

Reactive Systems on AWS

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Abstract

Today, architects and developers are expected to implement highly scalable and resilient distributed system on Amazon Web Services (AWS). This whitepaper outlines best practices for designing a system based on reactive principles using the AWS Cloud platform and offers a reference architecture to guide organizations in the delivery of these systems.

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Introduction

Microservice application requirements have changed dramatically in recent years. Many modern applications are expected to handle petabytes of data, require close to 100% uptime, and deliver sub-second response time to users. Typical N-tier applications can't deliver on these requirements. Today reactive architectures and reactive systems have been adopted by a growing number of enterprises, because it is necessary to design applications in a highly scalable and responsive way. But what exactly is a reactive system?

The [Reactive Manifesto](#), describes the essential characteristics of reactive systems including: responsiveness, resiliency, elasticity, and being message driven.

Being message driven is perhaps the most important characteristic of reactive systems. Asynchronous messaging helps in the design of loosely coupled systems, which is a key factor for scalability. In order to build highly resilient systems, it is important to isolate services from each other. Microservices are an architectural and organizational approach to software development where software is composed of small independent services that communicate over well-defined APIs. These services are owned by small, self-contained teams. Isolation and decoupling are an important aspect of the microservices pattern as well. This makes reactive systems and microservices a natural fit.

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Characteristics of reactive systems

The following sections outline the essential characteristics of reactive systems.

Responsive

Responsiveness means that systems respond in a timely manner. It is crucial to reduce latency between request and response. Latency is an important factor that can, under certain circumstances, be decisive for the success or failure of a service. It directly influences the behavior of the consumer of the website or webservice. Imagine, you want to check out your shopping cart on an e-commerce website and processing of the payment takes a significant amount of time or even crashes. This results in an overall bad user experience. Latency is often correlated with conversion rate. Responding in a timely manner ensures these systems deliver a consistent behavior and quality of service.

Resilient

A resilient system stays responsive in the face of failure. A resilient workload has the capability to recover when stressed by load, attacks, and failure of any component in the workload's components. If a failure occurs in one component, this must be contained in the source of the failure by isolating it from others. As a result, this prevents a small failure from causing a major outage of the complete system.

Elastic

A reactive architecture remains responsive under varying workload. This elasticity requires you to be able to scale a system dynamically and add or remove resources to react to changes which leads to the avoidance of bottlenecks. These systems support predictive as well as reactive scaling based on metrics used to monitor an efficient use of resources.

Message driven

In order to react to changes between services, reactive systems rely on asynchronous message-passing. This helps ensure loose coupling, isolation, and location transparency. Location transparency can be achieved by using a message queue or a similar system to access data without the explicit knowledge of the location. This can be achieved using network resources like DNS. The main advantage of this approach is that it's not important where exactly the resource is located. This is key for

resiliency and elasticity, because a failover mechanism can be implemented that abstracts the actual resource behind a network name. In reactive systems, asynchronous message-passing is also used to distribute information of failures or other errors as messages. By using this pattern, the system enables better load management by monitoring the message queues and implementing a mechanism for [backpressure](#). This allows non-blocking communication which leads to less system overhead. One of the biggest challenges to effectively scale large systems is the bottleneck that is introduced by shared resources. This communication pattern helps minimizing concurrent access.

But what's the difference between message-driven and event-driven? According to K. Mani Chandy, Professor of Computer Science at the California Institute of Technology, events can be defined as [a significant change in state](#)¹. An event can be a change in an AWS environment. For example, [Amazon EC2 Auto Scaling](#) generates events when it launches or terminates instances. A message however has a clear direction: it's a command sent to a system. The destination reacts on the message and starts an action.

Observability and tracing

As already outlined, reactive systems are defined as message-driven and resilient, which means, a reactive system - by nature - will be a distributed system. This necessarily includes additional network communication. In a traditional monolithic application (for example, a JavaEE application) the complete application resides in the same memory on one device, potentially with full redundant copies on other machines to allow for failover. In many cases, monolithic applications have better latency compared to distributed application but with limitations in scalability and availability. The example application discussed later shows patterns and best practices to reduce latency, but in many cases, workloads that have very low latency requirements such as high-frequency trading, are not good candidates for reactive systems. Due to the distributed nature of reactive systems that involve communication over network and across server-boundaries, the additional latency has a huge impact on the performance of the overall application.

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If there is an error in a traditional monolithic application, for example an exception was found in one of the log files, debugging this problem is often relatively easy due to the non-distributed nature of the application. A typical microservices based application that passes messages for communication is harder to debug, because it is sometimes not possible to reproduce the exact state of the complete system and replay events in order

to reproduce issues. Each service has a separate log file, even though those log files are often consolidated in a central system such as [Amazon CloudWatch Logs](#) or [Amazon OpenSearch Service](#). An additional critical piece of the puzzle is to correlate an event with a specific set of log entries. Each event needs a unique identifier which needs to be logged on each step of its journey through different microservices. You can add the following [tracing header](#) to incoming HTTP requests that don't already have one using services such as [Application Load Balancer](#) or [Amazon API Gateway](#):

```
X-Amzn-Trace-Id: Root=1-5759e988-bd862e3fe1be46a994272793
```

This tracing header can be used to correlate events with log entries. In addition, you can use services such as [AWS X-Ray](#) to trace and analyze requests as they travel through your entire system, from Application Load Balancer or Amazon API Gateway APIs to the underlying services, making it much easier to identify issues and visualize service calls. AWS X-Ray helps developers analyze and debug production, distributed applications, which are built using a microservices architecture. X-Ray's service maps let you see relationships between services and resources in your application in real time. You can easily detect where high latencies are occurring, visualize node and edge latency distribution for services, and then drill down into the specific services and paths impacting application performance.

