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Design and implementation of the stacked, synchronised and iconographic timeline-structured electronic patient record in a UK NHS Global Digital Exemplar hospital

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ABSTRACT

Background Conventional electronic screen visualisation formats, which use tabs, dropdown menus, lists and multiple windows, present huge navigation challenges to health professionals. A unifying and intuitive interface for the electronic patient record (EPR) has been an elusive goal for software developers for decades.
Methods Since 2009, by working in an agile way, we have built and implemented a fully operational and dynamic system, the University Hospital Southampton Lifelines (UHSL), within our clinical data estate, in a UK university hospital. UHSL permits the continuously updated display of the EPR on a single desktop computer screen in an intuitive format. During this iterative evolution, we have resolved a number of practical challenges in data display, while maintaining our core aims of end-user optimisation and radical simplification of the interface. Concurrently, we have upcycled a significant volume of clinical e-content, some from as far back as 1991, into UHSL, and at a marginal cost.
Outcomes UHSL went live in 2017 for all authorised staff at the hospital. It displays all e-records for 2.5 million patients and for more than 100 million documents and reports. It significantly reduces the screen time to navigate the individual EPR, and it offers substantial productivity gains in designated clinical services.
Conclusions UHSL has considerable further development potential as a National Health Service EPR interface, for the integration, display and ease of understanding of medical records across primary, secondary and community care.

Summary

What is already known?

- The search for a simple unifying and efficient architecture for the 'whole of life' electronic patient record (EPR) for each and every citizen has so far proved elusive.
- Current and legacy computer-based graphical user interfaces are not optimised for the visualisation and interpretation of the EPR.
- The need to open multiple tabs, windows, screens and PDF documents can impede information retrieval, comprehension and decision making, when compared with traditional paper records.
- Poor EPR design which is not focused on the true visual and cognitive needs of the end user creates avoidable clinical risk, user fatigue, operational inefficiencies and reduced healthcare productivity.

What does this paper add?

- The University Hospital Southampton (UHS) Lifelines represents a new approach to the presentation and visualisation of electronic clinical records, using multiple timelines and icons to represent documents, events and reports.
- It permits all records to be consolidated on a single computer screen, optimising human visual pattern recognition to permit intuitive comprehension, navigation and decision assistance.
- It provides overview, zoom and filter functions, with real-time and direct access to the details on demand of selected electronic document content over short and long timescales.
- It has proved sufficiently promising in beta testing that it was adopted directly into the primary EPR for all records and all authorised users at UHS in 2016.

INTRODUCTION

Healthcare systems across the world are engaged in an epochal transition from paper to digital systems. A unifying and intuitive interface for the electronic patient record (EPR) has been an elusive goal for software developers and clinicians for decades. Paper is a technology for information transfer which has evolved over many centuries, with many powerful features which are well adapted to the human brain. Digital systems offer many advantages over paper, but they also bring many challenges in the organisation and presentation of clinical data to health professionals without resulting in data overload. Conventional electronic screen visualisation formats, which use tabs, dropdown menus, lists and multiple windows, present substantial comprehension challenges to end users. Digital systems for professional healthcare applications are as yet rarely developed to robust user interface standards to optimise them for the perceptual capabilities of the human user.[1 2]

The UK Government Digital Service has transformed our understanding of the principles of development of public sector information systems since 2010. It has placed prior discovery of the true needs of the end user at the centre of all digital system developments.[3]

'Digital by Design' enshrines the intent to make all Information Technology (IT) systems so functionally compelling and satisfying to use ('Digital by Default') that they will always be the user's system of choice, rather than through organisational convenience and compulsion ('Digital by Diktat'). It also enshrines the core principle that the benefits of digitisation lie not in replicating the paper process in code, but in new approaches to information management that deliver greater functionality than is possible with paper.

Computer-assisted data visualisation strategies in effective IT system design

The human occipital cortex subconsciously processes huge volumes of visual information with great speed and efficiency. It is wholly adapted to static and dynamic pattern recognition, recall and interpretation of shape, movement, colour, depth, distance and relative position. This biological truth is captured in the old aphorism that 'one picture is worth 1000 words'. Edward Tufte[4] has played a major part in advancing our awareness of the power of data visualisation.

Computer-assisted data visualisation is a fertile area for practical adaptation. The data deluge of the modern age mandates new approaches to the adaptation and presentation of digital information to the human brain, if the end user is not to be overwhelmed with digital noise.

Professor Ben Shneiderman, Dr Catherine Plaisant and their team at the Human Computer Interaction Laboratory (HCIL) of the University of Maryland in the 1990s reported an information architecture to support the visualisation of personal histories,[5] which evolved into the HCIL Lifelines model for visualising a clinical history,[6] which was not further exploited at the time.

