Quantum Computing and the Evolution of Database

BCIS 5420

Found. of Data Base Mngt. Systems

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Source:

Quantum Databases

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ABSTRACT

We introduce *quantum databases*, a new database abstraction that allows to defer the making of choices in transactions until an application or user forces the choices by observation. Conceptually, a transaction is in a quantum state – in one of many possible worlds, which one is unknown – until fixed by observation. Practically, our abstraction enables late binding of values read from the database. This allows more transactions to succeed in environments with high contention. This is particularly important for applications in which transactions compete for scarce physical resources represented by data items in the database, such as seats in airline reservation systems or meeting slots in calendaring systems. In such environments, deferral of the assignment of resources to consumers until all constraints are available to the system will lead to more successful transactions. Through entanglement of queries and transactions, a notion that we have explored in previous work, quantum databases can enable collaborative applications with a constraint satisfaction aspect directly within the database system.

reserve plane tickets some time in advance and there is time on the order of days – or months – between the time the booking transaction commits and the time the seat actually needs to be used.

In this paper, we observe that both flexibility and the time delay from resource request to usage can and should be exploited by the system for optimal resource allocation. The system can exploit user flexibility by explicitly keeping track of preferences and "don't cares"; it can also exploit the delay by deferring resource allocation as late as possible. Usually, requests for resources arrive over time from different users and the system has no knowledge of the future request sequence. Allocating a resource too early may prevent other requests from being fulfilled; for example, if a traveler – Mickey – who does not care about his seat is assigned the last available window seat on a plane, a subsequent user who only wants a window seat may be turned away, unless Mickey is willing to be reseated to an aisle seat. Reseating Mickey could be nontrivial and may require executing compensation logic; for example if he is traveling with his family and they all want to sit in the same row several people may need to be reseated.

Agenda

Quantum Database

- **Definition**
- **Academic and Commercial status of dev.**
- **Quantum Database vs Traditional Databases**
  - Schema Approach
  - Powerful Search Tool
  - Architecture
- **Prototype by Cornell University**
  - Setup
  - Results
  - Next steps

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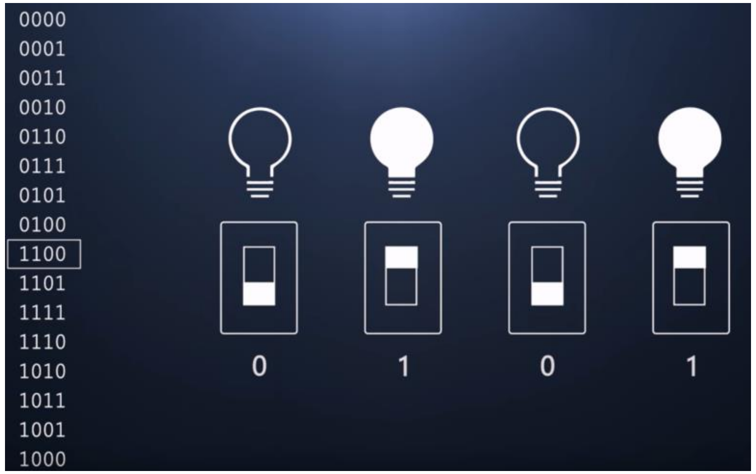
Quantum Computing: Definition

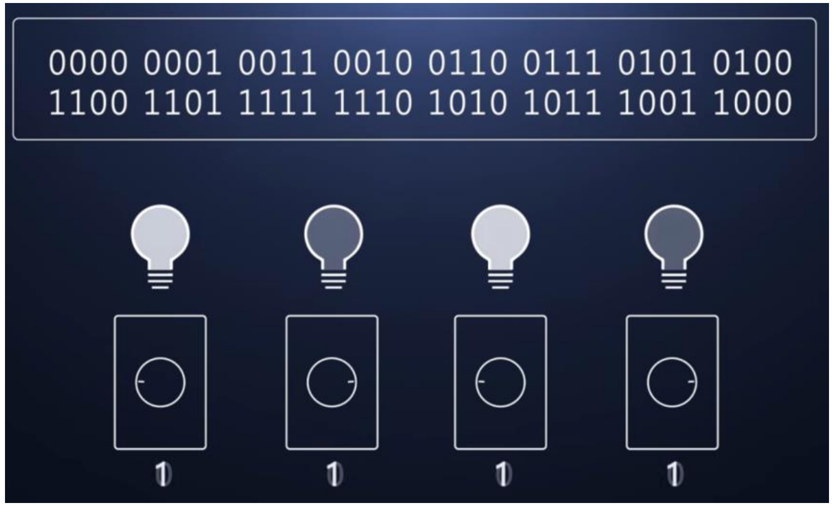
CLASSIC COMPUTING

- A CLASSICAL computer has a memory made up of BITs, where each bit is represented by either a 1 or a 0;
- CLASSICAL Computing is based on Transistor Model that operates on ZERO or ONE (binary model has 16 values)
- **BUT you can only operate one combination at time**



