Quantum Computing and Artificial Intelligence

Prof. Giovanni Acampora

Department of Physics “Ettore Pancini”

University of Naples Federico II

Italy

Content

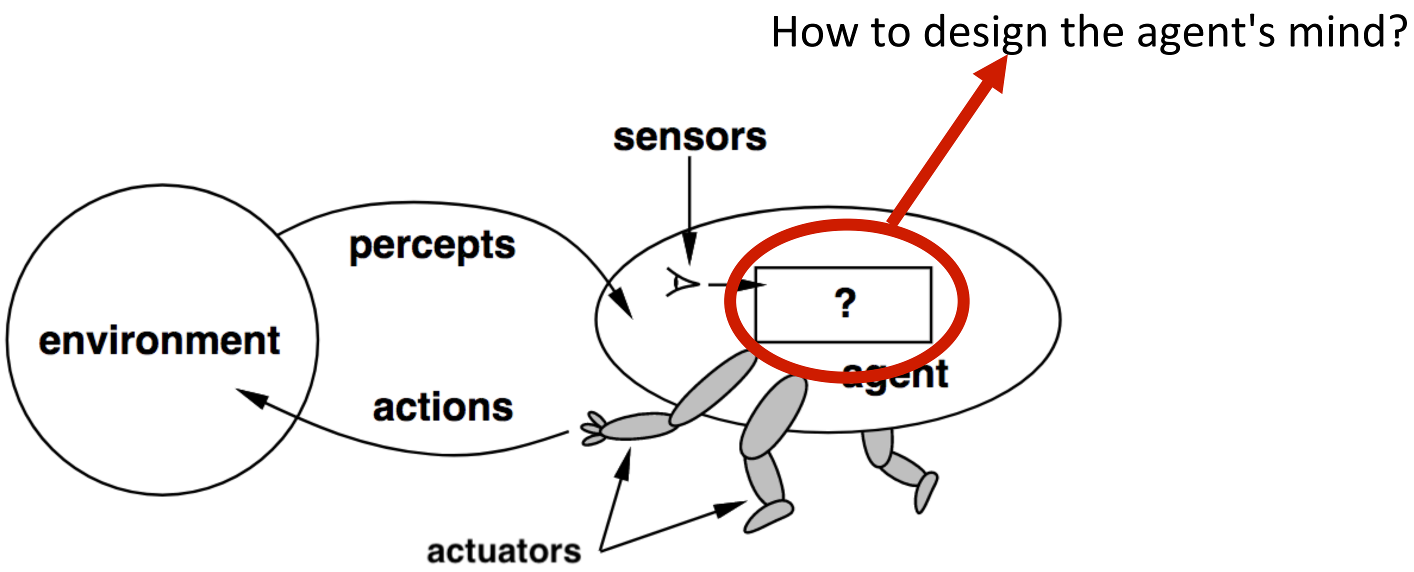
1. Introduction to Artificial Intelligence
2. Introduction to Quantum Computation
3. Quantum Computing for Artificial Intelligence
4. Artificial Intelligence for Quantum Computing

Introduction to Artificial Intelligence

Introduction to Artificial Intelligence

- The birth of artificial intelligence coincides with the “Dartmouth Summer Research Project on Artificial Intelligence”, a workshop held in 1956, where a group of scientists jointly worked to clarify and develop ideas about the so-called thinking machines.

Artificial Intelligence: definitions



- Artificial Intelligence is defined as the field as the study of "intelligent agents": any device that perceives its environment and takes actions that maximize its chance of successfully achieving its goals.

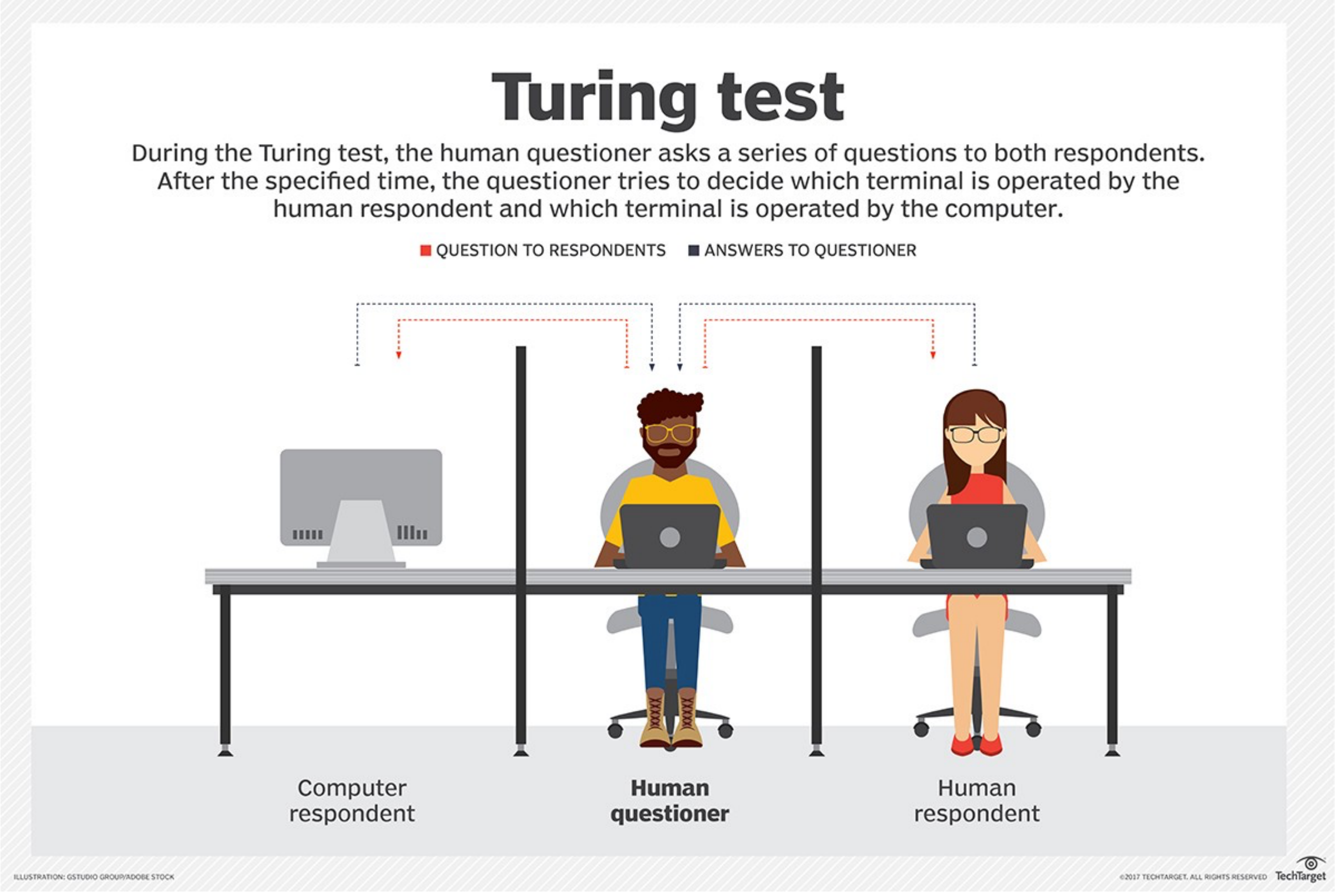
Artificial Intelligence: definitions

Thinking Humanly	Thinking Rationally
"The exciting new effort to make computers think ... *machines with minds*, in the full and literal sense." (Haugeland, 1985) "[The automation of] activities that we associate with human thinking, activities such as decision-making, problem solving, learning ..." (Bellman, 1978)	"The study of mental faculties through the use of computational models." (Charniak and McDermott, 1985) "The study of the computations that make it possible to perceive, reason, and act." (Winston, 1992)
Acting Humanly	**Acting Rationally**
"The art of creating machines that perform functions that require intelligence when performed by people." (Kurzweil, 1990) "The study of how to make computers do things at which, at the moment, people are better." (Rich and Knight, 1991)	"Computational Intelligence is the study of the design of intelligent agents." (Poole *et al.*, 1998) "AI ...is concerned with intelligent behavior in artifacts." (Nilsson, 1998)

The definitions on top are concerned with *thought processes* and *reasoning*, whereas the ones on the bottom address *behavior*. The definitions on the left measure success in terms of fidelity to *human* performance, whereas the ones on the right measure against an *ideal* performance measure, called **rationality** (Russell and Norving, 1995).