Shneiderman's 'Mantra' of data visualisation[7] sets out the functional requirements of a system for the visualisation of a complex, large and/or heterogeneous data set. It distilled to the following system tasks: 'Overview, Zoom, Filter, and Details-on-Demand'.[8]

The abstraction of knowledge, insight and actionable intelligence to drive optimal clinical decision making is rarely derived from one document or page in the individual clinical record. Instead, it often emerges from the temporal relationships of a number of documented events, in parallel with investigations and information on comorbidities, which tell a richer story.

Adaptation of the HCIL Lifelines model to our intent

We were particularly influenced by two projects in the 1990s from the HCIL Maryland team:

- *The HCIL Filmfinder model*[9] showed us how to compress a large data set onto a single screen and how a single icon could be used to open a window to a large volume of content.
- *The HCIL Lifelines model*[6] provided the conceptual framework for our concept of EPR.

The Lifelines concept describes a stacked and synchronised series of timelines on the Y axis of the interface, and time is plotted along the X axis. Interactive icons are displayed in time and place on the graphic, according to their allocated time and subject metadata.

In consequence, UHS Lifelines (UHSL) is dynamic both in time and in functional adaptability. The timeline evolves continuously, and new icons are added directly as the underlying documents are generated and authorised. New timelines can be added as new data sources on new subjects become available.

Lifelines and the University Hospital Southampton clinical data environment

The University Hospital Southampton (UHS) IT programme has considerable autonomy for innovation within the UK National Health Service (NHS) digital transformation programme. Since the mid-1990s, UHS has mandated a standard format for all clinical documents and reports. Consistent metadata on the source, subject field and date-time stamp has been applied to each item, according to a long-established clinical subject taxonomy (see box 1).

By 2009, the hospital had amassed a large quantity of clinical documents and reports on more than two million patients. However, the clinical user experience of the IT system had not kept pace. Digital documents were primarily accessed through standard legacy computer interfaces. These make for a slow and taxing user experience in clinical service, when large volumes of time-structured information from multiple subject fields need to be assimilated and acted on in a short time frame.

We recognised the potential of the HCIL Lifelines model as a core framework for our evolving EPR. In this paper, we describe the development of the resulting clinical data visualisation system, the UHSL, which:

- Offers overview, zoom, filter and details on demand functionality.
- Is truly 'Digital by Design' through its relentless focus on end-user optimisation.
- Substantially simplifies the challenges of clinical data visualisation of longitudinal data over decades from many subject fields.

METHODS

Our digital infrastructure and testbed

The UHS clinical data environment (CDE) comprises a complex and unique architecture of legacy computer systems to serve a wide variety of operational needs

Box 1 Document and data feeds into UHS Lifelines as of September 2018

UHS clinical disciplines supplying clinical documents to UHS Lifelines.

- Surgery.
- Medicine and elderly care.
- Cancer care.
- Trauma and orthopaedics.
- Cardiovascular and thoracics.
- Obstetrics, midwifery and gynaecology.
- Child health.
- Ophthalmology.
- Emergency department.
- Neurosciences.
- Dermatology.

Clinical documents from partner healthcare units.

- The local independent sector treatment centre (run by Care UK).
- Southern Health NHS Trust (community health services in Hampshire).
- Solent NHS Trust (community health services in Hampshire).

Departmental results of tests and imaging.

- Histopathology and cytopathology reports.
- Endoscopy attendances.
- Nuclear medicine reports.
- Radiology reports (including plain X-rays, CT, MRI, mammograms and ultrasound scans).

Administrative information.

- Records of hospital inpatient admissions (from our patient administration system).
- Miscellaneous administrative documents.

NHS, National Health Service; UHS, University Hospital Southampton.

(figure 1). It has been in continuous evolution and adaptation for three decades. For clinical purposes, the key structural element of our CDE (figure 1) is an integration engine (coloured purple), which provides the foundation and the common point of reference for every patient record.

Within this complex and evolving system architecture, our digital documents and reports are stored in a data system which is owned and supported by UHS (coloured red/brown). The data sources for the UHSL project are currently and primarily within this element of the CDE.

Alongside the live CDE is a test and development system which permits a wide range of digital innovation and experimentation without intrusion or risk to live data.

Agile software development is an open-ended process. The development team works towards a system which best meets the end user's operational needs, through a continuous and iterative process of small design and writing 'sprints'. It requires continuous review, assessment and adjustment, as 'Showing the Thing' visually promotes feedback and insight.