Reactive programming and reactive streams

It is important to make a distinction between reactive systems and reactive programming because these two completely different concepts are often confused. Reactive systems are responsive, resilient, elastic, and message driven as per preceding paragraphs. This description shows that reactive systems are an architectural approach to design distributed responsive systems. Reactive programming, however, is a software design approach which focuses on asynchronous data streams. Everything in the application is seen as a stream of data which can be observed (observer pattern). An interesting approach to simplify the challenges of reactive programming are [Reactive eXtensions](#), an “API for asynchronous programming with observable streams”. Reactive Programming can help to build a system based on the principles of the Reactive Manifesto, but the use of reactive programming doesn't necessarily mean that a system is reactive.

[Reactive Streams](#) is an initiative to define a standard for asynchronous stream processing with non-blocking backpressure. The main goal of this concept is to control the exchange of streaming data across an asynchronous boundary. Backpressure is an

integral part of this model: The recipient is only sent as much data as it can process or buffer in and the receiver explicitly requests the data according to its capacity. This means, the sender may only send as much data as the receiver has requested.

The goal behind the Reactive Streams' specification is to create the basis for compatible implementations that can communicate with each other. This specification includes a minimal set of interfaces, methods, and protocols, that define operations and entities that are necessary to implement a compatible version.

Typical use-cases for reactive systems

In the previous section, the essential characteristics of reactive systems was outlined. What do typical use cases for reactive systems have in common? Potentially millions of messages flow into the backend system. The impact of this requirement is a backend system that is able to quickly scale out and is resilient.

Advertising technology (Ad tech) face an interesting challenge to collect or track a lot of information. Usually this is a tracking pixel on a website that ingests data into a system. Depending on the campaign and its success, the amount of data that needs to be collected and transformed may significantly vary and is not always predictable. The following sections take a closer look at an example implementation for a tracking system for ads.

For **eCommerce**, it's a similar situation: if a product goes viral on social media or an advertising campaign is surprisingly successful, a lot of people will visit the eCommerce website and order products.

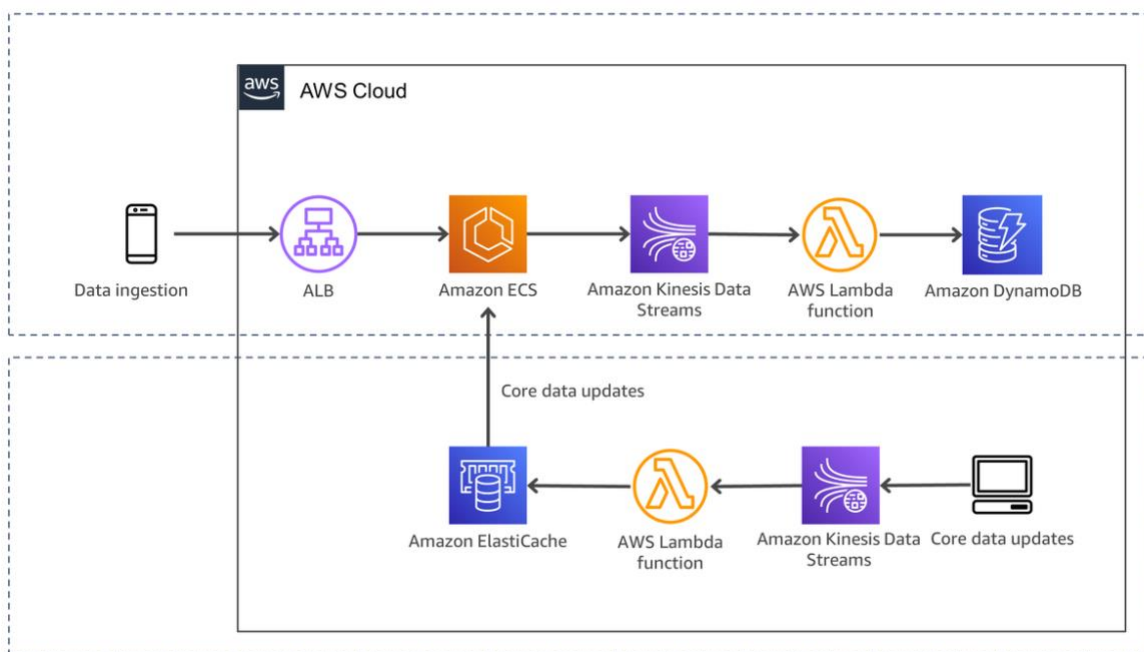
For **IoT**, you need to be able to manage millions of connected devices that produce a huge amount of sensor data. This data needs to be collected, stored, and analyzed. Often it is necessary to send additional data back to the connected devices to update the status. The complete system has to be responsive in order to deliver feedback to users or trigger changes in the devices or machines within a short span of time.

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Example architecture

To help explain how reactive principles can be applied to real world application, the following [example architecture](#) implements a reactive system for the following common ad-tech use case.

Many ad-tracking companies collect large amounts of data in near-real-time. In many cases, these workloads are very spiky and heavily depend on the success of the ad-tech company's customers; they also need to be responsive and resilient, as these systems form part of the backbone of many ad-tech companies.



Example architecture

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In this example architecture the system can be logically divided into one part focused on *data collection* and another part focuses on *core data updates*. The *data collection* subsystem is responsible for collecting, validating, and persisting the tracking data, potentially enriching it with some core data in the process. In the *core data update* subsystem, the data that is used to validate and enrich the incoming raw tracking data—this typically includes data on ad inventory, campaigns, publishers, publishers' remaining campaign budgets, and etc.—receives updates from upstream back-office systems (not implemented in the example architecture) and notifies all subscribers about the changed and added data.

Typically for an ad-tracking use case, the data collection subsystem can be separated further into a real-time part and a *non-real-time* part. For the real-time part, it is most important to collect data as quickly as possible and ask several questions such as:

- Is this a valid combination of parameters?
- Does this campaign exist?
- Is this campaign still valid?

Because response time has a huge impact on conversion rate in advertising, it is important for advertisers to respond as quickly as possible. Any information required to decide on a response should be kept in memory to reduce communication overhead with the caching infrastructure. The tracking application itself should be as lightweight and scalable as possible. For example, the application shouldn't have any shared mutable state. In the example architecture, one main application running in Amazon ECS is responsible for the *real-time part*, which collects and validates data, responds to the client as fast as possible, and asynchronously sends events to backend systems.

