University of Stuttgart
Institute for Computational Physics

SimTech

Topical Meeting – Machine Learning

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Overview:

Simulating Stochastic Processes with Quantum Devices

Part I

May 11th, 2022

About Me

- B.Sc. + M.Sc. Simulation Technology
- Since high school interested in ***Machine Learning***
- Since university interested in ***Quantum Computing***
- Ph.D. → ***Quantum Machine Learning***

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- B.Sc. + M.Sc. Simulation Technology
- Since high school interested in ***Machine Learning***
- Since university interested in ***Quantum Computing***
- Ph.D. → ***Quantum Machine Learning***
- My focus: holism and real-world scenarios
- Application: simulation of stochastic processes

Agenda

- Today:
  - Simulation of stochastic processes
  - Why quantum computing is relevant here

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- Today:
  - Simulation of stochastic processes
  - Why quantum computing is relevant here
- Next time:
  - What is the connection to machine learning?

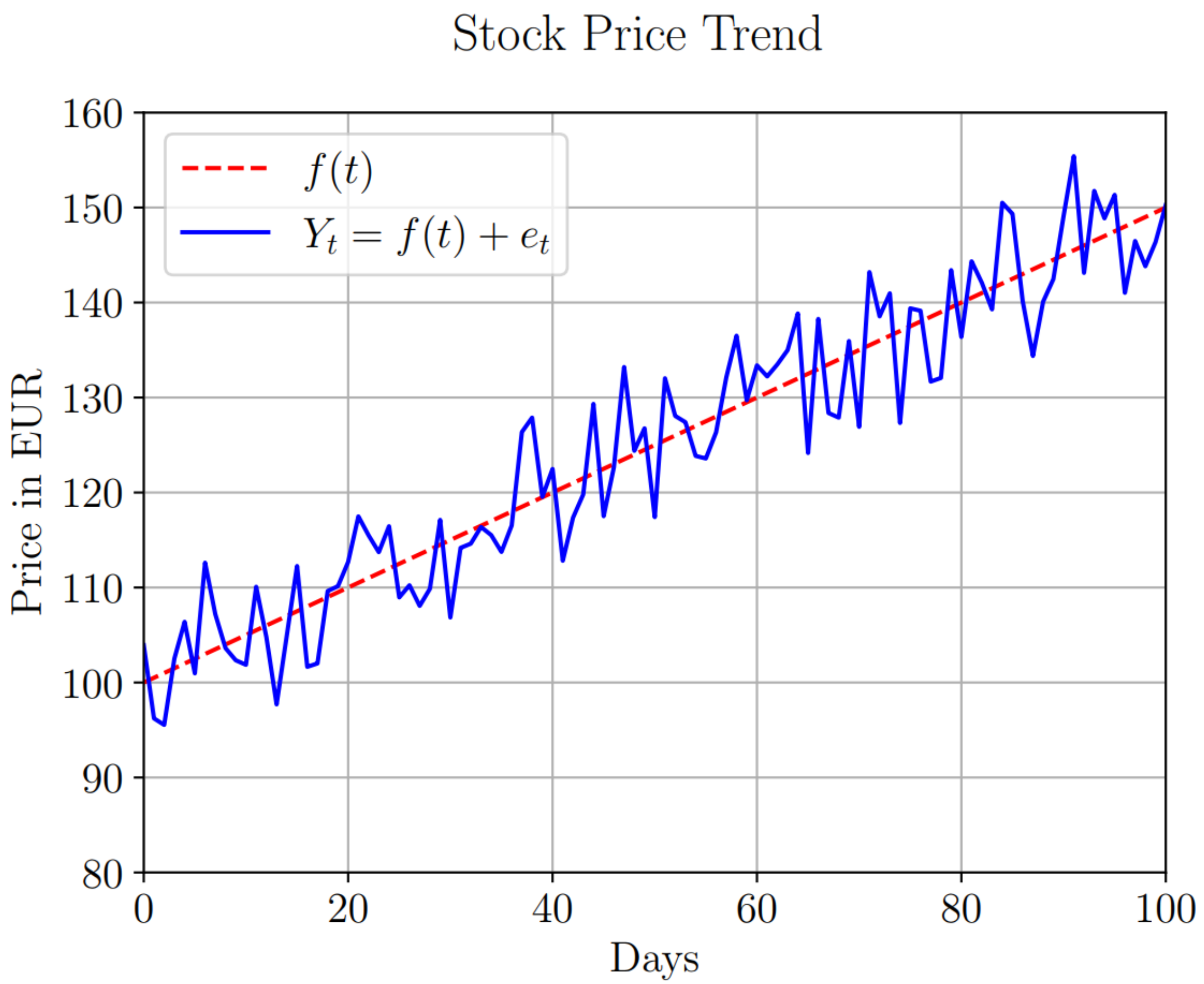
Simulating Stochastic Processes

Stochastic Processes

Assume linear trend $f(t)$

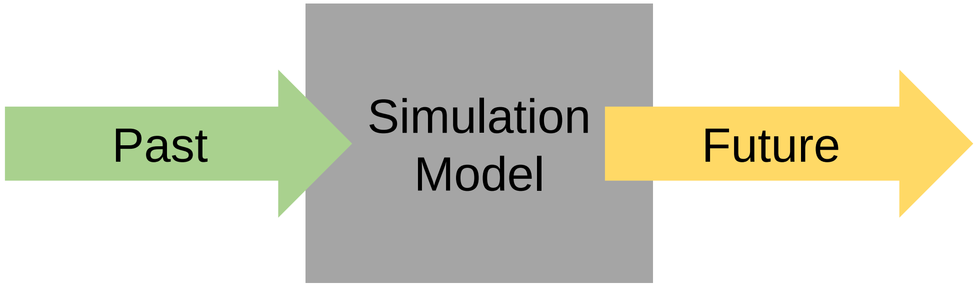
Add some noise e_t

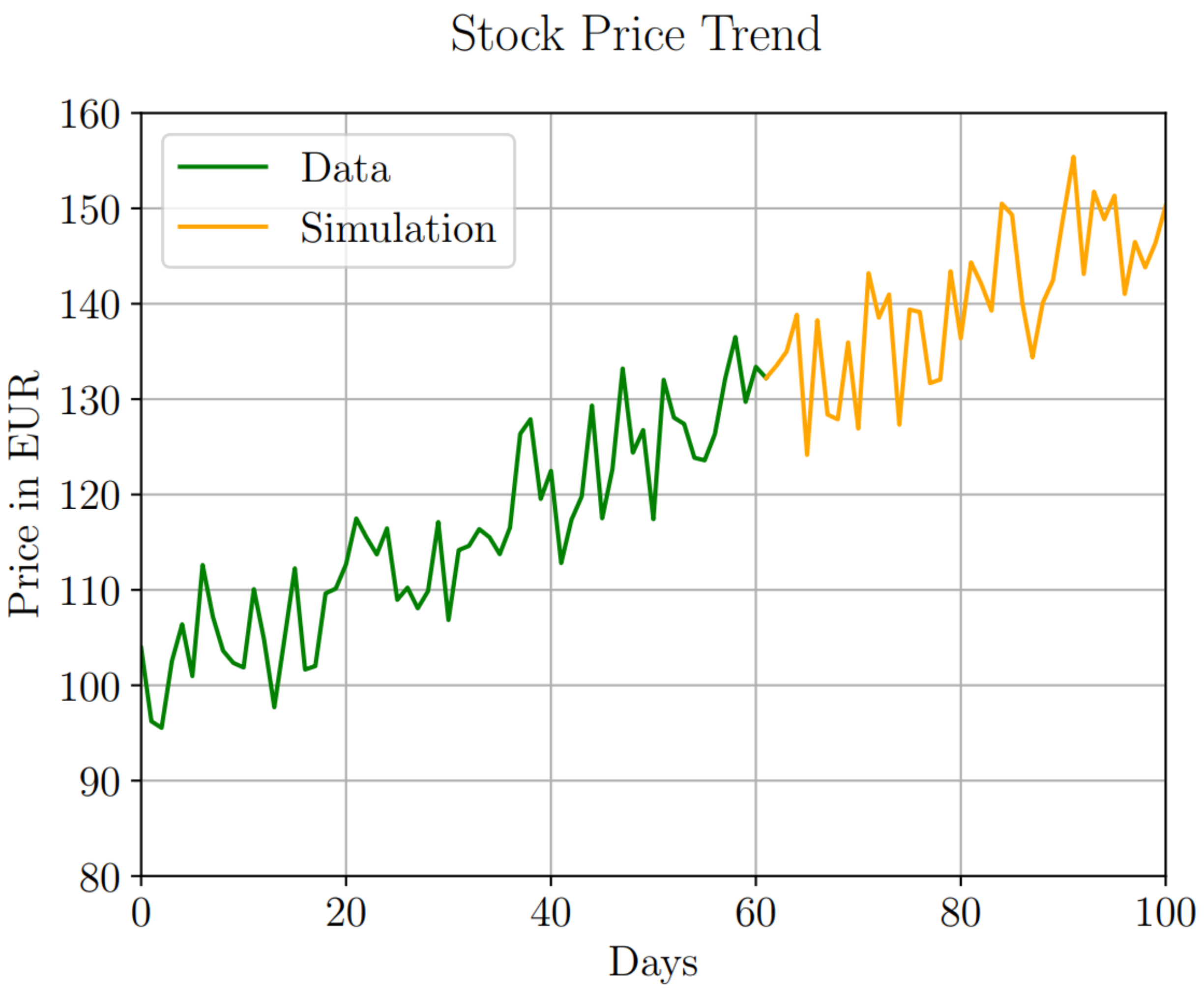
→ e_t is a stochastic process



Stochastic Processes

Assume data drawn
by a stochastic process





Stochastic Processes

An easy example: flipping a coin

0

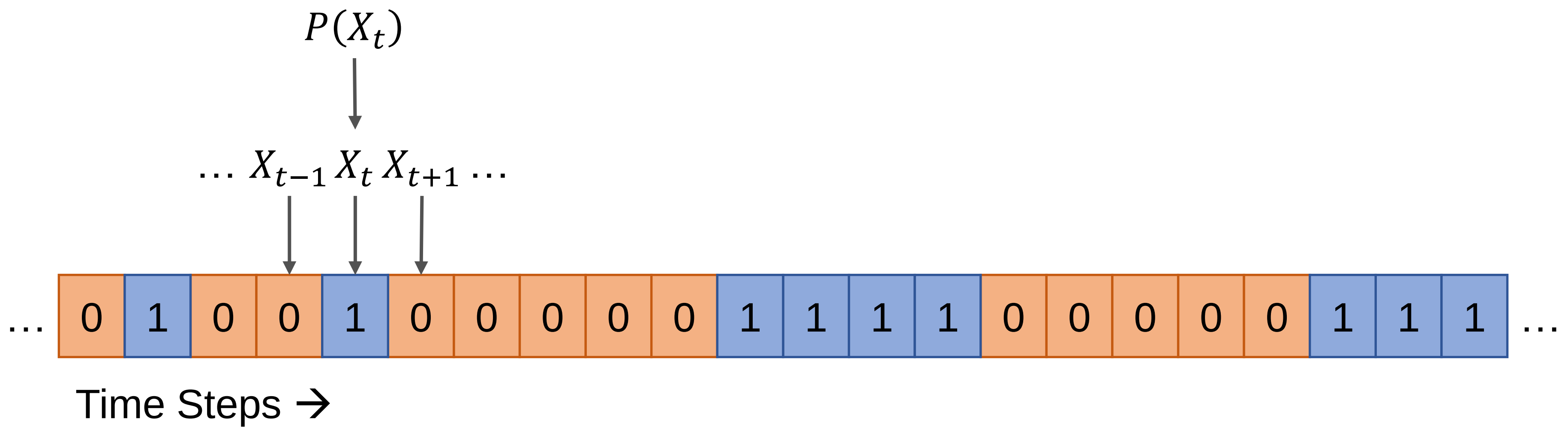
1

Stochastic Processes

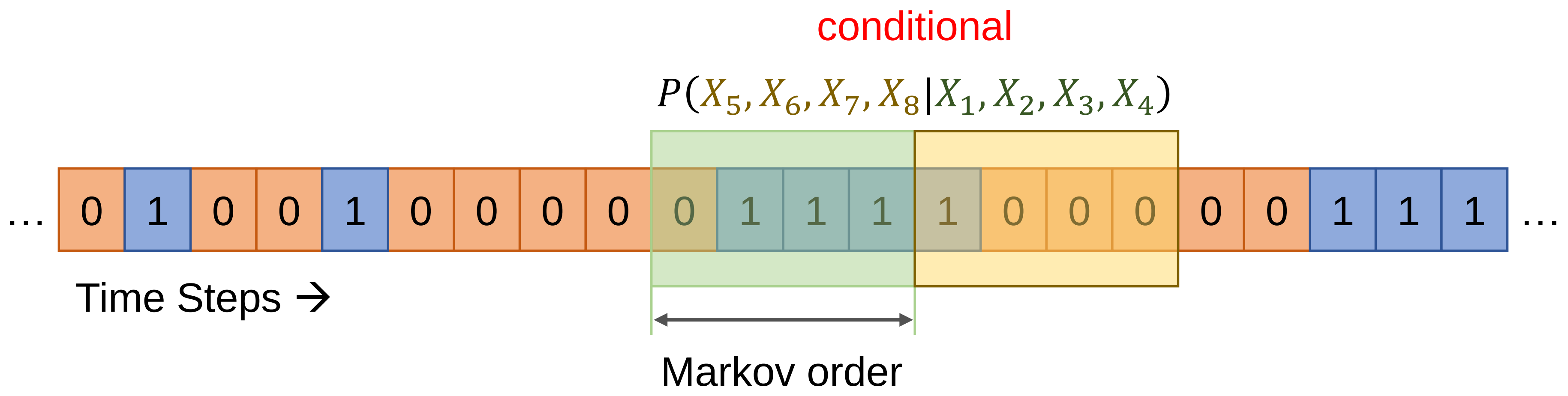
…	0	1	0	0	1	0	0	0	0	0	1	1	1	1	0	0	0	0	0	1	1	1	…