The ability to 'fail early, fail fast' if one approach is not producing the right result creates a very efficient development process with minimal wastage, when compared with major software projects. The iteration is open-ended, adapting to inevitable changes in IT circumstances and systems. As such, an agile development project is quite unlike a conventional clinical research project or a clinical trial, where the end points are clearly defined in advance, or a clinical cohort study, when the cohort size is finite and defined.

Our 'agile' team comprised the concept lead and clinical end user (DAR), working iteratively with the system consultant and programming lead (AAH), who in turn had a long history of engagement and intimate knowledge of the UHS CDE as its principal designer. This proximity and mutual understanding of the user and of the system engineer and the harmonisation of the probabilistic thinking of the clinician and the creative but rigid linear demands of the system engineer were a key element in the success of the project.

By the nature of the project, it was initially optimised for a surgical outpatient service, with a focus on documents, histopathology reports and imaging reports. However, the wider utility of the system to the clinical service became apparent as we recruited more timelines and more content.

Our philosophical approach was to use a browser-based system which is accessible from any personal computer on the local and wide area network. This eliminates the need for specific software installation or configuration, and additional licensing costs. Documents and reports can be called on from elsewhere in the system at will. The user interface is delivered as pages encoded with HTML (hypertext mark-up language). The current version of UHSL is a C#.NET (Microsoft) application with data sourced from an Oracle 11G relational database.

The selection of content for display on UHS

In 2009, we initiated an unfunded, curiosity-driven research and development project to develop a timeline-structured EPR interface within the UHS CDE. We named this UHSL in recognition of the intellectual origins of the programme in the Maryland concept. We were constrained and pragmatic in the use of the available data resources of documents and reports, which were in effect 'upcycled' into the new visualisation format. We adopted the following general design objectives for the system, in that it should:

- Be optimised for the specific needs of the end user (in this case, an outpatient clinician), intuitive usability criteria and qualitative feedback.
- Display all available clinical e-documents and reports in a logical framework.
- Fulfil Sheiderman's mantra for visualisation of the entire data set.
- Be visually rich, dynamic and interactive, and accrue new content in real time.
- Work fast and seamlessly within the UHS CDE.
- Be intuitive in daily use, to maximise voluntary uptake by the workforce and to minimise the costs of training and implementation.

