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The bridge to possible

The Quantum Network Development Kit

Developing quantum network simulations, the easy way

Stephen DiAdamo, Quantum Research Scientist

Agenda

- What is a quantum network?
- What are quantum network simulations? Why do we need them?
- Developing a quantum network simulation: Why is it hard?
- Cisco’s QNetLab Project: Why does it make things easier?
- QNDK Demo

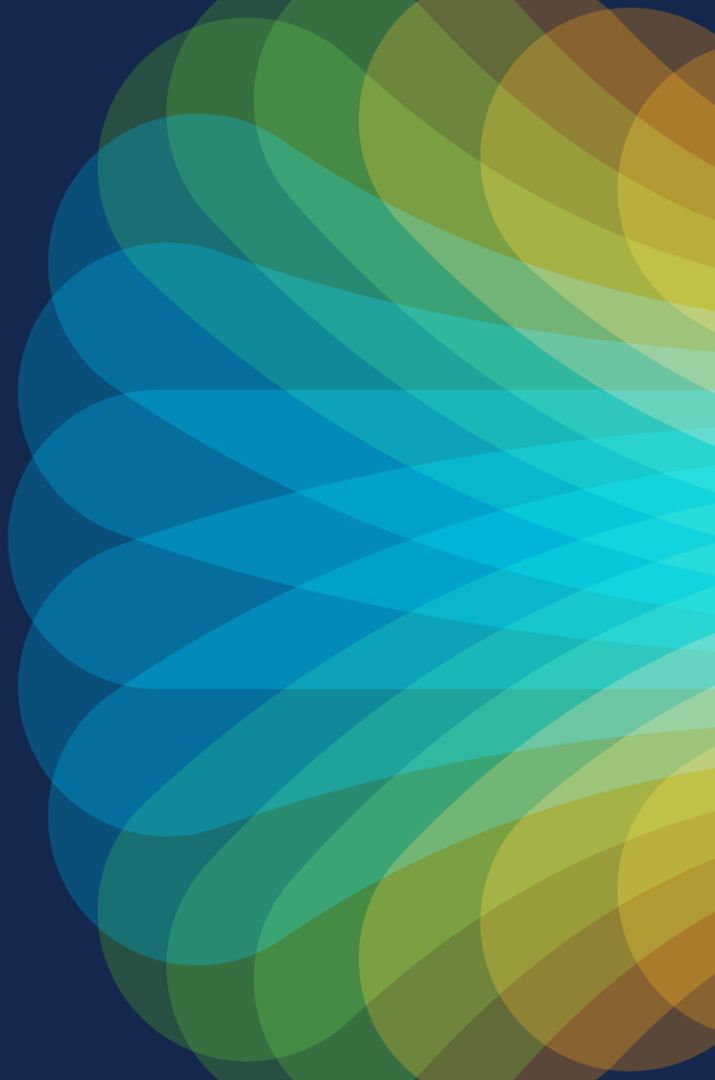
By the end of this presentation, you will:

1. Understand what a quantum network is and does
2. Know how a network simulation is created and used
3. Know why developing quantum network simulations is hard
4. Understand why our QNetLab project simplifies the process

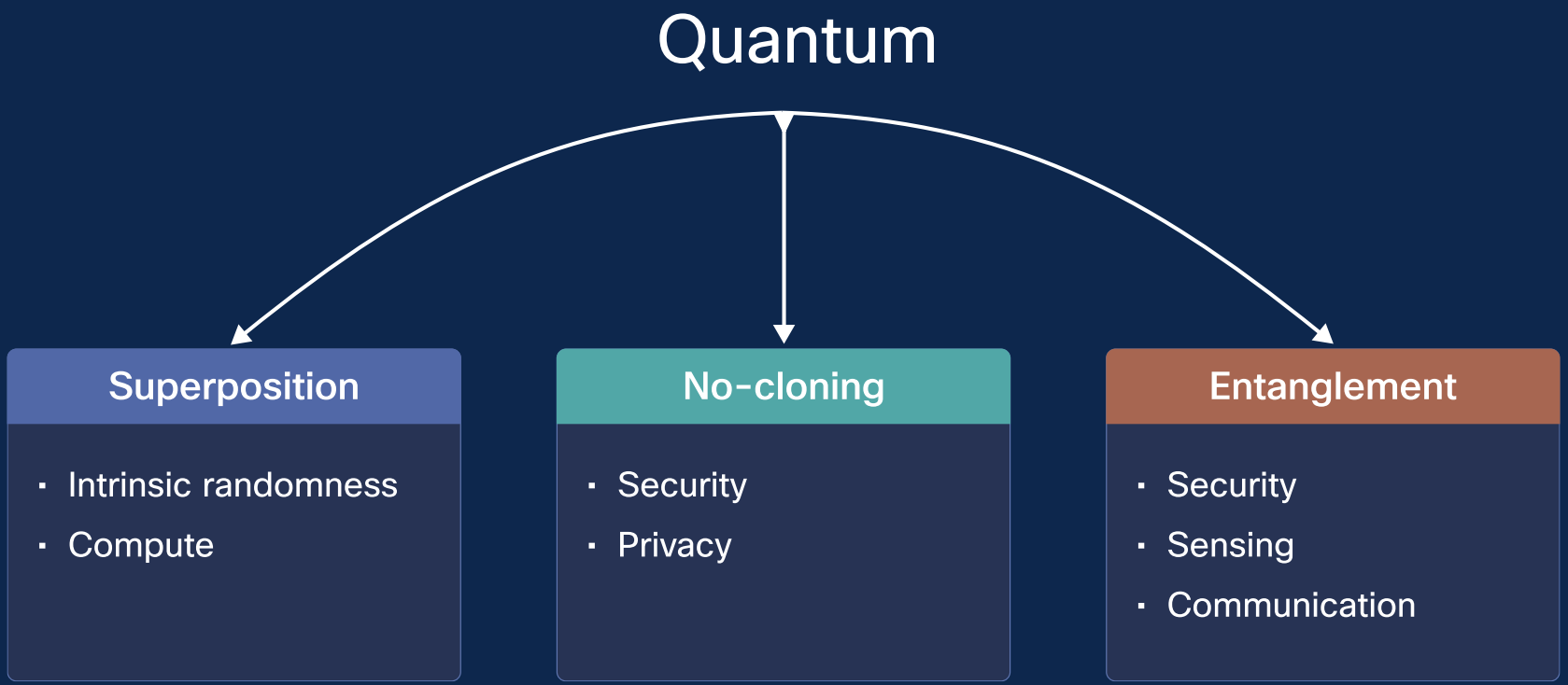
Who am I?

- Stephen DiAdamo
- Ph.D. in Quantum Networks
- Amateur violinist
- Research Scientist in Cisco Research
  - Quantum Network Simulation & Design

What is a quantum network?

