



Channel Islands

CALIFORNIA STATE UNIVERSITY

WHIRLPOOL: Content Aggregation using N-node Distributed Web Crawler

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1 | Introduction

A *web crawler* is a long running program that collects pages from the web and stores them to the disk either in raw format or after extracting its contents. Sometimes they are also referred as *random walker*, *worm*, *spiders*, *robot*. Crawlers serve variety of purposes. Web search engines are very well-known systems powered internally through crawlers. Other uses are web data mining for performing analytics, archiving portions of the web - a relevant active project is the Wayback Machine from The Internet Archive[21] operating since 2000. Most recently, there is an ongoing attempt from Software Heritage[22] to preserve publicly available source code.

This thesis is an attempt to implement a small-scale, special purpose crawler for collecting data on job postings from numerous job portals active on the web. This will help job seekers monitor openings of interest and act accordingly. This thesis does not deal with data mining but instead focuses on the design, implementation, and deployment of web crawler to perform data collection on given seed set. The crawler architecture builds on a open blueprint design of *Mercator*[8] which describes the design in enough detail but leaves out implementation specifics to developers.

1.1 Contributions

- **Use of Message Queue:** In one case, the paper doesn't provides information on how the subsystems that make up a crawler are connected together. This thesis makes use of message broker to facilitate collaboration between components thus providing asynchronous, event-driven style of communication. It also highlights its strengths & weakness.
- **Crawl Ordering Problem:** A more crucial issue is without having a target to crawl, the problem of crawling becomes endless, infinite crawling even for specialized crawler such as this. This thesis discusses the crawl ordering strategy to shape its crawling only to specific content.
- **Distributing the crawl:** Furthermore, this thesis shows the shortcomings of linear hashing used for partitioning hosts to distribute the crawl and instead employs consistent hashing[13] algorithm and discuss its merits over it.
- **Development strategy:** Given this complex program at hand, it becomes obvious to separate the concerns by developing and testing each component in isolated pieces. This thesis leverages docker containers to build the project in stages. It allows to split the development and production environment by building images for the target platform to run the component.
- **AWS Services:** For running the crawler activity, this thesis makes the most of AWS 12-month free tier access by combining together suite of services and sketches an infrastructure to setup, deploy and demonstrate the program.
- **Microservices:** Lastly, this thesis explains the philosophy, principles behind microservices [18] by relating it to work done in this thesis.

1.2 Motivation

Implementing a web crawler can be seen as a fancy project and its complexity can easily be overlooked. Given the apparent simplicity of basic crawling algorithm. It poses numerous challenges. First of all, crawling the whole web is simply unrealistic even for the world's most advanced crawlers. Considering the current scale of web and while it's still evolving, it is important to think thoroughly about characteristics of a crawler, because this brings control in the hands of developers, it enriches the value of problem they are trying to solve, it gives them a choice to either seek broad coverage over fresh content or maintain a balance between the two. Even a small scale version of a crawler can be built to be sophisticated and scalable. Moreover, building a crawler sets a playground to address problems such as concurrency, throughput, and load balancing. It is a program quite different from traditional, client-server paradigm that can fanout from single source file to modular, independent services that interact with each other through endpoints.

When discussing a system like crawler, people often critic saying that

“Stop worrying about scale. You're not Google/Amazon. Just use a relational database.”

Well, that is true; building for scale without enough evidence from the metrics such as logging, locks you into an inflexible design. It is also a form of premature optimization. Along the same lines, there is also an urge felt to overengineer and loose focus on simplicity. Engineers loves to solve puzzles and challenge of building complex software. Overengineering is basically building a solution that is much more complex than is really necessary. This occurs when developer at a job tries to predict every possible use case and every edge case, eventually losing focus on the most common use cases.

However, the author of this thesis believes that it important to survey different technologies as each have their own strengths and weaknesses and choose the right tool for the job. The inclusion of message broker, docker, and AWS services to build the crawler are introduced with a mindset of promoting good design which will allow one to add more details and features later on. The design begins with a reasonable level of abstraction and with multiple iterations will gives better results.

2 | Background

This chapter primarily attempts to familiarize the reader with enough groundwork related to web crawler. It also elaborates on the miscellaneous resources that are integrated to support the objective of this thesis. It begins by explaining the basic steps taken by a crawler, followed by describing key features that underpin its system design. Properties of a crawler are discussed in the following section. A chronological walk through of highly established crawlers and key differences are noted later in the section. A section is dedicated to explaining the role of Message Queues. The remainder of this chapter covers different AWS services and docker used to interweave an environment for executing a complex program.

2.1 Basic Crawling Algorithm

The basic operation of any HTTP based crawler goes like this:

```
1: Let  $I \leftarrow \{1,2,3,4,5\}$  such that seed set  $S = \{U_i | i \in I\}$ 
2:  $U_f \leftarrow S$ ; where  $U_f$  is a Frontier queue
3: procedure SPIDER( $U_f$ )
4:   while  $U_f \neq \emptyset$  do
5:      $u \leftarrow \text{Pop}(U_f)$ 
6:      $p \leftarrow \text{Fetch}(u)$ 
7:      $T \leftarrow \exists p [\{\text{Extract}(p, t) \mid t \text{ is a text } \}]$ 
8:      $L \leftarrow \exists p [\{\text{Extract}(p, l) \mid l \text{ is a link } \}]$ 
9:      $U_f \leftarrow U_f \cup L$ 
10:     $\exists u [\{\text{Delete}(U_f, u) \mid u \text{ is a already fetched URL}\}]$ 
11: end
```

2.2 Features of a Crawler

The web is not a centrally hosted data warehouse but instead is comprised of billions of independent web hosts, operating within its limits. Taking this into consideration, a web crawler exhibits most of the following traits:

- **Being polite to web hosts:** A crawler shouldn't induce too much burden on target host at the time when they crawl. By not regulating this behavior, it is blocking the web site from pursuing its purpose or business and eventually there is a higher possibility of have ramifications on the operator running the crawler.
- **Resilient to spider traps a.k.a infinite loops:** Some hosts mislead crawlers into fetching page after page that never reach an end. Thus, a crawler should be robust to such fallacies.
- **Distributing load:** A crawler can make itself capable by distributing the load across multiple machines. Distributing the load across multiple machines is also a *shared nothing architecture*. It can make the crawler download web pages based on geographical proximity reducing request-response latency.
- **Scaling:** Scaling and Distributed may sound similar but subtle difference is a scalable crawler's sole purpose is to cop up with load as it comes, in this case, pacing the crawl rate as well as enhancing the crawl rate. With scalability in mind, the architecture needs to be rethought on every order of magnitude of load increase.
- **Page quality:** A crawler should seek broad coverage by being an explorer but at the same time it should be biased towards first selecting websites it is intended to crawl.
- **Extensible:** Like any complex program, a crawler system design should be flexible and extensible on top of its core modules.

2.3 Crawl Ordering Problem

The purpose of a web crawler can be viewed as traversing the web graph. The crawling order appears naturally to be breath-first problem (download pages following the links as they appear). But since the web is so massive and still expanding such a crawling activity is considered infinite and the crawler itself can be said to be *random walker* with no purpose. Most of the commercial or even open source crawlers have some sort of crawling order policy built into their system. It is a must for small-scale, special purpose crawler to order the extracted URLs because the act of acquiring content is restricted by various factors.

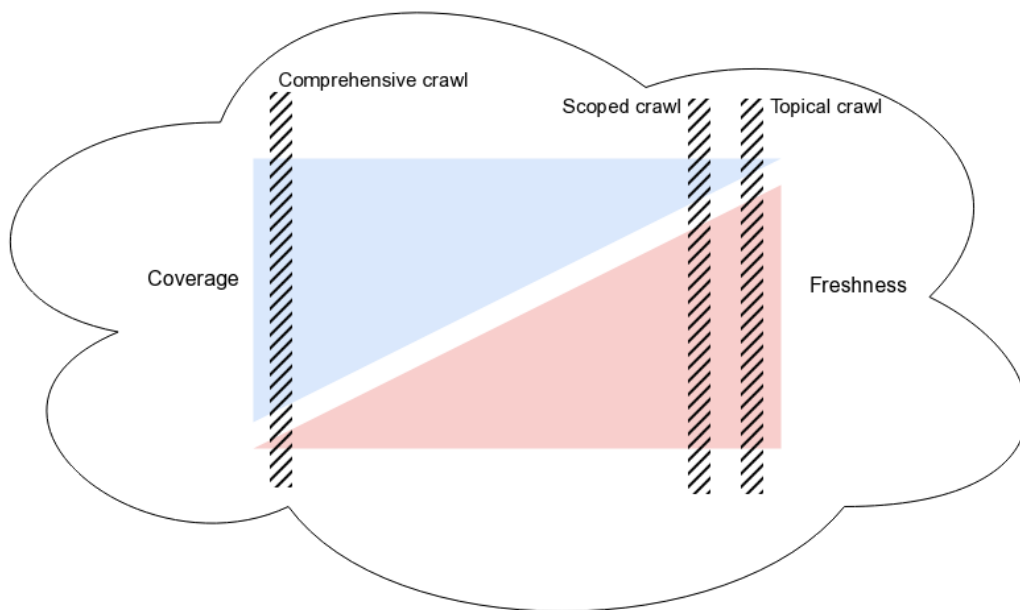


Figure 2.1: Crawl ordering based on Coverage vs. Freshness

Coverage: Focus is on fetching pages that crawler deems required.

Freshness: Here the focus is on revisiting, redownloading already visited pages. Since web 2.0, pages are capable of dynamically changing content and popularity of Single Page Applications(SPA) has enabled rendering data through view logic controlled by javascript.

As shown in the figure 2.1, *Comprehensive Crawling* focuses on maximizing coverage by reaching out to content of all types. A particular page p is weighted important by counting external links outside current site's perimeter. Crawl order policies like Breath-first Search, PageRank, and other variations are applied. Such activity is carried out by Commercial Search Engines.

On the other hand, *Scoped Crawling* narrows its crawling activity to certain portion of the web i.e only crawl a specific category (e.g everything about Stock Market). The crawling order is determined based on a degree to which a page p falls under its umbrella. In contrast to Comprehensive, Scoped crawler is suitable for data-mining task

by performing data collection on topic of interest. *Topical Crawling* is a form of Scoped Crawling in which page relevance is determined by - given a page p links to another page p' and is in-scope (within bounds) either directly or through a series of subsequent links. There are 3 techniques to order URLs to crawl.

1. Fish Search (Binary classification). Here, the relevance is measured by treating links within visited page either relevant/irrelevant upto a certain height.
2. The relevance is estimated by doing textual analysis on text surrounding a link in a visited page p that points to yet-to-be visited page q .
3. Train and query a Machine Learning classifier to get the score of set of topics of interest to crawl.

This crawler has to balance its greediness level by considering page relevance. It is possible that a already relevant page p may not always yield a new relevant page but it might would after going through several links of irrelevant pages. If the crawler is designed to be too greedy then it will have zero coverage which in turn means it won't discover new pages in its journey. A decay factor can be used to allow irrelevant fetches with an ultimate intention of finding relevant page of interest.

Finally, freshness is the attribute that makes the design of crawler being either continuous or non-continuous. The question of balancing content coverage and freshness in a crawler is solely a decision of entity behind it. A *batch crawling* design requires the restarted of a crawler at periodic interval to download revised content of previously crawled pages. A *continuous* or *incremental crawling* design would be technically a program that never terminates to revisit previously crawled pages.

2.4 Related Works

Web crawling is well studied topic, several crawlers emerged and vanished, some designs weren't open while some were not documented. This section briefly talks about history of web crawlers that have existed and have made notable design decisions each passing year.

Wanderer was the first crawler that was written in Perl in 1993. It ran on a single machine. It was used for collecting statistics and later used to power first search engine.

MOMSpider came into existence in 1994. It rate-limited requests to the web servers by introducing *Robot Exclusion Policy*. It allowed crawler operator to exclude sites. No focus on scalability. It used DBMS to store URL's and state of crawls.

Internet Archive [21] crawler addresses the challenges of growing web. It was designed to crawl 100 million URL's. Used disk-based queue to store URL's to-be crawled. Made use of bloom-filter to determine whether a page was previously crawled and if so, that page was not visited again. It also addressed politeness concerns and optimized *robots.txt* lookups. Apache Hendrix is a open-source out-of-box crawler used by the Internet Archive project entirely written in Java.

Mercator [8] came out in 1999. The paper discusses the blueprint design of its crawler. Initially it was non-distributed. It addressed social aspects of crawling through its frontier scheme. The announcement of 2nd paper incorporated host splitting component that made the crawler execution model distributed. It was extensively used in web mining projects. It ran on 4 machines for 17-days crawling over 891 billion pages. The program was designed with extensibility in mind and implemented fully in Java. The blueprint design is discussed in much detail in section 2.5 as it forms the basis of crawler designed for this thesis.

The **Polygot** web crawler also had distributed design. It had crawler manager handling multiple downloading process. It ran on 4 machines for 18 days and crawled over 120 million pages.

IBM Webfountain crawler was distributed, featured multi-threaded crawling process called 'ants'. It was polite and can be configured to change politeness policies on fly. Re-downloading of pages a.k.a freshness was based on historical change rate of pages. Webfountain was written in C++ & used Messaging Passing Interface(MPI) to allow collaboration between processes. It was deployed on 48 nodes.

Ubicrawler [9], 2004, was yet another scalable distributed web crawler. It employed consistent hashing algorithm to cope up with addition/removal of nodes designated for carrying out crawling task. The consistent hashing is explained in detailed in chapter 3 section 3.3. By using this technique it demonstrated graceful performance degradation in the event of failure. It was deployed on 5 nodes and downloaded 10 million pages a day. This program was written entirely in Java.

Multicrawler [11], 2006, focused less on performance and crawl rate but more on detecting, transforming multiple formats of semantic web data.

IRLbot [10], 2009, is the most recent comprehensive crawler studied and implemented for over 3 years. It discusses its own implementation to address the increasing complexity of verifying unique URLs accumulated over time. Most notably it provides a solution to mitigate spider traps created by web sites. IRLbot was able to successfully crawled 6.3 valid HTML pages in a single day.

Apart from this, there exist open source web crawlers written in various languages notable ones are Apache Nutch(Java), Scrappy(Python).

2.5 Mercator Architecture

This section proceeds into detailed description of Mercator[8] web crawler surveyed in section 2.4. Figure 2.2 is a high-level composition of the same. As seen, Mercator specializes different steps defined in basic crawling algorithm covered in section 2.1 and adds several other steps to address the social and scalability challenges of web crawler. Its blueprint design offers horizontal scalability and therefore if implemented can run on more than one node. Each part that contributes to mercator crawler can also be referred to as a component, module, subsystem, etc. They can be used interchangeably from this point onward.