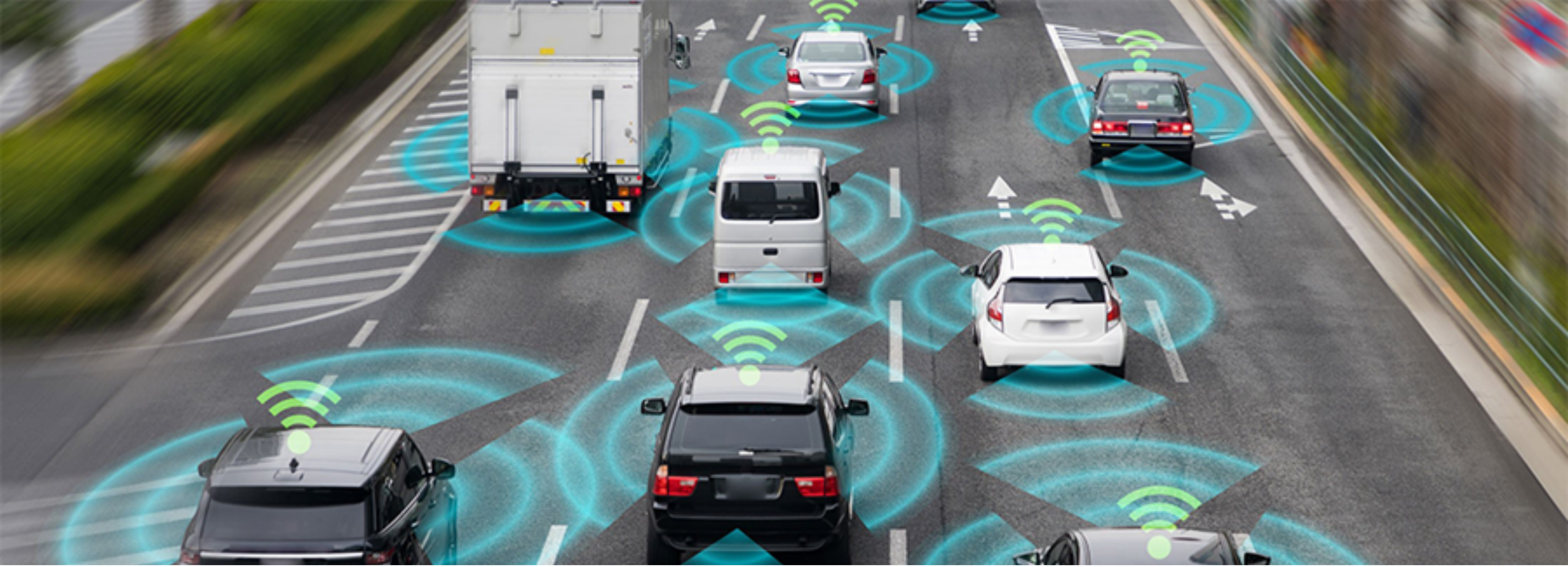
Artificial Intelligence: definitions

The capability of a machine to imitate intelligent human behavior

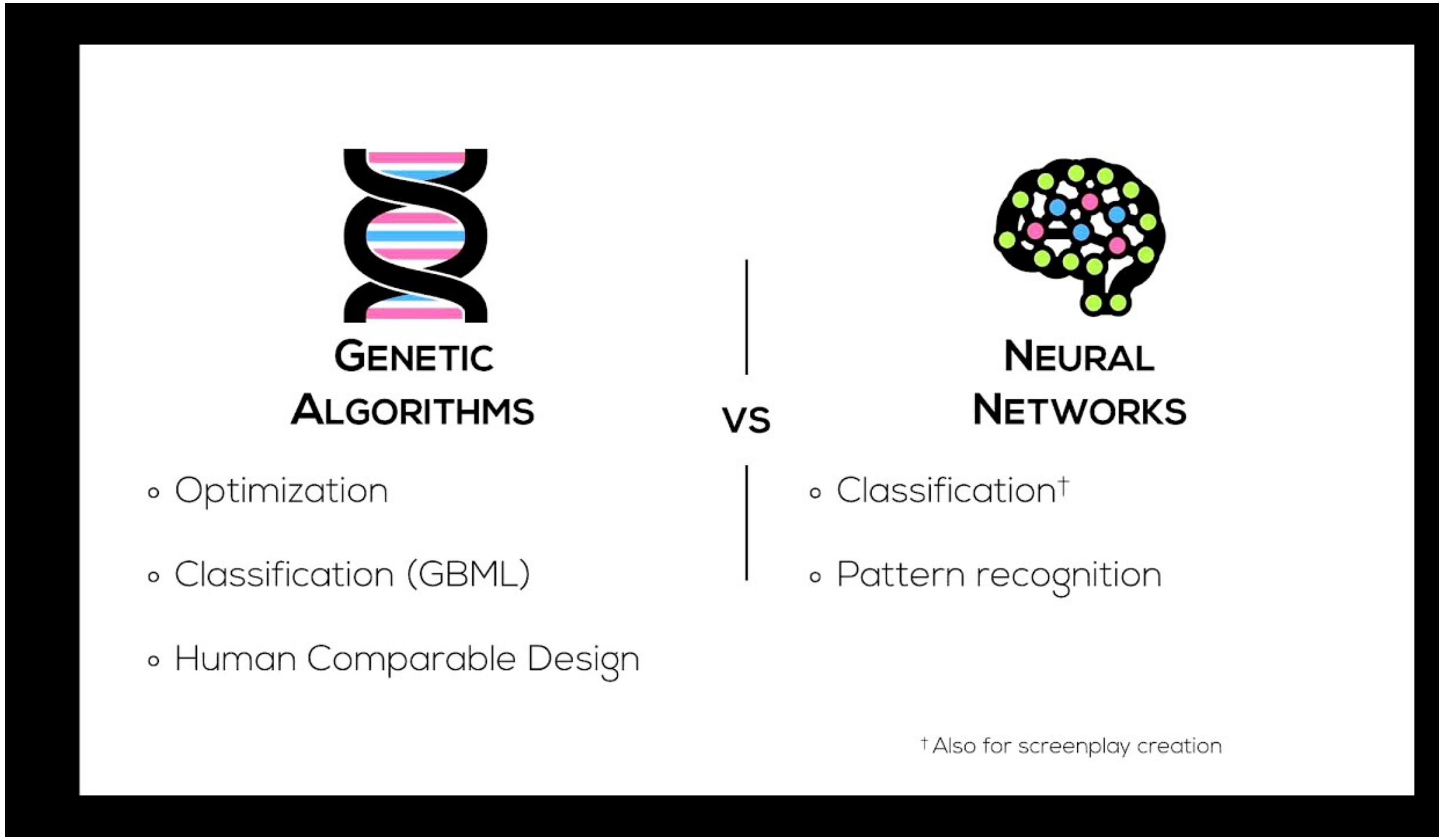


Artificial Intelligence: Definitions

- **The capability of a machine to imitate intelligent ~~human~~ natural behavior in order to optimally adapt itself to uncertain and unexpected situations in distributed environments.**



Artificial Intelligence: definitions



Artificial Intelligence: definitions

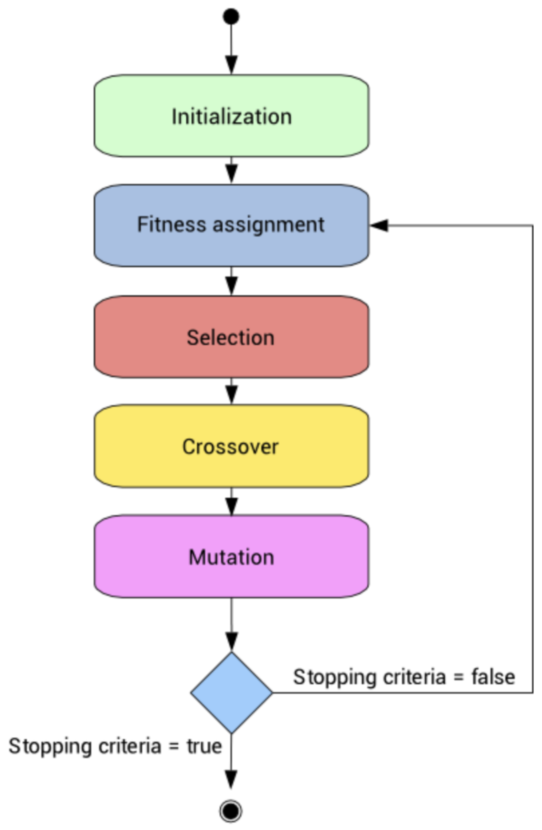
- Intelligent agents can be designed by involving different techniques. Among them:
  - Bio-inspired optimization algorithms
  - Machine learning methods

- A **genetic algorithm** (or **GA**) is a search technique used in computing to find true or approximate solutions to optimization and search problems.
- Genetic algorithms are categorized as global search heuristics.
- Genetic algorithms are a particular class of evolutionary algorithms that use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover (also called recombination).

Artificial Intelligence: GA

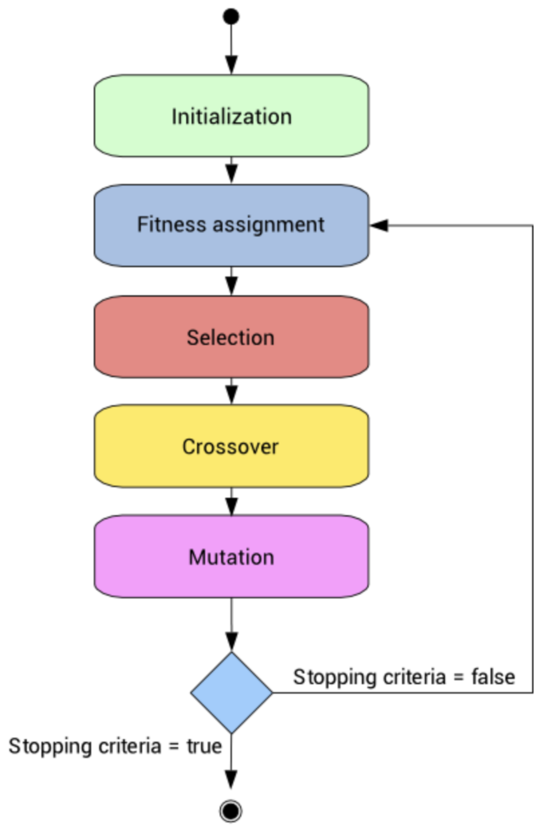
Artificial Intelligence: GA

- Genetic algorithms are implemented as a computer simulation in which a population of abstract representations (called chromosomes or the genotype or the genome) of candidate solutions (called individuals, creatures, or phenotypes) to an optimization problem evolves toward better solutions.
- Traditionally, solutions are represented in binary as strings of 0s and 1s, but other encodings are also possible.



