A Quantum-Inspired Model for SIMD-Parallel Computation

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LCPC 2017:

How Low Can You Go?

- Now it's all about power / computation
- Work only on active bits (bit-serial)
- Aggressive gate-level optimization
- Potential exponential benefit from Quantum?

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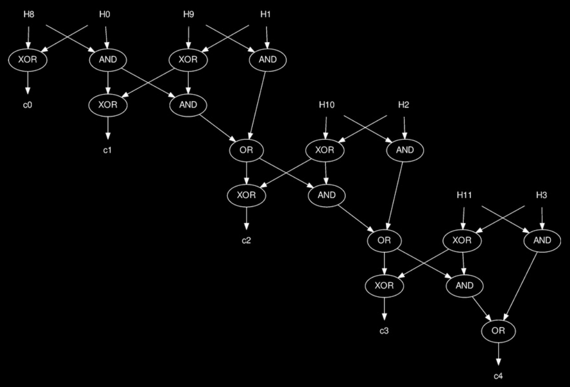
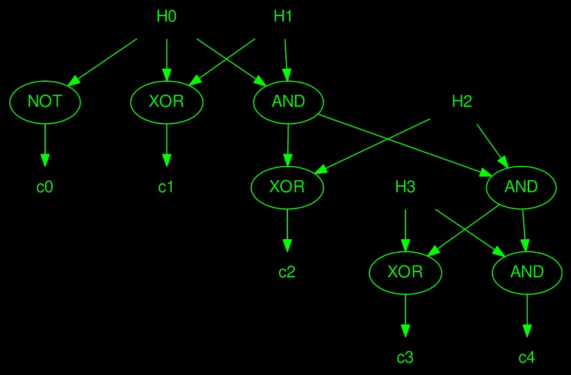
Gate-Level Optimization

```
int:4 a,b; b=1; c=a+b;
```

becomes 17 or 7 gate operations:





Gate-Level Optimization

```
int:8 a, b, c;
a = (c * c) ^ 70;
a = ((a >> 1) & 1);
a = b + (c * b) + a;
a = a + ~(b * (c + 1));
```

- About 206,669 gates unoptimized
- Optimized, it's just `a = 0;`

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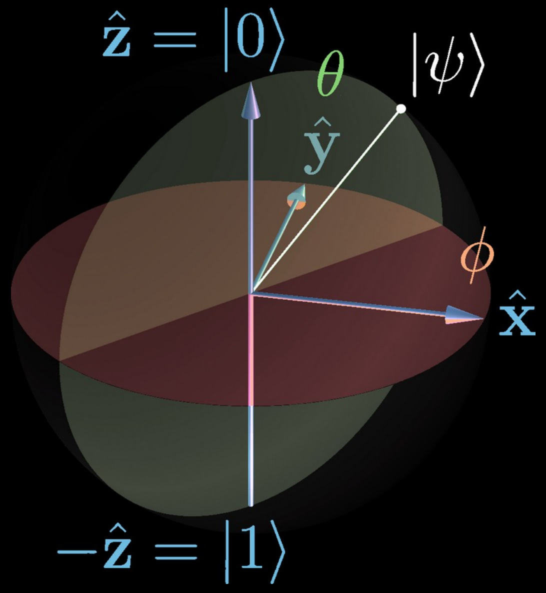
Quantum Computing

- Superposition: 1 qubit, all values
- Entanglement: *e* qubits, 2^e values
  - Exponentially less memory
  - Exponentially fewer gate ops



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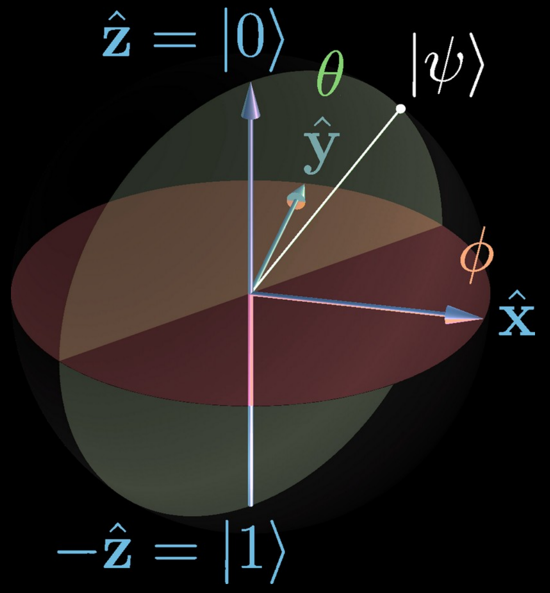
Quantum Computing

