Basic Operations And Structure Of An FPGA Accelerator For Parallel Bit Pattern 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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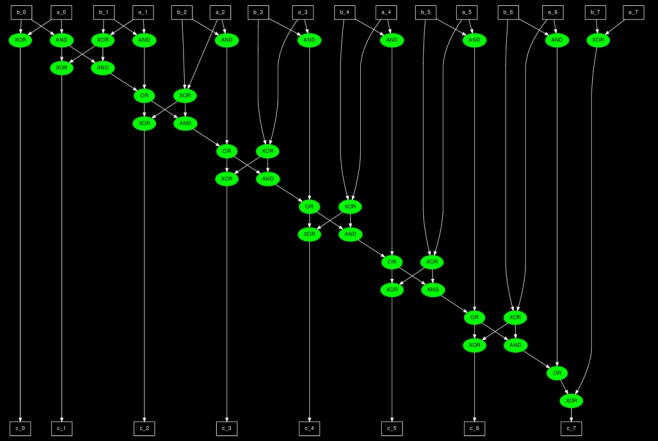
Savings at the Gate Level

```
int a, b, c; c = a + b;
```

- 32-bit Carry Lookahead:
  ~645 gates
- 8-bits active Ripple Carry:
  34 gates



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Parallel Bit Pattern Computing

- A **pbit** value is an **array of 2^e bits** (**AoB**)
  - Allows up to *e*-way entangled superposition
  - Value probabilities are in parts per 2^e
  - Each array index is an **entanglement channel**
- Operation on a pbit is **SIMD-parallel**:
  1 bit per each of 2^e bit-serial SIMD PEs

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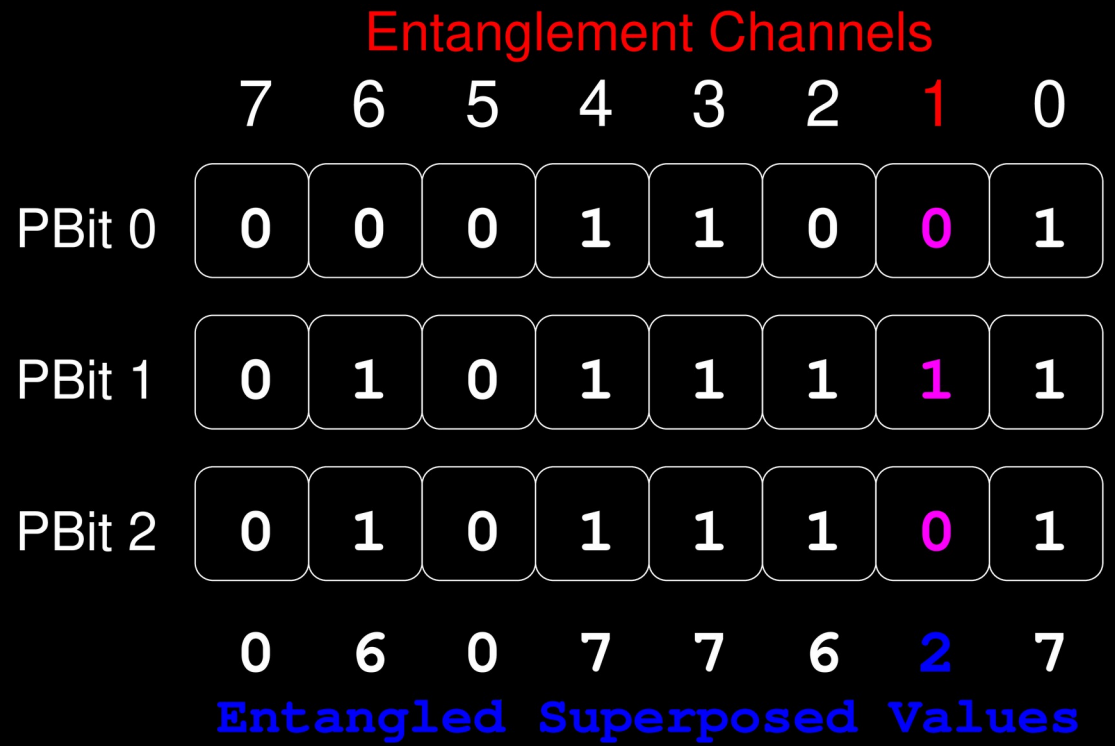
AoB for 3-way Entanglement



Probability	
0	2/8
1	0/8
2	1/8
3	0/8
4	0/8
5	0/8
6	2/8
7	3/8

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AoB Values Have Low Entropy

- **Don’t store AoB values!**
  - Store generative **regular expression** (**RE**)
  - Operate directly on RE-compressed form
- Each RE symbol is an AoB **chunk**
  - Only store **unique AoB chunks**
  - **Applicative caching** ⇒ no chunk recompute

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Where Is PBP Now?