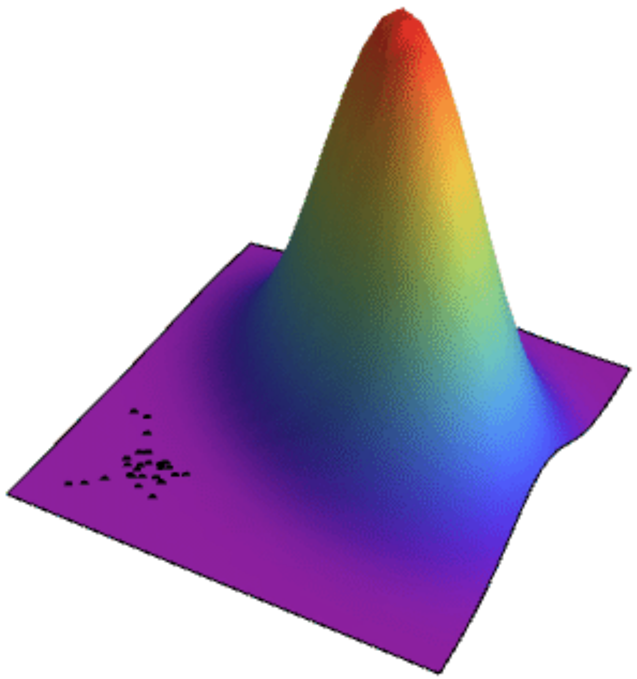
- The evolution usually starts from a population of randomly generated individuals and happens in generations.
- In each generation, the fitness of every individual in the population is evaluated, multiple individuals are selected from the current population (based on their fitness) and modified (recombined and possibly mutated) to form a new population.

Artificial Intelligence: GA



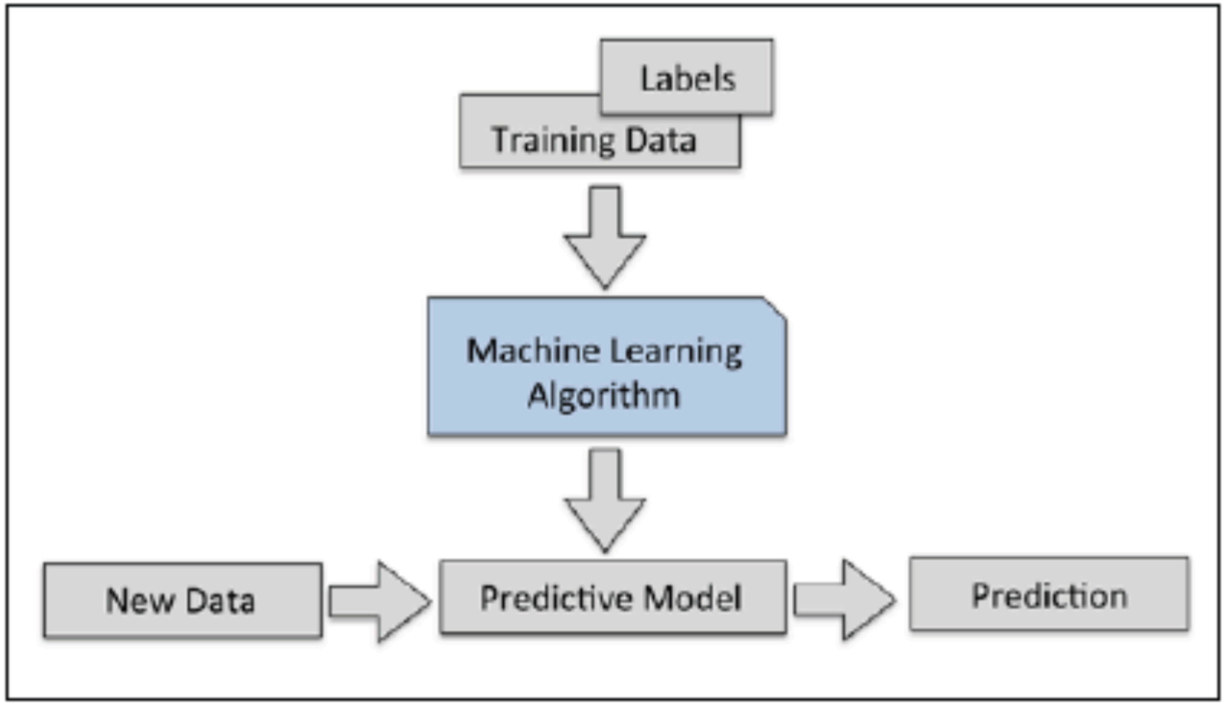
- The new population is then used in the next iteration of the algorithm.
- Commonly, the algorithm terminates when either a maximum number of generations has been produced, or a satisfactory fitness level has been reached for the population.
- If the algorithm has terminated due to a maximum number of generations, a satisfactory solution may or may not have been reached.

Artificial Intelligence: GA



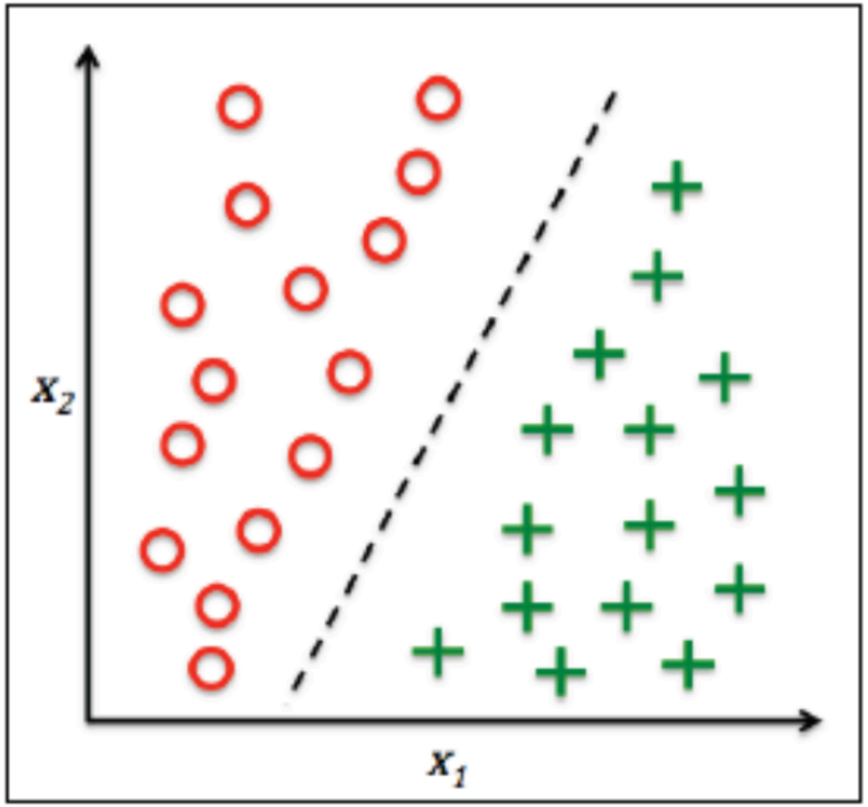
- The space of possible solutions can be described with a fitness landscape where each solution is assigned its fitness value. The goal of the genetic algorithm is to find the global maxima in this landscape which can be a challenging task when working with a complicated fitness function. The fitness landscape is typically a multidimensional surface, but in this example the elements of the population are represented as two dimensional vectors, so our fitness landscape becomes three dimensional. The simulation shows how the population evolves until reaching the global maxima.

Artificial Intelligence: GA



- Supervised learning algorithms are used to train classification and regression model starting from historical data

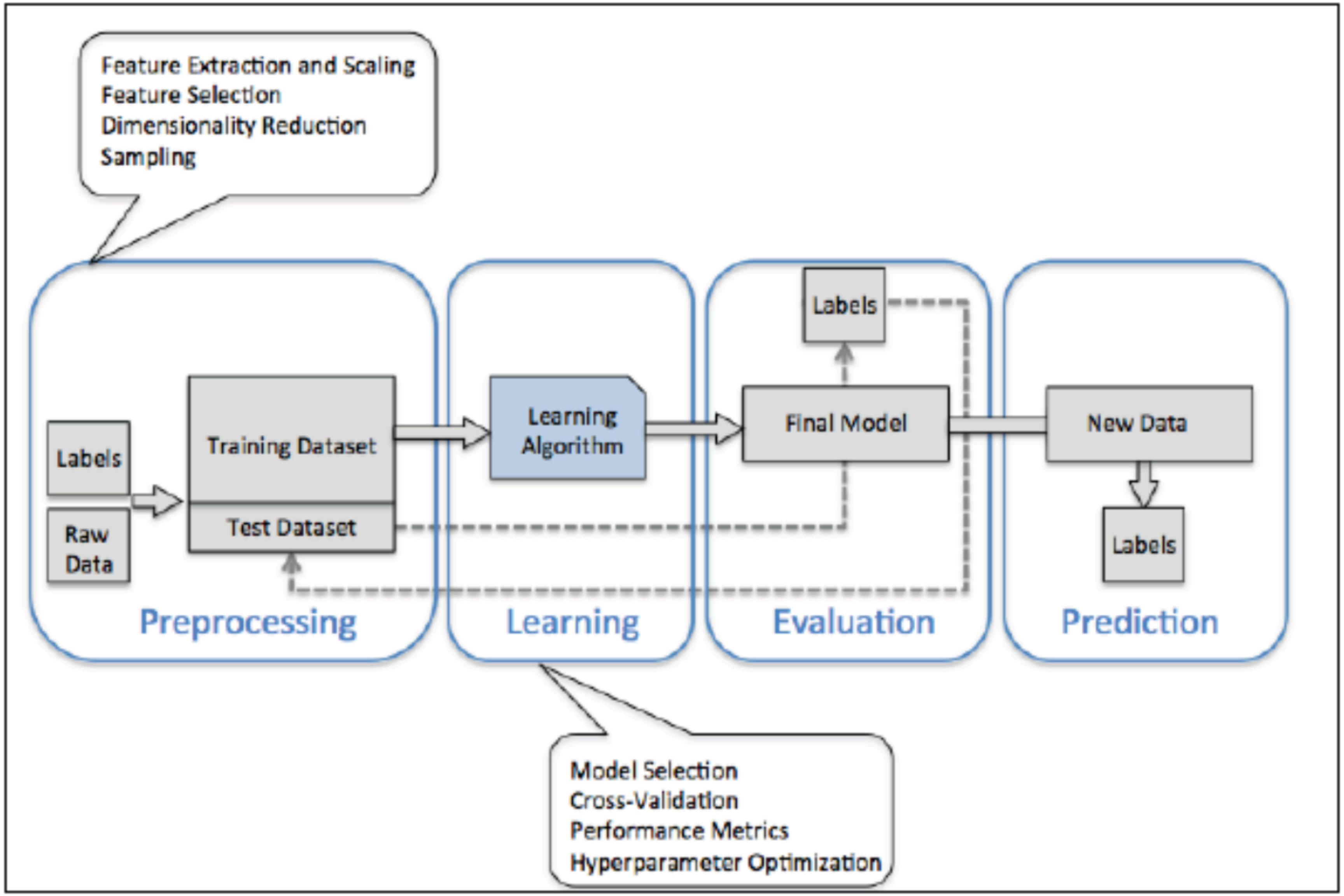
Artificial Intelligence: Supervised Learning

