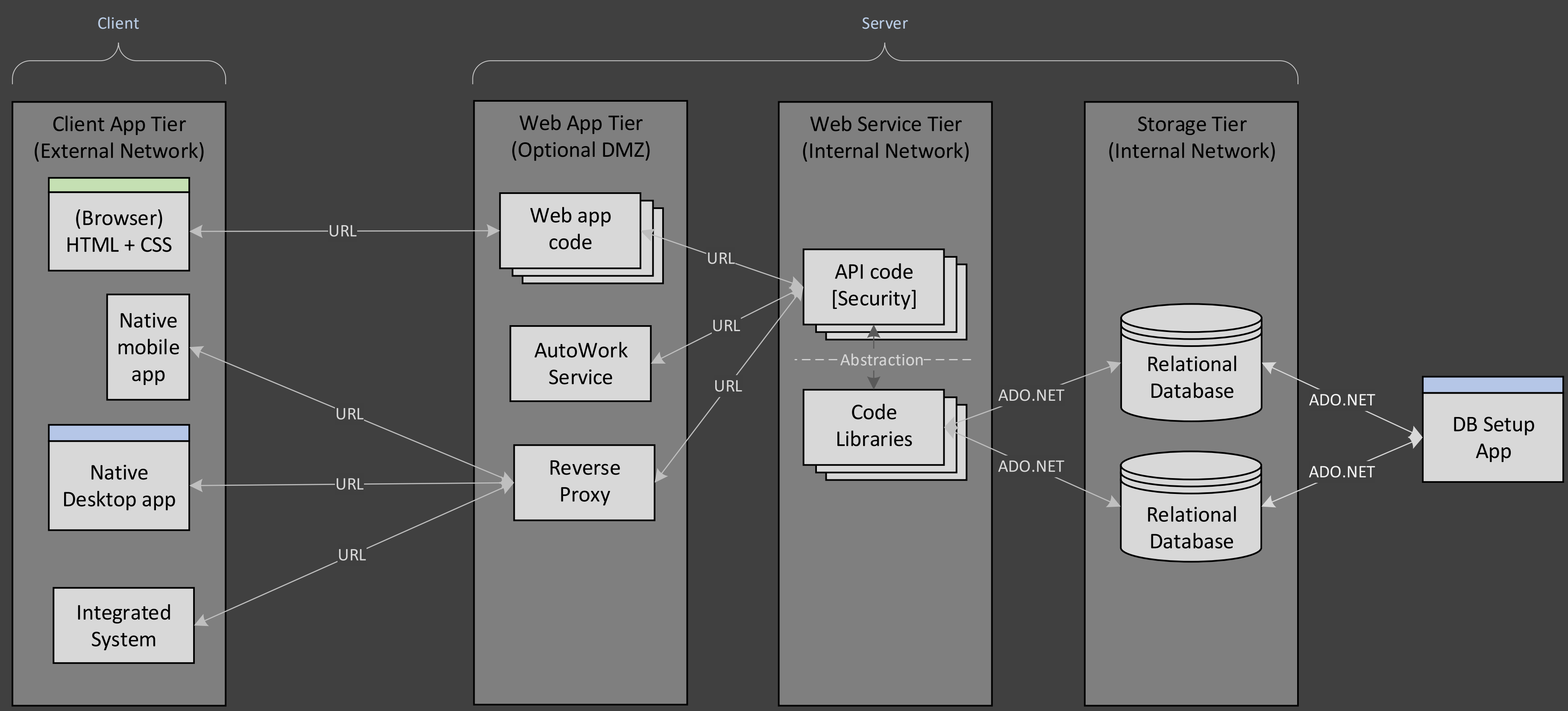
Modular Multi-tier Architecture



DGP uses a modular multi-tiered architecture that represents an optimal middle ground between the simplicity of a monolithic architecture and the scalability/complexity of a micro-services architecture. The multi-tier architecture is able to scale up and out to levels beyond the needs of almost all businesses, while also being able to collocate all of the tiers onto a single computer at the smallest scale. Systems will generally start out as a single computer in each distributed location and only add more processing nodes, storage nodes and infrastructure to each location if and when it is needed to accommodate the growth of the system.

From a high level it is a two-tier client/server architecture that consolidates as much of the logic as possible into the server tier, which act as the hub in a hub-and-spoke topology. Logically the server has two tiers, one for processing work (web services) and the other for data storage (database servers). The DMZ is an optional physical tier added primarily for network security, so the real hub of the entire system are the web service API's and the reusable libraries of code that are behind them.

Each tier is logically isolated from its adjacent tiers, and only communicate with the others using various types of RPC. This isolation allows each tier to evolve and scale independently of its adjacent tiers, adding new features and functionality on its own timeline. Another important aspect of this architecture is that all of the RPC's are IO bound. This allows for the very efficient use of thread pool threads, managed by the Task Parallel Library, combined with IO completion ports – all of which are managed automatically for a DGP system by the .NET Framework CLR itself.

