Digital health solutions
With the effective digital transformation of the health care industry, patient outcomes are improved and health care costs are reduced. According to the 2016 Report to Congress on Health Information Technology Progress, 96 percent of hospitals are using certified electronic health record (EHR) technology. However, EHRs are not sufficient by themselves to deliver the promise of a digital transformation due to the fragmentation and inconsistency of digital data across multiple EHRs, patient-generated data, device data, research data and other rich health care data sources.

In this paper, we describe how a platform-based approach can bring order and structure to the digital health ecosystem. We offer a reference architecture for a digital health platform (DHP) that addresses the fragmentation, lack of standardization and sub-optimization of data across the complex and heterogeneous health IT ecosystems used in many large health care organizations today.

HealthConcourse is Perspecta’s implementation of the digital health platform reference architecture described below.

**Business problem**

Patient health outcomes are sub-optimal when medical decisions are made without complete and relevant information. This occurs due to the fragmentation of health records across multiple sources with high heterogeneity, insufficient health data interoperability, lack of data standardization and minimal automation for extracting meaningful insights from the data.

To put this into context, consider the veteran experience: A veteran has health data stored in the Military Health System (MHS), Veteran Health Administration (VHA) system and private practitioner systems. Today’s tech-savvy veterans likely will create additional health data from medical devices, mobile apps and patient portals. The MHS and VHA have highly federated systems leveraging multiple solutions with multiple instances (e.g., over 130 Veterans Health Information Systems and Technology Architecture (VistA) systems in the VHA). In addition, both agencies are migrating to modern EHR platforms and will be undergoing a multiyear transition, where some care locations will use new technology to capture and manage patient records while others are still using legacy systems.
This creates a huge burden to bridge all the pieces of information needed for care delivery. For a chronically ill patient, there may be a care team, including several providers working for different organizations (some public, some private), different disciplines, different locations and different systems. All of these would need to have a common framework for managing shared workflow and consistent, comprehensive access to the patient’s record.

**Data, interoperability and APIs**

Accessing and harnessing data across a variety of systems is not a new problem. For decades, engineers have approached this problem using messaging strategies, data file or database sharing strategies and interface strategies. Recently, the use of RESTful (Representational State Transfer) application programming interfaces (APIs), or RESTful web services, combined with the rapidly emerging FHIR (Fast Health Interoperability Resources) standard is accelerating and standardizing health care interoperability. FHIR-based, RESTful APIs enable health care data sharing across a federated and fragmented environment without necessitating data migration or locking up data in centralized solutions that sometimes reduces an organization's control of the data.

However, the use of APIs does not, by itself, solve the problem of data fragmentation, lack of standardization or sub-optimization across a complex ecosystem. FHIR-based RESTful APIs are just the tip of the iceberg. To fully leverage the benefits of FHIR and APIs, more must be done than simply adding an API on top of an existing system of record. This is because the raw data is typically not in a state or format that lends itself to interoperability without manipulation. A recent review of data assets across the VHA concluded that the existing data “is unusable in its current state due to lack of normalization, duplication, being out of date and other noise and clutter. Our landscape analysis revealed a lack of a consistency when it comes to vocabulary, schema, and data formats.”[1] To be successful, a complete API strategy should:

1. **Address the differences between the raw data from the systems of records and the data requirements of FHIR and other interoperability standards.** Data transformation and translation against industry standards helps to standardize the data into a canonical form.

2. **Hide the complexity of the underlying data environment to the data consumer.** APIs and the platform behind them provide the opportunity to encapsulate the systems of record and shield the data consumers from the underlying data siloes and associated fragmentation. Aggregating the data from similar systems of record behind a single, more coarse-grained API reduces the burden on the systems of engagement that need this data. A thousand sources of data should not necessarily result in a thousand APIs.

3. **Consider opportunities to improve and enrich the raw data to maximize its use.** Once data is aggregated and standardized behind the API, questions can be asked of the data that could not be asked before. Opportunities exist to enrich the data with provenance, security, privacy, conformance and other types of metadata. Enrichment can also come in the form of new insights gleaned from the data through analytics and evaluation of the data against knowledge bases.

