Kwisatz

Enabling Activity Context

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ABSTRACT

Our ability to find digital data is reaching a tipping point: brute force search techniques are inefficient and searching multiple storage locations to find related objects is challenging. Prior research found using contextual clues facilitates finding specific digital objects. Despite modern systems collecting vast amounts of contextual information, our systems do not provide an efficient mechanism for using that information to facilitate more efficient *finding* of digital objects.

Kwisatz is our system for collecting, storing, and disseminating contextual information we call *activity context* to facilitate finding groups of related digital objects regardless of where those objects are stored. We find Kwisatz is a viable way to provide *activity context* and enabling its use by other services and applications.

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1 INTRODUCTION

TM ►*TBD*◄

2 BACKGROUND

TM ►*TBD*◄

3 ARCHITECTURE

Kwisatz is logically composed of three major components, each of which is an essential portion of providing the end-to-end systems level support for capturing, storing, and utilizing *activity data*. Each of these components consists of various smaller components assembled together to provide the necessary services.

In this section, I lay out the basic architecture of these components. In subsequent sections, I will drill down into this architecture and identify key aspects of the system design. In constructing this architecture, I have attempted to broadly address what I consider to be the key aspects of these components, including defining terminology and identifying potential use cases that may be relevant. Frequently, I will suggest potential implementations that would fit within this architecture: there is no expectation that I will implement even a majority of these potential implementations. Rather, the goal of using broad considerations is to assist in ensuring the system architecture is reasonably flexible. Ultimately, my goal is to demonstrate the architecture is itself viable as a system service.

- **Ingestion** — the activity data that are presented by various services within the system needs to support a rich and robust model in which captured data may be converted into a common form that permits utilization. §3.1

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Figure 1: *Kwisatz* Architecture Diagram TODO

- **Storage** — raw activity data, along with extrapolated activity meta-data, need to be stored in a format that is scalable and efficient as well as supporting a robust utilization model. §3.2
- **Utilization** — to realize the benefits of activity data, the system must have a useful model for using the activity data. §3.3

3.1 Ingestion

Activity data can arise from a variety of sources. For example, because my primary focus is on utilizing activity data to better inform logical data organization, I view data storage as being a key source of such information. Indeed, much of the prior work in this area has focused on utilizing information about data, including:

- **File Names** — the *file name* is a time honored way to embed information about the file itself. For example, in *Burrito* [106] the observation is that we capture parameter information within the file name. This is because it is the *only* way to safely capture this information in a way that is broadly viable across file systems.
- **Extended Attributes** — the *extended attribute* is a mechanism that provided a way for applications to create additional meta-data using an attribute/key model [197]. File systems that support extended attributes maintain them as meta-data of the file itself. Unfortunately, extended attributes suffer from two limitations: (1) file systems that do support them provide no mechanism for associating files based upon the extended attributes; (2) there is no uniform support or implementation of extended attributes.
- **File Meta-data** — most file systems support at least a minimal subset of meta-data elements, specifically timestamps and size. There is a lack of uniformity of other attributes: POSIX file systems typically support "mode" bits that represent access permissions as well as potentially other behaviors, as well as an access time, modification time, and change time. Creation timestamps are often maintained by file systems as well. A number of UNIX-like file systems maintain a creation timestamp. Windows includes the *creation* time of the file and that has been adopted by a number of UNIX-derived file systems, including ext4, jfs, and btrfs. Recent changes in Linux include a new system call, **statx** that permits applications to retrieve this information programmatically.
- **Directories** — the traditional hierarchical file system provides a mechanism for composing groups of files into a *directory*, which is a set of files. Some file systems restrict a file to being a member of a single directory, while others allow a

file to be a member of multiple directories. The Mutics file system included the ability to create links to files. Modern file systems may implement links as either direct references from the directory to the file ("hard links") or indirect references from an entry in the directory to the file ("soft links.") They have somewhat different semantics.

Views — in semantic file systems [95] there is less emphasis on reference counted relationships (e.g., hard links) or even persistence and more emphasis on creating logical groups ("virtual directories") of files based upon some criteria.

Kwisatz does not seek to *replace* any of these existing file storage mechanisms. Instead, it focuses on providing rich support for meta-data *about* digital objects, which includes files but should not be limited strictly to files.