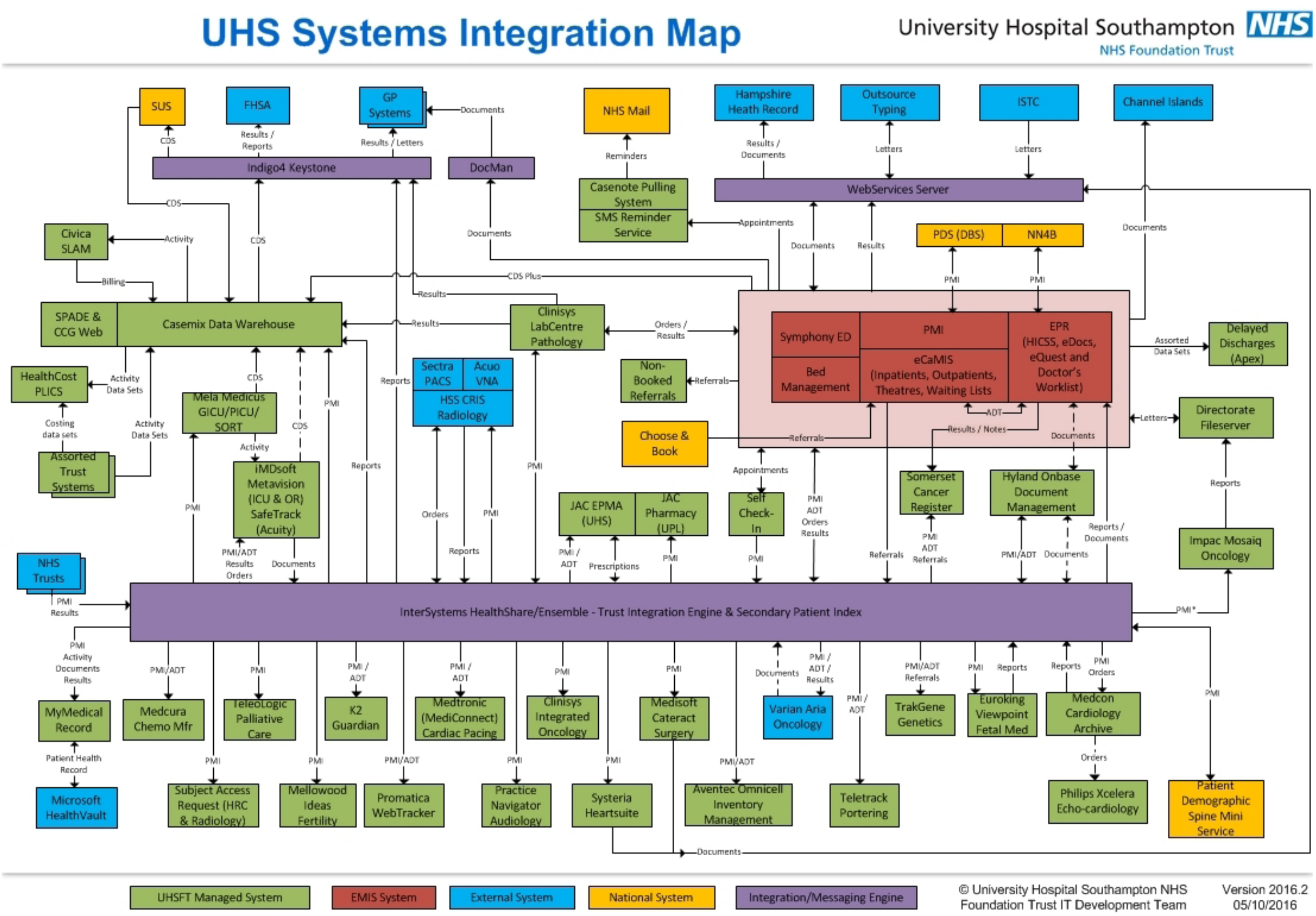

Figure 1 This 2016 systems integration map of the UHS digital infrastructure illustrates the complexity of a typical hospital IT system of systems, and by inference the requirement for common user interface which integrates information for the clinician user from a wide range of different systems. Courtesy of Ian Brewer, UHS. IT, information technology; UHS, University Hospital Southampton.

- Be economic to iterate and continuously adaptable to future needs and data resources.

These principles individually and collectively defined the agile development process, through which each iteration leads to the next step.

The subject taxonomy for the UHSL timelines

Each timeline is specific to a clinical discipline and subject content. Our own standard clinical document taxonomy was established at UHS in the 1950s in the era of paper records. Far-sightedly, metadata was applied progressively to key clinical digital documents and e-reports across the UHS CDE from 1995 onwards. The taxonomy of content for UHSL, as of late 2018, is as shown in box 1.

Reactivation of histopathology records back to 1990

Our digital cytopathology and histopathology records date back to 1990. They were archived in a variety of legacy formats. We were able to reactivate and upload on to UHSL some 500 000 archival records which were otherwise 'lost' to our clinicians.

The live version of UHSL (2016 onwards)

A workable alpha version was built in Microsoft Active Server Pages (ASP) code by mid-2010, following which it underwent continuous and iterative testing in various configurations in DAR's clinical service in outpatient, inpatient and multidisciplinary team configurations. By 2015, it was clear to us that UHSL could make a valuable contribution to the fast-evolving UHS digital strategy. It enables clinicians to identify pertinent information at speed to support our strategic aim to provide clinicians with more face time with their patients. We 'soft launched' UHSL as a 'Public Beta' module into the UHS proprietary CHARTS EPR in late 2016. This enabled us to resolve a number of display and navigation issues. Agile development continues.

Key technical and design features of the current version of UHSL (since 2015)

Display options for the overview screen

We consider it important to show the Overview Screen when any patient record is opened. This is because the Overview Screen:

- ‘Tells the story’ of the patient’s health most efficiently.
- Displays key information which the user might not otherwise seek out under time constraints in a busy clinic.
- Minimises the risk that the clinician will miss key information in the record, under the pressure of time, when compared with the demands of opening multiple tabs and windows in legacy data display systems.
- Fiilters Out timelines which hold no data, so that the user sees all available information most efficiently and without having to open ‘blind’ tabs.
- Allows the user to Zoom In and access Details on Demand for any document, event or report of any age and in real time.

The calendar timeline reset function

The overview default screen permits the display of 28 years of documents in one full-screen view. On pragmatic grounds for efficiency of display, we offer users a default view of the past 2 years of data. All prior events are listed on their timelines on the left hand end of the display. A ‘Calendar’ date (month/year) selector tool permits a rapid reset to any earlier date.

Display of icon metadata

The iconography is arbitrary in design, but it is easily understood. Each icon occupies 12×12 pixels of screen space. Each represents a single document, report or clinical event. Clicking on each icon opens up the document which ‘underlies’ it. Hovering on the icon displays the metadata for that document or report in a ‘balloon’.

