Donor electron and nuclear spins in silicon are excellent candidates for quantum bits (qubits) due to their compactness, tunability, long spin relaxation/coherence times and potential for large-scale integration with the microelectronics industry. There are three crucial elements of a spin based computer - (i) a well defined spin qubit that can be readout and controlled in a nano-device (ii) precise control of the coupling between two spin qubits for quantum operations and (iii) a robust method to transport the spin qubit to different parts of the quantum computer. Prior silicon quantum computing architectures place a heavy demand on fabrication, by requiring precisely placed single donors (separated by 10-15 nm) in silicon to demonstrate the above building blocks [1,2]. Here, we model several silicon nanodevices with classical and quantum simulation techniques [3], and propose methods to circumvent the above fabrication challenge.

We first present a non-invasive spatial metrology procedure that locates donor spin qubits to a precision several thousand times smaller than current statistical techniques, for high fidelity spin readout and control [4, 5]. We then investigate a method that offers massive tunability (10 orders of magnitude) of the exchange coupling between donor electron spins (30 nm apart), which is also compatible with current fabrication limitations. For spin transport, we model donor chains under a range of realistic experimental conditions, and highlight that high-fidelity spin transport (across ~100 nm) are achievable across them [6]. We then propose a novel technique to couple donor qubits (separated by several hundreds of nanometers) electrically via their dipole [7]. Finally, we will examine methods to couple donor qubits to superconducting resonators for large-scale integration into a scalable architecture [7,8]. With all the above, our modeling aids to estimate the required device topologies, qubit positions and electric fields – for high fidelity readout, control, exchange and transport of quantum spin information. Our results thereby provide a range of design considerations and feedback to experimentalists, who are in a global race to develop a fully scalable quantum computer.