Réseaux Quantiques

léments de sécurité et de fiabilité de l'informatic
et des algorithmes dans les réseaux quantiques

http://www.lri.fr/~kempe/ResQuant/

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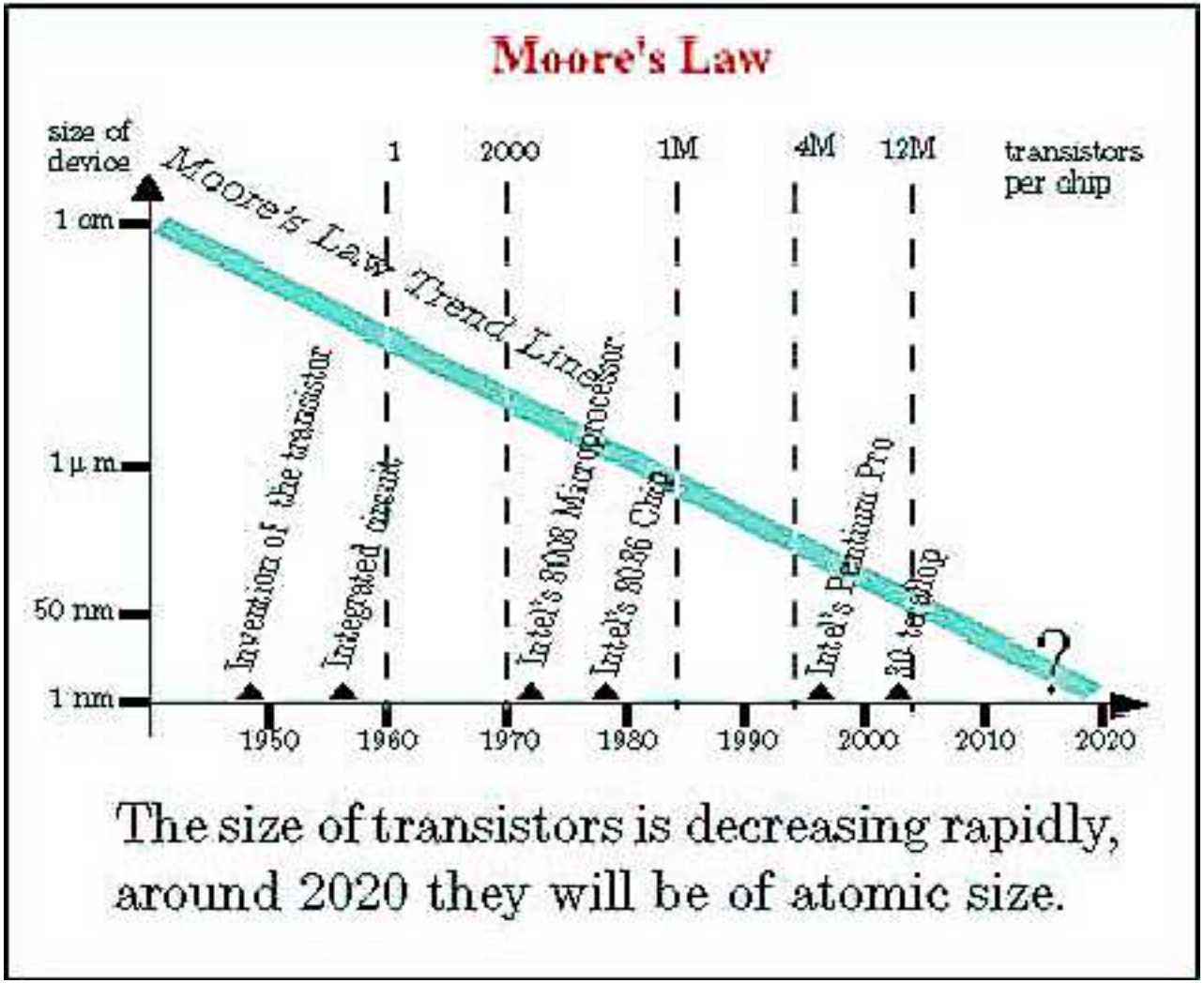
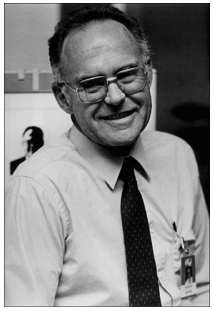
Fin de la loi de Moore ?