Continuous iteration and adaptability

Our ownership of the UHSL code permits much faster iteration, fixes and updates than is usually possible with large commercial systems.

Managing the problem of icon overload and clustering on timelines

As document numbers increase, more than one document may occupy the same point in space and time on any one timeline (‘Clustering’). In our system, each icon occupies 12×12 pixels of physical screen space on any timeline. We have considered and tested a number of possible solutions to this problem. In our 2010 iteration (V.1), multiple icons were allowed to overlap, but they progressively obscured each other as numbers of collocated icons built up (see figure 2).

Our current solution (2016+) is a hybrid format in which a single icon represents multiple documents when overlap occurs. The hover balloon lists all documents in the cluster, and the icon opens up a window which displays all of the contained documents in tabbed format (figure 3).

Clinical safety and risk management

The NHS mandates each Trust to have a clinical risk management process in place for health IT systems. Specifically, two mandatory standards, DCB0129 and DCB0160, in section 250 of the Health and Social Care Act 2012 by the Data Coordination Board (DCB), set out a specification, which defines the requirements and conformance criteria to be met by the user, and implementation guidance.

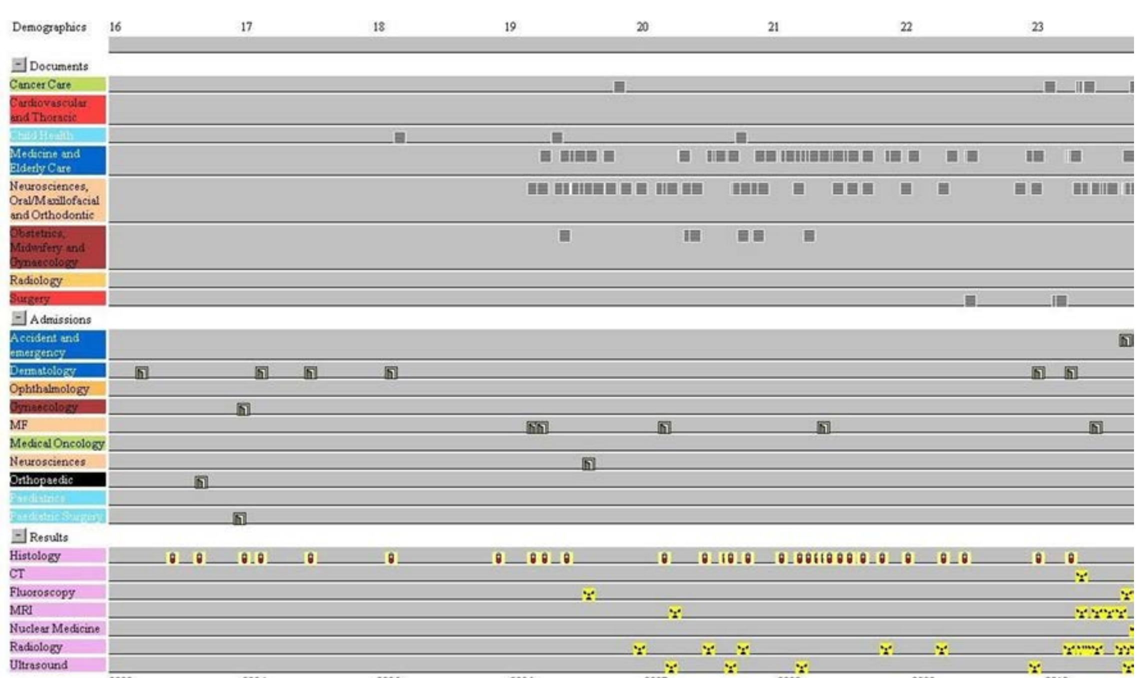

Figure 2 The first working version of UHS Lifelines, launched in 2010. The screenshot is of a young patient with complex medical needs and multiple hospital admissions. Each icon links to a specific document or report, located in time and subject context by metadata which has been standardised at University Hospital Southampton (UHS) since the late 1990s.