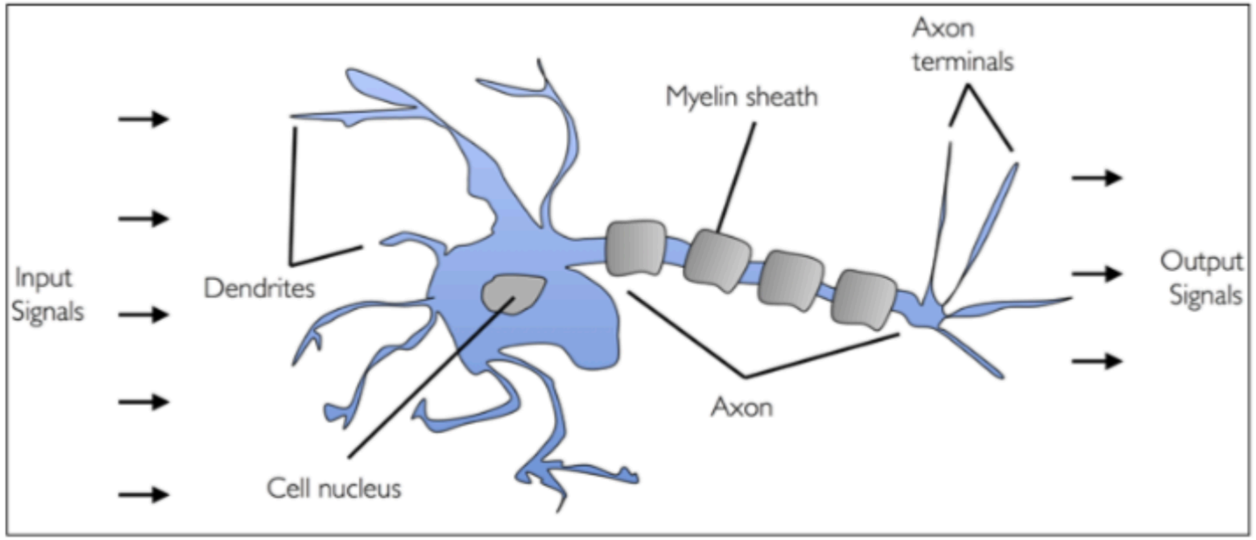


- The goal of the classification is to predict the categorical class labels of new instances based on past observations.
  - E-mail-spam detection is an example of binary classification.
  - Handwritten character recognition is an example of multi-class classification.

Artificial Intelligence: Supervised Learning

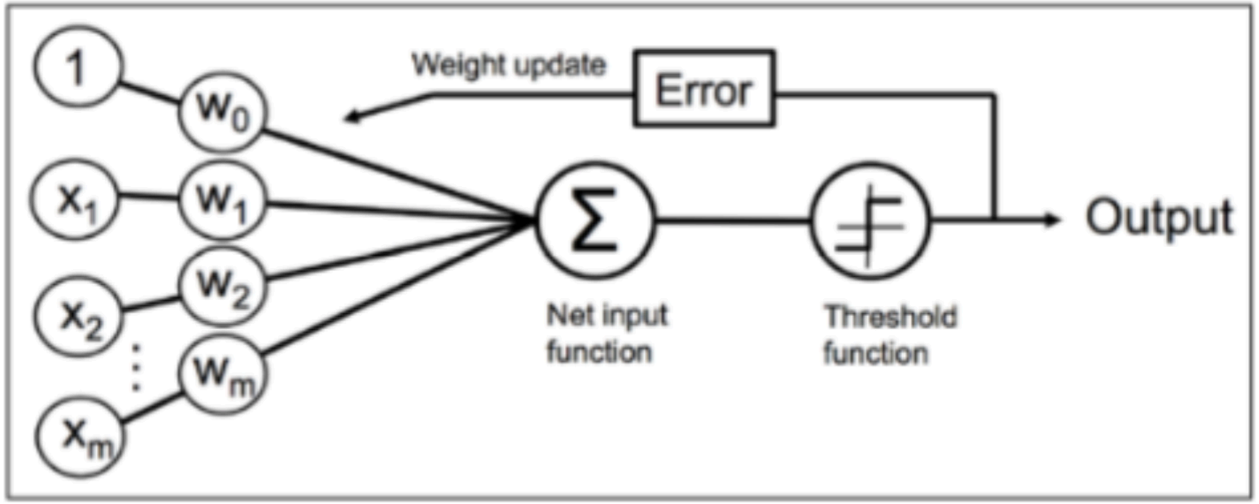
Artificial Intelligence: Supervised Learning





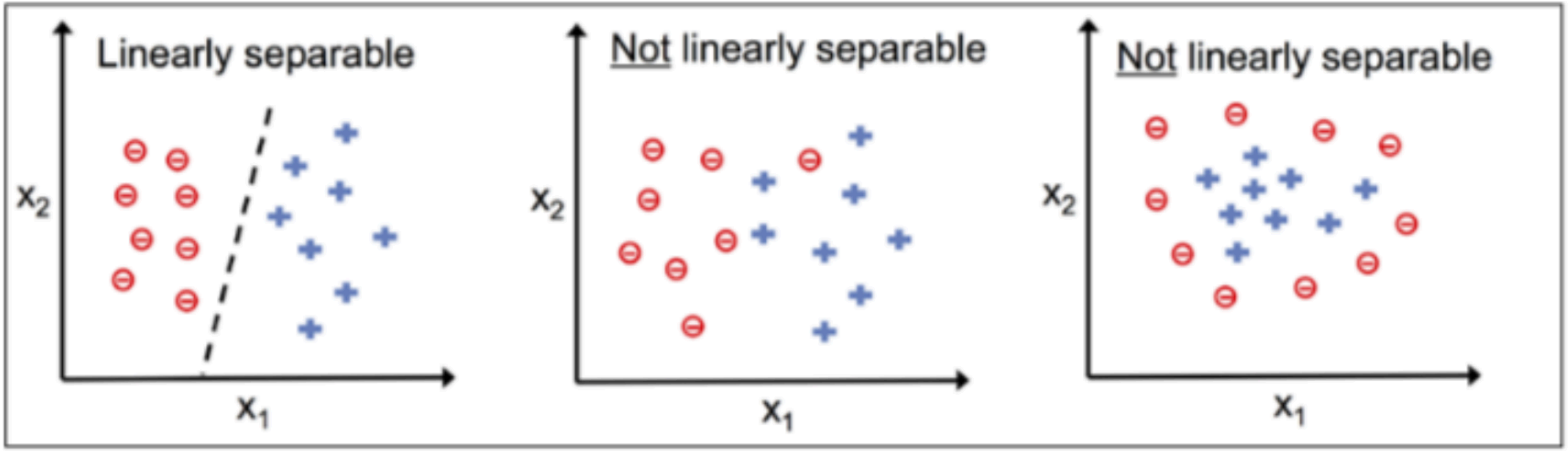
- The most simple supervised learning algorithm is based on the concept of artificial neuron, an abstract representation of a brain cell.
- The first artificial representation of a brain cell is the so-called McCulloch-Pitts (MCP) neuron introduced in 1943.
- It is completely based on the natural representation of a brain cell.

Artificial Intelligence: Supervised Learning



- McCulloch and Pitts described a brain cell as a logic gate with binary outputs;
- This gate collects and integrated the set of signals arriving at cell body;
- If the value of the integrated signals exceeds a given threshold, an output signal is generated and passed to other artificial cells by means of axons.

