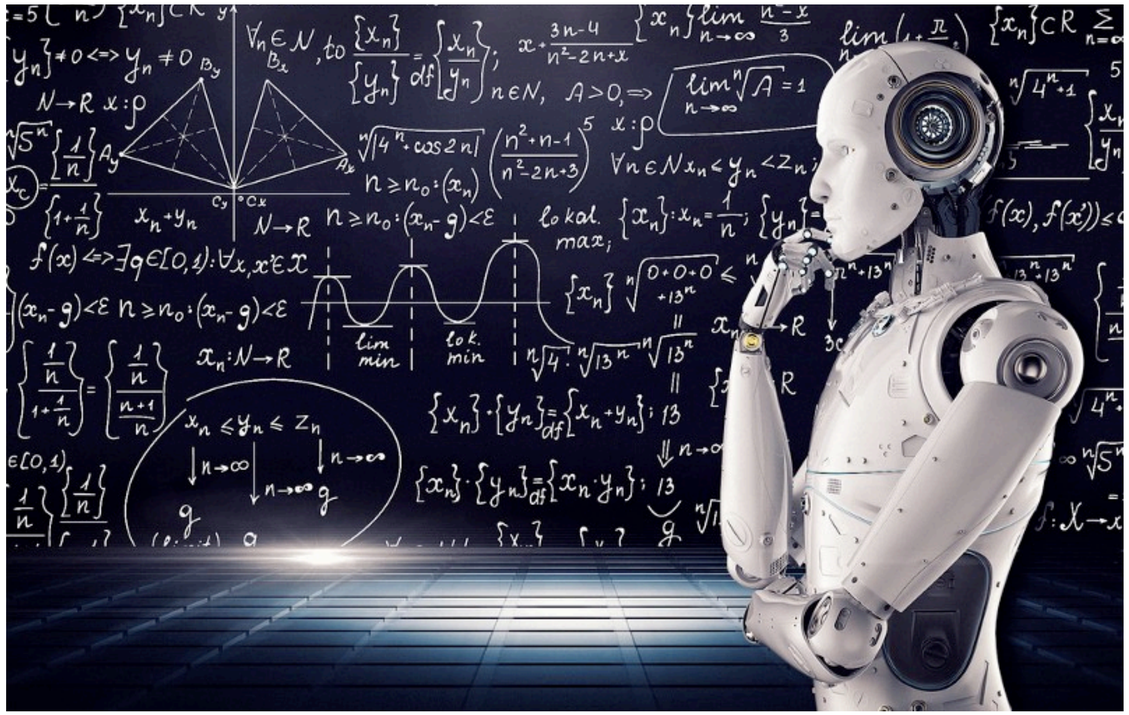




Intelligenza artificiale

"studia se e in che modo si possano realizzare sistemi **informatici intelligenti in grado di <u>simulare la capacità</u> e il <u>comportamento del pensiero umano</u>.**"

Wikipedia



È strettamente legata a:

- logica
- scienze cognitive
- filosofia

Intelligenza?
Non proprio…
È Apprendimento Automatico

Apprendimento automatico

O Machine Learning (ML)

Apprendimento automatico

O Machine Learning (ML)

ALGORITMO

Apprendimento automatico

O Machine Learning (ML)

ALGORITMO

AUTOMATICO
=
SENZA ISTRUZIONI SPECIFICHE

Apprendimento automatico

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ALGORITMO

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USA LA STATISTICA

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IMPARARE
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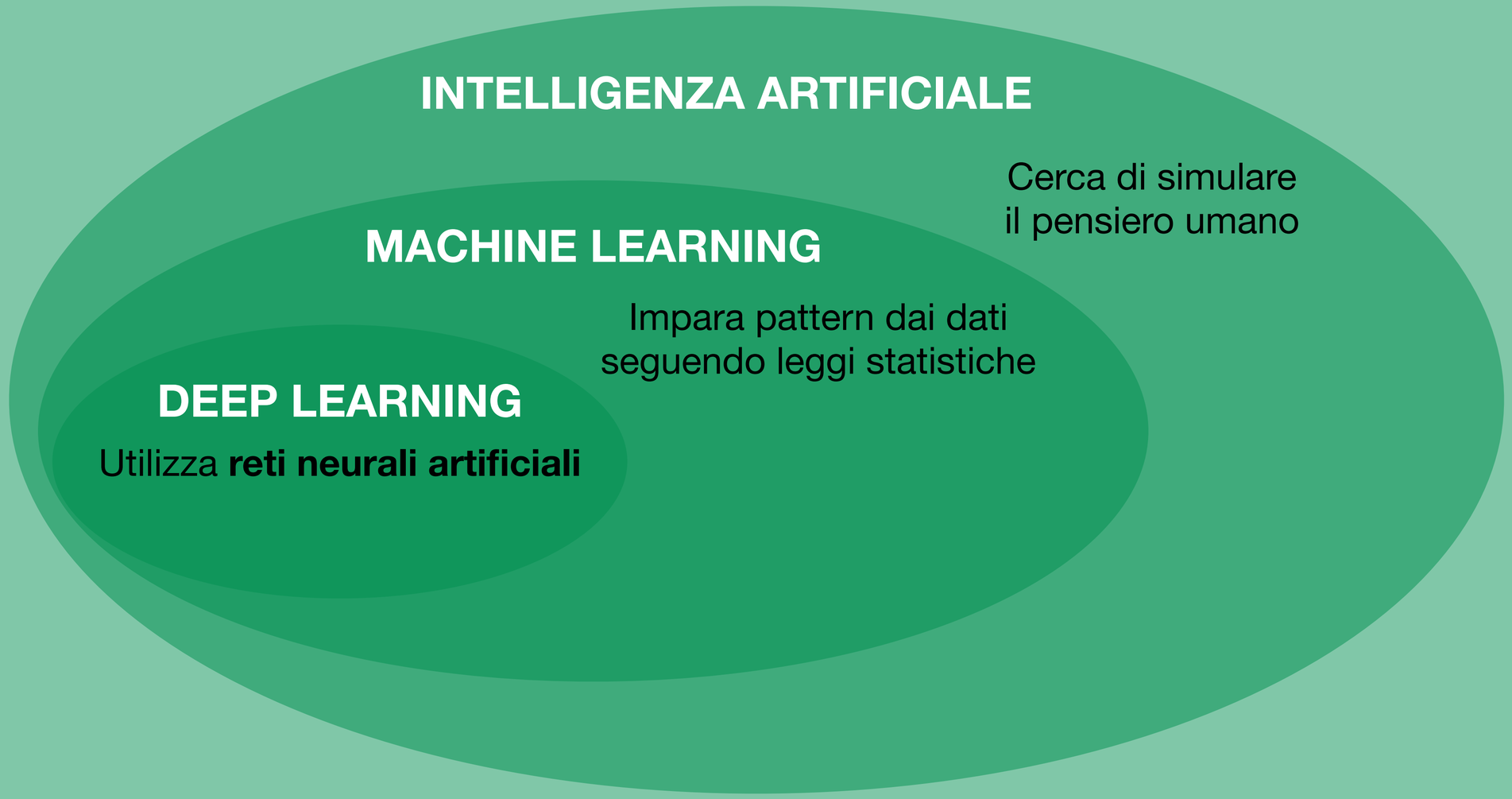
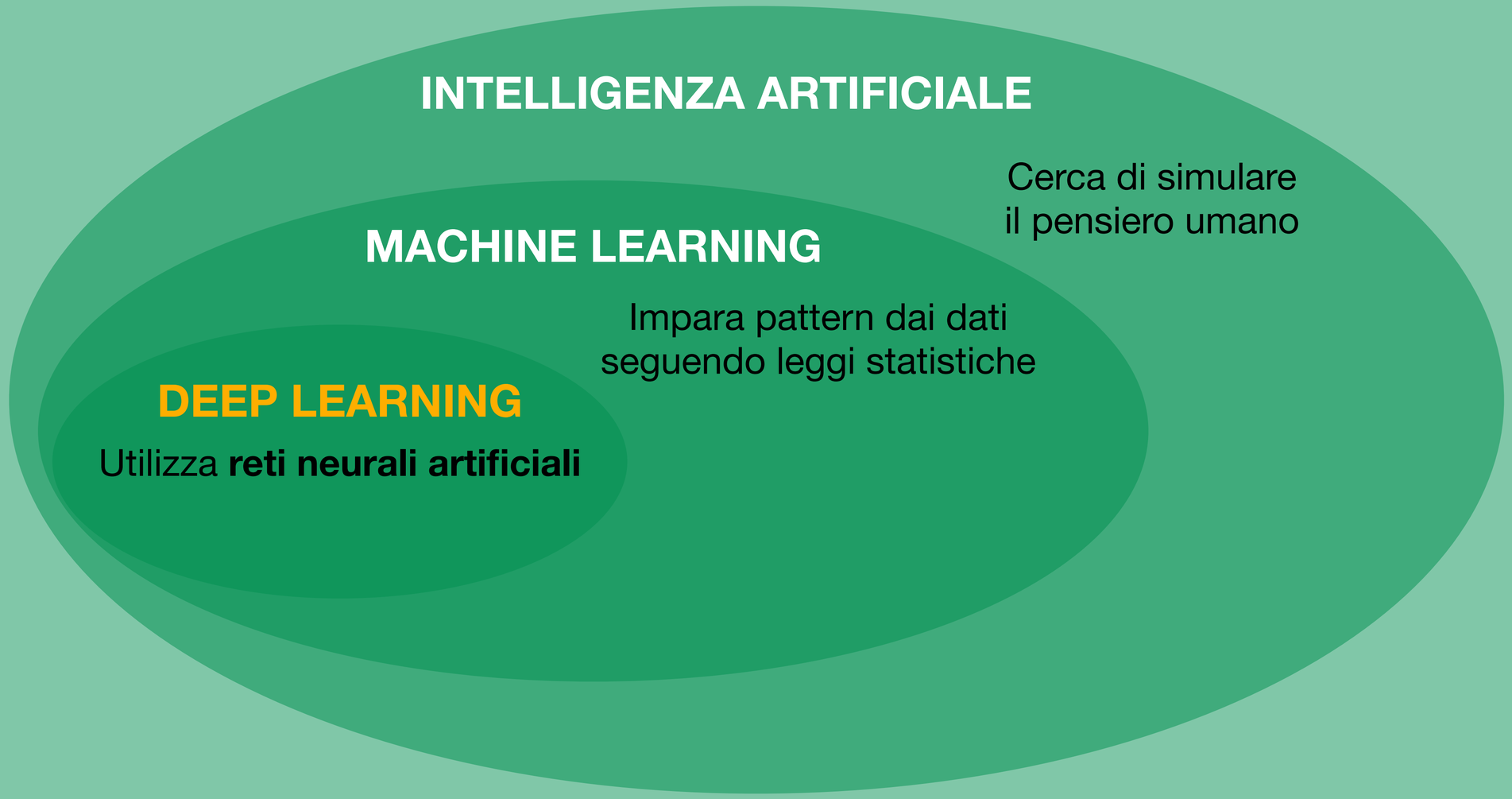