Meta-data is not strictly limited to the data that is available from the file system itself. Further, meta-data may be about digital objects that *existed* at some point in time but no longer exist: this is a reality of separating the storage from the meta-data service. Instead of focusing on maintaining a strongly referenced model, I instead adopt the model of the Internet, which means that meta-data may reference digital objects that no longer exist. Applications that use *Kwisatz* should be aware that the underlying data could cease to exist and act accordingly.

Other potential sources of meta-data are quite broad and include:

Semantic transducers — the term *transducer* was first introduced as part of semantic file systems [95]. The basic idea was that active components would *extract* semantic information from the contents of a file and then use it for indexing. Indeed, modern indexers work on this basic principle, without making any changes to the file system.

Content classifiers — one common use for machine learning is to identify the content of specific files, such as images or videos, to determine if the given file contains specific content: a cat, for example. Such classifiers can be more targeted, such as finding pictures of a specific person, or containing a *particular* cat. This information can then be used to cluster files together, such as the "video reels" that some service providers now give us on our personal devices.

Hashing — a *hash* can be computed on a given file to determine if the contents of said file has changed. For example, this can be used by "cloud storage" providers to determine if a given file has already been uploaded. Hashing can also be used to determine when files have changed.

Metrics — one common approach to information is to establish the logical proximity of the files, whether based upon the *content* of the file, or the *meta-data* of the file. For example, plagiarism tools like MOSS look for structural similarity (versus simpler textual similarity) by comparing the abstract syntax trees of code. This generates a measure of similarity. The *value* of the metric is not material to this project, but the *use* of metrics is because it allows us to create a logical distance between the objects. This can, in turn, be used to *cluster* objects that are "close to" each other.

Environment — our devices maintain multiple sources of environmental information. For example, location information (*GIS*) identifies where a device is located at a given time. Increasingly, our devices track other aspects of the environment, including the ambient temperature, our vital measurements such as heart rate and blood pressure, and even more detailed health information including data from pace makers, insulin pumps, and menstrual cycle trackers. The data from these is likely useful in creating associations between extrinsic events and human storage usage.

Social — our devices routinely track our social activity: with whom we are interacting via text, chat, e-mail, and video call, for example. Frequently, as part of this we share information — information that is subsequently stored, modified, and re-shared onwards. This type of activity data can be used to help us identify where information came from, what other digital objects were accessed as a result, and establishing data relationships based upon usage patterns. Web sites visited, Reddit posts liked, Discord messages exchanged, music listened to, purchases made, and even games played can all be used to construct associative relationships that make sense to human users.

In general, activity data can be *intrinsic* to the digital object, such as information based upon its semantic content, it's length, and contents as well as *extrinsic* to the digital object, such as what applications were used to access it, where things were done, with whom, etc. The *Kwisatz* architecture is influenced by my desire to ensure support for a broad range of activity data sources.

In §4 I delve into greater detail about handling activity data.

3.2 Storage

The choice of storage models, while important, is unlikely to give rise to significant research questions at this juncture: as we begin to understand the nature of the activity data we anticipate collecting, it is distinctly possible that new challenges will emerge. However, we have an extensive body of knowledge on how to handle high data rates ("drinking from the fire hose") as well as scaling approaches for managing potentially large bodies of data.

Thus, while the architecture is fairly neutral with respect to the details here, I anticipate the initial implementation of this will utilize "reasonable" limitations on activity data sources (e.g., curation to avoid excessive data loads).

An important aspect of the architecture is to propose a model for the data format that I propose using. This data format must be able to:

- Identify the *source* of the activity data. This permits interpretation of the captured data by any transducer familiar with the data generated by the given source.
- Specify the *version* of the activity data. My own review of numerous data sources suggests that it is common for many of them to change the format of the data over time; typically this *extends* the data format (common for systems-related activity data sources, for example) but sometimes it involves significant restructuring of the data that is available (common for web-based activity data sources.) By including a version, a transducer can determine if it understand the format of this data and permits evolution.
- Provide an ordering of the activity data. Typically this would be a "timestamp," though there is no reason this

needs to be a timestamp relative to any other data source. Further, when there are multiple providers of information, the interpretation of this Lamport clock is ultimately determined by the transducer. This *allows* both system relative and universal clocks but does not dictate their presence nor disallow clocks that are shared between activity data providers.

