

Title: Quantum Computing without Entanglement?

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URL: <http://pirsa.org/06100011>

Abstract: TBA

Why we do not understand MSE?

Ent of pure states

Ent of pure states

$$|\alpha\rangle \otimes |\beta\rangle$$

Ent of pure states

$$|\alpha\rangle \otimes |\beta\rangle$$

S

E_f

Ent of pure states

$$|\alpha\rangle \otimes |\beta\rangle$$

S

$$E_f(\rho) = S(\rho|_A)$$

Ent of pure states

$$|\alpha\rangle \otimes |\beta\rangle$$

S

$$E_f(p) = S(p|_A)$$

$$E_f(p \otimes p') = E_f(p) + E_f(p')$$

Ent of pure states

$$|\alpha\rangle \otimes |\beta\rangle$$

$$|00\rangle + |11\rangle$$

S

$$E_f(p) = S(p|_A)$$

$$E_f(p \otimes p') = E_f(p) + E_f(p')$$

Ent of Pure states

$$|\alpha\rangle \otimes |\beta\rangle$$

$$|00\rangle + |11\rangle$$

$$E_C$$

S

$$E_f(p) = S(p|_A)$$

$$E_f(p \otimes p') = E_f(p) + E_f(p')$$

Ent of pure states

$$|x\rangle \otimes |y\rangle$$

$$|00\rangle + |11\rangle \quad E_C$$

S

$$E_f(p) = S(p|_A)$$

$$E_f(p \otimes q) = E_f(p) + E_f(q)$$

Ent of pure states

$$|\alpha\rangle \otimes |\beta\rangle$$

S

$$E_f(\rho) = S(\rho|_A)$$

$$E_f(\rho \otimes \rho') = E_f(\rho) + E_f(\rho')$$

$$|00\rangle + |11\rangle$$

E_C, E_D

asymptotic
operational measures

Ent of pure states

$$|\alpha\rangle \otimes |\beta\rangle$$

S

$$E_f(p) = S(p|_A)$$

$$E_f(p \otimes p') = E_f(p) + E_f(p')$$

$$|00\rangle + |11\rangle$$

E_C, E_D

asymptotic
operational measures

efficient classical
simulation of non
entangled Q comp.

Ent of pure states

$$|\alpha\rangle \otimes |\beta\rangle$$

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$$E_f(p) = S(p|_A)$$

$$E_f(p \otimes p') = E_f(p) + E_f(p')$$

E_C, E_D

asymptotic
operational measures

efficient classical
simulation of non
entangled Q comp.

Why we do not understand MSE?

$\{P_i, |\alpha_i\rangle\}$

ρ

$|00\rangle$

$|11\rangle$

$$\frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

$$\frac{|00\rangle - |11\rangle}{\sqrt{2}}$$

Why we do not understand MSE?

$\{P_i, |\alpha_i\rangle\}$

$$\begin{array}{cc} \rho & \begin{array}{l} |00\rangle \\ |11\rangle \end{array} \end{array} \quad \begin{array}{l} \frac{|00\rangle + |11\rangle}{\sqrt{2}} \\ \frac{|00\rangle - |11\rangle}{\sqrt{2}} \end{array}$$

Why we do not understand MSE?

$$\{P_i, |\alpha_i\rangle\}$$

$$\rho \quad \begin{array}{l} |00\rangle \\ |11\rangle \end{array}$$

$$\begin{array}{l} \frac{|00\rangle + |11\rangle}{\sqrt{2}} \\ \frac{|00\rangle - |11\rangle}{\sqrt{2}} \end{array}$$

$$\sum P_i \rho_i$$

$$E_f = \min_{\{P_i, \rho_i\}} \sum P_i E(\rho_i)$$

$\uparrow$
 pure

Why we do not understand MSE?

$\{P_i, |\alpha_i\rangle\}$

ρ $\begin{matrix} |00\rangle \\ |11\rangle \end{matrix}$

$\bigcirc^S$

$$\frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

$$\frac{|00\rangle - |11\rangle}{\sqrt{2}}$$

$\sum P_i P_i$

$$E_f = \min_{\{P_i, P_i\}} \sum P_i E(P_i)$$

$\uparrow$
 pure

Why we do not understand MSE?

