CS3219
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github/SelwynAng

1 Software Applications, Deployment & Development Processes

1.1 Cloud Computing
- Software infrastructure hosted on an external data center with services delivered over the internet
- Different models
  1. **On-site:** User manages applications, data, runtime, middleware, OS, virtualisation, servers, storage, networking
  2. **IaaS:** User manages applications, data, runtime, middleware, OS | service provider manages the rest
  3. **PaaS:** User manages applications, data | service provider manages the rest
  4. **SasS:** Service provider manages everything
- Cloud native is the software approach of building, deploying and managing modern applications in cloud computing environments

1.2 Deployment (Software Delivery)
- Deployment comprises activities that make the software available for use after development (process between software acquisition and execution)
- **Deployment Issues:** Integration of the internet and related advances (Portability), Large-scale content delivery (Availability, Performance), Heterogeneous platforms (Interoperability), Dependency and change management (Maintainability), Coordination and communication among components (Performance), Security
- **Deployment Mechanisms:**
  1. Bare metal: (+): Complete control, physical isolation | (-): Wasted hardware resources, cost, scalability issues
  2. Virtual machine: (+): Improved resource utilization, flexible, scalable | (-): Vulnerable to side-channel attacks, noisy neighbor problem
  3. Container: (+): Lighter than VM, write once run anywhere, granular control | (-): Not suitable for all apps, not suitable for performance-critical applications
- **Container VS Orchestrator VS Serverless:**
  - Container: Provide the platform for building & distributing services
  - Orchestrator: Separate software that integrate & coordinate many parts, scale up/down deployment, provide fault tolerance, provide communication among containers
  - Serverless: Cloud provider dynamically manages the allocation and provisioning of servers (used for small, stateless, event-driven workloads, e.g., processing an image upload, API endpoints)

1.3 Software Development Process:
- Use waterfall model when requirements are well-understood, fixed, and effort predictable | Use iterative development for fuzzy and evolving requirements
- **CI/CD Pipeline:**
  - Continuous Integration: Development practice that requires developers to integrate code into shared repo several times a day → Each check-in is then verified via automated build
  - Continuous Delivery: Ensuring that every good build is potentially ready for production release (Manual deployment to production)
  - Continuous Deployment: Automating release of a good build to production environment (Auto deployment to production)
- **DevOps:** Blends software development & operations staff and tools → Reduce time between committing change to system and the change being placed into production while ensuring high quality

2 Specifying Software Requirements

2.1 Requirements
- **Definition:** Capability needed by a user, Capability that must be met or possessed by a system, Documented representation of a condition or capability, Specification what should be implemented
- **User centric Requirement:** Eg. As a user, I can upload a 20 mb image file into the system so that I can retain the original image without loss of quality
- **Product centric Requirement:** Eg. The system will support a range of graphic file formats up to 20 mb in size
- **Requirement Development Phases:** Elicitation → Analysis → Specification → Validation
- **Outcomes of Requirements Development Process:** (1): Software Requirements Specification (SRS), (2): Rights, responsibilities & agreements
- **SRS VS Product Backlog:** Product Backlog (Repo of work to be done, facilitates prioritization of work & planning), SRS (in-depth description of software product to be developed, direct/indirect requirements of system, only tells what work is to be done)
- **Validation:** Whether you have written the right requirements
- **Verification:** Whether you have written the requirements right

2.2 Types of Requirements
1. **Business:** Describe why organization is implementing the system
2. **User:** Describe goals or tasks user must be able to perform with the product
3. **System:** Describes connections between your system and outside world
4. **Functional:** Specifies something the system should do
5. **Non-functional/Quality:** Describes something not directly related to system functionality, but how well the system works
6. **Constraints:** States a limitation on design or implementation choices
7. **Data**

NOTE: Business Req to be in Vision and Scope document, User Req to be in User Requirements document, FRs, NFRs, System Req, Constraints to be in SRS