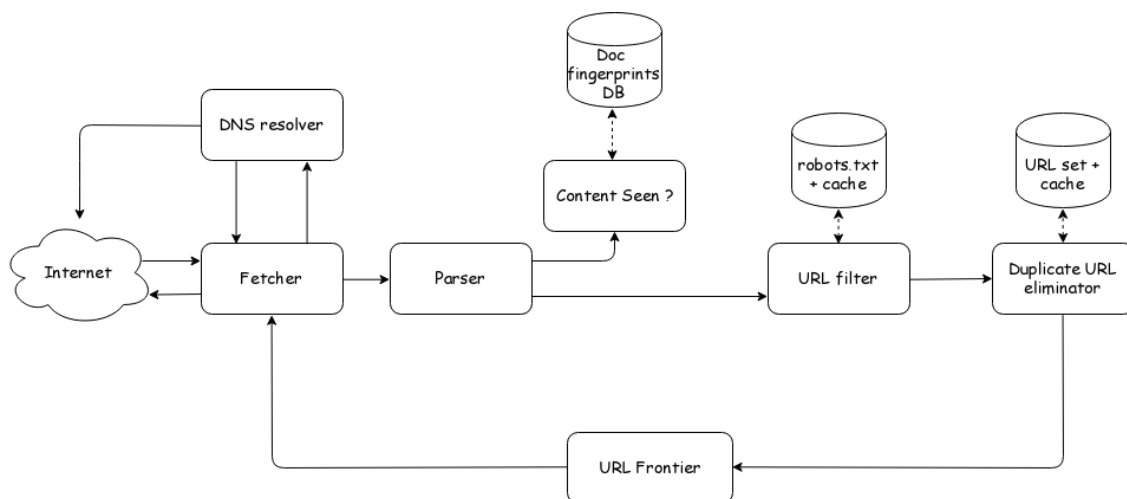


Figure 2.2: High-level organization of Mercator

Each work cycle begins and ends at the URL Frontier. Depending on what needs to be achieved, the entire crawler can run as a single process or can be partitioned into multiple processes - treating each subsystem as a process. Given a single URL, it goes through the cycle of being fetched followed by passing through various checks, filters and eliminations, then finally returned to the Frontier (for incremental crawling).

At the beginning of each logical loop cycle, a worker thread pops a URL from the Frontier data structure adhering to the priority and politeness policy. The output URL is then fetched by HTTP fetcher subsystem - which like any other web client contacts DNS module to get IP address of the corresponding web server. The web page is then retrieved and stored at a temporary location which is then picked up by parser subsystem which forwards the path to the page and extracted links to content seen and URL filter, respectively. The batch of URLs undergo a fixed set of pre-processing steps at the URL filter subsystem before being passed over to Duplicate URL eliminator (DUE). The DUE module tests each URL to determine whether the link should be added to the URL frontier.

2.5.1 Fetcher, Parser, and DNS

It occurred to designers of Mercator that the task of fetching each URL from seed set or newly discovered links is complex. First, the request made to the web server at a given URL endpoint will have several outcomes as a response. Therefore, it becomes a bottleneck to implement a fetcher as only single threaded, blocking synchronous module. Instead it should be written as a multi-threaded, synchronous I/O or non-block, asynchronous I/O to speedup the operation. Moreover, it is also inefficient to have DNS resolve a given URL's IP address each time a fetch request is made to the same web server. This can be fixed by having a cache of lookup pair for each web host in the frontier. According to Mercator designers, another difficulty is the lookup implementation itself of DNS entries is blocking; meaning that at a time only one request is considered and completed and all other requests queue up. The solution for this is yet again a multi-threaded approach or a asynchronous I/O wrapper.

2.5.2 Handling De-duplication

Any professional or sophisticated crawler has the capability to minimize De-duplication. De-duplication simply tests whether a web page with the same content has already been seen at another URL. As per figure 2.2, the content seen subsystem takes care of the same. There exist three established methods to solve this problem.

1. Document fingerprinting (checksums)
2. Bloom Filters
3. Shingles

(this will be expanded further)

2.5.3 URL Filtering

The URL Filter component takes input a batch of extracted URLs, applies a series of tests, modifiers on each URL, composes a newer batch of URL which fall in its criteria and forwards it to the next subsystem. For instance, assume a set of links $\{U_1, U_2, U_3, U_4, \dots, U_i\}$ extracted from page p , there is a possibility that some U 's link are relative to the page p , in such cases, this component normalizes such U 's turning them into absolute URLs. Also, the crawler can enforce a rule to exclude out of bound URLs - those that don't fall within a given list of domains.

```
User-agent: *
Disallow: /admin
Disallow: /jobman
Disallow: /reports
Disallow: /talentmatch
Disallow: /profman
Disallow: /regman
Disallow: /ows
Disallow: /config
Disallow: /m2
Disallow: /jobsearch/
Disallow: /job
Disallow: /feed/
Disallow: /resumepost
Disallow: /profile/
Disallow: /rss/
Disallow: /salary-calculator?title*
Disallow: /jobs?q*
Disallow: /jobs/?q*
Disallow: /canyouhackit/
Disallow: /career-paths?title
Disallow: /salary-calculator-for-tech-hiring
Disallow: /daf/servlet/
Disallow: /jobs/dc-*
Disallow: /jobs/djt-*
Disallow: /products/?
Disallow: *?CMPID*
Disallow: */jobs.html
Allow: /jobs
Allow: /register
Allow: /mobile

User-agent: Googlebot-News
Disallow: /
```

Figure 2.3: Robots Exclusion Policy set by dice.com

Apart from these, many hosts regulate what's allowed/not-allowed for downloading by placing a *robots.txt* file under root directory of a hosted web site. The standard is known as Robot Exclusion Protocol. Figure 2.3 shows a *robots.txt* of dice.com. Its interpretation beginning at line one goes like no crawler should visit */admin*, */jobman* pages, but it can visit */jobs*, */register*, and so on. A user-agent containing string Googlebot-news is not legally allowed to crawl any of its pages. For each domain, the crawler fetches *robots.txt* to test whether the URL under consideration passes the robot restrictions and only then it is added to its Frontier data structure. Given a high locality that many of the extracted links fall within the domain, it is efficient to cache *robots.txt* rule into an in-memory data store. The cache expires and redownloads *robots.txt* for each domain several times a day to stay in sync with the rule changes.

It should be noted that it is always safer and courteous to include a note in request header of the crawler indicating intentions to download the data, and also provide

your email address where the webmaster can contact you in case of any issues. Also, it is a good practice to enforce strict compliance with domain's robots.txt rules.

2.5.4 Duplicate URL Eliminator (DUE)

A batch of URLs qualified from URL filtering subsystem arrives at DUE. Sometimes it is also referred to URL-seen test. DUE guards the URL Frontier by eliminating multiple instances of the same URL from adding to the Frontier. It also keeps history of set of URLs that were previously added to the URL Frontier and those that are currently in it. The fire-and-forget, one-time crawl URLs are only crawled once. In continuous crawling Frontier scheme, some URLs are revisited periodically for new information, in such cases, the DUE has to delete its traces from its state.

Understanding the behavior of DUE explained in above paragraph, the size of URL set stored in relational database on disk will grow linearly as the size of web corpus grows irrespective of whether the crawler is continuous/non-continuous. Since the DUE has to make sure that it isn't adding duplicate URL to the Frontier, it will check against each entry in the URL set table. This will hamper DUE throughput and increase disk seek latency over time i.e the time taken to check and respond for existing entry increases. Each insertion in the URL set table is a fixed size checksum of textual URL along with the mapping to URL itself. The checksum algorithm should be such that it has exponentially small probabilistic bounds on the likelihood of collision in the URL set.

To reduce the number of operations required to DUE each URL in a batch, several optimizations can be combined. First, keeping an in-memory cache objects of popular URLs. The intuition for this is continuous crawling URLs endpoint will be revisited. But again with this, the cache hit rate is low as ratio of continuous to one-time crawls can be 20:1. Also as the computed checksums of the URLs are highly unique, it has lower locality, so the checksums that miss the cache will require disk access and disk seek. Secondly, taking advantage of high locality of checksum hostname(domain name) concatenating with checksum of absolute URL for that domain name results in same host names being numerically closer to each other. This in turn translates to access locality on the URL set.

2.5.5 URL Frontier

The URL Frontier subsystem receives a batch of URLs from its counterpart (it is either DUE or hostsplitter in case of Distributed crawling). It maintains those URLs in the Frontier and propagates them in some order whenever the fetch module seeks a URL from it.

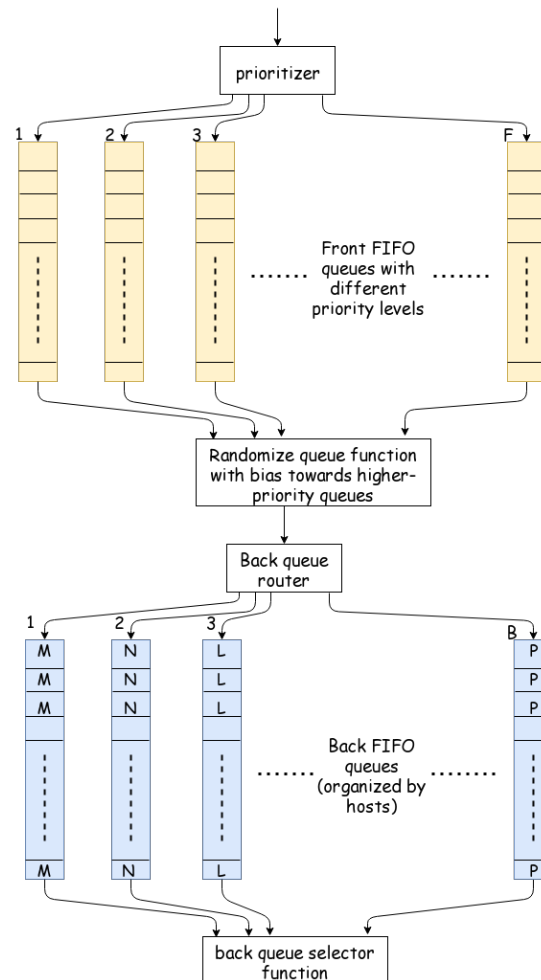


Figure 2.4: URL Frontier Scheme(based on Mercator)

Figure 2.4 is not just a simple queue but a complicated data structure. It includes multiple pages from the same host. It avoids trying to fetch all those pages from the same host at the same time because maybe the crawler can overload the server which is not a good policy. Also, the fetch module should not wait doing nothing, instead keep the module busy. Thus, it balances the tradeoff between not bombarding the server and also keeping the fetch module busy so that if fetch is not crawling that website at least it can go to some other server and fetch some pages from there.

Following are important considerations that dictate the order in which the URLs are returned or pulled from the frontier. As mentioned earlier, simple priority queue fails as there is high locality of pages that go to its own site, creating a burst of accesses to that site.

- **Explicit politeness:** obeys any specifications from webmaster on what portions of the site can be crawled, see section 2.5.3 for more details.
- **Implicit politeness:** Avoids hitting any site too often even though no specification exist on the site.
- **Freshness:** crawl some pages more often than others.

A common heuristic to handle politeness is to insert a time t gap between successive requests r such that,

$$t(r_i) > t(r_{i-1})$$

$$t(r_i) = (K.l(r_{i-1})) + TS_{now} \quad \dots K \text{ is a variable delay factor}$$

It is important to visualize URL Frontier diagram figure 2.4 before diving into its pieces. A URL follows the path into the Frontier and immediately encounters set of front queues F . It enters into one of these F queues. There are also another set of queues called B back queues. At some stage the URL will be pulled out of the front queue and then sent into one these back queues. Later, at some stage, it will be pulled out of that back queue and accessed by fetcher thread which then goes and actually fetches the document at that URL endpoint.

Each front queue F_m in range $\{1, 2, 3 \dots m\}$ and back queue B_n in range $\{1, 2, 3, \dots n\}$ is literally a *FIFO* queue. The incoming URL gets classified into one of the $1, 2, 3, \dots F$ front queues

- **Front queues** F_m manage prioritization. They influence the rate at which you ping the same web server again and again.
- **Back queues** B_n enforces politeness.

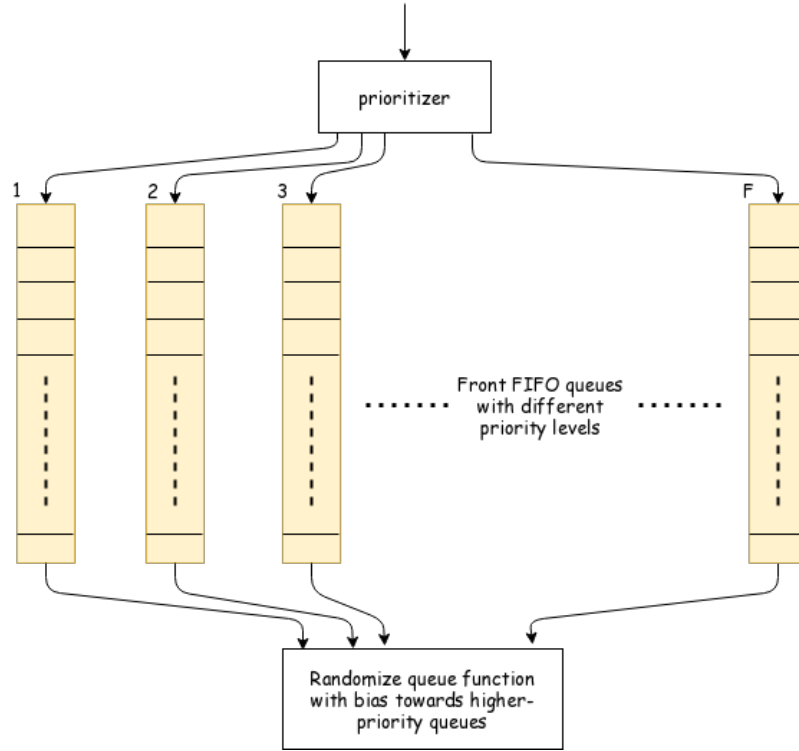


Figure 2.5: Frontier Front Queue

Figure 2.5 gives a close inspection on Front Queues F_m . Incoming URL is assigned a integer priority between 1 & m . Based on the priority assigned it is going to enter that particular queue. priority F_1 holds URLs for web servers that need to be crawled very very frequently. For instance, let L_s be links, $\forall L_s \in dice.com \mapsto F_1$ has highest crawling requirement whereas $\forall L_s \in jobs.com \mapsto F_m$ contains URLs which has least crawling requirement.

Heuristics for assigning priority,

- keeping track of how frequently the web pages are changing on a particular web server and how authoritative the pages are, if it occurs a case where a refresh rate is pretty high for any web server and pages happen to be important enough then those web servers are going to be crawled more often
- Application specific.