What is “under the API” is just as important as the use of APIs themselves. The APIs should be the gateway into a robust data processing platform capable of maximizing the usefulness of the data behind it.

**HealthConcourse reference architecture**

The HealthConcourse reference architecture is a general purpose reference architecture for a full featured, robust digital health platform (DHP). It describes the functions and components that constitute the solution “under the API.” The platform-based approach described by this reference architecture emphasizes modularity, interoperability and a common framework for optimizing how different solution components interact within a cohesive ecosystem. The reference architecture details the common elements required to effectively manage healthcare-related data across multiple sources of record in a fragmented and federated data landscape to reduce risk, cost and time to market. Implementations of this reference architecture, including HealthConcourse, provide the framework for delivering, managing, orchestrating and optimizing multiple health care services to address the needs of several stakeholders and use cases requiring access to the patient’s digital health record and other digital assets supporting health organization services (e.g., care delivery, customer service, operational management, analytics and asset management).
Separation of concerns

The DHP concept is predicated on the idea that health IT ecosystems comprising of multiple EMRs and other health-related data stores can no longer rely on a single “source of record” for managing the complete life cycle of health data. Further, no one system in a complex ecosystem can be solely responsible for managing data processing to drive all business processes or deliver integrated data views to all business users.

The DHP reference architecture is an implementation of “separation of concerns”—a design principle for separating solutions into distinct layers, components or sections that individually satisfy a core business requirement or “concern.”

At the macro level, a DHP and the ecosystem it operates within are separated into three distinct layers as shown in Figure 2. The proliferation of multiple systems of records (where fragmented data resides) and multiple systems of engagement (where consolidated and standardized data is needed) highlights the business problem. Essentially, multiple systems of record exist, including EMR platforms, non-clinical business systems, data warehouses, patient-generated data stores, medical devices, applications and others that each contribute a portion of data to the overall patient record.

In today’s complex health delivery organizations, the systems of record are a mix of older and newer solutions developed in-house or delivered from a variety of health care solution vendors. In nearly all cases, the data across these systems of record are not aligned to a canonical form and have variable conformance to industry data model, data exchange and medical terminology standards.

When applying the “separation of concerns” principle, the systems of engagement are decoupled from the systems of record. We see this pattern applied in health care with health information exchanges, SMART-on-FHIR applications, mobile applications, patient portals, analytics dashboards and other systems of engagement where the end-user application is decoupled from the data sources.

The benefits of separating the systems of engagement from the systems of record include:

- Better modularity so that individual components can be changed or replaced without cascading impacts across the ecosystem
- The ability to have a best-of-breed environment with minimal vendor lock-in, and greater portability of applications and components
- Longevity and portability of the overall architecture and ecosystem to ensure the systems can continue to provide business value as dependencies and infrastructure change over time
- Greater reusability of common capabilities to increase consistency, governance and time to market

However, separating the systems of engagement from the systems of record comes with challenges. The systems of engagement are encumbered by the fragmentation, lack of standardization and sub-optimization of data access and utility across a heterogeneous collection of systems of record. To address this challenge, the DHP fulfills the role of the systems of insight.

A system of insight is an intermediary between the systems of engagement and the systems of record that hides the complexities of the underlying data architecture to ensure that systems of engagement have the information they need to satisfy business
requirements. A well-designed DHP should address data acquisition, fragmentation, standardization, transformation, validation, knowledge extraction, organization and classification, metadata tagging, natural language processing, identity and terminology resolution and uniform data access through a secure set of discoverable APIs. DHP APIs should be aligned to industry standards to ensure predictability and portability. A DHP should also be context-aware to predict and tailor the data provided to systems of engagement based on knowledge of the end user, their access rights, preferences, workflow and the specific needs of the current tasks within their workflow.

**DHP core elements**

Tables 1 and 2 define the core elements of a DHP. These core elements should be implemented as a set of modular services orchestrated to work cohesively as part of a well-managed ecosystem. However, each core element doesn't necessarily correspond to a single, atomic unit of software or software component. The actual number, specificity and granularity of software components is open to interpretation provided that the following core elements are not collectively delivered as a single monolith application unable to achieve the benefits of extensibility, modularity, encapsulation and plug-and-play solution component migration over time.