INTELLIGENZA ARTIFICIALE
Cerca di simulare
il pensiero umano
MACHINE LEARNING
Impara pattern dai dati
seguendo leggi statistiche
DEEP LEARNING
Utilizza **reti neurali artificiali**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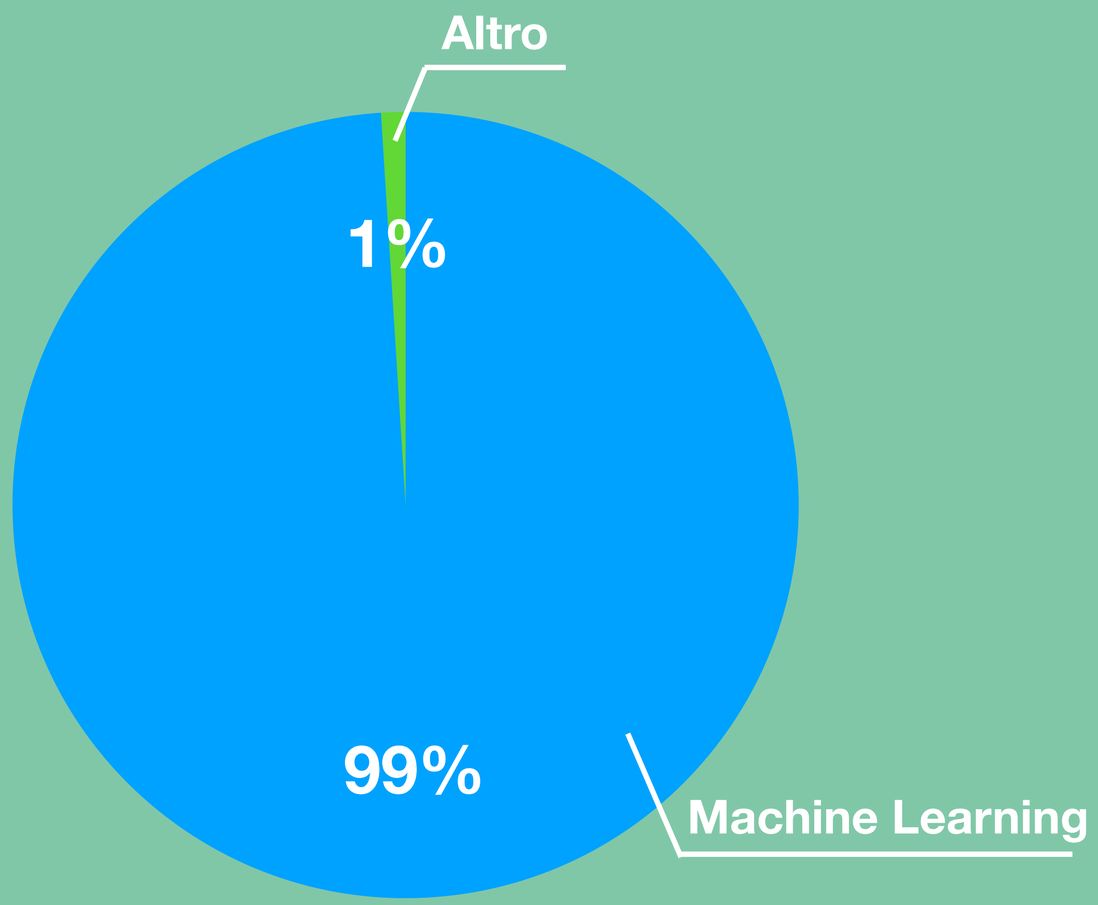
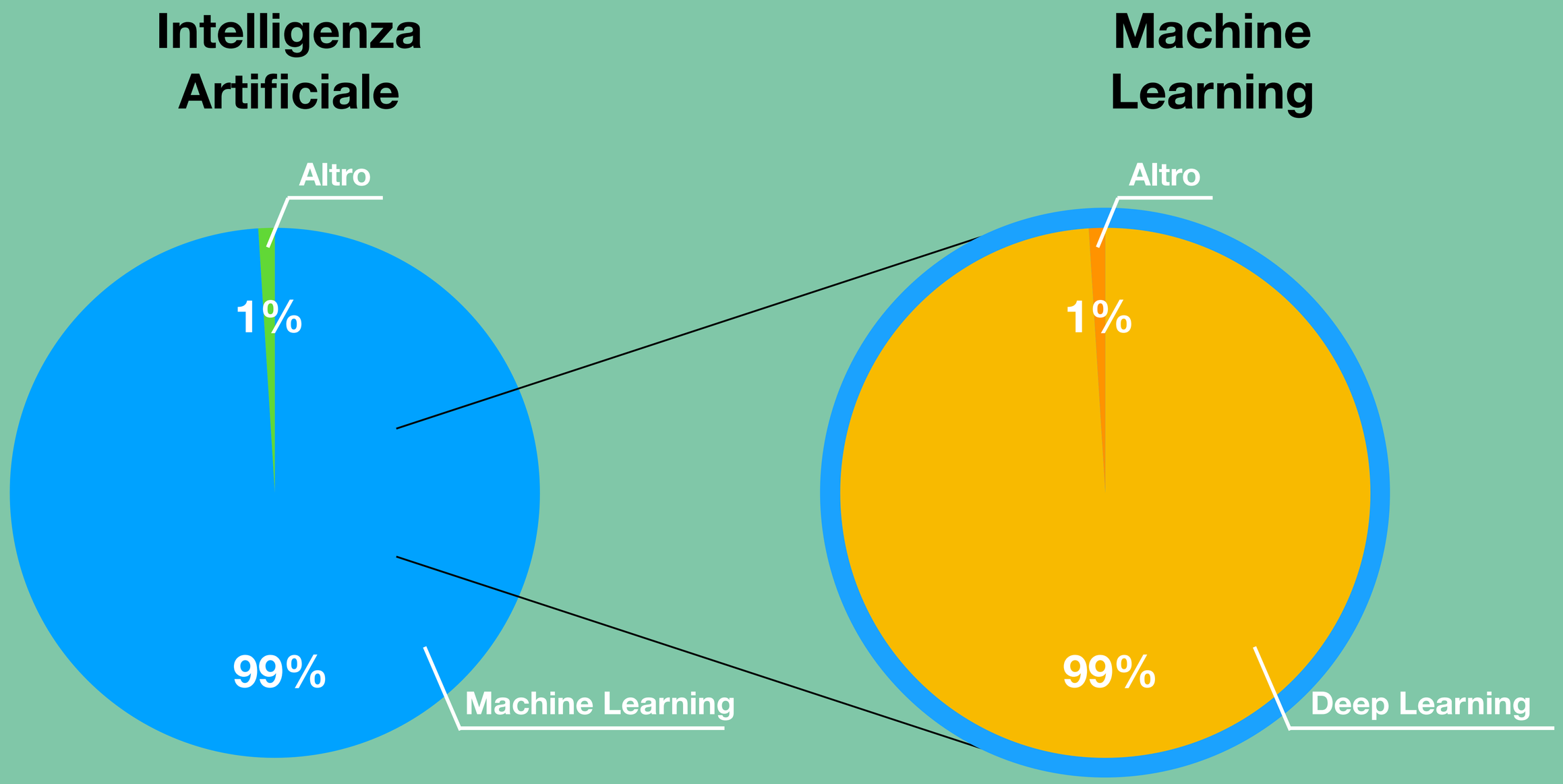
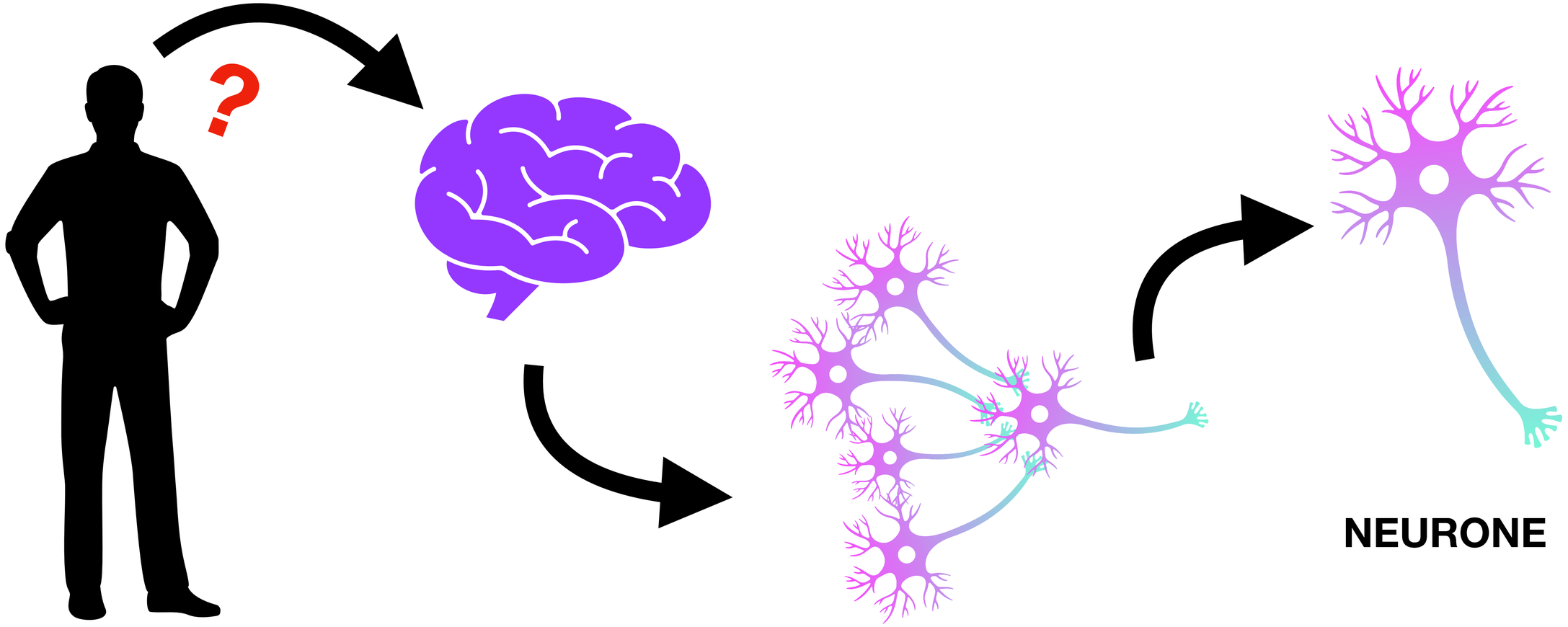
Intelligenza Artificiale



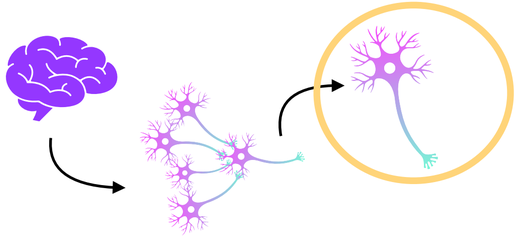

Intelligenza Artificiale
Altro
1%
99%
Machine Learning
Machine Learning
Altro
1%
99%
Deep Learning

RETI NEURALI

Cervello umano

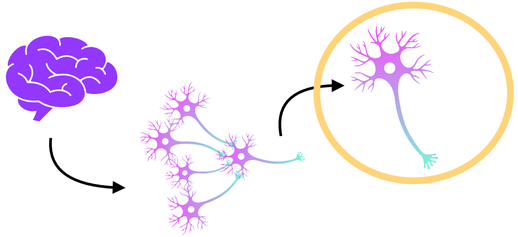


Il neurone



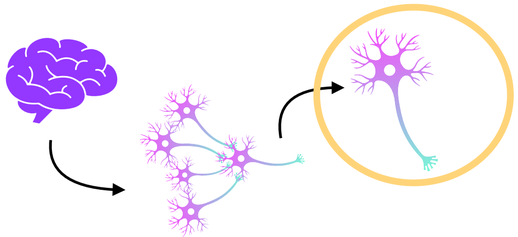
NEURONE

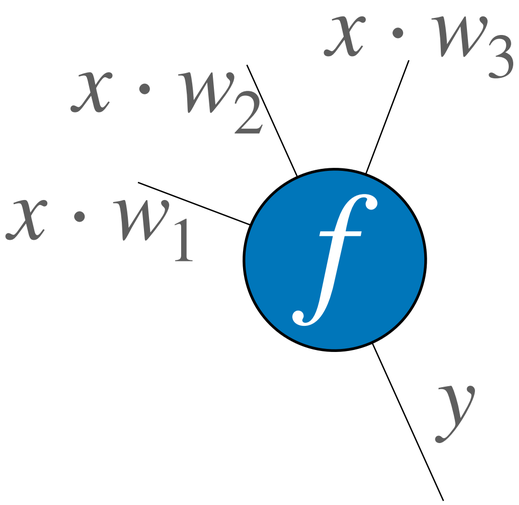
Il neurone



NEURONE

Il neurone artificiale (o percettore)





