Towards modeling implicit feedback with quantum entanglement

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Quantum Interaction
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Information Retrieval

- Concerned with retrieving all and only the documents relevant to any information need of any user
- Intrinsically dependent on
  - the user
  - the task the user is performing
- Difficulty of obtaining queries well designed for retrieval purpose
  - vague information need
  - limited experience in the search environment

Relevance Feedback

- Relevance information explicitly provided by the user used to
  - suggest query expansion terms
  - retrieve new search results
  - dynamically reorder existing results
- Effective but:
  - high user effort
  - benefit not always apparent
- How to remove the burdens of traditional RF?

Implicit Relevance Feedback

Alternative: **Implicit** Relevance Feedback (IRF)

- Using contextual features generated during user-information interaction

  Example of contextual features: display time, bookmarking, saving, printing, scrolling

- Requires a software tool which
  - monitors subject behavior
  - uses these interaction data as a source of IRF

Modeling Implicit Feedback

- Abstraction of the software tool to automate the feedback process
- Geometric Framework proposed in [1] to model Implicit Feedback
  - considers multiple source of evidence
  - personalized for each user
  - tailored for each search task
- Framework revisited with some QM concepts according to the proposal originally reported in [2] where QM was proposed for tackling the problem of IR

[1] M. Melucci and R. W. White.
Utilizing a geometry of context for enhanced implicit feedback.
In *Proceedings of the ACM Conference on Information and Knowledge Management (CIKM)*, pp. 273–282, Lisbon, Portugal, November 2007.

[2] C.J. van Rijsbergen.
The Geometry of Information Retrieval.
Cambridge University Press, New York, 2004.

Towards a Model of Implicit Feedback

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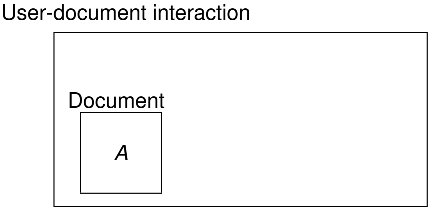
User-document interaction

Information Retrieval

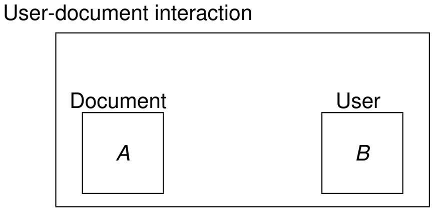
Towards a Model of Implicit Feedback



Information Retrieval

A visited document or the visit of the document

Towards a Model of Implicit Feedback



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Towards a Model of Implicit Feedback

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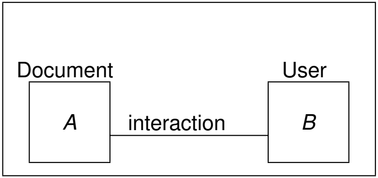

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AB user–document interaction as a composite system

Towards a Model of Implicit Feedback

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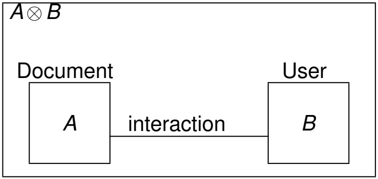

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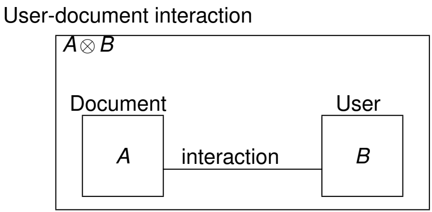
- relationship between A and B?

Towards a Model of Implicit Feedback



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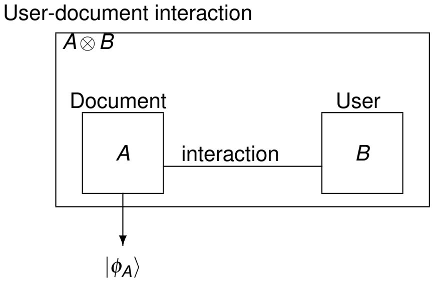
Quantum Mechanics

Towards a Model of Implicit Feedback



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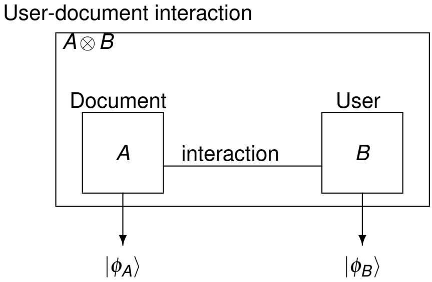
Quantum Mechanics