QUANTUM COMPUTING

- A QUANTUM computer can represent a 1, a 0, or any superposition of those 16 values at the same time. Know as a QUBITs STATES Superposition;
- It's not a switch. It's like a DIMER.
- **You can have 16 possibilities at the same time**



Quantum Computing: Use Case &Benefits

Use Case

- Quantum computers are most likely to be used when there's a huge volume of data to process within seconds; **(LARGE DATABASE)**
- It is well suited for specific areas such optimization (like shipping logistics) and image analysis;
- And applications in fields such as Medicine, Chemistry, DNA and others forms of molecular;

Benefits

- Can compute much faster than traditional computers.
- A quantum computer of sufficient scale will be able to process problems that would now take tens of billions of years of classical computing time

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Quantum Computing: Commercial Experiments

1. The Hardware
   - Two main approaches
     - Analog
       - Divided into Quantum Simulation, Quantum Annealing and Adiabatic Quantum Computation
     - Digital
       - Use Quantum Logic Gates to do computation
   - ➢ Google
     - Announced its intention to make its 72 qubit Bristlecone quantum processor available in the cloud
   - ➢ IBM
     - Since the program launched in May 2016, IBM Q has given users a way to utilize quantum computation without having direct access to a quantum computer.

2. The Software
   - ➢ Microsoft
     - Microsoft Quantum Development kit launched last May 2019

Quantum computing is at an inflection point, moving from fundamental theoretical research to an engineering development phase to commercial experiments.

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Quantum Computing: Academic Groups

1. University of California at Santa Barbara
    - Station Q, a research lab focusing on studies of topological quantum computing co-located with the theoretical physics department
2. Purdue University
    - Research Lab on Quantum Information & Communiction - Study of quantum mechanical systems which can be used for processing, transmitting, and storing information

3. Cornell University – MCMahon Lab
    - Focus: Experimental and theoretical quantum, photonic, and neuromorphic computing

4. and…more than 45 in USA, 8 in Canada, 5 in UK, 4 in Japan…

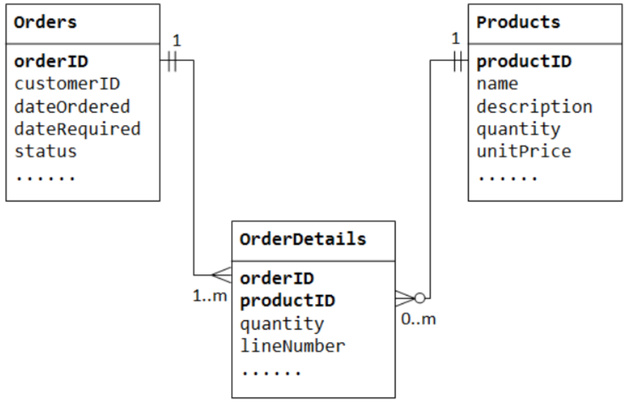
https://quantumcomputingreport.com/players/universities/

What is the impact/evolution on Classical Database ?

This field is still under research and there is no known implementation of such databases

Quantum Relational Database: Schema Approach

- In Relational model (classical database schema) data is stored in relations or tables (Row (r) and Column (c)



