An Overview on the Web of Clinical Data

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Abstract. In the last few years there has been an impressive growth of connections between medicine and artificial intelligence (AI) that have been characterized by the specific focus on single problems along with corresponding clinical data. This paper proposes a new perspective in which the focus is on the progressive accumulation of a universal repository of clinical hyperlinked data in the spirit that gave rise to the birth of the Web. The underlining idea is that this repository, that is referred to as the Web of Clinical Data (WCD), will dramatically change the AI approach to medicine and its effectiveness. It is claimed that research and AI-based applications will undergo an evolution process that will likely reinforce systematically the solutions implemented in medical apps made available in the WCD. The distinctive architectural feature of the WCD is that this universal repository will be under control of clinical units and hospitals, which is claimed to be the natural context for dealing with the critical issues of clinical data.

Introduction

Eric J. Topol, in his popular book \cite{7}, claims that medicine will inevitably be Schumpetered in the coming years. No matter if this excitement is motivated, we are still missing a crucial catalyzer for strongly accelerating the Schumpetering. At the moment, most studies are characterized by the relentless search for unified standards to share data. What if we get rid of any standard? It is worth mentioning that while from one side the diffusion of clinical data is carefully controlled, there are initiatives that come from patients motivated by the willingness of sharing their clinical data and experiences\footnote{See e.g. \url{https://www.patientslikeme.com/}}. The explosion of social networks have in fact strongly favored the birth of communities where people like to exchange ideas, make helpful connections, and feel supported when they need it most. On the other hand, there are also huge efforts in the building of health systems that can strongly benefit also from recent the development of AI, where the emphasis has been shifted to machine learning and processing on unstructured data. Amongst a number of attempts, the Canadian effort\footnote{\url{https://www.cifar.ca/docs/default-source/ai-reports/ai4health-report-eng-f.pdf}} is definitely worth mentioning.
This paper promotes the idea of building a universal repository of clinical data to collect the health records of people, that closely reminds the spirit of the Web. This universal collection would not represent only a truly paradigm shift on the access to clinical data by students and experts in medicine, but it would open the doors to the new grand challenge of building decision support systems that operate on a universal repository on the basis of the content of the health records, as well as with recommendations based on the discovering of similarities. This evolution of a such a project seems to be intimately connected with the very critical nature of clinical data. When considering the risks, the most natural answer is to refrain from such a crazy adventure, but we claim that the time has come to an in-depth analysis of risks and opportunities. The emerging novel solutions that could dramatically improve long-term developments in medicine, which can also go beyond the borders of single countries. Concerning the accessibility we propose that the major difference with respect to the Web, is that only the Clinical Units (CU) can access, while patients are expected to benefit from new services. Depending on specific initiatives from CU, the act of patient data donation could be rewarded in different ways (e.g. information services related to the patient clinical condition). The original spirit of the Web leads to conceive the traditional world-wide search engine service that can itself be immediately very important for the clinical activities. However, most important challenges are connected with the current developments of AI, which is expected to facilitate the development of intelligence apps. One can also expect that those apps will conquer the degree of autonomy that make them nearly indistinguishable from a medical assistant operating in team under the control of human experts.

An overview is given on the WCD by focussing mostly on the technological side of the project. Preliminary discussions on legal issues and the business model, along with the social implications are also given.