Time Steps →

Stochastic Processes



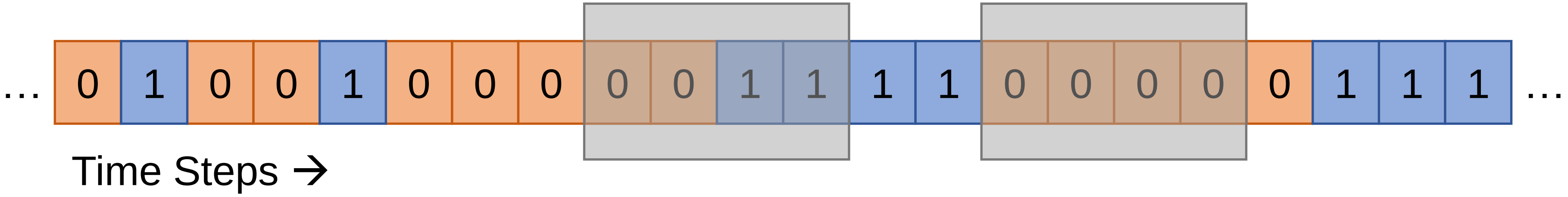
Stochastic Processes



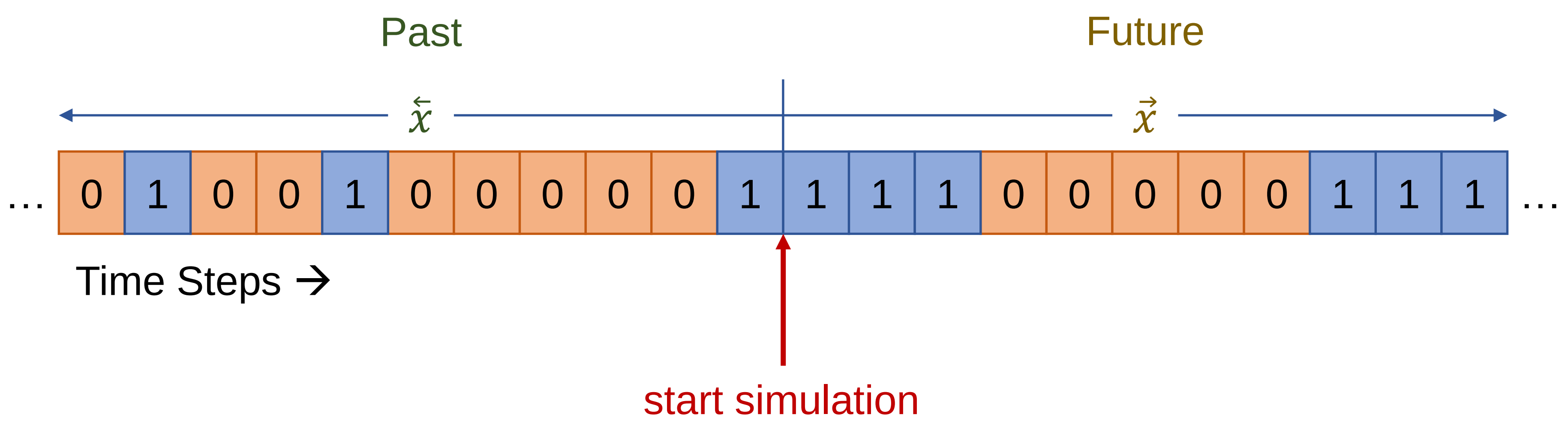