NEURONE

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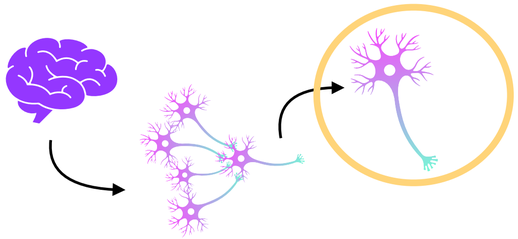

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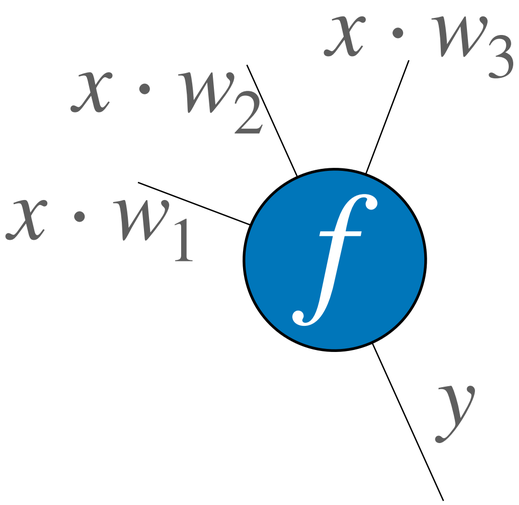
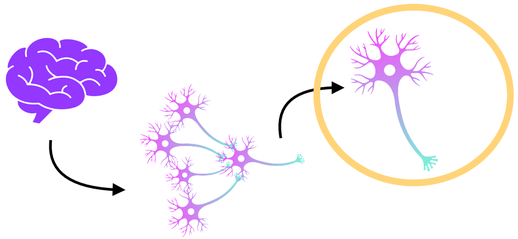


- x input

Il neurone artificiale (o percettore)



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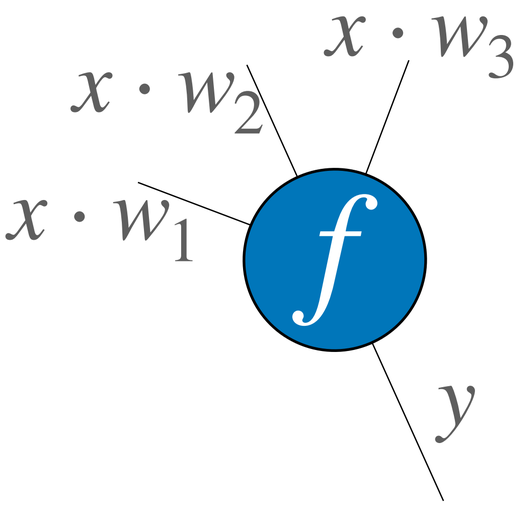
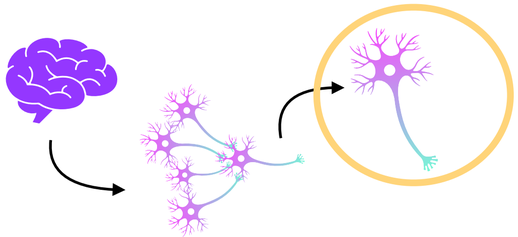
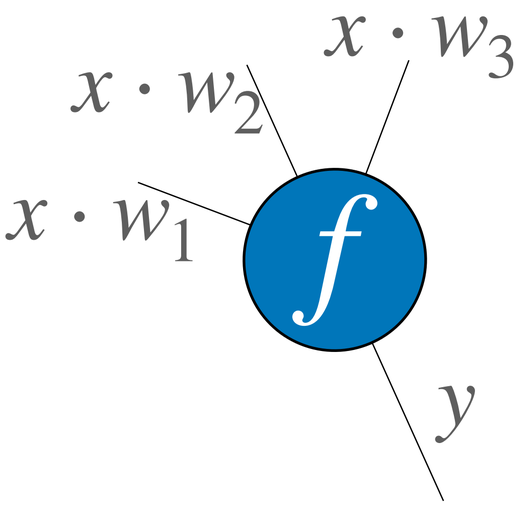


- x input
- w_i pesi (parametri)

Il neurone artificiale (o percettore)

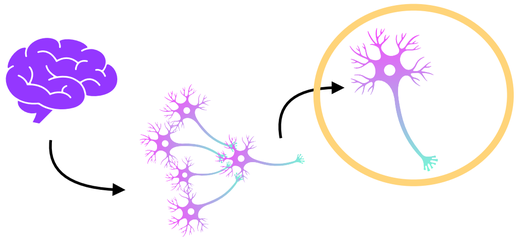


NEURONE



- x input
- w_i pesi (parametri)
- f funzione di attivazione

Il neurone artificiale (o percettore)



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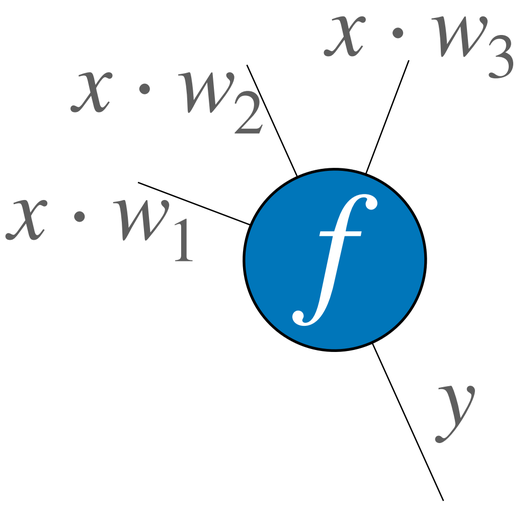

- x input
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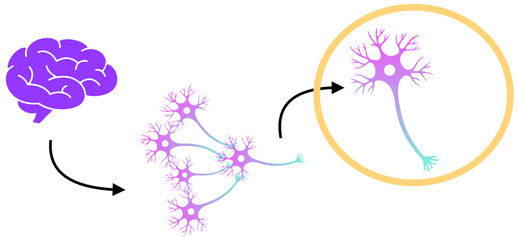
- f funzione di attivazione
- y output

Il neurone artificiale (o percettore)



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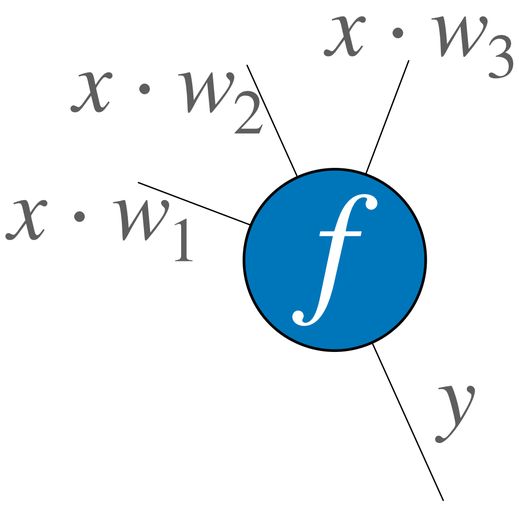
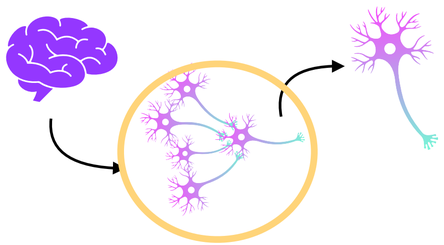
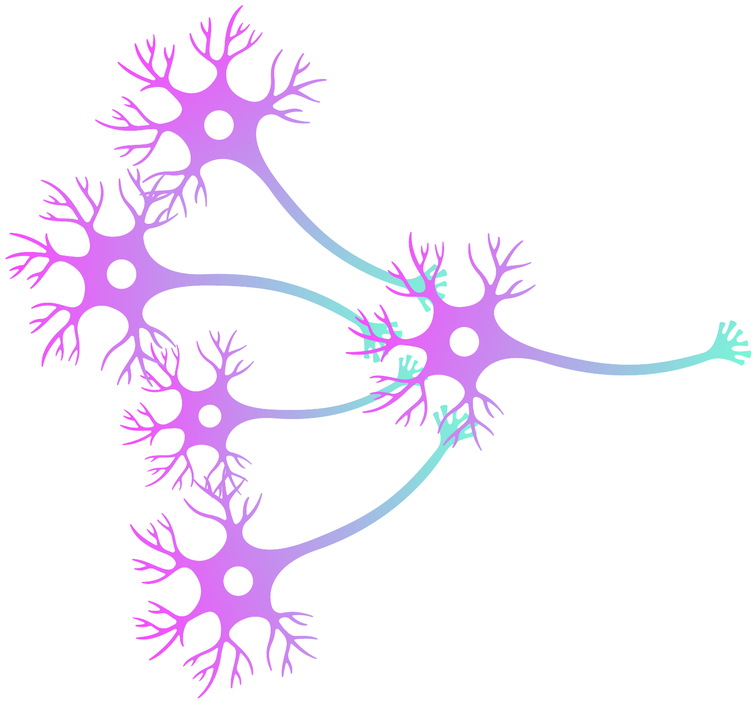


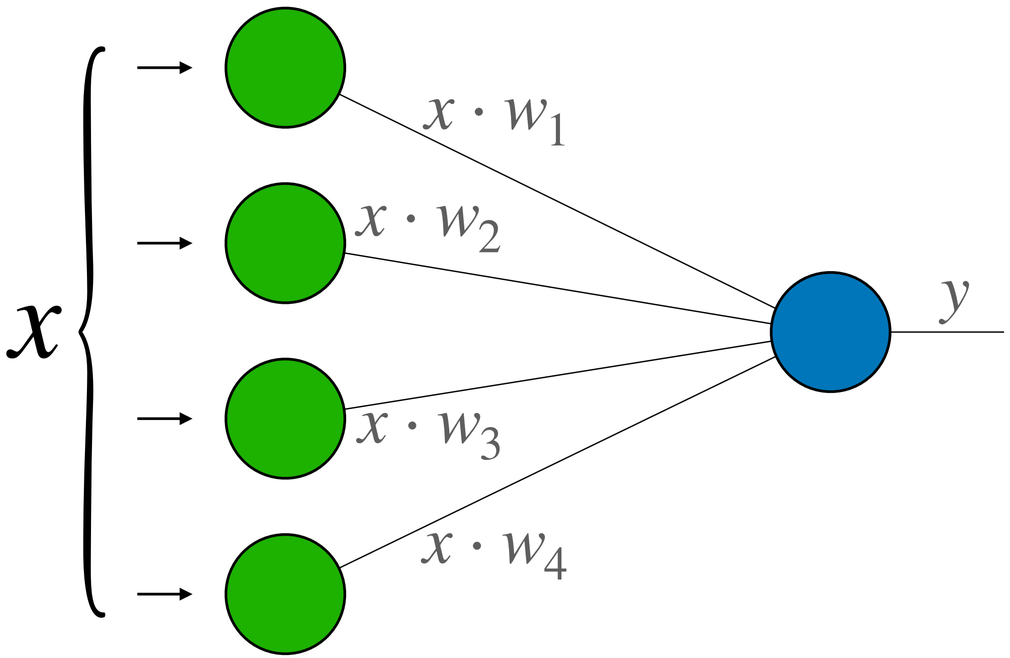
- x input
- w_i pesi (parametri)
- f funzione di attivazione
- y output

$$y = f(x \cdot w)$$

Reti neurali artificiali







Come impara una rete neurale artificiale?

