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Quantum Humanities:

A Vision for Quantum Computing in Digital Humanities

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Abstract The establishment of digital humanities as a research field has shown that the use of computers as tools, but also the use of methods and techniques from computer science, can contribute enormously to research done in the humanities. Since quantum computers are expected to become generally available in the next few years, it is promising to use the advantages of this new technology for addressing existing as well as completely new questions in the humanities. The use of quantum computers offers a great deal of potential: (i) they are much faster than classical computers in solving certain complex problems, (ii) solutions may be much more precise, (iii) they allow the solution of problem classes that can hardly been solved on classical computers, and (iv) their usage promises to be much cheaper than that of supercomputers. Parts of this potential are already used in different domains but are also particular promising for digital humanities research. This paper outlines the vision of such quantum humanities.

Keywords Quantum computing · digital humanities · clustering · classification · vestimentary communication

1 Introduction

The question is no longer whether quantum computers become reality, but when (National Academies of Sciences, Engineering, and Medicine 2019). The introduction of quantum computing is expected to be accompanied by groundbreaking changes and innovations: applications areas like product and material simulation, optimization in manufacturing, security or artificial intelligence – to name but a few – promise great potential to successfully address problems by the use of quantum computers. This potential can not only be harvested in industry, but also in research. With regard to applications in research, there are various domains that can be identified where quantum computers are already being used: for example in the natural sciences (Mihir et al. 2015), e.g. in molecule simulation in the material sciences (Kandala et al. 2017; McClean et al. 2019), or in artificial intelligence and machine learning (Dunjko 2016; Havlicek 2018; Otterbach et al. 2017). But the broad fields of research areas of the humanities bare great potentials too: first applications of quantum technologies have been proposed in the social sciences (Haven and Khrennikov 2013), but this application of quantum technology in the humanities is the only one due to our best knowledge.

The establishment of digital humanities (Berry 2012; Burdick et al. 2012) has already shown how promising the far-reaching use of computer-based methods and techniques in the humanities is and which new approaches to existing and new questions are revealed by the use of such trans- and interdisciplinary methods. In order to go one step further and benefit from the advantages of a quantum computer beyond the use of the classical computer, the vision of such a quantum humanities shall be outlined.

2 Vision

When taking a closer look to how research is done in the humanities, the method of hermeneutics has a very long historical tradition. Key to hermeneutics is interpretation, i.e. the explanation or description of texts or other objects of investigation. This fundamentally relies on what researchers can see, read, analyze and conclude

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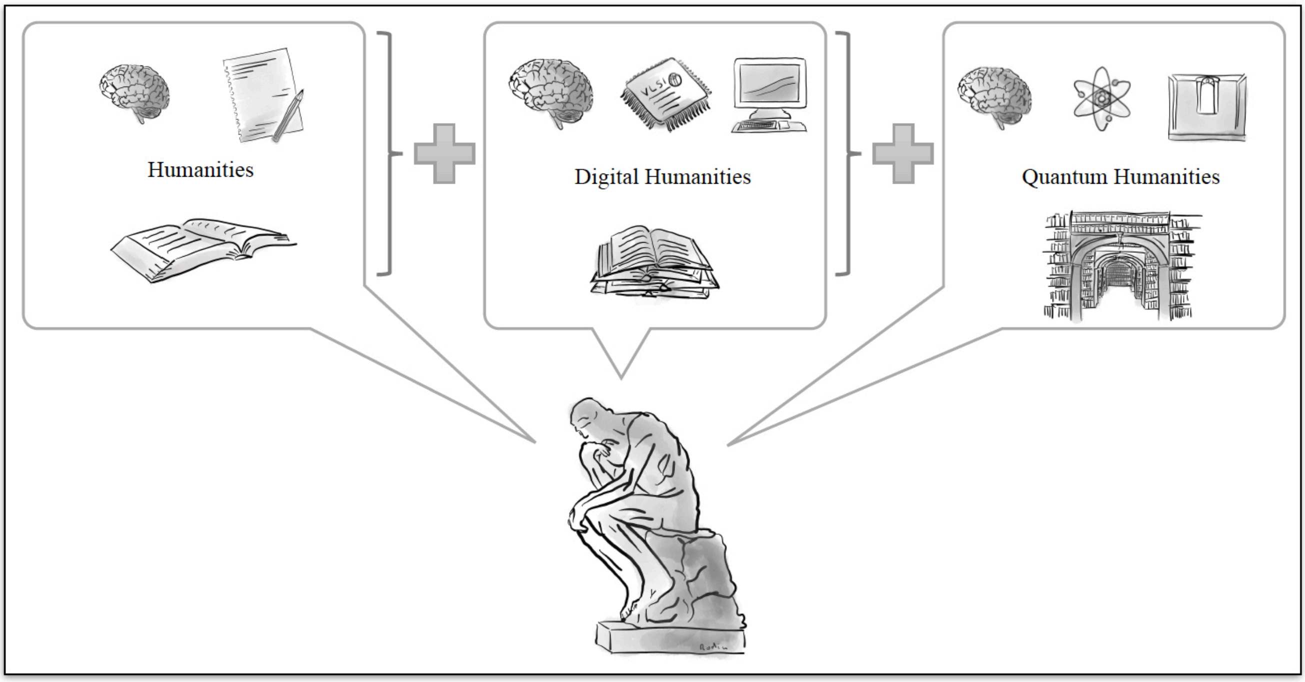

