Design and Engineering of Computer Systems

Lecture 28: Multi-tier application design

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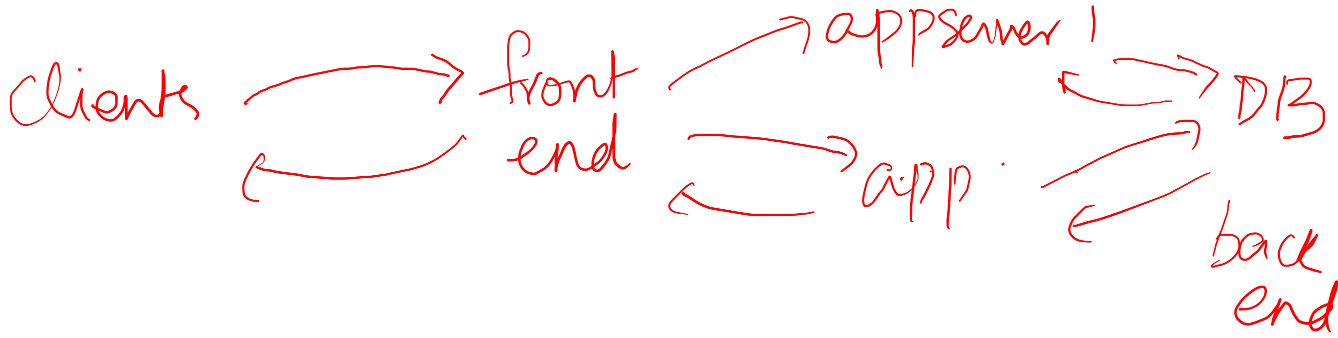
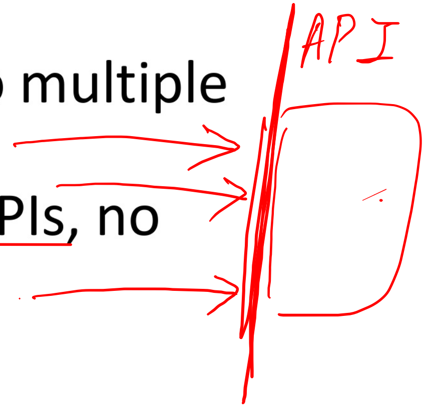
Multi-tier applications



- Real-world computer systems are built as multi-tier applications
  - Multiple components/tiers distributed across several machines
- High-level architecture of a multi-tier application
  - Clients access applications hosted in organizations or public clouds
  - Front-end components (e.g., web servers) receive user requests, reply to user with responses, consult various application servers to build responses
  - App servers contain business logic to process different types of user requests
  - Application data is stored in several database servers in the backend
- Example: e-commerce application has front-end web server, multiple application servers to handle different functions (e.g., product search, shopping cart, purchases), and multiple databases (e.g., product catalogue, user profile, order history)

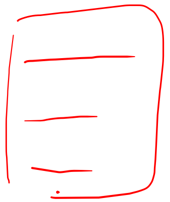
Decomposing applications into components

- Why to build applications in modular (not monolithic) design?
  - Easier to design, develop, optimize smaller components
  - Easier to replace/upgrade components without bringing down entire system
- General guidelines to modularize applications (not hard rules)
  - Identify what functionalities the system should provide
  - Identify what application data to be stored to satisfy functionality
  - Encapsulate one type of data and functions on data into one logical component (e.g., one component for product catalogue and related functions)
  - Each component / application server can be further decomposed into multiple micro-services (processes/threads) for separate functions/features
  - Components interact with each other via well-defined interfaces or APIs, no need to know the internal implementation details