Prova ed errore

DATI

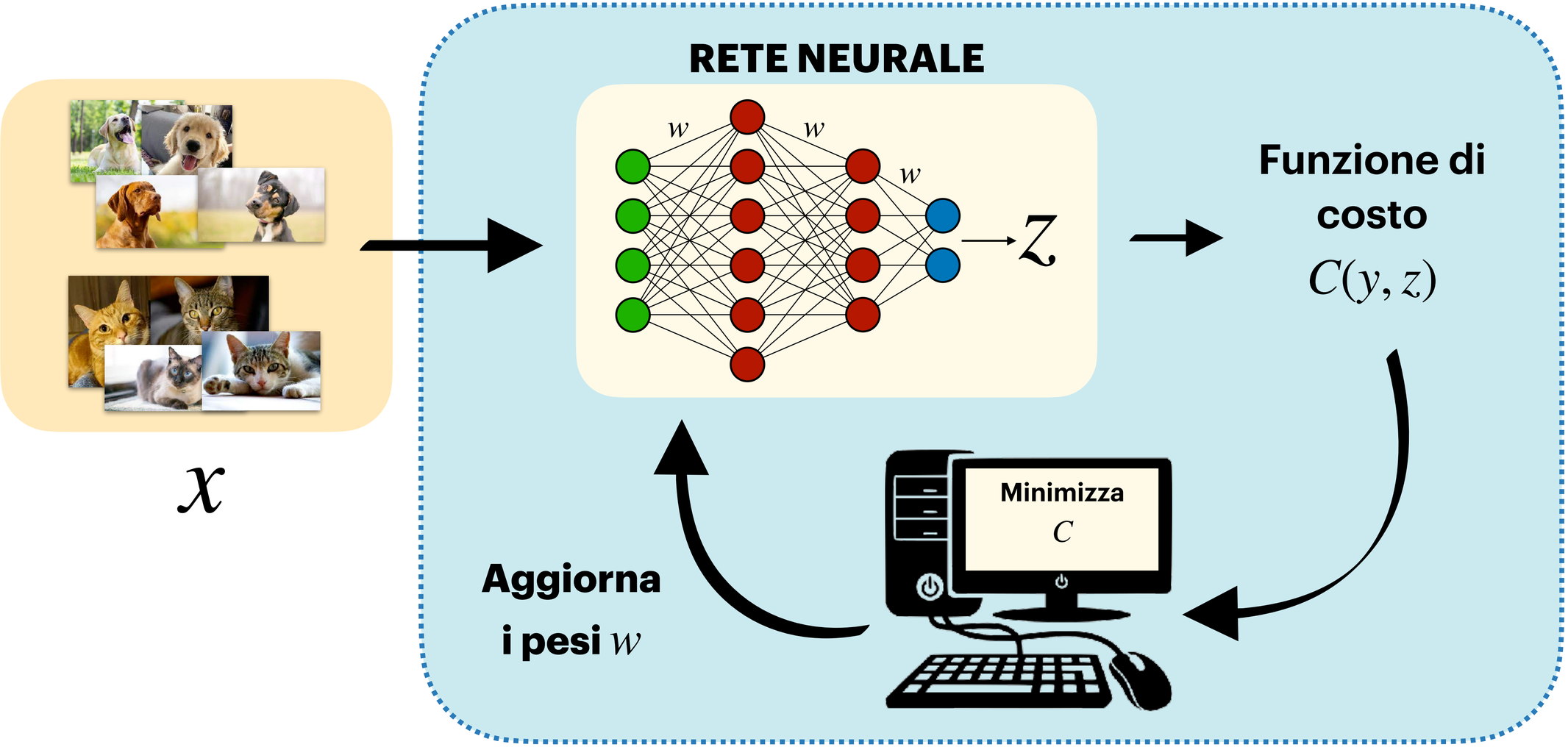
(x)

ETICHETTE (y)

CANE

GATTO

APPRENDIMENTO



Apprendimento automatico

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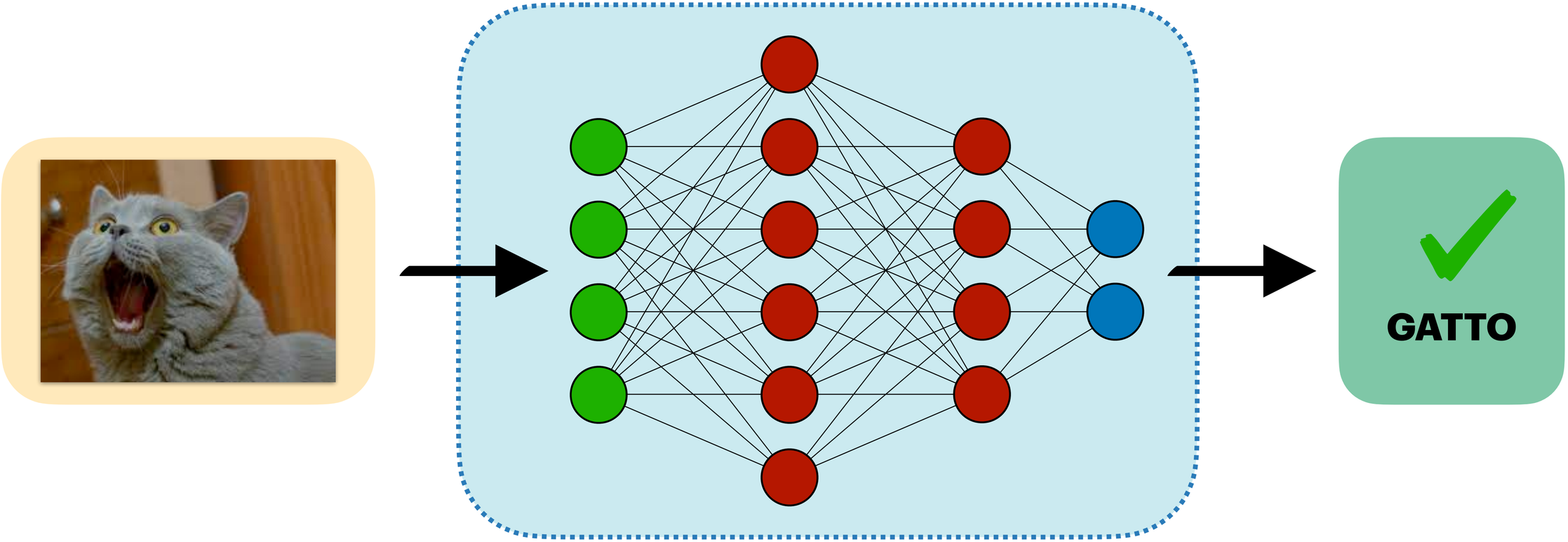
Generalizzazione



Cosa può fare il Machine Learning?

Classificazione di immagini

Assistenti vocali

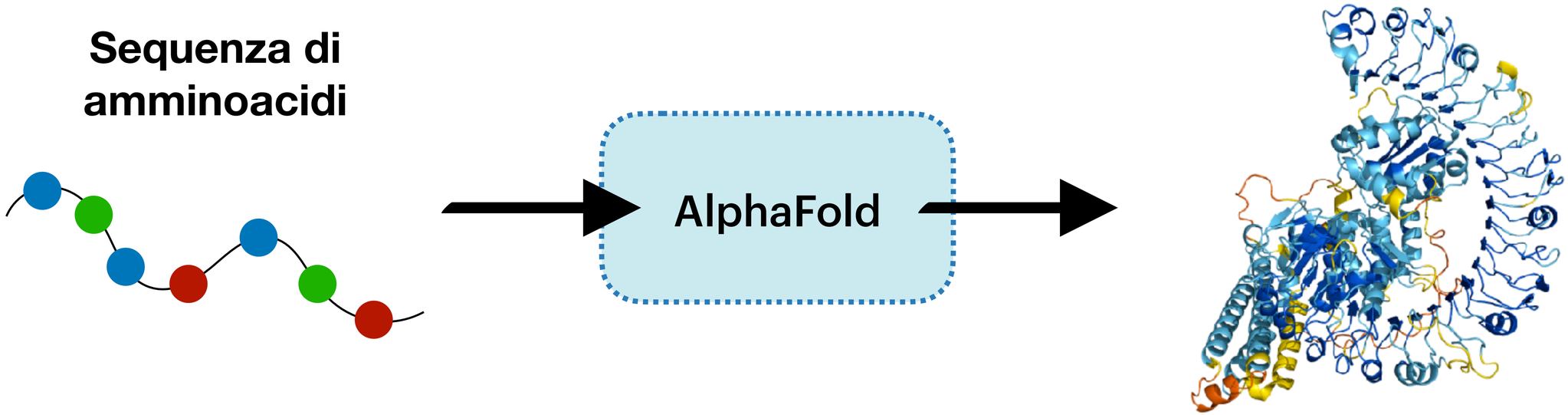
Ok Google!

Alexa che ore sono?

Hey Siri!

Predizione di Strutture di Proteine

AlphaFold



https://alphafold.ebi.ac.uk/

Reset Thread

Light Mode

OpenAI Discord

Learn More

Log out

ChatGPT

Examples

"Explain quantum computing in simple terms"

"Got any creative ideas for a 10 year old's birthday?"

"How do I make an HTTP request

Capabilities

Remembers what user said earlier in the conversation

Allows user to provide follow-up corrections

Trained to decline inappropriate

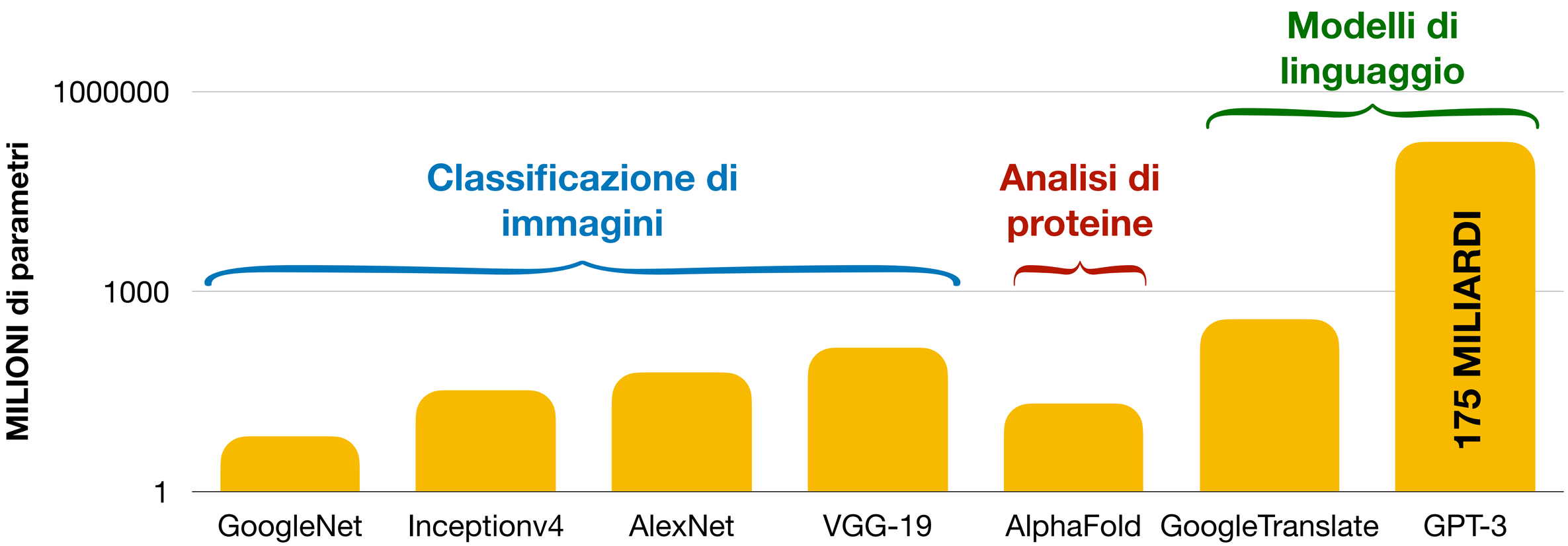
Limitations

May occasionally generate incorrect information

May occasionally produce harmful instructions or biased content

Free Research Preview: ChatGPT is optimized for dialogue. Our goal is to make AI systems more natural to interact with, and your feedback will help us improve our systems and make them safer.