"No exponential is forever. Your job is to
forever.", Andrew Gordon Moore Feb. 20

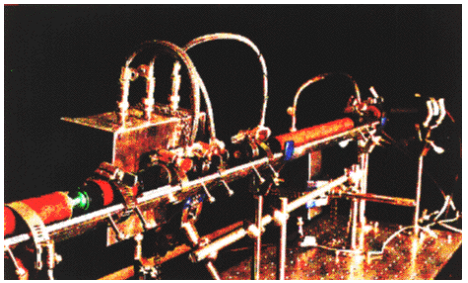
Phénomènes quantiques vers 2020…

- Approche actuelle : les supprimer
- Informatique quantique : les utiliser !

Cryptographie

- Protocole de distribution de clés secrètes [Bennett-Brassard 1984]

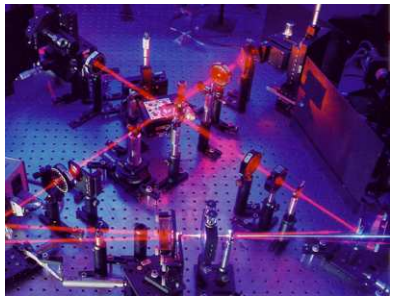
  Implémentation : ~100 km



Information quantique

- Téléportation [Bennett-Brassard-Crépeau-Jozsa-Peres-Wootters 1993]

  Réalisation : 1997 [Innsbruck]



Algorithmique

- Calcul de périodes [Simon, Shor 1994] Factorisation, log. discret...
- Recherche dans une liste non structurée [Grover 1996]

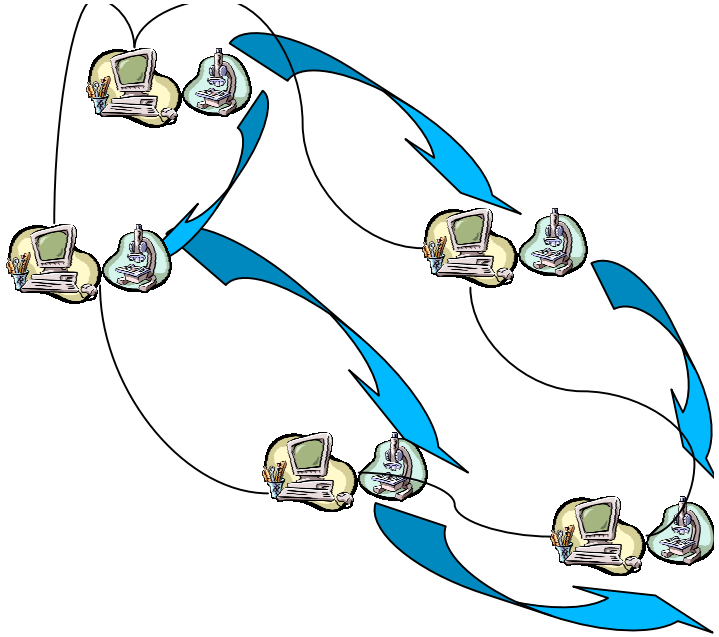
  Implémentation sur combien de qubits ?

  1995 : 2 [ENS], 1998 : 3,

  2000 : 5 [IBM] - 7 [Los Alamos]

  2001 : 8 [IBM]

Nature du réseau



- Postes locaux:
  Petit ordinateur quantique
  Ordinateur *classique*
- Transmission d'information quantique/classique

Objectifs du projet

- Fiabilisation
  codes correcteurs quantiques
  auto-test des architectures quantiques
- Routage
  marches aléatoires quantiques
- algorithmique de graphe
- Nouveaux algorithmes et protocoles de communication
- Characterizer le pouvoir des machines quantiques

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voir des machines/réseaux quantiques

