Design and Engineering of Computer Systems

Lecture 2: Principles of Computer Systems Design

Mythili Vutukuru

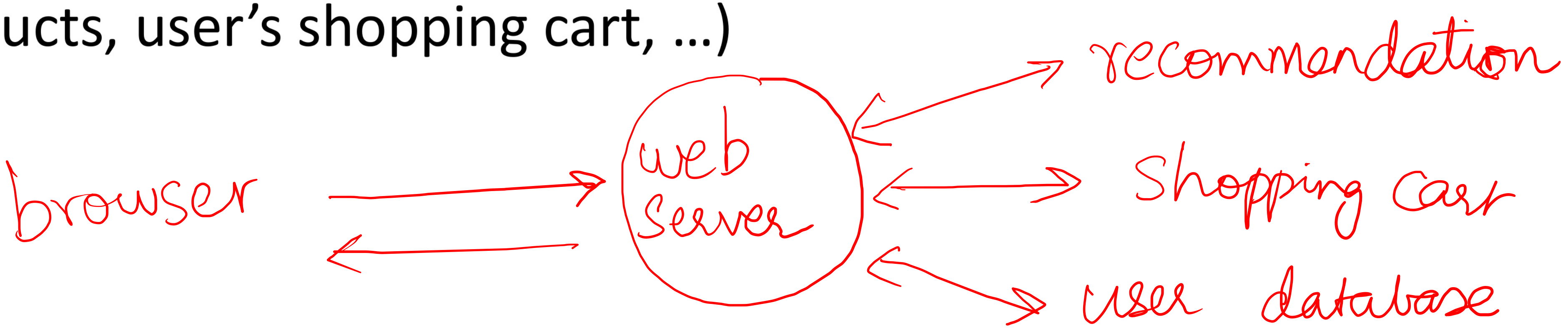
IIT Bombay

Principles of Computer Systems Design

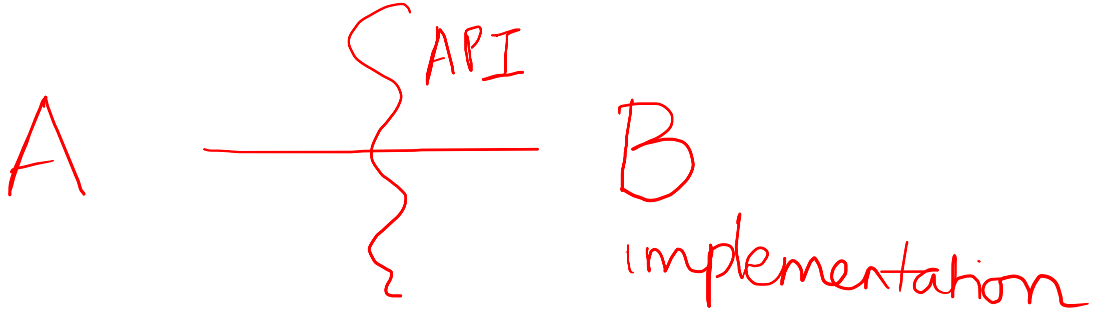
- Computer systems are complex, with strict expectations
  - Common design principles underlying the design of diverse systems
- This lecture: brief introduction to the common principles of computer systems design
  - Mostly common sense!
- Rest of the course: several examples of these design principles
- Understanding common principles and seeing common patterns across systems will help designing systems on your own