1 Web of Clinical Data: The universal repository

In the last few years the impressive growth of computer-based medical services have been mostly based on appropriate organization of clinical data. The structured organization of huge amount of such data has been playing a fundamental role also in many artificial intelligence based challenges to medicine. Based on an early intuition \[5\], this paper gives a view on a truly different way of collecting and organizing clinical data, which is claimed to open the doors to an explosive evolution of the field. We assume that medical information is stored in any multimedia document connected by hyperlinks, just like in the Web. It’s up to AI agents to interpret the information hidden in the repository, which is referred to as the Web of Clinical Data (WCD). Links in the WCD are expected to establish different levels of relations. The nodes of the graph are medical documents that can properly be linked and included in the WCD. Some links are used for connecting medical documents of a single patient corresponding to a certain specific clinical event, others are used for establishing relations between documents of different patients. No matter how the repository is created, we assume that
documents do not contain any identifiable reference to the identity of patients, which are only characterized by the Personal Code (PC). The repository can be supplied by anonymized data coming from clinical centers as well as from patients, who upload their data after having signed appropriate authorizations. As a result, the repository exhibits the very simple structure depicted in Fig. 1 where any type of multimedia medical document of a given patient is linked to his/her Personal Code. These documents are collected as a list for any individual thus exhibiting a forest structure. Ideally, one would like medical information supplied according to the structure of Fig. 1 where the anamnesis of any patient is represented by a list of clinical events, each of them properly organized into clinical data, diagnosis and therapeutic treatments. The distinctive underlying assumption of the WCD is that there is no need to provide such a structure, since it is up to the WCD Intelligent System that continuously process the clinical data to reconstruct the structure of Fig. 1. The identification of different clinical events might arise from the detection of the date on the documents. For example, it could be the case that the therapy adopted by a patient is related to a set of clinical data and to a specific diagnosis, but there is no hyperlink amongst these information. Just like humans, it’s up to an intelligent agent to realize that something is missing and reconstruct the links. Clearly, the presence of the date is a fundamental cue for linking documents of the same clinical event. However, documents with no identifiable date can also be supplied to the WCD.

**Fig. 1.** Patients can upload their own data in a truly unstructured form. Clinical data, diagnosis, and therapeutic documents are stored as a forest with separate data for each patient, that is characterized by an anonymous Personal Identification code. The separation and appropriate structured organization of this material can be created by opportune intelligent agents that contribute to the creation of the WCD.
Basically, the underlying principle is that they are also precious for medical inference, though one must consider their reduced significance due to the lack of a temporal collocation in the anamnesis of a patient.

The role of the WCD Intelligent System goes well beyond that of reconstructing the structure of data of simple patients. As we can see in Fig. 2, one can connect patients of the WCD so as to enrich the forest structure into a graph-based structure where links arise because of regularities discovered in the repository. For example, an intelligent agent can discover similarities between the clinical data of two patients. This can arise from data in different formats, ranging from text and different formats of signals. Similarities can also arise in the diagnosis and the therapeutic treatments, so as the original forest evolves towards a truly WCD with precious inferential information.

Fig. 2. Automatic construction of the WCD: The forest of patients grows up by appropriate links amongst similar data. Similarities arise from both text and image data and are discovered by intelligent agents.

2 Data anonymization, storage, and legal issues

The actual evolution of the WCD does require to clean a number of crucial legal issues connected with the distribution of clinical data. Their actual distribution is supposed to under the control of the Governing Board of the WCD, which will be composed of doctors, scientists in related disciplines, and layers. First of all, we need to clarify who is supposed to gain the permission for accessing the data along with the connected purpose. The WCD is conceived for boosting research
and world-wide medical treatment in clinical centers. As a consequence, the permission is granted to scientists and doctors upon approval from the Governing Board of the WCD. As it will be shown in the next section, this restriction on the accessibility poses fundamental constraints on the computer architecture, since the underlying assumption is that the repository can only be made available to Clinical Units (CU), which could be hospitals, research centers whose access comes with the duty of not to distribute data elsewhere. Basically, the intention is that of using the same legal framework which regulates the interaction of medical staff in sensible clinical data. Following related technical developments in the field of bank accounting, we only make the access available independently of the geographical position, whereas we do inherit and keep all the restrictions concerning the already established rules for the access. Clearly, this imposes neither restrictions on the place where data are stored nor on who provides the storing service, which does not necessarily corresponds with granting accessibility.

The issue of anonymization has been the subject of an in-depth investigation in the last few years, but only a few of them make significant efforts towards a rigorous treatment (see e.g. [3] for a very good example). Many circulating claims on the issue of anonymization are often quite generic; namely the inferential context is not well-defined, which facilitates restrictive claims on the supposed risks of making clinical data widely available. Formally, the problem of disclosing the identity from medical data seems to be generic and ill-posed. Clearly, textual documents on the anamnesis of a patient may contribute to discover the identity, whereas the inference from signal biomedical signals cannot rely on cues that can somehow reveal the identity. One can at most believe of some geographical connections that are expected to give rise to a certain disease. Notice that giving a collection of medical data under the conditions of the WCD, the identity disclosure is only possible provided that the databases of clinical centers are violated, which is in fact an event that can happen regardless of the WCD initiative.