2.3 Software Quality Attributes:
- **External:** Observed when software is executing, impacts UX, develops user's perception of software quality *(Eg. Availability, Performance, Robustness, Safety, Security, Reliability, Integrity, Deployability, Compatibility, Installability, Usability, Interoperability)*
  1. Security: Specifying security features at SRS ensures that acceptance tests include testing for security | About privacy, authentication, integrity
  2. Safety: About whether a system can harm someone or something
  3. Performance: Responsiveness of system, impacts UX, includes response time, throughput, data capacity, dynamic capacity, predictability in real-time systems, latency, behavior in degraded modes or overloaded conditions
  4. Availability: Planned uptime of system ($\frac{Uptime}{Uptime+Downtime}$)
  5. Usability: Measures the effort required to prepare input, operate, and decipher output of software
- **Internal:** Not directly observed when software is executing, perceived by developers/maintainers, encompasses aspects of design that may impact external attributes *(Eg. Efficiency, Scalability, Verifiability, Portability, Maintainability, Testability, Modifiability, Reusability)*
  1. Scalability: Ability of application to accommodate growth in application usage (*Vertical scaling:* increasing capacity of system by adding capability to machines used which is easier to maintain, but causes single point of failure | *Horizontal Scaling:* increasing capacity of system by adding additional machines which increases fault tolerance, but adds costs and complexity)

3 High Level Design - Software Architecture

3.1 Software Architecture
- **Definition:** Structure of system, which comprise software components, externally visible properties of those components, and the relationships among them
- **Consists of:** (1): Component (element that models an application-specific function, responsibility, requirement, task, process), (2): Configuration (Topology/Structure), (3): Connector (Element that models interactions among components for purpose of transfer of control/data)

3.2 Common Definitions
1. **Control Flow:** Reasoning is on computation order, how the focus of control moves throughout the execution
2. **Data Flow:** Reasoning is on data availability, transformation, latency, how data moves through collection of computations
3. **Call and Return:** Control moves from 1 component to another and back, can be hierarchical/non-hierarchical
4. **Message:** Data sent to a specific address (each component has a unique address other components can send messages to)
5. **Event:** Data emitted from a component for anyone listening to consume (message sent to publishing infrastructure where consumers may later retrieve, is immutable, ordered in sequence of creation)

3.3 Decomposition & Packaging
- **Slicing:** (1): Horizontal Slicing: designing by layers, (2): Vertical Slicing: designing by feature
- **Principle of Modularity:** Modularization results in shorter development time, better flexibility, better comprehensibility | Decomposing big chunk into smaller chunks with well-defined APIs
- **Types of Cohesion:** Functional, Layer, Communicational, Sequential, Procedural, Temporal, Utility
- **Types of Coupling:** Content, Global variables, Control, Data, External, Temporal, Inclusion/import

3.4 Architectural Styles
- **How code is divided:**
  1. Technical Partitioning: Focus on separation of concerns (Eg. Presentation, Services, Persistence)
  2. Domain Partitioning: Aligned with the domain (Eg. Customer, Shipping, Payment)
- **How is it deployed:**
  1. Monolithic: Deploy all logical components that make up the application as 1 unit, application runs as 1 process
  2. Distributed: Application consists of independent logical components, logical components run as individual processes, communicate over network
- **Types:**
  1. Layered (Technical & Monolith):
     - Lower level layers provides functionality for higher level layers
     - *Open layer architecture:* 1 layer can talk to another layer, which can be layers away
     - *Close layer architecture:* 1 layer can only talk to a neighboring layer
     - More layers result in scalability by allowing each layer to run in different server, but communication becomes expensive
     - Less layers result in performance optimization, no context-switching overheads, but difficult to modify, impractical
  2. Modular Monolith (Domain & Monolith): Separation by domain (business) concern, reduces coupling (Eg. Order domain, recipe domain, where each domain consists of presentation, logic & persistence layers)
  3. Event-driven (Technical & Distributed):
  4. Microservices (Domain & Distributed):
  5. Pipe & Filter:
     - Data enters system and flows through components one at a time until data is assigned to some final destination (Data Sink)
     - Components consist of *Filters, Data Source, Data Sink*, where each component can read and produce
     - *Filter* transforms input streams, computes incrementally → output begins before input is consumed, is independent, shares no state with other filters
     - *Pipe* transmits output of 1 filter to input of another filter
     - *Purpose:* Divides the app's task into several self-contained data process steps & connect these steps to data processing pipeline via intermediate data buffers → Data flows in streams (good for image, audio, video, or batch data processing with limited user interaction)
  6. Model-View-Controller
     - View (widgets in UI, buttons, text boxes), Controller (coordinates btw. Model and View), Model (business logic)
     - *Benefits:* Separation of concerns, Facilitates extensibility, Restricted communication reduces complexity & side effects, Better testability (easy to mock components), Frameworks provide MVC solution
     - *Web MVC:* Controller (handles user HTTP requests, select model, prepare view), View (renders HTTP response), Model (business logic & persistence)
     - *Single Page Applications (SPA):* Send query and retrieve data in background without refreshing webpage