Modularity

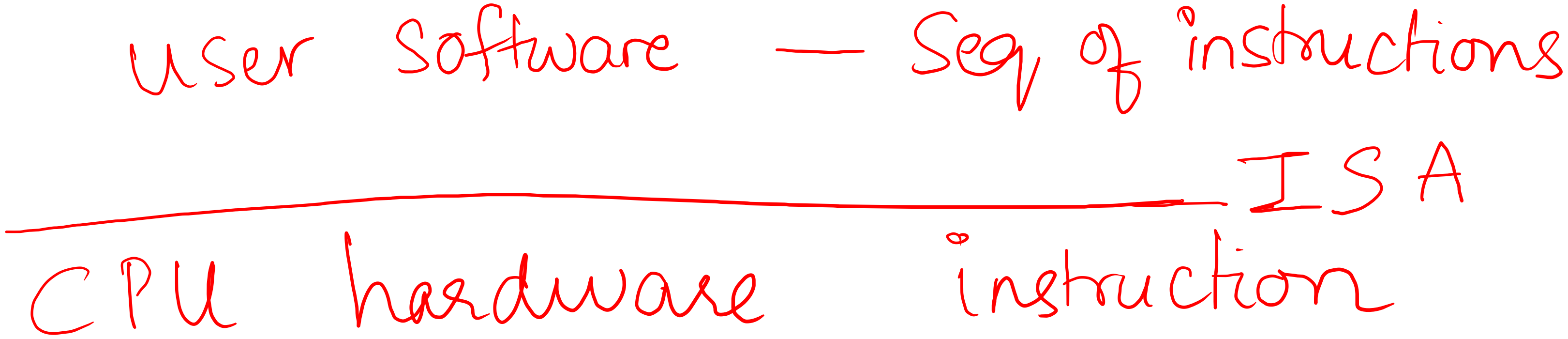
- Systems are composed of multiple independently developed modules ("microservices") which interact with each other
- Example: when e-commerce server displays a webpage to user, information on the page is sourced from multiple modules (personalized recommendations, offers of the day, sponsored products, user's shopping cart, …)



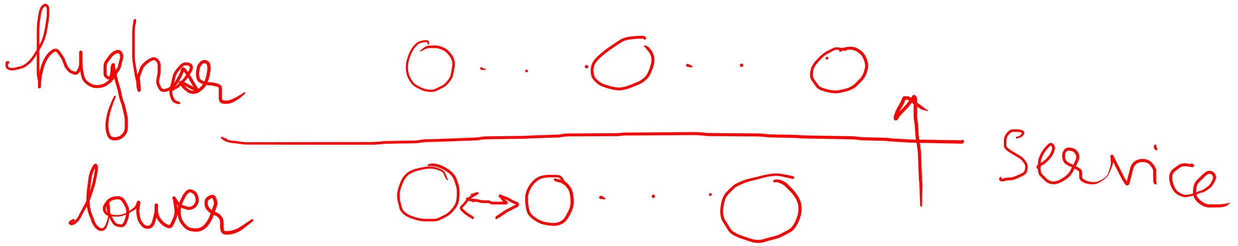
Abstraction



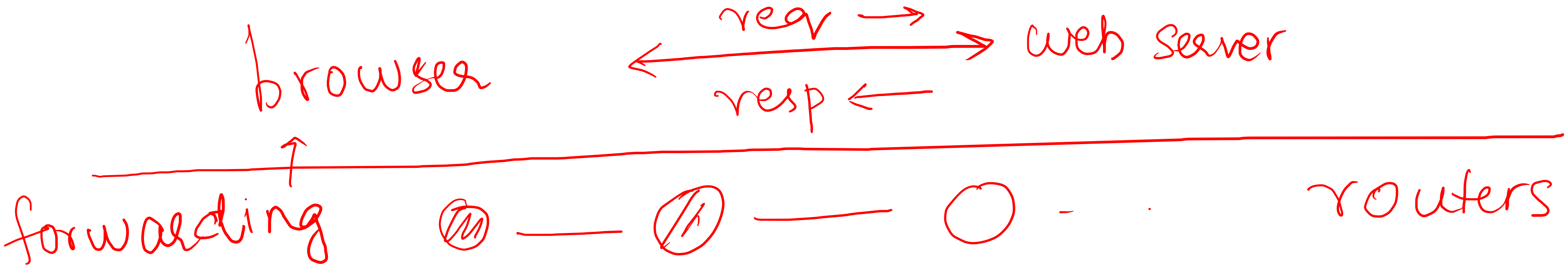
- Two modules interact via an API (application programmer interface)
  - Need not know the implementation details, only interface
- Example: users write software consisting of sequence of instructions, CPU hardware executes instructions
  - Interface: instruction set of CPU
  - Software need not know how CPU executes instructions