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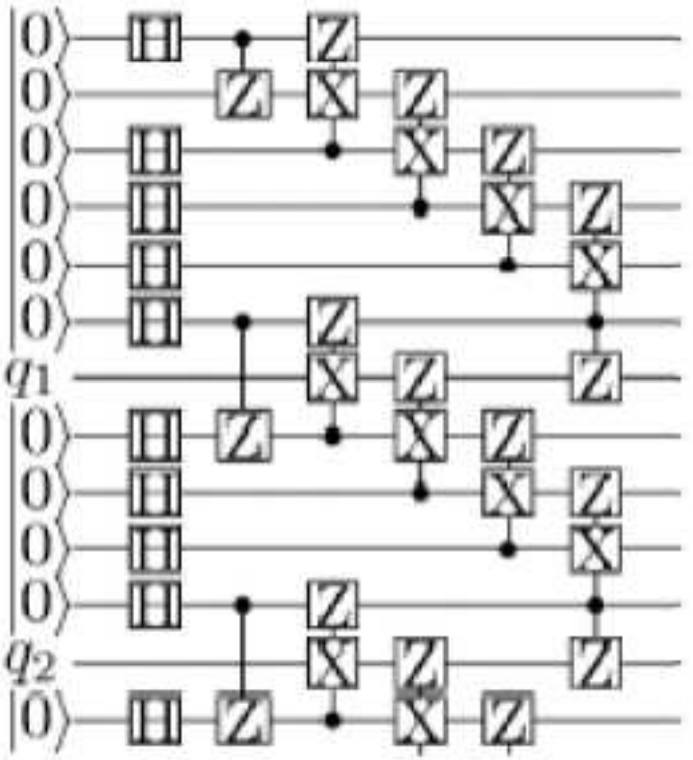
Contexte

- Milieu : air libre ou fibre optique
- Tansmission : information quantique entre processeurs et mémoires

Solution : codes convolutifs

- Codage : complexité linéaire
- Décodage : complexité linéaire
- Application : réduction d'erreur



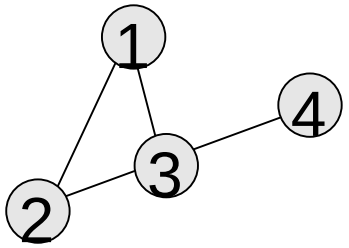
Exemple

- Code (5,1,2)

Extension

- Turbo-codes ✓
- Décodage itératif ✓
- Codes à matrice de parité creuse ✓

Modèle



Matrice d'adjacence Tableau d'adjacence

	1:	2:	3:	4:
1:	0	1	1	0
2:	1	0	1	0
3:	1	1	0	1
4:	0	0	1	0

1: 2 3
2: 3 1
3: 1 4 2
4: 3

n arêtes m nœuds

Problèmes

	Matrice d'adj.	Tableau d
-Connectivité, arbres de plus courts chemins	$\Theta(n^{1.5})$	$\Theta(\sqrt{nr}$
-Présence de triangle	$O(n^{1.3})$	$O(\sqrt{nr}$
-Propriété monotone	$O(n^{2-c})$	

s résultats:

xte

r deboguer un ordinateur quantique ?

faire confiance à des fournisseurs de services
s (cryptographiques)?

on : auto-test

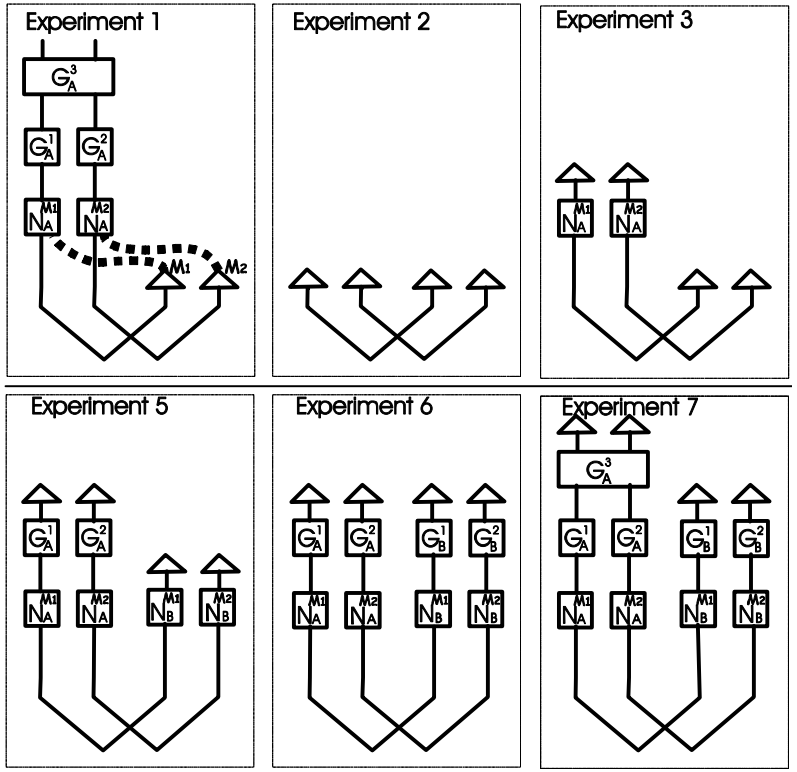
une architecture qui puisse être auto-testée