Fig. 1 Towards Quantum Humanities.

by themselves. As Figure 1 depicts, the introduction of the digital humanities has added the use of computational methods and technics to support hermeneutical approaches as well as opening up new approaches that could hardly be realized before. Based on data collections, data analytics, semantics or visualization, for example, much broader approaches to existing or new questions are supported.

While the usage of classical computers in the digital humanities is been applied very successfully to address certain problems of the humanities, these computers are limited when taking the potential of quantum computers into account. Therefore, we suggest to use the term quantum humanities when unleashing the power of quantum technologies in solving problems of the humanities. The technology of quantum computers is so different from classical computers and promises such fundamental advantages, that it is worth to not only consider quantum computing as an enrichment and expansion of methods and approaches established in the digital humanities, but as a new field in its own. In bringing together computer science, mathematics, physics and the different fields from the humanities, such as literature and history studies, media science or musicology, quantum humanities is a promising field to address existing and new problems with completely new approaches.

But which fundamental advantages are to be expected when using a quantum computer? First, quantum computers solve certain types of problems significantly faster (Rønnow et al. 2014) than classical computers (e.g. decrypting passwords (Shor 1995), determining global properties of Boolean functions (Deutsch 1985), unstructured search (Grover 1996) etc.). Second, they allow the processing of vast amounts of data in a single step (Nielsen and Chuang 2010). Third, their results promise to be much more precise than those achieved by classical computers (Havlicek et al. 2018). Forth, the use of quantum computers allows the solution of problem classes that were previously considered practically unsolvable (complexity class BQP (Nielsen and Chuang 2010)). Fifth, there exist problems that can only be solved on a quantum computer, i.e. they cannot be solved on a classical computer at all (Raz and Tal 2018). Sixth, the use of a quantum computers promises to become significantly cheaper than that of a conventional supercomputer (computing cost can be assumed to be approx. 200 Euro per hour (Dickel 2018) – an important aspect in the financially often strained humanities). Seventh, they are much more energy efficient (Nielsen and Chuang 2010).

In addition to use the superiority of quantum computers over classical computers in known problem domains, it is important to determine which open or new problems of the field of humanities are suitable to be addressed by means of a quantum computer. Problems that come to mind are those that benefit from clustering and classification techniques as we will sketch in section 3; these techniques are already proven to have superior properties. In addition, since quantum computers can solve problem categories that cannot be solved on classical computers, quantum computers might help to address problems in the humanities that are out of scope of digital humanities.

Although quantum computers are becoming commercially available (IBM Q Experience; Intel 2018; Jelly 2018; Linn 2017), the advantages stated before assume an ideal quantum computer. But the available quantum computers are not ideal, they have some deficiencies, which require to consider question like the following: How many qubits are available? What is their coherence and connectivity? How many layers of operations are required by an algorithm and how many can be performed without errors on a given quantum computer? A current answer to some of the questions is the proper use of so called NISQ (Noisy Intermediate-Scale Quantum) computers (Preskill 2018; Tannu and Qureshi 2018). They already allow to solve realistic problems and we intend to use them for the prototypical implementation of the use case outlined.

Despite the limitations of nowadays quantum computers their promising advantages deserve an in-depth investigation in selective use cases from the humanities to build up knowledge and evaluate the idea of quantum humanities.