Virtually all of the functionality, along with all of the data in DGP systems are consolidated in the server tier. This provides several advantages:

1. Keeping all of the logic and data in the secure server tiers greatly improves the overall security of the system. This is especially true for sensitive data that never needs to be transported outside of the centralized and well protected server tiers.
2. Client applications can be built much more quickly and at a lower cost, since the client apps themselves contain little or no logic and are just a presentation layer (thin client). This also makes testing the client apps faster and easier as well.
3. Thin client applications are able to run very well on low-powered devices with limited bandwidth, since client applications only need to collect input data from users and display finished results of the server-side work to the users (one page at a time thanks to the server-side pagination).
4. It is much easier to test, debug and fix centralized functionality compared to logic distributed into remote applications.
5. It is much easier to maintain and deploy centralized web services compared to installing/updating remote applications.

The primary problem for this type of centralized functionality will usually be the slow responsiveness of applications that must call remote servers for every UI action. In fact, this type of centralized architecture is only feasible when the web service API's that are being called are extremely fast. Fortunately, DGP web services focus on high performance and efficiency, and those capabilities enable the use of this type of centralized architecture.

The minimum standard for UI performance is that *a UI must display the results of every action and also be fully interactive in less than one second.* A practical example would be: when a user clicks a button in the UI, the application responds by displaying a new screen of data, and after displaying the data the app is then ready to immediately respond to the next user action – all in less than a second.

The reasons why one second is the important threshold are explained very well in this video from a Google engineer responsible for mobile and web app performance: https://www.youtube.com/watch?v=Il4swGfTOSM. These performance standards are applicable to all types of applications, whether they are web, native, or mobile.

One second is the upper limit of the performance standard, but faster performance will further increase the scalability of a system, improve the user experience, and also further reduce costs. So overall, faster is better (subject to eventual diminishing returns).

Client Application Functionality

- Maintain User State (values cached temporarily in memory)
    - Endpoint URL's selected by the user
    - UserName and Password input by the user in the Connect screen
    - Authenticate the server response returned by the Login method
    - Web service information returned by the Login method
    - Pagination information per UI module
    - Encryption keys needed for end-to-end encryption of file content (received from the server)

- HMAC Hash Authentication
    - Create HMAC Hash Values used to Authenticate the Client App to the Server
    - Verify HMAC Hash Values used to Authenticate the Server to the Client App*

- Create API Request Messages
    - Create properly formatted API request messages (XML fragment)
    - Use the PGP-style hybrid cryptosystem to encrypt request messages and decrypt response messages
    - Use HTTP/HTTPS to POST API request messages to the web service API endpoint

The API request messages are limited to a maximum of 64K in size by the.NET XML reader in order to insure that the request messages will remain below the .NET 85,000 byte limit and not end up being stored in the LOH.

<u>API Request Message</u>

```
<ReqMsg>
  <UserName />                 - DGP system account name
  <ReqID />                    - unique ID created by the client app for each request message, and echoed back in the response
  <ReqToken />                 - HMAC hash of the Time value using the account password as the secret key
  <Time />                     - UTC Unix time of the request for the TTL check and the HMAC hash authentication to the server
  <MList>                      - a collection of one or more API methods to be called
    <Meth>
      <MName />                - the name of the API method being called
      <PList>                  - a collection of zero or more input parameters for the API method
        <Prm>                  - name/value pairs for each input parameter
          <Name />                          - the name of the input parameter for the API method
          <Val><![CDATA[ … ]]></Val>        - each input parameter value is encapsulated within a CDATA block
        </Prm>
      </PList>
    </Meth>
  </MList>
</ReqMsg>
```

- Read API Response Messages
    - Accept HTTP/HTTPS response from the web service endpoint
    - Read properly formatted API response messages (XML fragment)

The API response messages are limited to a maximum of 64K in size by the.NET XML reader in order to insure that the response messages will remain below the .NET 85,000 byte limit and not end up being stored in the LOH. Limiting the size of the response messages depends on the server-side pagination of tabular data.