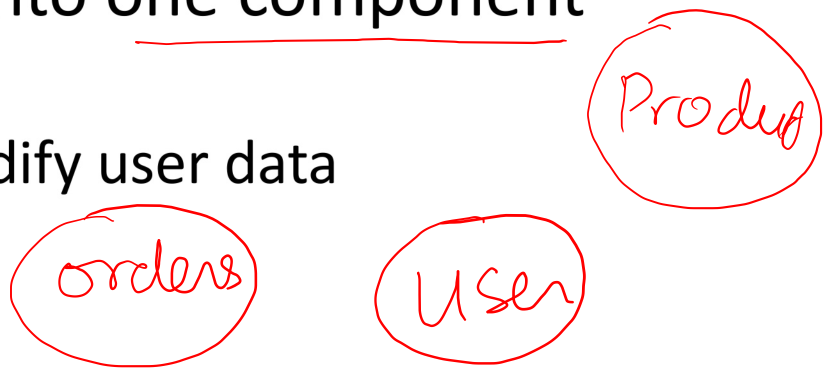


Example: functional requirements

- Functional requirements of a simplified e-commerce system
  - Maintain user authentication and profile information, billing details
  - Add products to catalogue, search with keyworkds
  - Add items to shopping cart, view shopping cart
  - Checkout, billing, shipping of items
  - Keep order history, support cancellations and returns
  - Recommend future purchases based on past history



- Group together (app data + functions on data) into one component
  - Product catalogue, add/search/buy/return products
  - User profile database, add/delete/authenticate/modify user data



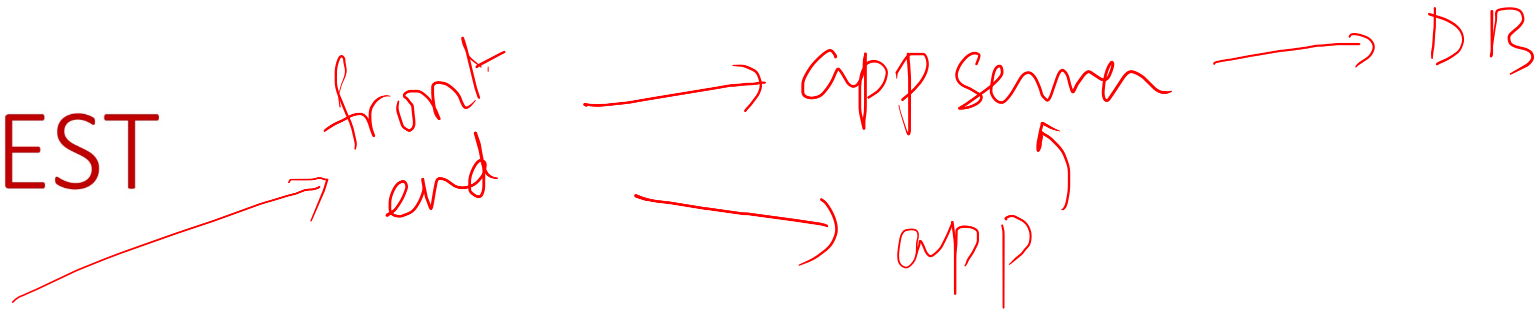
Example: modular architecture of e-commerce application

Component	Data maintained	Functions / microservices
User profile	User information, password, billing info, shipping address	Add new user, authenticate login, update info, delete user
Products	Catalogue of products available	Add products (used by supplier), search by keywords, buy, return
Shopping cart	Shopping cart for each user	Add item, delete item, view cart
Orders	For each order placed, details of items purchased in that order, billing and shipping information	Create new order (from shopping cart), billing for order, shipping and tracking of order, retrieve order history of user, cancellations and returns
Recommendations	What products to recommend for each user based on past history of purchases	Retrieve recommendations

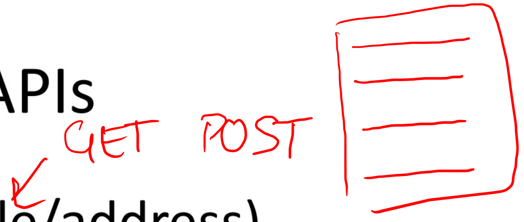
Application data storage options

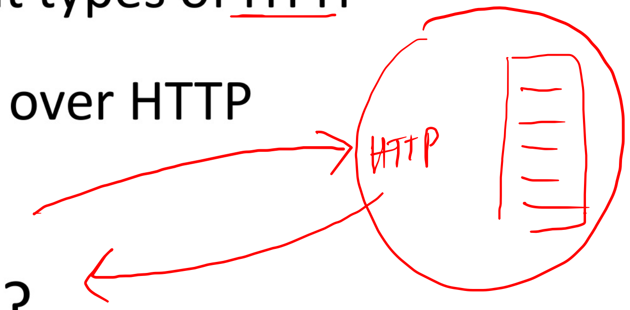
- Relational database management systems (RDBMS)
  - Store structured data in the form of relational database tables with strict schema
  - Provide strong guarantees (ACID – Atomicity, Consistency, Isolation, Durability)
  - Support for transactions (complex operations spanning multiple tables)
- NoSQL data stores: for unstructured data (e.g., key-value stores) or semi-structured data (e.g., document stores) or specialized data (e.g., graphs)
  - Dynamic or flexible schema, no strict consistency guarantees or transaction support
  - Easier to scale, better performance than RDBMS
  - In-memory only for transient data, disk storage option if persistence needed
- Many data stores available, choice depends on type of data in app server
  - User profile data stored in RDBMS, shopping cart stored on NoSQL key-value store
- Data moves from one data store to another as it is processed
  - User clicks on videos stored temporarily in NoSQL, aggregated and stored in RDBMS