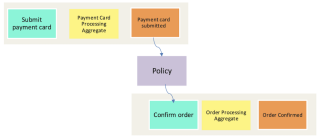
3.5 REST Architecture
(Not an architecture by itself)
- **Definition:** Defines constraints for transferring, accessing, and manipulating textual data representations in a stateless manner across a network of systems → Provide uniform interoperability between different applications on the internet (HTTP to request access and use data)
- **Constraints:**
  1. Client-Server: REST apps should have client-server architecture for separation of concerns → Improve portability of UI & scalability of server components
  2. Stateless: No client state (session) maintained on server → Server is bound by no. of concurrent requests & not the no. of clients interacting → Improve scalability, reliability, monitoring
  3. Cache-able: Response from server should include if data is cache-able or not → Client returns data from its cache in response to subsequent requests → Improves network efficiency, but client can potentially receive stale data
  4. Layered System: App must be organized as a layered system → Improved overall system complexity by restricting complexity to individual layers, intermediary servers may improve system availability & performance, provide data transformation & filtering
  5. Uniform Interface: Uniform way of interacting with a given server irrespective of device/application, exploits HTTP/HTTPS requests & responses
     - *Resource Identifier:* Stable, global, unique method to identify resources
     - *Resource Representation:* Components perform operations on resource representations
  6. Code-on-demand: Allow client functionality to be extended by downloading executable code, simplifies client from having to pre-implement all functionality, allows extensibility
- **Advantages of REST:** Systems are less tightly coupled, provides scalability, usability, accessibility
- **Disadvantages of REST:** Being stateless decrease network performance by increasing repetitive data sent in series of queries | Using URI degrade efficiency since info is transferred in standardized form rather than one which is specific to app's needs

4 Microservices Architecture

4.1 Microservices Architectural Style
1. A single application as a suite of small services
2. Each microservice offers a well-defined business capability (Features in microservice should be highly related)
3. Each microservice is defined to be developed & deployed independently (Services do not need to share any of their code or implementation with other services → minimal dependency on each other, services are owned by different teams)
4. Microservices communicate with each other through well-defined mechanisms (Synchronous: RESTful APIs, gRPC, GraphQL, Asynchronous: Event-based publish & subscribe)

4.2 Domain Driven Design
- Complex system is fundamentally a collection of multiple domain models (sub-domains)
- **Domain:** Problem space that a business occupies and provides solution to
- **Sub-domain:** Component of main domain, belongs to problem space
- **Bounded Context:** High cohesive boundary relevant to the sub-domain → Belongs to solution space
- **Types of Collaborations between different Bounded Contexts (BC):**
  1. Shared Kernel: 2 contexts are developed independently, but they end up overlapping some subset of each other's domain
  2. Upstream-Downstream: 2 contexts are in provider (upstream) - consumer (downstream) relationship
     - *Supplier-Customer Relationship:* Supplier is the BC that provides a service, functionality or data to another BC, while Customer is the BC that consumes the functionality/data (Eg. Order Context supplies order data, Recommendation Context fetches the order data)
     - *Conformist Relationship:* 1 BC (the conformist) fully adopts the model of another BC without trying to impose its own requirements or interpretations (Eg. Payment service must align entirely with the bank's API and data structures, regardless of whether it fits the payment service's internal domain model or not)
- **Aggregate:** A cluster of related objects that we treat as a single unit for purpose of data changes (Has *transactional boundary*, which means any changes to aggregate will either all succeed or none will succeed | Has *consistency boundary*, which means all processes or objects external to aggregate are only allowed to read aggregate's state & its state can only be modified by executing corresponding methods of aggregate's public interface)
- **Aggregate Root:** Parent entity of the aggregate → designated as aggregate's public interface

4.3 Event Storming
- Command causes Events (Eg. User/external system issues a command)
- We treat Aggregate as a unit for the purpose data changes → Eg. Order Processing Aggregate consists of Confirm order Command & Order confirmed Event
- Policy: WHEN event THEN command (basically links 2 aggregates together, Eg. When payment card is submitted event happens, then execute confirm order command)
- A BC solves 1 problem & can contain more than 1 aggregate
- 2 different aggregates can be created to solve 1 problem delimited by 1 BC