The prioritizer function for whirlpool is explained in chapter 3, subsection 3.3.6.1. Also randomize queue strategy on how the items get pulled out of this F Front queues is explained in chapter 3, subsection 3.3.6.2. This sums the top half of the picture.

The back queue B exist to achieve politeness because the crawler shouldn't hit the server too frequently. Again, there are B back queues from $\{1, 2, 3, \dots, n\}$, so when the URLs are pulled out in biased order from F Front queues, they are going to enter into one or more of these back queues.

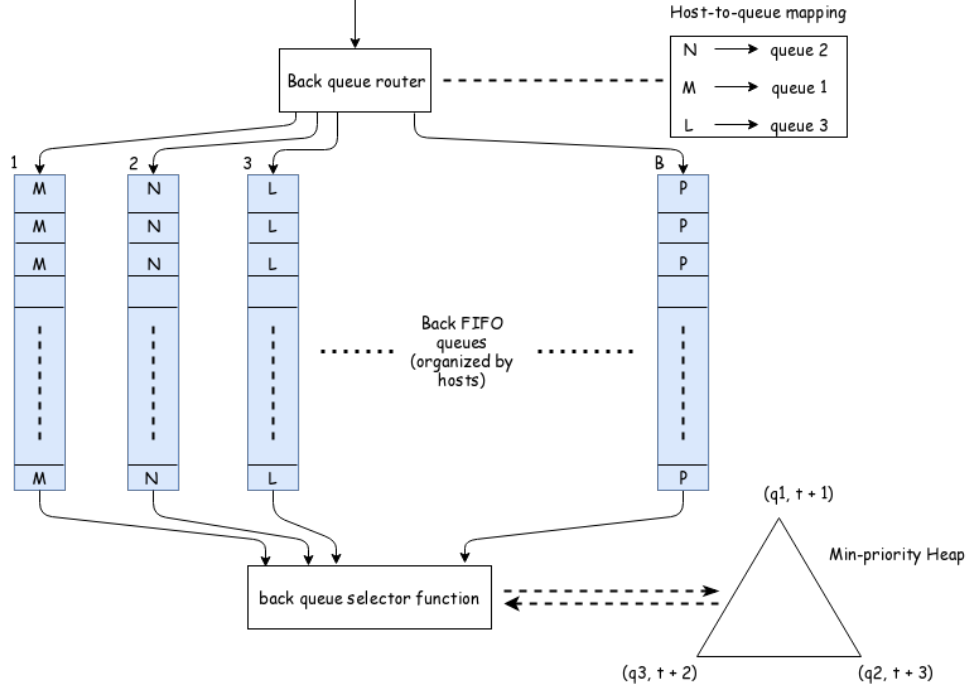


Figure 2.6: Frontier Back Queue

Recall the heuristic to handle politeness explained earlier, each back queue B_n corresponds to a particular domain. For e.g back queue B_1 is for server *monster.com*, B_2 could be the server *indeed.com*, and so on. So all the URLs which have base name *dice.com*, when they emerge from the front queue enter queue B_1 . Furthermore, Back queues maintains a minimum priority heap data structure in which the keys are such that the parent key k is less than the key of both of its children i.e $k < 2k$ and $2k + 1$ and so the smallest item in the heap is at the root of the heap.

The size and vertex $V(q, t)$ of the heap is B . the key q from vertex pair (q, t) in it maps to one of the servers/back queues B_n . The value t is going to be threshold timestamp th_{ts} which is the value of time before which I am not allowed to hit the same server B_n again. The very fact that back queue structure maintains a minimum heap is that its particular root represents the server which has the least value of the timestamp. Its the very server that is allowed to query next before it queries any of those other servers. A URL u is pulled out from the head of server queue q and fetched by fetch module. This is handled by back queue selector function

While this cycle continues, the back queue router ensures the server queues B_n are non-empty. It is busy with pulling a URL u' from the head of front queue picked up by some randomize front queue function. Following this, it checks whether server queue q exists for u' , if so, then it gets added to that queue. It goes again to pull another URL w , this time it sees that server queue q is now empty and there insert w in it and renames the q to q' . During the same iteration, the process sinks a new vertex $V'(q', t')$

on to the min-heap based on the meta-information of w such as time t' .

2.5.6 Distributing Web Crawl

A crawler program as a whole can be distributed for various reasons. A distributed crawler can crank up crawling rate. This is achieved by making an identical clone of single node crawler and replicating it onto another machine. Another advantage of distributing the crawl is that a subset of websites are crawled by a machine which is geographically closer to its data center/region. The immediate question is how does mercator extend its architecture and also how do these nodes communicate and share URLs is shown in figure 2.7.

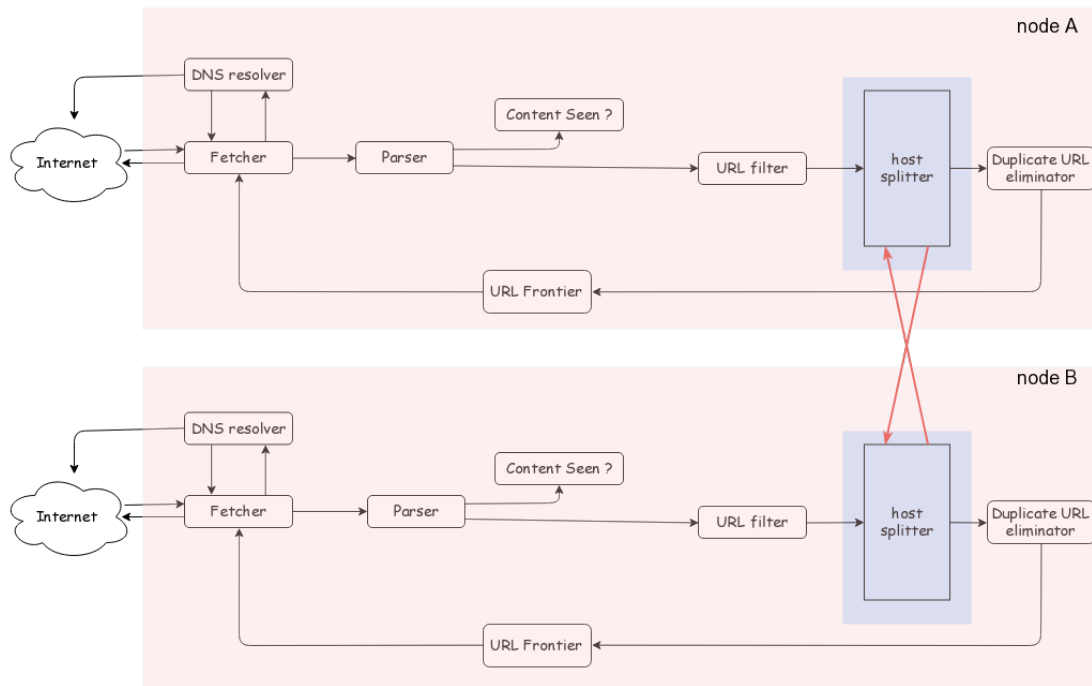


Figure 2.7: Host Partitioning

Lets say there are 3 different nodes designated to crawl the web M_1, M_2, M_3 . All the hosts that are being crawled are partitioned into 3 sets. Imagine taking every single web server on the web or in the seed set, taking the URLs for those servers, and hashing those URLs in the integer range $i \in \{1, 2, 3\}$. For instance, web server address *usjobs.com* could get hashed to an integer 2. So all those URLs that are being stored by that web server will be parsed by node M_2 while the other two nodes do not fetch documents located on *usjobs.com*.

The key to the implementation is the host splitting component shown in figure 2.7. The component at machine M_1 computes which machine is meant to crawl the URLs of *usjobs.com*. It takes the URL, looks at its server's address and hash it to the integer 2 upon which it knows M_2 is supposed to crawl URLs located on this server and therefore sends it to node M_2 . Looking at the snapshot of node M_2 , it has passed content seen, URL filter tests which confirms the incoming URL from different node is valid and need not go through the tests again. The only thing node M_2 has to check is whether that URL already exists in its own local URL frontier version or its own DUE. If the URL is new, the node will add it to its own URL frontier. At the same time node M_1 simultaneously receives URLs that it is supposed to crawl from those other nodes $\{M_2, M_3\}$.

2.6 Automata Analogy

2.7 Software Design Principles

This section mentions few core design principles necessary to maintain healthy code-base and knowledge to build scalable software. The design patterns are abstract and universally applied in different programming paradigms.

2.7.1 Open-Close Principle

When a certain code is designed with an intent to extend it but does not need any modification whenever requirements change or when new use-case is requested, such code is said obeying open-close principle. In other words, it is open for extension and closed modification. This design process gives more flexibility to the program and make future changes cheaper.

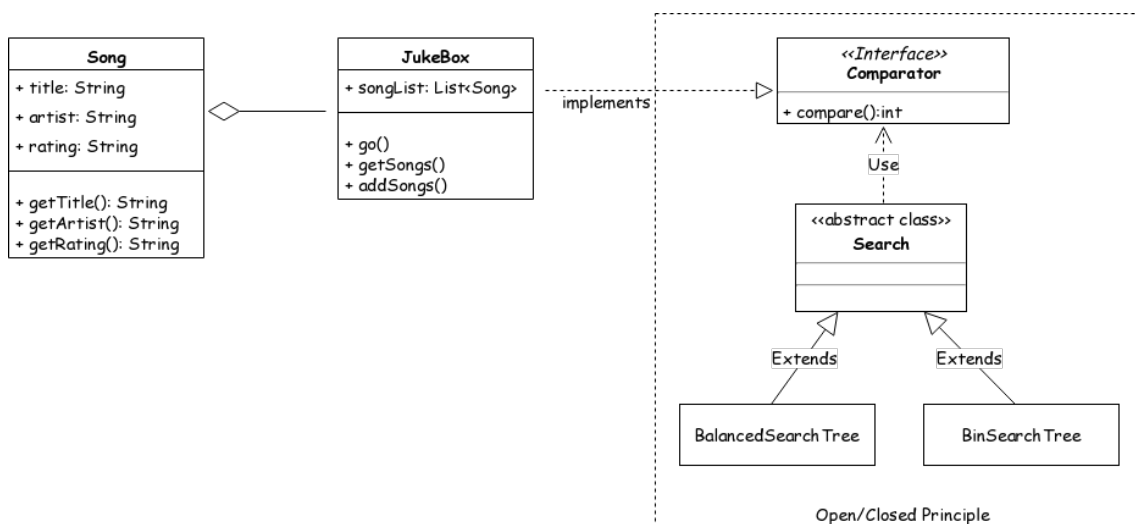


Figure 2.8: A example JukeBox program using Open/Close Principle

Consider an example of this principle in image 2.8, the Jukebox inner class implements **Comparator** interface, overriding `compare` method to search on different attributes of the class (eg. search on title, artist, etc). That method is invoked from concrete implementation of abstract **Search** class. algorithm upon calling `Collections.search()`. The search functionality offered by two concrete class vary independently and their run-time doesn't affect each other. Even more search algorithms can added without affecting existing search. The same comparators in **JukeBox** can also be used to perform sorting on songs called by respective sorting algorithm overriding `sort` method from `sort` interface.

2.7.2 Dependency Injection

Dependency Injection(DI) promotes open-closed principle and reduces loose coupling. It is one of the most important topics applicable to almost all software produced. DI provides references to objects the class depends on instead of allowing class to gather dependencies by itself. The dependent class doesn't take into account the how, where and what of implementation. This makes great impact on the flexibility of software design.

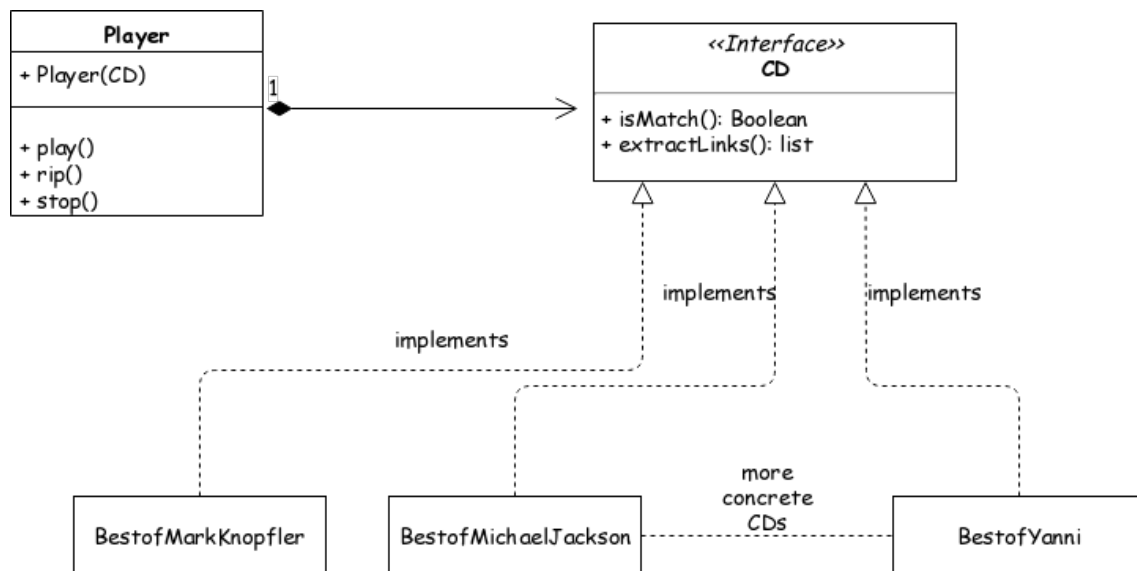


Figure 2.9: CD Player using Dependency Injection

Figure 2.9 shows an implementation using Dependency Injection. The **Player** class is a dumb box; it does not know anything about Compact Disc(CDs) shown above i.e **BestofMarkKnopfler**, **BestofMichaelJackson**; it is dependent on its client to provide with working instance of **CD**. Without DI, the **Player** can create and play only records that were hardcoded in its implementation. Anytime, a new records need to be played, **Player** class needs changes to its code. This violates Open-Close principle. DI makes the code reusable and increases unit tests.

DI can be achieved in multiple ways depending on the programming language in use. For dynamic languages like javascript and python, the support for higher order functions can perform dependency injection whereas static, class based language such as java, DI is achieved using DI frameworks.

2.7.3 Dependency Inversion

Dependency Injection is subclass of broader principle called Dependency Inversion. Its aim is same as DI - to make the class as simple and less coupled to the rest of the system. Inversion concept is observed in MVC frameworks. Its promotes the philosophy of coding to contract. Contract being the creator of plugins and not worrying who will use them; the inversion figures out which class to instantiate. It can load dependencies on a scale of 100.