3 Use Case

As first step to underpin this vision we provide a use case from the media science, namely identifying costumes from clothes based on quantum machine learning algorithms. This is done by first clustering clothes in a training step, followed by a classification step based on a larger set of clothes. This contains the potential to participate in gaining more precise results for the application area (Havlicek 2018), as well as to build first application knowledge for the quantum humanities. The clothes stem from a database created based on methods from digital humanities (Barzen et al. 2018). To check the feasibility of our approach, near-term quantum computers (the mentioned NISQ machines) are planned to be used.

A NISQ quantum computer can be used already today to speedup unsupervised machine learning, especially clustering (similar has been proven for adiabatic quantum computers in (DWave White Paper 2018)). For this purpose, a hybrid environment is used, i.e. the computation is split between a classical environment and a quantum computer, thus making use of the principle of variational algorithms (Biamonte 2019; McClean et al 2015).

The elements to be clustered, as shown in Figure 2, are represented by feature vectors in a k-dimensional space (k is the number of features), and the distances between any two elements are computed by means of a (suitable) Euclidian metric. This can be interpreted as building a fully-connected weighted graph, where the weights are the distances between two elements (i.e. the nodes of the graph). Clusters are derived by splitting the elements into groups where the groups have a maximum distance from each other. Thus, the weighted maximum cut of the graph has to be computed (Gupta and Chan 2014; Sivaramakrishnan and Karimi 2007). This is an optimization problem that can be solved by a quantum approximate optimization algorithm (QAOA) (Fahri et al. 2018; Coles et al. 2018; Zhou et al. 2018: Crooks 2018).

Once the clusters have been determined, new cloths maybe classified, e.g. by means of support vector machines (Murty and Raghava 2018; Schölkopf et al. 2002). On a quantum computer, support vector machines achieve an exponential speedup (Rebentrost et al. 2013). Variational quantum classifiers that are suitable modifications of support vector machines for NISQ quantum computers are known (Havlicek 2018; IBM Q Experience).

3.1 Clustering Clothes

The database $C = \{c_1, \ldots, c_n\}$ of clothes (Barzen 2018) exploited for this use case contains a huge collection of individual clothes worn in films, each clothes is described by a large number of properties $P = \{p_1, \ldots, p_m\}$. The types of these properties are defined by means of an extensive ontology (Barzen 2013). Each property p has an associated domain $dom(p)$ of possible values. For each clothes $c \in C$ the value of the property p assigned to c is denoted by $v(c, p)$, i.e. v is a map

$$v : C \times P \to \bigcup_{i=1}^{m} dom(p_i) \quad (1)$$

with $v(c, p) \in dom(p)$. Most of the domains are categorial, consisting of an enumeration of potential values (or strings in general). These values can be uniquely mapped to numbers, i.e. we assume an injective map $\mu : dom(p) \to \mathbb{R}$ for properties with categorial domains. Thus, without loss of generality, each domain is the set of real numbers $\mathbb{R}$.

Out of these properties a subset $\{f_1, \ldots, f_k\} \subseteq \{p_1, \ldots, p_m\}$ is determined as features characterizing clothes. Note, that selecting an appropriate feature set is a process that requires lot of background knowledge in clothes, or it has to be done iteratively. The features $\{f_1, \ldots, f_k\}$ correspond to independent dimensions of a