Stochastic Processes

stationary

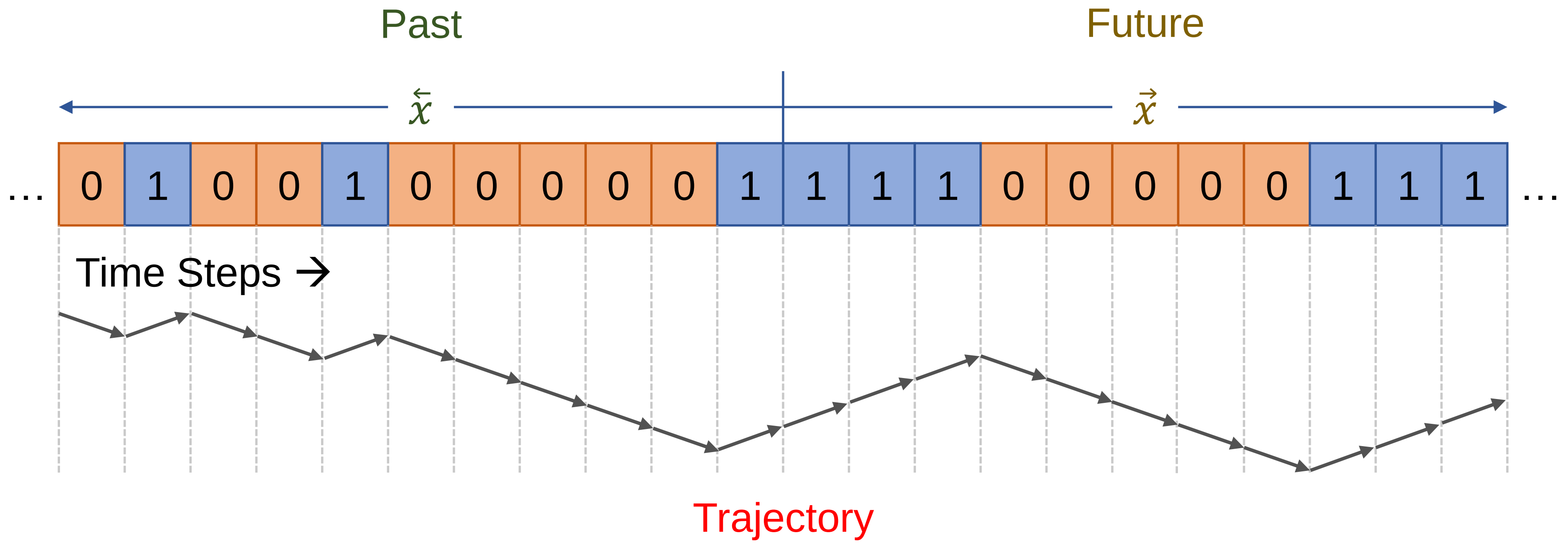
$$P(X_1, X_2, X_3, X_4) \;=\; P(X_5, X_6, X_7, X_8)$$



