|BF> (Bra-Ket-Fuck): A Vacuum-Initialized Clifford+T Quantum Tape Architecture for Linear Nearest-Neighbor Compilation and Formal Verification

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Technical Whitepaper · Architecture Specification v1.0 · October 2026

Abstract

Modern quantum programming frameworks operate predominantly on high-level Directed Acyclic Graphs (DAGs) representing arbitrary all-to-all quantum circuits. While ergonomic for algorithm design, these abstractions obscure physical Linear Nearest-Neighbor (LNN) hardware constraints [10, 11], complicate formal verification in theorem provers [14], and leave quantum loop semantics ambiguous. Conversely, existing minimal esoteric quantum languages—most notably Ihope127's *Quantum brainfuck* (QBF) [12]—suffer from non-physical $|1\rangle^{\otimes N}$ initialization, the absence of native Pauli bit-flip primitives, and exorbitant gate synthesis overhead. In this whitepaper, we introduce **|BF> (Bra-Ket-Fuck)** and its underlying execution model, the **Dirac–Müller Abstract Machine (DMM)**. |BF> unifies Urban Müller's minimal 1D tape pointer semantics [1] with Paul Dirac's bra-ket Hilbert space formalism [3, 4] over a physical $|0\rangle^{\otimes N}$ vacuum ground state. We present the complete operational semantics of |BF>, prove its BQP-universality via the Clifford+T universal basis [5, 6], demonstrate its 8× instruction-count reduction over QBF for the nearest-neighbor CNOT primitive, and specify an $O(1)$ per-instruction transpiler targeting **OpenQASM 3.0** [13] dynamic circuits.

1 Introduction & Motivation

In classical theoretical computer science, Urban Müller's Brainfuck (1993) [1] established an enduring milestone: demonstrating that a discrete tape machine requires only eight syntactic tokens (`> < + - . , [ ]`) to achieve Turing completeness. Far from being a mere curiosity, minimal instruction set architectures (ISAs) serve as foundational razors for compiler verification, decidability bounds, and hardware micro-architectures.

As quantum computing transitions from theoretical algorithms to Noisy Intermediate-Scale Quantum (NISQ) processors [15] and early fault-tolerant lattices, quantum software engineering faces an analogous foundational gap:

1. **The QTM-to-Circuit Disconnect:** Bernstein and Vazirani (1993, 1997) [2] formalized BQP (Bounded-Error Quantum Polynomial-Time) using Quantum Turing Machines (QTMs) with local tape heads. However, industrial languages (Qiskit, Cirq, OpenQASM [13], Q#) abandon tape semantics for circuit DAGs that assume arbitrary non-local qubit connectivity.
2. **Intractability of Formal Verification:** Proving the mathematical soundness of optimizing quantum compilers in proof assistants (Lean 4, Coq, Isabelle) is virtually impossible when the source language embeds full Python or complex type systems. A minimal 12-token BQP-universal calculus makes mechanized correctness proofs (in the spirit of the verified optimizer VOQC [14]) tractable.
3. **Dynamic Control Flow & Halting:** Defining iteration (`[ ]`) when loop conditions reside in quantum superposition exposes fundamental tensions between unitary evolution and projective measurement (the quantum halting problem [8, 9]).
4. **Compiler Fuzzing:** Optimizing transpilers rely on peephole synthesis and unitary equivalence checking ($U_{\text{opt}}^{\dagger} U_{\text{spec}} \propto I$). Minimal tape programs generate dense, non-idiomatic gate sequences ideal for differential fuzzing of industrial transpilers; the reference toolchain applies exactly this technique to itself, comparing the abstract machine, two independent transpiler implementations, and an exact OpenQASM interpreter on randomly generated programs.

To address these challenges, we define **|BF>**

(Bra-Ket-Fuck)—a play on Dirac's bra-ket notation ($\langle\psi||\phi\rangle$) [3] and Brainfuck's pointer tokens (`<`, `>`).