$\{P_i, |\alpha_i\rangle\}$

ρ $\begin{matrix} |00\rangle \\ |11\rangle \end{matrix}$



$$\frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

$$\frac{|00\rangle - |11\rangle}{\sqrt{2}}$$

$\sum P_i P_i$

$$E_f = \min_{\{P_i, P_i\}} \sum P_i E(P_i)$$

pure

Why we do not understand MSE?

$$\{P_i, |\alpha_i\rangle\}$$

$$\rho \quad \begin{array}{l} |00\rangle \\ |11\rangle \end{array}$$



$$\frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

$$\frac{|00\rangle - |11\rangle}{\sqrt{2}}$$

$$\sum P_i P_i$$

$$E_f = \min_{\{P_i, P_i\}} \sum P_i E(P_i)$$

pure

$$E_f(\rho^{(n)}) \stackrel{?}{=} n E_f(\rho)$$

$$E_D \leq E_C \leq E_F$$

$$E_D \leq E_C \leq E_F$$

$$E_D \leq E_C \leq E_F$$

Open Question

Can we simulate

Q

comp

with no ent?

$$E_D \leq E_C \leq E_F$$

Open Question

Can we simulate Q comp with no ent?

$S_0, S_1, \dots$



$$E_D \leq E_C \leq E_F$$

Open Question

Can we simulate Q comp with no ent?

$S_0, S_1, \dots$



$$E_D \leq E_C \leq E_F$$

Open Question

Can we simulate Q comp with no ent?



$P_0, P_1, \dots$

P_1, α_1^0

$$E_D \leq E_C \leq E_F$$

Open Question

Can we simulate Q comp with no ent?



$S_0, S_1, \dots$

P_1, α^0

fact 1


MSE

fact 1



$$\begin{array}{l} 100 \\ 11 \end{array}$$

$$\begin{array}{l} 100 \rangle | \alpha_0 \rangle \\ + 111 \rangle | \alpha_1 \rangle \end{array}$$

fact 1



$$\begin{array}{l} |00\rangle \\ |11\rangle \end{array}$$

$$\begin{array}{l} |00\rangle|\alpha_0\rangle \\ + |11\rangle|\alpha_1\rangle \end{array}$$

fact 1



$|00\rangle$
 $|11\rangle$

$|00\rangle|d_0\rangle$
 $+ |11\rangle|d_1\rangle$

start with

○ MSE, somebody else acting on rest of state
and saying something E changes.

fact 2:



fact 2:



Universal $\odot$ computation can be performed
with $\odot$ drawing $\odot$ MSE throughout the comp.

fact 2:



Universal $\odot$ computation can be performed
with heavy $\odot$ MSE throughout the comp.

claim:

$$\{a\}, \{z^{\frac{1}{2^n}}, z^{\frac{1}{2^{n+1}}}\}$$

claim:

$$\neq |\alpha\rangle, \left\{ \frac{1}{2^n}, 2^{\otimes n} |\alpha\rangle \right\}$$

Mixture of "basis states."

claim:

$$\nexists |\alpha\rangle, \left\{ \frac{1}{2^n}, 2^{\otimes n} |\alpha\rangle \right\}$$

Mixture of basis states.

$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \begin{pmatrix} a|\alpha\rangle + b|\beta\rangle \\ \begin{pmatrix} |\alpha|^2 & a|b|^* \\ a^*b & |b|^2 \end{pmatrix} \xrightarrow{M} \end{pmatrix}$$

claim.
 $\forall |\alpha\rangle$

$$\left\{ \frac{1}{2^n}, 2^{\otimes n} |\alpha\rangle \right\}$$

Mixture of basis states.

$$\frac{1}{2} |\alpha|^2 a b^*$$

$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

$$a|0\rangle + b|1\rangle$$

$$\begin{pmatrix} |a|^2 & ab^* \\ a^*b & |b|^2 \end{pmatrix} \xrightarrow{M}$$

$$\begin{pmatrix} |a|^2 & 0 \\ 0 & |b|^2 \end{pmatrix}$$

$$\frac{1}{2} I, \frac{1}{2} Z$$

claim.
 $\forall |\alpha\rangle$

$$\left\{ \frac{1}{2^n}, 2^{\otimes n} |\alpha\rangle \right\}$$

Mixture of basis states.