The *non-real-time* part of the application consumes the generated events and persists them in a NoSQL database. In a standard tracking implementation this includes clicks, cookie information, and transactions; once stored, these are later matched asynchronously and persisted in a data store. At the time of publication, matching is not implemented in the example architecture. However, you can use big-data frameworks like Hadoop or Spark for the matching implementation. The results of this matching process and other back-office processes (fraud checks, billing of providers of ad inventory, payouts to ad space providers, and etc.) often result in updates to the *core data*, and is then fed back into the core data updates subsystem via an event stream.

In the example architecture shown in the architecture diagram, the request (ad impression or clicked ad) is ingested to the Application Load Balancer which routes the incoming request to one of the service instances in the main application. The L1 cache – which is stored in the memory of the application - stores the most recent core data updates. In addition, there is an open connection to the L2 cache. The application processes each incoming request separately. It implements this in a responsive and resilient manner and doesn't write directly to a database. Using Amazon Kinesis Data Streams new events are added to a data stream and consumed by an AWS Lambda function which writes the data into an Amazon DynamoDB table. The data stream – implemented with Amazon Kinesis Data Streams - acts as a main buffer to decouple the database from the application and ensure that this event data under load isn't lost.

With this architecture you can reliably process a huge number of events and store them safely. The application does not live in a vacuum - typically, it needs to rely on other data that is not present in the event. In the ad tech example, this *core data* would include information about the available event inventory, the ad publishers, their budgets and preferences, etc. This data lives in a variety of upstream systems - the challenge is that it needs to be available to our application at any time and without having to wait for the source system. To reduce latency of access to this *core data* and to simplify the architecture, Amazon ElastiCache for Redis is used as the main interface, which means all the necessary data is cached for the application. As with any cache, you still need to track updates to our core data sets. These source systems are out of scope for this whitepaper, but assume that you get update events whenever something changes. In this situation, you rely on message-passing. The application offers an event stream that all the source systems can write to whenever they see a change. This offers a fairly minimal interface to the outside world and decouples it from our system; using Kinesis Data Streams you can handle various request rates without having to worry a lot about the infrastructure. In some situations, you might have to deal with different request rates and many different types of data, depending on how many source systems the core data comes from. Similar to how this is done in the main event pipeline, you can use a Lambda function to have an elastic, resilient processing mechanism to process new data on the stream and updates the main cache to make it available to the application.

Using an event driven and non-blocking framework

The main application in the example architecture, is using a framework called [Eclipse Vert.x](https://docs.aws.amazon.com/whitepapers/latest/reactive-systems-on-aws/reactive-systems-on-aws.html), which is a toolkit for building reactive applications on the JVM. Vert.x is *event driven* and *non-blocking*. This version has been archived. For the latest version of this document, visit: <https://docs.aws.amazon.com/whitepapers/latest/reactive-systems-on-aws/reactive-systems-on-aws.html>. This means Vert.x applications can handle a large number of concurrent connections using a small number of kernel threads. The same or similar patterns and paradigms can be used with Akka, Micronaut or other frameworks. Vert.x uses a simple, scalable, actor-like deployment and concurrency model based on so called *verticles* which are chunks of code extending an abstract class. Due to the polymorphic nature of Vert.x, verticles can be implemented in different languages and a single application can consist of verticles written in multiple languages. The verticles communicate with each other using the event bus - which supports publish/subscribe, point-to-point, and request-response messaging - by sending messages. In the example architecture this means that it has the same architectural principles on a micro- as well as on a macro-level. The different parts of the architecture communicate by exchanging messages and this also applies to the internal communication of the main application.

In most cases Vert.x calls your handlers using a thread called an event loop. Aside from

the updates to the external Redis cache the application also keeps its own L1, in-process cache. Whenever the Redis cache is updated, you need to update the in-process cache. Going with the design principles you will want to get these updates pushed into the application. But why is it necessary to store data in a L1-cache? This is important to distribute core data changes using Redis, because it is necessary to reduce the number of accesses to the L2-cache. After 10 minutes the data is automatically invalidated and a data refresh is necessary. This behavior is a trade-off, because you might run into situation where you have to deal with stale data. Doing so also protects the application from failures that cause the Redis cluster to become unreachable or slows down its responses. The following code snippet shows an excerpt from the verticle which is responsible for the communication with Redis, that you can use to subscribe to the event bus.

```
void registerToEventBusForPubSub(final EventBus eb) {
    eb.<JsonObject>consumer(REDIS_PUBSUB_CHANNEL_VERTX)
        .handler(received -> {
            JsonObject value =
received.body().getJsonObject("value");

            String message = value.getString("message");

            JsonObject jsonObject = new JsonObject(message);
            eb.send(CACHE_REDIS_EVENTBUS_ADDRESS, jsonObject);
        });
    redis.connect()
        .onSuccess(conn -> {
            conn

.send(cmd(SUBSCRIBE).arg(Constants.REDIS_PUBSUB_CHANNEL))
                .onSuccess(res -> LOGGER.info("Subscribed
to " + Constants.REDIS_PUBSUB_CHANNEL))
                .onFailure(err -> LOGGER.info("Subscription
failed: " + err.getMessage()));

        })
        .onFailure(err -> LOGGER.info("Failure during
connection: " + err.getMessage()));
}
```

In this code snippet, the Redis client first subscribes to the Redis channel using `redis.connect()`. After successful subscription, data is sent to the verticle over the

event bus. The verticle unwraps the data and sends it to the caching verticle to store the data in the L1-cache. This is a very fast and lightweight implementation and you can reuse existing infrastructure, because Redis is already being used for caching purposes.

The reactive manifesto and AWS services

The following section focuses on how to map compute and messaging services to the four principles of the reactive manifesto. This section only focuses on a limited set of services which are also used in the example implementation examined in the last chapter.