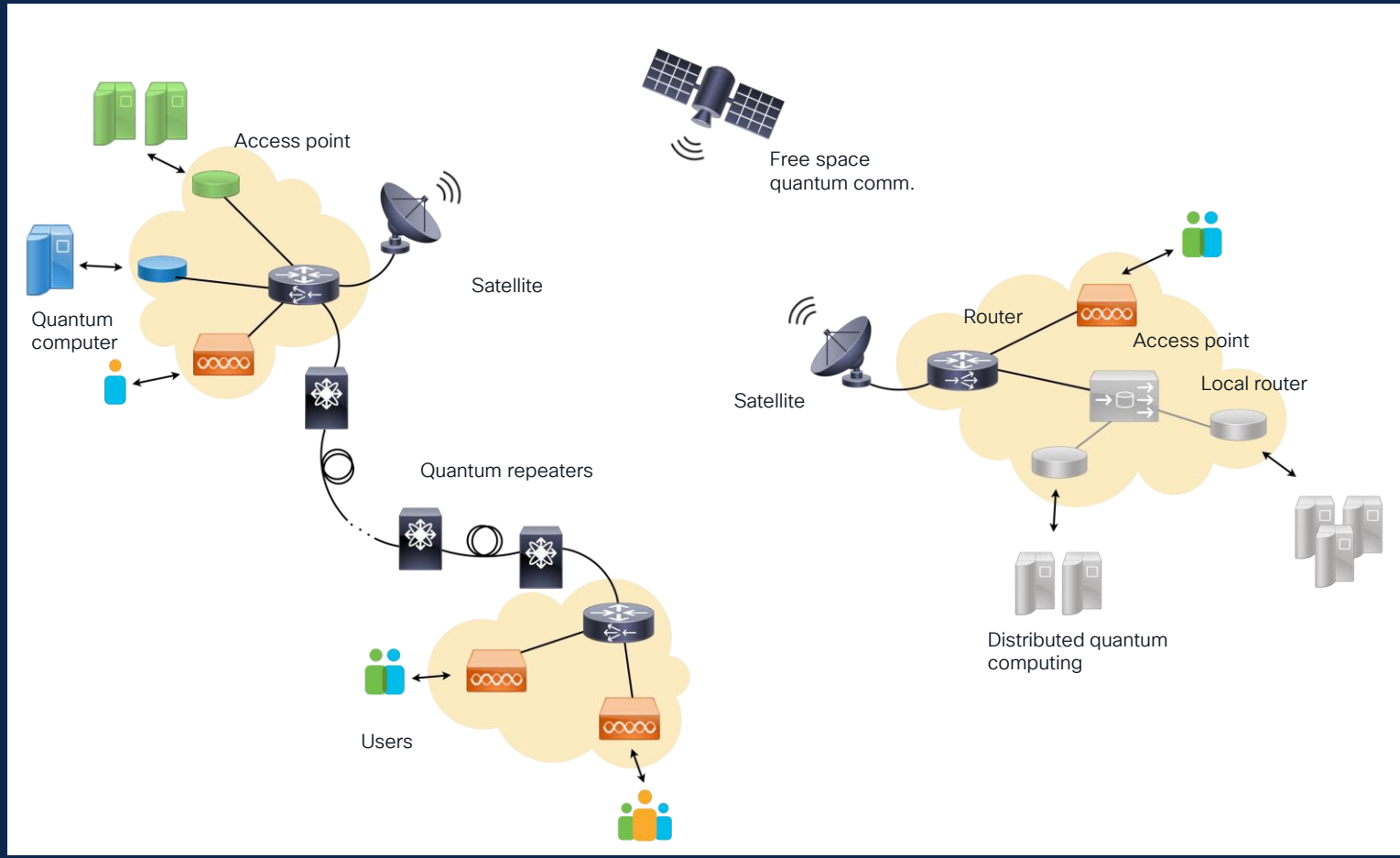


What is quantum?



What is a quantum network?

- A quantum network is a network that transmits quantum systems over a complex network of users

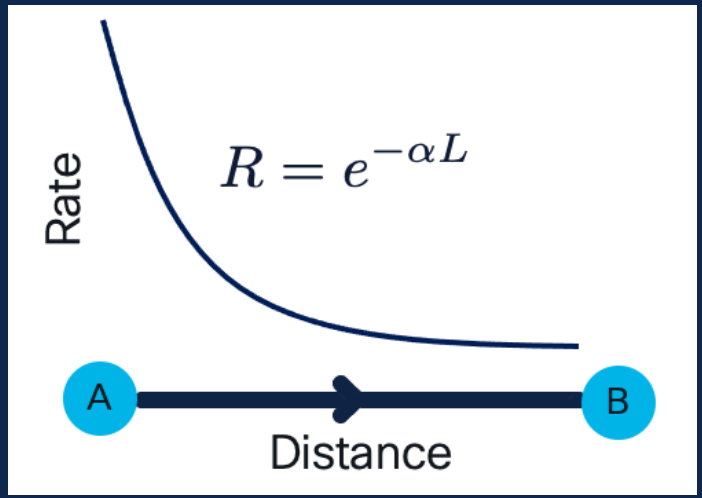


Applications of quantum networks

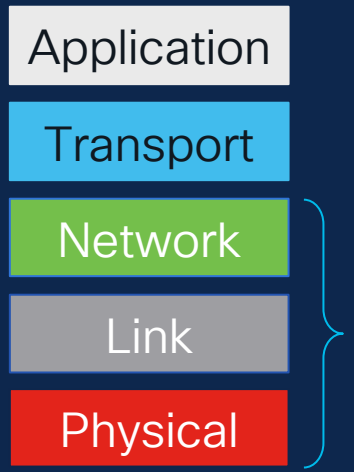
- Cryptography
- Distributed sensing
- Clock synchronization
- Distributed quantum computing
- Privacy-preserving computing

Challenges of quantum networks

- Rate-Distance tradeoff
- All optical
- Noisy outputs
- Quantum state decoherence



Quantum network stack



Cryptography, privacy-preserving computing, enhanced sensing,...