After data is retrieved from the systems of record, the core elements listed below effectively create a data processing pipeline that navigates across logical layers of services so that data is systematically integrated, normalized, enhanced, evaluated, curated, exposed and made available as an aggregated and standardized data set.

**Table 1. DHP pipeline layers and core elements**

<table>
<thead>
<tr>
<th>Pipeline layer and core element</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Data integration and transformation services (i.e., extract, transform, load (ETL) services)</td>
<td>Capabilities to retrieve data from the systems of record using messaging, API and database adapters so that data can be acquired and integrated into the DHP and subsequently transformed from the source format into a defined canonical model.</td>
</tr>
<tr>
<td>Canonical data model</td>
<td>The standard model that all incoming data is mapped and transformed to. Having data in a canonical form can improve alignment to industry standard data models and terminologies as well as improve the predictability, consistency and computability of the data. These data characteristics are essential for more complex data processing and analytics including the data enhancement and knowledge services described below.</td>
</tr>
<tr>
<td>Data standardization services</td>
<td>Capabilities to resolve differences in terminology and identities (e.g., patient, provider and organization identifiers). Extraction of structured data from free text using NLP to turn unstructured data into more discrete, structured data elements aligned to the canonical model.</td>
</tr>
<tr>
<td>Data segmentation and classification</td>
<td>This section also encompasses capabilities for managing reference data including medical terminologies, taxonomies, ontologies and directories of provider, business services and organizations.</td>
</tr>
<tr>
<td>Data enhancement services</td>
<td>Capabilities to augment the raw data from the systems of record by adding metadata to better index, describe and/or classify the data. Common metadata may include provenance information, conformance information and data classifications. Data classification or segmentation is very powerful for subdividing the data to enable functionality like fine-grained consent, attribute-based access control and clinical research.</td>
</tr>
<tr>
<td>Knowledge services</td>
<td>Capabilities to manage knowledge repositories (e.g., CDS, CQM and calculators) and/or implement analytical and statistical models to extrapolate insights from the raw data aggregated from the systems of record. This layer also includes services implementing business rules for record duplication, record reconciliation (e.g., medications and allergies), and record semantics such as grouping records relevant to a long-running chronic disease episode of care.</td>
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</table>
The additional core elements in Table 2 are cross-cutting in nature providing capabilities leveraged at all layers making up the data processing pipeline.

**Table 2. DHP cross-cutting layers and core elements**

<table>
<thead>
<tr>
<th>Pipeline layer and core element</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Business services</td>
<td>Capabilities to understand the specific business requirements of a common business function such as ordering and scheduling. There are no required or correct number of business services and their implementation details depend on the needs of target environment. Their purpose is to understand common business needs and predict, curate, package and deliver the data and insights required for a common business function. Business services are typically composite services that utilize the services in the underlying layers and orchestrate a tailored flow based on a specific need. They may also include additional business logic of common capabilities appropriate for the business purpose they serve.</td>
</tr>
<tr>
<td>Data utilization services</td>
<td>Capabilities enabling the use and delivery of data to systems of engagement. Query services provide the data to consumers and consent management ensures appropriate access and, where necessary, redaction of data based on consent provisions defined by organizational policies or patient preferences. Other capabilities include visualization services that support graphic representations of the data.</td>
</tr>
<tr>
<td>Secure data access services</td>
<td>Capabilities to expose the aggregated, standardized and enriched data set and inferred insights to the systems of engagement. Standardized APIs promotes discoverability, predictability and consistency. API management enforces API access policy, governance and management, and often includes monitoring, analytics and access control capabilities. Security controls for authentication, authorization and encryption as well as monitoring, threat detection, auditing and logging are common features of API management solutions.</td>
</tr>
<tr>
<td>Data management services</td>
<td>Capabilities for managing the data within the DHP as it is acquired, integrated and processed. This cross-cutting capability includes the ability to store the data in long-term databases (e.g., data lake) or temporary caches and index the data for rapid search and retrieval. Data stored outside the system of record should be kept current and in sync with the source systems. Advanced master data management capabilities may be employed to track the source of truth for different data elements and ensure currency, consistency and integrity of data with the source systems.</td>
</tr>
<tr>
<td>Orchestration services</td>
<td>Cross-cutting capabilities to manage the data processing pipeline by managing and executing configurable internal data processing workflows and calling business logic modules or external services as part of a SOA.</td>
</tr>
<tr>
<td>Context services</td>
<td>Capabilities enabling a DHP to be context aware and able to listen for, predict and appropriately respond to new data and business events and activities in the surrounding ecosystem. This is important to ensure that a DHP is optimized for the broader IT ecosystem in which it is deployed and achieves a higher level of predictability, accuracy and utility than a standard, CRUD (create, read, update and delete) data access solution. Context services rely on events raised as part of an event-driven architecture and utilize subscription mechanisms often found in publish-and-subscribe solutions. Once informed of new events, context services invoke the appropriate underlying DHP services to trigger data retrieval, data processing and knowledge execution capabilities aligned to the business events being raised.</td>
</tr>
</tbody>
</table>
Figure 3 provides a conceptual representation (reference architecture) of how the core elements and services listed in Tables 1 and 2 are organized relative to each other to create a cohesive system of insight. The DHP, as the system of insight, provides the cohesion that bridges data from disparate, disconnected data sources and provides the integrated, aggregated and standardized dataset that overcomes the challenges currently faced by the systems of engagement.