API design: REST



- Front-end, app servers, backend components interact over well-defined interfaces or APIs: how to design these?
- REST (Representational State Transfer): popular way to design APIs
  - Reuse HTTP client-server mechanism for data beyond web pages
  - Data stored in a component represented as URLs (e.g., /user/foo/profile/address)
  - Data can be created, updated, read, or deleted (CRUD) via different types of HTTP requests (GET, POST, ..)
  - App data exchanged via standard serialization formats (e.g., JSON) over HTTP
  - Easily implemented by existing HTTP frameworks
  - Responses can be cached like web content fetched over HTTP

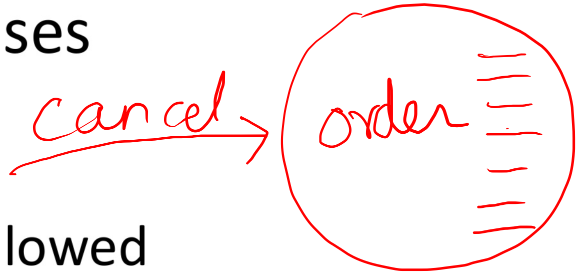




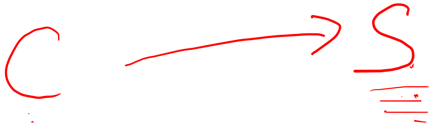
- What do clients use to communicate with front-end servers?
  - Standard application layer protocols, e.g., HTTP, SMTP
  - REST-based APIs, e.g., accessing mapping service from mobile app

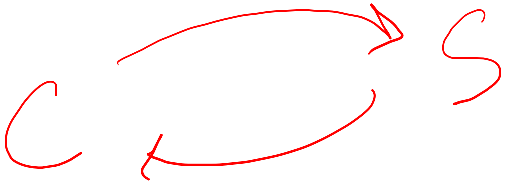
API design: RPC

- REST-based APIs are popular but may not be suitable in all cases
  - Not easy to represent all data in a component as URLs
  - Cannot do all actions using fixed set of HTTP verbs (GET, POST, ..)
  - REST (HTTP) is stateless, no dependence on previous state of data allowed
  - Example: “cancel” order API not easy in REST, need to do action depending on state (whether confirmed or not) of order, HTTP DELETE verb is not suitable



- Alternate way of designing APIs: use RPC frameworks
  - Components interact and exchange data using remote procedure calls
  - Can customize interface: messages exchanged in requests and responses between client and server, function/services provided by server
  - Needs close coordination between client and server, not suitable for external facing interfaces, more useful for inter-component interactions within system





API design: publish-subscribe

- RPC and REST are client-server model: one component (client) sends a request and waits for response from server to proceed

- Some interfaces need more asynchronous interaction, for example:
  - Server making purchases pushes order info to recommendation server, no response is expected. Recommendation server runs algorithms asynchronously on orders to come up with recommendations for user.
  - User uploads video to video upload server, which pushes video to another server that converts video into various resolutions later on asynchronously
- Such interactions between components are called publish-subscribe model, happen via frameworks called message brokers or task queues
  - Some components publish information to a task queue, other components subscribe for this information and process it
  - Subscribers can subscribe to specific topics selectively
  - Message brokers provide temporary storage of messages, high performance reliable message delivery using network protocols

Summary

- In this lecture:
  - How to design multi-tier applications
  - Design choices for data storage, APIs
- Work out an end-to-end design of any computer system you use in your day-to-day life. Think through what are the functional requirements, how to modularize, what kind of data stores you will need, and what kind of APIs will be appropriate.