- A list of *attributes*. These are in the format of "extended attributes," with both an identifier as well as a value. This permits attributes that can be the same across sources, as well as allow the same "attribute" to have different meanings for different sources. This is neither required nor prohibited within the *Kwisatz* architecture. This ability provides very broad support for activity data, as well as *post hoc* supplementation by transducers.
- The *raw data* originally captured by the activity data provider. This allows the capture of information without requiring interpretation at the time it is captured. In cases where there is no additional raw data, this can remain empty. Note that this is *not* anticipated as being an area in which to store the digital object's data.

As a concrete example, I have implemented an activity data provider that scans and captures the change data from the NTFS USN Journal on a Windows 11 computer. The raw data is captured, and then certain elements of the data can be augmented. For instance, the raw data provides a *file id* that is used to obtain the name of the file. Similarly, the raw data also provides a *directory id* that is used to obtain the path of the containing directory. This is relative to the NTFS volume (which does *not* include a drive letter.) Thus, the transducer for this can utilize the *volume id* to map to the current drive letter, making this name available for ordinary Windows applications (which tend to use drive letters, even though they aren't visible to the NTFS file system controlling a given volume.)

Subsequent to this, I envision a separate transducer that can be used to compute the hash value of the file's contents. That hash value could then be incorporated into the attributes list of the corresponding change journal record (assuming the file has not changed by the time the hash value has been computed, of course.)

This data format can then be easily captured as a JSON expression, which can then be used to store the relevant data in a database (e.g., DynamoDB or MongoDB, for example.) This decouples the specific details of how the data is stored from the format required of the data gathering elements.

I discuss this in greater detail in §5.

3.3 Utilization

It is essential to have a model for utilizing activity data in order to realize its potential. The *Kwisatz* architecture is generalized with an eye towards permitting a range of potential use cases.

Underlying the structure of the data are elements that I anticipate will be used to establish relationships. For example, the *metric* concept described earlier (§3.1) naturally fits with data clustering mechanisms. This is consistent with a *graph* representation in which the edges correspond to some relationship and the weight of the edge corresponds to a metric. Similarly, it can be useful to add labels to the data, in order to understand specific characteristics of that information. The emphasis on using graph modeled storage (§3.2) is also consistent with this. Thus, the logical way to utilize this information is to focus on exploiting the inherent graph structure of the data.

Given this model of exploring graph data, it makes sense to then consider using an existing graph query language — reserving the right to limit its use to some subset as part of the exploratory work I am doing. One motivation for this would be that such languages *already* work with commonly used graph databases and thus leverage prior work in using graph structured information effectively.

I discuss this in greater detail in §6.

4 INGESTION

There is no single mechanism for retrieving activity data because each source for such data provides it in multiple different ways. Thus, for the purposes of our analysis we found it useful to categorize data sources based upon how we retrieved the information. Thus, one of the jobs of an ingestion agent is to retrieve the data and then put it into our common format, which will permit us to use that information for subsequent processing and analysis.

4.1 Models

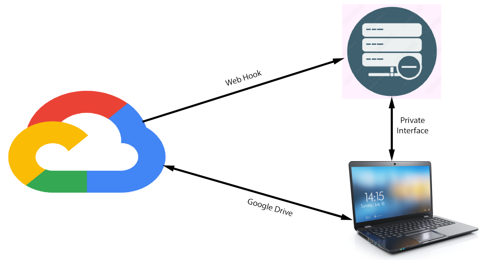
In our work we have found multiple ways that activity data can be retrieved:

Systems API — one common approach for retrieving activity data is via an operating system defined application programming interface (API). For example, the eBPF mechanism commonly found in several operating systems represents a general mechanism for retrieving activity data from a variety of sources. To that extent it provides a general extensible framework for activity data, with the format of the data being returned dependent upon its source. Similarly Microsoft Windows has an operating system mechanism known as *Event Tracing for Windows* that is used extensively by Microsoft to provide detailed activity data for essentially all portions of their operating system. A more focused interface on Windows is the USN Journal, which is supported by the NTFS file system. Each of these provides a specific interface for retrieving data that is directly visible to the local system.