Stochastic Processes

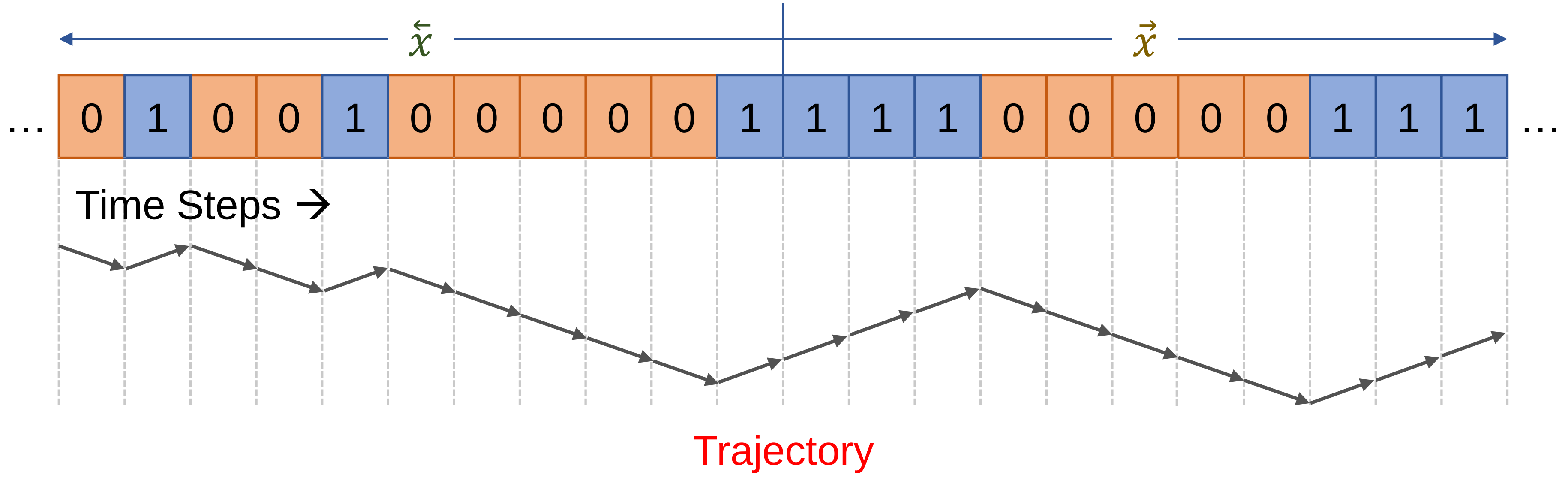


Stochastic Processes



Stochastic Processes

- Simulating = sampling trajectories
- Trajectory is governed by $P\left(\vec{X}|\overleftarrow{X}\right)$



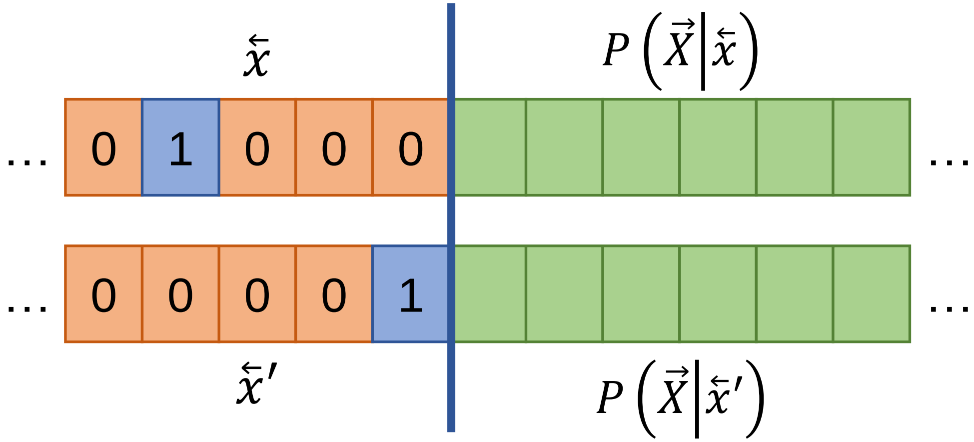
Why Stochastic Processes?

Stochastic Processes

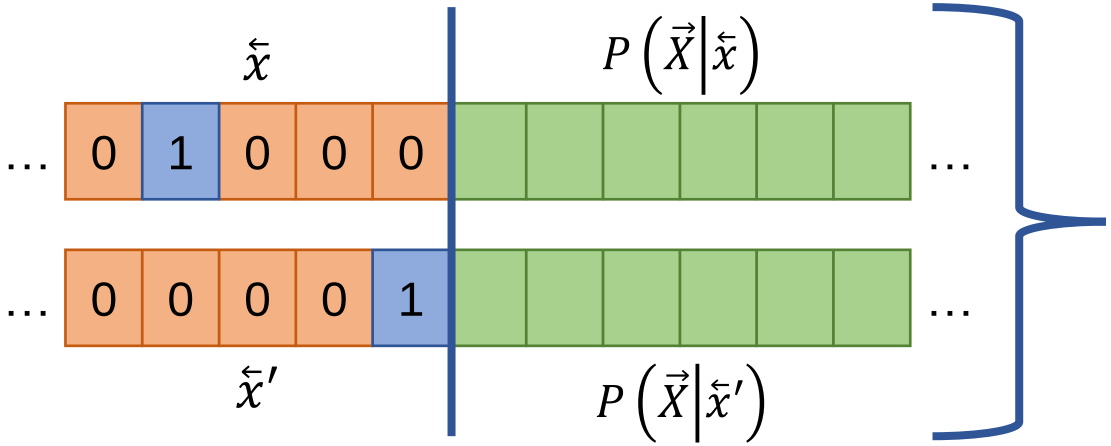
Theoretical statement: Quantum Models are “**better**”

