CC5212-1
Procesamiento Masivo de Datos
Otoño 2017

Lecture 2: Introduction to Distributed Systems

Aidan Hogan
aidhog@gmail.com

MASSIVE DATA NEEDS DISTRIBUTED SYSTEMS …

Monolithic vs. Distributed Systems

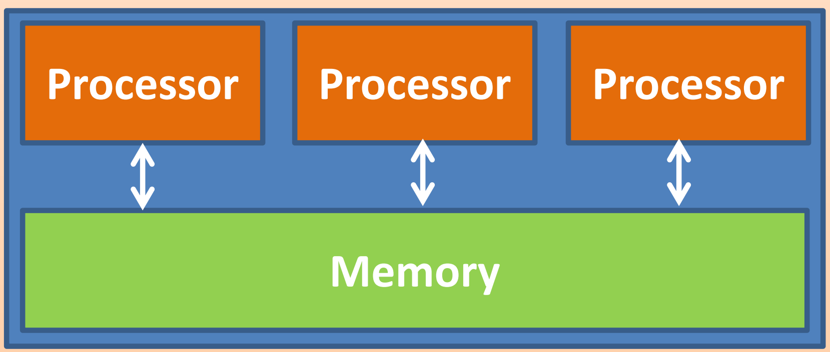
- One machine that's *n* times as powerful?

- *n* machines that are equally as powerful?