End-to-end (logical) quantum information transmission

Switching, routing, scheduling

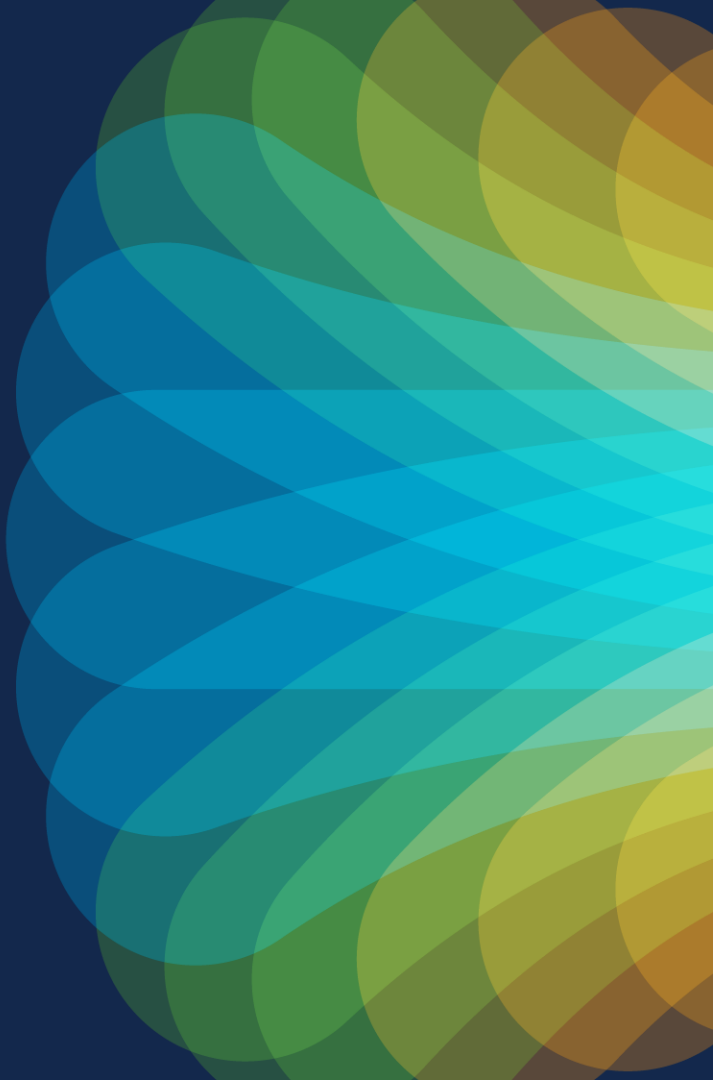
Transporting physical qubits, error correction, purification

Requirements: quantum memory, detector, source, channel

Summary

- Quantum networks connect quantum devices and enable quantum message transmission and entanglement distribution
- Quantum networks use many ideas from classical networks with a quantum “twist”
- Many of the protocols and components are in a research phase, much development is needed
- Researching quantum networks requires simulation

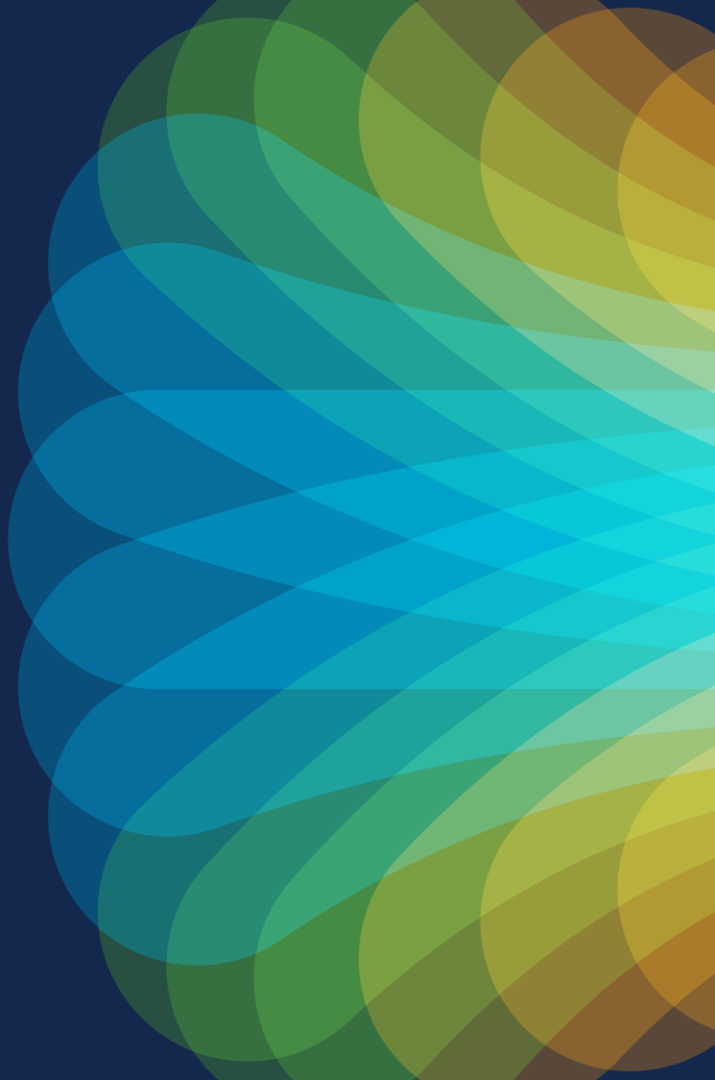
What is a quantum network simulation?



What is a quantum network simulation?

1. A software program that simulates aspects of quantum networking
2. Models the physical properties of the hardware
3. Simulates communication and network traffic
4. Provides timing for throughput, latency, and noise estimates

Why do we need simulation?