**Figure 3. DHP conceptual reference architecture**

This DHP reference architecture aligns well to health ecosystem descriptions from leading health care organizations such as Health Services Platform Consortium (HSPC) and Health Level 7 (HL7). The reference architecture incorporates several of the core services and capabilities described in the 2018 HSPC Roadmap[3], including the use of the HL7 FHIR specification[4] for data transport and API definitions, HSPC recognized standard medical terminologies, terminology services, the CDS Hooks specification[5] and data segmentation used for patient right of access and consent[6].

The reference architecture also incorporates several of the core services defined in the HL7/OMG Health Services Specification Project (HSSP)[7], including message transport services, terminology services, health services directory services, record locator services, identity management services, data retrieval services, data mapping and transformation services, event management services (e.g., context services), health care security services and clinical decision support services. Implementations of this reference architecture are encouraged to also be faithful implementations of the API specifications and related requirements for the services defined by FHIR, HSPC and HSSP.

**HealthConcourse—Perspecta’s digital health platform**

The Perspecta HealthConcourse offering is a realization of the DHP reference architecture. HealthConcourse is a DHP with an open architecture and open, standards-based APIs built on the FHIR standard. FHIR resources are used as the canonical data model within HealthConcourse, and FHIR API specifications are used to define the HealthConcourse APIs. HealthConcourse transforms the raw data retrieved from the systems of record into FHIR resources. The data ingestion pipeline of HealthConcourse includes a configurable collection of services (described below) that implement many of the capabilities defined in the DHP reference architecture above (e.g., terminology services, natural language processing services, clinical decision support services, etc.). Serialized FHIR resources are used as the input and output of most of the pipeline services resulting in standards-based internal interoperability that enables modularity, encapsulation, agnosticism and a plug-and-play approach.

HealthConcourse can be used as both a demonstrable reference implementation of a DHP and an operational solution. As a reference implementation, HealthConcourse is useful as an example of how to bring cohesion amongst the types of data siloes and disparate technologies common in a complex ecosystem. We have built a demo environment to showcase the reference implementation, which includes several systems of record and systems of engagement to mimic the complexity and heterogeneity of a real-world health care IT ecosystem. This environment includes multiple EMRs (e.g., VistA instances, Cerner Millennium and Allscripts), patient data sources, medical and consumer devices and a diverse and varied set of systems of engagement. The patterns, best practices, lessons learned and the expertise acquired building the reference implementation and demo environment are transferable to other technology stacks. Although we have implemented an operational solution with a pre-determined set of technologies, the platform itself is technology agnostic and supports plug-and-play. It can be configured and recreated using a different set of technologies and products. Figure 4 shows the solution components we have implemented and the underlying technologies chosen to deliver the capabilities.
As an operational solution, HealthConcourse is available to customers as a managed service leveraging many of the proven technologies already in place (Figure 4). Since our implementation is an evolving ecosystem that changes routinely to incorporate new technologies, realize new capabilities or support new use cases and data sets, the architecture and collection of technologies and partners continuously evolves. This type of rapid evolution is only possible when using a platform-based approach that embodies the principles of encapsulation and modularity. The managed service offering currently uses DXC Technology’s Open Health Connect (OHC) integration and analytics engine as the core engine. Future versions will also support alternative engines such as the InterSystems HealthShare platform or the open source NIFI technology. Offering technology options allows us to align an implementation to a customer’s technology preferences and leverage existing licenses where applicable. The full range of technologies incorporated into HealthConcourse are detailed in the following sections.