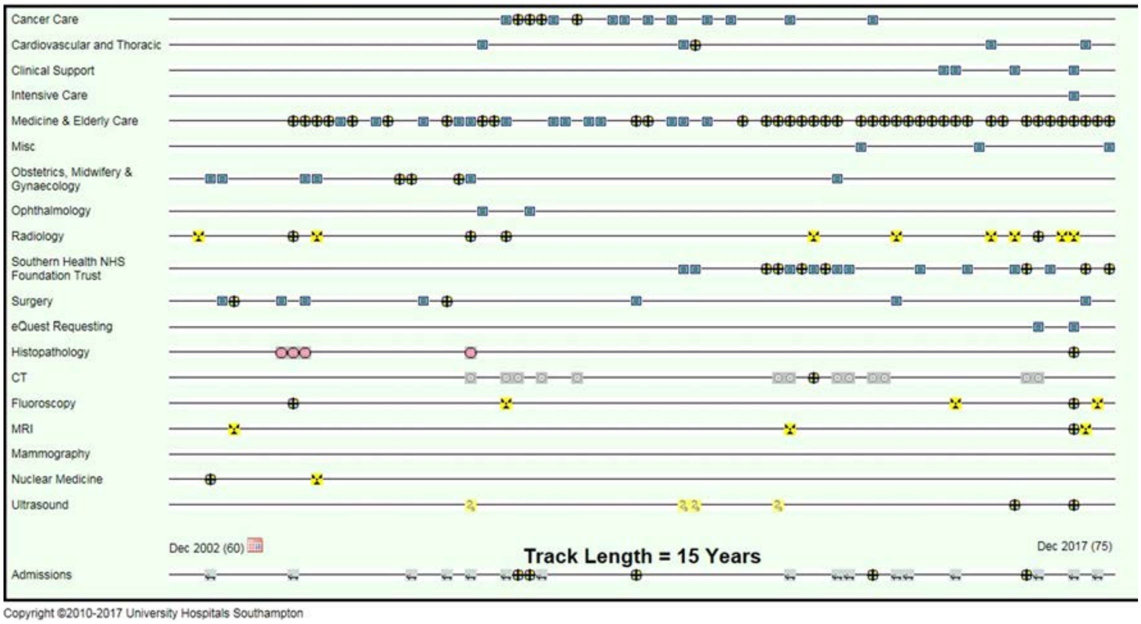

Figure 3 This screenshot is taken from our most recent version of UHS Lifelines, in 2019. It illustrates a patient with complex medical comorbidities to show how readily the format organises large volumes of documents and reports. The 'hot cross bun icons' identify multiple documents. Clicking on the multiple document icon opens and displays those documents as individual tabs. The icons on the admissions timeline both provide core information on the admission and act as a dynamic link to other inpatient data systems. NHS, National Health Service; UHS, University Hospital Southampton.

Specifically, DCB0129 promotes the effective application of clinical risk management in the *Development* and maintenance of health IT systems. DCB0160 addresses the *Deployment*, use, maintenance or decommissioning of health IT systems within the health and care environment, under the direction of a local clinical safety officer.

UHS maintains a mirror test environment of our live and deployed systems, within which the code for UHSL has been continuously maintained and developed for cross validation and quality assurance purposes. Within the legislative and institutional safety framework, the module progressed from Alpha to Live Beta over 5 years (from 2012 to 2016) of rigorous testing and evolution (by DAR, AAH and DC) in one clinical service, with fortnightly review and evaluation meetings, and continuous communications to identify and to iron out glitches and instabilities before we were confident to launch a live system in 2017. We maintain an open reporting culture and systems for all users, for feedback and the identification of practical issues in a very dynamic development environment.

Outcomes (results)

Since August 2017, UHSL is now available to the entire user base of some 5000 authorised users across our clinical data estate. It is accessible as an application on our primary EPR dashboard. Authorised users include clinicians, nursing and allied health professionals, clinical research nurses, and secretarial and administrative staff.

Qualitative observations

Ease and speed of use

During development and alpha testing of the UHSL model, it was rapidly apparent that it offered considerable advantages over our legacy EPR e-document format, which used separate tabs for each clinical subject field, and which displayed documents in vertical list mode, along with the metadata. Thus, for a complex clinical case, UHSL automatically opens all tabs and displays every document as an icon on the UHS 'grid', enabling clinicians to see at a glance what information is there.

The system currently also displays histopathology and cytopathology reports, all imaging reports, blood group and transfusion data (important for anaesthetists), and hospital admissions. All temporal and subject relationships between the icons are immediately apparent. This presentation transforms the speed and ease of visualisation of a patient record. It is particularly valuable for patients with complex histories and multiple comorbidities, reducing 'time to overview' from minutes to seconds.

UHSL is currently optimised for outpatient, emergency admission and anaesthetic preassessment use, providing an overview of clinical histories over the past days, weeks, months and years. It also provides immediate access to historical records which would otherwise be unavailable or which could only be found with considerable searching through past files.

High-frequency, inpatient generated data (fluid and physiological charts, nursing commentaries and so on) generally have a different taxonomy, timescale and content, which are currently structured and optimised within the Hyland OnBase 18 Electronic Document Management System (EDMS). The dynamic hospital admission timeline icons (see figure 3) now link Lifelines directly to OnBase inpatient content.