2 The Dirac–Müller Abstract Machine

2.1 State Space Formulation

Let a `|BF>` machine of register width $N \in \mathbb{N}^+$ be defined as a tuple $\mathcal{M} = (\mathcal{H}_N, p, \mathcal{C})$, where:

- $\mathcal{H}_N = (\mathbb{C}^2)^{\otimes N}$ is a 2^N-dimensional complex Hilbert space spanned by the computational basis $\{|b_0 b_1 \dots b_{N-1}\rangle : b_k \in \{0,1\}\}$.
- The quantum tape initializes to the physical vacuum ground state:

$$|\Psi_0\rangle = \bigotimes_{k=0}^{N-1} |0\rangle_k = |00\dots0\rangle \tag{1}$$

- $p \in \mathbb{Z}_N = \{0, 1, \dots, N-1\}$ is the classical tape head pointer initialized to $p_0 = 0$.
- $\mathcal{C} \in \{0,1\}^*$ is the classical measurement transcript stream.

At any execution step t, the composite state of the quantum register is represented by the normalized state vector:

$$|\Psi(t)\rangle = \sum_{x=0}^{2^N-1} \alpha_x(t)|x\rangle, \quad \alpha_x(t) \in \mathbb{C}, \quad \sum_{x=0}^{2^N-1} |\alpha_x(t)|^2 = 1 \tag{2}$$

2.2 Unitary Gate Primitives & Hilbert Lifting

Single-qubit instructions in `|BF>` act exclusively on the active cell p. To apply a local 2×2 unitary operator $G \in U(2)$ to qubit p, the machine constructs the lifted $2^N \times 2^N$ unitary operator $\mathcal{U}_p(G)$ via Kronecker tensor products:

$$\mathcal{U}_p(G) = \left(\bigotimes_{k=0}^{p-1} I_2\right) \otimes G \otimes \left(\bigotimes_{k=p+1}^{N-1} I_2\right) \tag{3}$$

The fundamental single-qubit gates mapped to `|BF>` tokens are:

$$X_{(+)} = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \quad Z_{(\mathrm{Z})} = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \tag{4}$$

$$H_{(\mathrm{H})} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}, \quad T_{(\mathrm{T})} = \begin{pmatrix} 1 & 0 \\ 0 & e^{i\pi/4} \end{pmatrix} \tag{5}$$

For exact reversibility, the decrement token `-` maps to the Hermitian adjoint of the phase shift $T^\dagger = \mathrm{diag}(1, e^{-i\pi/4})$. Together with CNOT, the gate set $\{H, T, \mathrm{CNOT}\}$ forms the Clifford+T universal basis [5, 6].

2.3 Nearest-Neighbor Entanglement (`^`)

To enforce physical Linear Nearest-Neighbor (LNN) locality [10, 11], `|BF>` restricts two-qubit interactions to adjacent cells $(p, p+1)$. The entanglement token `^` applies a Controlled-NOT ($\mathrm{CNOT}_{p\to p+1}$) with control qubit p and target qubit $p+1$:

$$\mathrm{CNOT} = |0\rangle\langle 0| \otimes I_2 + |1\rangle\langle 1| \otimes X = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix} \tag{6}$$

Lifted to $\mathcal{H}_N$, the global operator for $p \in \{0, \dots, N-2\}$ is:

$$\mathcal{U}_{p,p+1}(\mathrm{CNOT}) = I_2^{\otimes p} \otimes \mathrm{CNOT} \otimes I_2^{\otimes(N-p-2)} \tag{7}$$

For an open linear array, executing `^` at boundary $p = N-1$ would raise a hardware boundary exception; for a periodic 1D ring architecture, it cyclically couples cells $(N-1, 0)$. The reference implementation adopts the ring convention throughout (pointer arithmetic is taken $\bmod N$); programs intended for an open chain must therefore avoid `^` at $p = N-1$, since the $(N-1, 0)$ coupling is not nearest-neighbor on an open array.

2.4 Projective Measurement (`.`) & Reset (`,`)

The output token `.` performs a projective von Neumann measurement on qubit p in the Pauli-Z computational basis. Let the orthogonal projection operators on cell p be:

$$\Pi_m^{(p)} = \mathcal{U}_p(|m\rangle\langle m|), \quad m \in \{0,1\} \tag{8}$$

By the Born rule, the probability of observing classical bit $m \in \{0,1\}$ is:

$$P(m) = \langle\Psi|\Pi_m^{(p)}|\Psi\rangle = \sum_{x : b_p(x) = m} |\alpha_x|^2 \tag{9}$$

Upon sampling outcome m, the state vector collapses non-unitarily and renormalizes:

$$|\Psi'\rangle = \frac{\Pi_m^{(p)}|\Psi\rangle}{\sqrt{P(m)}} \tag{10}$$

and m is appended to the classical output stream $\mathcal{C}$. Active reset `,` re-initializes cell p unconditionally to $|0\rangle$.