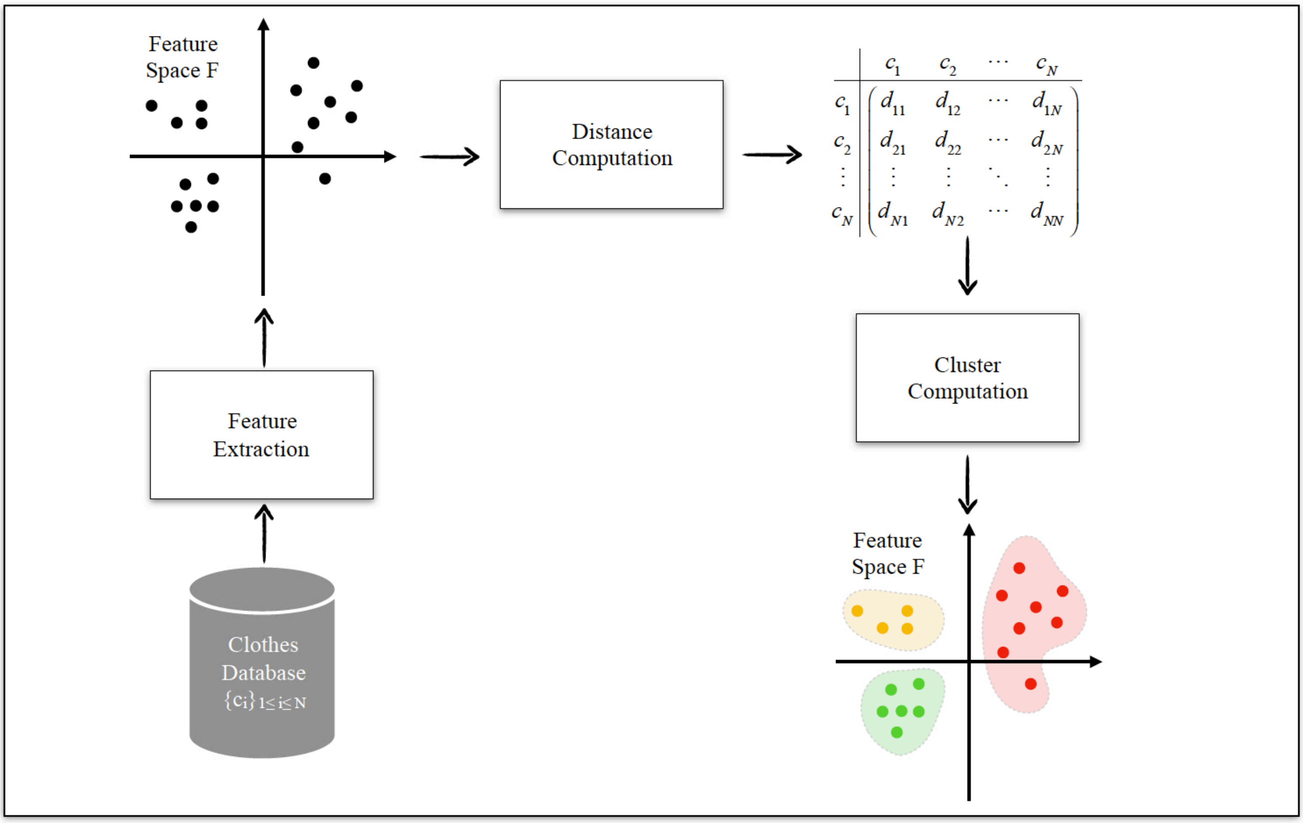

Fig. 2 Clustering.

feature space F, i.e. F is a k-dimensional vector space $\mathbb{R}^k$. The value of the feature f_i of a clothes c is the coordinate of c along the f_i dimension in the feature space F. This way a map $\varphi : C \to F$ is defined, referred to as feature extraction: $\varphi(c) := (v(c, f_1), \ldots, v(c, f_k)) \in F$.

Next, a metric $d : F \times F \to \mathbb{R}_{\geq 0}$ is defined. This can be the usual Euclidian metric, but other metrics might be suitable too in order to achieve desired results; selecting an appropriate metric is an important aspect of the overall proceeding. The metric is used to compute the distance $d_{ij} := d(\varphi(c_i), \varphi(c_j))$ between any two clothes c_i, $c_j (1 \leq i, j \leq N)$, resulting in the distance matrix $D = (d_{ij})_{1 \leq i,j \leq N}$. This corresponds to a weighted graph $G(C)$ with set of vertices $\{\varphi(c_i)\}$, edges $\{\{\varphi(c_i), \varphi(c_j)\} \mid 1 \leq i, j \leq N\}$ and weights d_{ij}. Computing weighted maximum cuts for this graph finally results in a clustering of the clothes C, i.e. a split of C into disjoint collections $B_1, \ldots, B_q$.

3.2 Classifying Clothes

The classes $B_1, \ldots, B_q$ have been computed by either using all of the clothes in C or a subset of it: the set of clothes used is considered to be the training data for determining the classes of the multi-class problem. Several alternatives for solving a multi-class problem based on support vector machines (SVMs) exists like one-versus-all or pairwise-classification. However, corresponding support vector machine variants can be used to determine the corresponding classifiers.

When a new clothes c^* is to be processed, as Figure 3 depicts, its features are extracted and the corresponding feature vector $\varphi(c^*) = (v(c^*, f_1), \ldots, v(c^*, f_k))$ is build. Based on the classifiers determined before, the new clothes c^* will be assigned to one of the classes.