Layering

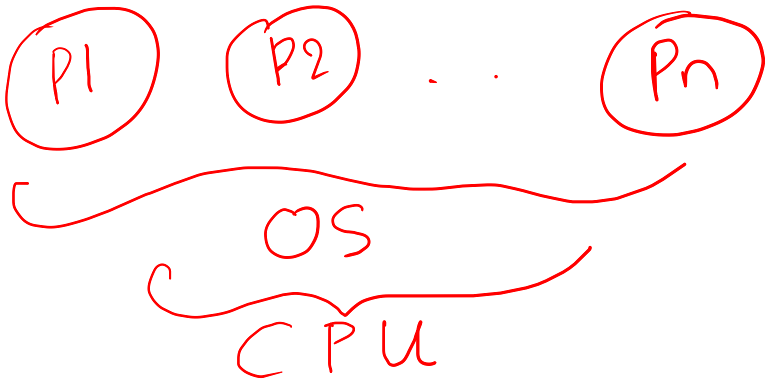


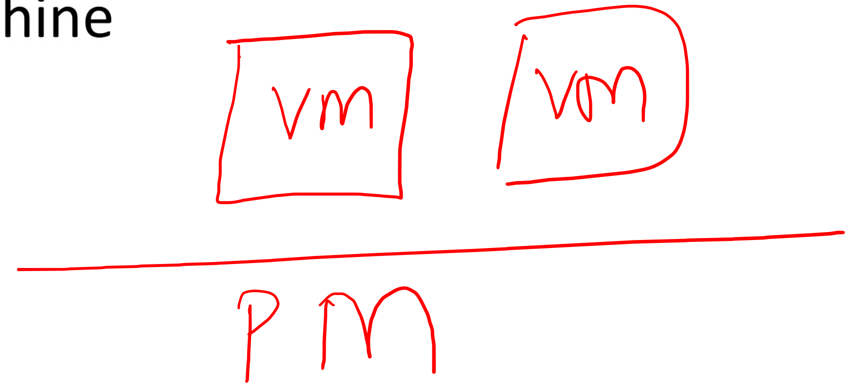
- Modules organized into layers
  - Lower layers implement a functionality, and provide a service to higher layers
  - Higher layers use service from lower layers, build additional functionality
  - Peers in a layer interact without worrying about other layers
- Example: web browser requests webpage from web server, web server returns the response
  - Higher layer: browser and server are peers, exchange web request/response
  - Lower layer: routers and switches in the network forward data bits



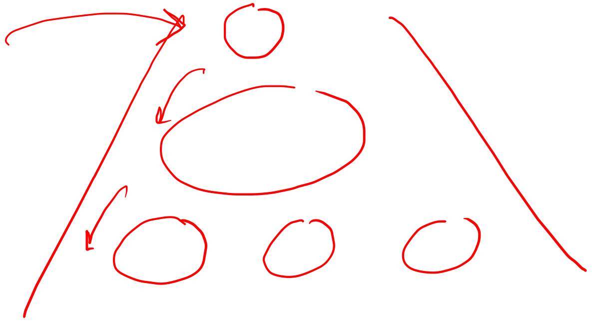
Virtualization

- One physical object, appears as multiple virtual objects
  - Multiple users can use the object, without realizing they are sharing
- Example: multiple processes share a CPU on the computer, but each thinks it is running exclusively on the CPU
  - OS multiplexes multiple processes on same CPU
- Example: multiple virtual machines on same physical machine
  - Illusion of multiple machines on one machine