Basically, the WCD initiative faces the ill-position of the issue of sensible data by adopting a strategy where anonymization and authorization is granted by design. The act of autonomously data uploading does exhibit the stronger patient’s intention to make data available. It is worth mentioning that the interaction with clinical centers follows the other way around, namely data are downloaded by the patients. Hence, we can think of keeping the same communication channel where this time patients upload their own data, which can come from different sources. This information flow with clinical centers very much resembles the one they establish with their own banks. The level of security and the type of information exchange shares in fact the same needs. As patients decide to upload their data to their own preferred clinical center (more are possible), we start creating a repository which is promoted to the WCD, only after a further check, whose details are defined by the WCD Governing Board. The bottom line is that the WCD does subscribe the current scenario for the access to clinical data, the only difference being that of making the data widely available to world-wide authorized clinical and research units. In this framework, we expect that most
claims on sensible information might vanish thanks to the governing philosophy of the WCD.

3 Overall architecture

The access requirements pointed out in the previous sections for the WCD open an interesting computer architecture problem that is mostly connected with the storing of a growing repository that must be distributed worldwide. At the same time, each CU is also expected to access the whole WCD repository. In order to satisfy these requirement the architectural solution proposed for the WCD is the one depicted in Fig. 3.

Fig. 3. Overall architecture of the WCD, where Clinical Units act as macro-nodes. Each such unit is used for storing patients’ data in a truly unstructured form (Patient Local WCD - PLWCD), while additional meta-data are created in the (Semantic-Local WCD - SLWCD). The WCD is also stored in an encrypted form onto a cloud system.

The repository can be given a formal description at local level thanks to the Uniform Resource Locator of any document, that can be constructed by following the same principles used in the Web. For example, the reference to the ECG diagnosis in a certain CU could be \text{wcd.ao-siena.1492.ecg-careggi-june-2020.dia}, whose structure is based on separate fields which provide information on the patient, the specific document and where it was archived. This is sketched below

\text{wcd.ao-siena.1492.ecg-careggi-june-2020.dia}
where we easily induce the general structure of the URL. Basically, the ECG
document named ecg-careggi-june-2020.dia is a diagnostic document (ex-
tension dia) corresponding to patient 1492 of Clinical Unit ao-siena of the wcd.
This document is supposed to be directly accessible within the CU where it is
stored for any type of processing. However, since this document is also supposed
to be accessed outside the CU where it has been generated, one needs to make
it available world-wide.

There are a number of studies on architectural solutions for related problems
that inspire the solution to this general framework (see e.g. [4, 1, 9, 6]). Interest-
ingly, related studies [8] have also been carried out in the context of medi-
cal applications. The solution prospected in Fig. 3 is naturally following classic
search engine technology where there is a global repository. Interestingly, this
analogy comes with the fundamental difference that data are encrypted and,
consequently, not accessible within the global Web repository.

**Search engine primitive**
The basic idea is that of caching of the documents on a Cloud System (CS)
in an encrypted format. Basically, any document created in a CU is encrypted
and backed up to the CS. This allows us to carry out a classic information re-
trieval search [4] where all documents produced in the CU are uploaded to the
CS along with their encrypted keywords. This allows the CS to construct the in-
verted indexes to be used for searching. Classic encryption solutions can be used
for handling the security of the interaction between the CUs and the CS. Classic
searching primitives based on propositional calculus are supposed to be used,
whereas the major assumption is not to assign the CS higher-level services. The
underlying assumption is in fact that of moving to the CUs any solution based
on AI agents. It is worth mentioning the this horizontal keyword-based search
service is in fact the first one which is offered on top of the WCD. Interestingly,
the search primitives are also of crucial importance as a building layer for any
service app.