2.5 Loop Semantics (`[ ]`): Copenhagen vs. Coherent

`|BF>` defines two formal execution profiles for bracketed blocks `[` B `]`:

1. **Profile D (Dynamic / Copenhagen Loops):** Entry `[` executes a projective measurement $\Pi_m^{(p)}$ on the cell p currently under the head. If $m = 0$, the instruction pointer jumps past `]`; if $m = 1$, body B executes and `]` branches back to `[`, which re-measures the cell under the (possibly displaced) head, exactly as in classical Brainfuck. Loop-test measurements are not appended to $\mathcal{C}$. This maps directly to OpenQASM 3.0 [13] mid-circuit measurement loops whenever the body has zero net displacement $\Delta p(B) = 0$ (otherwise the head position after the loop is data-dependent).

2. **Profile C (Coherent Bounded Unitary):** For a body B with net pointer displacement $\Delta p(B) = 0$, no measurements or resets, whose operations leave cell p invariant (acting non-trivially only on cells $k \neq p$), and whose nested blocks are themselves Profile C admissible (with all enclosing control cells likewise left invariant), `[` B `]` compiles to a coherently controlled unitary conditioned on qubit p [7]:

$$\mathcal{C}_p(U_B) = \Pi_0^{(p)} + \Pi_1^{(p)} \cdot U_B \tag{11}$$

Under Profile D such a block would never terminate when $m = 1$ (the body cannot reset cell p), so the reference implementation selects Profile C automatically whenever it is admissible and Profile D otherwise. Note that $\mathcal{C}_p(U_B)$ couples the control p to *every* cell touched by B: each `^` inside B becomes a Toffoli gate and each single-qubit token a controlled gate. Profile C blocks are therefore *not* nearest-neighbor operations, and their cost must be accounted for after lowering; the reference transpiler offers an LNN mode that decomposes them exactly into 1- and 2-qubit gates and routes those onto an open chain with SWAPs (Sec. 4.2).

2.6 BQP-Universality Theorem

Strictly speaking, BQP-*completeness* is a property of decision problems; for a programming model the appropriate notion is *BQP-universality*: uniform families of polynomial-length programs decide (with bounded error) exactly the languages in BQP.

Theorem 1 (BQP-Universality of `|BF>`)**.** *The Dirac–Müller Abstract Machine $\mathcal{M}$ operating on an N-qubit tape initialized to $|0\rangle^{\otimes N}$ under the loop-free instruction set* {`>`, `<`, `+`, `H`, `Z`, `T`, `-`, `^`, `.`} *is BQP-universal.*

Proof. For hardness, we simulate an arbitrary uniform polynomial-size quantum circuit family over the universal gate set $\{H, T, \mathrm{CNOT}\}$ [5]; by the Solovay–Kitaev theorem [4] this gate set defines BQP with only polylogarithmic overhead. Let $\mathcal{C}$ be an N-qubit circuit with $M = \mathrm{poly}(N)$ gates. The single-qubit generators $\{H, T\}$ map directly to native `|BF>` instructions (`H`, `T`). Although two-qubit entanglement `^` is restricted to adjacent cells $(p, p+1)$, any non-local CNOT between distant qubits j and k ($|j-k| > 1$) can be synthesized via a linear nearest-neighbor SWAP network [10, 11] requiring $2(|j-k|-1)$ adjacent SWAP gates. Each adjacent SWAP on $(p, p+1)$ decomposes into three CNOTs:

$$\mathrm{SWAP}_{p,p+1} = \mathrm{CNOT}_{p\to p+1}\mathrm{CNOT}_{p+1\to p}\mathrm{CNOT}_{p\to p+1} \tag{12}$$