The ease and speed of display of data translated into the following practical observations:

- With experience, pattern recognition of the timeline, icon and metadata displays allows the clinical observer to 'read the clinical story' with significant fidelity, even before the underlying documents are opened.
- The need to print out documents to reconstruct the story is eliminated because the history can be so quickly and easily read.
- Surgical clinical decision making is improved and de-risked, in that comorbidities and significant morbid histories were immediately apparent from the taxonomic and iconographic display patterns.
- Clinical productivity in the test outpatient service improved by up to 25%, in that substantially more patients could be seen in unit time in any clinic, and/or that patient 'face time' was substantially increased through the reduction in 'screen face' time.
- There was a substantial reduction in user fatigue from multiple clicks, mouse movements and multiscreen navigation.
- The use of UHSL was intuitive and enjoyable because of the added interest and security offered by the interface when compared with legacy formats.

Quantitative pilot studies

In a pilot study, two of our surgical trainees reviewed 40 new referrals to the UHS head and neck clinics in January 2019. For each patient they recorded the number of clicks and time taken to access their referral letter, including the time taken to load the patient on the system, along with imaging and histopathology reports.

— The average time taken per patient to access the three core records (referral letter, imaging and histology) was 17.6 s using UHSL, compared with 36.1 s using the conventional UHS CHARTS EPR interface.

— The average number of clicks per patient was 3.9 using UHSL, compared with 8 clicks using CHARTS. Once the commercial EPR was loaded, the subsequent tasks were much quicker using UHSL (finding imaging reports in 3.0 s vs 13.7 s in CHARTS; and histopathology reports 1.6 s vs 11.4 s) (E Crossley and C Findlay, personal communication, March 2019).

DISCUSSION

We have developed UHSL from the original Maryland concept, with a very small, self-assembling team, with limited resources and with no prior commission or specifications. This has been a challenging, fascinating and rewarding exercise.

The key lesson of our work on UHSL to date is that user need takes centre-field in the agile and iterative development process. By 'Showing the Thing' visually as the project evolved, it became possible immediately to see lines of development in clinical software which would otherwise not be apparent in the raw data.

We recognise that this project does not fit a standard clinical research template. It The project has been a pragmatic and evolving exercise in clinical software engineering to upcycle existing data into more usable formats.

In the course of this project, UHSL has demonstrated unforeseen properties in terms of enhanced clinical decision assistance, clinical productivity, clinical risk mitigation, predictive analytics in pattern recognition and controls to confidentiality. Among our key observations, we note the following:

The capacity of UHSL for progressive content expansion

The capacity of UHSL for progressive content expansion, through the addition of content feeds from diverse data sources, suggests a direct route to a universal and adaptable EPR interface for all UK citizens, from conception to death, thus supporting the emerging aim of the UK Government to enable citizen's data to be shared between relevant agencies.

Our initial design intent was to build a simple system which would allow us to visualise an existing set of documents and records across and within the UHS CDE. We continue to examine the benefits and practicalities of adding additional legacy and perhaps new data feeds to the core architecture, including the codisplay of haematology, biochemistry and microbiology test results, and key prescribing activity, all of which provide different display challenges to optimise them for a range of clinician and administrative user needs, but which may deliver great value.

The need for a standard subject taxonomy for personal health data

If the UHSL model is to scale up from a single hospital to a national interface, there is a need to develop a standard taxonomy for clinical subject matter at all levels of healthcare. This will ensure that a consistent visual framework can be developed to open standards for maximum utility, much as internet protocols have transformed the world wide web.

The inherent controls to confidentiality in the iconography

With simple adaptations, UHSL will permit the selective open/shut control to access to the underlying data.[10]

The ability to read the clinical story from the visual display

This suggests a fast-track route to applied predictive analytics, and a logical step between the source data and the ambitions of artificial intelligence to parse and read the entire clinical record.

The need for further quantitative studies

There is a need for further quantitative studies to evaluate the system across a wider range of user needs, and the value of detailed analysis of activity digital data (dwell times, routes of access and egress, user-specific usage patterns, and so on) to help us further design with data.

The value of incremental development

Rather than specify a huge national waterfall programme and huge cost and risk of failure as shown by the National Programme for IT, we believe that our agile approach has demonstrated a safe, pragmatic and incremental route to a wholly integrated and easily understood EPR by every citizen in the UK, as the constraints to free and safe information flow between primary, secondary, community, social, dental and mental healthcare, and patient-generated data are overcome.