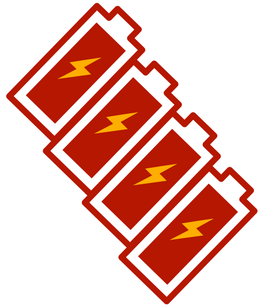
Più è difficile, più parametri servono



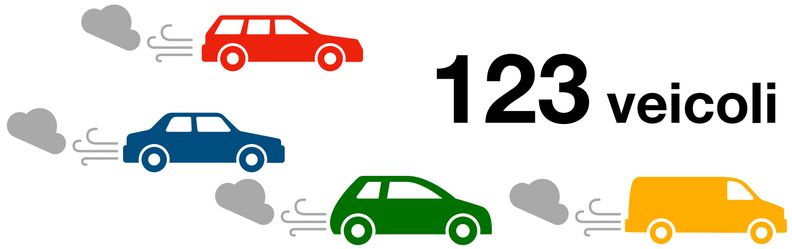
Quanta energia è necessaria?

Consumo per la creazione di GPT-3

1.287 megawattora

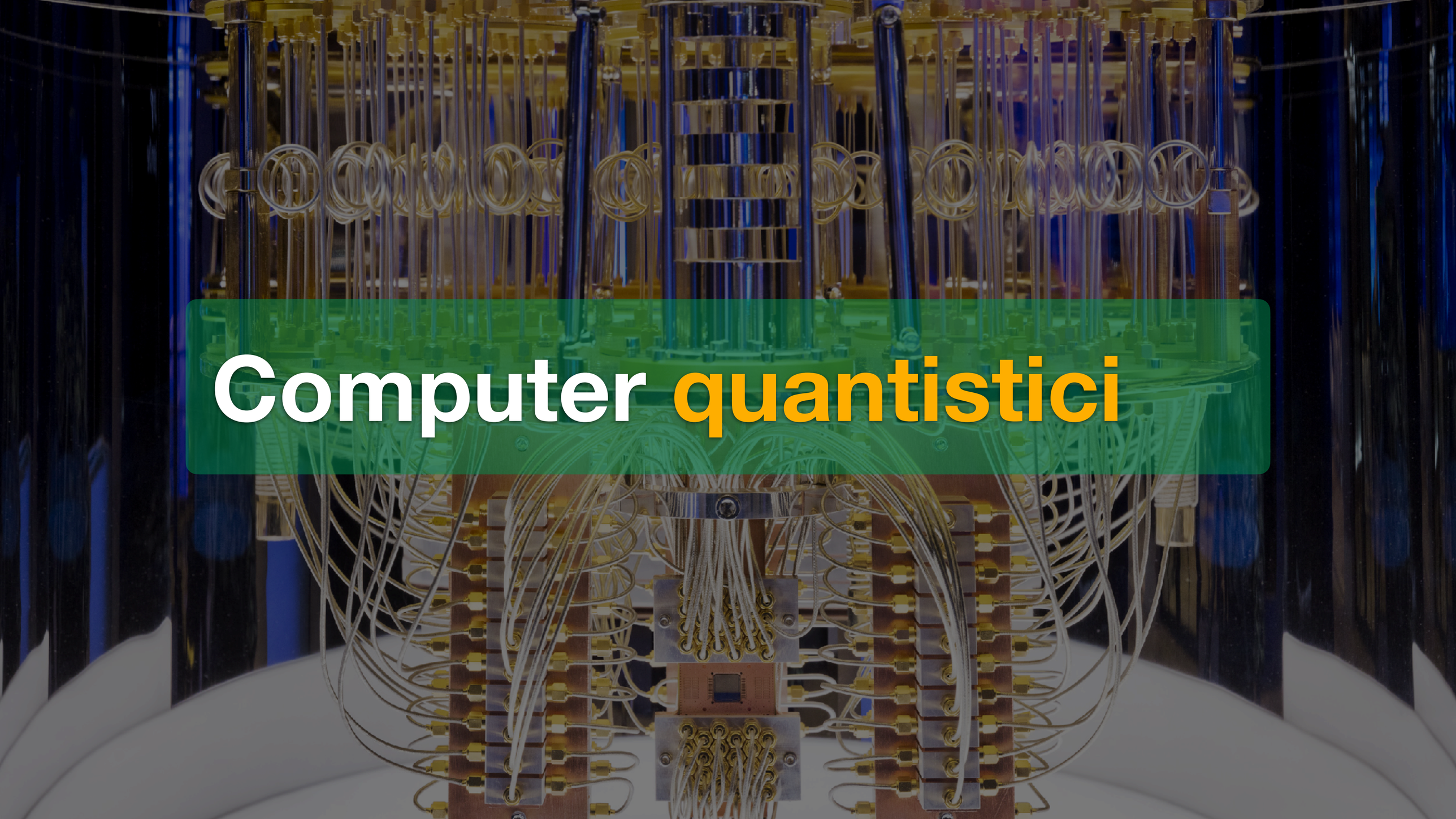


552 tonnellate di anidride carbonica



123 veicoli a benzina guidati per un anno

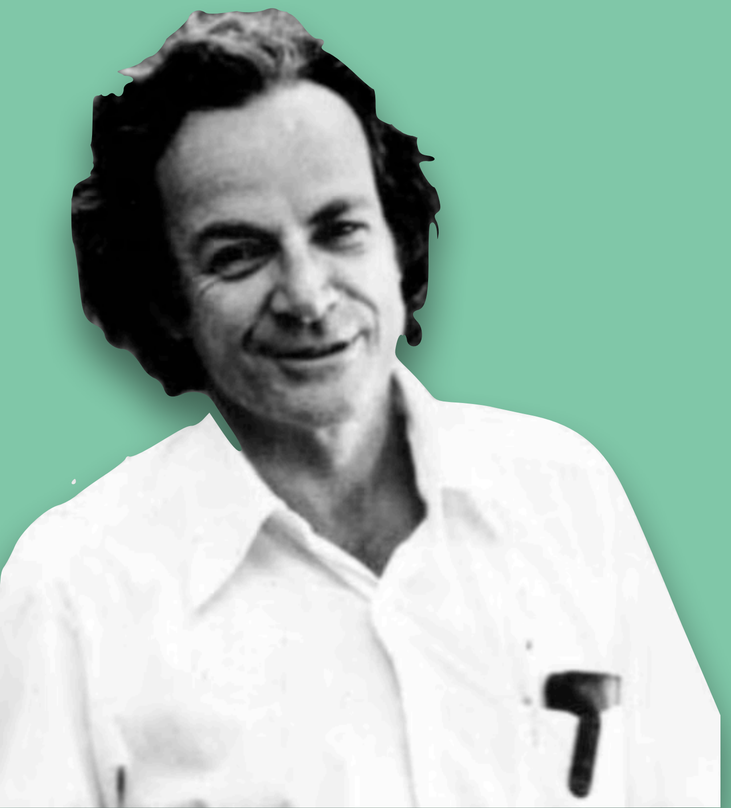
FONTE: https://www.euronews.com/



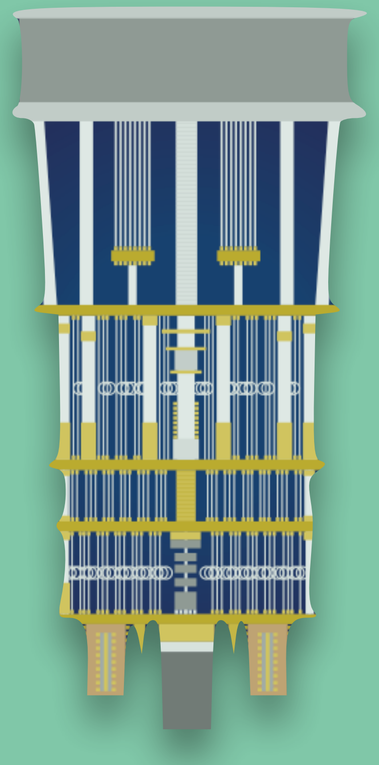
Computer quantistici

Richard Feynman

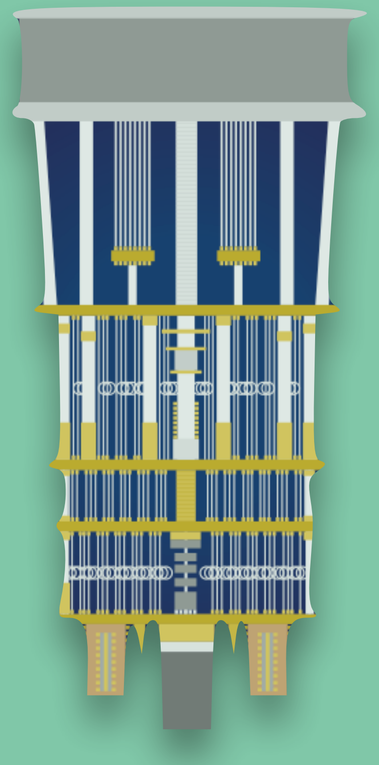
(1918-1988)



“La natura non è classica, dannazione, e se volessi fare una simulazione della Natura, sarebbe meglio la facessi quantistica!”



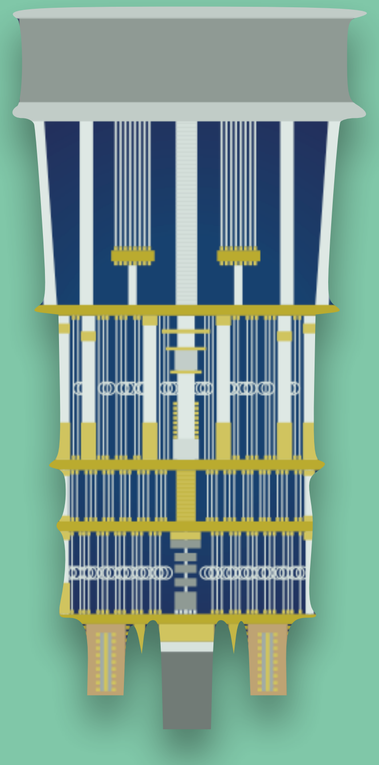
Computer quantistico



Computer quantistico

↓

sfrutta le **proprietà quantistiche** della materia



Computer quantistico

↓

sfrutta le **proprietà quantistiche** della materia

↓

per elaborare dati

QUESTO È UN FRIGORIFERO

Computer quantistico

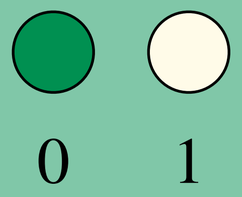
↓

sfrutta le **proprietà quantistiche** della materia

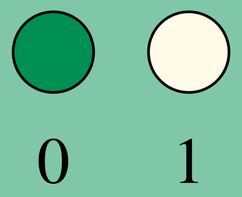
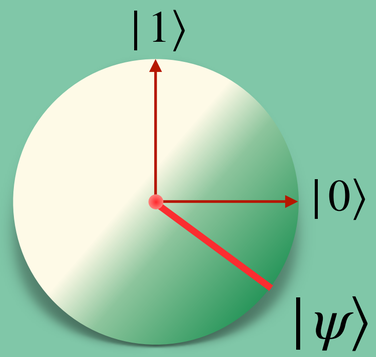
↓

per elaborare dati

Unità di informazione

BIT	
Computazione Classica  	

Unità di informazione

BIT	QUANTUM BIT
Computazione Classica  0 1	**Computazione Quantistica**  $\|\psi\rangle = \alpha\|0\rangle + \beta\|1\rangle$