<u>API Response Message</u>

```
<RespMsg>
  <UserName />                  - DGP system account name
  <ReqID />                     - unique ID created by the client app for each request message, and echoed back in the response
  <Time />                      - UTC Unix time of the response
  <Auth />                      - state of the request message authentication (OK, NoMatch, Expired, Disabled, Error, Exception)
  <Info />                      - optional information regarding Auth states other than OK
  <SvrMS />                     - the time spent on the server executing all of the API method calls in the request message batch
  <MethCount />                 - the number of methods called in the request message batch
  <RList>                       - a variable collection of one or more API method results
    <Result>
      <RName />                 - the name of the method result, used by the client to match results to method calls
      <RCode />                 - code indicating the state of the method result (OK, Empty, Error, Exception)
      <DType />                 - the data type of the result value (Int, Num, Text, DateTime, XML, JSON, DataTable)
      <RVal><![CDATA[ … ]]></Val>             - each return value is encapsulated within a CDATA block
    </Result>
  </RList>
</RespMsg>
```

- UI Feature Toggles
    - Application functionality enabled/disabled based on the web service version
    - Application functionality enabled/disabled based on user account role membership
    - Automated functionality enabled/disabled based on role membership, such as Remote Monitoring

In the UI, the effects of the feature toggles are applied when customizing the navigation menu. First, menu items are shown or hidden based on the role membership of the user account. Second, each section of the UI also has its own minimum web service version (which is a date value). Certain sections of an application may require functionality from newer versions of the web service. If a user connects to an older web service that has not been updated, the sections that require a newer version would not be displayed even if the account was authorized to use them.

- Error Handling and Logging
    - Logging to the local Event Viewer
        - All errors and exceptions are first written to the Event Viewer on the computer where they occurred
    - Logging to central database tables
        - All errors and exceptions are also written to the DGPErrors table in the SysMetrics database
        - When external, they are written by calling a web service API method (RemoteErrLog)
        - When internal, they are written by calling a data access method (ServerErrLog)
        - Errors and exceptions that may occur while writing to the SysMetrics database are themselves written to the local Event Viewer

Optional Functionality

- Remote Monitoring
    - Performance metrics for all of the major sections of the UI are displayed in the status bar for users to observe for all environments of a system (especially useful in production environments).

- For members of the RemoteMonitor role, the performance metrics (plus some other useful information) is saved to the LatticeMetrics table of the SysMetrics database.
- Lattice users are able to verify the functionality of both logging to the local Event Viewer and logging to the centralized database table using the "Test Error Logging" menu item in the User menu.
- Users that are members of the Testing role are able to run many end-to-end API test files that test and verify all of the functionality in a system. The test results can optionally be saved to the TestResult table of the SysMetrics database for future analysis.

XML is used for the API request and response messages for the following reasons:

1. Cross Platform Ubiquity
   Structured text messages can be created and read by almost all of the most commonly used programming languages. In addition, almost all of these programming languages have the capability to work with XML already built in, and therefore do not require any 3rd party tools or SDK's in order to create API request messages or read API response messages.
2. CDATA Blocks
   All input parameter and method result values in API messages are enclosed within CDATA blocks, which eliminates the need to escape or encode the data they contain. This allows any type of data to be transported within the messages without breaking the structure of the messages themselves.
3. Memory Stream Reader
   XML provides the ability to read messages as forward-scrolling cursors through a memory stream, eliminating the need for serialization/deserialization of the API messages. This mechanism is approximately 140 times faster than the fastest serialization/deserialization available. It is also the basis for the "tolerant reader" functionality needed by the API Test Harness and other DGP applications.
4. Security
   XML can only contain data, and unlike JSON it is not possible to inject executable instructions into it. In addition, only XML fragments are used for DGP API request and response messages. Almost all of the potential ways to exploit XML security vulnerabilities rely on the XML header (external entity attacks, expansion attacks, exploits for strong data types etc.).

Security

Client applications use TLS to encrypt and secure the API messages sent to and received from the web service API's. Another optional message encryption is available that mimics the hybrid cryptosystem used in PGP, but that only works for native applications.

In general, almost all functionality and data in a system are consolidated and collocated in the server tiers, so the client applications are only used to present data to the user and save data from the user. All security logic and most sensitive data stays on the servers and are not pushed out to each remote client application endpoint. Native apps are immutable compiled binaries and are therefore immune to many types of hacking that inject code into dynamic (interpreted) applications in one way or another. Web applications are not as secure in terms of immutability, but the use of a Server Side Rendering (SSR) architecture and session objects to keep all logic and security data on the web app server helps to significantly improve their security. Native client applications cache the same security data as the web app session object in their own local memory.

Scalability

The "scalability" of a UI mainly refers to its ability to work well and meet all of the performance requirements no matter how much data is stored in a system. This is made possible using two techniques. The first are mechanisms to only work with a small segment of the large sets of data at a time, and the second is good search functionality that is integrated with the segmentation mechanisms. The segmentation of the data is mandated by the 64K limit to the size of API Request and Response messages enforced by the DGP web services. This is done both for performance and security reasons, and it helps to avoid creating objects in the .NET Large Object Heap.

Some examples of this segmentation are the server-side pagination logic used for all of the primary tables in the DGP database schemas. The Search methods implement the pagination using SQL Server Offset Fetch statements. Combined with the Count methods using the same search criteria, the UI screens are able to move forward and backward through large datasets, one page at a time. The number of rows in the pages of data must be adjusted to avoid exceeding the 64K limit for API Request and Response messages.