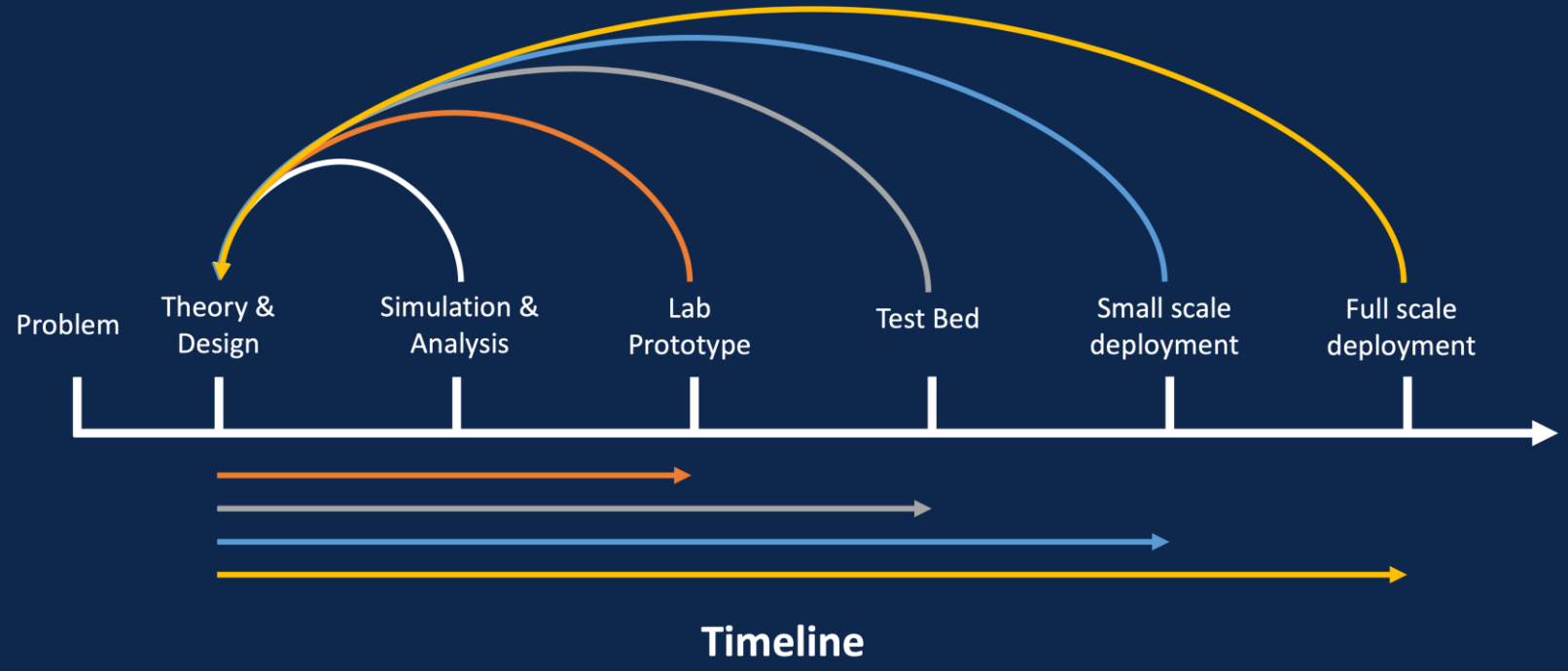
For a quantum network to exist there needs to be:

1. Strong use-cases
2. Quantum-capable hardware components
3. Network control software

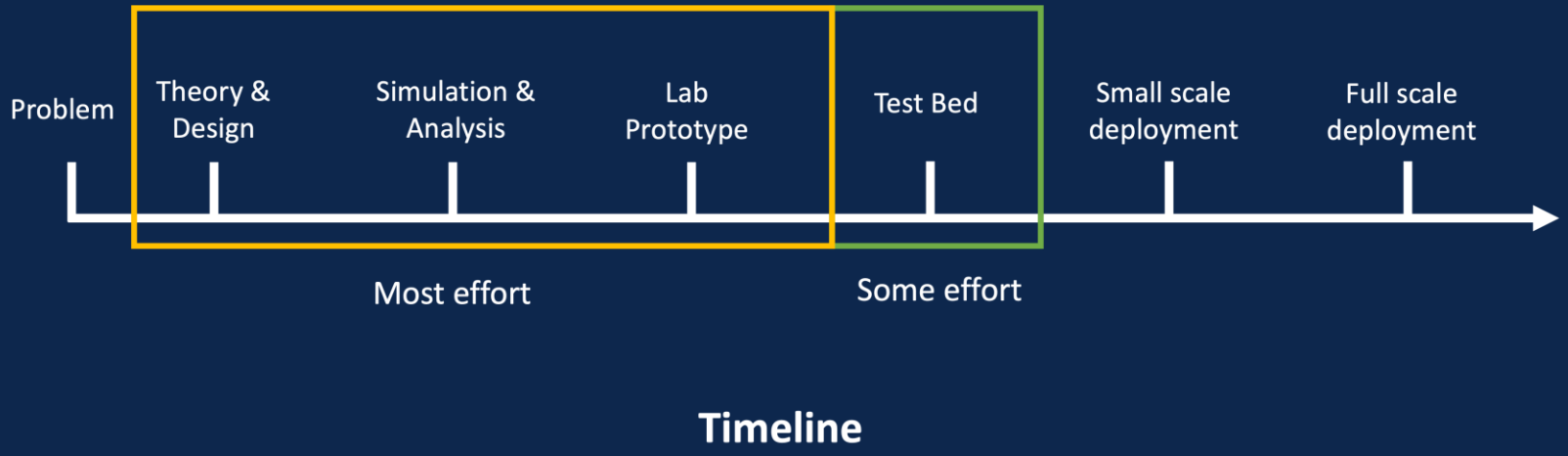
State of quantum networks

- Quantum networks are in very early stage:
  - Required hardware is not yet available
  - Protocols to control the hardware are not developed
  - Applications for using the quantum network are not well established

The lifecycle of network technologies



Where are we with quantum networks?



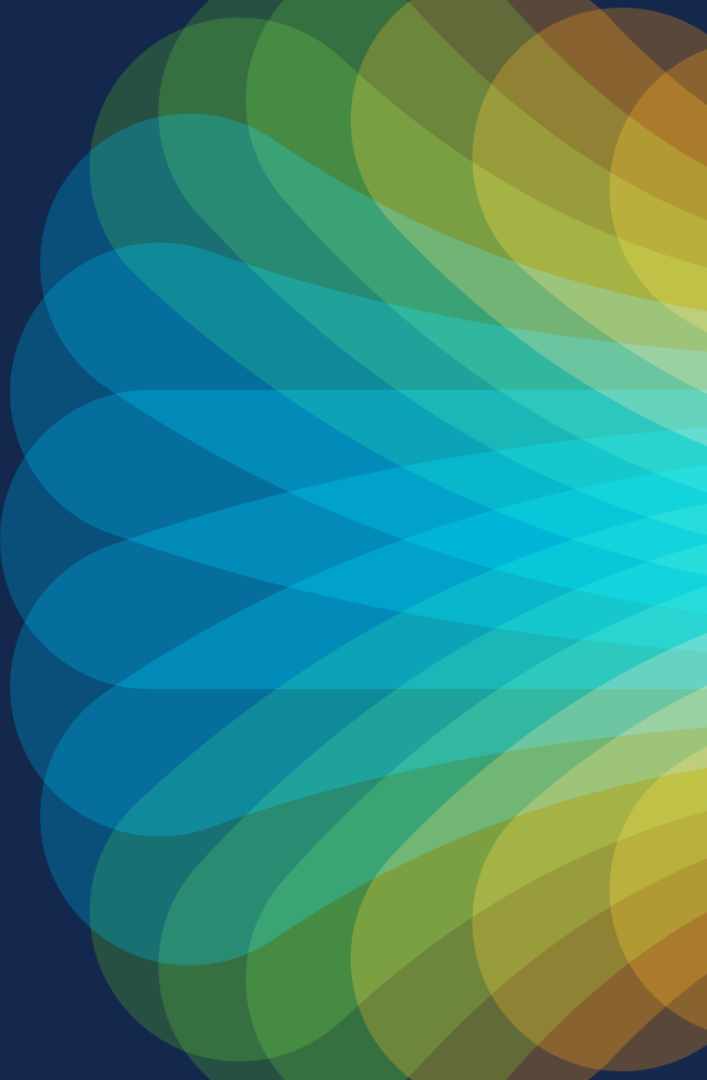
Why quantum network simulation?