Sovrapposizione

Se però abbiamo tanti qubit…

1) $a_1|0\rangle + a_2|1\rangle$

2) $a_1|00\rangle + a_2|01\rangle + a_3|10\rangle + a_4|11\rangle$

$\vdots$

N)

Sovrapposizione

Se però abbiamo tanti qubit…

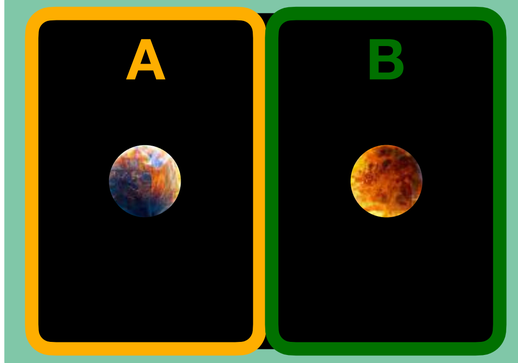
1) $a_1|0\rangle + a_2|1\rangle$

2) $a_1|00\rangle + a_2|01\rangle + a_3|10\rangle + a_4|11\rangle$

$\vdots$

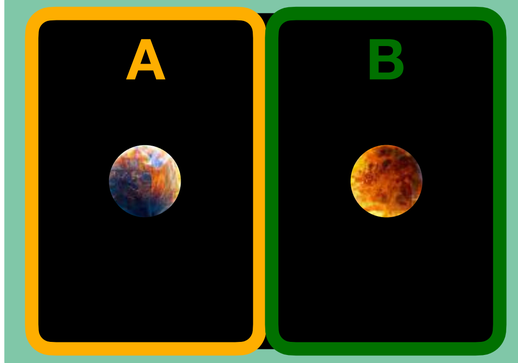
N) $a_1|0...00\rangle + a_2|0...01\rangle + \ldots + a_{2^n}|1...11\rangle$

Entanglement



Sistemi separabili → possono essere descritti **separatamente**

Entanglement



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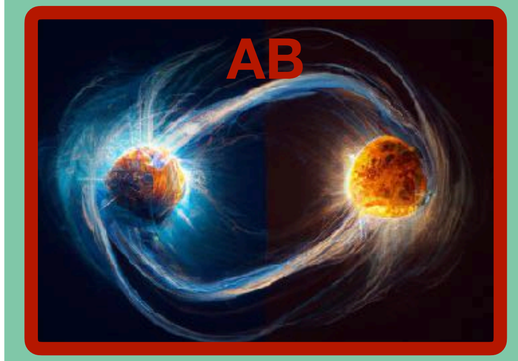
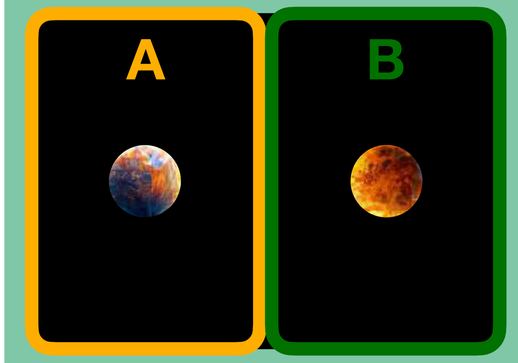
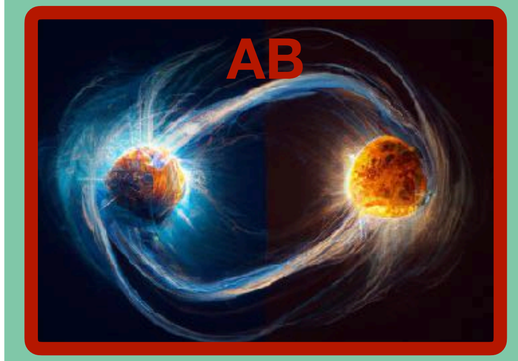


Sistemi entangled → **NON** possono essere descritti **separatamente**

Entanglement



Sistemi separabili → possono essere descritti **separatamente**

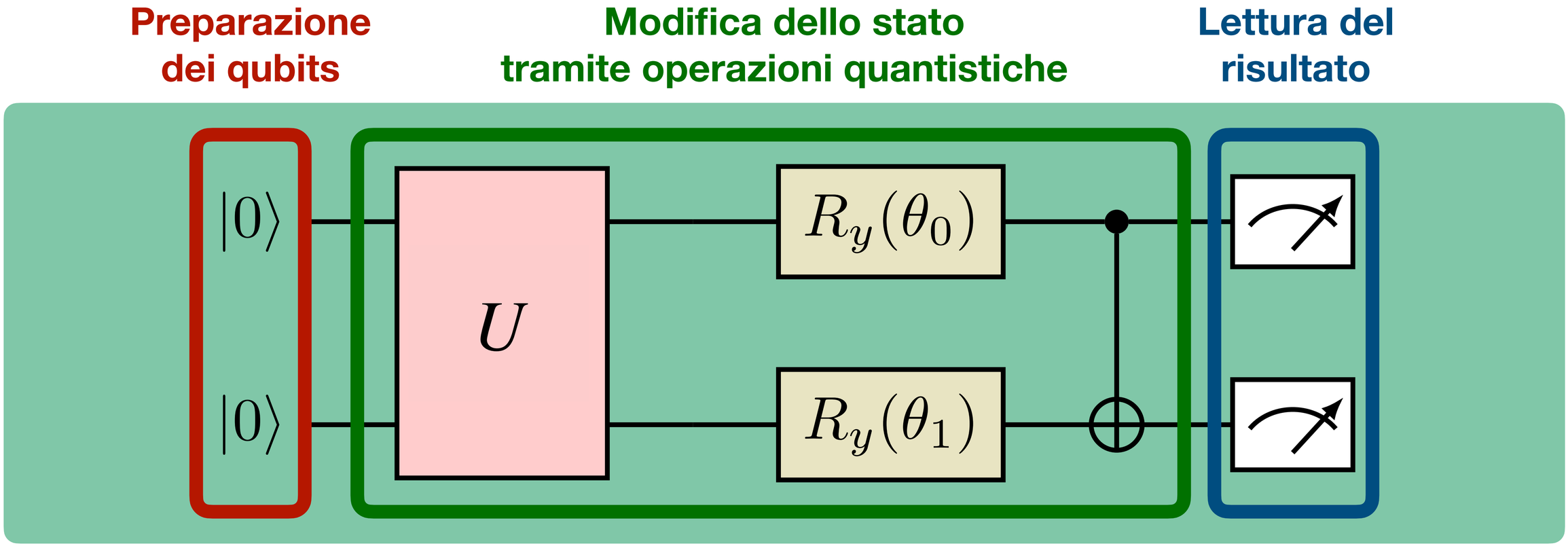


Sistemi entangled → **NON** possono essere descritti **separatamente**

Correlazione **NON-CLASSICA**

Computazione quantistica

Quantum Computing



Quantum computing **Machine Learning**

Quantum Machine Learning (QML)