→ Use less memory, can be more accurate, …

Classical Models

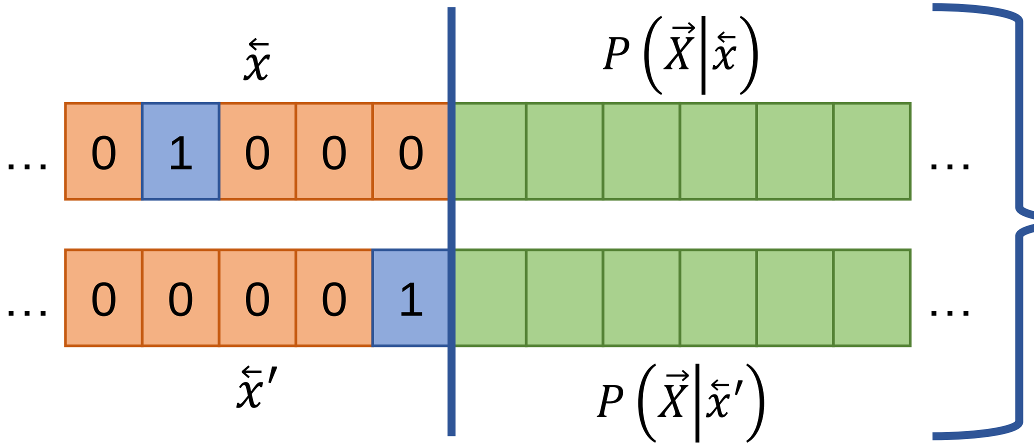


Classical Models



$$\overleftarrow{x} \sim \overleftarrow{x}' \Leftrightarrow P\left(\vec{X}\middle|\overleftarrow{x}\right) = P\left(\vec{X}\middle|\overleftarrow{x}'\right)$$

Classical Models



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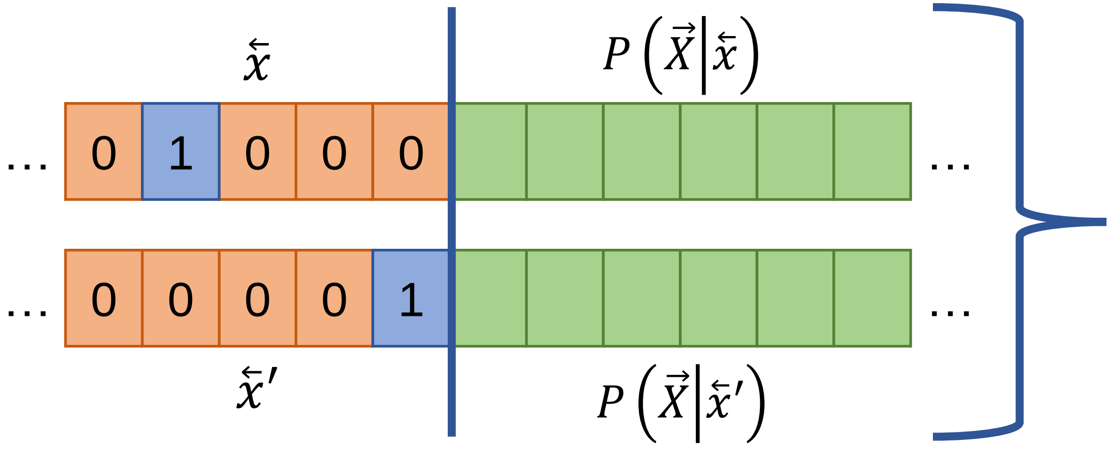
causal sates $\{S_i\}_{i=1}^{N}$ (minimal)

Classical Topological Complexity: $d_c = \log_2 N$

Classical Models



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Classical Topological Complexity: $d_c = \log_2 N$

(minimal memory requirement [in bits] to perfectly simulate a process)

Quantum Models

Quantum Topological Complexity: d_q

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Quantum Topological Complexity: $\boldsymbol{d_q}$

(minimal memory requirement [in qubits] to perfectly simulate a process)