**HealthConcourse technologies and products**

Within HealthConcourse, the data orchestration services orchestrate a comprehensive workflow that traverses the services, technologies and products across all the layers detailed below.

**Data integration and transformation:** Data is acquired and integrated into the platform through the Viaduct component in OHC. These services include agents that actively pull data from systems of record and listeners that receive data passively from systems of record. Each system of record can provide a different data access mechanism and use a variety of data exchange patterns. As such, Viaduct comes with an extensive collection of adapters as well as a highly configurable and scriptable data ingestion capability.

All inbound data structures are transformed into FHIR STU 3. OHC internally handles most transformations including transforms from older FHIR versions, HL7 v2 messages and non-standard data structures such as the proprietary data feeds from many medical devices. Clinical document architecture (CDA) documents require a more complex transformation. For this, we leverage the MDMI transformation engine and data structure maps. MDMI has its own internal canonical model with very specific and atomic data elements that can be used to map the structures of FHIR resources as well as CDA-based documents.

**Data standardization:** Data standardization addresses free text data and differences between records in terminology, identities and references to non-clinical entities. If the inbound data is a free text clinical note, OHC will call our Natural Language Processing service which is based on the cTAKES and UIMA framework with additional enhancements from experts at the University of Utah. The NLP service will identify and extract core clinical elements such as diagnoses and use this information to create new FHIR resources. With this capability, it is now possible to use information embedded in free text to drive downstream processing that requires FHIR resources.

Once all data structures are represented as FHIR resources, the contents are standardized using terminology services. Terminology differences amongst the resources are mediated against Wolters Kluwer’s Health Language terminology service. Examples include adding the preferred text to a concept that has localized nomenclature or translating an ICD-10 code for a condition into a SNOMED-CT code. Terminology mediation is important to ensure that identical concepts are recognized as being the same by downstream processing even if the source data uses different terms or codes to describe the concepts.
Standardization also includes standardizing references to non-clinical entities like patients, providers, organizations and locations. Patient identifiers can be mapped across systems of record using OHC’s internal master patient index (MPI) capabilities. In our demo environment, we use test and synthetic data that do not necessarily align to the same patients so we use personas to represent compositions of records as a proxy. Future enhancements of HealthConcourse will also include a robust set of provider and organization directories.

**Data enhancement services:** After data is in a normalized and standardized form, it can be evaluated and enhanced. The primary output of this layer of services is metadata added to the FHIR resources that improve the utility and understanding of the data from the sources. For instance, HealthConcourse includes a security labeling service that analyzes data, compares the contents to taxonomies such as the sensitivity data set managed by the Health Language terminology service, adds metadata tags based on matches to the categories in the taxonomy and then updates the FHIR resources in OHC. Using the sensitivity data set from Health Language allows us to identify portions of the patient record at the individual FHIR resource level that fall under different sensitivity categories. For instance, we can identify all the condition, medication, observation and procedure resources related to mental health and add metadata tags to these resources. Doing this allows us to implement fine-grained consent management whereby patients can decide exactly who can see their mental health data and for what purpose.

Data enhancement also includes data profiling and data quality and validation. Using a FHIR profile validation service, we test conformance of the FHIR resources passing through the system against commonly used FHIR profiles such as the U.S. Core profiles and determine which resources are conformant against these profiles. Conformance information is added as metadata tags to the resources. This is important for downstream processing where profile conformance is required to use FHIR resources for things like clinical decision support and evaluation of clinical quality measures. We also leverage the Perspecta Arroyo technology to perform data quality and validation analysis by checking the contents of the FHIR resources against the rules defined by the specification for each FHIR resource. Data type checking, cardinality and optionality validation and alignment of instance data to specified enumerations (e.g., ensuring that a medication is in the medication value set specified by the FHIR resource definition) are examples of rules encoded into these services.