Inversion is identified as 'Hollywood Principle' - Don't call us, we will call you. Features found in a piece of software supporting DI framework include:

- expands code only through plugin/extensions
- plugins are independent and can be added or removed any point of time.
- system auto-detects plugins, configures which plugins should be used and how
- defines interface for each plugin type

2.7.4 Principles for designing scalable systems

When a piece of software needs to grow to a size requiring horizontal scalability, careful thought must be given to tradeoffs between endless scalability and practicality of each solution. Also assessment of not overengineering the solution needs to be taken into account. Three techniques that help design scalable systems. Each one has different advantages and different cost.

- **Adding identical copies of components:** This is easy and most common scaling strategy applied to application build from scratch. Identical copies of components or server equally serve incoming request. A client request to any one of random cluster of clones yields correct results. This scaling strategy is not restricted only to client-server applications but also applicable to autonomous program like web crawlers. Mercator crawler described in this report uses exact copies of crawler onto individual machines and distributes traffic through its host splitter component.
- **Functional partitioning:** Identifying parts of the system focused on specific functionality and creating independent subsystems out of them. Figure 2.10 shows

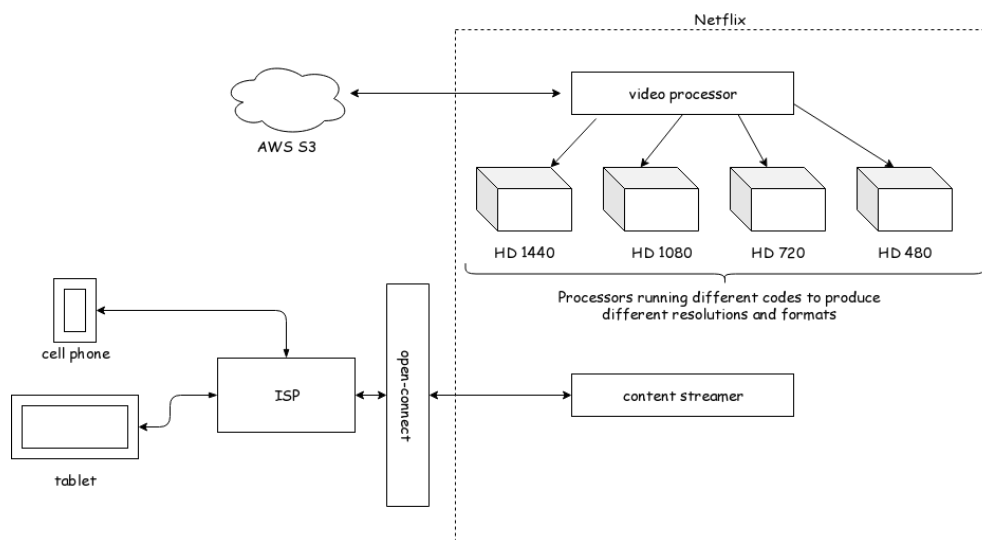


Figure 2.10: Functional Partitioning in Netflix as an example

how a netflix streaming service is divided into two major subsystems - the video processor and the content streamer. This brings a lot of benefits but also increasing engineering challenges. The main benefits are both service operate independently, parallel teams work on independent codebases. Each service scales independently of other.

- **Data partitioning:** Refers to maintaining subset of data onto each machine and controlling its state independent of other machines. This is the application of shared-nothing principle. With no data sharing, there is no data synchronization, no need for locking on global data store, and so failures can be isolated because nodes are not dependent on each other. A simplistic approach of data

partitioning is distributing objects among machines based on first english alphabets of lookup key which maps to actual machine. A more sophisticated technique will use consistent hashing to partition subset of data fairly among machines and keeps distribution fair when capacity is increased/decreased. Hence, data when partitioned correctly, provides endless scalability - adding more users, handle more parallel connections, collecting more data and deploy program onto more servers.

2.7.5 Managing State

Managing state is often overlooked aspect when addressing the scaling problem of the application. If not done properly, it can create barriers to scale the application well. In a program environment where identical copies are used to perform some computation, nodes using its own local/in-memory to cache objects are extremely difficult/tricky to coordinate cache invalidation. In such cases, it is best to maintain a global shared cache store so there is only one copy of each object and easier to invalidate.

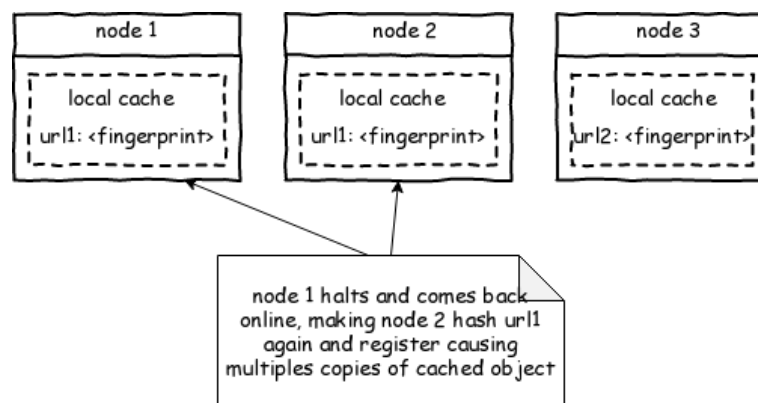


Figure 2.11: redundant copies of same cached object

Once you have a shared resource such as shared cache, for accessing them, locks are used to prevent race conditions and to synchronize access to shared resources. To achieve Horizontal Scalability(HS), distributed locks systems such as zookeeper [15] or chubby [16] can be considered. Many apps use local locks which causes bottlenecks. Instead of trying to share locks on web servers, you should push the state out of applns servers similar to http session data store.

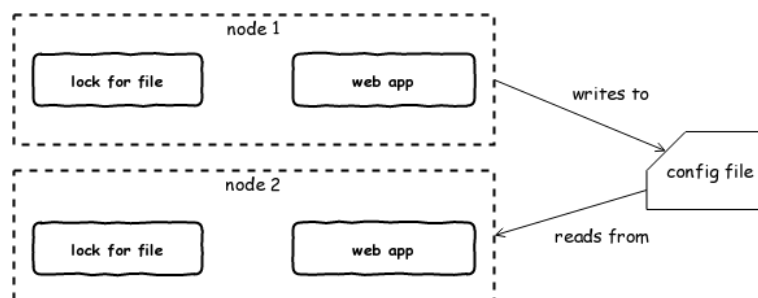


Figure 2.12: local locks preventing HS

To avoid this, use a combination of functional partitioning and scaling out using clones. Remove the locking functionality from the application code and create an independent service from it. Then let your web app servers use shared lock service to share locks globally.

Potential disadvantage to using shared lock management is increased latency. Locks can be easily implemented with memcached/redis but not as robust as Zookeeper, as you can't get notifications when a lock gets released.

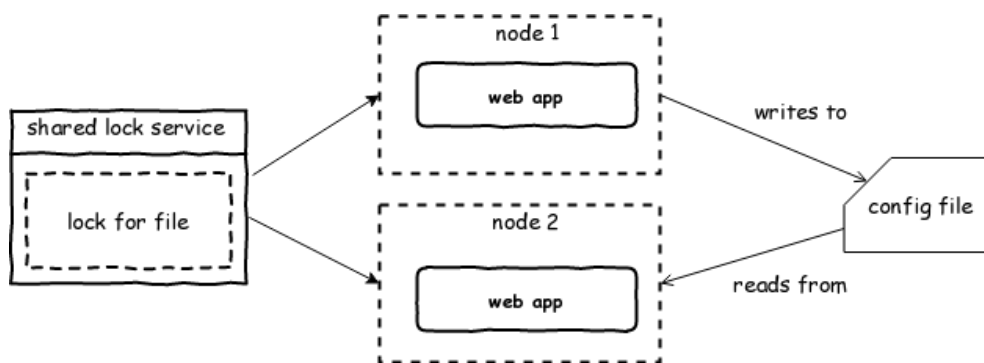


Figure 2.13: clones using shared locks

2.8 Event-Driven Architecture

2.8.1 Message Queues (MQ)

2.8.2 MQ Advantages

2.8.3 RabbitMQ as a Message Broker

2.9 Amazon Web Services

2.9.1 Identity & Access Management (IAM)

2.9.2 Virtual Private Cloud (VPC)

2.9.3 Internet Gateway (IGW)

2.9.4 Network Address Translation (NAT)

2.9.5 Elastic Compute Cloud (EC2)

2.9.6 Relational Database Service (RDS)

2.9.7 Elastic Cache

2.9.8 MongoDB

2.9.9 AWS Cloudformation

According to aws documentation [17], cloudformation(CF) is a service which lets you model and set up aws resources so that you spend less time managing resources and focus more on application logic that runs on those resources. Basically, in a template you describe all resources that make your architecture. You dont need to individually create and configure aws resources and figure what what's dependent on what.

some scenarios that demonstrate how aws cloudformation can help.

- simplify infrastructure management
- quickly replicate infrastructure
- easily control and track changes in your infrastructure

Some of the big concepts in CF are *Templates*, *Stacks*, and *ChangeSets*.

- **Templates:** CF uses templates saved in TXT, YML, or JSON as a blueprint for building AWS resources. The templates can be reused on altogether different regions by supplying input parameters at the time of stack creation.
- **Stacks:** CF manages related resources as a single unit called a stack. Creating, updating, and deleting a collection of resources is done by creating, updating, and deleting stacks. All the resources in a stack are defined by the specified CF template. To create resources which involves - Auto-Scaling group, Elastic Load Balancer(ELB), and an Amazon RDS database instance, create a stack by submitting the template consisting of those resources and CF provisions all those resources on your behalf. This requires a service role to be present before CF can actually create resources, refer to section 4.5 under whirlpool operations. To addon, Stacks can be operated using AWS CF console, APIs, and AWS CLI.
- **ChangeSets:** Making changes to the running resources in a stack, updates the stacks. Before changes are applied to the resources, a change set is generated which is a summary of proposed changes. ChangeSets makes the operator see how the his/her changes might impact current running resources, especially for critical resources, before implementing them. For example, if the name of the db identifier of Amazon RDS instance is changed, CF will create a new database and delete the one one. Data in the old database gets lost unless it was already backed up. If the given changeset is generated, operator will see that the change will cause database to be replaced and therefore the operator will be able to plan accordingly before update to a stack is applied.

2.9.10 AWS Monthly Calculator

2.10 Docker Containers

A docker container along with docker-engine is something.

2.10.1 DockerFile

(place a sample of the file here)

- RUN is an image build step, the state of the container after a RUN command will be committed to the docker image. A Dockerfile can have many RUN steps that layer on top of one another to build the image. Note that each RUN command will create a new layer and therefore affects the size of the container. It is advisable to club together unix command in a single RUN statement to avoid unnecessary container size increase.
- CMD is the command the container executes by default when you launch the built image. A Dockerfile can only have one CMD. The CMD can be overridden when starting a container with docker run 'image' other_command. *ENTRYPOINT* is also closely related.
- VOLUMES useful to map a directory from container to host. Can be specified explicitly or using docker volumes - docker volume create 'sample-volume' and setting external volume to true.
- ARG ENV
- FROM base-image as some-other-image used to specify targets to package a specific build
- external networks

2.10.2 Docker Compose

docker-compose is installed separately and is optional

3 | Implementating Whirlpool

3.1 Mission

Domain	Okay to crawl ?
CareerBuilder	yes
indeed.com	yes(restrictive)
job.com	yes
ladders	yes
linkedIn	No
glassdoor	yes(restrictive)
monster	yes(restrictive)
simplyhired	yes
us.jobs	yes
dice.com	yes(restrictive)
idealist.com	yes

