Quantum Search

ed. Dominic Widdows (Microsoft Bing)

Quantum Interaction Conference Tutorial

Paris, 2012

What next in Search?

- “Aren’t you guys done yet?”
  - Not unless you like what you’ve got so far!
- “Can you find a hotel near here with a room available between these dates?”
- What’s the representation?
- What’s the (trans)action?
- And many other queries
  - “What’s my dog allergic to?”
  - “What complications may arise from X and Y?”

What is Quantum Search?

- Common structures shared between quantum mechanical systems and search engines
  - Mathematical structures, rather than physical structures
- How did this analogy come about?
  - Grassmann's *Ausdehnungslehre* (1860s)
  - Not the physical vectors of Hamilton and Gibbs, but abstract spaces.
  - Like Riemann and Einstein for Relativity, think of Grassmann and Birkhoff & von Neumann for QM.

State Vectors and Quantum Systems

- Since the 1930s, the standard mathematical model for QM is a Hilbert Space
  - Vector space with inner product (where sequences converge). Note that dimension > 3, so not physical space.
  - Form a basis of functions (like in Fourier Analysis) and then the quantum wavefunction is a vector
  - “Observables” are linear (self-adjoint) operators on these wavefunctions
  - Spectrum (eigenvectors) of these operators are pure states, mutually orthogonal
  - Squared probability of observing a system in this state is given by the scalar product of the system’s state vector and the pure-state’s eigenvector

Vector Model for Search

- Salton, 1970s / 1980s
- Form a term-document matrix
  - M(a, b) records the (weighted) occurrence of term a in document b.
- Each row is a term-vector
  - Can be added together to form document vectors d, query vectors q
  - Search proceeds by finding nearest document vectors with largest scalar product q ● d
- No a priori reason for assuming different topics are orthogonal, but in practice they often are!

“Quantum IR” in the early 2000s

- Geometry of Hilbert spaces gives us a unified model for probability, logic, operators, conditionals
- Users interacting with system leads to state changes, observables that don’t commute, possibly entangled concepts
- Projecting concept vectors onto orthogonal subspaces can be used to model negation and disjunction in WordSpace models
- Logic is non-distributive
  - Disjunctions are bigger than set unions, involve “closure”

Then what?
(This is as far as the tutorial got!)

- Exploration of non-distributive lattices and implication for search, and interaction models
  - Glasgow group particularly, Keith, Guido, Alvaro, Sachi, Leif
- Concept representation and entanglement
  - Queensland Group, particularly Peter, Kirsty
- Compositional operators in concept spaces
  - Really taking off …
- Relationship discovery using entanglement
  - Particularly Trevor. Time for a demo …

Quantum Interaction or Standard ML?

- So far, most of these advances have been developed first, and the analogies with QM have emerged subsequently.
  - We could have gone from Grassmann to eHarmony without Schrodinger's Cat
  - Really the big deal in the past 10 years is "feature models" for machine learning
    - Some researchers are aware of the quantum angle, some aren't
- Is this a problem? If so, why?

Pause for differences

- Are linear spaces much too flat and homogeneous?
  - "Filaments" of meaning; space is sparse in practice
    - Sahlgren et al, Kanerva, Plate et al
    - Manifold learning is a possible next step for ML generally
- Are subspaces really what we want for concept lattices? Many other geometries are available.
- Are orthogonal spaces and self-adjoint operators too restrictive?
  - In SemanticVectors, search is (still) a projection, but building indexes and assembling queries uses permutations and other operators which aren't self-adjoint.

Underexplored mathematical ground

- Entanglement
  - Superposition of product states is more reliable for concept learning than any individual product state, or superposition of simple states
- Projection operators
  - “Tiger moth”, “tiger economy”, “tiger costume”
- Tensor products
  - Great results from Oxford, but doesn’t solve the multi-level matching problem
  - Tensors, matrices, correlations, permutations?
- Chaining together operators to really “navigate” information (user sessions, inference and reflection)
- So we’ve plenty to work on …

What's the big goal?

- What are searchers trying to accomplish?
  - Finding relevant documents – NO!
- What are authors trying to accomplish?
  - Sampling words from a distribution – NO NO NO!
- We are creatures with purpose
  - And we're lazy when possible

What's broken in "classicism"?

- "Cause" is only mechanical cause and must precede effect.
  - Newton is so successful that Kant and Hume convince everyone that if it's not mechanics it's not science. Ooops.
- Boolean logic is the "Real" logic.
  - Concept combination "should" be intersection of sets.
- Language "should" be formal and unambiguous.
  - We're "surprised" to discover that everyone reuses words rather than invent new ones.

What's "fixed" but confusing in QM?

- Interaction between the system and the observer
- Uncertainty, which depends partly on how you pose questions and what you're willing to sacrifice
- Decision ("Collapse")
  - Many real hypothetical states become one real actual state

Compulsory Aristotle Quotes

"If we look at the ancients, physics would be solely concerned with matter." (Physics, Book II, Ch 2)

"One way of solving the difficulty … consists in pointing out that the same things can be explained in terms of potentiality and actuality. So, the difficulties which constrain people to deny the existence of some of the things we mentioned are now solved. For it was this reason which also caused some of the earlier thinkers to turn so far aside from the road which leads to coming to be and passing away and change generally. " (Physics, Book I, Ch 8)

It may therefore be argued that it is necessary that affirmations or denials must be either true or false. … Now if this be so, nothing is or takes place fortuitously, either in the present or in the future, and there are no real alternatives; everything takes place of necessity and is fixed. … These awkward results and others of the same kind follow, if it is an irrefragable law that of every pair of contradictory propositions, whether they have regard to universals and are stated as universally applicable, or whether they have regard to individuals, one must be true and the other false, and that there are no real alternatives, but that all that is or takes place is the outcome of necessity. .. . It is therefore plain that it is not necessary that of an affirmation and a denial one should be true and the other false. For in the case of that which exists potentially, but not actually, the rule which applies to that which exists actually does not hold good. (De Interpretatione, around Ch 9)

My summary:

- The past can be remembered, but not changed. The future can be changed, but not remembered.
  - (That's not Aristotle, but it's common sense.)

“Decision-Information Uncertainty Principle”

- “The more you investigate, the less useful the investigation.” (Diminishing returns.)
- Making a decision D, chosen from D1, D2, D3, etc.
  - Real consequences ensue that will have a measurable value, Val(D).
  - In the presence of risk, Val(D) is unpredictable.
- Your information state is F (“facts-at-hand”)
  - You can put more work Cost(F) into acquiring more facts, which can reduce but not eliminate risk.
- There appears a relationship:

$$\Delta(\text{Cost}(F))\ \Delta(\text{Val}(D)) > K.$$

What dynamics would we need to model the spread of information?

- Consider a great, singly-authored, mass-produced work, e.g., *A Tale of Two Cities.*
  - How does it "evolve" over time?
  - What kind of "entropy" does it have?
- Consider a great collated work, e.g., the Bible.
  - How does it "evolve" over time?
  - There appears to be diversifying entropy to begin with, and then reification and organization which is negative entropy.
- There is time-evolution, and it's not an invertible unitary transformation. What is it?