Quantum Models need less memory i.e. $d_q < d_c$

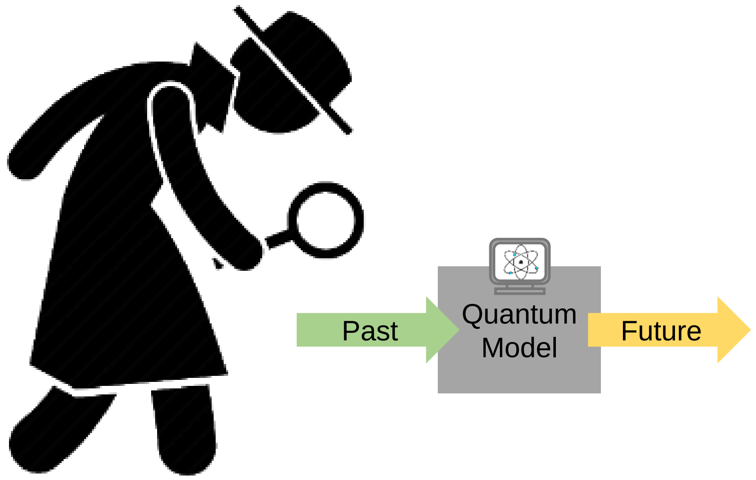
If $\hat{d}_q = \hat{d}_c \implies$ Quantum Models are more accurate

Well, nice!

So, what's the problem?

Problem

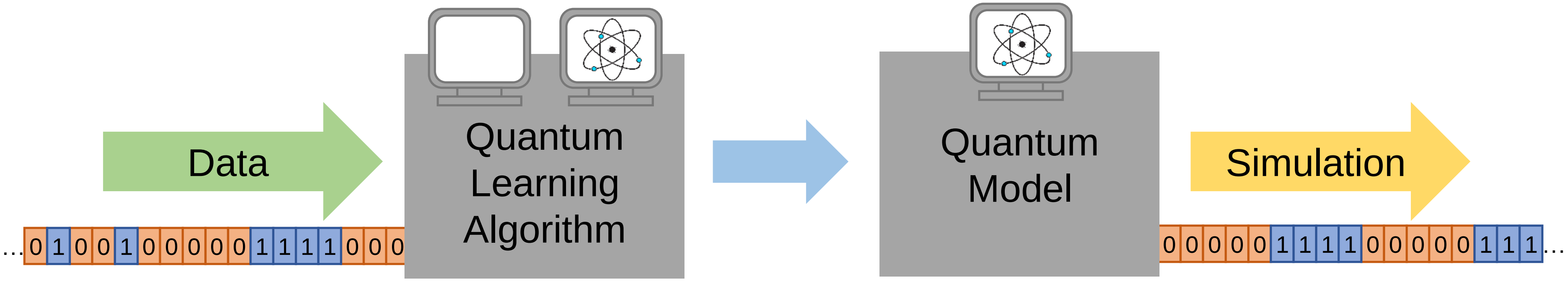
The models are hard to find / learn



Solution

Master Thesis

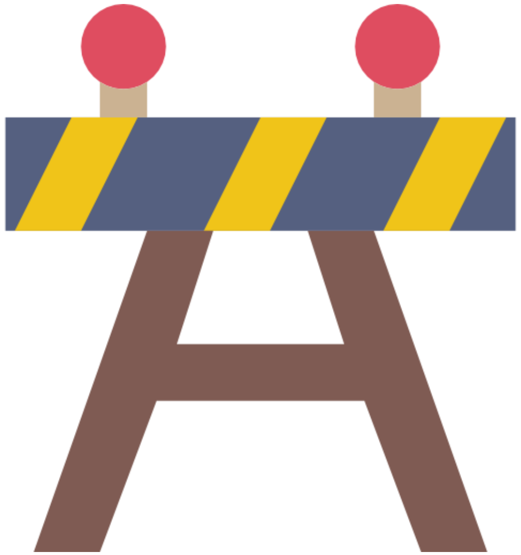
Developed a quantum learning algorithm for quantum simulation models, which uses only data as input.



Limitations

- Simple stochastic processes

  → Discrete, binary, stationary, small Markov order
- Extension not straightforward
- Quantum computer was only simulated
- The theory is not yet fully developed



Skepticism

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- Ryan Sweke, Free University of Berlin, 2020.

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- How to measure a quantum advantage?
- Do we have a practical advantage?
- Is the advantage useful?
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→ We need a holistic view of using quantum devices for real-world scenarios

Thanks!

A discussion
is highly
welcome.