Service introduction

Amazon ECS

Amazon Elastic Container Service (Amazon ECS) is a fully managed container orchestration service. It is a shared state, optimistic concurrency system that provides flexible scheduling capabilities for your tasks and containers. In the reference architecture, Amazon ECS with AWS Fargate is used to run the main application which is implemented using Java. One of the objectives in the development of the application was to keep the latency as low as possible, because in this part increased latency has a negative impact on the conversion rate. For this particular use case, it's recommended to use Amazon ECS instead of AWS Lambda. If the different components of the application were split into individual Lambda functions and these were orchestrated with AWS Step Functions, this would have a negative impact on latency, which is not a problem for many use cases, but in this particular case, keeping latency as low as possible is a very important aspect of the overall application.

Amazon EKS

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[Amazon Elastic Kubernetes Service](https://docs.aws.amazon.com/whitepapers/latest/reactive-systems-on-aws/reactive-systems-on-aws.html) (Amazon EKS) gives you the flexibility to start, run, and scale Kubernetes applications in the AWS Cloud or on-premises. Amazon EKS helps you provide highly-available and secure clusters and automates key tasks such as patching, node provisioning, and updates. Amazon EKS was not used for the implementation of the sample architecture; however, it is possible to use Amazon EKS instead of Amazon ECS.

AWS Lambda

AWS Lambda is a serverless compute service that lets you run code without provisioning or managing servers, creating workload-aware cluster scaling logic,

maintaining event integrations, or managing runtimes. With Lambda, you can run code for virtually any type of application or backend service - all with zero administration. AWS Lambda's role in the example architecture is to receive messages from the Amazon Kinesis Data Stream, which is very low implementation overhead. Lambda integrates natively with Kinesis Data Streams. The polling, checkpointing, and error handling complexities are abstracted when using this integration. This allows the Lambda function code to focus on business logic processing.

Amazon Kinesis Data Streams

Amazon Kinesis Data Streams is a massively scalable and durable real-time data streaming service. In this architecture, Kinesis Data Streams is used to decouple key application components, such as processing incoming data and persisting the enriched data in Amazon DynamoDB. This split is possible because the writing of the data can be done asynchronously, while the response to the requesting client should happen as quickly as possible.

Amazon ElastiCache

Amazon ElastiCache offers a fully managed in-memory data store, compatible with Redis or Memcached that enables you to power real-time applications with sub-millisecond latency. The service can scale-out, scale-in, and scale-up to meet fluctuating application demands. Write and memory scaling is supported with sharding. In this architecture, Redis is used in two different ways: source for core data, and pub/sub implementation to actively update the L1-cache in the main application.

Amazon DynamoDB

Amazon DynamoDB is a key-value and document database that delivers single-digit millisecond performance at any scale. It is a fully managed database with scalability and high availability built in. DynamoDB is used in this architecture as the central repository for the result data, since DynamoDB is fully managed, multi-region, multi-active, durable database for internet-scale applications.

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Principles and services

Responsive <https://docs.aws.amazon.com/whitepapers/latest/reactive-systems-on-aws/reactive-systems-on-aws.html>

As previously mentioned, being responsive means that systems respond in a timely manner, even under heavy load. To meet this requirement, special attention must be paid to latency. In the example architecture, an Application Load Balancer serves as the single point of contact for clients. The load balancer distributes incoming application

traffic across multiple targets, such as EC2 instances, in multiple Availability Zones. This increases the availability of your application, and you can add one or more listeners to your load balancer. Elastic Load Balancing publishes data points to Amazon CloudWatch for your load balancers and your targets. CloudWatch enables you to retrieve statistics about those data points as an ordered set of time-series data, known as metrics. You can think of a metric as a variable to monitor, and the data points as the values of that variable over time. For example, you can monitor the total number of healthy targets for a load balancer over a specified time period. Application Load Balancer exposes the metric `TargetResponseTime` which is the time elapsed (in seconds) after the request leaves the load balancer until a response from the target is received. Based on this metric, it is possible to scale out the number of services running in an Amazon ECS cluster by defining Amazon CloudWatch Alarms.

Another important component for reducing latency is the use of caches. At this point you have to differentiate between an in-memory cache inside the application and external caches such as Redis or Memcache, which are offered as a managed service within the framework of Amazon ElastiCache. In-memory caches can be used directly in the application via corresponding libraries. Depending on the extent to which outdated data can be tolerated, this type of cache should be updated shortly after records are changed, and can be implemented via a pub/sub mechanism. In addition, a least-recently-used (LRU) strategy and the limitation of cache entries in terms of quantity and time are also useful. There are several strategies and picking the right caching strategy has a huge impact on the overall performance of the system.

The following section outlines popular caching strategies:

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Cache-aside

The cache-aside strategy is one of the most common design patterns for cache access. The cache sits next to the database and first the cache is checked to see if a value is found there. If it is not there, the database is queried and the value is then stored in the cache. This means, data is read lazily on first read. One major advantage of this strategy is that the architecture is resilient to cache failures: if your cache fails, the system can still work, but it will have a major impact on response time and latency. It is a common best practice to invalidate cache entries if data is updated or deleted. In addition, a time to live (TTL) is used to automatically invalidate cache entries.

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Read-through

This read-through strategy is similar to cache-aside, one major difference is that the cache is responsible for reading from the database. With a read-through cache, this is

used as a central storage for data: all read accesses go to the cache. If no entry is found when reading, the missing data is fetched from the database by the cache. A read-through cache loads data lazily if the data is accessed for the first time.

Write-through

The write-through strategy ensures that entries that are written into the cache are also put into the central storage behind it (for example, a database). Amazon DynamoDB Accelerator (DAX) is a write-through caching service that is designed to simplify the process of adding a cache to DynamoDB tables. Because DAX operates separately from DynamoDB, it is important that you understand the [consistency models of both DAX and DynamoDB](#) to ensure that your applications behave as you expect. Usually, write-through caches are combined with read-through caches, because an isolated write-through cache will only introduce additional latency.

Write-back (write-behind)

The write-back strategy, stores entries directly in the cache by the application and after a delay are stored in a database. This type of caching is particularly suitable for write-intensive applications, because services don't have to wait for data being persisted to the database. Database updates can be stored in a queue and applied asynchronously. Often this pattern is combined with a read-through cache if the workload is read- and write-heavy.