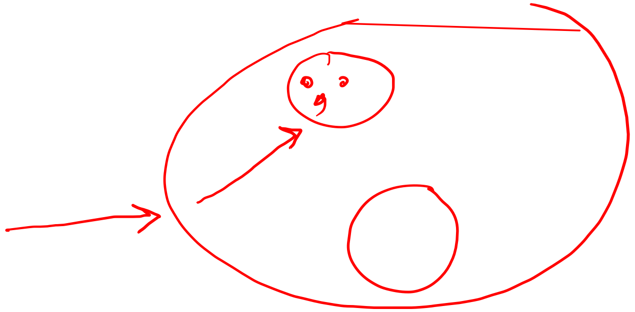


Hierarchy



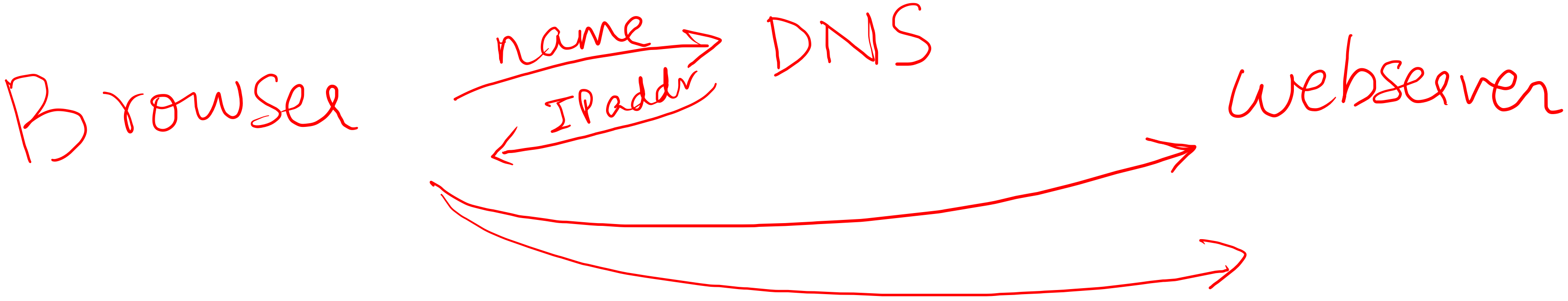
- Smaller self-contained units at lower levels assembled into larger units at higher levels of hierarchy
  - Solve problem at a higher level first, then deal with lower level details
- Example: Internet addressing is hierarchical
  - Every machine connected to the Internet has an address (“IP address”) of the format: larger network identifier + smaller sub-network identifier + individual machine identifier
  - Message to a computer routed to bigger network first, then to smaller network

large network ID + subnet ID + host ID



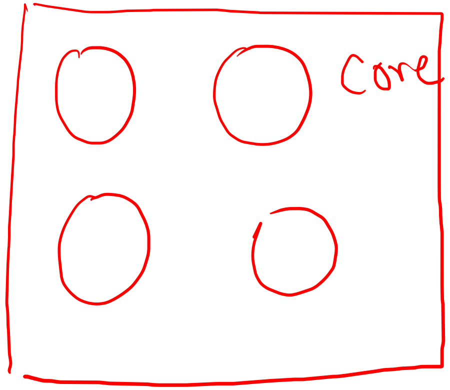
Indirection

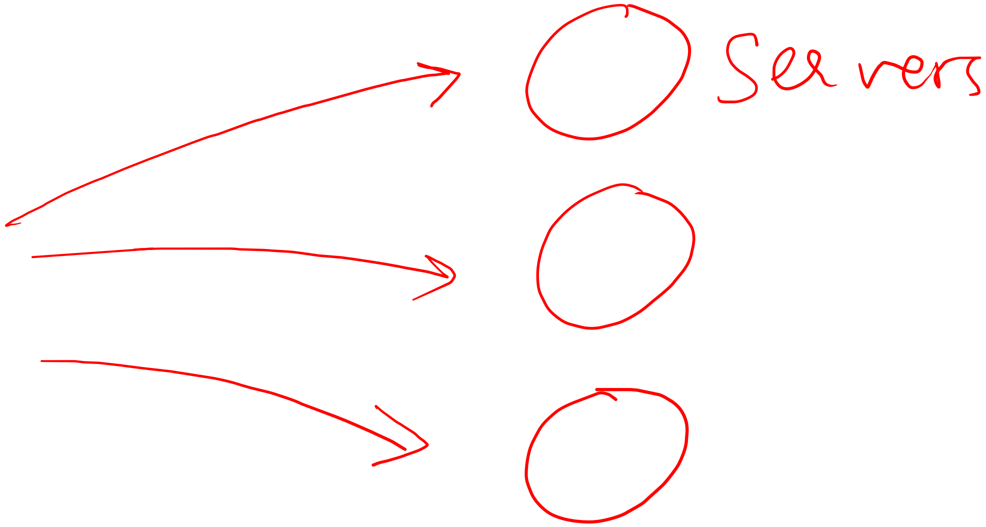
- Insert an intermediate entity in a communication between two entities, to hide details of a direct connection
  - Assign a "name", translate the name later to an address
- Example: Internet URL name resolution
  - Web servers have an address (IP address), which browser must contact
  - Browser requests a web page using a name (www.iitb.ac.in)
  - DNS is a service that maps the name to server IP address
  - Hides low level server address details from users