Because the reversed CNOT is equivalent to target-control Hadamard conjugation, $\mathrm{CNOT}_{p+1\to p} = (H_p \otimes H_{p+1})\,\mathrm{CNOT}_{p\to p+1}\,(H_p \otimes H_{p+1}) \equiv$ `H>H<^>H<H`, an adjacent SWAP is expressed in `|BF>` as:

$$\mathrm{SWAP}_{p,p+1} \equiv \texttt{\^{}H>H<\^{}>H<H\^{}} \tag{13}$$

Since pointer shifts (`>`, `<`) incur zero quantum gate depth, each non-local gate compiles to $O(N)$ native tokens (SWAPs plus head movement), giving a total program length of $O(N \cdot M) = \mathrm{poly}(N)$. Final projective readout via `.` samples the computational basis, reproducing the output distribution of $\mathcal{C}$ exactly.

Conversely, a loop-free `|BF>` program of length $T = \mathrm{poly}(N)$ on N qubits corresponds to a sequence of at most T elementary Clifford+T operations and terminal-or-mid-circuit projective measurements (the latter may be deferred), which can be simulated by a uniform quantum circuit family [2] in time $\mathrm{poly}(T)$. Hence `|BF>` is BQP-universal. (Profile D loops with unbounded iteration counts are excluded from the theorem, since their running time is not bounded by the program length.) □

Metric / Feature	Esolangs QBF	`|BF>` (Ours)
Tape Ground State	$\|1\rangle^{\otimes N}$ (Excited)	$\|0\rangle^{\otimes N}$ (Vacuum)
Universal Basis	$\{H, CV, \text{SWAP}\}$	$\{X, H, Z, T, \text{CNOT}\}$
Pauli-X (Bit-Flip) Cost	Requires Ancilla + H, CV	1 token (`+`)
$\text{CNOT}_{p,p+1}$ Source Cost	8 tokens (`>%<!!>%<`)	1 token (`^`)
$\text{CNOT}_{p,p+1}$ 2Q Gate Depth	2 two-qubit gates	**1 two-qubit gate**
Bell Pair Program (from ground state)	`%>%<!!>%<` (9 tokens, $\|\Psi^-\rangle$)	`H^` (2 tokens, $\|\Phi^+\rangle$)
Readout Mechanism (`.`)	CNOT onto output qubit	Born Projective Collapse
OpenQASM 3.0 Mapping	Multi-gate synthesis	$O(1)$ per token

Table 1: Architectural comparison between Esolangs QBF and `|BF>`.

3 Comparative Analysis: `|BF>` vs. Esolangs QBF

In 2006, Ihope127 proposed *Quantum brainfuck* (QBF) on the Esolangs wiki [12] using the token set `< > % ! & , . [ ]`, where `%` is Hadamard, `!` is Controlled-V ($CV = \text{diag}(1, 1, 1, i)$), and `&` is SWAP. While historically notable, QBF has practical drawbacks that `|BF>` addresses:

3.1 The Vacuum Ground-State Issue

QBF has no single-qubit bit-flip or phase primitive: its only diagonal gate, CV, acts as the identity on every computational-basis input except $|11\rangle$, so a deterministic single-qubit $S = \text{diag}(1, i)$, and from it $Z = S^2$ and $X = HZH$, is available only by using a neighbouring cell held in $|1\rangle$ as control. QBF's specification sidesteps this by initializing all tape cells to $|1\rangle^{\otimes N}$ [12]. Physically, superconducting transmon and trapped-ion qubits relax to the $|0\rangle$ ground state; preparing $|1\rangle^{\otimes N}$ requires N active π-pulses prior to execution and exposes idle tape cells to T_1 amplitude-damping decay ($|1\rangle \to |0\rangle$) [15]. `|BF>` restores the physical $|0\rangle^{\otimes N}$ initialization by providing `+` as a native Pauli-X.

3.2 Gate Synthesis Bloat in QBF

To execute a single $\text{CNOT}_{p\to p+1}$ in QBF, one must square the Controlled-V gate to obtain $CZ = (CV)^2 = \text{diag}(1, 1, 1, -1)$ and conjugate the target by Hadamards [7]:

$$\text{CNOT}^{(\text{QBF})}_{p\to p+1} = (I \otimes H) \cdot CV^2 \cdot (I \otimes H) \equiv \texttt{>\%<!!>\%<} \tag{14}$$

This requires **8 source instructions**, **4 quantum gates** (including two costly 2-qubit gates), and **4 pointer shifts**. In `|BF>`, $\text{CNOT}_{p\to p+1}$ is a single native primitive (`^`).