All of these caching strategies have advantages and disadvantages, which can be mitigated by appropriate logic (invalidation, pre-warming etc.). Therefore, additional logic is necessary, which has to be implemented and tested.

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Resilient

Everything fails, all the time.

- Werner Vogels (CTO, Amazon.com)

According to the [AWS Well-Architected Framework](https://docs.aws.amazon.com/whitepapers/latest/reactive-systems-on-aws/reactive-systems-on-aws.html), resiliency is the ability for a system to recover from a failure induced by load, attacks, and failures. Depending on the service used, resiliency is either part of the service offering or has to be designed by the customer, depending on the specific requirements. The following section discusses resiliency for different AWS services and how this can be implemented.

AWS Global Infrastructure

The AWS Global Infrastructure consists of multiple building blocks that provide different levels of independent, redundant components. AWS partitions resources and requests via some dimension. These partitions or *cells* are designed to be independent and in the case of an error, contain faults to within a single cell. For example, Amazon Route53 uses the concept of shuffle sharding to isolate customer requests into cells.

AWS also offers the fault isolation construct of Availability Zones (AZs). Each AWS Region consists of multiple, isolated, and physically separate AZs within a geographic area. Each AZ is separated by a large physical distance from other zones to avoid correlated failure scenarios. An AZ consists of one or more discrete data centers with redundant power, networking, and connectivity in an AWS Region. Despite being geographically separated, Availability Zones are located in the same regional area. This enables customers to use AZs in an active/active or active/standby configuration. Some AWS services are deployed as strictly zonal services. These services are used to independently operate resources (instances, databases, and other infrastructure) within the specific AZ.

While AWS control planes typically provide the ability to manage resources at a regional level (multiple AZs), certain control planes (including Amazon EC2 and Amazon EBS) have the ability to filter results to a single Availability Zone.

The most pervasive fault isolation construct is that of the AWS Region. Regions are designed to be autonomous, with dedicated copies of services deployed in each region. Regional AWS services internally use multiple Availability Zones in an active/active configuration to achieve the availability design goals for each service.

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AWS Lambda

In addition to the benefits of the AWS global infrastructure, AWS Lambda offers several features to help support your data resiliency and backup needs. Lambda runs instances of your function in multiple AZs to ensure that it is available to process events in case of a service interruption in a single zone. If you configure your function to connect to a virtual private cloud (VPC) in your account, specify subnets in multiple AZs to ensure high availability. To make sure that your function can always scale to handle additional requests, you can reserve concurrency for it. Setting reserved concurrency for a function ensures that it can scale to, but not exceed, a specified number of concurrent invocations. This ensures that you don't lose requests due to other functions consuming all of the available concurrency. For asynchronous invocations and a subset of invocations triggered by other services, Lambda automatically retries on error with

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appropriate delays between retries. Other clients and AWS services that invoke functions synchronously are responsible for performing retries. In addition, you can configure Lambda to send requests to a dead-letter queue if all retries fail for asynchronous invocations. A dead-letter queue is an Amazon Simple Notification Service (Amazon SNS) topic or Amazon Simple Queue Service (Amazon SQS) queue that receives events for troubleshooting or reprocessing. You can use versioning in Lambda to save your function's code and configuration as you develop it. Together with aliases, you can use versioning to perform blue/green and rolling deployments.

Amazon ECS

[Amazon Elastic Container Service](#) (Amazon ECS) schedulers leverage the same cluster state information provided by the Amazon ECS API to make appropriate placement decisions. A *task placement strategy* is an algorithm for selecting instances for task placement or tasks for termination. A *task placement constraint* is a rule that is considered during task placement. For example, you can use constraints to place tasks based on AZ or instance type. Amazon ECS supports two *launch types* that determine how instances of tasks (containers) are being launched:

Each task that uses the AWS Fargate launch type has its own isolation boundary and does not share the underlying kernel, CPU resources, memory resources, or elastic network interface with another task. AWS Fargate is a serverless compute engine for containers that works with both Amazon ECS and Amazon EKS. Fargate removes the need to provision and manage servers, lets you specify and pay for resources per application, and improves security through application isolation by design.

When a task that uses the EC2 launch type is launched, Amazon ECS must determine on which EC2 instance in your ECS cluster to place the task based; this decision is based on the requirements specified in the task definition, such as CPU and memory. Similarly, when you scale down the task count, Amazon ECS must determine which tasks to terminate. You can apply task placement strategies and constraints to customize how Amazon ECS places and terminates tasks. Task placement strategies and constraints are not supported for tasks using the Fargate launch type. By default, Fargate tasks are spread across AZs.

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Amazon EKS

[Amazon Elastic Kubernetes Service](#) (Amazon EKS) runs Kubernetes control plane instances across multiple Availability Zones to ensure high availability. Amazon EKS automatically detects and replaces unhealthy control plane instances, and it provides automated version upgrades and patching for them. This control plane consists of at

least two API server nodes and three `etcd` nodes that run across three AZs within a region. Amazon EKS leverages the architecture of AWS Regions in order to maintain high availability. Because of this, Amazon EKS is able to offer an [SLA for API server endpoint availability](#).

For the data plane (for example, your worker nodes), you have to create at least a single node group spanning across multiple AZs. You can also start one node group per Availability Zone. The Kubernetes [Cluster Autoscaler](#) automatically adjusts the number of nodes in your cluster when pods fail to launch due to lack of resources or when nodes in the cluster are underutilized and their pods can be rescheduled onto other nodes in the cluster.

Amazon EKS integrates Kubernetes with AWS Fargate by using controllers that are built by AWS using the upstream, extensible model provided by Kubernetes. These controllers run as part of the Amazon EKS managed Kubernetes control plane and are responsible for scheduling native Kubernetes pods onto Fargate. The Fargate controllers include a new scheduler that runs alongside the default Kubernetes scheduler in addition to several mutating and validating admission controllers. When you start a pod that meets the criteria for running on Fargate, the Fargate controllers running in the cluster recognize, update, and schedule the pod onto Fargate.