1. Validating and benchmark network designs and protocols

2. Developing network applications for hardware we don’t have

3. Predicting required network requirements

Developing quantum network simulations



Developing a simulation

1. Decide on protocol
2. Define parameters
3. Write code
4. Run simulations
5. Analyze

1. Decide on a network protocol to simulation

1. What application do I want to simulate? QKD? DQC?
2. What communication steps are needed to perform the application?
3. Do I care about robustness? routing? timing?
4. How do I measure correctness and efficiency?

2. Define the network parameters

1. The network topology (e.g., star, bus, mesh, etc.)

2. The hardware parameters (e.g., fiber loss, switch frequency, etc.)

3. Traffic model (e.g., Poisson, interval, etc.)

3. Write the simulation code

1. Choose from the various simulation libraries

2. Write the protocol steps as detailed as desired

3. Develop the network layers where necessary

4. Run the simulation over various parameters

1. Change various network parameters to validate and benchmark the protocol

2. Run many instances of the simulation over long durations

3. Collect data

5. Generate plots and analyze

1. Plot the data and compare against state-of-the-art

2. Analyze for hardware properties necessary to fulfil minimum performance requirements

Key decisions to make

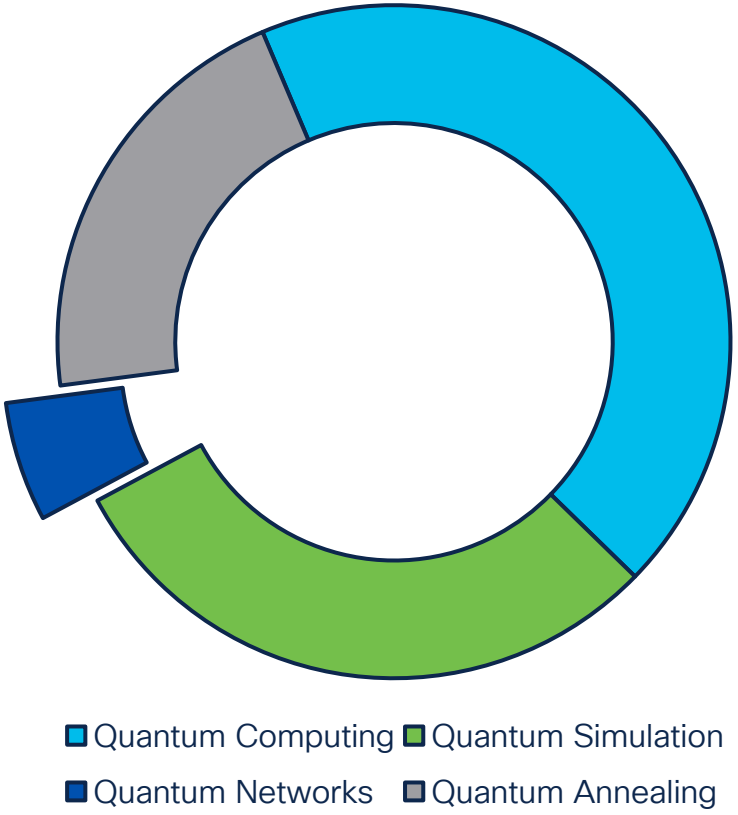
1. What aspects of the protocol are interesting?
2. What simulation engine to use?
3. What if the engine doesn’t do what I need it to?

What tools exist?

There are various software tools for network simulation:

1. Discrete event simulators
2. Network emulators
3. Quantum key distribution simulators
4. A variety of open-source libraries for a specific use

Most efforts are in quantum computing which can rarely be used for quantum network simulation



Source: https://qosf.org/project_list/

How I got into quantum network simulation

- Many ideas for quantum network applications that needed to be tested
- Had to teach beginners what quantum networks are and how they are used
- The available tools were all “bottom up” rather than “top down”

Problems in quantum network simulation

1. The quantum network simulation ecosystem is not unified
2. There are many “one-off” projects that can’t be easily built on and become “stale”
3. Protocols tend to be simulation-engine specific
4. Most importantly…

Writing quantum network simulations is hard!

Challenges

1) Limited graphical interfaces 

2) Strong knowledge of coding required 

3) Need a powerful computer to run simulations 

4) Need to know a lot about quantum networks 

How can we solve this?

1. Developing a “one-stop-shop” for quantum network simulation
2. Focusing on both community and software aspects
3. Take a unifying approach rather than re-inventive
4. Everything open source

QNetLab

Mission

Make programming quantum networks easy for everyone!

Near-term project goals

Build a software tool that:

1. Adds a graphical user interface 
2. Simplifies simulation development 
3. Allows remote access to run simulations 
4. Simplifies the entry barrier 

Longer-term project goals

1. Allow community sharing 
2. Create a universal quantum network simulation language 
3. Convert simulation to physical hardware execution 
4. “No-code” protocol development 