4 Conclusion and Outlook

We sketched a vision for the new field of quantum humanities. The potential benefits of using quantum computing concepts and technology for the humanities have been shown. A use case for applying quantum algorithms in the media sciences has been outlined. This use case is based on our large data set containing descriptions of clothes in films. Currently, we are in the process of identifying features of clothes from this data set and experiment with clustering algorithms (such as max-cut) as well as classification algorithms (like support vector machines) on an IBM quantum computer and Qiskit (IBM Q Experience; IBM Qiskit Artificial Intelli-

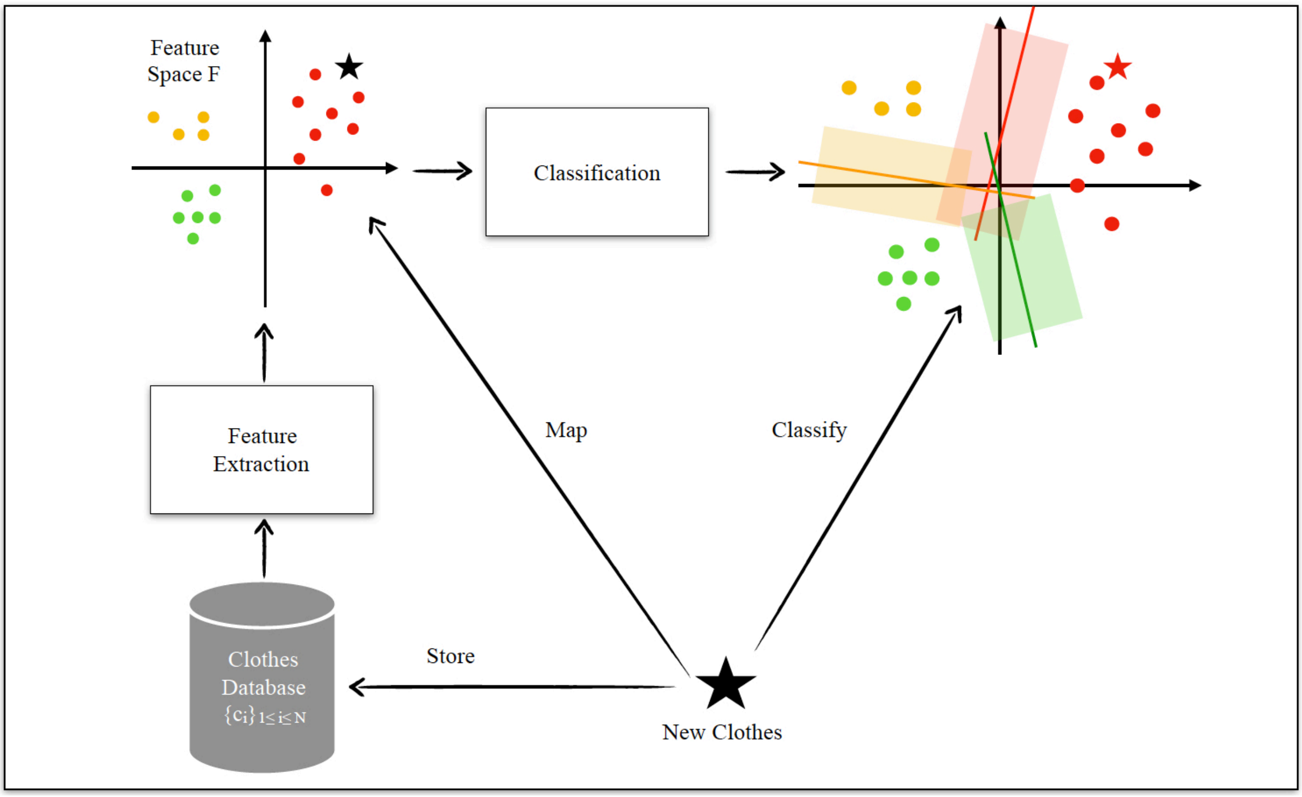

Fig. 3 Classification.

gence) to determine costumes in films. We will compare the achieved results with those achieved in a classical environment.

Our goal is to propose a first draft of a development method for quantum applications in the digital humanities, as well as to provide first, possibly reusable components for further use cases from different domains of the humanities. Thus, we want to contribute initial knowledge for the digital humanities community to enable the transition to the quantum humanities where applicable.

We consider this as a jump-start towards our vision of the quantum humanities that participate in the practical advantages of the use of quantum computers, but that also contains the potential to consider completely new questions in the humanities.

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