4 Compilation to OpenQASM 3.0

A primary engineering contribution of `|BF>` is its $O(1)$ per-token translation into **OpenQASM 3.0** [13], the intermediate representation supported by IBM Quantum, AWS Braket, and Quantinuum.

4.1 Formal Translation Schema

Pointer shifts (`>`, `<`) are tracked statically by the compiler and incur zero quantum gate overhead. This requires the head position after every block to be known at compile time, which holds for Profile C blocks ($\Delta p = 0$ by definition); the transpiler therefore also requires $\Delta p(B) = 0$ for Profile D loops and rejects other programs. Each `.` token writes its own transcript bit `c[k]` (k = static occurrence index), so that repeated measurements of the same cell (e.g. qubit recycling) never overwrite earlier outcomes; loop tests use a separate register `guard`.

`|BF>`	Compile-Time Action	Emitted OpenQASM 3.0
`>`	$p \leftarrow (p+1) \bmod N$	*(Zero gate emission)*
`<`	$p \leftarrow (p-1) \bmod N$	*(Zero gate emission)*
`+`	Emit Pauli-X	`x q[p];`
`H`	Emit Hadamard	`h q[p];`
`Z`	Emit Pauli-Z	`z q[p];`
`T` / `-`	Emit $\pi/8$ Phase / Adj.	`t q[p];` / `tdg q[p];`
`^`	Emit Nearest-Neighbor CX	`cx q[p], q[p + 1];`
`.` (k-th)	Emit Mid-Circuit Measure	`c[k] = measure q[p];`
`,`	Emit Active Reset	`reset q[p];`
`[` (Profile D)	Emit Dynamic Loop Header	`guard[p] = measure q[p]; while (guard[p] == 1) {`
`]` (Profile D)	Re-measure & Close Loop	`guard[p] = measure q[p]; }`
`[` B `]` (Profile C)	Control the gates of B by `q[p]` (conjugation-aware)	`cx`→`ccx`, `x`→`cx`, `h`→`ch`, `z`→`cz`, `t`→`ctrl @ t`, …

Table 2: Syntax-directed translation from `|BF>` to OpenQASM 3.0. OpenQASM 3.0 gate modifiers apply to named gates only, so Profile C blocks are lowered gate by gate (nested blocks use `ctrl(`k`) @`).

4.2 Conjugation-Aware Control and LNN Routing

A naive lowering of `[` B `]` adds the control to every gate of B. Since $\mathcal{C}_p(VUV^{-1}) = V\,\mathcal{C}_p(U)\,V^{-1}$ for arbitrary unitaries, gates that are undone later inside B need no control at all. The reference transpiler finds such prefix/suffix pairs with a dynamic program over each block (nested blocks first) and merges adjacent phase gates. A coherently controlled SWAP macro then costs one Toffoli and two CNOTs (8 CNOT-equivalents) instead of three Toffolis and four controlled-Hadamards (22). Both lowerings remain available. In LNN mode the output is further decomposed exactly into 1- and 2-qubit gates (Clifford+T Toffoli, recursive multi-controlled phases) and routed onto an open linear chain by adjacent SWAPs with a tracked qubit layout, so that every 2-qubit gate acts on neighbouring

physical qubits. All modes are checked against the abstract machine exactly by an independent OpenQASM interpreter.