- Superposition: 1 qubit, all values
- Entanglement: *e* qubits, 2^e values
  - Exponentially less memory
  - Exponentially fewer gate ops
- Limited coherence, no cloning, only reversible logic gates, ...



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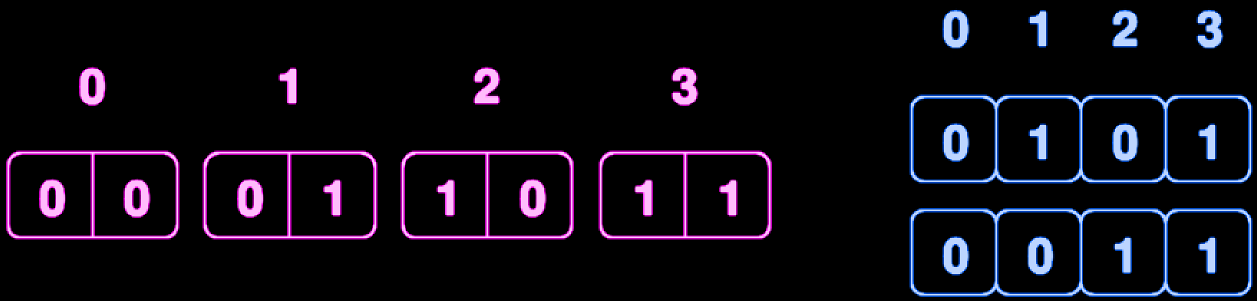
Encoding *e*-way Entanglement



- Array of Values (AoV): array of 2^e k-bit values
- Array of Bits (AoB): k 2^e-bit arrays
- Array indices are **entanglement channels**

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Bit Pattern REs: A Full Adder

```
a=H(0);                                  (01)+
b=H(1);                                  (0011)+
cin=H(2);                                (00001111)+
sum=xor(xor(a,b),cin);                   (01101001)+
cout=or(and(a,b),and(xor(a,b),cin));     (00010111)+
```

Simplify REs, e.g., by run length encoding (RLE):

$(01101001)^+ \rightarrow (0^1 1^2 0^1 1^1 0^2 1^1)^+$, $(00010111)^+ \rightarrow (0^3 1^1 0^1 1^3)^+$

Parallel Bit Pattern Computing

- Operate directly on compressed REs
  - Up to exponential reduction in storage, gate ops
- Avoids major quantum problems:
  - Forever coherent, error free
  - Cloning: fanout, non-destructive measurement
  - Use any gates, not just reversible logic
  - We know how to build scalable hardware

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Where's the Parallelism?

- 32-way entanglement: AoB is 4294967296 bits
- Each RE symbol is a 4096-bit parallel chunk

Time	Work	Operations
1	1	SWAP, ALL, ANY, measurement
$1..2^{20}$	$1..2^{20}$	DUP, POPulation count, ...
$1..2^{20}$	$1..2^{32}$	CSWAP, AND, OR, XOR, ...