Auto-test de familles de portes

Auto-test inconditionel d'une paire EPR

ainsi que des appareils de mesure

Test robuste!



ésultats:

Contexte

- Information codée sur des photons
- Stockage difficile

Pas le temps de calculer le chemin !

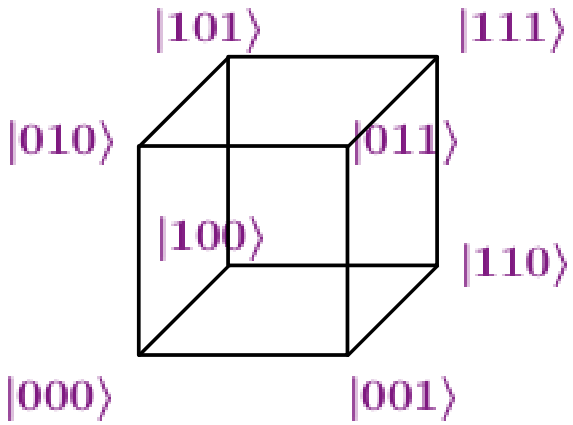
Solution : marche quantique

- Destinataire aléatoire

Temps d'atteinte ?

Cas de l'hypercube

- Classiquement : $O(2^n)$
- Quantiquement : $O(n)$!



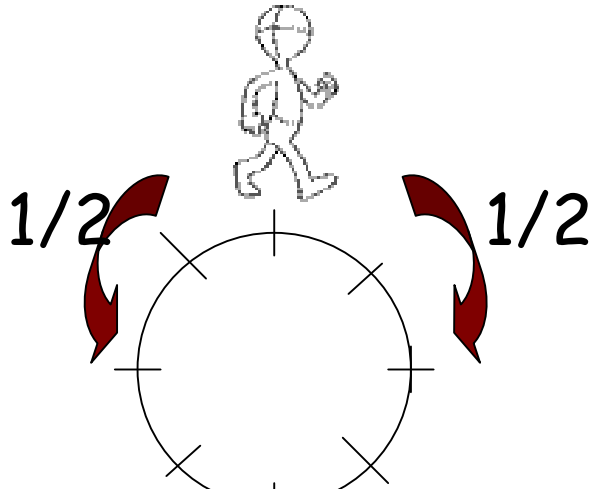
s résultats:

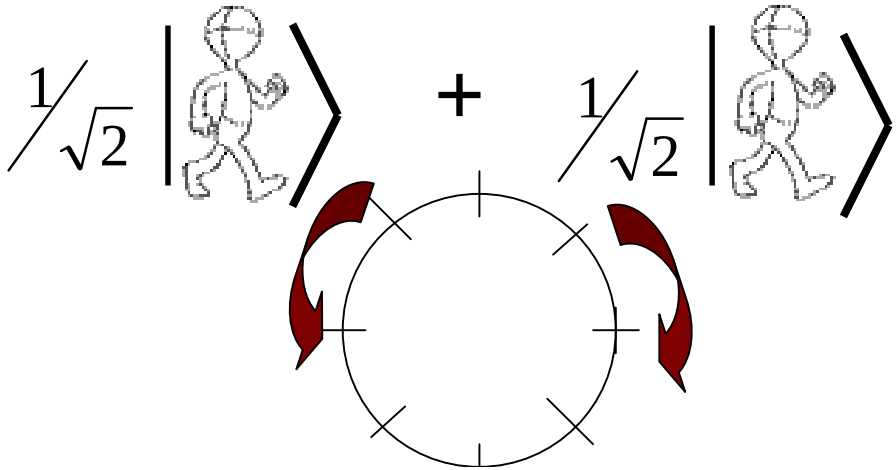
ı: use random walks for network tasks (routing, randomized algorithms)