Figure 3.1: Topical crawling seed set

3.2 Characteristics

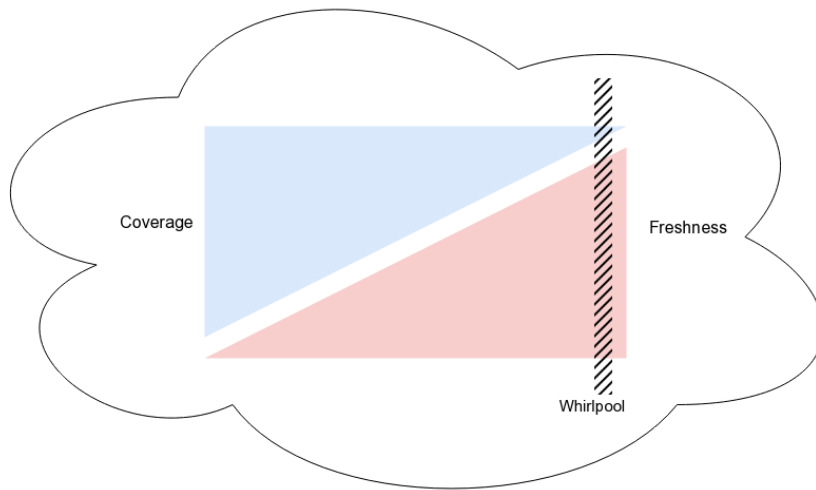


Figure 3.2: Crawl order policy of Whirlpool

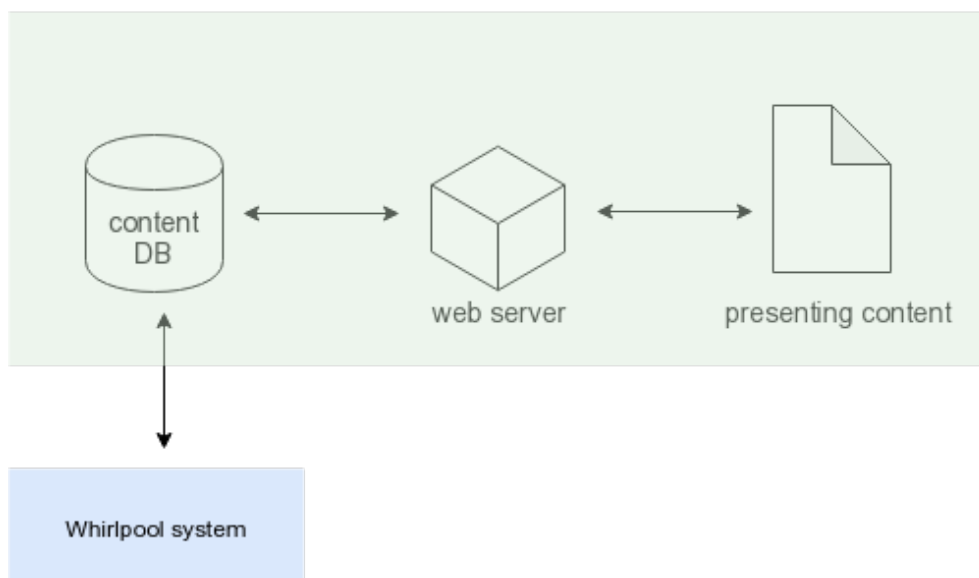


Figure 3.3: Presenting collected data

3.3 Internals

3.3.1 RabbitMQ as a Central Message Bus

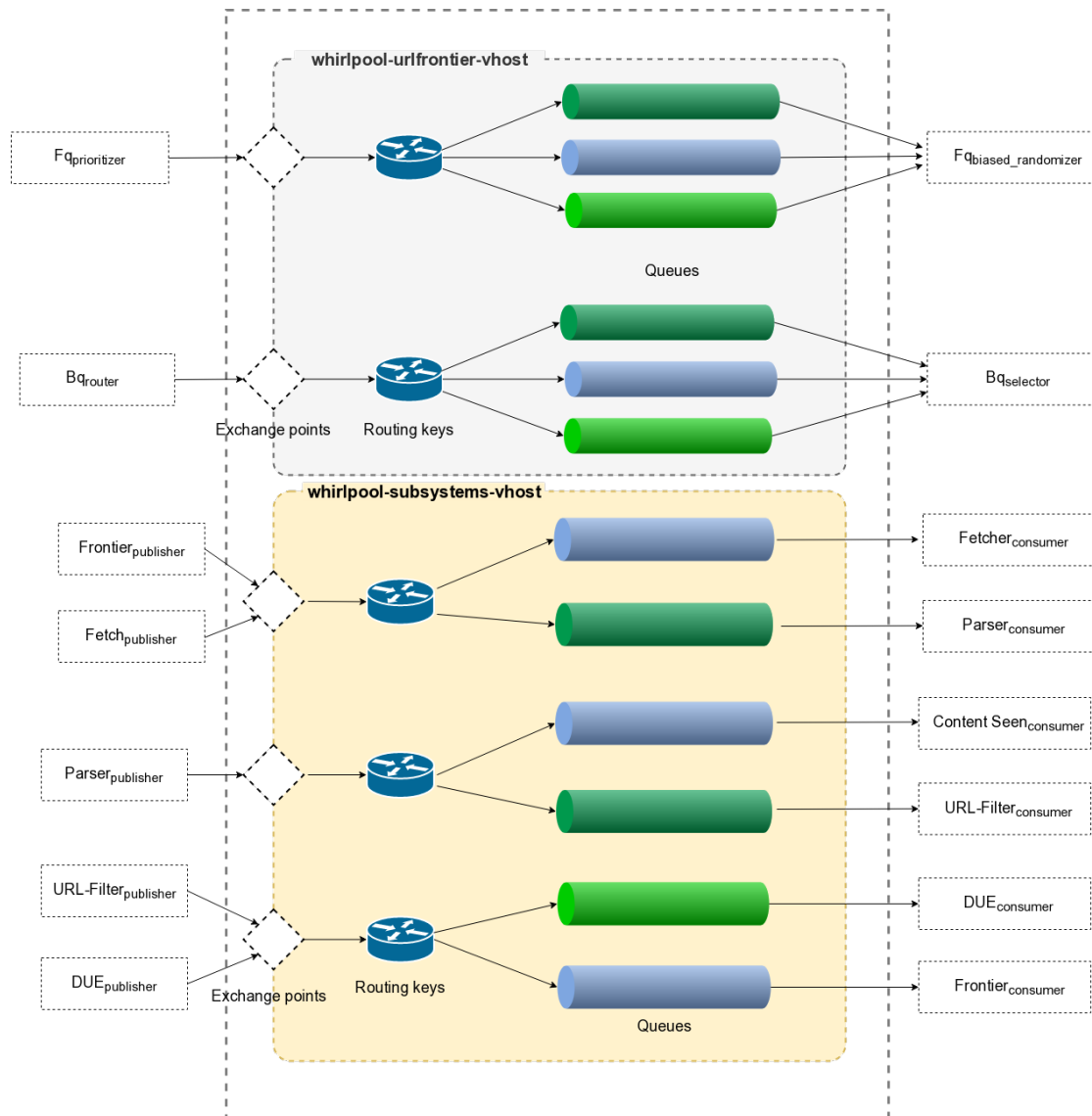


Figure 3.4: Message Distribution using RabbitMQ Direct Exchange

The initial rabbitmq configuration is shown in the <https://github.com/rihbyne/whirlpool-rmq/blob/master/setup.j>. The subsystems only need to know the exchange points and submit message payload to it. The exchange points take care of routing payload to its recipient queue. The payload is static, and doesn't contain any business logic, this leaves the subsystems highly decoupled from each other.

3.3.2 Shared Services with Docker

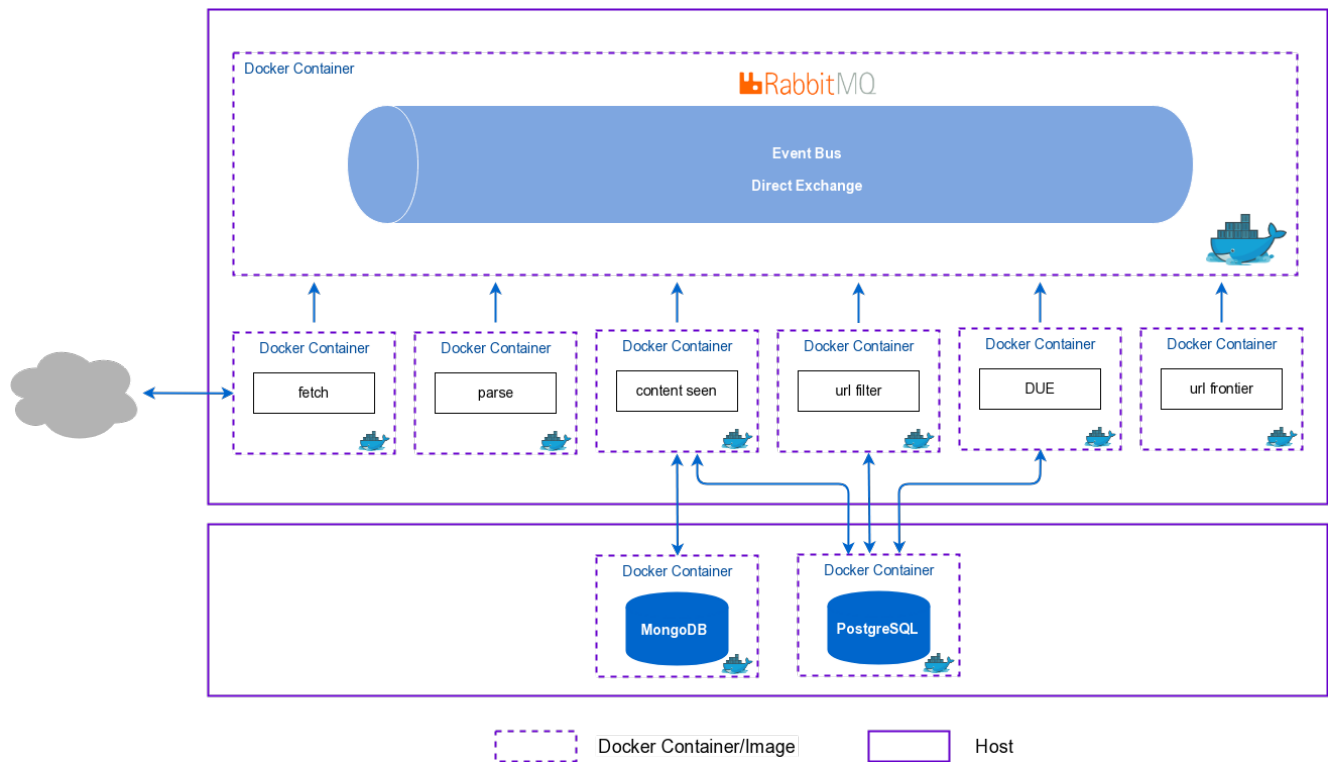


Figure 3.5: Single-node Whirlpool Subsystem Isolation using Docker

3.3.3 Developing with Docker

showcase a dev docker setup(docker-compose.build.yml)

3.3.4 Parser & its Crawl Ordering Problem

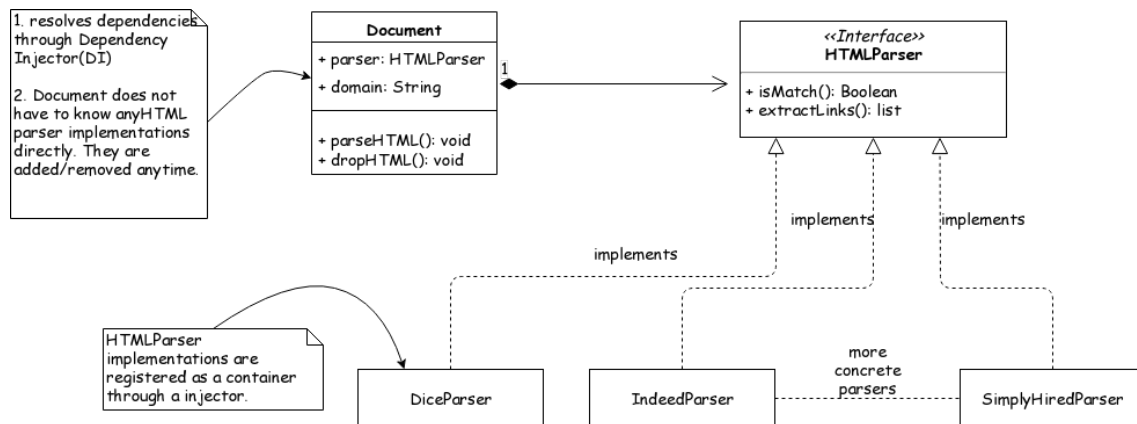


Figure 3.6: Whirlpool Parser subsystem using Dependency Injection

3.3.5 URL filtering algorithm

3.3.6 URL Frontier

3.3.6.1 Prioritizer Policy

3.3.6.2 Front Queue Biased Selection Policy

3.3.7 Distributing the crawl (Linear vs. Consistent Hashing)

4 | Whirlpool Operations

This chapter discusses server farm assembly for running whirlpool on a on-demand hardware resources offered by AWS. It uses altitude analogy to illustrate important additions in infrastructure at various levels in detail. The last section explains hardware configuration of resources used and their pricing details.

4.1 Infrastructure from 10,000 feet

Given a working knowledge of AWS and behavior of application that will run on top of its resources, it becomes much easier to combine different tools to architect AWS solution. For this project, identical copies of crawler application are deployed onto more than one machine. Special attention is paid to managing the state of the crawler. Combining understanding of theory discussed in section 2.7.5, intuition, and experience, the program maintains a global datastore(ContentDB) shared across all crawler processes. A running crawler process dumps downloaded data since the scope of the crawler for this thesis is confined to only data-collection. Also, the message broker RabbitMQ which forms the communication backbone is stateful(local) to a crawler process. So spinning each new crawler node will have its own RMQ bound to it. The internal metadata that crawler maintains which leverages a relational database and in-memory cache is also shared across crawler nodes to overcome scalability challenges and issues addressed in the theory of managing state in section 2.7.5. Lastly, the crawler program which forms the core business logic of this thesis shouldn't be part of DMZ zone.

Keeping above paragraph in mind, figure 4.1 shows a AWS assembly containing four subnets numbered 1-4 within a VPC. The Internet Gateway(IGW) is active and attached to this VPC. Public subnet 1 is explicitly associated with route table 1 which consist of route rule that directs traffic from subnet 1 to the outer public internet. The data transfer in crawling process is such that it will make connection requests to the web sites and pull data into the amazon cloud, thus the inbound data transfer cost from the internet into amazon cloud is free. Security-wise, the crawler nodes should never except incoming connections from internet. These nodes are placed in private subnet 4. By default a private subnet within a AWS VPC is accessible to/from other subnets only within its VPC CIDR block and is denied any inbound/outbound connections to the internet. As a best practice, subnet 4 is allowed only inbound connections. This is done by associating subnet 4 with route table 2. A route in table 2 directs internet traffic to NAT instance deployed in public subnet 1 which further takes from Internet Gateway(IGW) attached to the VPC all the way into public internet.

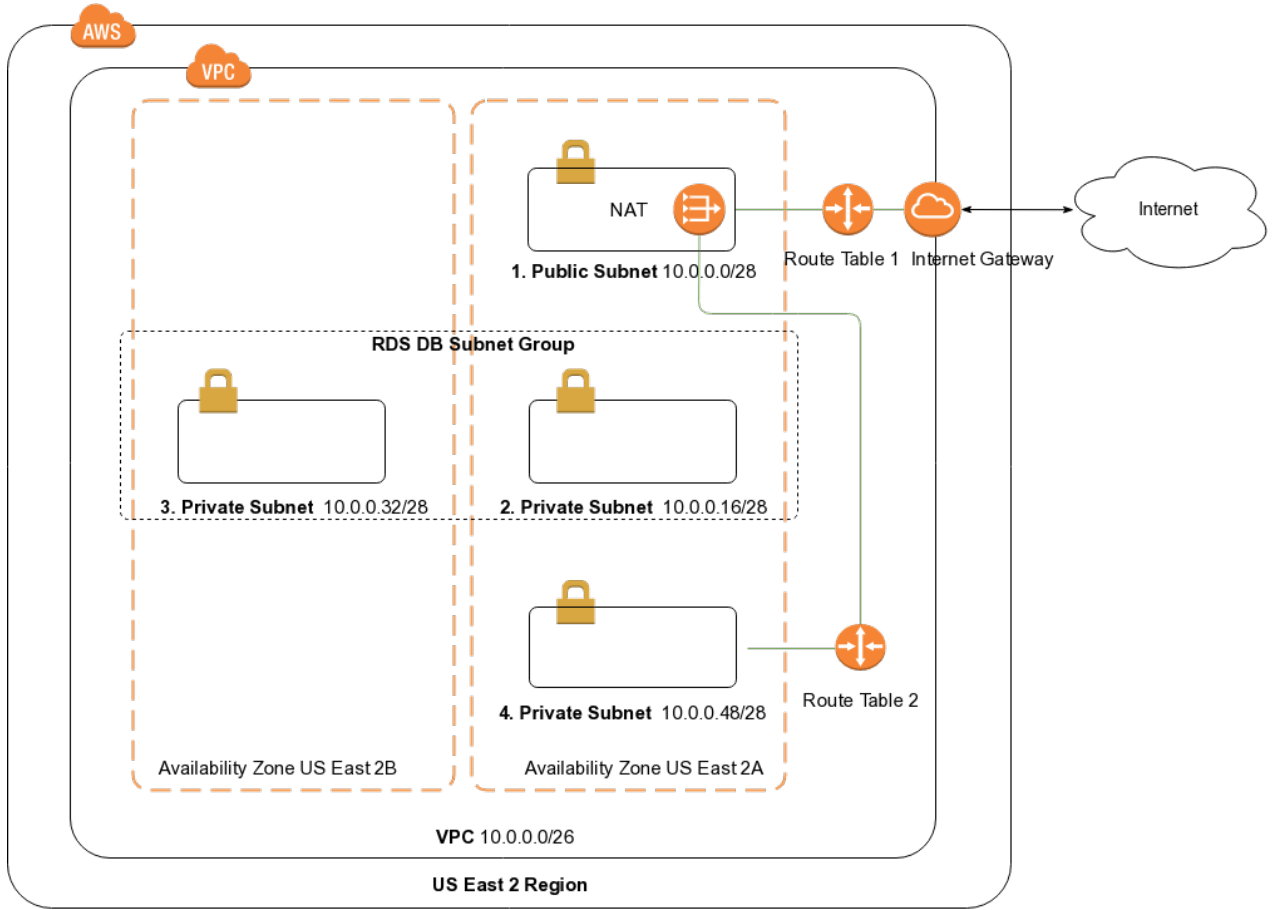


Figure 4.1: Whirlpool Infrastructure using VPC, AZ, and Subnet Sizing

The VPC in figure 4.1 uses Classless Inter-Domain Routing (CIDR) block of **10.0.0.0/26** which gives a range of **64** IPv4 addresses. This thesis uses a tool [20] to calculate CIDR blocks. AWS VPC reserves first four and last IPv4 addresses of each subnet created for internal usage and therefore cannot be assigned to any instance of any resource. The primary CIDR block size of VPC is then used to create 4 subnets each with a non-overlapping CIDR block size. The minimum subnet size allowed is **28** and **16**.