In addition to self-managed nodes, Amazon EKS offers managed node groups. With Amazon EKS managed node groups, you don't need to separately provision or register the Amazon EC2 instances that provide compute capacity to run your Kubernetes applications. You can create, automatically update, or terminate nodes for your cluster with a single operation. Nodes run using the latest Amazon EKS optimized AMIs in your AWS account. Node updates and terminations automatically and gracefully drain nodes to ensure that your applications stay available.

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Amazon DynamoDB

DynamoDB is a regional, cell-based service that offers a high degree of resiliency out of the box. The service provides on-demand backup capability. It enables you to store full backups of your tables for long-term retention and archival. Point-in-time recovery helps protect your DynamoDB tables from accidental write or delete operations. With point-in-time recovery, you don't have to worry about creating, maintaining, or scheduling on-demand backups.

Amazon ElastiCache

Amazon ElastiCache helps mitigate common failure modes that could affect your

(external) caching layer and thus the overall system's responsiveness and resiliency. There are two types of failures you need to plan for, individual cache node failures and broad AZ failures. The best failure mitigation plan will address both kinds of failures.

Minimizing the impact of failures

To minimize the impact of a node failure, it's recommended that your implementation use multiple nodes in each shard and distribute the nodes across multiple AZs. When running Redis, AWS recommends that you enable multi-AZ on your replication group so that ElastiCache will automatically fail over to a replica if the primary node fails.

Minimizing the impact of AZ failures

To minimize the impact of an AZ failure, it's recommended launching your nodes in as many different Availability Zones as are available. Spreading your nodes evenly across AZs will minimize the impact in the unlikely event of an AZ failure.

Other precautions

If you're running Redis, then in addition to the previous recommendations, it's recommended that you schedule regular backups of your cluster. Backups (snapshots) create a `.rdb` file you can use to restore your cluster in case of failure or corruption.

Amazon Kinesis Data Streams

Amazon Kinesis Data Streams is a massively scalable and durable real-time data streaming service. High availability and durability are achieved by synchronously replicating data to three AZs.

Failure can occur at the following levels when you use an Amazon Kinesis Data Streams application to process data from a stream.

- A record processor could fail
- A worker could fail, or the instance of the application that instantiated the worker could fail
- An EC2 instance that is hosting one or more instances of the application could fail

<https://docs.aws.amazon.com/whitepapers/latest/reactive-systems-on-aws/reactive-systems-on-aws.html>

For more information, refer to [Disaster Recovery in Amazon Kinesis Data Streams](https://docs.aws.amazon.com/whitepapers/latest/reactive-systems-on-aws/reactive-systems-on-aws.html).

Elastic

[Elasticity](#) is “The ability to acquire resources as you need them and release resources when you no longer need them. In the cloud, you want to do this automatically.”

Depending on the service, elasticity is sometimes part of the service itself. Other services require vertical scaling. A third group of services integrate with AWS Auto Scaling. The following section discusses elasticity for different AWS services and how this can be implemented.

AWS Lambda

AWS Lambda has elastic scalability already built in: the service executes your code only when needed and scales automatically, from a few requests per day to thousands per second. The first time you invoke your function, AWS Lambda creates an instance of the function and runs its handler method to process the event. When the function returns a response, it stays active and waits to process additional events. If you invoke the function again while the first event is being processed, Lambda initializes another instance, and the function processes the two events concurrently. As more events come in, Lambda routes them to available instances and creates new instances as needed. When the number of requests decreases, Lambda stops unused instances to free up scaling capacity for other functions. The function's *concurrency* is the number of instances that serve requests at a given time. Concurrency is subject to a regional quota that is shared by all functions in a region. AWS Lambda offers [Reserved concurrency](#) and [Provisioned concurrency](#) to control concurrency. Reserved concurrency guarantees the maximum number of concurrent instances for the function. When a function has reserved concurrency, other function can't use that concurrency. Provisioned concurrency initializes a requested number of execution environments so that they are prepared to respond immediately to your function's invocations. For more information, see [AWS Lambda function scaling](#).

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Amazon ECS and Amazon EKS

[Amazon ECS cluster auto scaling](#) gives you control over how you scale tasks within a

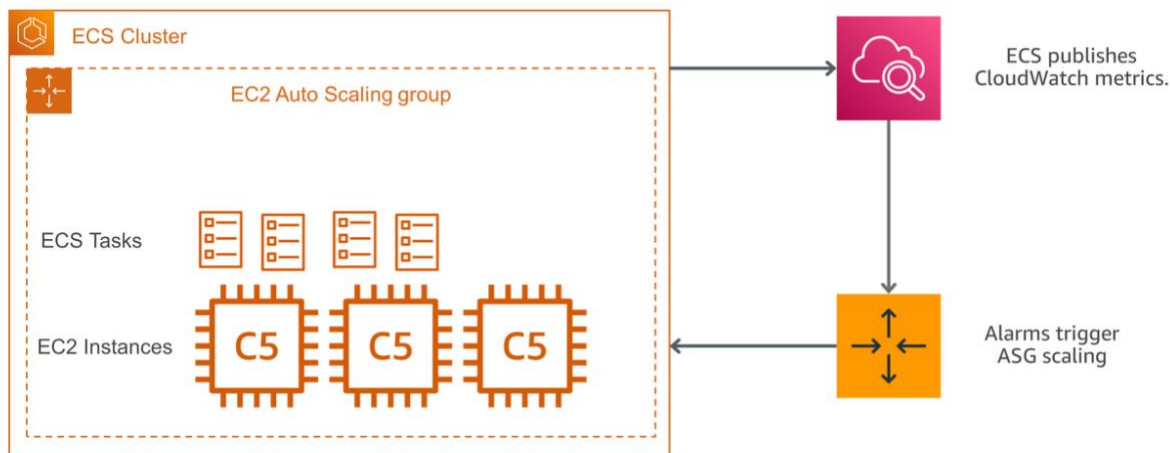
cluster. Each cluster has one or more capacity providers and an optional default capacity provider strategy. The capacity providers determine the infrastructure to use for the tasks, and the capacity provider strategy determines how the tasks are spread across the capacity providers. When you run a task or create a service, you can either use the cluster's default capacity provider strategy or specify a capacity provider strategy that overrides the cluster's default strategy.