Parallelism

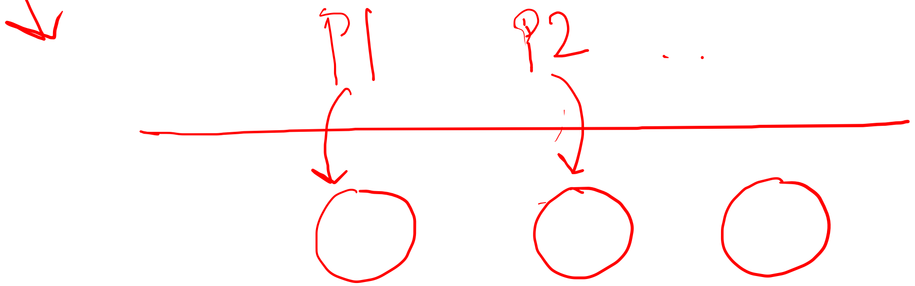
- Running multiple tasks in parallel for better performance
- Example: modern CPUs have multiple CPU cores, each running a program in parallel
- Example: a web server has multiple replicas to process requests in parallel

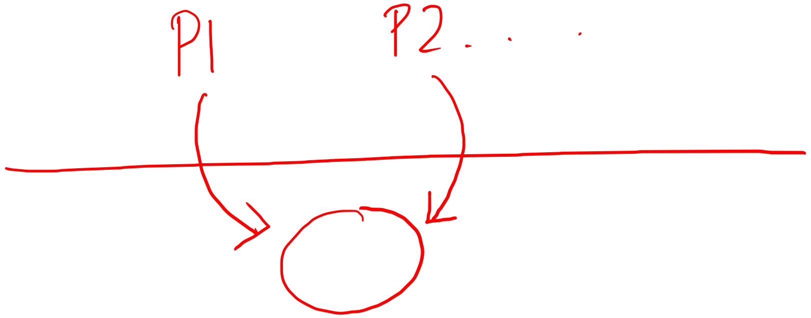




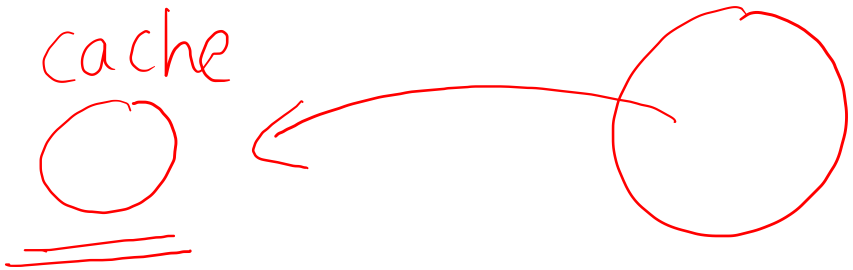
Concurrency

- Doing multiple tasks at the same time concurrently
- Related to, but different from, parallelism
- Example: multiple programs running concurrently on a CPU
  - Multiple CPU cores can run multiple programs in parallel
  - Or, multiple programs run concurrently on single CPU core (concurrency without parallelism)

