Tutorial to teach quantum circuits using the ZX-calculus IBM Quantum <sup>1</sup>University of Oxford, <sup>2</sup>IBM Quantum Lia Yeh<sup>1,2</sup> and James Weaver<sup>2</sup> Outside this tutorial, where can one learn ZX-calculus... The idea: Teach quantum computing with diagrams. Outside Oxford Courses at U of Oxford • Learn what they mean mathematically • Write quantum circuits in ZX-calculus For high school students: For Oxford graduate students: • Coming soon: Quantum Theory in Pictures book Quantum Natural Language Processing Forms: matrices, braket, unit circle, Bloch sphere, ZX • Quantum Processes and Computation by Coecke and Gogioso, along with its lectures • Quantum Software Graduate level and up: Recommended: a high school degree; knowing matrix For software developers: • Picturing Quantum Processes textbook by multiplication, complex numbers, & basic probability Coecke and Kissinger, and its upcoming sequel • Quantum computing bootcamp by Kissinger and van de Wetering For quantum computing researchers: zxcalculus.com Goal: Go from what is a qubit to quantum teleportation • ZX-calculus for the working quantum computer • About 200 research papers so far scientist review by van de Wetering Let's use the ZX-calculus to teach **QUANTUM CIPCUITS** The 1<sup>st</sup> diagram rewrite (ightbulb in 'on' state passes' Is it on?" test with probability 1 Basis states Phase gates test process of flicking the light switch Color Change Spider Fusion we are, (connected apply rewrite hence we proved a rule from are one above here new diagram equation When you do a phase gate but the phase is zero, sign this merger surrender to the pink the spider dies. When Alice did a Bell measurement, Quantum teleportation two bits, a and b, were born. Bell measurement **Alice State** Alice tells **~~** Bob **Bell state** a & b After meeting 3-legged green and pink spiders, 0  $|-\rangle\langle--|+|+\rangle\langle++| \leadsto$ corrections  $|00\rangle\langle 0| + |11\rangle\langle 1| \rightsquigarrow$ our two bits, a and b, learned... **Bell measurement Alice State**  $|\Psi\rangle$ and how to be XOR'd. how to be copied... **Bell state**  $(a\pi)$  $(a\oplus b)\pi$  $(b\pi)$ **Alice State Bell measurement** Flow of quantum information Wire **Bell state** bending hmm... Bob conjugate sliding any map faround a bend adjoint adjoint With these diagrams, we have the power conjugate to bend the W Bob swap inputs wires however and outputs Rest in peace, a and b. we want.