Provenance services add additional information to the data set that helps specifies and tracks core attribution information (i.e., who, what, when, why and where aspects). It is important to know where the data in a FHIR resource was sourced from and what transformations, translations or other manipulations occurred during the data processing pipeline.

**Knowledge services:** Knowledge services include a clinical decision support (CDS) service that internally uses the “CDS Hooks” enabled knowledge engines leading knowledge providers including HarmonIQs ClinIQ knowledge management product, Motive’s clinical decision product and Medical Algorithm’s library of calculators and other health-care-related computations. It is important for HealthConcourse to integrate multiple knowledge providers to address the large and ever growing volume of medical knowledge in the health care industry – It’s estimated that by 2020, medical knowledge will double every 73 days. As data passes through the pipeline, it is evaluated against the rules in the knowledge engines of these solutions. When the criteria of a rule are satisfied, a CDS suggestion or information card is returned that is then packaged into a GuidanceResponse FHIR resource and added to the integrated data set in OHC. Unlike most CDS Hooks implementations, HealthConcourse does not maintain a synchronous session with an end-user who would normally be the recipient of a CDS suggestion. As such, CDS suggestions are cached in OHC until a system of engagement requests the data.

Another knowledge service is our clinical quality measure (CQM) service. This service uses the HarmonIQs CQF-Ruler product to calculate clinical quality measures. Patient data in the pipeline is passed to this service and used to calculate the metrics. The outcomes of each clinical quality measure are stored in a MeasureReport FHIR resource and added into the integrated data set. An example outcome of this feature is the ability to determine if a patient should be in the cohort of people needing a colorectal screen (the “denominator”) and if they actually received a recent colorectal screen (the “numerator”). This kind of information can identify gaps of care or be used to create reports cards for a patient’s state of health.

Knowledge services can also be realized as an implementation of business rules that provide value-add services to the data set. For example, HealthConcourse includes a record deduplication service that routinely compares the content of comparable records for a patient and algorithmically identifies and flags potential duplicates. As more data is integrated for a patient from multiple systems of records, the potential for data duplication increases which adds unnecessary complexity and “noise” to the data set. Other examples of value-add knowledge services targeted for future development include data reconciliation services (e.g., medical reconciliation), record linking services (e.g., identifying all the encounters that make up a larger condition based episode of care) and record semantic services (e.g., defining non-obvious relationships between records based on ontologies and knowledge bases).

**Business services:** Business services are an emerging area within HealthConcourse. Our first set of business services target care planning and coordination and include a care plan management service that understands how to organize data and logic relevant for a care plan and how to manage the lifecycle of care plans as they are executed, changed and extended by the care team members. Notification services and subscription services are part of this solution, allowing the care planning service to communicate across the care team members, including the patient.

Additional business services will be added to HealthConcourse opportunistically based on high priority customer and industry use cases.
Data utilization services: Data utilization includes query support, consent management and data visualization capabilities. OHC has an internal FHIR server that provides APIs and supports queries conformant with the FHIR STU 3 specification. Additionally, HealthConcourse is integrated with the Microsoft FHIR server managed service providing an additional data utilization layer on top of the HealthConcourse data cache. The Microsoft FHIR server managed service runs on Azure and comes with the benefits of automated monitoring, security and scalability.

Built into the OHC FHIR server is our consent management solution that evaluates the sensitivity metadata tags added during the data enhancement activities against consent provisions defined in the consent FHIR resources. These consent FHIR resources are created by our consent management user interface (details below in the systems of engagement section) and are stored and managed by our consent authority service. The consent authority service is deployed on blockchain. Managing consent records is an excellent use case for blockchain[8] as consent records need to be universally accessed by all points of care for a patient, need to be decentralized with a distributed ledger and need to be immutable except by the approved consent management user interface.