4.3 NISQ Fidelity Considerations

On physical quantum processors with single-qubit gate error $\epsilon_1 \approx 10^{-4}$, two-qubit CNOT error $\epsilon_2 \approx 5 \times 10^{-3}$, and dephasing time T_2, the circuit survival fidelity $\mathcal{F}$ scales according to standard NISQ phenomenological models [15, 16] as:

$$\mathcal{F} \approx (1-\epsilon_1)^{G_1}(1-\epsilon_2)^{G_2} \exp\left(-\frac{D \cdot \tau_g}{T_2}\right) \tag{15}$$

where G_1, G_2 are 1Q and 2Q gate counts, D is circuit depth and τ_g the gate duration. For uncontrolled code, `|BF>` avoids QBF's 2× two-qubit gate expansion of CNOT and its state-initialization overhead, and its pointer semantics make every `^` a nearest-neighbor ($q_p \leftrightarrow q_{p+1}$) gate, so no hidden routing SWAPs (3 CNOTs each [10, 11]) are introduced on linear or ring topologies. This does not make `|BF>` programs depth-optimal, and it does not extend to Profile C blocks, whose lowering introduces multi-qubit controlled gates between the control cell and distant cells; their nearest-neighbor cost is made explicit by the LNN routing mode.

5 Canonical Quantum Algorithms in `|BF>`

To illustrate the expressiveness and spatial locality of the Dirac–Müller Abstract Machine, we present three canonical quantum algorithms implemented directly in `|BF>`, alongside their compiled quantum circuit representations.

5.1 Tripartite GHZ State Preparation

The 3-qubit Greenberger–Horne–Zeilinger ($|\mathrm{GHZ}_3\rangle$) state [17] exhibits maximal non-local tripartite entanglement:

$$|\mathrm{GHZ}_3\rangle = \frac{|000\rangle + |111\rangle}{\sqrt{2}} \tag{16}$$

In `|BF>`, preparing $|\mathrm{GHZ}_3\rangle$ requires only 3 unitary tokens and 1 pointer shift (10 tokens including full register readout):

```
H^>^<.>.>.
```

Listing 1: 3-Qubit GHZ preparation and readout in `|BF>`.

- **`H`:** Applies Hadamard to q_0, evolving $|000\rangle \to \frac{1}{\sqrt{2}}(|000\rangle + |100\rangle)$.
- **`^`:** Applies $\mathrm{CNOT}_{0\to1}$, yielding $\frac{1}{\sqrt{2}}(|000\rangle + |110\rangle)$.
- **`>^`:** Shifts the tape head to $p = 1$ and applies $\mathrm{CNOT}_{1\to2}$, producing $|\mathrm{GHZ}_3\rangle = \frac{1}{\sqrt{2}}(|000\rangle + |111\rangle)$.
- **`<.>.>.`:** Returns to $p = 0$ and performs projective Z-basis readout across q_0, q_1, q_2, yielding classical bitstrings 000 or 111 with equal probability $P = 0.5$.

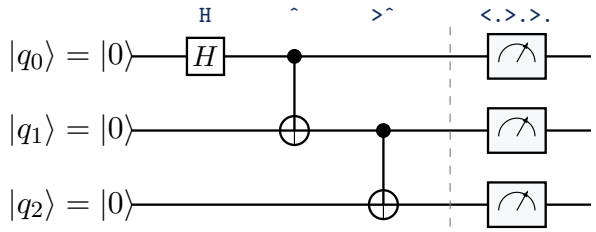


Figure 1: Compiled circuit for $|\mathrm{GHZ}_3\rangle$ preparation (`H^>^<.>.>.`).

5.2 Quantum Teleportation Protocol

Quantum teleportation [18] transfers an arbitrary state $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$ from sender qubit q_0 to receiver qubit q_2 using an entangled Bell pair shared across (q_1, q_2) and two classical feed-forward bits:

```
>H^<^H.>. [>+<+] < [>>Z<<+] >>
```

Listing 2: Quantum Teleportation in `|BF>`.

1. **Bell Resource (`>H^`):** Shifts pointer to q_1 and entangles (q_1, q_2) into $|\Phi^+\rangle_{12} = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$. The joint 3-qubit state factors into the Bell basis on (q_0, q_1):

$$|\Psi\rangle = \frac{1}{2}\Big[|\Phi^+\rangle_{01}|\psi\rangle_2 + |\Phi^-\rangle_{01}(Z|\psi\rangle)_2 + |\Psi^+\rangle_{01}(X|\psi\rangle)_2 + |\Psi^-\rangle_{01}(XZ|\psi\rangle)_2\Big] \tag{17}$$

2. **Bell Measurement (`<^H.>.`):** Returns to q_0 via `<`, applies $\mathrm{CNOT}_{0\to1}$ (`^`) and H on q_0, and measures $q_0 \to c_0$ (`.`). Shifts to q_1 via `>` and measures $q_1 \to c_1$ (`.`). The pointer remains at cell $p = 1$.

