T3.5-P15

xQuake: Distributed Seismic Event Detection Analytics at the Edge

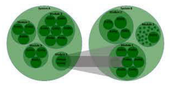
Introspective Systems

Caryl Johnson, Kay Aikin and Harley Benz

CTBT: SCIENCE AND TECHNOLOGY 2017 CONFERENCE

xGraph

The xGraph is a unique paradigm addressing "wicked problems" involving the distributions of scarce resources in high dimensional decision spaces by attacking such problems as a computational ecosystem of autonomous and adaptive entities. These entities are organized into a fractal graph framework representing systems of systems with entities organized as 'Modules', much as atoms are organized into molecules, which are then organized as autonomous 'Systems' with the fractal nature derived from the concept that 'Systems' themselves can appear as 'Modules' in higher order systems.



The xQuake processing framework is a derivative of a much larger ecosystem of collaborative autonomous 'Systems' as might be found in an industrial or military enterprise, and as such it is designed to be integrated into a much broader scale adaptive enterprise scale architecture. In this paradigm 'Modules' representing waveforms pick themselves, events compete for scarce resources (picks and other data) while calculating their own hypocenters, and catalogs and archives organize themselves as self-organizing criticalities in the context of complexity theory applied to systems of systems. As unfamiliar as these concepts might seem, they are in fact proven in actuality as the framework that was used to implement the GLASS 3.0 associator for the USGS National Earthquake Information Center (NEIC) as discussed in poster T3.5-P7.

xSensor



The xSensor component is an xGraph system component that runs in the processing environment of a remote digital seismograph. Traditionally, such instruments use dedicated public or private internet links or satellite telemetry from the more remote stations to a central analysis center for phase picking and other analytical process. In the xSensor concept, such processing is carried out at the sensor, only metadata (such as event detections) are forward, and seismogram snippets are retrieved only as needed.

xChron



The xChron system is one of two types of major datastores shown in the diagram. The xChron system accepts data objects (JSON format) in arbitrary time order, assigns a unique identifier (GUID), and stores them in a very deep persistent archive. The xChron system also provides two very important output options used in the xQuake implementation. The first is simply to stream the data after an ID is assigned to other xGraph systems, most notably the xGlass associator component. The second service is a demand query for data within a specific time sequence for analysis of historical data.

xEarthworm



Many regional seismic networks, especially those in the international community use a processing framework by the principal author of this poster working with a dedicated team at the USGS facility in Menlo Park, CA in the early '90s. The 'Earthworm' system was based on an original architectural system that was called 'Rings and Things', which itself was the earliest ancestor of the xGraph which now forms the bases of a very similar approach based on modern streaming connected microservices.

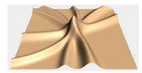
xSnippet

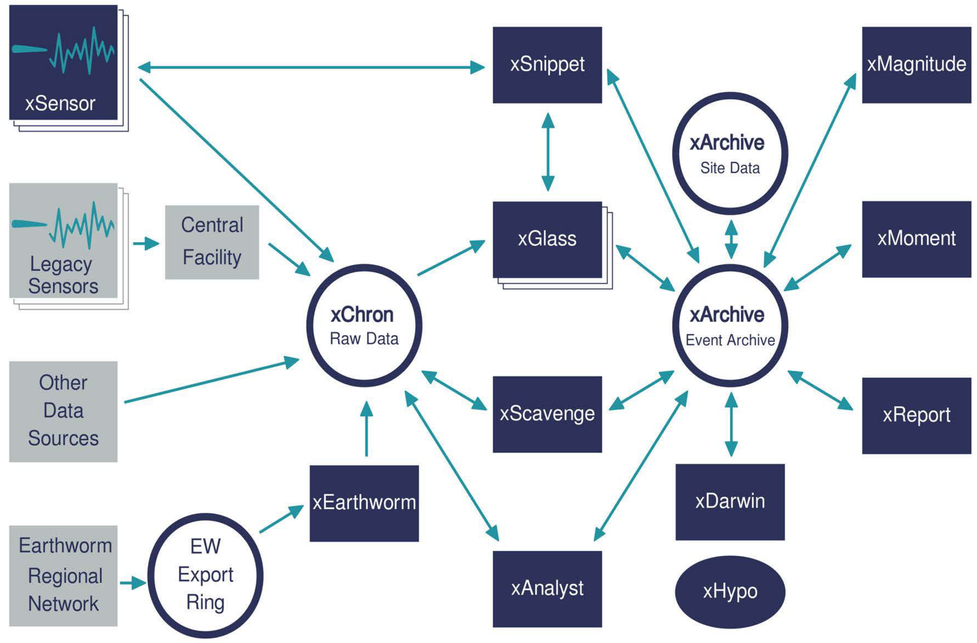


The xSnippet component is actually just a message switch that redirects requests for waveform segments to the appropriate source. Although it appears to 'Systems' that virtualize this component as an active entity in its own right, it actually is just a reflection of a subordinate component that actually performs the waveform segmentation operations.

xGlass

The aggregation of data and the nucleation of a possible new event is the purview of the xGraph modules. There are literally thousands of these distributed in both global as well as regional and local arrays. Each is responsible for the nucleation of event that happen in their vicinity. The process, which is shared by the later xDarwin System is based on kernel stacking of a representation of the Bayesian probability density function (PDF)in a 4D space-time continuum. A 2D horizontal submanifold is shown in the inset where the sum of the PDFs for 5 P-wave arrival times is shown. The nucleation process is based on the method of synthetic annealing (SA), wherein the temperature is related to the data errors. During the SA process, the error is reduced from a value that is commensurate with spacing of the xGlass hypothesis generators to that of the intrinsic errors of the data. Scalability for very large networks is achieved by distributing the xGlass modules over multiple cores. In a very real sense, this approach can be thought of as the logical extension of Richter's string method for calculating epicenter from S-P intervals.