Kibana provides data visualization services for lightweight analytics. These visualization services augment, but do not replace, the computationally-intensive analytics supported by the data lake (see data management service for details).

Data access services: At the end of the data processing pipeline are the API management services and security services. API managers manage outside access to the APIs and provide authentication and authorization security features. HealthConcourse APIs have been shown to work with two different API managers to demonstrate the portability and lack of vendor lock-in of these APIs. First, the APIs were managed by the IBM API Connect solution. Later on, the APIs were migrated to the Microsoft API Manager product. MS API Manager provides a rich developer portal for accessing documentation and learning about how to connect, authenticate and use the HealthConcourse APIs. We use OAuth-based security controls for authentication and authorization.

Data access services also include solutions for encrypting data in motion. Perspecta’s SecureIO product sets up a security gateway that encrypts data between the HealthConcourse server and the systems of engagement. This has demonstrated with mobile apps leveraging the SecureIO mobile app service that encrypts all data communicated with the mobile device with TLS (transport layer security).

Data management services: The data management layer is a cross-cutting set of services leveraging capabilities embedded within OHC and Microsoft data management products. Cassandra is used as a no-SQL database to cache FHIR resources as JSON objects. Elastic Search is used to aggregate and index the data for rapid retrieval within this cache. OHC’s Viaduct component includes mechanisms to update the cache on demand or on a scheduled job. Caching is preferred for transactional queries from the systems of engagement; however, caching data as FHIR resources is not optimized for computationally-intensive analytics. As such, HealthConcourse leverages Microsoft’s data lake within their business intelligence services to recast the data in a form more amenable to complex analytics. The machine learning used to create our “patient like me” dashboard (described below as systems of engagement) is an example of leveraging a data lake strategy.

Orchestration services: Orchestration is conducted by the highly configurable Viaduct component of OHC. Viaduct has an internal scripting language with a graphical editor allowing developers to design custom orchestration workflows that navigate OHC components, custom scripts and external services. This capability is critical for HealthConcourse's platform-based approach whereby third party solutions are encapsulated, interfaced through standards-based APIs and inserted into the data processing pipeline and other important workflows.

Context services: Context services allow HealthConcourse and other implementations of the DHP reference architecture to understand the events occurring in the environment in which they are deployed. Context services allow HealthConcourse to operate in an event-driven architecture, which is necessary to make HealthConcourse predictive, aware and responsive of the run-time environment. The critical component is the Apache Kafka framework for a highly scalable management of a publish-and-subscribe (pub/sub) capability. Pub/sub is used to define topics that event-listeners subscribe to and event-publishers publish events to. When an event is published, event-listeners are notified and can act accordingly. HealthConcourse is both an event publisher and listener. As an event listener, HealthConcourse can survey the business and data events and take action proactively. For instance, a business event like a patient admission can trigger curation of data and knowledge services within HealthConcourse that are appropriate for the patient’s chief complaint and knowledge of the clinical workflows that likely ensue after admission. Likewise, when a data event is posted such as the recording of a new observation or availability of a new lab result within a source system, HealthConcourse can be triggered to refresh the data cache and retrieve and evaluate the new information.

Another key component leverage at this layer are business process models (BMP) and BMP engines. BMPs define process and activity workflows in a computable way that can be ingested and executed in a BMP engine. As activities, tasks and decisions are encountered within the instrumented workflow, events are risen and published on the pub/sub framework.

HealthConcourse demo environment: systems of record and systems of engagement

The HealthConcourse demo environment includes data from a variety of sources. Specific EMR systems were chosen for integration because they are representative of those used by the VHA and the Defense Health Agency (DHA). The Veterans Health Information
The systems of engagement layer includes several user-interface applications and platforms developed by Perspecta. These include:

- The demo environment includes several running instances of VistA to recreate some of VA’s environmental complexity around managing multiple, parallel VistA systems. Some of these VistA systems are accessed directly through VistA RPCs (remote procedure calls) and other instances are accessed via the InterSystems HealthShare platform—the preferred technology for managing VistA data access for the VA going forward. In addition, an Allscripts “sandbox” is included as it represents the kind of EMR system that active military patients or veteran patients may encounter when they receive care from private care providers. Some of the data loaded into VistA is synthetic health data generated from the Synthea synthetic data generator created by the MITRE Corporation[9]. This gives us a rich and robust data set to work with without breaching patient privacy or incurring security concerns.