5 Data Patterns in Microservice Architecture

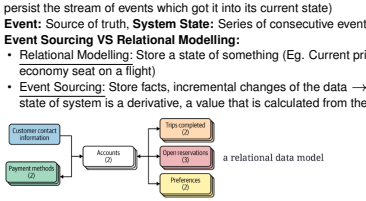
5.1 Database-server-per-service Pattern
- Each service has its own database server
- (+): Loose coupling, allow scaling services at database level, easier to replace underlying database technology to something appropriate with each service
- (-): Hundreds of microservices → Different kinds of database → Explosion of no. of DB clusters → Expensive, unmanageable
- However, Data independence ≠ Each microservice to own cluster of DB → Microservices do not modify the same data by having:
  1. Private-tables-per-service: Each service owns a set of tables that must only be accessed by that service
  2. Schema-per-service: Each service has a database schema that is private to that service

5.2 Data Delegate Pattern
- Multiple services require data from a single table → Not loosely coupled
- Can be solved via Data Delegate Pattern (hide shared data behind a delegate service) → Authoritative service for all things related to the other services which require common data → Stop accessing database directly from other services

5.3 Data Lake Pattern
- Data lake is a read-only, query-able data sink (shared space containing copy of data from all concerned microservices) → Owner microservices just stream relevant data into data lake

5.4 Sagas Pattern
- Every step of a transaction defines a compensating action → Compensating action executes if we need to roll back the transaction due to later failure → Compensating action is registered on a routing slip & passed along to next step → If 1 of the later steps fails, it kicks off execution of all compensating actions on routing slip, "undo" modifications & bring system to reasonably compensated state
- Sagas ≠ ACID transactions → Sagas does not promise that when a distributed transaction is rolled back, system will necessarily get back to initial state (Eg. Initial state has 0 notifications, but if we cancel reservation, final state has 2 notifications)
- Sequence of events does matter & should be constructed carefully → Better to move steps that are harder to compensate for towards end of transaction (Eg. Move notification to end of process, would save from having to send a lot of correction messages)

5.5 Event Sourcing
- **Definition:** Is about storing facts and any time you have state change → For each modification of state, log (store) the event representing the result of the action (Instead of focusing on persisting the state of the app, you should persist the stream of events which got it into its current state)
- **Event:** Source of truth, **System State:** Series of consecutive events
- **Event Sourcing VS Relational Modelling:**
  - Relational Modelling: Store a state of something (Eg. Current price of economy seat on a flight)
  - Event Sourcing: Store facts, incremental changes of the data → Current state of system is a derivative, a value that is calculated from the events



- **Event:**
  - Has 3 parts (unique id, event type, data)
  - Events acts as data that describes some action/fact, Events are notifications of some change in state/data, Events are recordings of what happened
  - Projection function takes current state and a new event to calculate new state → Take rolling snapshots (saving projections) to speed up calculation of new state from the last snapshot
- **Event Store:** Database storage that can reliably store a sequence of data entries (Store new events, assign correct sequence, notify event subscribers)

5.6 Command Query Responsibility Segregation (CQRS)
- The way we query & the way we store data do not have to be the same → Separate write path from read path (Should something go wrong, internal state of database can be recovered from the log & writes and reads can be optimized independently)
- **Commands:** Operations that change application state & return no data (have side effects within application)
- **Queries:** Operations that return data but do not change application state
- Model used for commands will differ from model used for queries (Data can be stored in different tables/databases for command and query models)

6 More Patterns in Microservices Architecture

6.1 Service Instance per Host Pattern
- Run each service instance in isolation on its own host
- **Service Instance per VM:** Package each service as a VM image → Each service instance is a VM
- **Service Instance per Container:** Each service instance runs in its own container → Container image is a file system image consisting of the applications & libraries required to run the service

6.2 Immutable Infrastructure & Infrastructure as Code
- **Immutable Infrastructure:** Cannot be changed after it is created (updating immutable object requires it to be destroyed and replaced with a new one) → Contain behavior and structures that are easier to predict & reproduce because they do not change
- **Infrastructure as Code:** All infrastructure must be represented as a set of machine-readable files/code

6.3 Service Collaboration & Communication
- **Service Collaboration:**
  1. Orchestration: Rely on central brain to guide and drive process (Eg. Service A sends instructions to other services directly)
  2. Choreography: Inform each part of system of its job, let them work out the details (Eg. Service A publishes an event that other services subscribe to)
- **Service Communication:**
  1. Request/Sync Response: Client makes a request to service & waits for a response
  2. Notification: Client sends a request to service but no reply is expected or sent (one-way request)
  3. Request/Async Response: Client sends a request to service, which replies asynchronously