3. **Dynamic Feed-Forward (`[>+<+]<[»Z«+]»`):** At $p = 1$, if $c_1 = 1$, the loop `[>+<+]` steps to q_2 (`>`), applies Pauli-X (`+`), returns to q_1 (`<`), and flips q_1 from $|1\rangle$ to $|0\rangle$ via `+` (or reset `,`) to cleanly exit the dynamic while-loop after a single execution. Next, `<` moves the tape head to q_0; if $c_0 = 1$, `[»Z«+]` branches to q_2 (`»`), applies Pauli-Z (`Z`), returns to q_0 (`«`), and flips q_0 to $|0\rangle$. Finally, `»` parks the pointer at q_2, holding $|\psi\rangle$.

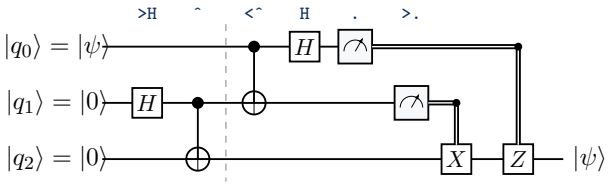


Figure 2: Quantum Teleportation circuit generated from `|BF>`.

5.3 2-Qubit Grover Search Algorithm

Grover's search [19] amplifies the amplitude of a marked state $|\omega\rangle \in \{0,1\}^2$ (here $|\omega\rangle = |11\rangle$) in a 4-element database using a single oracle query ($P(|11\rangle) = 1$). Because $\mathrm{CZ}_{0,1} = (I \otimes H)\,\mathrm{CNOT}_{0\to1}\,(I \otimes H)$, a Controlled-$Z$ phase oracle is expressed in `|BF>` via the 7-token macro `>H<^>H<` (three gates):

```
H>H< >H<^>H< H+>H+< >H<^>H< +H>+H< .>.
```

Listing 3: Complete 2-Qubit Grover search for $|\omega\rangle = |11\rangle$ in `|BF>`.

- **Initialization (`H>H<`):** Prepares the uniform superposition $|s\rangle = H^{\otimes 2}|00\rangle = \frac{1}{2}(|00\rangle + |01\rangle + |10\rangle + |11\rangle)$.
- **Phase Oracle U_ω (`>H<^>H<`):** Applies $\mathrm{CZ}_{0,1}$, flipping the phase of $|11\rangle$ to yield $\frac{1}{2}(|00\rangle + |01\rangle + |10\rangle - |11\rangle)$.
- **Grover Diffuser $D = 2|s\rangle\langle s| - I$ (`H+>H+< >H<^>H< +H>+H<`):** Conjugates $\mathrm{CZ}_{0,1}$ by $H^{\otimes 2}X^{\otimes 2}$, which yields $H^{\otimes 2}(I - 2|00\rangle\langle 00|)H^{\otimes 2} = -D$, i.e. the diffuser up to an irrelevant global phase, reflecting amplitudes about the mean to isolate $|11\rangle$ with probability 1.0.

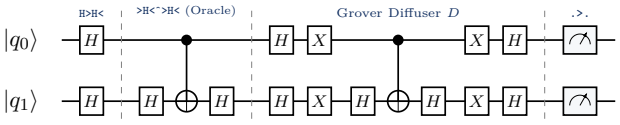


Figure 3: 2-Qubit Grover search circuit in `|BF>` isolating $|11\rangle$.

6 Conclusion

`|BF>` (Bra-Ket-Fuck) demonstrates that an esoteric quantum tape language need not sacrifice physical realism for mathematical minimalism. By grounding the Dirac–Müller Abstract Machine in the $|0\rangle^{\otimes N}$ ground state, adopting the universal Clifford+T basis, and restricting the native two-qubit gate to nearest neighbors, `|BF>` can serve as a formal verification calculus, a compiler fuzzing target, and a compact front-end for OpenQASM 3.0 [13]. Coherent (Profile C) control remains its main source of non-local, multi-qubit cost.

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