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Amazon ECS publishes Amazon CloudWatch metrics with your service's average CPU and memory usage. You can use these and other CloudWatch metrics to scale out your service (add more tasks) to deal with high demand at peak times, and to scale in your service (run fewer tasks) to reduce costs during periods of low utilization.

In order to scale the underlying infrastructure, Amazon ECS offers integration into Auto Scaling with ECS Cluster Auto Scaling. ECS Cluster Auto Scaling uses the ECS Capacity Provider construct in ECS to manage Amazon EC2 Auto Scaling groups on your behalf. For Amazon EKS, there is a similar approach with the [Kubernetes Cluster Autoscaler](#). It automatically adjusts the number of nodes in a cluster when pods fail to launch due to lack of resources or when nodes in the cluster are underutilized and their pods can be rescheduled onto other nodes in the cluster.

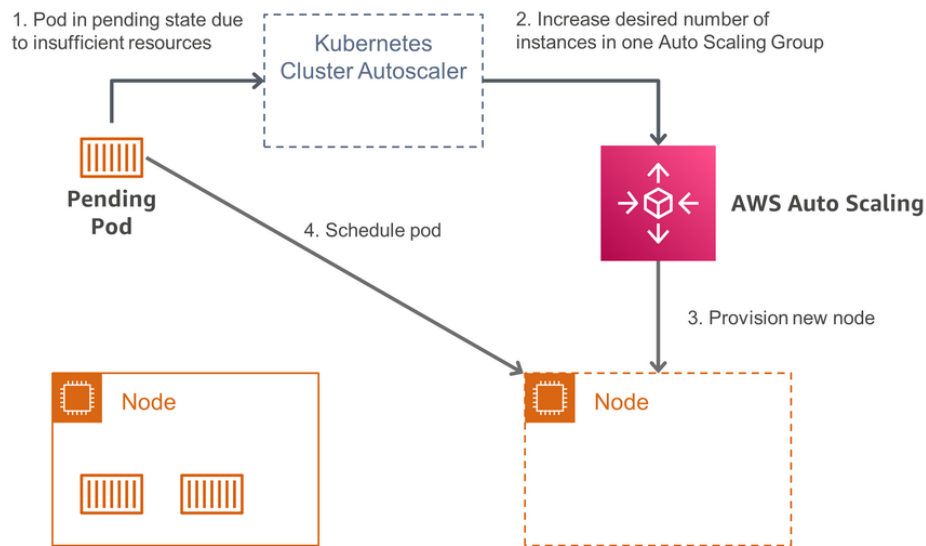
Amazon ECS Service Auto Scaling supports several types of automatic scaling that influence the number of tasks for a given ECS service. Amazon ECS cluster auto scaling however is a capability for ECS to manage the scaling of Amazon EC2 Auto Scaling groups. With Amazon ECS cluster auto scaling you can configure ECS to scale your Auto Scaling groups automatically, and just focus on running your tasks. ECS will ensure the Auto Scaling groups scale in and out as needed with no further intervention required. ECS cluster auto scaling relies on ECS capacity providers, which provide the link between your ECS cluster and the Auto Scaling groups you want to use. For more information, refer to [Amazon ECS Cluster Auto Scaling](#).



Scaling with Amazon ECS

A similar approach is available for Amazon EKS with the [Horizontal Pod Autoscaler](https://docs.aws.amazon.com/whitepapers/latest/reactive-systems-on-aws/reactive-systems-on-aws.html). The Horizontal Pod Autoscaler (HPA) requires that a metrics source (such as the Kubernetes metrics server) is installed on your Amazon EKS cluster to work. You do not need to deploy or install the Horizontal Pod Autoscaler on your cluster to begin scaling your applications.

The Horizontal Pod Autoscaler automatically scales the number of pods in a deployment, replication controller, or replica set based on that resource's CPU or memory utilization, custom metrics are also supported. This can help your applications scale out to meet increased demand or scale in when resources are not needed, thus freeing up your worker nodes for other applications. When you set a target CPU utilization percentage, the Horizontal Pod Autoscaler scales your application in or out to try to meet that target.



Scaling with Amazon EKS

Amazon Kinesis Data Streams

[Amazon Kinesis Data Streams](https://docs.aws.amazon.com/whitepapers/latest/reactive-systems-on-aws/reactive-systems-on-aws.html) offers provisioned capacity: each data stream is composed of one or more shards that act as units of capacity. Shards make it easy to design and scale a streaming pipeline by providing a predefined write and read capacity. As workloads grow, an application may read or write to a shard at a rate that exceeds its capacity, creating a *hot shard* and requiring you to add capacity quickly. As your streaming information increases, you require a scaling solution to accommodate all requests. If you have a decrease in streaming information, you might use scaling to reduce costs. Currently, you scale an Amazon Kinesis Data Stream shard programmatically. AWS Lambda integrates natively with Kinesis Data Streams, the integration abstracts polling, checkpointing, and error handling complexities. By default, Lambda invokes one instance per Kinesis shard. Lambda invokes your function as soon as it has gathered a full batch, or until the batch window expires. For more information, see [Reading Data from Amazon Kinesis Data Streams](https://docs.aws.amazon.com/whitepapers/latest/reactive-systems-on-aws/reactive-systems-on-aws.html).

Message driven

A message-driven architecture uses messages to communicate between decoupled services and is common in modern applications built with microservices, since asynchronous message-passing between loosely coupled services helps to ensure isolation and provides location transparency. The following section discusses different messaging patterns and how these can be implemented on AWS.