- $|\phi_A\rangle$ abstraction of the visited document – reduced to a vector

Towards a Model of Implicit Feedback



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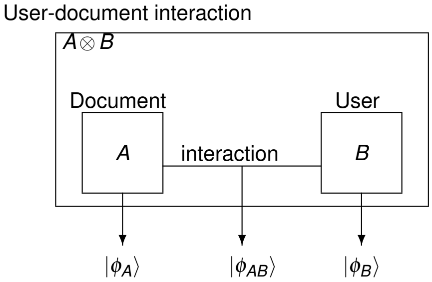

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- $|\phi_A\rangle$ abstraction of the visited document – reduced to a vector
- $|\phi_B\rangle$ abstraction of the user who visited the document – reduced to a vector
- $|\phi_{AB}\rangle$ interaction between A and B element of $A \otimes B$

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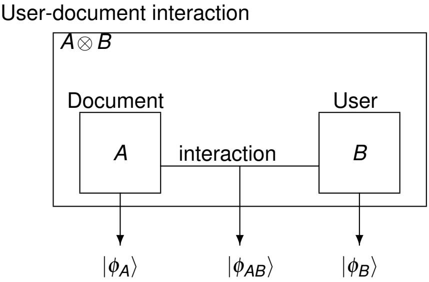

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$|\phi_A\rangle$ abstraction of the visited document – reduced to a vector

$|\phi_B\rangle$ abstraction of the user who visited the document – reduced to a vector

$|\phi_{AB}\rangle$ interaction between A and B element of $A \otimes B$

- $|\phi_{AB}\rangle$ entangled or separable?

Schmidt Decomposition

Bipartite System AB

- Bipartite pure state $|\phi_{AB}\rangle$ separable iff can be written as

$$|\phi_{AB}\rangle = |\phi_A\rangle \otimes |\phi_B\rangle$$

- In general $|\phi_{AB}\rangle$ is written in any orthonormal product basis $\{|i_A\rangle \otimes |j_B\rangle\}$ as

$$|\phi_{AB}\rangle = \sum_{i=0}^{N_A} \sum_{j=0}^{N_B} C_{ij}\ |i_A\rangle \otimes |j_B\rangle \quad \text{where } C_{ij} \text{ element of a matrix } C$$

- Schmidt Decomposition Theorem

There always exists a product bi-orthonormal basis $\{|e_A^i\rangle \otimes |e_B^j\rangle\}$

$$|\phi_{AB}\rangle = \sum_{i}^{\min\{N_A,N_B\}} \lambda_i\ |e_A^i\rangle \otimes |e_B^i\rangle$$

where λ_i nonzero singular eigenvalues of C.

λ_i: obtained by Singular Value Decomposition of $C \rightarrow C = B\Lambda A \rightarrow \lambda_i = \{\Lambda\}_{i,i}$

Schmidt Number: number of nonzero singular eigenvalues of C

A Methodology for Implicit Feedback

Possible Methodology

1. preparation of the interaction data
2. computation of a contingency matrix
3. decomposition of the contingency matrix
4. analysis of entanglement

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Interaction Data

- subset of the document features of the dataset

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- subset of the document features of the dataset
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  - bookmark
  - saving
  - access frequency
  - scrolling

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Interaction Data

- subset of the document features of the dataset
  - display time
  - bookmark
  - saving
  - access frequency
  - scrolling
- usefulness scores assigned to each document

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A Methodology for Implicit Feedback

normalization of the dataset

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choice of a subset of subject IDs and a subset of task IDs

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normalization of the dataset

⇓

choice of a subset of subject IDs and a subset of task IDs

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selection of the five features for each subject

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choice of a subset of subject IDs and a subset of task IDs

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selection of the five features for each subject

$\Downarrow$

computation of the average value of every feature from the tuples of the chosen subject and task identifiers

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choice of a subset of subject IDs and a subset of task IDs

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⇓

grouping average values by usefulness score into a binary scale

A Methodology for Implicit Feedback

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grouping average values by usefulness score into a binary scale

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normalization of the obtained 2×5 matrix