CIDR block size is given by $2^{(32-x)}$, substituting $x = 26$ yields,

$$2^{(32-26)} = 64 \quad \text{IP addresses}$$

$$4 \text{ subnets formation} = \underbrace{16}_{\text{public subnet}} + \underbrace{\overbrace{16 + 16}^{\text{DB Subnet Group}}}_{\text{private db subnet 1} \quad \text{private db subnet 2}} + \underbrace{16}_{\text{private crawler subnet}}$$

$$\text{Actual IP addresses available} = \underbrace{11}_{\text{public subnet}} + \underbrace{\overbrace{11 + 11}^{\text{DB Subnet Group}}}_{\text{private db subnet 1} \quad \text{private db subnet 2}} + \underbrace{11}_{\text{private crawler subnet}}$$

Public subnet IP range = **10.0.0.0/28** → (0 - 15)

Private db subnet 1 IP range = **10.0.0.16/28** → (16 - 31)

Private db subnet 2 IP range = **10.0.0.32/28** → (32 - 47)

Private crawler subnet IP range = **10.0.0.48/28** → (48 - 64)

4.2 Infrastructure from 5,000 feet

Figure 4.2 shows the final assembly of whirlpool crawler project.

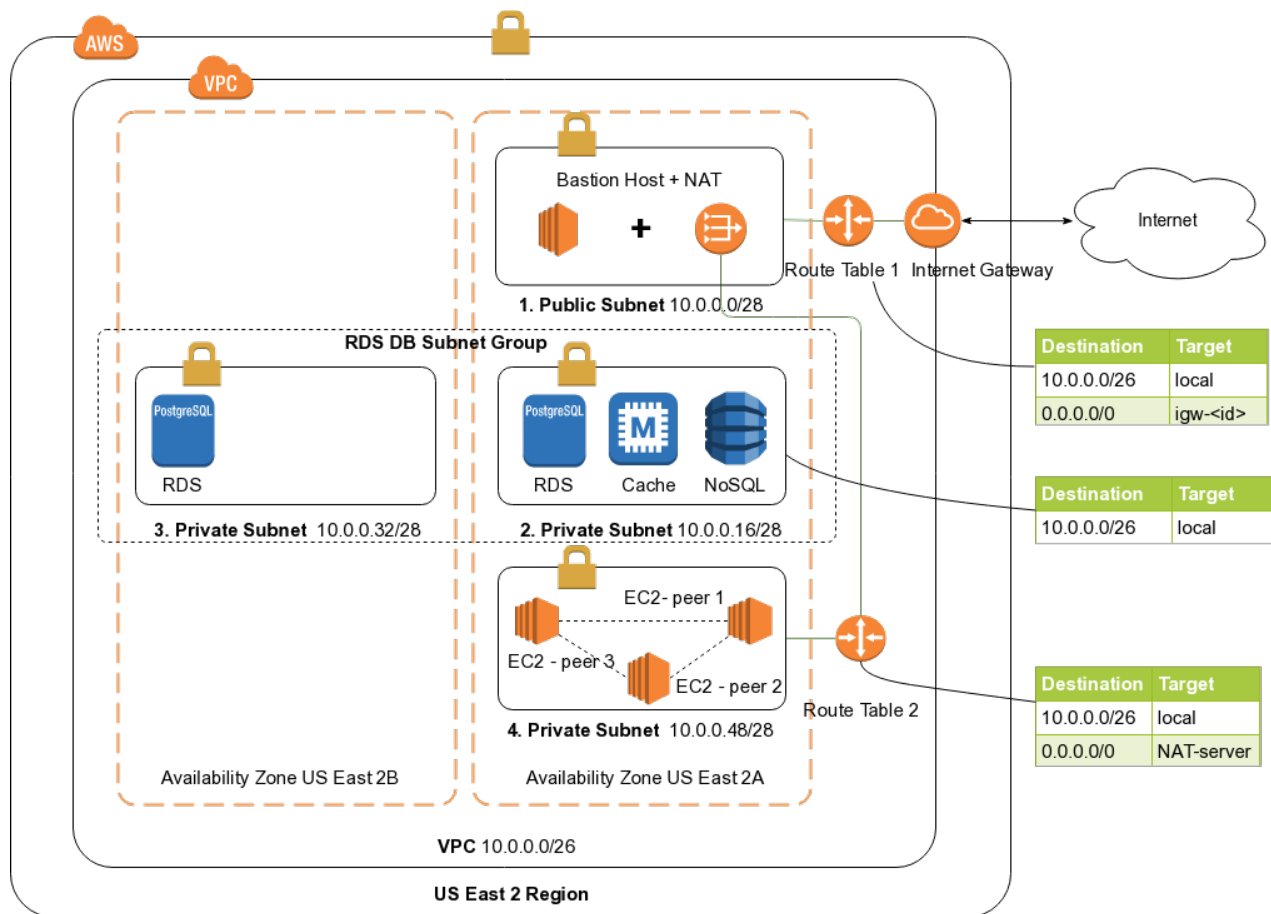


Figure 4.2: Whirlpool infrastructure with Route tables, NAT

Each subnet gets assigned a main route tables which cannot be deleted but instead can be overridden with custom route tables immediately effective on subnets as evident in figure 4.2 with route tables 1 & 2. Speaking of NAT instance in public subnet 1, is like any other AMI linux image but ships with pre-configured iptables. NAT forwards traffic from instances in subnet 4 to the internet and send the response for corresponding request back to those instances in subnet 4. It won't allow outside clients to initiate connections with instances in subnet 4. The custom route (shown in route table 2) directs the traffic originated within any of the private subnet peers matching subnet mask **0.0.0.0/0** to NAT server. The custom route (shown in route table 1) scopes all packets matching **0.0.0.0/0** route to IGW. The traffic from private crawler subnet flows to NAT Instance and then to the IGW. The NAT translate back-and-forth source and destination IPs of private instances assuming external property - source/destination check is disabled.

The subsystems of whirlpool leverage relational database (Amazon RDS) to maintain a history of URLs, NoSQL (EC2-mongoDB) to store extracted text. AWS does not have managed instance of MongoDB and requires the interested party to operate, maintain on an EC2 Instance. Also, later on, a cache server (AWS ElastiCache) can be adopted

to optimize lookup efficiency against relational database by those subsystems dependent on it. Given this requirement, its safer to form a private subnet 2 dedicated to placement of data stores and in-memory cache as shown in the figure 4.2. This way, the data store subnet would stay safer accepting network connections within the VPC, specifically only from instances allowed by statefull firewalls(VPC security groups) attached to it. For relational database, amazon's RDS DB subnet group mandates 2 subnets, each in different availability zones to successfully launch the instance. Thus, a private subnet 3 in the figure.

Following are a list of VPC security groups in place for figure 4.2 which regulate in/out flow of traffic attached to EC2 instances, elasticCache, and RDS instance respectively.

Type	Protocol	Port Range	Source	Description
SSH	TCP	22	sg-<bastion node>	only allows ssh to crawler nodes from bastion instance
Custom	TCP	8080	sg-<bastion node>	access RMQ management console access ssh tunneled to client host

Table 4.1: Inbound rules of Security Group(sg) for EC2 crawler in private subnet 4

Type	Protocol	Port Range	Source	Description
SSH	TCP	22	sg-<bastion node>	ssh only from bastion instance
Custom	TCP	27017	sg-<crawler node>	mongo traffic from crawler nodes
Custom	TCP	27017	sg-<bastion node>	egress mongo traffic tunneled to client host

Table 4.2: Inbound rules of Security Group(sg) for MongoDB in private subnet 2

Type	Protocol	Port Range	Source	Description
SSH	TCP	22	0.0.0.0/0	open to the world. Safely handle pvt. keys.
HTTP	TCP	80	sg-<crawler node>	accept non-ssl http traffic from crawler node
HTTPS	TCP	443	sg-<crawler node>	crawler downloads SSL HTTP traffic

Table 4.3: Inbound rules of Security Group(sg) for bastion host in pub subnet 1

Type	Protocol	Port Range	Source	Description
Custom	TCP	5432	sg-<crawler node>	accept sql request from crawler node
Custom	TCP	5432	sg-<bastion node>	egress rds tunneled to client host

Table 4.4: Inbound rules of Security Group(sg) for AWS RDS in pvt subnet 2 and 3

Type	Protocol	Port Range	Source	Description
Custom	TCP	11211	sg-<crawler node>	allow memcache traffic from crawler nodes
Custom	TCP	11211	sg-<bastion node>	egress cache traffic tunneled to client host

Table 4.5: Inbound rules of Security Group(sg) for AWS ElastiCache in pvt subnet 2

4.3 Bastion Host

As per the wikipedia article, a person named Marcus J. Ranum defined the term bastion host while discussing a article on firewalls as

“...a system identified by the firewall administrator as a critical strong point in the network security. Generally, bastion hosts will have some degree of extra attention paid to their security, may undergo regular audits, and may have modified software.”

Not necessarily in the context of AWS but also in data centers of IT organization, a bastion host sole purpose is to provide access to private network from external network such as internet. In a typical AWS VPC setup, an instance in a public subnet with a security group that includes a inbound rule to accept SSH traffic from trusted client host establishes secure remote connectivity after which the instance(bastion host) acts a jumping point to ssh into various private instances belonging to various private subnets within its VPC. With bastion host in place, a administrator uses ssh-agent forwarding to authenticate to private instances. Agent forwarding doesn't require administrator to store private keys on the bastion host and AWS best practices forbids storing private key files on servers. Figure 4.2 demonstrates a special network configuration where bastion host is placed in DMZ zone separated from private, trusted networks such as subnets 2, 3, and 4. Another benefit bastion hosts provide is not having to expose various management ports to internet to configure utility/application services on private instances of the infrastructure.

Agent forwarding is enabled by passing below flag when login into a remote node.

```
$ ssh -A user@ip
```

Since whirlpool assembly contains multiple networks, following ssh aliases in .ssh/config saves from typing.

```
1 # access to whirlpool bastion and its private nodes
2 Host whirlpool-bastion
3     HostName ec2-x-x-x-x.us-east-2.compute.amazonaws.com
4     User ec2-user
5     IdentityFile ~/.ssh/whirlpool-jumbox.pem
6     ProxyCommand none
7
8 Host whirlpool-crawler-1
9     HostName ip-x-x-x-x.us-east-2.compute.internal
10    User ubuntu
11    IdentityFile ~/.ssh/whirlpool-jumbox.pem
12    ProxyCommand ssh whirlpool-bastion -W %h:%p
13
14 Host whirlpool-mongodb
15    HostName ip-x-x-x-x.us-east-2.compute.internal
16    User ubuntu
17    IdentityFile ~/.ssh/whirlpool-jumbox.pem
18    ProxyCommand ssh whirlpool-bastion -W %h:%p
```

4.4 Monitoring services with SSH Tunnels

This project steals concepts behind ssh tunnels [14] and applies them to its own AWS architecture, figure 4.2, to keep track of activities happening inside it. SSH tunnels are nicely explained by Scott Wiersdorf in his article; the source is listed in references. Image 4.3 shows a **client-host** connecting to an example **web-server** on port 80 tunneled through **tunnel-host** using ssh utility.

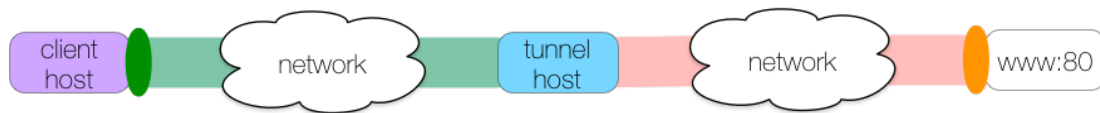


Figure 4.3: simple tunnel [14]

SSH tunnels involves two hosts - **client-host**, and **tunnel-host**. The **client-host** specifies the tunnel to be created. On the other hand, **tunnel-host** creates the tunnel connections. Both the hosts are defined as single bash command. The traffic between **client-host** to **tunnel-host** is secured by secure shell. All the TCP traffic past the **tunnel-host** is not secured by SSH. The connections in SSH tunnels are initiated at only one end and so the listening end of the tunnel is referred to as tunnel ingress and terminating end of the tunnel is referred to as tunnel egress as illustrated in the image 4.4.

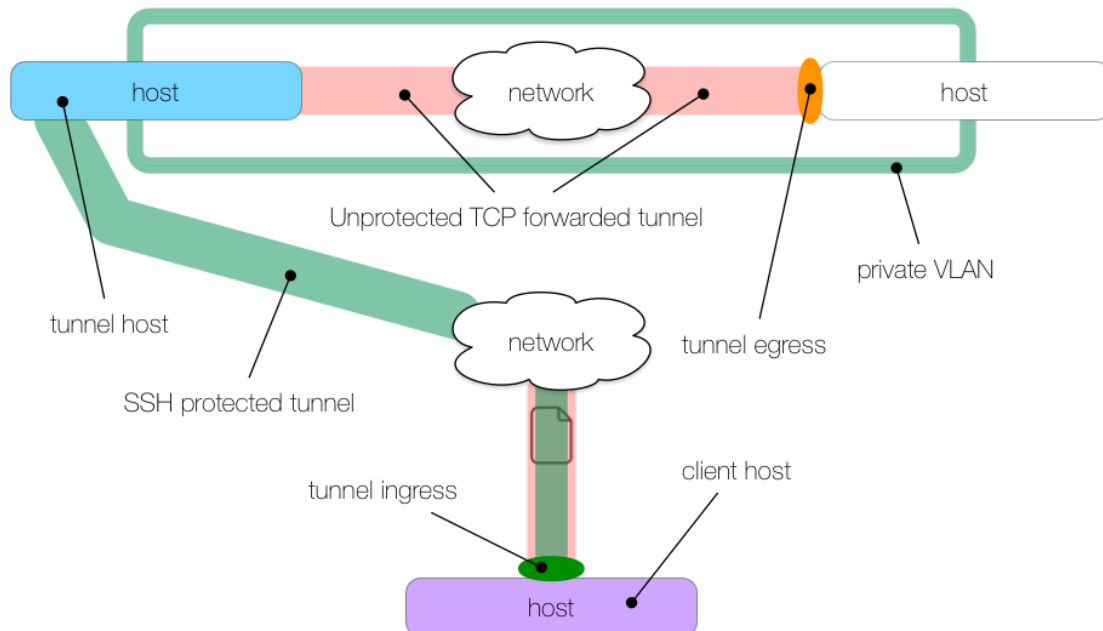


Figure 4.4: poor man's VPN [14]

In the case of whirlpool network topology, **client-host** is the machine used to ssh into **bastion-host**. The **tunnel-host** is the **bastion-host**(NAT instance) and this is where the SSH connection ends. Bastion-host forwards TCP connection to a specified private instances within whirlpool AWS deployment because SSH agent-forwarding is enabled, discussed in previous section. The specified private instance is the egress and ingress is the **client-host** bound to a particular port.

