

# Future Computing Architecture and Programming Paradigms

(mod. Quantum Computing Architectures, Programming and Applications)

**Florian Krötz**

kroetz@nm.ifi.lmu.de

MNM-Team, LMU Munich

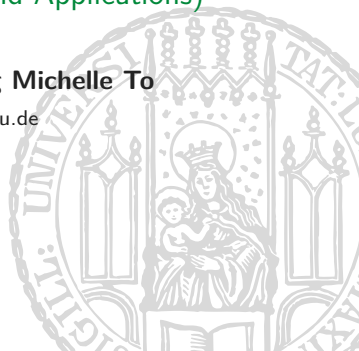
**Korbinian Staudacher**

staudacher@nm.ifi.lmu.de

**Xiao-Ting Michelle To**

to@nm.ifi.lmu.de

March 13, 2024



### (I) Quantum Random Number Generator

Implement the quantum random number generator in a simulator of your choice.  
Then change the probabilities of measuring  $|0\rangle$  and  $|1\rangle$  to  $\frac{3}{4}$  and  $\frac{1}{4}$  respectively.

## (II) Entanglement

The four Bell states addressed in the lecture are:

$$\begin{aligned}
 |a_1 a_0\rangle = |00\rangle &\Rightarrow \Phi^+ = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle) & |a_1 a_0\rangle = |10\rangle &\Rightarrow \Phi^- = \frac{1}{\sqrt{2}}(|00\rangle - |11\rangle) \\
 |a_1 a_0\rangle = |01\rangle &\Rightarrow \Psi^+ = \frac{1}{\sqrt{2}}(|01\rangle + |10\rangle) & |a_1 a_0\rangle = |11\rangle &\Rightarrow \Psi^- = \frac{1}{\sqrt{2}}(|01\rangle - |10\rangle)
 \end{aligned}$$

In this task, you are working with a 2-qubit register.

1. Draw the circuit that sets a register to the Bell state  $\Psi^- = \frac{1}{\sqrt{2}}(|01\rangle - |10\rangle)$ .
2. Calculate the intermediate states  $|\psi_0\rangle$ ,  $|\psi_1\rangle$  and  $|\psi_2\rangle$  of the circuit in a).

### (III) Teleportation

In this task, a qubit is to be teleported; however,  $|a\rangle$  and  $|b\rangle$  are not in the Bell state  $|\beta_{00}\rangle$  at the beginning – as in the example from the lecture – but in the Bell state  $|\beta_{10}\rangle$ .

1. Calculate the state  $|\psi_2\rangle$  of the teleportation circuit.
2. How to adapt the circuit to perform a successful teleportation based on  $|\beta_{10}\rangle$ ?

**Note:** All you have to do is take care of the gates after the measurement!