- In Quantum Database a Row(r) and a Colunm(c) both are represented by qubits;
- Using superposition of states would allow a single vector of (c) qubits to represent **ALL** (r) rows
- **BENEFITS: multiple simultaneous states my be relevant to database compression**

source: http://www.dcs.gla.ac.uk/~wpc/reports/qdb/qdb.html

Quantum Database: Powerful Search Tool

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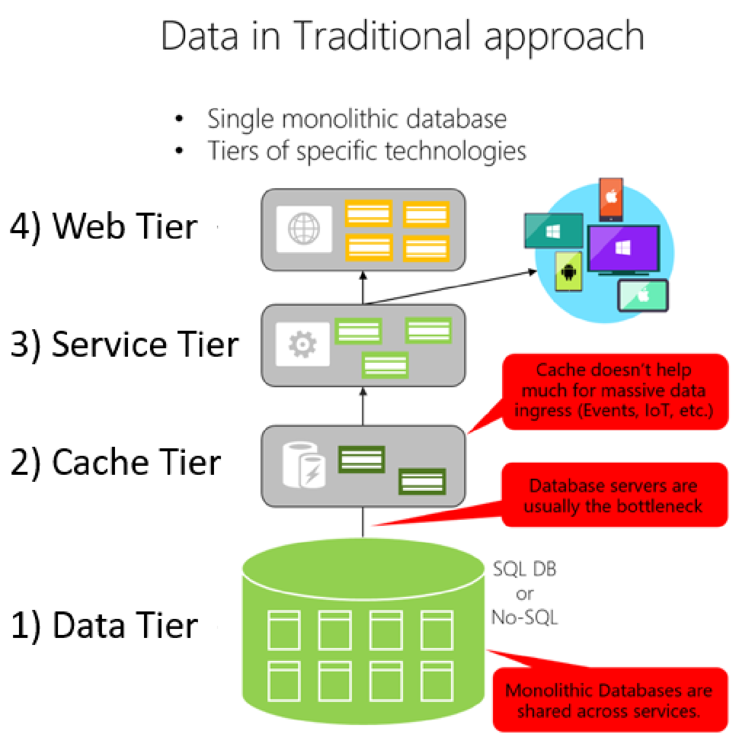
- A standard Search engine takes a period of time that is roughly proportional to the number of elements in the search.
- In the worst-case scenario, the algorithm has to search through all the elements to find just one.

- **Grove's Algorithm**
  - The time it takes is proportional to the square root of the number of elements (Quadratic speed-up);
  - Using QUBITs, an algorithm can search both 0 and the 1 at the same instant;
  - In 1996 when Grover did his work, these were little more than a distant dream
- More than 20y later, physicists at University of Maryland say they have executed Grover's algorithm on a scalable quantum computer for the first time
- **BENEFITS: a quadratic speed-up is a towering achievement.**

source: https://www.technologyreview.com/s/604068/quantum-computing-now-has-a-powerful-search-tool/