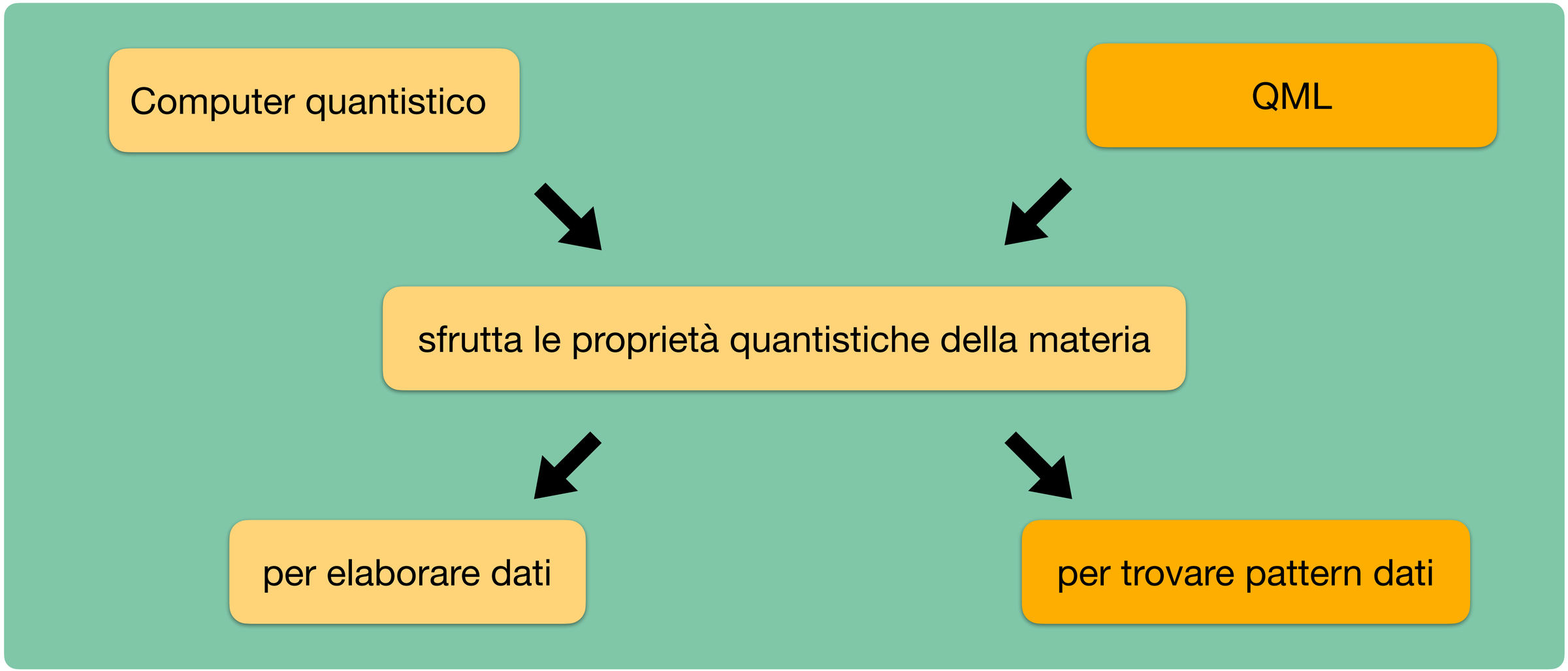
Quantum Machine Learning

Computer quantistico

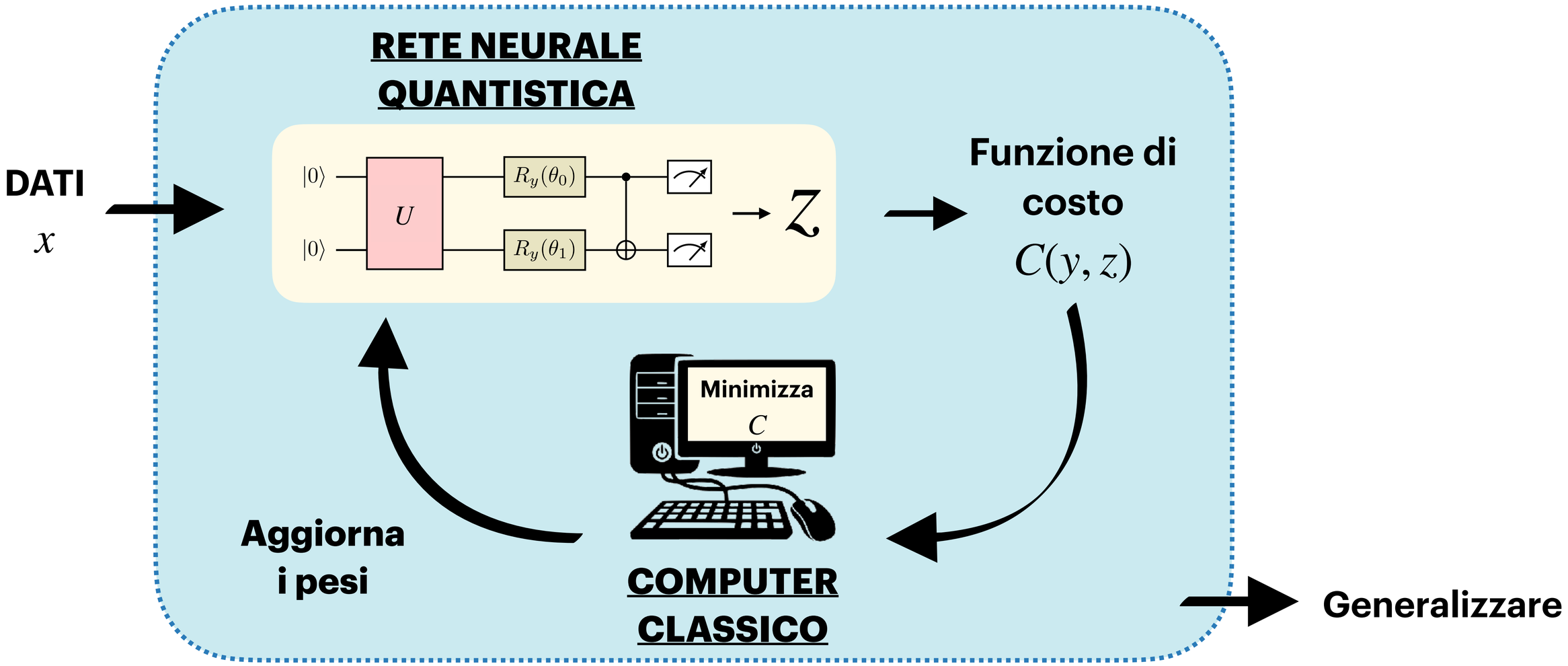
sfrutta le proprietà quantistiche della materia