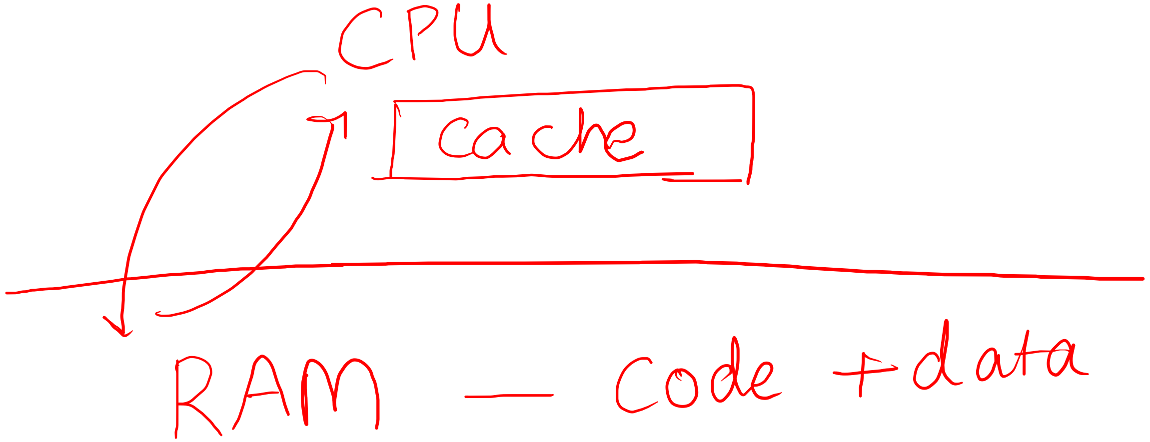




Caching

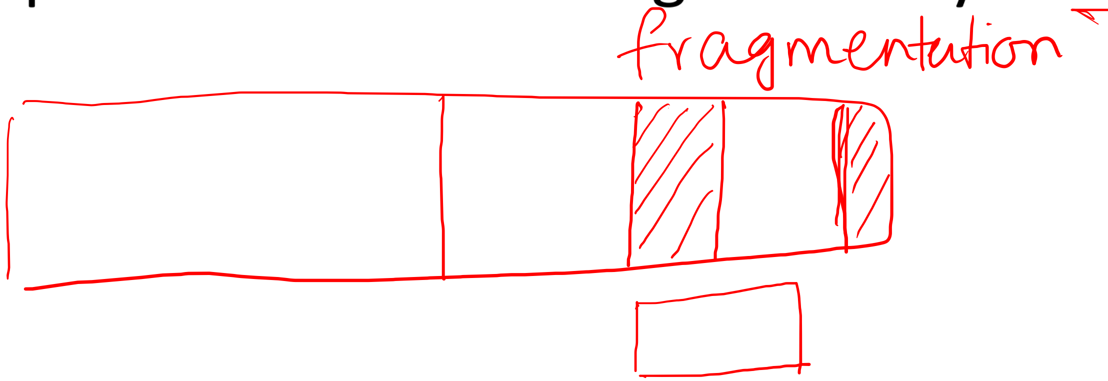


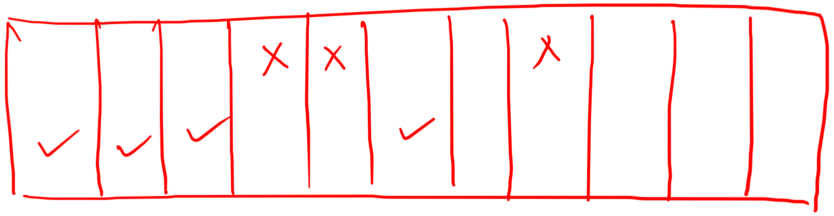
- Store frequently/recently used objects close by, for quicker access in the future
- Example: memory hierarchy in a computer
  - Program instructions+data stored in memory, fetched by CPU during execution
  - Recently used instructions+data stored closer to CPU in CPU caches



Fixed sizing

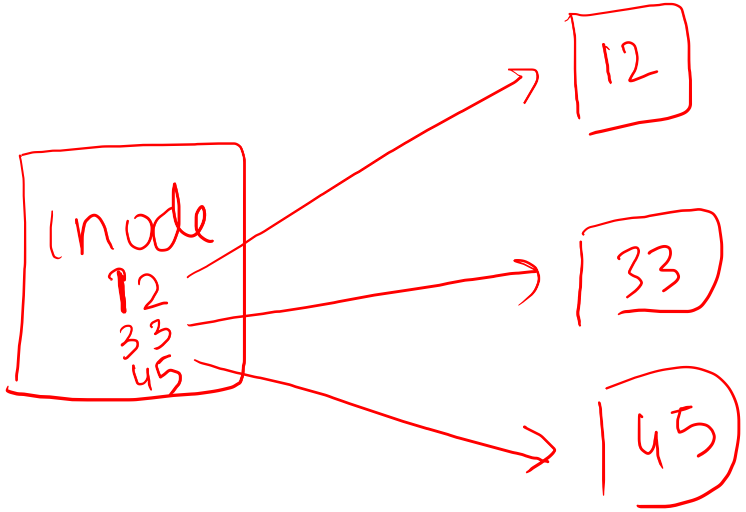
- Use standard/fixed sizes of allocating resources, to avoid fragmentation of resource
- Example: RAM (main memory) is divided into fixed size chunks called "pages"
  - A program is assigned memory for code+data in granularity of pages
  - Even if lesser than page size required, full page allocated
- Example: data is stored in granularity of blocks on disk