Event sourcing and CQRS

In the context of microservices architectures, event sourcing decouples different parts of an application by using a publish/subscribe pattern, and it feeds the same event data into different data models for separate microservices. Event sourcing is frequently used in conjunction with the Command Query Responsibility Segregation (CQRS) pattern to decouple read from write workloads and optimize both for performance, scalability, and security. Updates and queries are conventionally completed using a single datastore. You can use CQRS to separate these two workloads if they have different access patterns for throughput, latency, or consistency. When you separate command and query functions, you can scale them independently.

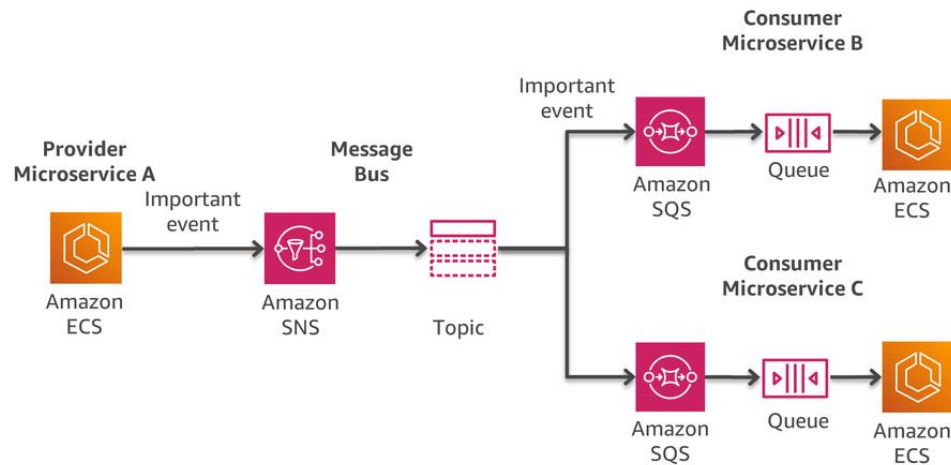
AWS messaging services

AWS messaging services enable different software systems and end devices - often using different programming languages, and on different platforms - to communicate and exchange information. Amazon Kinesis Data Streams is a scalable and durable real-time *data streaming* service. A data stream is a logical grouping of shards, each shard is an append-only log and a unit of streaming capability. It contains an ordered sequence of records ordered by arrival time. In the example architecture Kinesis Data Streams is used to decouple services. Another option would be to use Amazon Managed Streaming for Apache Kafka (Amazon MSK), a fully-managed service that enables you to build and run applications that use Apache Kafka to process streaming data. Amazon MSK provides the control-plane operations, such as those for creating, updating, and deleting clusters. It lets you use Apache Kafka data plane operations, such as those for producing and consuming data. One of the major advantages of services like Kinesis Data Streams or Amazon MSK is the ability to replay events within a defined *retention period*.

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A different pattern for asynchronous service-to-service communication is the publish/subscribe (pub/sub) model. In a pub/sub model, any message published to a topic is immediately received by all of the subscribers to the topic. Amazon SNS is a fully managed pub/sub messaging service that enables message delivery to millions of subscribers. Amazon SQS is a message queue service used by distributed applications to exchange

messages through a polling model, and can be used to decouple sending and receiving components—without requiring each component to be concurrently available. Using Amazon SNS and Amazon SQS together, messages can be delivered to applications that require immediate notification of an event, and also persisted in an Amazon SQS queue for other applications to process at a later time. When you subscribe one or more Amazon SQS queues to an Amazon SNS topic, you can publish a message to the topic and Amazon SNS sends an Amazon SQS message to each of the subscribed queues.



Pub/Sub with Amazon SNS and Amazon SQS

If you already have applications designed to use industry standard APIs and protocols for messaging, including JMS, NMS, AMQP 1.0 and 0.9.1, STOMP, MQTT, and WebSocket. Amazon offers [Amazon MQ](#), a managed message broker service for Apache ActiveMQ and RabbitMQ that makes it easy to set up and operate message brokers in the cloud. For brand new applications in the cloud, it is recommended you consider Amazon SQS and Amazon SNS. Amazon SQS and SNS are lightweight, fully managed message queue and topic services that scale almost infinitely. For existing applications using industry standard APIs and protocols, Amazon MQ is a proposed service.

Fanout

The *Fanout* scenario is when a message published is replicated and pushed to multiple endpoints, which allows for parallel asynchronous processing. For example, you can develop an application that publishes a message to an SNS topic whenever an order is placed for a product. Then, Amazon Simple Queue Service (Amazon SQS) queues that are subscribed to the [Amazon Simple Notification Service](#) (Amazon SNS) topic receive identical notifications for the new order. A service attached to one of the SQS queues can handle the processing or fulfillment of the order.

Filtering

By default, an Amazon SNS topic subscriber receives every message published to the topic. To receive a subset of the messages, a subscriber must assign a *filter policy* to the topic subscription. A filter policy is a simple JSON object containing attributes that define which messages the subscriber receives. When you publish a message to a topic, Amazon SNS compares the message attributes to the attributes in the filter policy for each of the topic's subscriptions. If any of the attributes match, Amazon SNS sends the message to the subscriber. Otherwise, Amazon SNS skips the subscriber without sending the message.

Conclusion

After reviewing the concepts for reactive systems, you should have a good understanding of the landscape of potential AWS services you can choose to build a reactive system on AWS.

The key patterns in this paper, highlighted the necessary concepts for implementing the foundational building block for reactive systems. The characteristics of reactive systems based on the definition of the reactive manifesto.

The example architecture utilizes the same patterns on a micro-level which are being used on an architectural macro-level. The AWS services are a great starting point to implement reactive principles and microservices improve isolation of different workloads. In combination with managed services, you can focus on the business requirements and remove the undifferentiated heavy lifting.

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Further reading

For additional information, refer to:

- [Implementing Microservices on AWS](#)
- [Database Caching Strategies Using Redis](#)
- [Performance at Scale with Amazon ElastiCache](#)

Document revisions

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Notes

- ¹ K. Mani Chandy Event-Driven Applications: Costs, Benefits and Design Approaches, California Institute of Technology, 2006

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