per elaborare dati

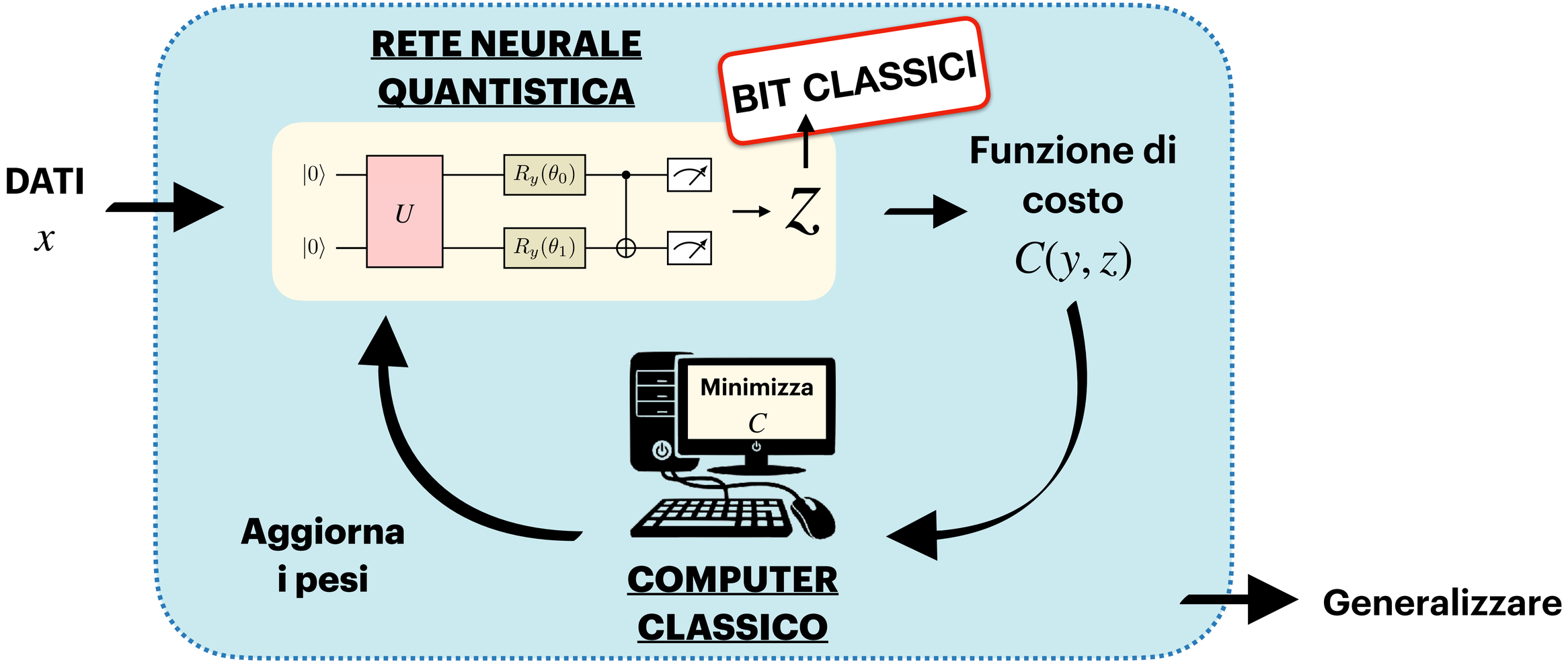
Quantum Machine Learning



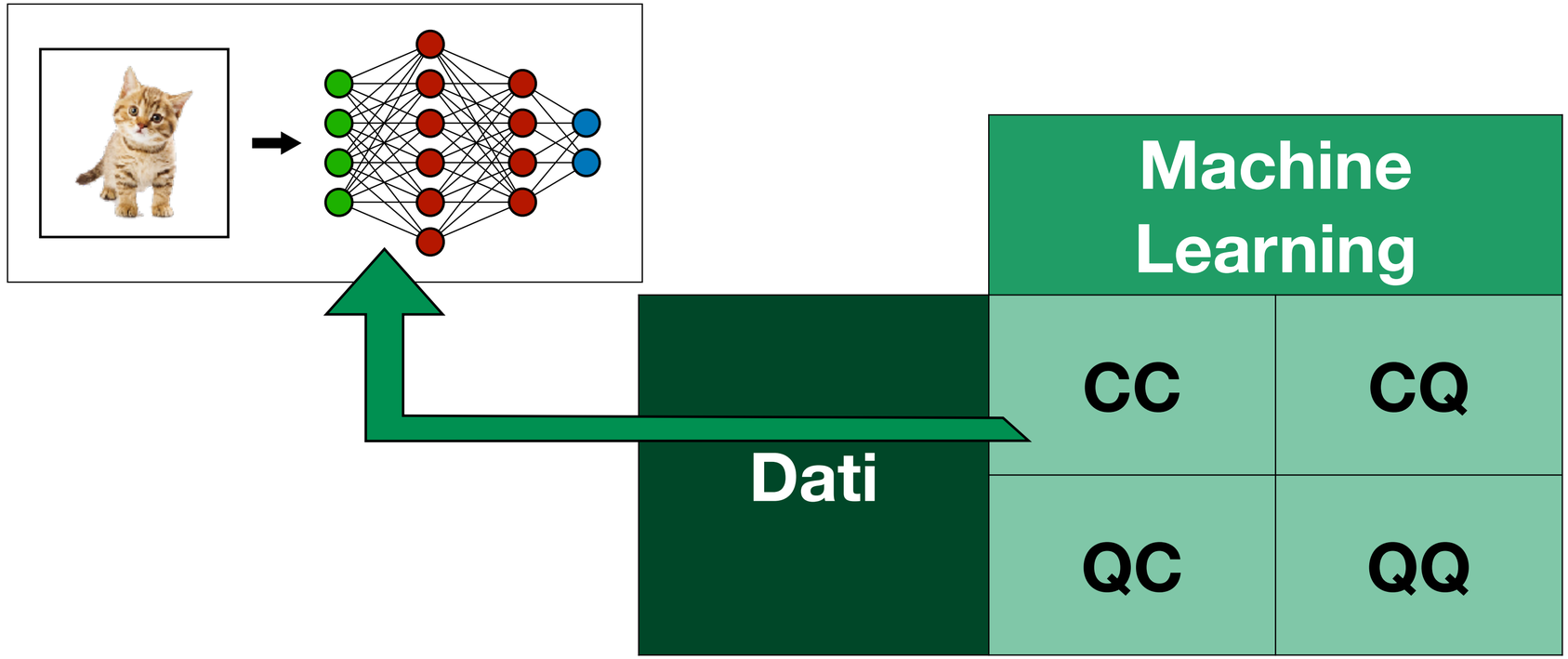
Quantum Machine Learning

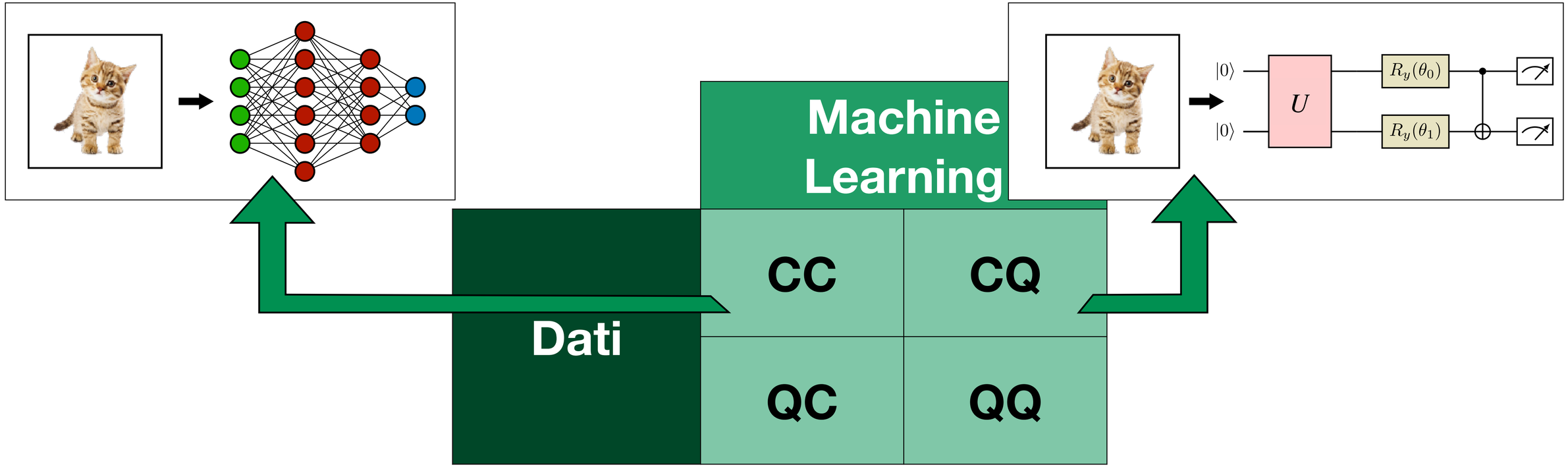


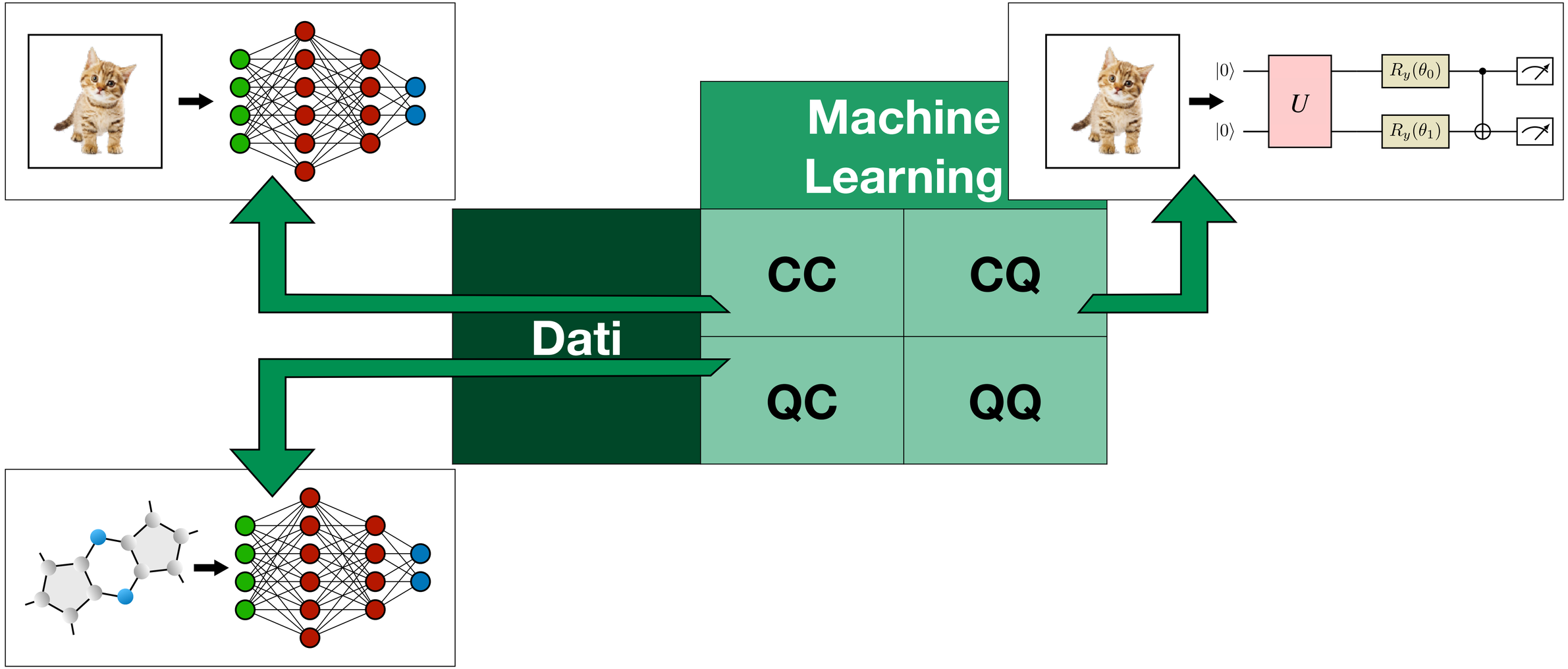
Quantum Machine Learning



	Machine Learning	
Dati	CC	CQ
	QC	QQ


Machine Learning
Dati
CC
CQ
QC
QQ


Machine Learning
Dati
CC
CQ
QC
QQ
$|0\rangle$
$|0\rangle$
U
$R_y(\theta_0)$
$R_y(\theta_1)$


Machine Learning
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$|0\rangle$
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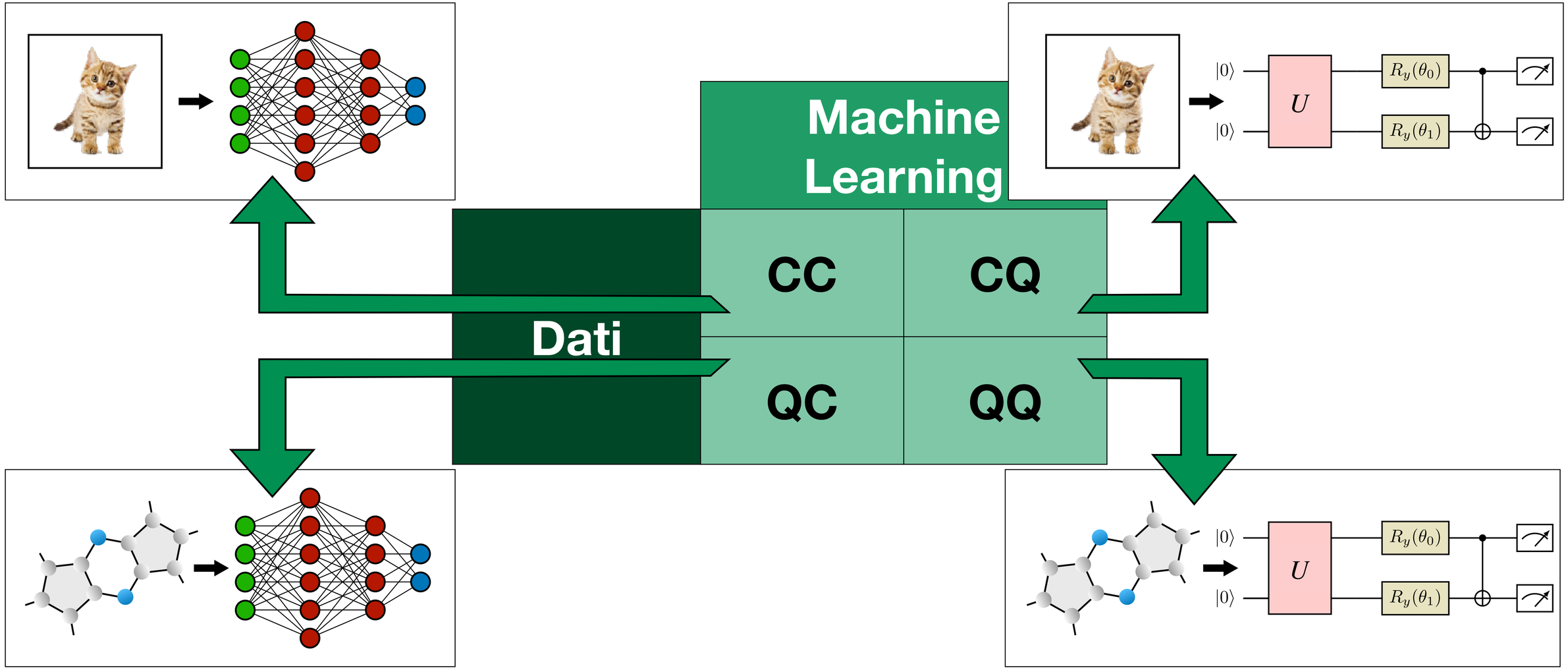
$R_y(\theta_1)$


Machine Learning
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$|0\rangle$
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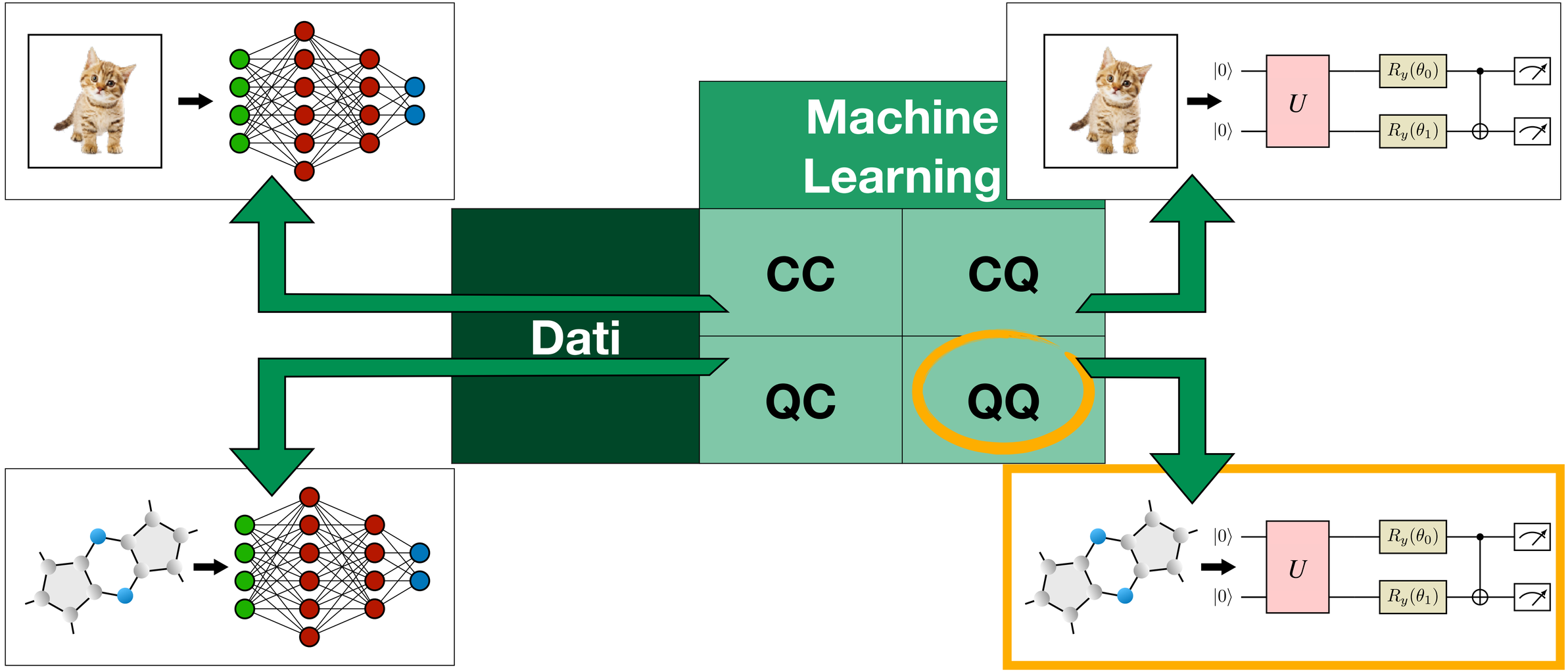
Machine Learning
Dati
CC
CQ
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$|0\rangle$
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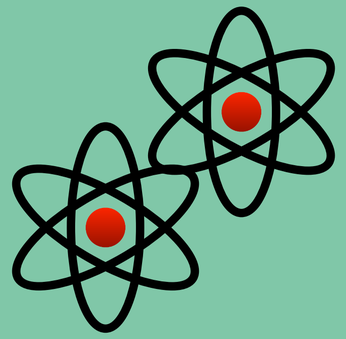
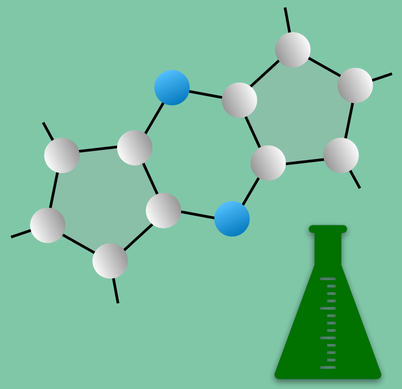
U
$R_y(\theta_0)$
$R_y(\theta_1)$

Dove può fare la differenza il Quantum Machine Learning?



FISICA



CHIMICA

BIOLOGIA

ECONOMIA

E tanti altri campi…

Dario Gerace

Supervisore
Professore ordinario

Francesco Scala

Quantum Machine Learning
Dottorando 2° anno

Francesco Ghisoni

Quantum Machine Learning
Dottorando 1° anno

Davide Cugini

Quantum Simulations
Dottorando 1° anno

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