**Service Apps**
Any service in the WCD is supposed to be given by apps running in CU com-
puter servers. Any computation does require to select the documents that are
pertinent to the service, so as they are temporarily downloaded in the CU server.
Basically, these apps are expected to operate on a proper selection of information
from the WCD that is expected to be useful for their objective. The structure
of any service is sketched as

1. create the primary app cache
2. $q \leftarrow \text{QueryFromService}(\text{input})$
3. $\text{RetrievedDocCollection} \leftarrow \text{WCD-retrieve}(q)$
4. run BodyApp($\text{RetrievedDocCollection}, \text{input}$)
5. $\text{free}(\text{RetrievedDocCollection})$
First, the app may need to create its own cache (primary cache) from the WCD to optimize the performance. This step may also be omitted, so as all the processing is based only on the input being process. The second step consists of formulating the searching query on the basis of the input to the app. Then, as the query is fed to the `QueryFromService`, pertinent documents are retrieved and stored in the secondary cache `RetrievedDocCollection`. These locally retrieved collection, along with the primary cache is used for carrying out the task assigned to the app. Basically, the actual processing is carried out by `BodyApp` on the second argument `input` by exploiting the local cache.

**Example 1.** Suppose we want to discover patients whose clinical data are similar to those of a given patient. The reference for inspecting the similarity is defined by document `input=ecg-careggi-june-2020.dia`, which is in fact a document under diagnosis. This document comes with a number of attached metadata, like for instance, the specific type of diagnosis (ECG signal). The document, along with its attached metadata represent the `input` of the service, which is expected to compose the query `q` automatically by using `QueryFromService`. As the query is obtained, it is used to collect `RetrievedDocCollection` and, finally, the body of specific part of the app `BodyApp` is used to discover which documents are similar.

### 4 WCD enrichment apps

Patients and staff from the CUs are generally expected to upload clinical data in the general unstructured form of a multi-media document. Clearly, it could be the case that single patients directly provide information in a truly structured way according to Fig. 1. Whenever this does not happen, the purpose of WCD enrichment apps is that of creating the missing structured representation.

The first important enrichment task is that of segmenting patients' clinical events. The most informative cue comes from the eventual presence of the date in the document. As it is available, the task of its detection is a well-posed problem either for textual or image-based documents. In both cases the extraction of the data could be quite a complex problem. However, in both cases we are in front of classic problems of pattern recognition that have been the subject of massive investigation (see e.g. [2], for early studies). It is worth mentioning that whenever the date is either missing or badly recognized, the segmentation of patients' event can also rely on different cues. For example, there are cases in which a certain drug is prescribed upon a corresponding diagnosis, so as two documents can be placed in the same medical event. Clearly, this task can become very sophisticated and very well represents the type of challenges that are open with the WCD.

Other important enrichment tasks involve the separation between clinic, diagnostic, and therapeutic data. This is essentially a document classification task. While there is a huge literature for attacking this problem the specific context of the WCD provide a number of additional cues to solve it successfully. Hence enrichment apps contribute to create the structured view of the forest indicated in Fig. 1. Moreover, the successive discovery of links between different patients
of the same CU depicted in Fig. 2 is another tasks of enrichment apps. This problem is basically one of discovering the similarities between multimedia documents, which has also been the subject of a massive investigation. In addition to links between documents of the same type, we can find links between text and documents, a task which clearly needs the additional step of extracting textual description from images. Overall, enrichment apps create the WCD locally to each CU. However, their task goes beyond the discovery of local links. In order to generate global links upon discovery of relationships between documents of different CUs, enrichment apps rely on the software architecture described in Section 3. In particular, the discussion of Example 1 concerning the discovery of global similarities for a given document provides an insight on how to attack the problem. Clearly, once the similarities have been found, we need to update the index of the WCD by its enrichment with the discovered links. While this is carried out in the CUs, the inverted indexes in the CS must be updated accordingly. Notice that the process of constructing the WCD by this similarity inspection needs to be frequently carried out because of the continuous update of documents on the CUs.

5 WCD service apps and medical assistants

The creation of the WCD along with the associated high-level meta-data associated with the documents open the doors to the development of medical service apps ranging from the field of diagnosis to that of therapeutic treatment. The
underlying philosophy in the development of service apps is that they do not simply operate on a specific CU, but on the WCD. Depending on the dimension of the CU, the apps might have different configurations, but they are conceived for working at global level.