Abstract

Over two decades ago, the Earthworm regional seismic processing system was introduced as a state-or-the-art analytical system for regional seismic event detection and analysis. Today it is still in wide spread use worldwide, despite amazing advances in distributed processing, cloud-based computing, data storage and edge-based analytics. The xQuake system, designed and built by the original architect of Earthworm, incorporates these advances into a plexus of microanalytics with interconnecting streaming hubs (e.g. Apache Kafka brokers), a modern version of Earthworm's "rings and things", with a GPU accelerated browser interface. A centerpiece of xQuake is xGlass, an extension of the GLASS 3.0 global associator developed for the USGS/NEIC providing fusion of multiple sensor types within a 3D GIS context, locally adaptable global travel-time models, and seamless application across teleseismic, regional, and local domains. The foundation for xQuake is the open source xGraph (eXecutable Graph) framework with analytics and database functions designed for the integration of extremely large and complex systems using algorithms drawn from the biomimetic concept of a computational ecosystem, artificial intelligence and complexity theory. The ultimate goal is to migrate analytics to the sensors themselves (the edge) in a truly distributed and adaptive System of Sensor Systems (SoSS) framework.

xArchive



The xArchive is the second form of deep, adaptive storage used in the construction of the xQuake system of systems. Its primary purpose is to provide permanent archiving of events once the analytics is completed. An object in the xQuake application of the xArchive system comprises all of the information for an event including hypocenter, ancillary derived data (magnitudes, moments, etc), as well as snippets of waveforms that were retrieved during the analytical processes. The xArchive component is similar to the xChron in that it archives information in time sequence, but it differs in several important ways. Most importantly, as analysis proceeds, it retains a linked list of evolving versions in reverse time. Further, it also maintains an index of the most recent version of each event, something that is generally referred to as an Earthquake or Event catalog, which can be queried using temporal interval queries. Both the xSites and xEvents systems are examples of this component, each maintaining a complete record of changes.

xDarwin



During the nucleation process engaged by the thousands of xGlass entities comprising the may globalized or localized detection arrays, a very large number of hypocenters (xHypo) are nucleated. Eventually, all of these must coalesce into single entities such that a minimum number represents the a definitive event catalog. This process is facilitated by the xDarwin System, which is essentially a competition broker between pairs of hypocenters. The approach is one of evolutionary programming, where two hypocenters compete for the scarce resource, the data, under the constraint that in the end there can be only one, and no two events can share the same datum. In the diagram, an event can be thought of as a spider with many legs, each representing a datum. The process of allocating data between individual entities is euphemistically refered to as the 'Dance of the Tarantulas', after am experience the author had at the Goldstone Deep Space antenna while a graduate student. This is precisely the mechanism by which a catalog of unique events merges by the complexity theory process of self-organizing criticalities.

xSite



In the xGraph implementation, a module exists representing every component at every network site. The xSite module maintains current state data for that component, including static parameters such as location and filters and such as well as dynamic state information related to station health and information integrity. The core of this analysis is carried out by assessing noise levels, the number of times a site produces a signal or datum which is not used and the number of times a station should have reported a signal when it did not. This information is then reported to maintenance and operational personnel.

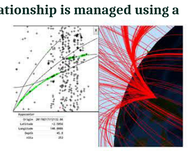
xScavenge



The xScavenge System is an example of an interaction broker. Its role is to constantly monitor incoming data and relate it to existing event in the event archive. Event compete for each datum in a kind of agoric auction process, and the highest offer associates that datum. Eventually, the final resting place of any particular datum is determined by the results of the xDarwin process.

xAnalyst

There are a number of points of interaction between an xGraph framework and the humans that are expected to manage it. All of the human-computer relationship is managed using a browser interface, but the way the visualization is created is totally different than the familiar HTTP approach. Instead of delivering content from a remote server as is the usual case, an xGraph framework essentially extrudes itself into the browsers process as an endogenous System that attaches directly to the DOM. Effectively, the web server is exported to the browser and all of the visualization is created locally with back channel communication in JSON messaging over a dedicated web socket interface. An analyst timing station then is extremely responsive, rendered in 3D, and potentially updated in real-time as additional data or contributions from other analysts are received.



xHypo

Probably one of the more unfamiliar concepts in the xQuake implementation is the idea that events locate themselves. The idea is an extension of the nucleation process used by the xGlass associator modules. The core of the approach is to discover the peak in a stacked kernels representing the probability density function based on reciprocity for each datum. The inset diagram shows this for a 2D submanifold of the 4D time-space solution domain. The stacked kernels constructively interfere at the hypocenter, and the actual location is determined using the Hedgehog algorithm develop by Keillis-Borok to explore and characterize the highly nonlinear PDF kernel stack. Each xHypo calculates its own hypocenter which in turn is used to establish an agoric process that determines the outcome in the xDarwin event evolution process.