Artificial Intelligence: Supervised Learning

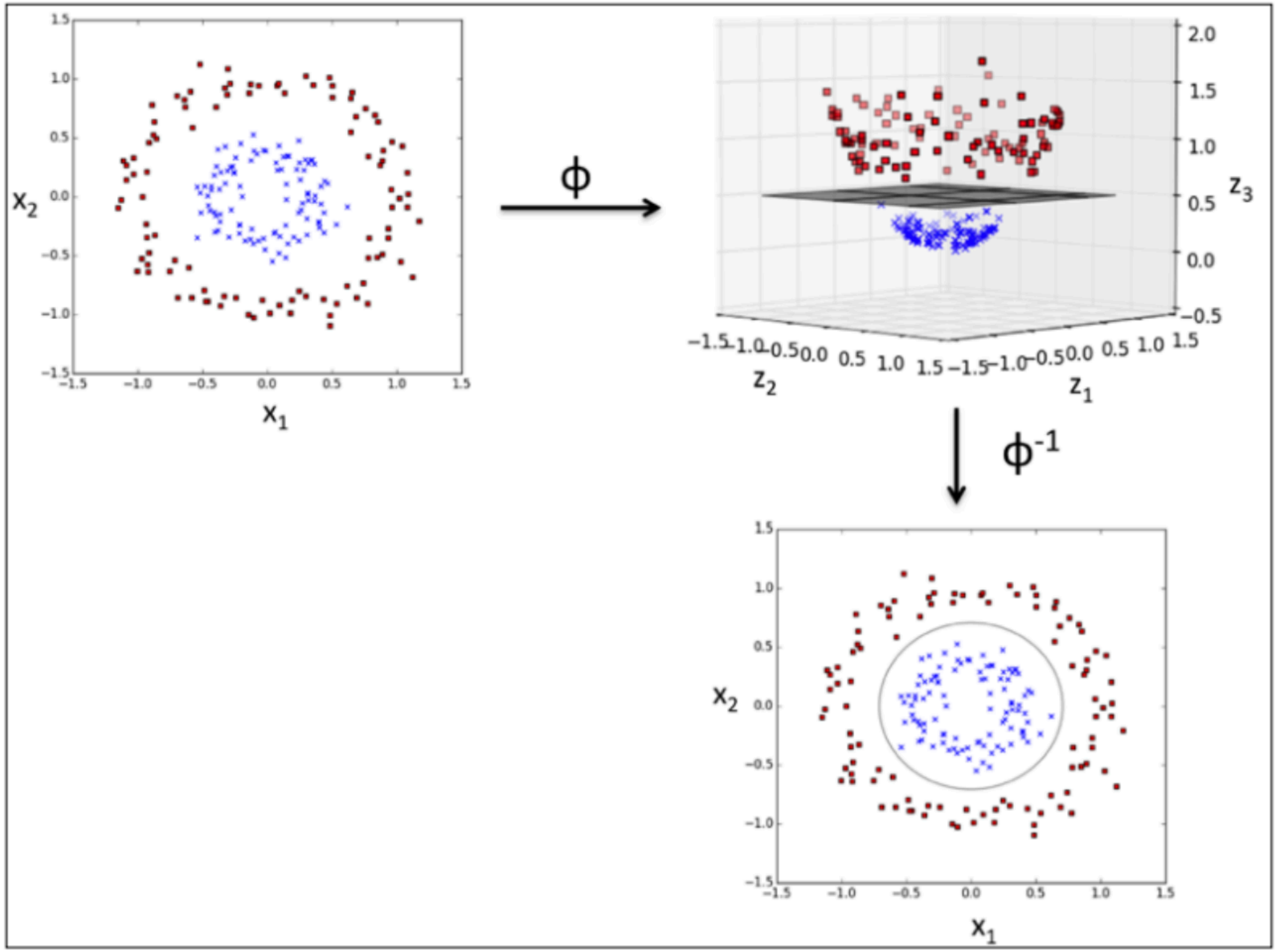


Artificial Intelligence: Supervised Learning

- The convergence of a neuron is only guaranteed if the two classes are linearly separable
- Other similar algorithms: Logistic regression, SVM, etc.

Artificial Intelligence: Supervised Learning

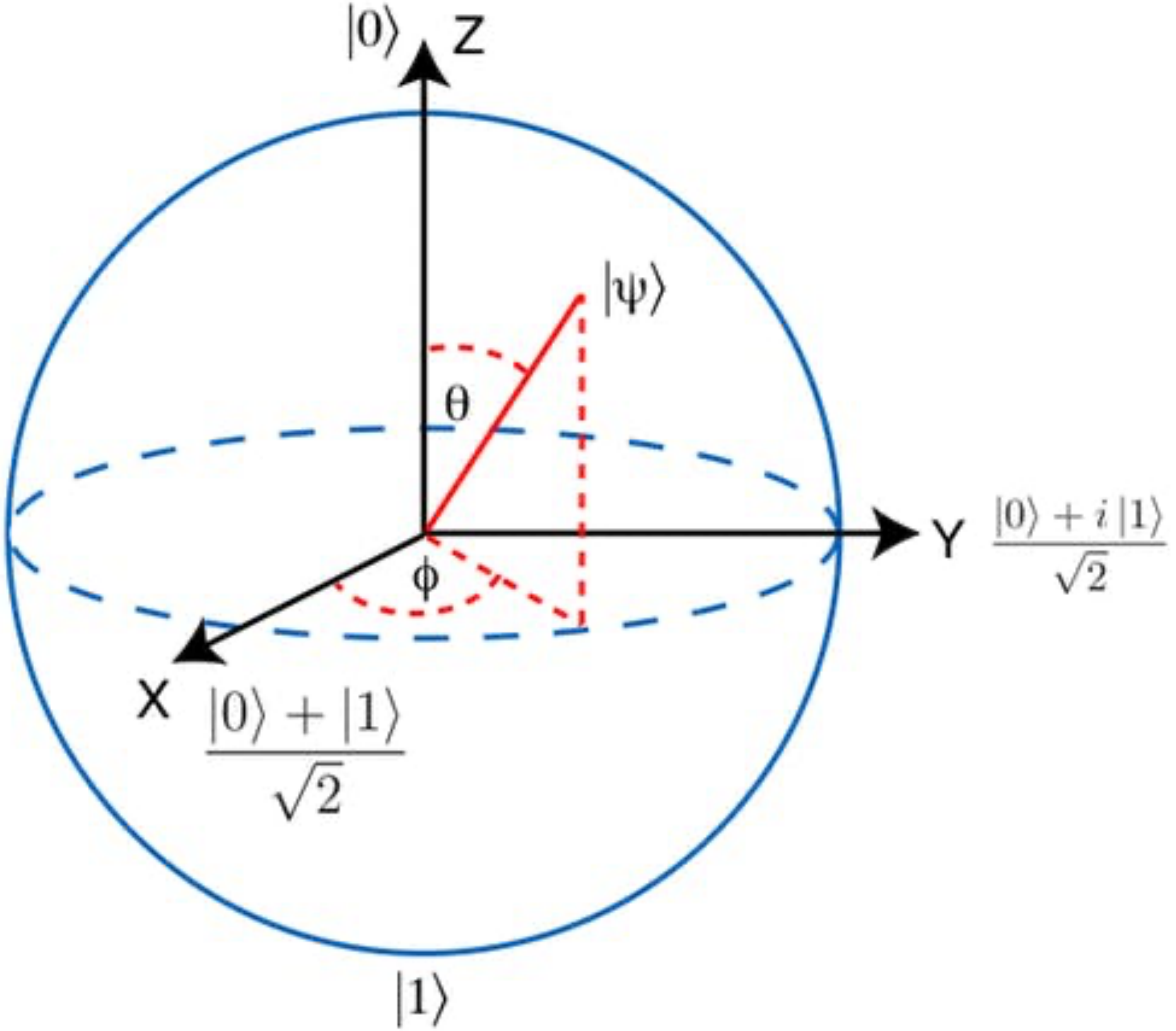
Kernel Functions



Can alternative computation paradigm improve the performance of AI systems?

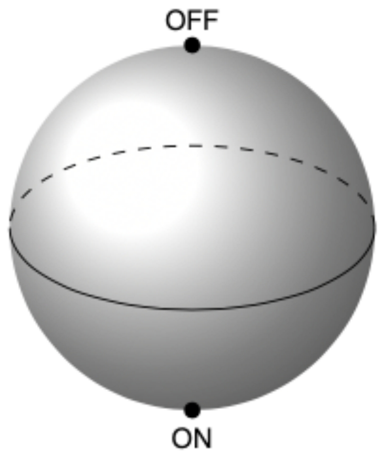
Can AI to be used for improving the design of alternative computation paradimg?