The project economics

As a curiosity-driven project, UHSL has been developed and continues to evolve at a tiny fraction of the cost which has been incurred in commissioning a commercial software house to build, maintain and upgrade a similar system in a waterfall contract, without the daily flexibility of our own strategy. As Trust employees, DAR and DC contributed extensively at no additional cost to the Trust. AAH was modestly remunerated for his work, with much additional work undertaken on a pro bono basis. All development work was done on existing computer systems and with existing data, so there were no leading or capital costs. However, investment will be needed to scale up this product and leverage its potential value to UHS.

The importance of the soft launch

We have made UHSL readily available to all users across the Trust on the primary EPR and within a number of other applications. However, in a dynamic and complex clinical data estate which is in continuous evolution, and where our EDMS project has presented major integration challenges, we have preferred to leave users to find their own uses and to feed back their needs into the development programme. Thus, for example, when the value of the system was recognised by anaesthetic colleagues, we added the 'transfusion' timeline from haematology data to help them identify previous major haemorrhagic events.

Implementation in other software environments

As yet, UHSL is bespoke to the UHS CDE, and it cannot be directly exported. However, a common open source code set for the UHSL model would help developers to accelerate the uptake and testing of the system across a range of healthcare applications.

We recognise that modern and readily accessible coding tools, such as Orange, Mongo, Bootstrap and Tableau, might help to add functionality to the visualisations. However, we have preferred to keep the interface as clean and simple as possible during the development programme to minimise user choices and distractions.

IN SUMMARY

We have described an agile and iterative digital exercise that started out in 2009 as a simple 'what if?' question between the three authors. This has led to the development and practical proof of concept of a powerful data visualisation system in live clinical use. We consider that it has substantial further development potential as a standard architectural framework for the EPR of every citizen. Our work also demonstrates the value of the agile development approach to clinical software, as promoted in parallel by the Government Digital Service in many other public sector applications.

Atul Gawande[11] has recently asked why doctors hate their computers. The problems which he describes of poor interface design, system bloat and user burn-out will be well understood by all users of clinical EPR systems from all sources. Our work to date on UHSL has encouraged us to the view that while a single picture may be worth a thousand words, an end-user optimised data visualisation interface simplifies the appreciation and interpretation of a thousand (document) images.

We recognise that there is much still to be done to build on this early development work. However, at this point, we feel it important to draw the attention of the system to the wider clinical informatics community, to stimulate debate and to accelerate further innovation in the search for a unitary EPR for primary, secondary, social and community care, for every citizen in every health economy.

Twitter David Cable @cabledUhs

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Contributors DAR conceived and led the project. He provided the primary user evaluations throughout the development phase of the programme, and wrote the draft manuscript. AAH wrote the software, led the systems integration and contributed to the manuscript. DC managed the project interface with the UHS Clinical Data Estate, participated in all discussions and contributed to the manuscript. EC and CF undertook the pilot project on naive clinical user evaluation.

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REFERENCES

1 West VL, Borland D, Hammond WE. Innovative information visualization of electronic health record data: a systematic review. *J Am Med Inform Assoc* 2015;22:330–9.
2 Lesselroth BJ, Pieczkiewicz DS. *Data visualisation strategies for the electronic health record*. Nova Science Publishers Inc, 2011: 1–59.
3 UK government digital service design principles. Available: https://www.gov.uk/guidance/government-design-principles [Accessed 28 Aug 2018].
4 Tufte ER. *The visual display of quantitative information*. Cheshire, Connecticut: Graphics Press, 1983.
5 Plaisant C, Shneiderman B, Mushlin R. An information architecture to support the visualization of personal histories. *Inf Process Manag* 1998;34:581–97.
6 Plaisant C, Mushlin R, Snyder A, *et al*. Lifelines: using visualization to enhance navigation and analysis of patient records. *Proc AMIA Symp* 1998:76–80.
7 Shneiderman B. The eyes have it: a task by data type taxonomy for information Visualizations. *Proceedings of the 1996 IEEE Symposium on Visual Languages*, Washington, DC, USA, 1996:336–43.
8 Shneiderman B. A Grander goal: a Thousand-Fold increase in human capabilities Educom review. *Educom review* 1997;32:4–10.
9 HCIL Maryland Filmfinder. Available: http://www.cs.umd.edu/hcil/pubs/video94.shtml [Accessed 1st Sep 2018].
10 Dasgupta A, Maguire E, Abdul-Rahman A. Opportunities and challenges for Privacy-Preserving visualisation of electronic health record data. *Proc IEEE Vis Workshop in Visualisation of Health Records*, 2014.
11 Gawande A. *Why doctors hate their computers*. New Yorker Magazine, 2018.