$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

$$\begin{pmatrix} |\alpha|^2 & \alpha b^* \\ \alpha^* b & |b|^2 \end{pmatrix} \xrightarrow{M}$$

$$\begin{pmatrix} |\alpha|^2 & 0 \\ 0 & |b|^2 \end{pmatrix}$$

$$\frac{1}{2}I, \frac{1}{2}Z$$

$$\frac{1}{2} \begin{pmatrix} |\alpha|^2 & \alpha b^* \\ b \alpha^* & |b|^2 \end{pmatrix}$$

$$+ \frac{1}{2} \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

claim:
 $\forall |\alpha\rangle$

$$\left\{ \frac{1}{2^n}, 2^{\otimes n} |\alpha\rangle \right\}$$

Mixture of basis states.

$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

$$\begin{pmatrix} |a|^2 & ab^* \\ a^*b & |b|^2 \end{pmatrix} \xrightarrow{M}$$

$$\begin{pmatrix} |a|^2 & 0 \\ 0 & |b|^2 \end{pmatrix}$$

$$\frac{1}{2} I, \frac{1}{2} Z + \frac{1}{2} \begin{pmatrix} |a|^2 & 0 \\ 0 & |b|^2 \end{pmatrix}$$

claim:
 $\nexists |\alpha\rangle$

$$\left\{ \frac{1}{2^n}, 2^{\otimes n} |\alpha\rangle \right\}$$

Mixture of basis states.

$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

$$\begin{pmatrix} |\alpha|^2 & a b^* \\ a^* b & |b|^2 \end{pmatrix} \xrightarrow{M}$$

$$\begin{pmatrix} |\alpha|^2 & 0 \\ 0 & |b|^2 \end{pmatrix}$$

$$\frac{1}{2}I, \frac{1}{2}Z$$

$$\frac{1}{2} \begin{pmatrix} |\alpha|^2 & a b^* \\ b a^* & |b|^2 \end{pmatrix} + \frac{1}{2} \begin{pmatrix} |\alpha|^2 & -a b^* \\ -b a^* & |b|^2 \end{pmatrix}$$

fact 1



$$\begin{matrix} 100 \\ 11 \end{matrix} \rangle$$

$$\begin{matrix} 100 > 100 \\ + 111 > 111 \end{matrix}$$

start with

- ○ MSE, somebody else acting on rest and saying something E changes.

fact 2:



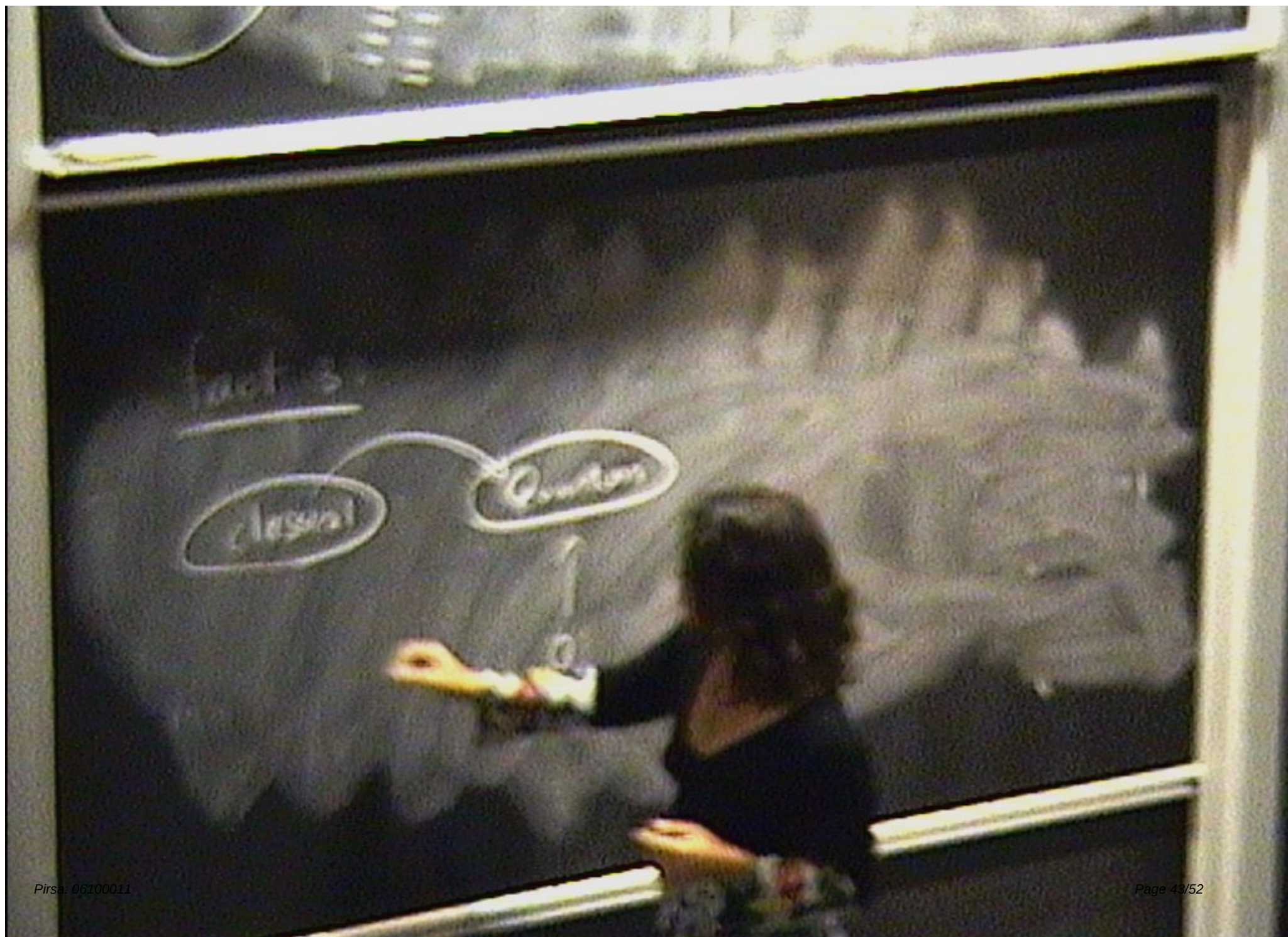
Universal $\odot$ computation can be performed
with $\odot$ drawing $\odot$ MSE throughout the comp.

$| \beta_0 \rangle$

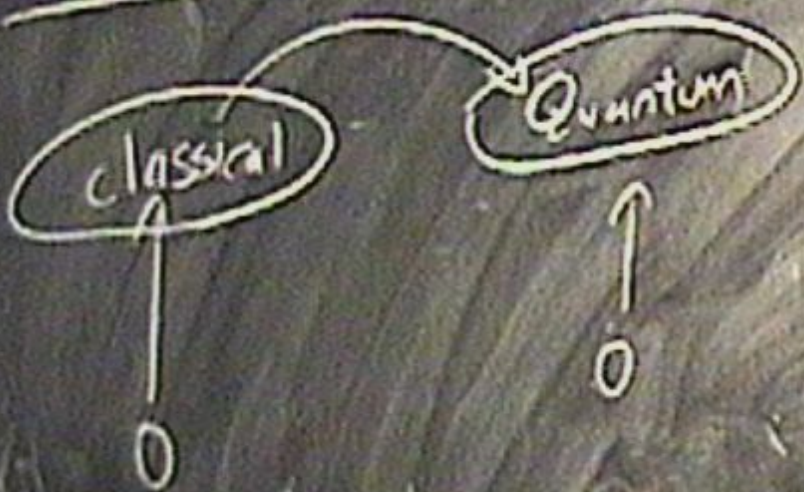
$| \alpha_0 \rangle$
 $| \alpha_1 \rangle$
 $\vdots$