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The Programming Model

- Two programmer-visible layers of abstraction:
  - `pbit` – like the earlier example, but `pbit_`
  - `pint` – variable precision (un)signed integers
- Just-in-time optimizing compilation lowers pint to pbit and aggressively optimizes pbit gate DAGs, which get lazy evaluated… details in the paper

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pint Sqrt(29929): 310 gate ops

```
int main(int argc, char **argv) {
  pint_init();
  pint a=pint_mk(16,29929); // 16-bit 29929
  pint b=pint_h(8,0xff);    // H(0)..H(7)
  pint c=pint_mul(b,b);     // c=b*b, still 8-way
  pint d=pint_eq(c,a);      // where c==29929
  pint e=pint_mul(d,b);     // make non-sqrts 0
  pint pint_measure(e);     // prints 0,173
}
```

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pint factor(221)

```
int main(int argc, char **argv) {
  pint_init();
  pint a=pint_mk(8,221);   // 8-bit 221
  pint b=pint_h(8,0x00ff); // H(0)..H(7)
  pint c=pint_h(8,0xff00); // H(8)..H(15)
  pint d=pint_mul(b,c);    // d=b*c, now 16-way
  pint e=pint_eq(d,a);   // where d==221
  pint f=pint_mul(e,b);  // make non-factors 0
  pint pint_measure(f);  // prints 0,1,13,17,221
}
```

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Implementation Layers

- Chunk: 4096-bit AoB, 12-way entanglement
- FBP (factored bit parallel): REs of chunks
- Pbit (pattern bit): DAGs of gate-level operations
- Pint (pattern int): 1-32 pbit DAGs
- C++ wrapper: not yet complete

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Conclusion & Future Work

- Parallel Bit Pattern computing is
  - Disturbingly competitive with quantum
  - Fully implementable at scale NOW
- Working on…
  - Improving prototype software, C++ wrappers
  - GPU version, **Tangled** Verilog architecture
- Automatic parallelization for this target?

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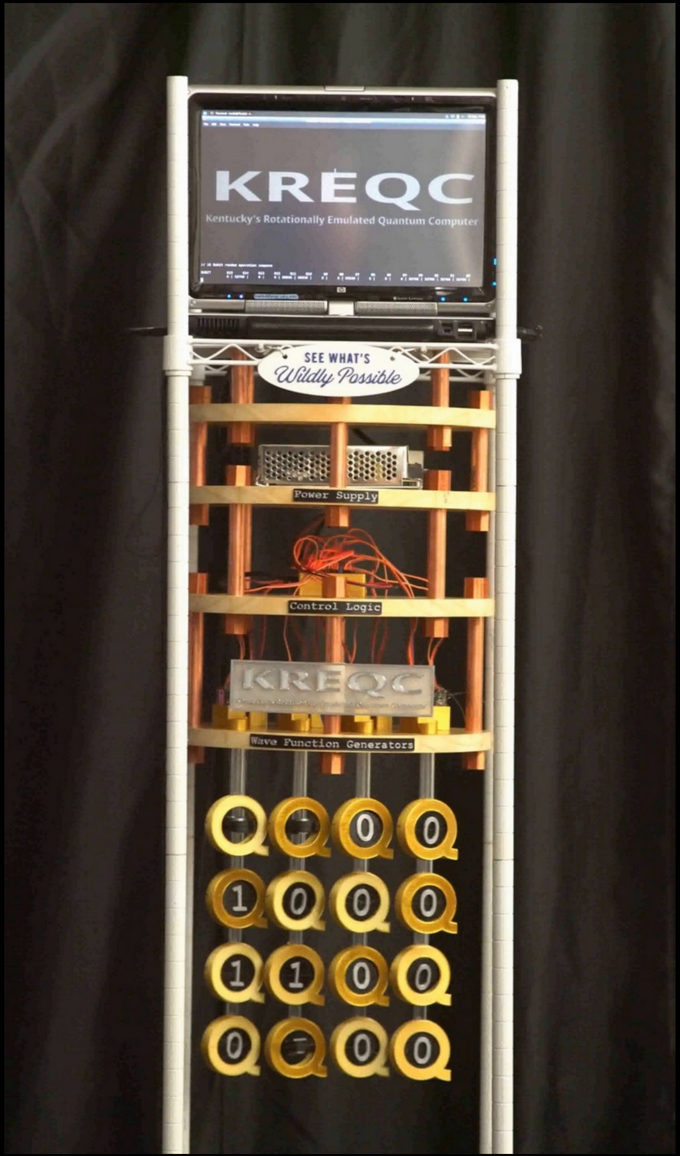

16 pbits
(Q-bits display)

16-way
Entangled

AoB execution

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