A second example is the limitation on the maximum number of subfolders allowed in the FileStore application. The folder tree is built incrementally when the user clicks on a parent folder. The list of subfolders in this case is the equivalent of a page of data, and is subject to the same maximum size limitations.

Another type of scalability applies to the application itself. Using a modular architecture for the application allows additional functionality to be added easily over time (as opposed to a monolithic architecture, which is simple to start with but can become increasingly complex over time. This modular architecture consists of a navigation system that loads subsections of an application into the main application screen. Using DGP Lattice as an example, the WinForm subsections are built as user controls which fill the main application screen when displayed by the navigation menus. New user controls can then be added to an application as needed, along with new navigation items to display those subsections.

Performance

The standard for performance is that every user action in a UI must be displayed in a screen and the UI returned to a fully interactive state in less than one second. The performance of the client applications depend greatly on the performance of the web services, since that is the source of all the functionality and data in a DGP system. Native applications are deployed as binary executables, which helps improve their performance rendering screens once the data has been returned from the server. Web applications built using Server-Side Rendering (SSR) require time to call the appropriate web service API's and then build the finished HTML + CSS that incorporates the data from the server. This process must be completed by the web app in 100 MS or less to meet the 1 second overall performance requirement. By default, the browser only needs to render the pre-built HTML + CSS for each screen, which does not require much time. JavaScript libraries can be used to augment the functionality of the HTML + CSS as necessary, but they should be used in a way that does not interfere with the DOM and CSS pipelines in the browser, which otherwise can significantly delay the display of the page.

For both high performance and as the basis for the tolerant reader functionality, DGP applications read the API messages as one-way forward scrolling cursors through the HTTP request/response memory stream. This event-driven technique is roughly 140 times faster than the fastest serialization/deserialization implementations currently available. It is also the basis for the tolerant reader functionality which allows for the evolution of the API messages over time without breaking backward compatibility.

Availability

The availability of a system depends on the redundancy of its production environment locations. By default, there will generally be 3 locations, separated geographically. Native applications use a system list file to keep track of the URL's used to connect to the web services in each of the 3 locations. If a problem occurs with the location they are connected to, they would manually reconnect the native app to the web services in one of the other locations.

Web applications are hosted in each location by default (although they can be hosted outside of a location as needed). If a problem occurs with the location they are using, the user would manually switch their browser to the URL of one of the other locations.

Logging, Metrics and Monitoring

Logging is intended to capture data about events that have occurred in the remote application. This includes exceptions, errors and information. The basic pattern is to log data about the event locally to the Event Viewer, and then call an API method to log the same data to the DGPErrors table of the SysMetrics database. Tools would then monitor the DGPErrors table for the event data to be displayed in real-time dashboards, used for reporting and analytics, etc.

Metrics and monitoring takes a more proactive approach to collecting data about the system in an effort to verify that the system is running correctly and performing well. DGP monitoring consists of collecting end-to-end performance data from production systems under actual workloads during each day. Additional monitoring is actually a specialized type of testing used to collect data about important functionality within a system and save it to the LatticeMetrics table of the SysMetrics database.

API Version Dependencies

The Login method returns the version date of the web service to which it has connected. This version date can be used as a feature toggle in the client application to enable or disable functionality that depends on newer versions of the API's when connecting to older versions of the web services.

The Lattice application is an example of this functionality. It receives the list of user account roles in the response from the Login method, and enables sections of the navigation menus accordingly. The logic to use the role membership as feature toggles also compares the version date of the web service to the minimum date values needed to support that section of the UI, and if the web service is older than that date, it will disable the section even if the user role membership would allow it to be used.

Universal Compatibility

The objective of a universal compatibility approach is to 1) allow any programming language to work with a single "generic" implementation of the web service API's, and 2) eliminate the need to develop and maintain client SDK's for each supported programming language.

Eliminating the need for client SDK's significantly reduces the amount of development and maintenance work for the provider of the API's, shortening delivery times and reducing their total cost. Also, this creates a very clear division between client application functionality and server-side API functionality. This allows the provider of the web service API's to only be responsible for the maintenance of their own server-side code and have no responsibility for any client application code whatsoever. This avoids potentially contentious support situations where the provider of the web services is responsible for the functionality of their SDK's that have been embedded within the code of the client application.

In order to achieve these objectives, a lowest-common-functionality approach is used for the API request and response messages, which are treated as formatted text messages, not as objects. They are not strongly typed, have no static structure, and therefore any of the major programming languages can work with them directly as text to create API request messages and read API response messages. The structure of the messages (XML fragments) is somewhat flexible, and uses a tolerant reader to allow additional elements to be appended in certain areas of the messages without breaking backward compatibility of the messages themselves.