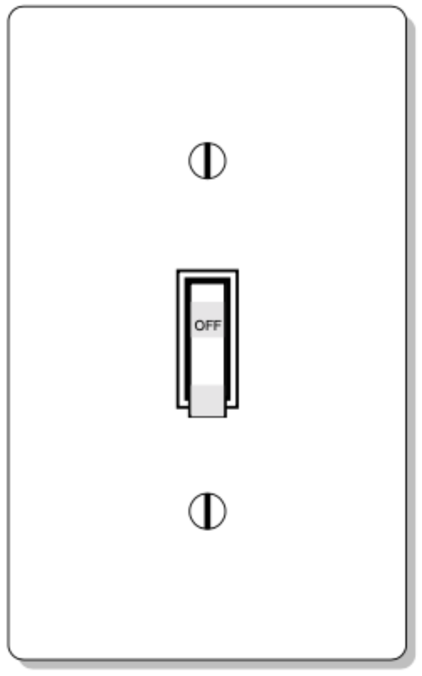
Introduction to Quantum Computation



Quantum Computing: Definitions

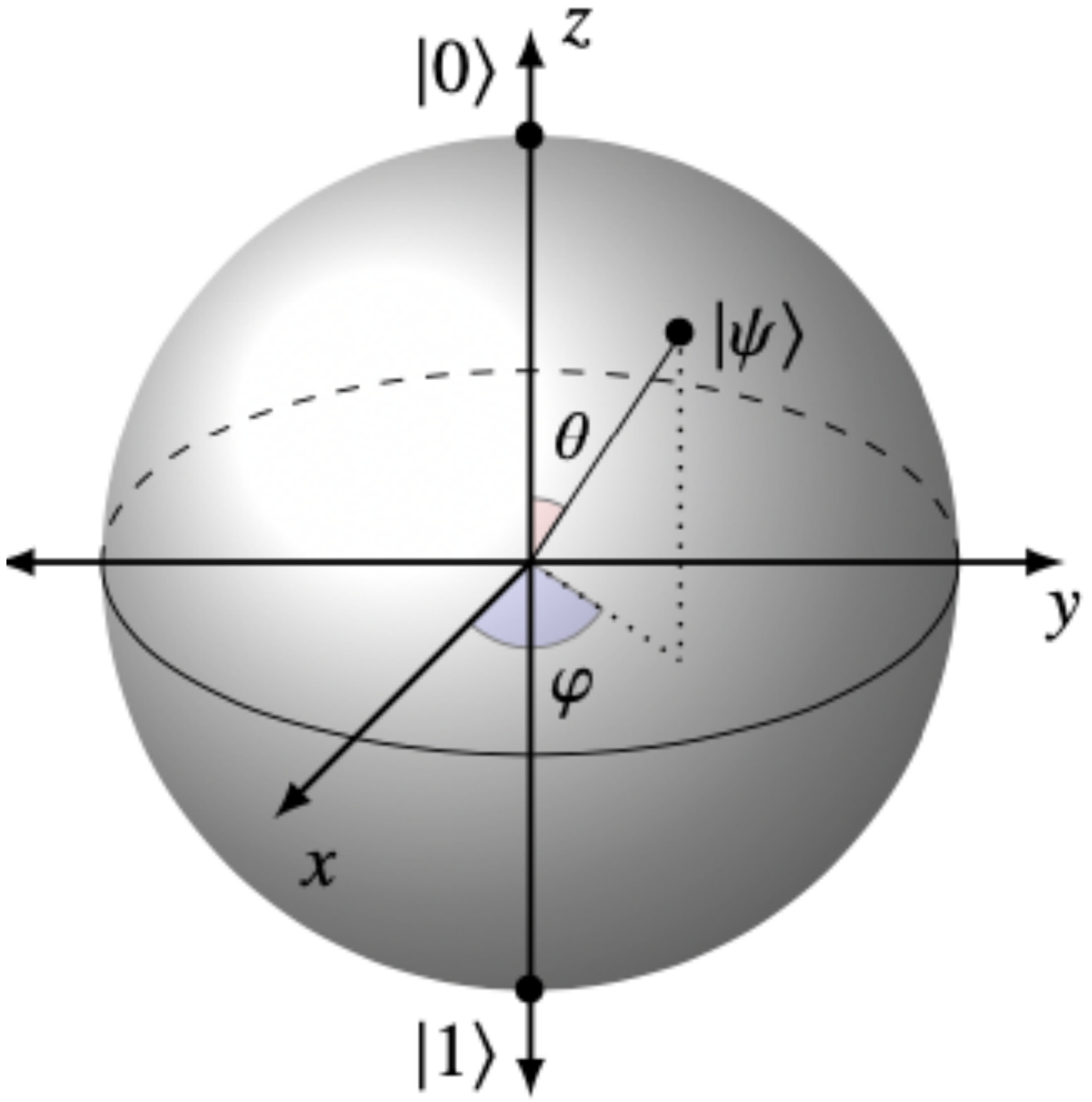
- Quantum Computing is the use of quantum-mechanical phenomena such as superposition and entanglement to perform computation better than classical computers.
- It uses the concepts of Qubit to store information

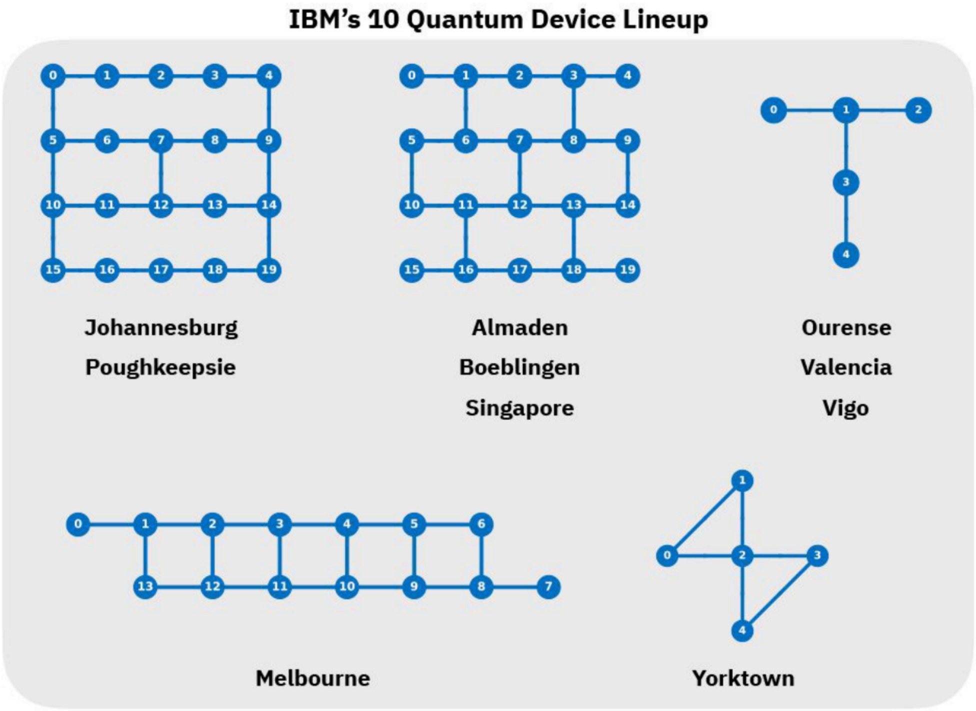


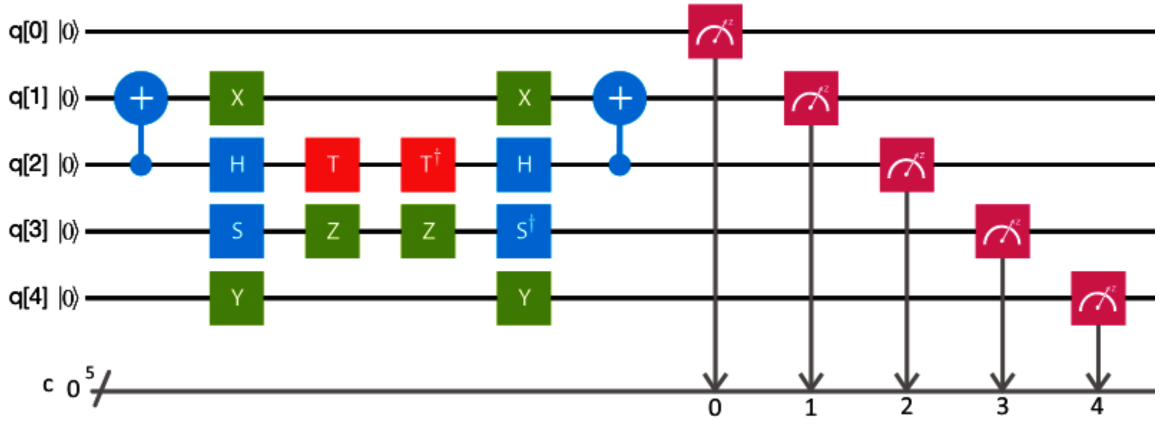


Quantum Computing: Definitions

- In the diagram on the right, the position of your finger on the qu-switch is now indicated by two angles, θ and φ. The picture itself is called a Bloch sphere and is a standard representation of a qubit.
- Quantum gates transform quantum information contained in qubits
  - Quantum gates are reversible
  - It is its own reverse (or *inverse*) operation. Applying it two times in a row is the same as having done nothing at all.