Quantum Database: Architecture

- Comparing Classical Database Architecture x Quantum Database



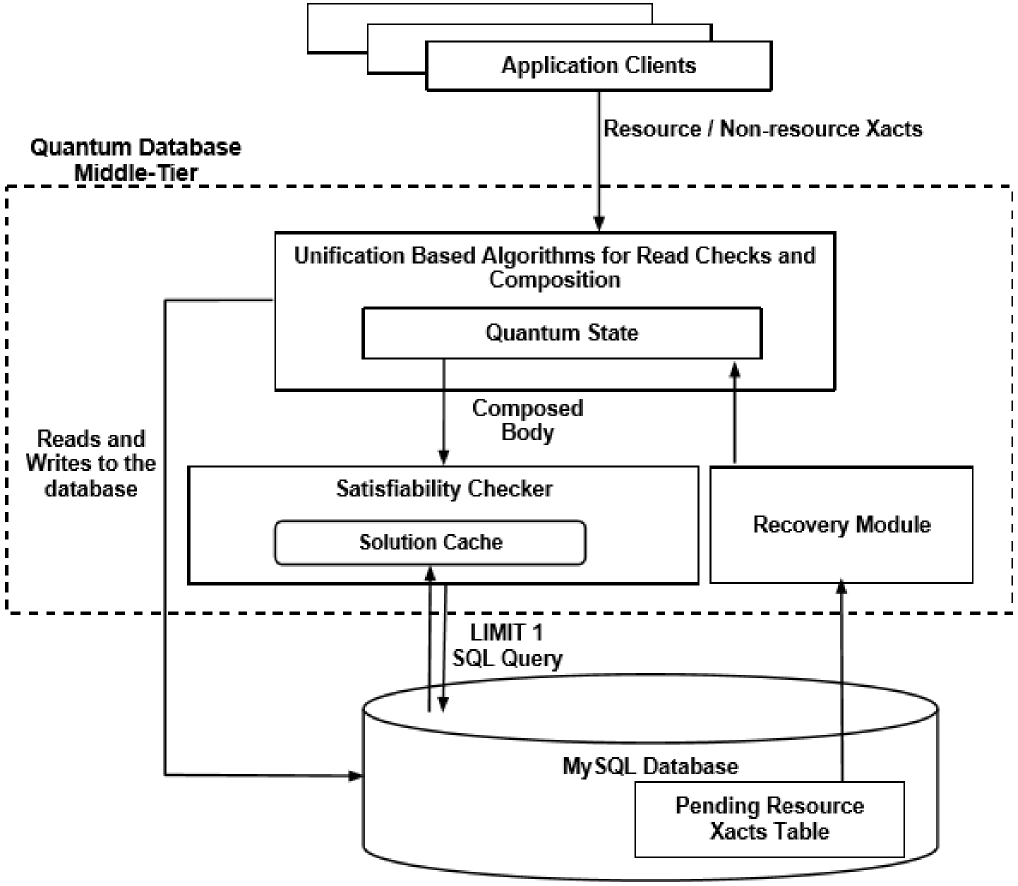


Figure 4: Quantum Database System Architecture

Quantum Database Prototype by Cornell University

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Quantum Databases

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Application Scenario

Travel application

http://www.cs.cornell.edu/~sudip/QuantumDB.pdf

Quantum Database Prototype by Cornell University

Application Scenario

“ Travel application”

1. Workload of simulated resource transactions to model the output of the front-end social travel application;
2. Workload simulates users desiring to coordinate with their friends on flights and to sit in adjacent seats;
3. Compares this workload against a workload of traditional database transactions called “intelligent social” (IS) user;
4. We ran all experiments on a 2.13GHz Intel(R) Xeon(R) E5606 with 48 GB of RAM and MySQL query
5. The complexity/overhead of a quantum databases is by checking and maintain all variants/numbers of transaction.

Order of Arrival	Characteristic	Max. Number of Pending Xacts
`Alternate`	T_i entangles with T_{i+1}	1
`Random`	T_i entangles with T_j for some i, j < N	$\lceil N/2 \rceil$
`In Order`	T_i entangles with $T_{i+N/2}$	$\lceil N/2 \rceil$
`Reverse Order`	T_i entangles with T_{N-i}	$\lceil N/2 \rceil$

Table 1: Four different transaction arrival orders and the maximum number of pending transactions in the quantum database assuming a transaction remains pending until its partner arrives.

Quantum Database Prototype by Cornell University

- Definition 3.1 (Quantum Database).
  - Let D be a completely new initial database.
  - Also, let T0,...,TN be a sequence of N resource transactions.
  - A quantum database, denoted as $\widehat{D}$, , represents the set of all possible database states.
  - A grounding for transaction Ui is consistent if it corresponds to a valid grounding of Bi on the database obtained by applying U0 through Ui−1 to D