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Example - All subjects and All tasks

$$\mathbf{C} = \begin{bmatrix} \text{display time} & \text{bookmark} & \text{saving} & \text{frequency} & \text{scrolling} & \\ -0.162 & -0.066 & 0.020 & -0.037 & 0.004 & \text{useless} \\ 0.201 & 0.082 & -0.025 & 0.043 & -0.005 & \text{useful} \end{bmatrix}$$

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Decomposition of the contingency matrix: SVD of $\mathbf{C} \Rightarrow \mathbf{C} = \mathbf{B}\Lambda\mathbf{A}$

$$\Lambda = \begin{bmatrix} 0.9999 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0059 & 0.0000 & 0.0000 & 0.0000 \end{bmatrix}$$

$$\mathbf{A} = \begin{bmatrix} \text{display time} & \text{bookmark} & \text{saving} & \text{frequency} & \text{scrolling} \\ 0.902 & 0.182 & 0.108 & -0.375 & 0.023 \\ 0.367 & 0.074 & 0.033 & 0.927 & 0.007 \\ & & \cdots & & \end{bmatrix}$$

Example - All subjects and All tasks

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Analysis of the Entanglement

- $\lambda_{1,1} = 0.9999 \approx 1 \Rightarrow_{Schmidt\ \ Decomposition} |\phi_{AB}\rangle \approx |1_A\rangle \otimes |1_B\rangle$
- all the subjects and tasks: $A \otimes B$ is a product state vector
- is entanglement somehow related to the subject or to the task?

Example - Subject 1 and Task 1

$$
\mathbf{C} = \begin{bmatrix} \text{display time} & \text{bookmark} & \text{saving} & \text{frequency} & \text{scrolling} & \\ -0.158 & -0.094 & -0.052 & -0.110 & 0.835 & \text{useless} \\ 0.014 & 0.128 & -0.052 & 0.256 & 0.411 & \text{useful} \end{bmatrix}
$$

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Decomposition of the contingency matrix: SVD of $\mathbf{C} \Rightarrow \mathbf{C} = \mathbf{B}\Lambda\mathbf{A}$

$$\Lambda = \begin{bmatrix} 0.94 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.33 & 0.00 & 0.00 & 0.00 \end{bmatrix}$$

$$\mathbf{A} = \begin{bmatrix} \text{display time} & \text{bookmark} & \text{saving} & \text{frequency} & \text{scrolling} \\ 0.145 & 0.243 & -0.053 & -0.188 & 0.939 \\ 0.031 & 0.473 & 0.092 & -0.827 & -0.288 \\ & & \ldots & & \end{bmatrix}$$

Example - Subject 1 and Task 1

$$\mathbf{C} = \begin{bmatrix} \text{display time} & \text{bookmark} & \text{saving} & \text{frequency} & \text{scrolling} & \\ -0.158 & -0.094 & -0.052 & -0.110 & 0.835 & \text{useless} \\ 0.014 & 0.128 & -0.052 & 0.256 & 0.411 & \text{useful} \end{bmatrix}$$

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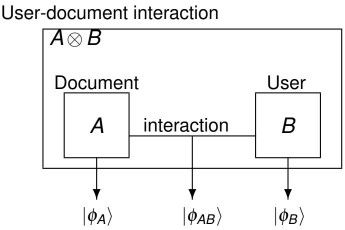
Analysis of the Entanglement

Second singular value is significantly greater than 0

$\Rightarrow$ Schmidt number is significantly greater than 1

$\Rightarrow$ $|\phi_{AB}\rangle$ is entangled

Concluding Remarks and Open Issues



- User visiting a document
  - ⇒ state of the system (A) is the pure state of the observable which describes the measurement of the style of interaction
- User assessing the usefulness of a document
  - ⇒ the state of the system (B) is to the pure state of the observable that describes the measurement of usefulness
- State of $A \otimes B$ separable
  - ⇒ measurement of a property does not influence the state of the other observable
- What happens if the composite state of $A \otimes B$ is entangled?

Open Issues

- When the composite state of $A \otimes B$ is entangled
  - how does the state of B behave?
  - what pure state of B does it collapse to?
- When does the collapse occur, given that it occurs?
- Entangement used to verify the existence of a relationship between user and information.

  How to use it for retrieval purpose?