6.4 Event Driven VS Request-Response Communication
- **Event-Driven:** Async pattern, Real-time data, Loose coupling between components in the system (No service knows of existence of any other service, and no service owns the entire workflow), Event (something happened), Best for cases where components need to react to changes in state/real-time data processing is needed (Eg. IoT systems, real-time analytics)
- **Request-Response:** Sync pattern, Introduces latency (if requester waits for response), Tighter coupling since requester needs to know details of responder, Request (do this), Best for cases where client needs specific info (Eg. web APIs, database queries)
- Real-time data: Data that is published as it is generated, with no known end of data being published → Travelling in streams/queues that are built to handle large volumes of data

6.5 API Gateway
- A server that is the single point of entry into the system
- Encapsulates internal system architecture & provides an API that is tailored to each client
- Have other responsibilities such as authentication, monitoring, load balancing, caching, etc
- **Backends for Frontends:** A dedicated backend service is created for each frontend interface (e.g., web, mobile, or other client applications) → Allows each frontend to interact with its own backend service, which is tailored to its specific needs

6.6 Service Discovery
- **Service Discovery:** API Gateway needs to know location (IP address and port) of each microservice with which it communicates
  1. Client-side Discovery Pattern: Client queries a service registry & determines network locations of available service instances → then uses a load-balancing algorithm to select 1 of the available service instances & makes a request
  2. Server-side Discovery Pattern: Client makes a request to service via load balancer → Load balancer queries service registry & routes each request to an available service instance
  3. Service Registry Pattern: Service instances are registered with service registry (database of services, their instances & their locations) on startup & deregistered on shutdown → Client of the service and/or routers query the service registry to find available instances of a service

7 Event Driven Architecture

7.1 Events

- **Definition of Event:** Way for a software component to let rest of system know that something important has just happened (allow passing of info between components)
- **Initiating Event:** Originates from an end user & kicks off a business process
- **Derived Event:** Internal events generated in response to initiating event
- **Structure of Event:**
  - Events are typically represented in key/value format (Key: For ID, routing and aggregation operations on events | Value: Complete details of event)
  - Unkeyed: Describes a singular statement of fact (Eg. typically used for system-wide notifications or triggers that are consumed by subscribers interested in general behaviors rather than specific entities) | Entity: Unique thing and is keyed on the unique ID of that thing | Keyed: Contains a key but does not represent entity

7.2 Asynchronous Communication

- **Definition:** When software component broadcasts info to other components, it does not wait for response, nor does it care if other components are available or not (Fire-and-forget)
- **Diagram notation:** Dotted lines for async, Solid lines for sync
- **Pros (+):** Better responsiveness (less time to get response for a request), Better availability (other components' availability don't matter)
- **Cons (-):** More complex/fragmented error-handling than sync comms

7.3 Event Driven Architecture (EDA)

- **Definition:** Way of designing & building apps that are based on exchange of events (relies on async comms when sending & receiving events)
- **Components in EDA:** (1): Event Producers (Publishers): Publish data into streams/queues | Event Brokers: Implements an event broker/event bus | Event Consumers (Subscribers): Listen for & consume event data
- **EDA VS Microservices (MS) Architecture:**
  1. Communication & Performance: EDA relies on async comms (fast), MS communicates via sync using REST and occasionally async comms (sync comms creates latency)
  2. Bounded Contexts & Data Ownership: Nice-to-have for EDA, Foundational for MS
  3. Event VS Request: EDA is built on event processing (responding to something that has happened), MS is built on request processing (responding to something that needs to happen)

7.4 Event Driven Microservices

- **Definition:** Microservices communicate by producing & consuming events (Each event stream has 1 and only 1 producing MS $\longrightarrow$ This MS is the owner of each event produced to that stream)
- **Event Data:** Serves as data storage & communication mechanism between services
- **Event Broker:**
  - Receives events, holds/stores events, and provides events for consumption
  - Event brokers use immutable, append-only event log $\longrightarrow$ Preserves state of event ordering, where events are given auto incrementing index ID
  - Consumer service "seeks" to index ID of last message it read (offset), then scans sequentially, and reads messages in order while recording its new index ID in the partition
  - Traits of Event Broker: Immutability (can alter previous data only by publishing new event with updated data), Ordering (data is served to consumers in same order it was published), Indexing (events are assigned indexes), Partitioning (event streams are partitioned into sub-streams), Infinite retention (Events can be retained for infinite time), Replayability (Any consumer can read whatever data it requires)
  - Event Partitions: Producers write events over many partitions, each partition is an append-only event log, load-balanced consumers share the partitions between them
  - Scalability: Reading & writing can be done in parallel with events in partitions $\longrightarrow$ Scaling is straightforward (with Kafka, hitting scalability wall is impossible)