Following are the commands fired to monitor, diagnose services inside AWS. Note the egress **10.0.0.56:8080** and ingress is an omitted **localhost** on port **8080**. The bastion host **whirlpool-bastion** forwards TCP to egress. **N** indicates no commands over SSH. This command is used for monitoring RabbitMQ server running on **10.0.0.56:8080**. The corresponding firewall rules is enabled for the same.

```
$ ssh -L 8080:10.0.0.56:8080 whirlpool-bastion -N
```

This command is used for making private ec2-mongodb instance available on **localhost**.

```
$ ssh -L 27017:10.0.0.26:27017 whirlpool-bastion -N
```

This command is used for making private RDS instance available on **localhost**.

```
$ ssh -L 5432:whirlpool-postgres-prod.ytrewqgfdsa.us-east-2.rds.
amazonaws.com:5432 whirlpool-bastion -N
```

This command is used for making private memcache instance available on **localhost**.

```
$ ssh -L 11211:whirlpool-cache.qwerty.0001.use2.cache.amazonaws.com
:11211 whirlpool-bastion -N
```

4.5 IAM and roles

Showcase few IAM policies related to whirlpool project here.

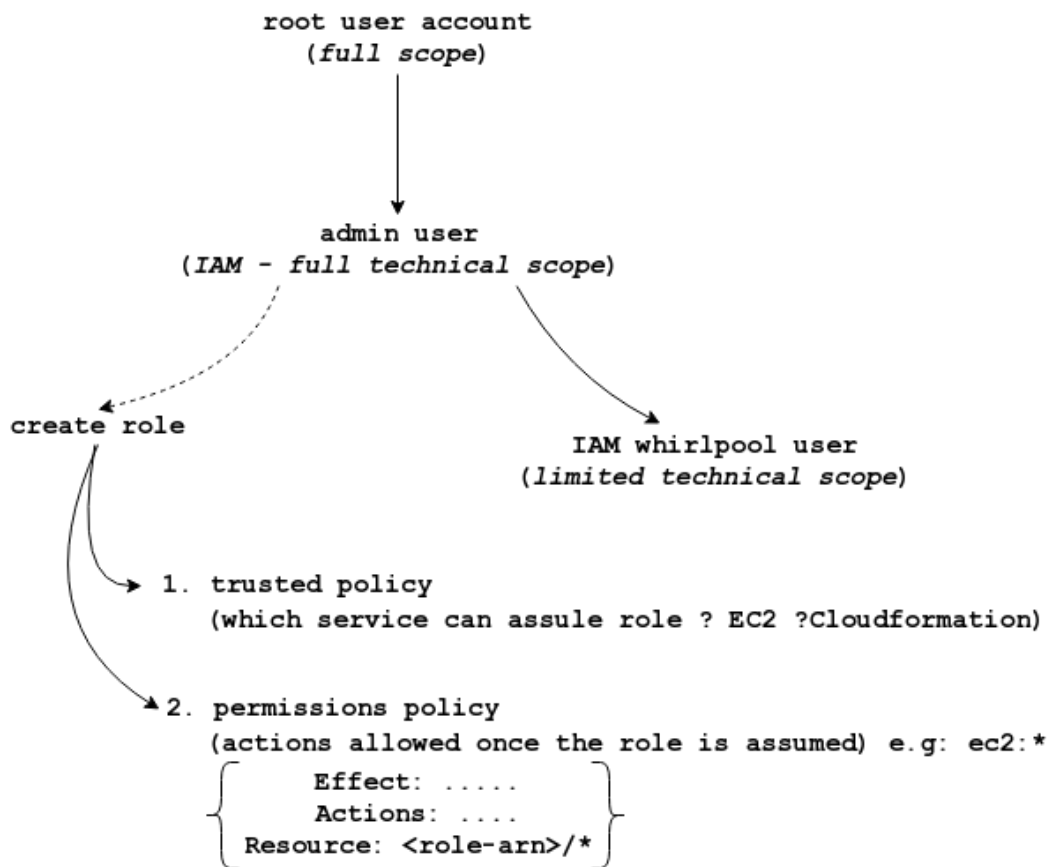


Figure 4.5: Existing accounts and service role

This project is run under IAM whirlpool user with limited technical privileges by enforcing IAM policies, delegated by IAM administrator. The IAM administrator has full technical access but not billing access granted by AWS root user account. A service role exist because AWS cloudformation as a service provisions other services on behalf of whirlpool user by assuming a service role. Use of service role in context of this project is shown in figure 4.5.

A service role contains a trust policy and permissions policy. Existing iam policies are added as permissions policy under 'actions'. Under 'resource/principal' property, cloudformation which assumes role is specified as a trust policy. A restricted IAM whirlpooluser doesn't need to be given permissions to create/modify/delete roles instead only list/describe/use roles. Note, this works only if IAM policies attached to whirlpool IAM account has **IAM:passrole** action included.

Following are the restrictive, custom, managed IAM policies effective under whirlpool IAM account.

```
1 - whirlpool-user-iam-cache-vpc-policy.json
2 - whirlpool-user-iam-cloudformation-policy.json
3 - whirlpool-user-iam-cloudformation-role.json
4 - whirlpool-user-iam-cloudformation-s3-policy.json
5 - whirlpool-user-iam-ec2-vpc-policy.json
6 - whirlpool-user-iam-policy.json
7 - whirlpool-user-iam-rds-vpc-policy.json
```

Below is the code snippet of **whirlpool-user-iam-ec2-vpc-policy.json**, one of existing IAM policies attached to IAM whirlpool account.

```
1 {
2   "Version": "2012-10-17",
3   "Statement": [
4     {
5       "Effect": "Allow",
6       "Action": [
7         "ec2:RunInstances",
8         "ec2:RebootInstances",
9         "ec2:StopInstances",
10        "ec2:StartInstances",
11        "ec2:TerminateInstances",
12        "ec2:Describe*",
13        "ec2:AttachVolume",
14        "ec2:DetachVolume",
15        "ec2:DeleteVolume"
16      ],
17      "Resource": [
18        "arn:aws:ec2:us-east-2:612113937920:volume/*",
19        "arn:aws:ec2:us-east-2:612113937920:instance/*",
20        "arn:aws:ec2:us-east-2::image/*",
21        "arn:aws:ec2:us-east-2:612113937920:network-interface/*",
22        "arn:aws:ec2:us-east-2:612113937920:key-pair/*",
23        "arn:aws:ec2:us-east-2:612113937920:security-group/*"
24      ]
25    },
26    {
27      "Effect": "Allow",
28      "Action": [
29        "ec2:*Route*",
30        "ec2:DeleteNetworkAcl",
31        "ec2:DeleteNetworkAclEntry",
32        "ec2:DeleteRoute",
33        "ec2:DeleteRouteTable",
34        "ec2:AuthorizeSecurityGroupEgress",
35        "ec2:AuthorizeSecurityGroupIngress",
```

```

36         "ec2:RevokeSecurityGroupEgress",
37         "ec2:RevokeSecurityGroupIngress",
38         "ec2>DeleteSecurityGroup"
39     ],
40     "Resource": "*",
41     "Condition": {
42         "StringEquals": {
43             "ec2:vpc":
44                 ↪ "arn:aws:ec2:us-east-2:612113937920:vpc/vpc-0c7a0ba5e8cad5b83"
45         }
46     },
47     {
48         "Effect": "Allow",
49         "Action": "ec2:RunInstances",
50         "Resource": "arn:aws:ec2:us-east-2:612113937920:subnet/*",
51         "Condition": {
52             "StringEquals": {
53                 "ec2:Vpc":
54                 ↪ "arn:aws:ec2:us-east-2:612113937920:vpc/vpc-0c7a0ba5e8cad5b83"
55             }
56         },
57         {
58             "Action": [
59                 "ec2:Describe*",
60                 "ec2:*KeyPair*",
61                 "ec2:*Nat*",
62                 "ec2:*Gateway*",
63                 "ec2:*subnet*",
64                 "ec2:CreateSecurityGroup",
65                 "ec2:CreateVolume",
66                 "ec2:ModifyVolume",
67                 "ec2:createTags",
68                 "ec2>DeleteTags",
69                 "ec2:CreateRouteTable",
70                 "ec2:ReplaceRouteTableAssociation"
71             ],
72             "Effect": "Allow",
73             "Resource": "*"
74         }
75     ]
76 }

```

4.6 AWS Services Hardware Specification & Cost Estimation

AWS resource specification							
US East (Ohio) Region							
Compute: Amazon EC2 Instances:							
Description	Instances	Usage	Type	Billing Option			
Ccrawler Node	3	50% utilization/month	Linux on t2.mciro*	On-Demand (No contract)			
Content DB (MongoDB)	1	50% utilization/month	Linux on t2.mciro	On-Demand (No contract)			
Bastion & NAT Instance	1	50% utilization/month	Linux on t2.mciro	On-Demand (No contract)			
Storage: Amazon EBS Volumes							
Description	Volumes	Volume Type	Storage	IOPS	Throughput	Snapshot Storage	
crawler nodes	3	General Purpose SSD (gp2)	8GB	100	128 MiB/sec	0 GB/month	
Content DB (MongoDB)	1	General Purpose SSD (gp2)	15 GB	100	128 MiB/sec	0 GB/month	
Amazon RDS: On-Demand DB Instances							
Description	DB Instances	Usage	DB Engine & License	Class & Deployment			Storage
Content Seen, URL filter, DUE	1	50% utilization/month	PostgreSQL	db.t2.micro standard (Single-AZ)			General Purpose 20 GB
Amazon Elastic Cache: On-Demand Cache Nodes							
Cluster Name	Nodes	Usage	Node Type				
used by fetcher, filter, due, contentseen	1	50% utilization/month	cache.t2.micro				
Amazon VPC Service:							
Data Transfer:							
In	10 GB/Month						

Figure 4.6: Whirlpool Hardware Specification on AWS

From table 4.6 under Amazon EC2 services, crawler nodes and the Bastion host sits on a on-demand EC2 instance which is of type t2.micro. The t2.micro has single core virtual CPU (vCPU) with 1 GiB of Memory. Each crawler node runs a message broker - RabbitMQ to interconnect the crawler subsystems. According to RabbitMQ Documentation [6], the host should have at least 128 MB memory available at all times. Moreover, it won't accept any new messages when it detects that it's using more than 40% of available memory. Being said that, there is always an option to change the current instance type from t2.micro to t2.small and so on depending on usage. MongoDB which collects extracted text is also hosted on On-Demand t2.micro instance type, which is a 1 GB, dual-core vCPU operating at 50% of its capacity.

Coming to Amazon Storage, the crawler node is coupled with Elastic Block Storage (EBS) volume of 8 GiB. The volume is general purpose SSD capped at 100 IOPS giving a throughput of 128 MB/sec. For MongoDB an EBS volume of 15GB is used. It is formatted with XFS filesystem for its data directory as recommended in its production checklist.

Whirlpool uses one On-Demand RDS instance with PostgreSQL engine operating at 50% utilization monthly. The underlying managed Operating System is a db.t2.micro deployed in a single AZ. PostgreSQL to store fingerprints of a web page content at a given URL, robots.txt attributes of each site, and URLs already enqueued to be crawled.

Amazon ElasticCache provides a choice between Memcached & Redis Instance. It will be used by URL filter subsystem of whirlpool.

Table 4.7 provides approximate monthly billing information of AWS services used by this project to build, test, and run experiments. The calculation was performed using AWS monthly calculator. At the time of this writing, the author is enrolled in 12-month AWS Free tier access which discounts most of the services the crawler system leverages.

AWS Resource Cost Estimation				
Service Type	Components	Region	Component Price	Service Price
Amazon EC2 Service (US East (Ohio))				\$25.95
	Compute:	US East (Ohio)	\$21.25	
	EBS Volumes:	US East (Ohio)	\$4.70	
	EBS IOPS:	US East (Ohio)	\$0	
Amazon RDS Service (US East (Ohio))				\$8.89
	DB instances:	US East (Ohio)	\$6.59	
	Storage:	US East (Ohio)	\$2.3	
Amazon ElastiCache Service (US East (Ohio))				\$6.23
	On-Demand Cac	US East (Ohio)	\$6.23	
Amazon VPC Service (US East (Ohio))				\$0.00
AWS Data Transfer In				\$0.00
	US East (Ohio) Region:		\$0.00	
AWS Support (Basic)				\$0
	Support for all AWS services:		\$0	
	Free Tier Discount:			\$-26.82
	Total Monthly Payment:			\$14.25

Figure 4.7: Whirlpool Hardware Cost Estimation on AWS

With the free-tier in use, the total price is dropped almost by 50 %. Under free tier, EC2 is limited to 750 hours/month which equates to approx. 24 hours/day for 30 days using only Linux, RHEL. Any combination of EBS (SSD/Magnetic) is 30 GiB. Amazon RDS again limited to 750 hours/month upto 20GB of general purpose SSD database storage. Amazon ElasticCache - 750 hours. NAT instance is priced similar to other EC2 crawler instance types. There is no charge for data transfer between cross-region multi-AZ as this implementation is only us-east-2 single AZ. Also, the data transfer into AWS cloud is free.