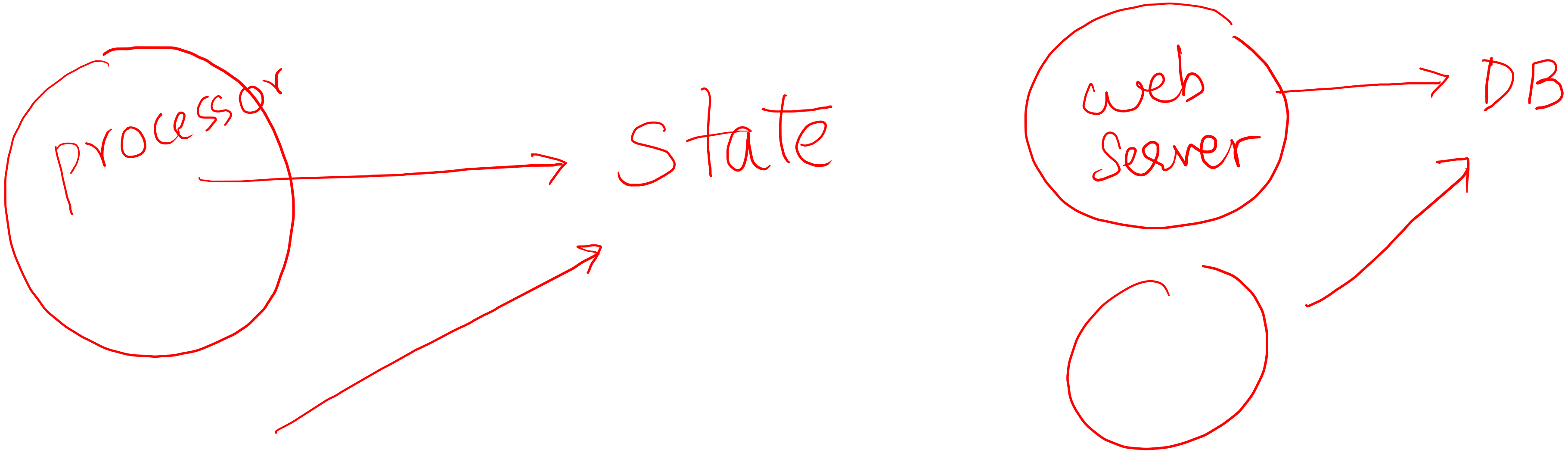
Indexing

- Collect metadata about data (information) in one place for easy lookup
- Example: index node (i-node) of a file
  - Data of a file is spread across multiple blocks on disk
  - Index node of a file stores information about all blocks of a file in one place



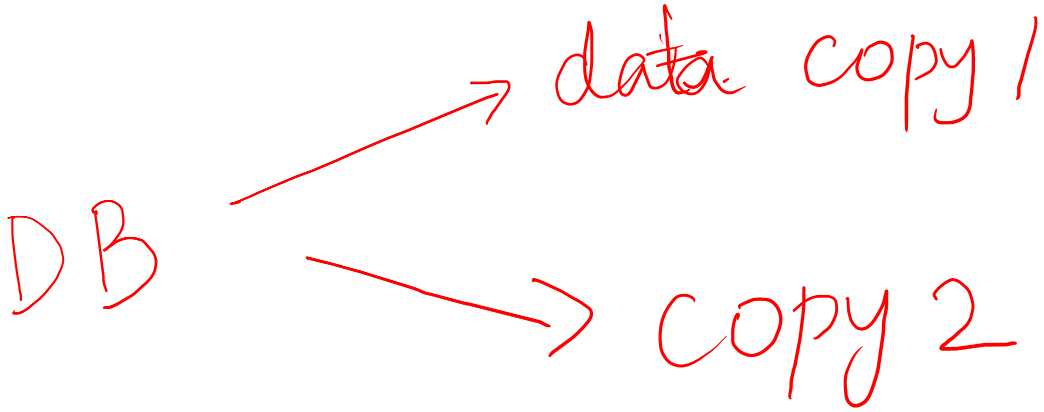
Separate state from computation

- Processing generates state. Store state separately from processor, so that state can be saved even if processor fails.
- Example: web server stores user data in a database. Even if server crashes or is replaced, user data can be accessed by another server