- **Avoids major quantum restrictions:**
  Coherence, cloning, measurement, gate types
- PBP implementations:
  - ≥16-way in software

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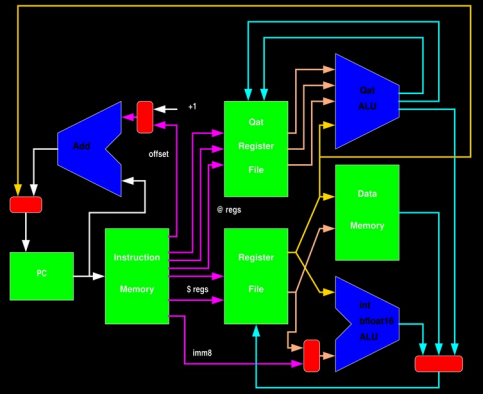

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- PBP implementations:
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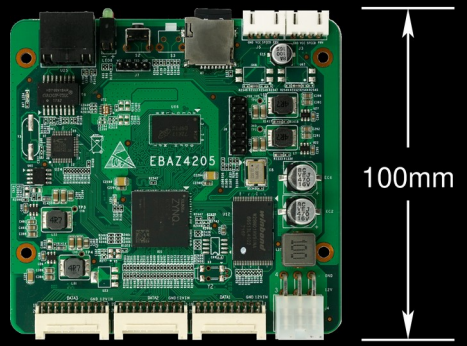
  - **FPGA AoB chunk coprocessor**



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New AoB Chunk Primitive Operations

- Target **EBAZ4205** Zynq Z7010, *surplus* ≤$20
- PL implements a **PBP Chunk coprocessor**
  - 10-way entangled within a chunk, ≥16 in REs
  - ≥1024 registers for ***unique*** chunk values
  - Classical constants: `@0` is `0`*, `@1` is `1`*
  - `@`(**h**+2) is **Hadamard h** pattern (`0`^{h}`1`^{h})*

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Arithmetic/Logic Operations

Instruction	Description	LUTs	Delay
`and @a,@b`	`@c=AND(@a, @b)`	1024	1
`or @a,@b`	`@c=OR(@a,@b)`	1024	1
`xor @a,@b`	`@c=XOR(@a,@b)`	1024	1

- Conventional gates simpler than reversible
- Note **`not @a`** is **`xor @a,@1`**; **`cnot`** is **`xor`**

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Permutations

Instruction	Description	LUTs	Delay
`rot @a,b`	`@c=RotateLeft(@a,b)`	5120	4
`flip @a,b`	`@c=Flip(@a,b)`	5120	4

- No such things in previous PBP models...
- RotateLeft is like a Quantum phase shift
- Flip is a generalized sorting network

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Entanglement-Channel Addressing

Instruction	Description	LUTs	Delay
`tog @a,b`	`@c=Toggle(@a,b)`	576	2
`dom @a,b`	`@c=Domino(@a,b)`	1079	3
`meas @a,b`	`@c=Measure(@a[b])`	273	7

- Alter specific channels with **`tog`** or **`dom`**
- Read a channel with **`meas`** (can use random **`b`**)

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Aggregate Operations

Instruction	Description	LUTs	Delay
`first @a`	`First b` where `@a[b]==1`	976	5
`ones @a`	count of `Ones` in `@a`	1444	5

- Result is an integer, not a register number
- Can summarize an entangled superposition
- Can be exponentially faster than Quantum

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Future Work (nothing's concluded yet)

- PBP is very new, but progressing well...
  - Compiler infrastructure has been built
  - Software & full custom processor design
  - "Toy" Quantum apps ⇒ a new & better model
- The current work is a key step, creating practical hardware to show **reduced power/computation**

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