What these goals achieve

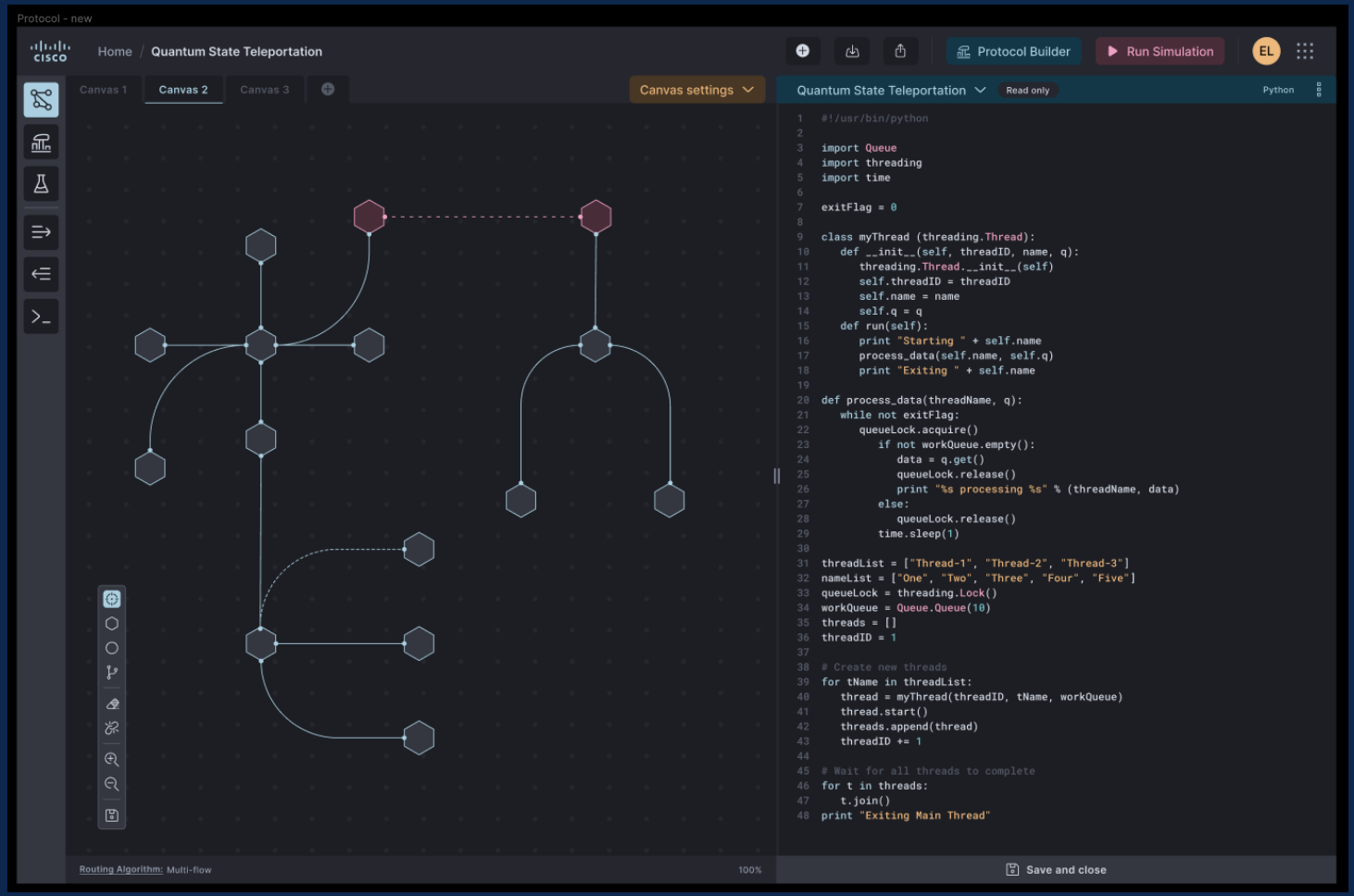
1. Streamline simulation development
   - Reuse, repurpose, recycle code

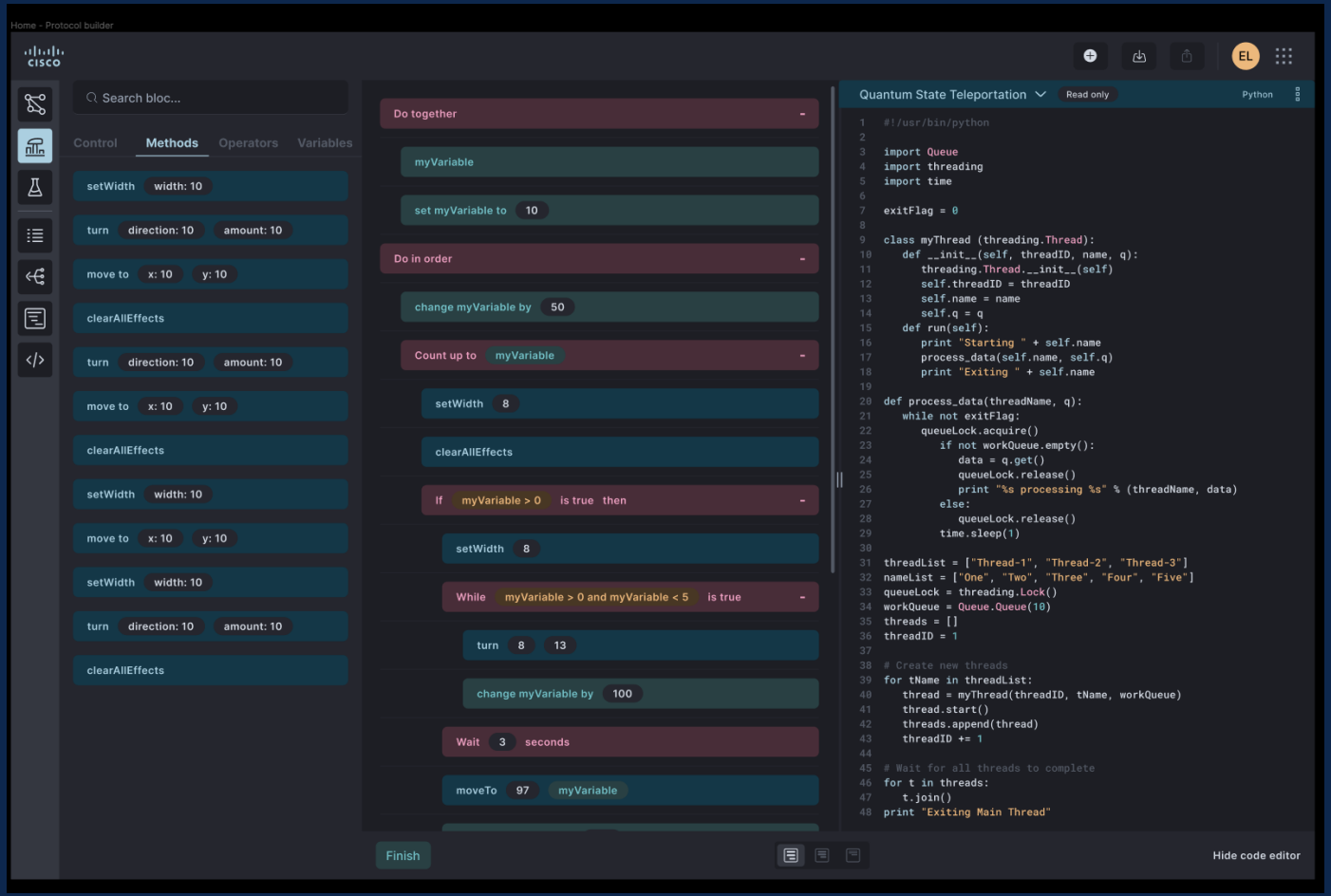
2. Creates a platform for education and resource sharing
   - Community simulations, tutorials, blogs