$| \beta_T \rangle$

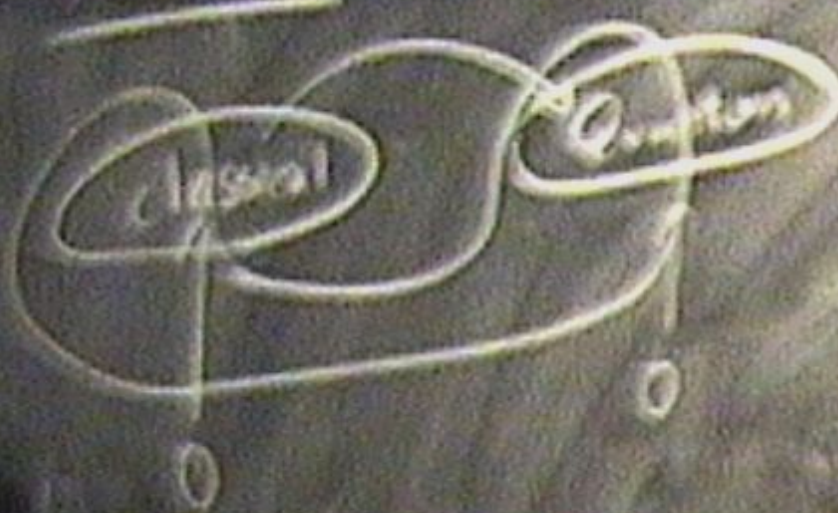
$| \alpha_T \rangle$



fact 3:



fact 3.



$\log \frac{E_0}{E_c}$

(logarithmic scale)

National Bureau

Standard deviation

of the mean

of the sample

$$\int_{\partial D} \left(\frac{1}{2} \frac{\partial \phi}{\partial \nu} + \frac{1}{2} \phi \right) dS = \sum_{j=1}^n E_j \cdot \text{area}(\Sigma_j) = \sum_{j=1}^n E_j \cdot E_j$$

act 2:

classical sample

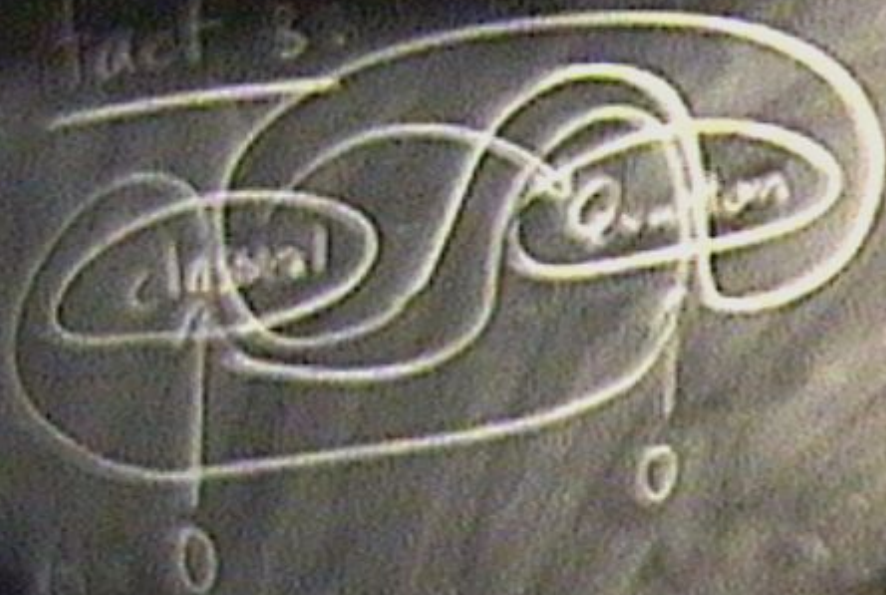
Universal Quantification can be performed with $\forall$ over the comp.

 1007
11 47

MSB 1007/17
* 1007/17

① MSB, something like nothing or restlessness
and saying nothing & thought

fact 3:



MSE ←

MSE ←

$\mathcal{S}$: mixtures ←

classical / quantum

MSE ←

ρ : mixtures ←

classical / qu

$$\frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

MSE ←

ρ : mixtures ←

classical / quantum

$$\frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

$$\left(\begin{array}{c} | \phi_i, | \alpha_i \rangle \rangle \\ | \phi_i, | \beta_i \rangle \rangle \end{array} \right)$$

fact 2:



Universal $\odot$ computation can be performed
with $\odot$ drawing $\odot$ MSE throughout the comp.

$|\beta_0\rangle$

$|\alpha_0\rangle$

$|\alpha_1\rangle$

$|\beta_T\rangle$

$|\alpha_T\rangle$