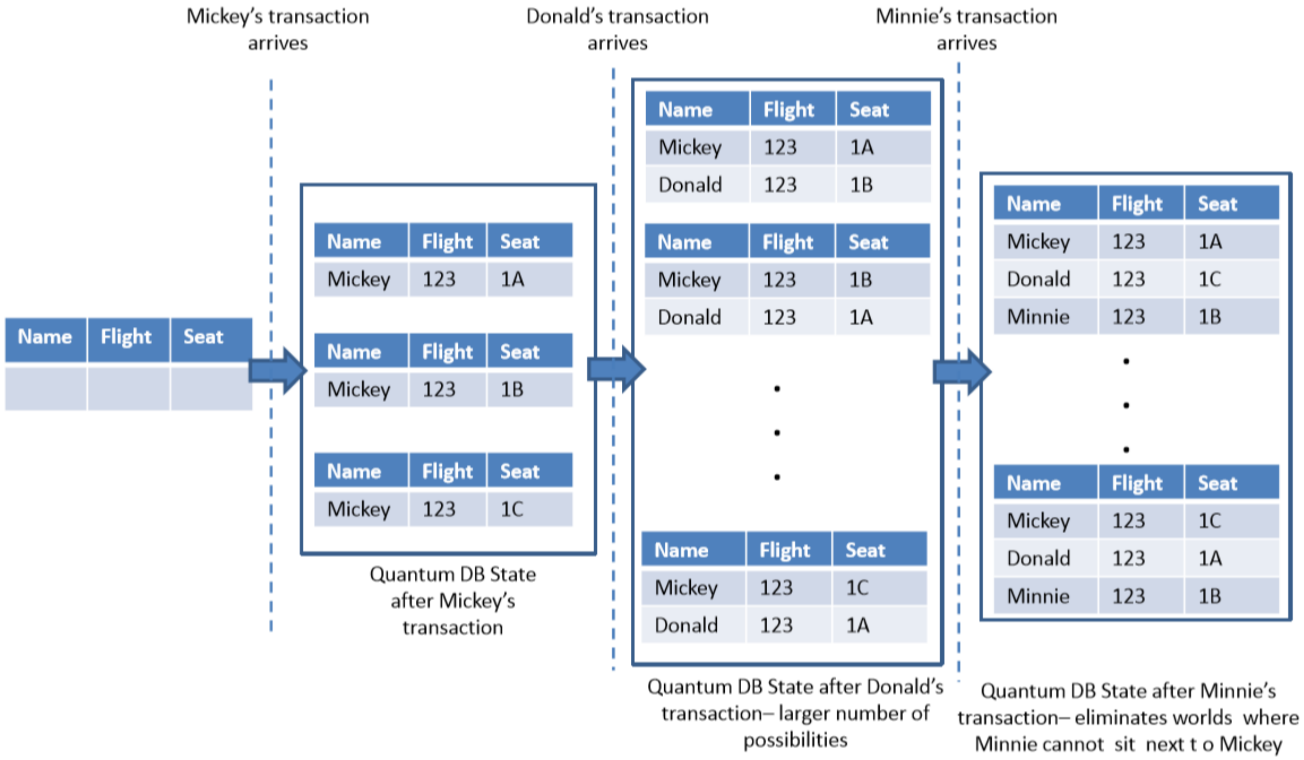

Figure 2: Evolution of an extensional quantum database

Quantum Database Prototype by Cornell University

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- **Reads**
  - What should happen when a quantum database representing a set of possible worlds is read ?
    - What should happen when a quantum database representing a set of possible worlds is read ?
  - Option 1:
    - Return all possible values for the read to the user
  - Option 2:
    - Pick a single value and return it, which can be done under two different semantics (S)
      - S1 = pick a single possible value and return it , so Mick would see a particular seat number but have no guarantees that this number will remain fixed.
      - S2 = pick a single value and fix it at that time on the database
  - The Prototype use the S2 option because this approach completely hides the uncertainty and allows the programmer to assume that he or she is working with a standard database reads.
- **Writes**
  - Write are significant more complex because they may cause the formula associated with the pending transaction to become unsatisfiable;
  - All writes need to pass through a check and are rejected if the check fails; >>>> Quantum Gate

Quantum Database Prototype by Cornell University

- **Results**
  - Order of arrival
    - They started with a database containing a single flight with 102 seats (34 rows of 3 seats each), and an issue sequence of 102 transactions according to each order

The quantum database achieves the maximum possible coordination for all of the four workloads;

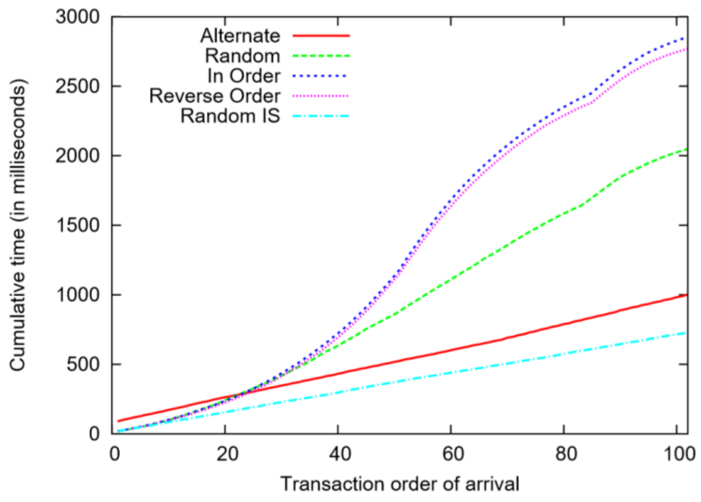

Figure 5: Cumulative time of transaction execution for different orders of arrival of transactions.