3. Enables access for everyone
   - No installation or hardware needed (web based)

Step 1: Quantum Network Development Kit

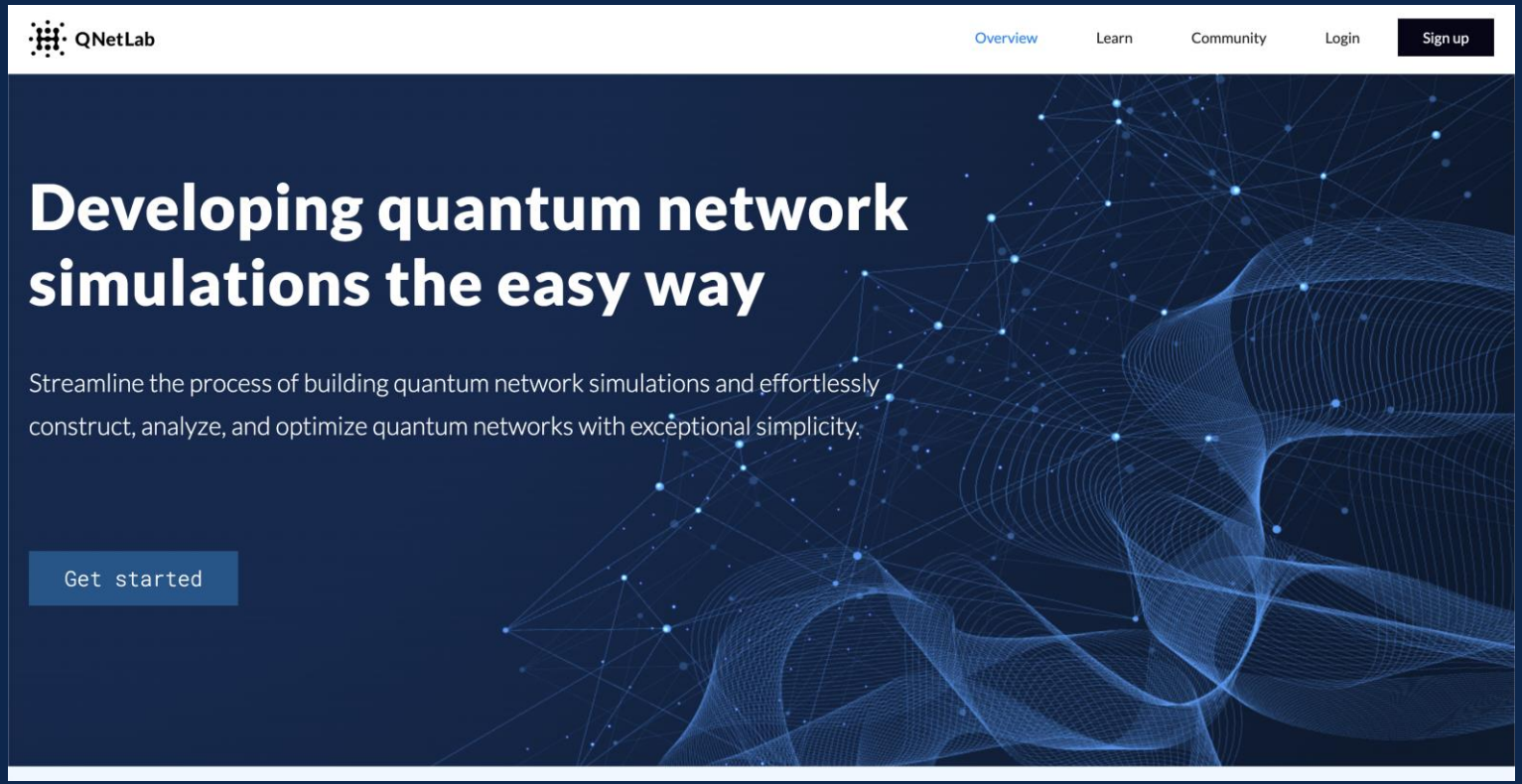
1. Build a web based graphical user interface
2. Provide pre-built simulations
3. Run simulations on the cloud
4. Limit the amount of code writing
5. Integrate various simulation engines