sical: Randomized algorithms very successful

ı : construct a Markov chain (simple, local transitions)
(1) stationary distribution gives solution to problem ⇒ Mixing time
(2) which hits the desired solution ⇒ Hitting time

/ tool: Quantum Walks!





lassical random walk

Flip coin for direction

Walk conditioned on outcome

...	-2	-1	0	1	

Quantum "coined" walk:

$\{|\rightarrow\rangle,|\leftarrow\rangle\} \otimes$

...	-2	-1	0	1	2

States $|\rightarrow,x\rangle$ and $|\leftarrow,x\rangle$

- Coin flip:

$$|\rightarrow\rangle \Rightarrow \frac{1}{\sqrt{2}}|\rightarrow\rangle+\frac{1}{\sqrt{2}}|\leftarrow\rangle$$

$$|\leftarrow\rangle \Rightarrow \frac{1}{\sqrt{2}}|\rightarrow\rangle-\frac{1}{\sqrt{2}}|\leftarrow\rangle$$

- Shift:

$$|\rightarrow,x\rangle \Rightarrow |\rightarrow,x+1\rangle$$

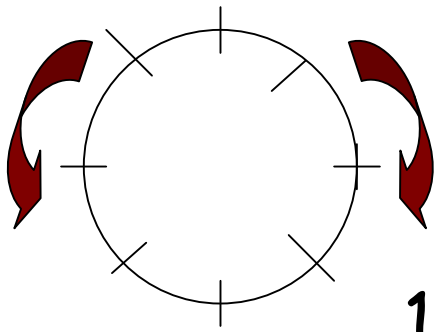
$$|\leftarrow,x\rangle \Rightarrow |\leftarrow,x-1\rangle$$

ıple line:

...	-2	-1	0	1	2	...

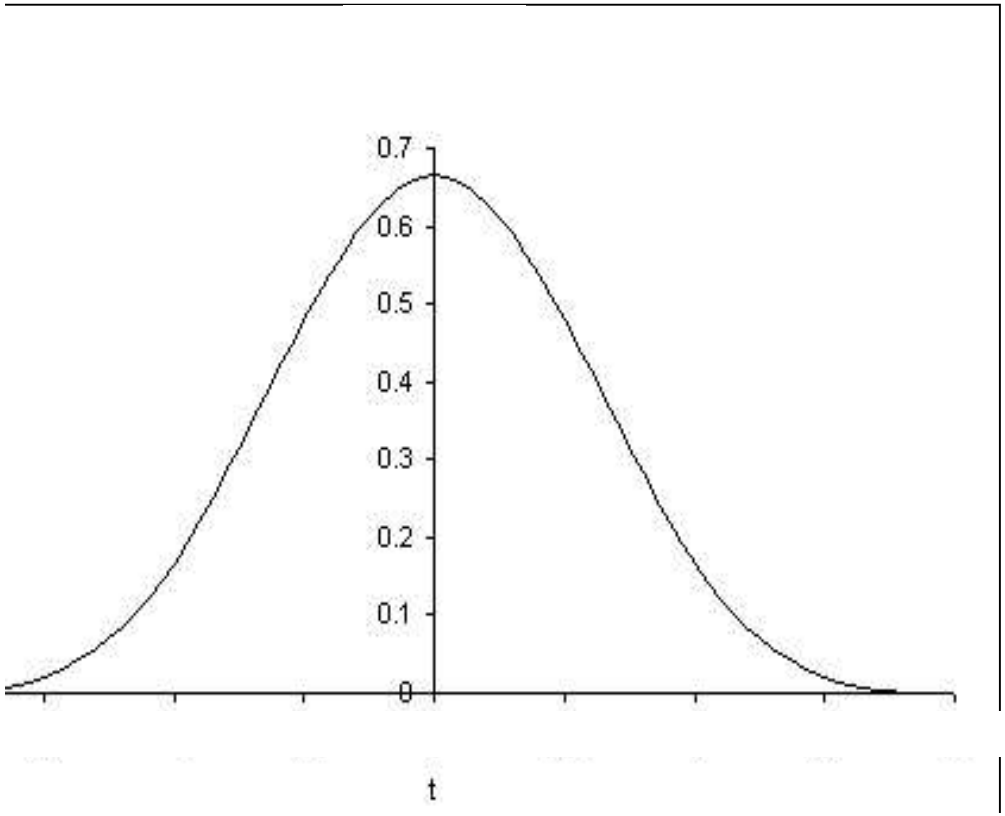
g time on N-circle:

classical: $O(N^2)$ quantum: $O(N)$

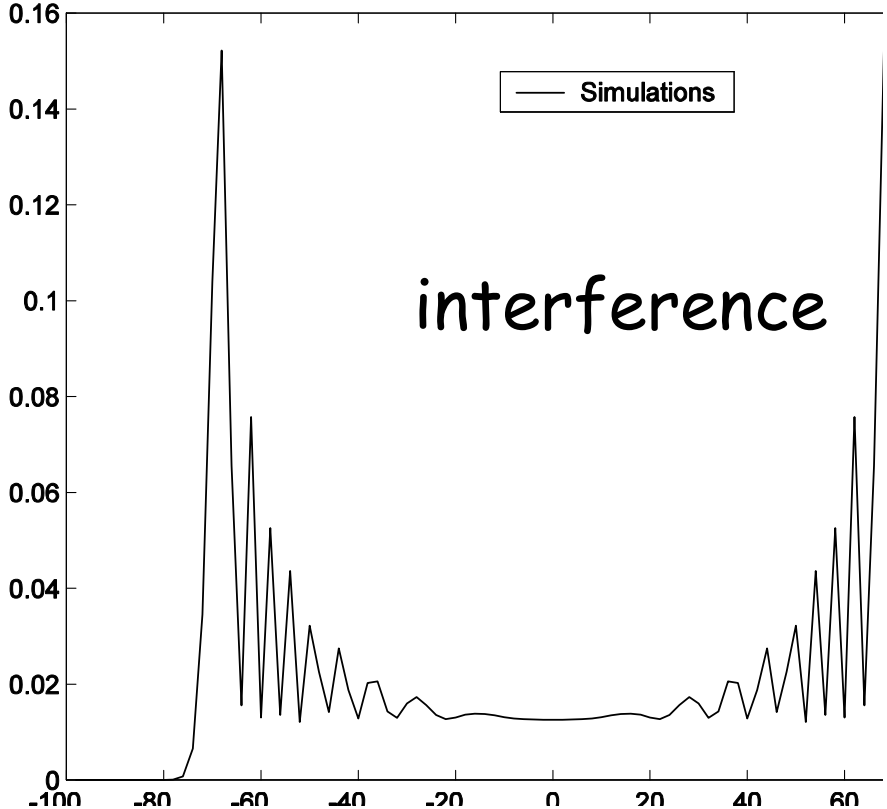


Probability distribution (measurement after T steps):

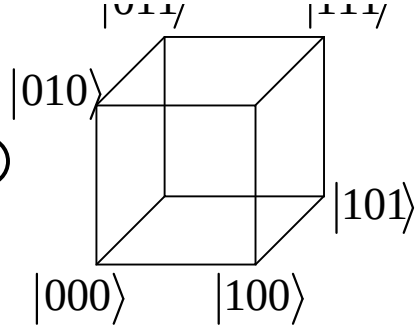
lassical:

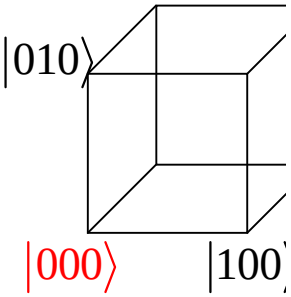


Quantum:



pace: $\{|\leftrightarrow\rangle, |\swarrow\nearrow\rangle, |\updownarrow\rangle\} \otimes$





ssical: from v to opposite corner, hitting-time exponential

$$T = 2^n(1 + O($$

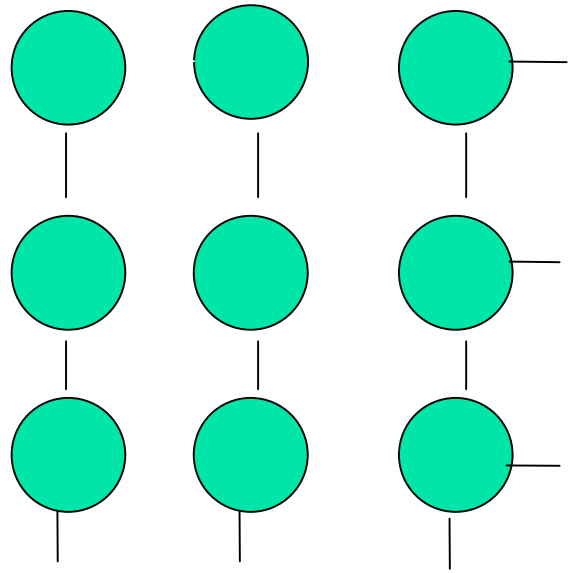
antum: polynomial

Hitting-time from v to opposite corner :

n known: $T \approx \frac{\pi}{2} n$ n unknown: $T = O(n^2)$

or decentralized routing in networks!
outing nodes do not know destination of packet, still routing is
ential advantage over the classical setting.

Set of items S, some marked.



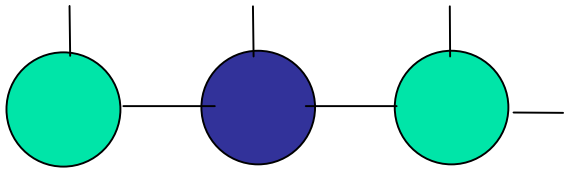
ric Algorithm:

Start with a uniform superposition over all S.

Apply one coin (transition rule) if S marked,

another if S not marked.

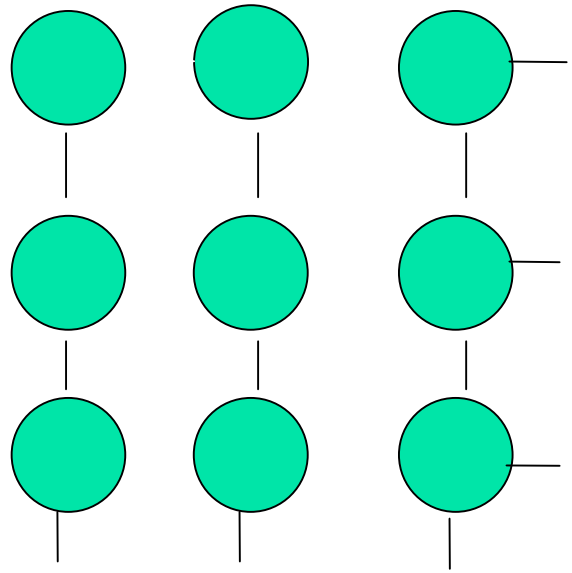
Measure after T steps



tum walk leads to a state in which marked S have higher amplit

"leaky"
Quantum walk

Set of items S, some marked.



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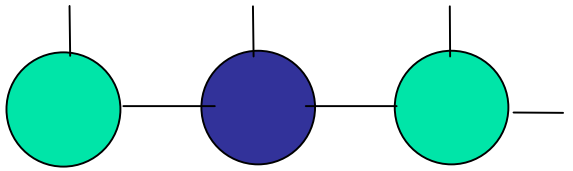

tum walk leads to a state in which marked S have higher amplit

ications :

spatial search [Ambainis,Kempe,Rivosh'05]

Commmunication

- Nouveaux protocoles de transmission
- Characterisation du pouvoir des modèles de communication

Algorithmes

- Analyse des algorithmes pour isomorphisme de graphe et recherche locale

Pouvoir des machines quantiques

- Etude de la décoherence (bruit)
- Etude des modeles physiques sur réseau
- Analyse des nouveaux modèles de calcul (calcul adiabatique sur réseau)

...