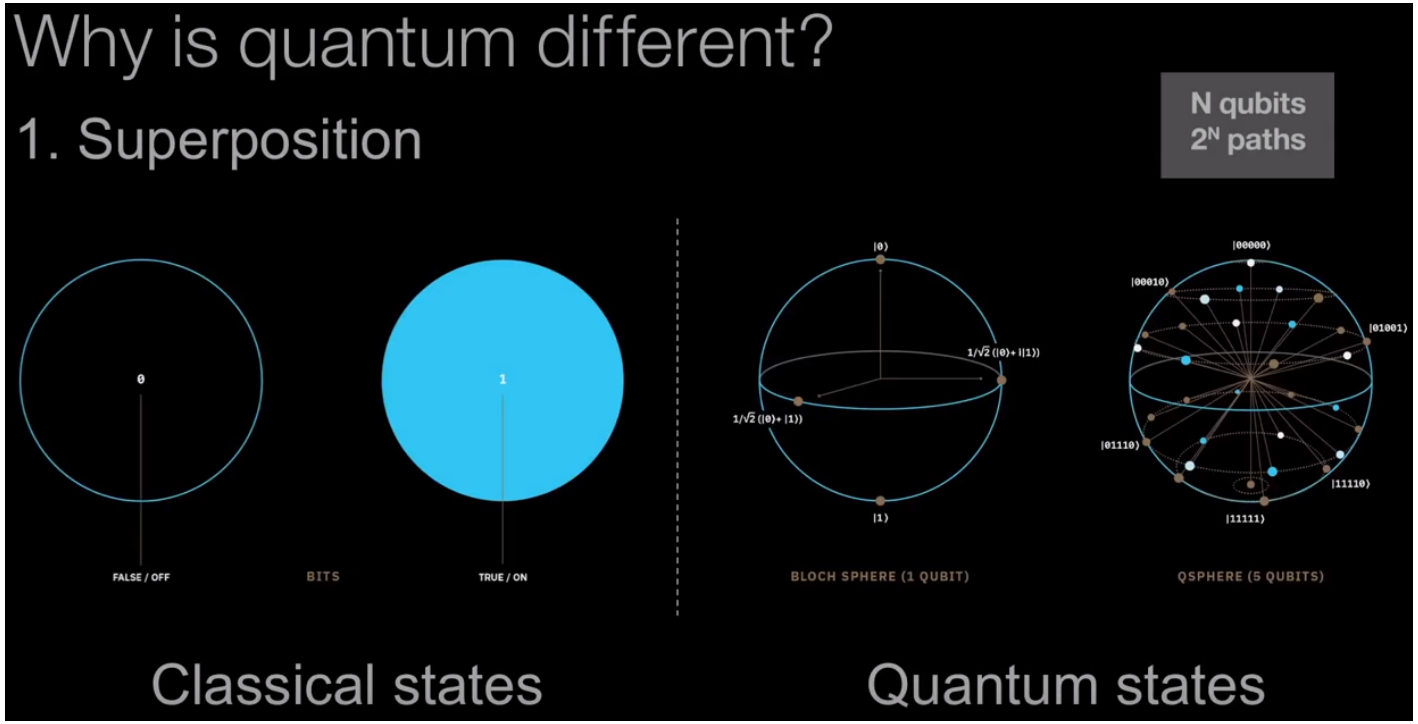




Quantum Computing: Definitions

- Quantum Processors (IBM)
- Quantum Circuits

Quantum Computing: Definitions



- Quantum is different is in how it can work with simultaneous values.
- Classical computers uses bytes as the individual units of memory or storage. A byte is broken down into eight bits. Each bit can be 0 or 1. Doing the math, each byte can represent $2^8 = 256$ different numbers composed of eight 0s or 1s, but it can only hold *one value at a time*.
- Eight qubits can represent all 256 values *at the same time*.

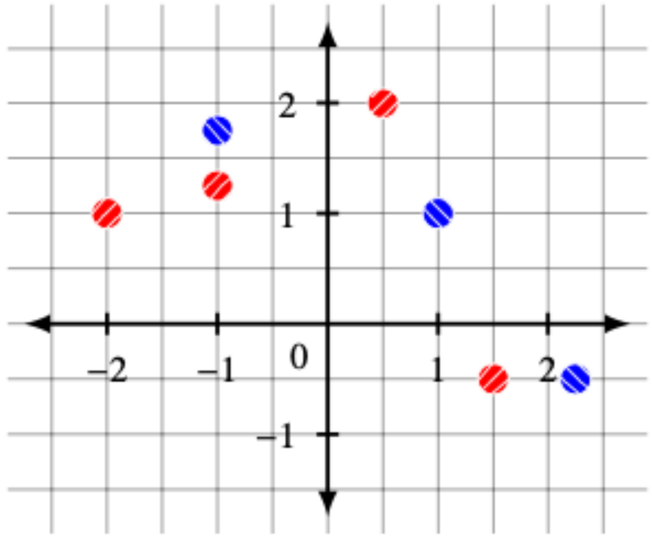
Quantum Computing for Artificial Intelligence

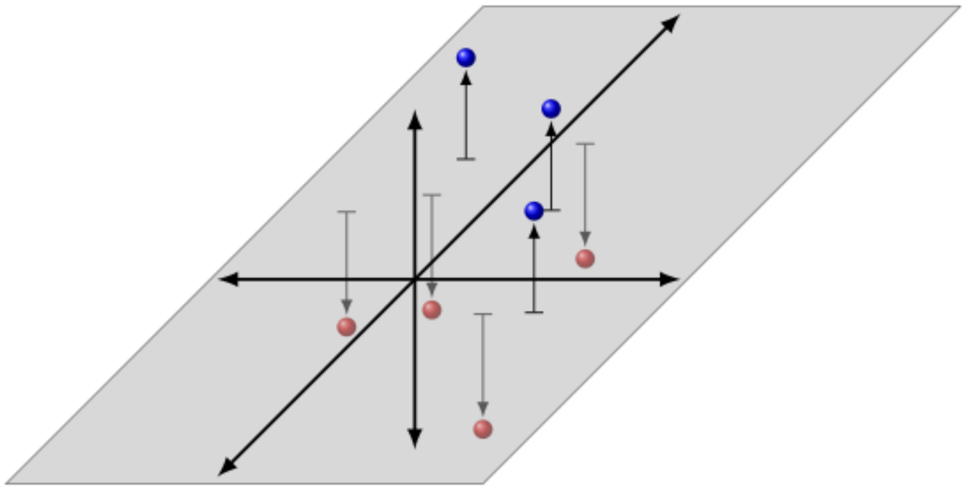
Quantum for AI

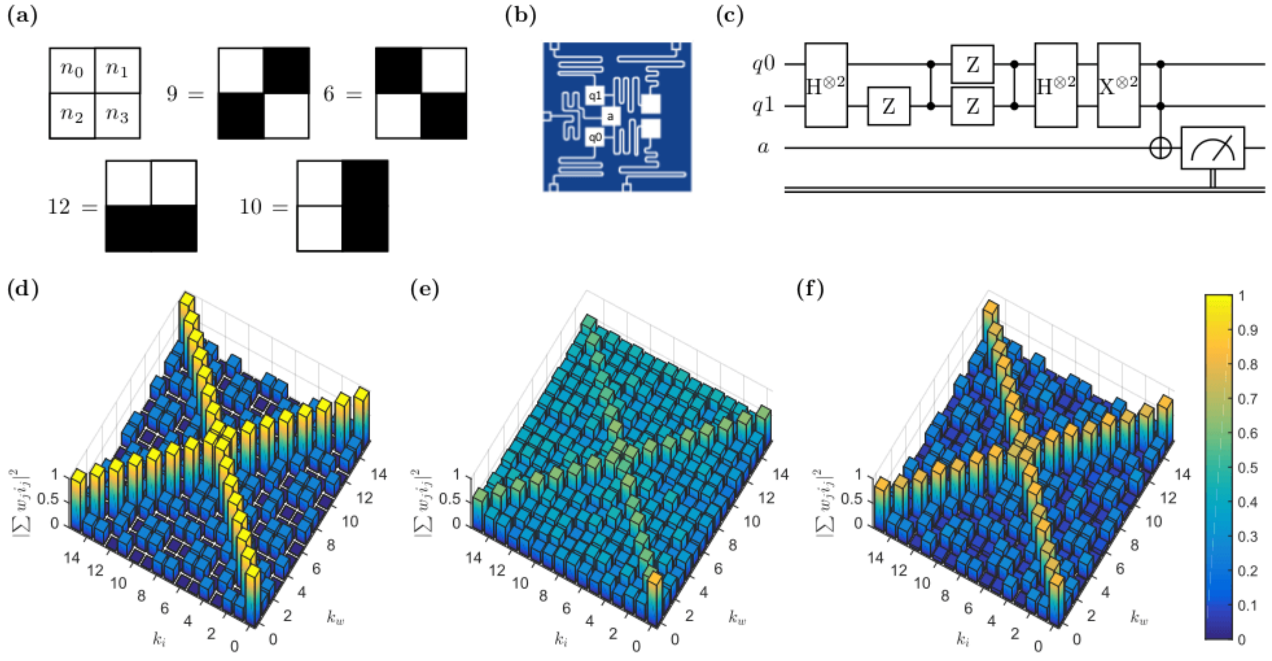
- These three cases are in some sense the “small, medium, and large” ways quantum computing might complement classical techniques:
  - There is a single mathematical computation somewhere in the middle of a software component that might be sped up via a quantum algorithm.
  - There is a well described component of a classical process that could be replaced with a quantum version.
  - There is a way to avoid the use of some classical components entirely in the traditional method because of quantum, or the entire classical algorithm can be replaced by a much faster or more effective quantum alternative.

Quantum for AI

- There is a single mathematical computation somewhere in the middle of a software component that might be sped up via a quantum algorithm.
- A quantum computer with 1 qubit provides us with a two-dimensional working space. Every time we add a qubit, we double the number of dimensions. For 10 qubits, we get 2^{10} = 1024 dimensions. Similarly, for 50 qubits we get 2^{50} = 1, 125, 899, 906, 842, 624 dimensions.