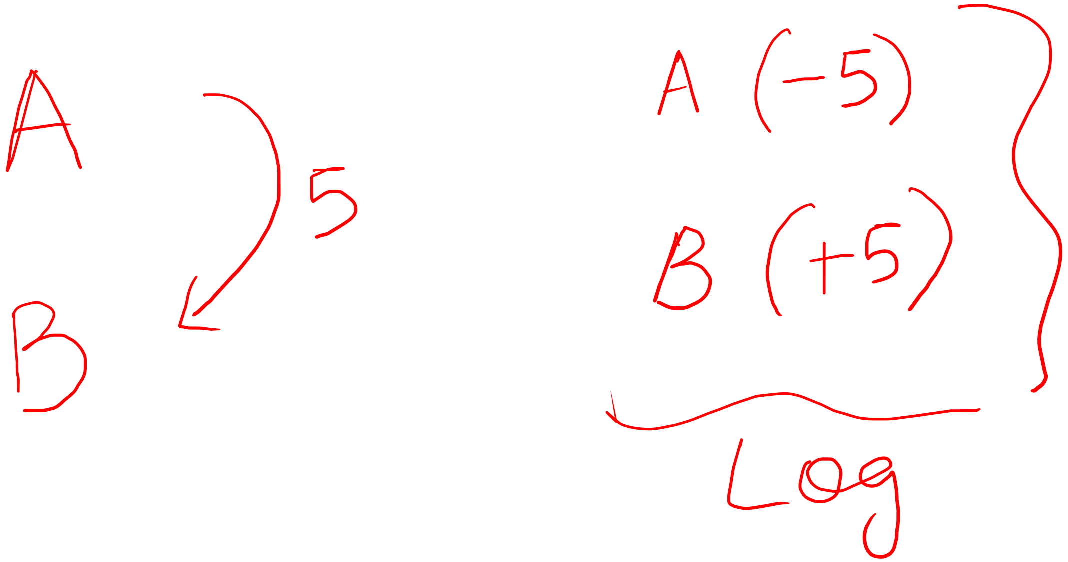
Replication

- Save multiple copies of state of a system, so that at least one copy will survive failures
  - Of course, care to be taken to ensure multiple copies are consistently updated
- Example: databases replicate user data in multiple locations for fault tolerance



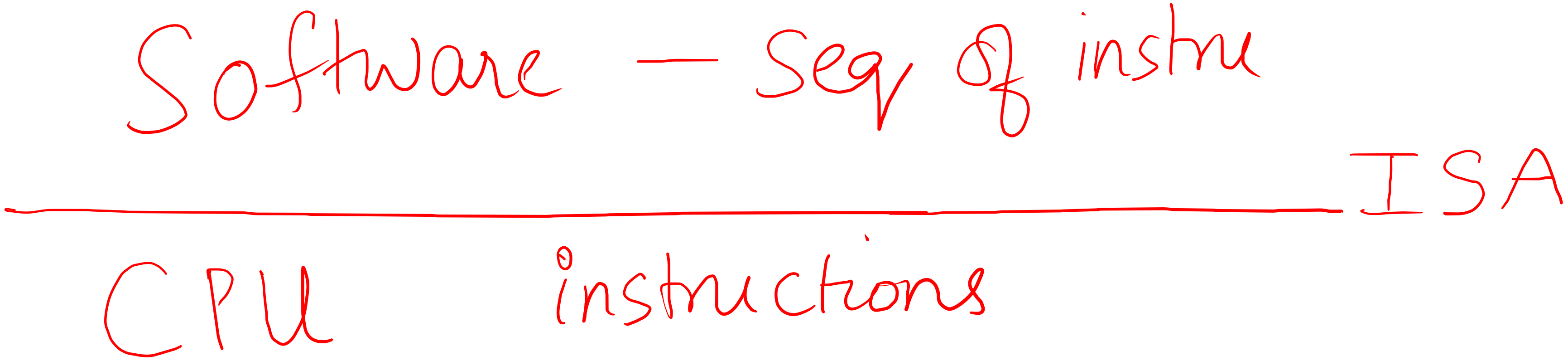
Logging

- Keep a record of all actions, so that any missed actions can be completed later
- Example: when making multiple changes to data in a database, keep a log of actions. If failure after doing some actions, can resume remaining actions by replaying from log.



Unlearning

- Sometimes, if there is good reason, ignore the standard principles
- Example: ignore the principle of abstraction, use information about CPU hardware (e.g., CPU cache structure) to optimize software programs



Summary

- This lecture:
  - Common principles of designing computer systems
  - Inter-related ideas, mostly common sense
  - We will keep revisiting them throughout the course
- Observe real life computer systems you interact with, and see these principles in action