4.7 Boot Process

A fresh installation of whirlpool crawler comprising of multiple services begins by first packaging production code for each service as docker image. The below code snippet shows **Dockerfile** of **whirlpool-fetch** component. Lines 1, 28, and 31 show **dev** and **prod** target images get derived from **base** image. The specialized image produced differ by configurations, environment variables, etc.

```
1 FROM node:10.16.0 as whirlpool-fetch-base
2
3 ARG WH_FETCH_ROOT=/home/whirlpool/whirlpool-fetcher
4 WORKDIR $WH_FETCH_ROOT
5
6 RUN apt-get update \
7     && apt-get install -y --no-install-recommends netcat \
8     && rm -rf /var/lib/apt/lists/* \
9     && useradd --create-home --shell /bin/bash whirlpool \
10    && chown -R whirlpool:whirlpool $WH_FETCH_ROOT
11
12 # files necessary to build the project
13 COPY package.json ./
14 COPY .babelrc ./
15 COPY .eslintrc.js ./
16 COPY .eslintignore ./
17 COPY package-lock.json ./
18
19 RUN mkdir logs/ \
20     && npm install --no-audit
21
22 COPY config/ config/
23 COPY src/ src/
24
25 # docker image for dev target
26 FROM whirlpool-fetch-base as whirlpool-fetch-dev
27
28 COPY scripts/wait-for-it.sh scripts/wait-for-it.sh
29 ENTRYPOINT ["bash ./scripts/wait-for-it.sh"]
30
31 # docker image for prod target
32 FROM whirlpool-fetch-base as whirlpool-fetch-prod
33
34 COPY scripts/wait-for-it-prod.sh scripts/wait-for-it-prod.sh
35 ENTRYPOINT ["bash ./scripts/wait-for-it-prod.sh"]
```

The below command packages production docker image from base layer, skipping dev layer.

```
$ docker build -t whirlpool-fetch-prod:latest --target whirlpool-fetch-prod .
```

Production docker images for rest of the whirlpool components are packaged using same structure and pushed to dockerhub registry. One thing to note is its not recommended to always use the **latest** tag while publishing the package but instead use semantic version tags.

```
1 - rihbyne/whirlpool-rmq:latest
2 - rihbyne/whirlpool-parse-prod:latest
3 - rihbyne/whirlpool-contentseen-prod:latest
4 - rihbyne/whirlpool-urlfilter-prod:latest
5 - rihbyne/whirlpool-due-prod:latest
6 - rihbyne/whirlpool-urlfrontier-prod:latest
```

Next, provisioning AWS resources by firing up stack creation using Cloudformation(CF) template and AWS-cli. All required AWS components for whirlpool project such as Internet Gateway(IGW), ec2-instances, VPC Security Groups, Subnets, etc are expressed in YAML of template. Following represents justa gist of omitted cf template which spans multiple pages.

```
58 # ----- defines AWS resources for whirlpool project -----
59 Resources:
60   # define internet gateway to attach to already existing VPC
61   whirlpoolIGW:
62     Type: AWS::EC2::InternetGateway
63     Properties:
64       Tags:
65         - Key: Name
66           Value: whirlpool-igw
67
68   # vpc internet gateway attachment resource
69   WhirlpoolGatewayAttachment:
70     Type: AWS::EC2::VPCGatewayAttachment
71     Properties:
72       VpcId:
73         Ref: WhirlpoolVPCId
74       InternetGatewayId:
75         Ref: whirlpoolIGW
76
77   # ----- define 4 subnets within an existing VPC -----
78   whirlpoolPublicSubnet1:
79     Type: AWS::EC2::Subnet
80     Properties:
81       VpcId: "vpc-0c7a0ba5e8cad5b83"
82       CidrBlock: "10.0.0.0/28"
```

Given snippet from whirlpool CF template uses **cloud-init** scripts that run shell scripts at launch. automating postgres post-initialization, docker & docker-compose setup. Finally, the shell script log is redirected to log directory for traceback.

```
629 # ----- define crawler node 1 -----
630 whirlpoolCrawlerNode:
631   Type: "AWS::EC2::Instance"
632   Properties:
633     AvailabilityZone: "us-east-2a"
634     BlockDeviceMappings:
635       - DeviceName: "/dev/sda1"
636         Ebs:
637           VolumeType: "gp2"
638           DeleteOnTermination: "true"
639           VolumeSize: "8"
640         NoDevice: {}
641     ImageId: !Ref UbuntuImageId
642     InstanceInitiatedShutdownBehavior: "stop"
643     InstanceType: !Ref InstanceTypeParameters
644     KeyName: !Ref SSHKeyPair
645     Monitoring: false
646     PrivateIpAddress: "10.0.0.56"
647     SecurityGroupIds:
648       - !GetAtt whirlpoolCrawlerSecGrpPvtSub4.GroupId
649     SourceDestCheck: true
650     SubnetId: !Ref whirlpoolPrivateSubnet4
651     Tags:
652       - Key: Name
653         Value: whirlpool-crawler-node
654       - Key: Capacity
655         Value: 8GiB
656       - Key: ec2-purpose
657         Value: mercator crawler
658       - Key: placement
659         Value: pvtsub4
660     Tenancy: "default"
661     UserData:
662       Fn::Base64:
663         !Sub |
664           #cloud-config
665           repo_update: true
666
667           packages:
668             - apt-transport-https
669             - ca-certificates
670             - curl
671             - software-properties-common
672             - gnupg
673             - netcat
```

```

674
675 runcmd:
676 - [ sh, -c, "export APT_KEY_DONT_WARN_ON_DANGEROUS_USAGE=1" ]
677 - [ sh, -c, 'curl -fsSL "https://download.docker.com/linux/ubuntu/gpg" |
↳ apt-key add -' ]
678 - [ sh, -c, "apt-key fingerprint F273FCD8" ]
679 - [ sh, -c, 'add-apt-repository "deb [arch=amd64]
↳ https://download.docker.com/linux/ubuntu $(lsb_release -cs) stable"' ]
680 - [ apt-get, update ]
681 - [ apt-get, install, -y, docker-ce ]
682 - [ sh, -c, "groupadd docker" ]
683 - [ sh, -c, "usermod -aG docker ubuntu" ]
684 - systemctl enable docker
685 - [ docker, network, create, whirlpool-net ]
686 - [ sh, -c, 'curl -L
↳ "https://github.com/docker/compose/releases/download/1.24.1/docker-compose-$(uname
↳ -s)-$(uname -m)" -o "/usr/local/bin/docker-compose"' ]
687 - [ chmod, +x, "/usr/local/bin/docker-compose" ]
688 - [ sh, -c, 'curl "https://www.postgresql.org/media/keys/ACCC4CF8.asc" |
↳ apt-key add -' ]
689 - [ sh, -c, 'echo "deb http://apt.postgresql.org/pub/repos/apt/
↳ $(lsb_release -cs)-pgdg main" > /etc/apt/sources.list.d/pgdg.list' ]
690 - [ apt-get, update ]
691 - [ apt-get, install, -y, --no-install-recommends, postgresql-client-11 ]
692 - [ rm, -rf, "/var/lib/apt/lists/*" ]
693 - [ sh, -c, "cd /root; touch .pgpass" ]
694 - pwd
695 - [ sh, -c, "chmod 0600 /root/.pgpass" ]
696 - [ sh, -c, 'echo
↳ "${RDSEndpoint}:5432:*:${RDSMasterUsernameParam}:${RDSMasterPWDParam}"
↳ > /root/.pgpass' ]
697 - [ sh, -c, "while !(nc -z ${RDSEndpoint} 5432); do sleep 3; done" ]
698 - [ psql, -h, ${RDSEndpoint}, -U, ${RDSMasterUsernameParam}, -c, "CREATE
↳ USER ${RDSWhirlpoolUserParam} WITH PASSWORD '${RDSWhirlpoolPWDParam}'"
↳ ]
699 - [ sh, -c, 'psql -h ${RDSEndpoint} -U ${RDSMasterUsernameParam} -c "GRANT
↳ ALL PRIVILEGES ON DATABASE ${RDSDBNameParam} TO
↳ ${RDSWhirlpoolUserParam}"' ]
700 output: {all: '| tee -a /var/log/cloud-init-output.log'}

```

The template file needs to be uploaded to S3 before CF reads it to create stack. Appropriate IAM S3 policy and bucket level policy imposed from administrator account, is effective to limit GET, PUT, LIST only to given CF template file. A constraint under IAM CF policies is set to allow stack creation/deletion/update from existing CF template.

```
$ aws s3 cp whirlpool-cf-template.yml s3://whirlpool-cf-templates/
```

This command schedules stack creation on CF dashboard triggered using aws-cli. It takes couple of minutes before all defined resources get created. The **create-stack** command contains arguments in key, value pair which map to input parameters and AWS specific parameters in the template.

```
$ aws cloudformation create-stack --stack-name whirlpool-crawler \
--template-url https://wh-cf-templates.s3.us-east-2.amazonaws.com/cf-
template.yml \
--parameters ParameterKey=rdspwd,ParameterValue=<password> \
ParameterKey=rdsdbname,ParameterValue=<mydb> \
ParameterKey=rdswhuser,ParameterValue=<exampleuser> \
ParameterKey=rdswhpwd,ParameterValue=<examplepassword> \
ParameterKey=rdsendpoint, \
ParameterValue=whirlpool-postgres-prod.cmogaprwtcsg.us-east-2.rds.
amazonaws.com
```

Once the stack on the CF dashboard is flagged 'green' indicating complete, production docker-compose is securely copied over to private e2 instances in the private subnet 4. The second command starts all the services specified in the compose file configuration.

```
$ scp prod-docker-compose.yml whirlpool-crawler-1:~/
$ docker-compose -f prod-docker-compose.yml up -d
```

```
ubuntu@ip-10-0-0-56:~$ docker-compose -f prod-docker-compose.yml up -d
Pulling whirlpool-rmq (rihbyne/whirlpool-rmq:latest)...
latest: Pulling from rihbyne/whirlpool-rmq
5b7339215d1d: Pull complete
14ca88e9f672: Pull complete
a31c3b1caad4: Pull complete
b054a26005b7: Pull complete
eef17c6cb6cf: Pull complete
d5a267fdfe2c: Pull complete
d499647c68af: Pull complete
ad88e7bd384a: Pull complete
ae1d871f3f62: Pull complete
7ceac8eb91d4: Pull complete
123e0b4887a6: Pull complete
38357d402cd8: Pull complete
308bcf927c99: Pull complete
00870a9a0146: Pull complete
Digest: sha256:d3b327a8ad8fbcebf2169724285b21de8b042d001721e37a9c650fa76fdda418
Status: Downloaded newer image for rihbyne/whirlpool-rmq:latest
Pulling whirlpool-fetch (rihbyne/whirlpool-fetch-prod:latest)...
latest: Pulling from rihbyne/whirlpool-fetch-prod
6f2f362378c5: Extracting [=====>] 34.87MB/45.34MB
494c27a8a6b8: Download complete
7596bb83081b: Download complete
372744b62d49: Download complete
615db220d76c: Downloading [=====>] 148.5MB/215.1MB
afaefeaac9ee: Download complete
0be21b88d1bd: Download complete
707f080d8674: Download complete
7cd6fdb97802: Download complete
c9626781f173: Download complete
7af74dc145ec: Download complete
9ec72faef758: Download complete
68f0a078590b: Download complete
a5afed1b6e13: Download complete
ae9adf8e375d: Download complete
589926404801: Download complete
49a12c285468: Waiting
d0bec0404887: Waiting
5ddc9d3e80c7: Waiting
84d501d9d638: Waiting
```

Figure 4.8: docker pull, extract, start containers

Deleting the stack **whirlpool-crawler** terminates ec2 machines and dependent components in chronological order.

```
$ aws cloudformation delete-stack --stack-name whirlpool-crawler
```

5 | Experiment Results & Justification

This section depends on lessons learned and any observations made in section 3. Yet to be completed

5.1 Whirlpool as a Microservice Application

To be completed

6 | Conclusion & Future Work

This chapter is a list of follow-up ideas that can be turned into potential projects. These are complex and important topics that deserve a report of their own. This paper won't do them justice by making them superficial side notes. The ideas are grouped by subject of interest.

6.1 Systems

6.1.1 Experimenting with Distributed Data

6.2 Search

6.2.1 Data Indexing using Elasticsearch Engine

6.3 Frontend

6.3.1 GUI Admin & Monitoring Dashboard

6.4 Machine Learning (ML)

6.4.1 Discovering new relevant websites by adding Comprehensive Coverage using ML techniques

6.4.2 Categorizing Jobs using Supervised/RNN classifier

7 | Timeline

I intend to graduate in fall 2019 i.e next semester. Below is my timeline to execute the thesis starting first week of June, 2019:

- (Week 1 - 7) First get the single node crawler running on local development environment. To achieve this,
- (Week 1) Build docker images of data stores involved. I will be using PostgreSQL for fingerprintDB, Robots Exclusion Policy, and DUE url set. The job data will be stored in MongoDB(development & production). Each data store will maintain local.yml & production.yml version of dockerfile which will point to local and aws version of databases, respectively.
 - (Week 1) Build docker image of RabbitMQ with default configuration. Followed by getting acquainted with enough terminology and tutorials to get started. This image will be shared with all subsystems of a crawler.
 - (Week 2) Initialize git repository for each subsystem of the crawler. Build docker image for each subsystem, specify RabbitMQ as its dependency. Bind each subsystem to a queue through a message broker depending on its role as a consumer/producer. Test for open connections of each consumer/producer.
 - (Week 2) Boot all the subsystems in sequence using docker compose. Test the message passing between services. This stage ensures the tooling required is up & running as expected.
 - (Week 3) URL Frontier queue is the 1st step of the crawler subsystem. Initially, maintain a single FIFO queue under the frontier with seed sets listed in section 3.1. Code functionality for consumer & producer scripts bound to a queue of fetcher & DNS subsystem.
 - (Week 4) Given the seed URL u and a page p , code functionality for consumer & producer scripts of Parser, Content Seen subsystems, respectively as separate services. Test message passing among fetcher, parser, & content seen.
 - (Week 5) Next, once we have extracted links from page p , code functionality for consumer & producer scripts bound to a queue for URL filter subsystem. Test message passing between this filter and previous subsystems implemented.
 - (Week 6) DUE tracks present & past history of URLs in Frontier regardless of whether they are 1-time crawl or continuous crawls. Implement consumer & producer scripts for DUE. Test message passing between subsystems implemented so far.
 - (Week 7) Write code for front(priority) and back(politeness) queue of URL Frontier subsystem. Verify messages published & consumed. Test message passing between subsystems implemented so far.

- (Week 8) At this stage, ensure the crawler as a whole is running as a single node on local machine.
- (Week 8 & 9) Next, Setup AWS Infrastructure for whirlpool by following the diagram. Build and test the docker images in isolation pointing to AWS data stores within the pvt subnets.
- (Week 10) Get crawler running on single node within a private subnet of AWS VPC.
- (Week 10 & 11) Initialize a repo. for host splitting module. Implement consistent hashing algorithm. This will parallelize crawling.
- (Week 11 & 12) Make 2nd identical clone of the crawler within a private subnet of AWS VPC. Observe & verify traffic is split equally between the nodes.
- (week 13) Demonstrate Whirlpool working to Dr. Soltys. Make any changes requested in the code or the report.

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