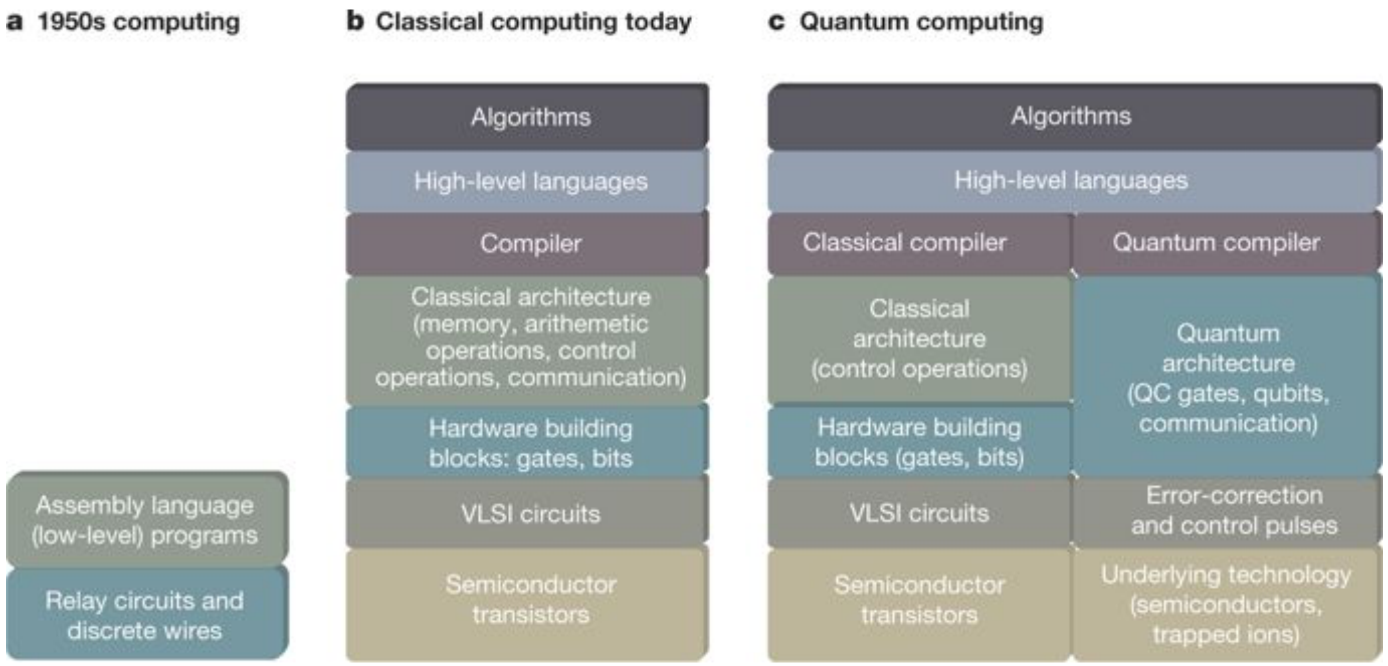




- There is a way to avoid the use of some classical components entirely in the traditional method because of quantum, or the entire classical algorithm can be replaced by a much faster or more effective quantum alternative.
- Tacchino et al. introduced a quantum information-based algorithm implementing the quantum computer version of a binary-valued perceptron, which shows exponential advantage in storage resources over alternative realizations. They experimentally test a few qubits version of this model on an actual small-scale quantum processor, which gives answers consistent with the expected results.

Artificial Intelligence for Quantum Computing

Artificial Intelligence for Quantum Computing

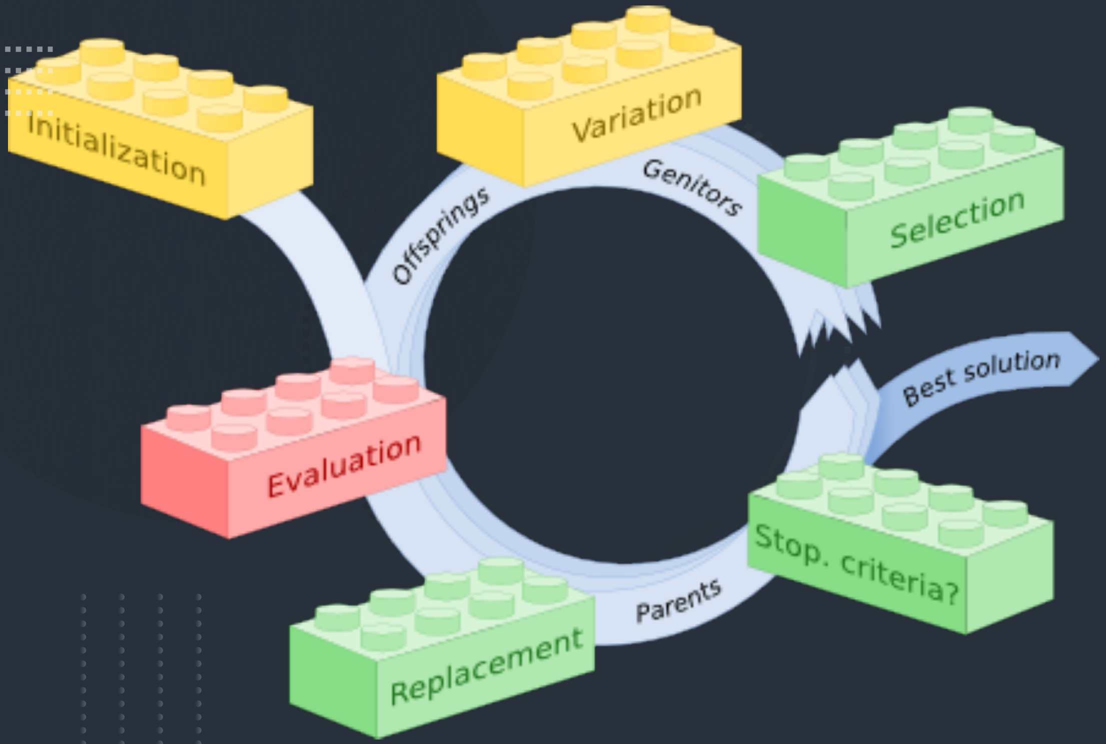


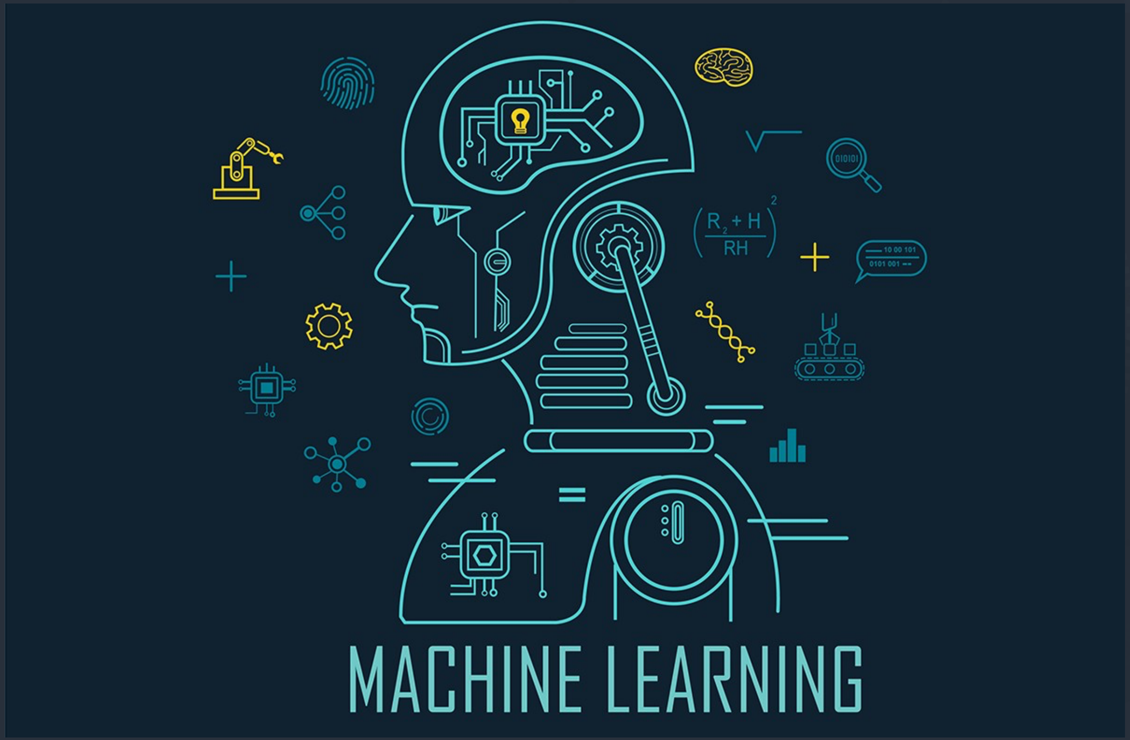
Artificial Intelligence for Quantum Computing

- Every quantum computer experiences decoherence, but quantum computers that are successful at delaying and minimizing decoherence perform better. That's why, when discussing a quantum computer and its ability to do computation, we need to discuss how well it does at preventing decoherence. To quantify that, the parameters T_1 and T_2 are particularly important:
  - T_1 helps to quantify how quickly the qubits experience energy loss due to environmental interaction (energy loss would result in a change in frequency, which would make coherent qubits experience decoherence).
  - T_2 helps to quantify how quickly the qubits experience a phase change due to interaction with the environment, again a cause of decoherence.

Artificial Intelligence for Quantum Computing

- Evolutionary algorithms could be useful to “compile” quantum circuits in order to generate equivalent circuits characterized by a better values of T_1 and T_2
- Pattern recognition techniques could be used to identify critical sequence of quantum gates in circuits and replace them with suitable collections of gates in order to improve T_1 and T_2






شكراً جزيلاً
thank you
danke
謝謝
ngiyabonga
teşekkür ederim
рахмат
Баярлалаа
спасибо
faafetai lava
mersi
kia ora
barka
welalin
tack
spas
vinaka
спасибі
blagodaram
dank je
misaotra
matondo
paldies
grazzi
mahalo
tapadh leat
gracias
хвала
asante
manana
obrigada
tenki
murakoze
kiitos
dankie
nanni
nandri
dhanyavad
mauruuru
köszönöm
hvala
gràcie
bayarlalaa
bedankt
enkosi
dziękuję
dankon
ačiū
akun
mochchakkeram
djiere dieuf
tau
дякую
mamnun
chokrane
chnorakaloutioun
gratias ago
gràcies
sulpáy
go raibh maith agat
sobodi
dēkuji
obrigado
sagolun
sukriya
kop khun krap
taiku
arigatô
takk
dakujem
trugarez
mèsi
didi madloba
ありがとう
najis tuke
terima kasih
tanemirt
grazie
rahmet
ευχαριστώ
diolch
dhanyavadagalu
shukriya
mercé
мерси
kam sah hamnida
rahmat
তোমাকে ধন্যবাদ
감사합니다
xièxie
merci