![Service apps onion skin view](image)

**Fig. 5.** Service apps onion skin view. The lower level only relies on the processing of data from the SLWCD. In a middle layer, apps operate by relying on the computation of other apps. Finally, in the last layer, medical assistant operate autonomously on the basis of all the info available in the lower levels.

Because of the need to make them available on the WCD, service apps are expected to run on popular operating systems. As we can see in Fig. 5, service apps can operate at different levels of abstraction. As the process conquer a certain degree of autonomy, service apps become a sort of medical assistant which can support decisions under the control of human experts. The long term view of the WCD is that the progressive construction of service apps is expected to contribute to medical treatment on specific patients, but also to the permanent creation of metadata that are expected to provide an important support for future medical decisions.

### 6 Conclusions

The described framework of the WCD suggests the development of a stable marriage between medicine and artificial Intelligence. While there is a benefit in the systematic developments of service apps thanks to the word-wide competition for medicine, a much better benchmarking context is created for research in artificial intelligence. Basically, it looks like the WCD can act as a fundamental catalyzer for both the disciplines. The current focus on specific benchmarks is
expected to be translated into a sort of permanent AI challenge in medicine, that will constantly refer to the WCD.

The philosophy behind the WCD is that of increasing the level of medical treatment by strongly promoting the CUs, which turn out to be the nodes of the WCD. As such, they are expected to control the world-wide repository of clinical data and will likely realize that there is a crucial benefit of assuming this role. The WCD will make available best medical practices worldwide, a service that has an enormous value and that might also be paid off. Pharma companies might be interested in advertisement on the WCD, which could the source of huge resources especially for best CUs. Simple metrics could in fact measure the number of access to documents uploaded to different CUs, so as to distribute money from advertisement. This will definitely bless the principle that in the WCD framework doctors carry out two different specific roles: First, their primary role is that of providing the appropriate medical assistance to single patients. Second, their successful treatments will be useful for future worldwide medical decisions. Finally, the conception of the WCD comes with the wish that its development will be primarily useful for the medical support to poor countries.

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References

1. Pedro Geraldo M. R. Alves and Diego F. Aranha. A framework for searching encrypted databases. J. Internet Serv. Appl., 9(1):1:1–1:18, 2018.
2. Heidi Bjering Stratti. Optimal operators in digital image processing. PhD thesis, 2008.
3. Khaled El Emam and Luk Arbuckle. Anonymizing Health Data: Case Studies and Methods to Get You Started. O’Reilly Media, Inc., 1st edition, 2013.
4. Z. Fu, K. Ren, J. Shu, X. Sun, and F. Huang. Enabling personalized search over encrypted outsourced data with efficiency improvement. IEEE Transactions on Parallel and Distributed Systems, 27(9):2546–2559, 2016.
5. M. Gori, Campiani G, Rossi A, and Setacci C. The web of clinical data. Journal of Cardiovascular Surgery, 23:717–718, 2014.
6. Yusheng Jiang, Tamotsu Noguchi, Nobuyuki Kanno, Yoshiko Yasumura, Takuya Suzuki, Yu Ishimaki, and Hayato Yamana. A privacy-preserving query system using fully homomorphic encryption with real-world implementation for medicine-side effect search. In Proceedings of the 21st International Conference on Information Integration and Web-Based Applications and Services, iiWAS2019, page 63?72, New York, NY, USA, 2019. Association for Computing Machinery.
7. Eric Topol. The Creative Destruction of Medicine: How the Digital Revolution Will Create Better Health Care. Basic Books, 2011.
8. Lei Xu, Chungen Xu, Joseph K. Liu, Cong Zuo, and Peng Zhang. Building a dynamic searchable encrypted medical database for multi-client. *Inf. Sci.*, 527:394–405, 2020.

9. Steven Zittrower and Cliff Changchun Zou. Encrypted phrase searching in the cloud. In *2012 IEEE Global Communications Conference, GLOBECOM 2012, Anaheim, CA, USA, December 3-7, 2012*, pages 764–770. IEEE, 2012.