The demo environment also includes patient-generated data captured through a patient facing portal developed by DXC Technology, data from medical devices (both consumer devices like Fitbits and home telehealth devices accessed through the CareInnovations Health Harmony platform), and data collected through health assessments. To further demonstrate the power of natural language processing, we trained the Google Home personal assistant to ask the questions defined in health assessments. Dictated answers were turned into text and acquired via the Google APIs into HealthConcourse.

Integrating with multiple EMRs, patient sources and devices allows us to recreate two important business challenges facing health care delivery today:

1. A patient is seen by multiple providers in different organizations (e.g., VHA, DHA and private practitioners) each using different EMR products.
2. A patient also collects data via portals, mobile apps, home telehealth instruments of consumer devices that occur outside an EMR-managed encounter with a health care provider.

The demo environment also includes several systems of engagement sitting on top of HealthConcourse. The objective of these systems is to demonstrate how HealthConcourse supports multiple use cases implemented by an array of apps and platforms developed by different companies and developers. This is possible when the apps share a common set of data requirements and have the ability to access this data through standards-based APIs.

The systems of engagement layer includes several user-interface applications and platforms developed by Perspecta. These include:

1. A general-purpose EHR viewer – The EHR viewer enables users to see the aggregated, standardized and enriched data for a select patient via the FHIR APIs. The EHR viewer shows the core clinical and demographic data obtained from the systems of record as well as the inferred data derived from evaluating the source data with knowledge bases added into the data processing pipeline.
2. A patient-facing medical record navigator (based on FHIR resource graphs) – The record navigator allows a patient to explore their medical record following the semantic links inherent in the FHIR resources. For instance, the interface enables the user to navigate the pathway from the patient resource to the associated encounter resources and to the associated medication, allergy, condition or other medical resources.
3. A consent manager app – The consent manager is used to manage patient-consent provisions and generate FHIR consent resources. The consent resources are stored and managed by our consent authority service deployed on our blockchain network.
4. A population and disease dashboard – The dashboards visualize data aggregated across the entire population to reveal population characteristics and disease profiles.
5. Machine learning dashboards – Examples include a “patients like me” dashboard that auto discovers patient cohorts through machine learning algorithms and a “diabetes prediction” dashboard that uses machine learning to stratify a population of patients into low, medium and high risk cohorts.

From our partners, we integrated four SMART-on-FHIR apps and one additional app that is not based on the SMART-on-FHIR specification. The four SMART-on-FHIR apps include PatientAide from DXC Technology, Diabetes+Me from Rimidi, Our CareHub from Expanded Apps and Fluidity Health and Cerner’s implementation of the ASCVD (atherosclerotic cardiovascular disease) risk calculator based on medical logic from the College of Cardiology[10]. These apps leverage the clinical data accessed from the variety of systems of record and provided via the HealthConcourse APIs. For the Cerner ASCVD SMART-on-FHIR app, the required patient data is captured via the Google Home Assistant using our voice dictation solution to capture patient’s answer to health questions. Cerner’s ASCVD app is embedded in the Perspecta EHR Viewer so that the ASCVD assessment data, calculated risks and data visualizations are seamlessly integrated as the presentation layer to reduce the cognitive burden on the end users. Care Innovations’ care-management application, Maestro, is also populated with our data, but it accesses HealthConcourse data via its own middleware platform called Health Harmony. With Health Harmony, we demonstrate the ability to support platform-to-platform data exchange as another pattern for harnessing DHP-mediated data.
A coalition of partners

Developing the many services and capabilities within HealthConcourse requires a coalition of partners with a variety of products aligned to the needs of the HealthConcourse reference architecture. Our partners and collaborators represent a thriving and evolving community of organizations that are collectively innovating within the Perspecta development lab.

Figure 5. Our primary partners

We also value the contributions of organizations indirectly involved through their contribution of open source software or developer sandboxes that we have interfaced with including Cerner, Allscripts, Google, AWS, Validic and Fitbit.

References

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