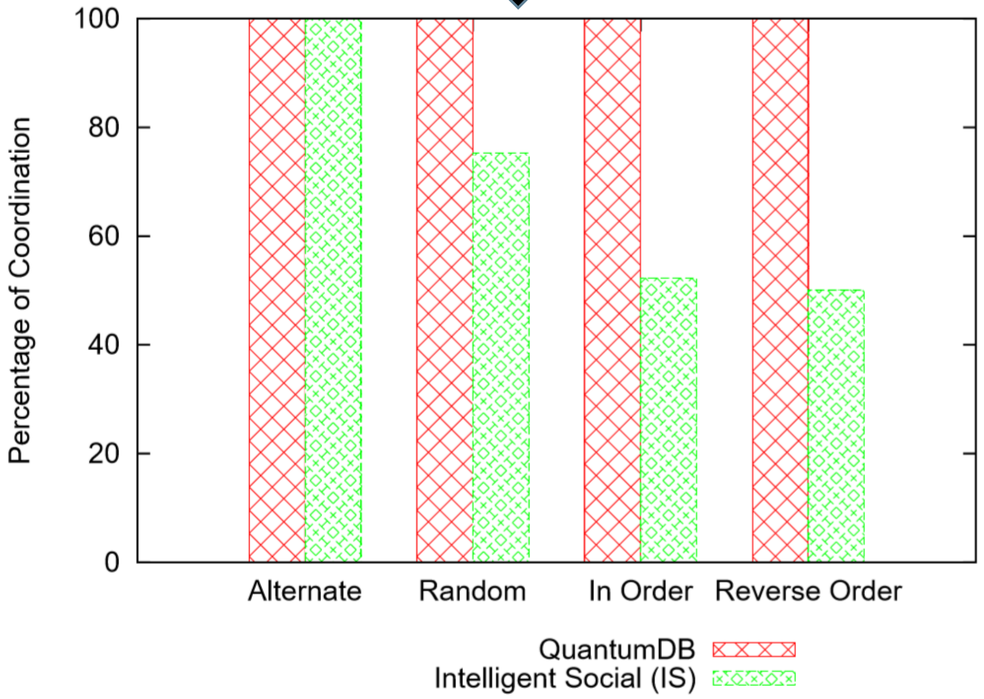

Figure 6: Percentage of coordination for different orders of arrival of transactions.

Quantum Database Prototype by Cornell University

- **Results**
  - Scalability
    - They tested scalability of system as the number of flights in the database is increased from 10 to 100. Each flight in the database has 150 seats (50 rows of 3 seats each).

- Initialize the system in a state where all flights are fully available seats;
- Use a Random order;
- Upon completion of all transactions each user has a seat and all available seats are booked.

K = number of transaction

	Quantum DB			Intelligent Social
	k=20	k=30	k=40	
% of successful coordination among the transactions >>>>>>	45.6	86.9	99.9	20.2

Table 2: Average percentage of successful coordinations

Quantum Database Prototype by Cornell University

- **Topics to Discussion**
  - System Design
    - Integration of quantum database functionality into the technology stack used by developers is a key issue.
  - Recovery
    - In many ways quantum database avoid rollbacks by performing resource allocation late and dropping constrains if they cannot be satisfied.
  - Efficiency of evaluation
    - A core aspect of maintaining a quantum database is checking and maintaining the satisfiability of the composed transaction formula.

- **Conclusion**
  - They presented Quantum database as a new way to declarative resource allocation;
  - Introduce the idea of deferred execution of transaction to improve allocation of resource in a dynamics system;
  - To make the idea practical, they proposed the unification based algorithms for efficiently maintaining the database

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Quantum Academic References

- **Quantum Relational Databases**

http://www.dcs.gla.ac.uk/~wpc/reports/qdb/qdb.html

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Deutsch, D. (1989). Quantum computational networks. *Proc. R. Soc. Lond.*, A425, 73-90.

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https://github.com/rmaestre/quantumSystem

- **Cornell University Quantum group**

https://arxiv.org/list/quant-ph/recent

- **Cornell University Quantum Database**

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- **Bell labs - Quantum computers can search arbitrarily large databases by a single query**
  - https://arxiv.org/pdf/quant-ph/9706005.pdf
- **Relational, NoSQL, Ledger Databases work, not Permissioned Blockchains.**
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- The Database Technologies of the Future
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Questions ?

Thank you