Web APIs — another common approach is to provide web interfaces to service providers that can be used to retrieve information, including activity data. Such web APIs may be directly accessible on the local system or may involve contacting a remote service provider. In each of these cases an agent can capture this data and store the relevant activity data in our common database. The specific details of the web API vary by provider. For example, the Dropbox service on a local system supports querying for changes via a web API against the local system. The Github API includes the ability to query for events on a polling basis.

Web hooks — some web services do not provide a direct event query interface and instead require creation of an intermediate agent via a registered web hook. In such a case, the web service provider is given the address of a distinct publicly available web service which is invoked

Figure 2: Google Drive API Web Hook



periodically with event information. Because the web hook must be publicly available an agent collecting data from such a service requires both a local agent on the machine where the activity data is being recorded as well as a public agent on an internet facing public machine.

Manual Scanning — some services do not provide any simple mechanism for detecting activity data directly. In such a case it is possible to construct an activity agent that manually scans for changes. One example if this would be the *rclone* facility which uses brute force scanning of a storage location to determine "what has changed" and then uses that information to synchronize copies of that data on a secondary copy. While simple, this approach is well-known and can be used when building a activity data gathering agent.

These various techniques are all *possible* but have potentially radically different performance characteristics that may limit their utility. Thus, we wanted to construct at least one example of each in order to better understand the viability of using activity data collection agents for each of these classes of service.

In some cases we found it was possible to create indirect monitoring mechanisms. For example, one service we commonly use — *Overleaf* — does not have a web monitoring API. However, it *does* integrate with Github repositories and thus we can simulate tracking Overleaf change data by using the Github APIs.

Another approach, which we did not explore for this work, would be to use API aggregation services such as Zappier. Such aggregation sites combine web APIs and may be a fruitful way to extract additional activity data from a broad range of sources.

We chose a single example of each of these types of activity data retrieval. This allows us to explore the space broadly and gain further insight into the viability of using such sources.

- For our systems API example we chose to use the Update Sequence Number (USN) Journal support provided by the NTFS File system in Windows [120]. This system provides a curated view of file system activity on drives where the USN journal has been enabled. By default the USN journal is enabled on the system drive and may be optionally enabled on other drives. This is a publicly documented API, has good performance, and provides a curated level of information that provides benefit without being "too broad."
- For our Web API example we use the Dropbox cloud storage system. This relies upon a local service on a specific computer. This service can be used to monitor activity on the Dropbox system. We used a standard Dropbox installation on Windows, Version 154.4.5353. TM ►*Add citation for Dropbox?*◄
- For our Web Hook example we use the Google Drive API. To do this we constructed a public facing web service that we could register with Google to receive changes (the "web hook"). We also constructed a local service that could run on a desktop computer to obtain the necessary credentials and provide them to Google as well as gather up data from our public facing web service. We show a simple diagram of this arrangement in Figure 2. Our implementation was simple and relied upon pre-installed certificates between client and webhook to provide cross-system authentication.
- For our manual scanning example, we chose to use TM ►*TBD*◄.

While building the various activity data collection agents we made a number of observations around potential challenges to constructing such agents:

- It is broadly useful to have *curation* over the data source. One of the challenges of reading from a "fire hose" is that the "signal-to-noise" ratio can be low. Instead, the emphasis should be on capturing discrete events that are useful.
- To use labels to identify the specifics of particular relationships and properties to capture information that can be used later requires a level of understanding of what the data source provides and how that compares with other data sources. For example, timestamps might be collected using a different interpretation of time zero so to use this information requires some means of comparing such cross-domain values. Similarly, in a system where multiple objects are grouped together via the naming system (e.g., files within a directory) it is useful to capture that relationship when the activity agent is recording information.
- TM ►*TBD*◄

4.2 Evaluation

Our evaluation of these activity data collection agents involves considering several key factors:

- The time and complexity of the code needed to implement the agent.
- The amount of data the agent generates per unit time.
- The performance impact of the agents on the system.
- TM ►*TBD*◄