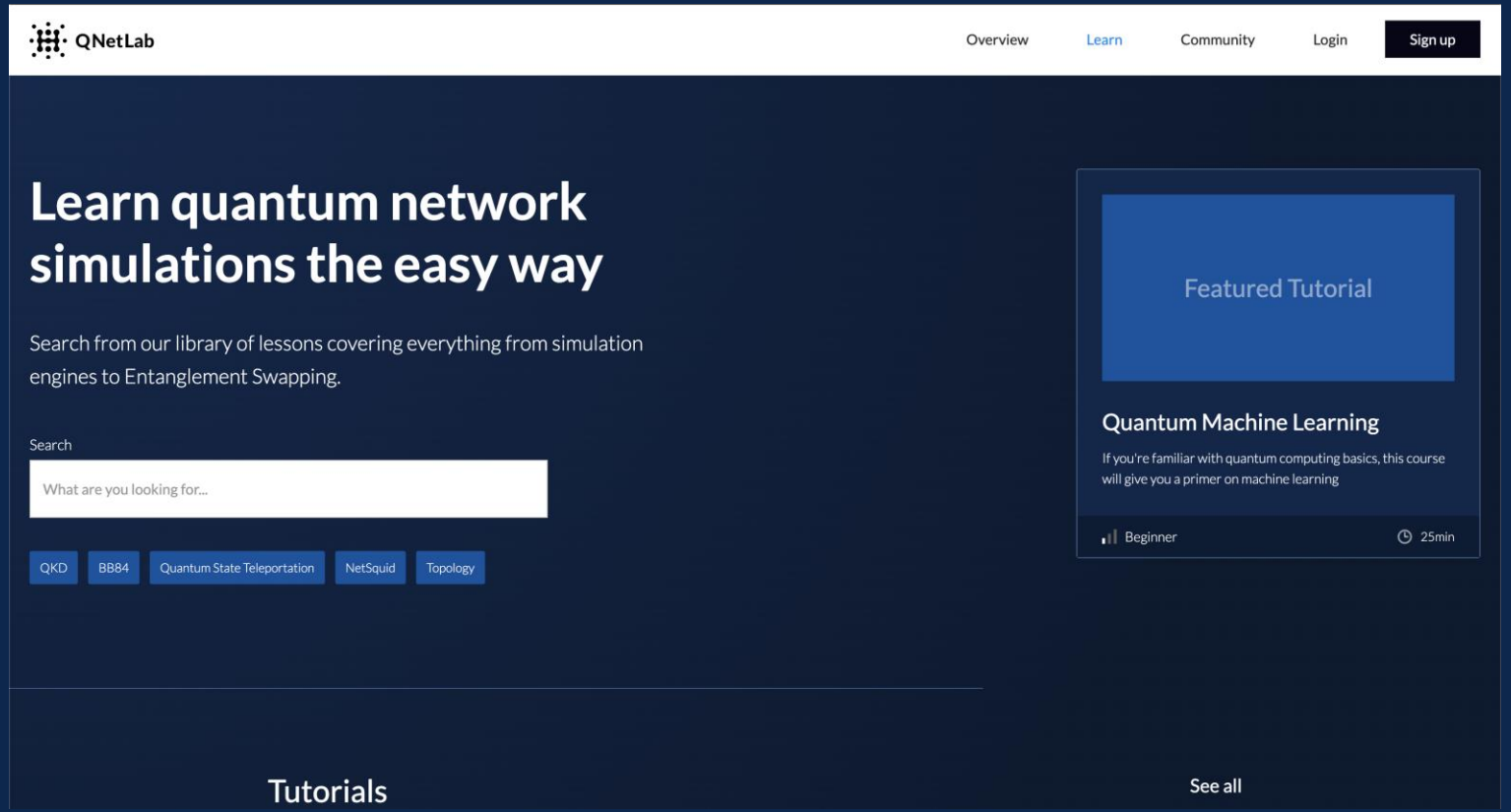




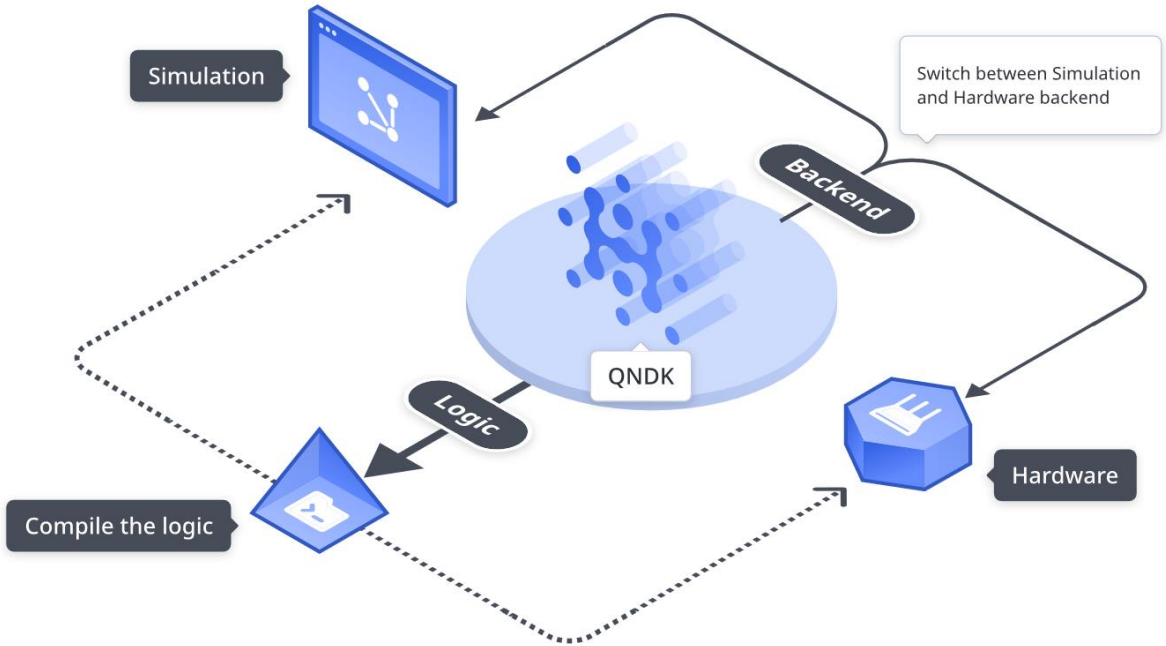
Step 2: Community building

1. Create a platform for resource sharing and learning
2. Allow users to upload their simulations and collaborate





Virtual Quantum Network Lab



QNDK Demo

Conclusions

- Quantum networks are young and simulation tools are essential for their development
- The QNetLab aims to unify and simply quantum network simulation development
- With the QNDK, we aim to greatly lower the entry barrier
- For collaboration discussions, reach out to: quantumlab@cisco.com

Continue the Discussion

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- Book your one-on-one Meet the Engineer meeting
- See what's coming by meeting with us in the Innovation Forum
- Book a meeting with us for an extended discussion on any Outshift area of research and development

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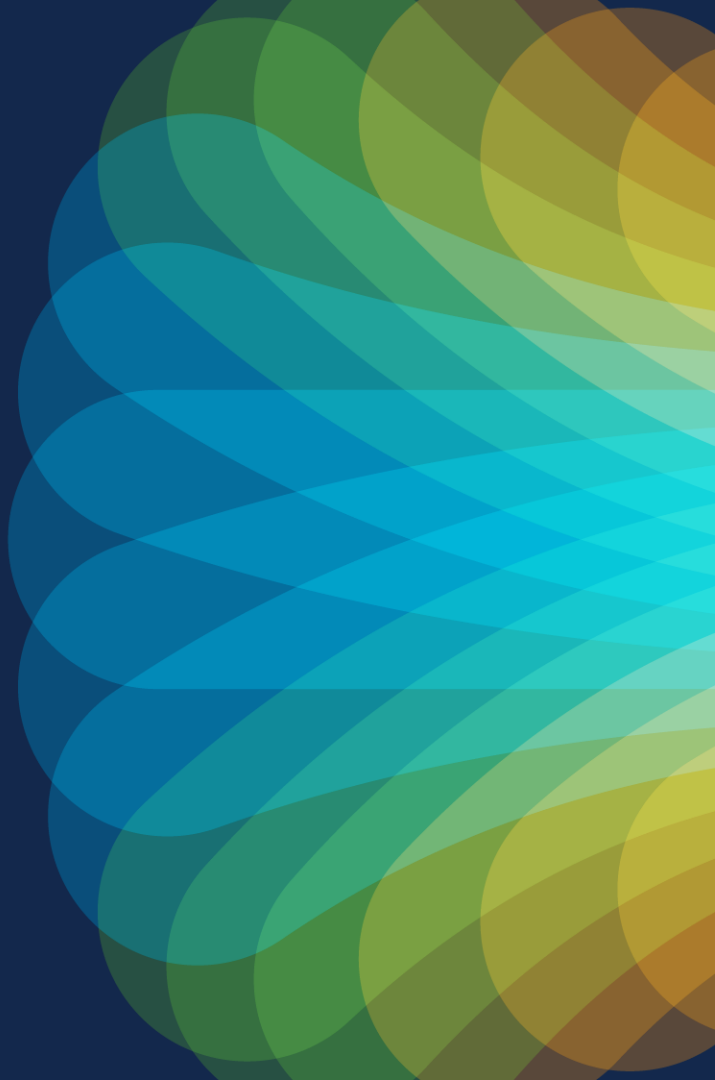

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