TM ►*So, the point here is to provide a straight-forward framework for evaluating the overhead associated with these activities as part of the evaluation.*◄

5 STORAGE

A "labeled property graph" includes:

node — in traditional mathematical graph descriptions this is the *vertex*. For my work this corresponds to a digital object, such as a file in a file system, a value in a key/value store, etc. Nodes within my/ system have *structure* because it must codify "where" the actual digital object is located in addition to the other information needed. For practical purposes I think of the "location" as being a uniform resource identifier (URI.) The benefit of this paradigm is that it relies upon an existing standard for identifying objects, which is sufficient for my work.

relationship — in traditional mathematical graph descriptions this is the *edge* that connects a pair of vertices.

identifier — this identifies the graph element (node or relationship).

label — this is a descriptive property related to the node or relationship. For example, a label might identify that a node is a *file* versus a *value* in a key/value store. Similarly, a label associated with a relationship would establish *what* type of relationship this represents, such as a *derived from* or a *contained by* relationship.

property — this is essentially a key/value pair, where the key represents the property and the value represents the data associated with that property. My goal is to permit some structure to a property, so that it may have a version associated with it, permitting more flexible upgrades to the format of the data.

I choose this model because it fits the data we collect and permits exploration of augmenting the model with distinct agents capable of adding specific property information as well as relationships.

Thus, *nodes* in this model represent data objects and activity events. This can be used to create different types of relationships. For example, *causal* relationships would show a flow from one data object to a second data object based upon an activity event that "explains" that transformation. This would be a way to capture *provenance* information. However, the model is not limited to this type of relationship. For example, data objects created when the same web page was being accessed could be identified by using an activity event node representing the web page access. This sort of contextual relationship is useful for finding related data objects that are not causally linked. This might occur, for example, when writing code. A developer could be shown other files they created when looking at the same page, allowing them to find that prior work.

Because our goal is to find assocations via explicit and inferred contextual information, we describe activity *events* and *contexts*. An activity *event* is a node that an activity provider inserts to represent some specific information about *what* happened. An activity *context* is created on demand and associates a set of activity events with another object (e.g., a data object). For a data object, this creates a relationship between the object and potentially related activity events.

Thus, the expectation is that we can retrieve the most recent instance of an activity event of interest (where I leave defining *of interest* to be determined.) For a simple demonstration, it likely makes sense to simply have a list of the "most recently added" instance for each activity provider and simply form the activity context by associating it. As the number of activity providers increases, further work will likely be needed to enable scaling.

Thus, an *activity context* can be associated with other objects. This will permit us to subsequently examine the context of operations that were ongoing at the time of interesting events.

This leads to a number of interesting questions to explore:

- Does it make sense to maintain temporal relationships in this fashion; in other words, does the newest activity context point back to the previous activity context, or do the activity events point back to the older activity event?
- Should an activity context be something added implicitly (e.g., each time one creates a *data* node, should the system automatically associate an activity context with it,) or explicitly (e.g., only when performed by an external agent.)
- How do we garbage collect this information? That's not likely an important question to answer for prototypes, but it will become an important question as systems such as this emerge.

5.1 Use Cases

While we expect numerous potential uses of activity context to be found, we have identified three interesting cases that we have used to drive our own exploration of activity context.

Search — search services are ubiquitous in storage solutions. Prior work has clearly identified that activity context information can be used to improve search outcomes [286]. Further, the ability to search across distinct storage domains provides benefits to users over the iterative search mechanisms they typically use.

Data Browser — our group did preliminary experimentation with an alternative file browser that worked using associations, rather than limiting themselves to hierarchical structure. This is also reminiscent of work done in the Human-Computer Interface (HCI) community regarding collaborative non-hierarchical data organization tools [63]. Our richer contextual environment is one that supports further exploration of alternative data visualization techniques.

TBD — TM ►*Need to find some other good use case here.*◄

5.2 Evaluation

6 UTILIZATION

6.1 Use Cases

6.2 Evaluation

7 CONCLUSION

TM ►*The idea that using behavioral advertising information could be beneficial to file search would potentially be of interest to aggregation companies because it would encourage use of these tools willingly: a "free" service subsidized by advertising.*◄

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