Parallel vs. Distributed Systems

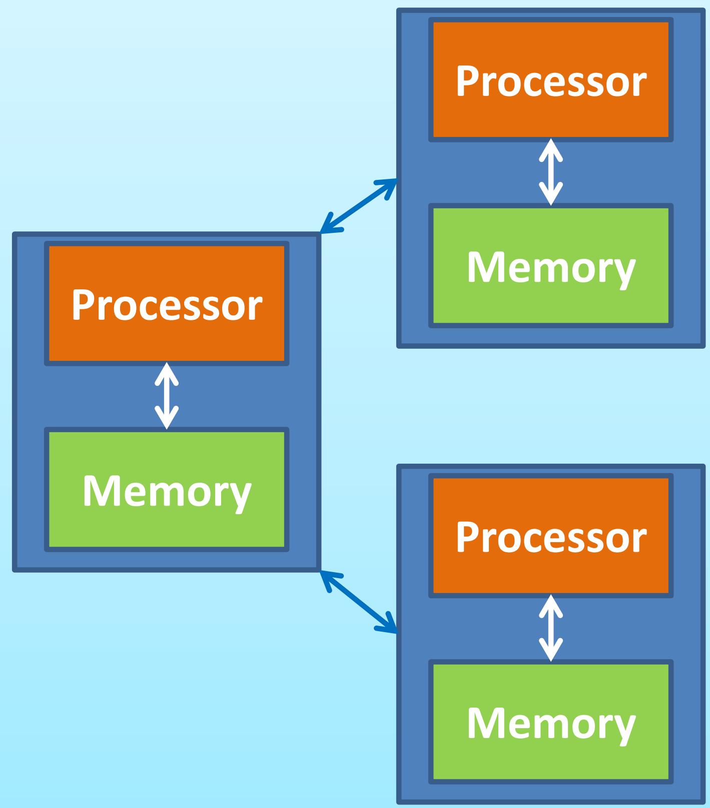
- Parallel System

  often *shared memory*



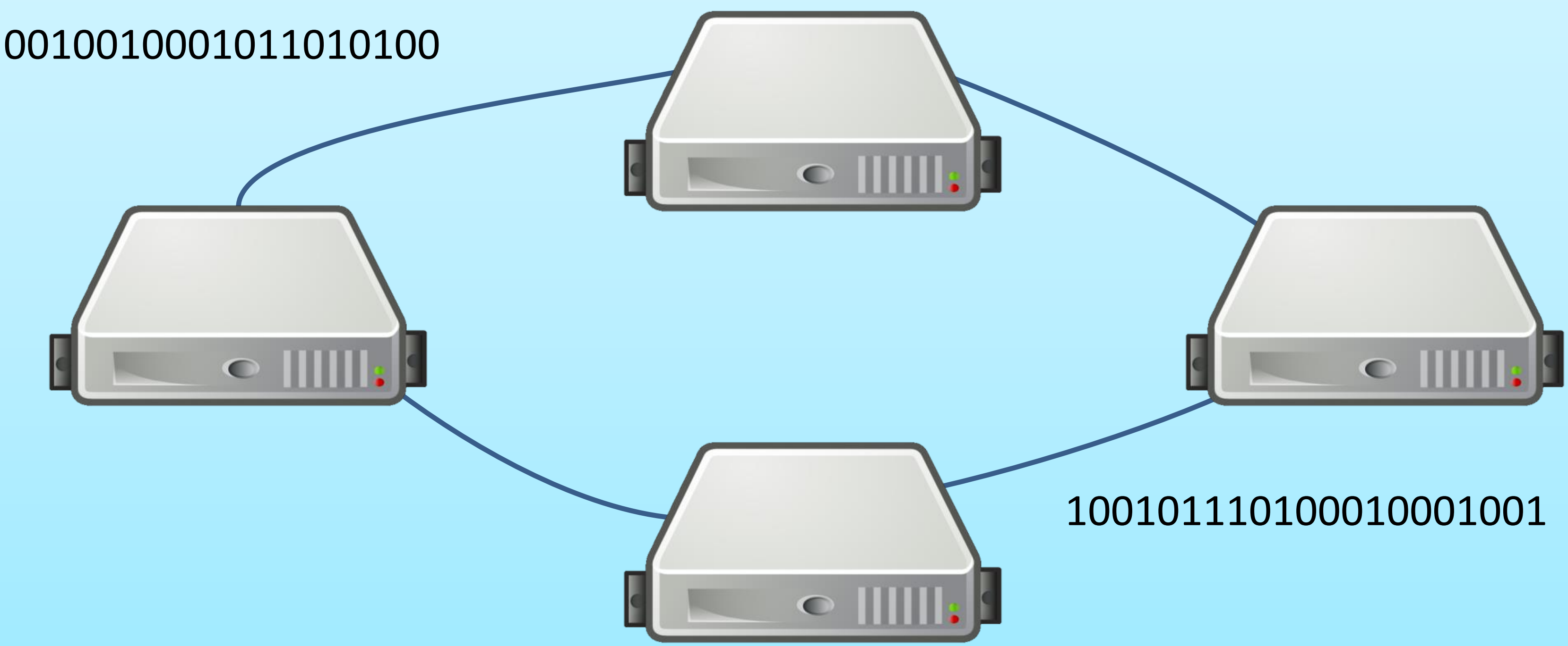
- Distributed System

  often *shared nothing*



What is a Distributed System?

"A distributed system is a system that enables a collection of **independent** computers to communicate in order to solve a common goal."



Disadvantages of Distributed Systems

(Possible) Advantages

- Cost
  - Better performance/price
- Extensibility
  - Add another machine!
- Reliability (ideally)
  - No central point of failure!
- Workload
  - Balance work automatically
- Sharing
  - Remote access to services

(Possible) Disadvantages

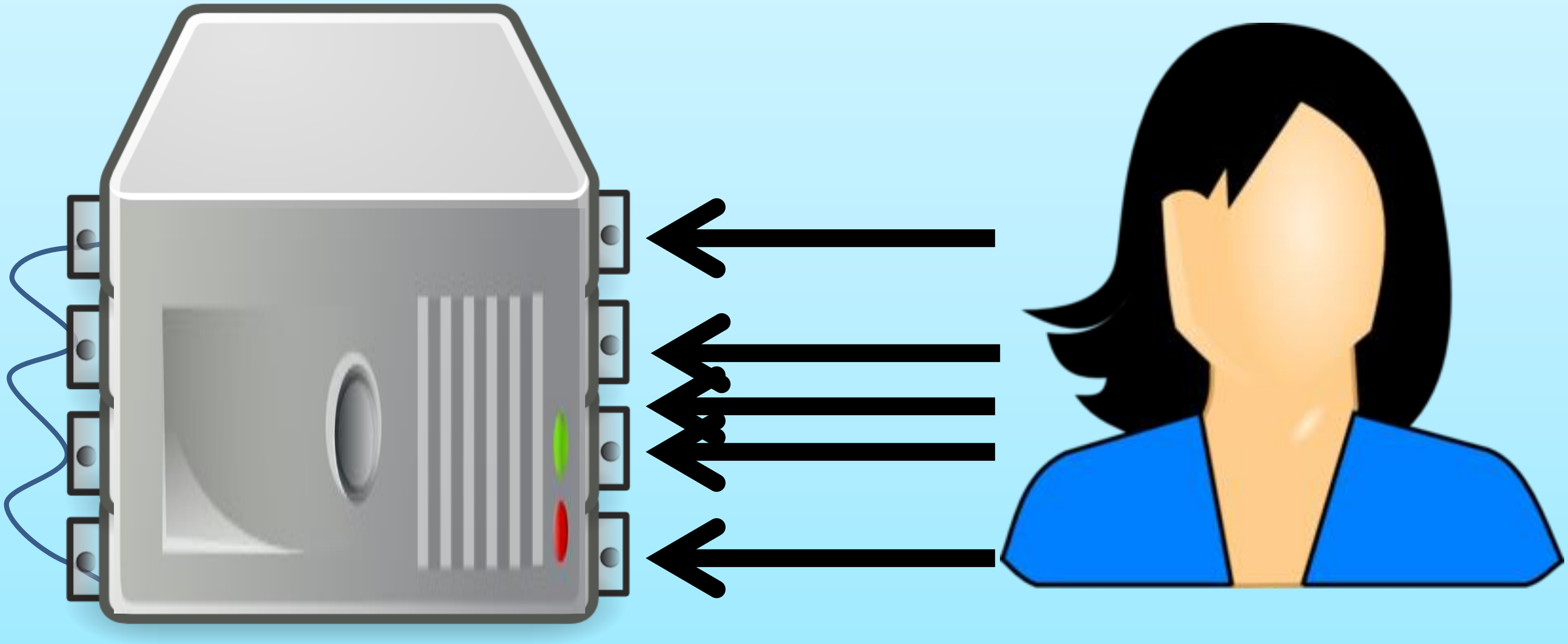
- Software
  - Need specialised programs
- Networking
  - Can be slow
- Maintenance
  - Debugging sw/hw a pain
- Security
  - Multiple remote users
- Parallelisation
  - Not always applicable

WHAT MAKES A GOOD DISTRIBUTED SYSTEM?

A Good Distributed System …

Transparency

… looks like one system



A Good Distributed System …

Transparency

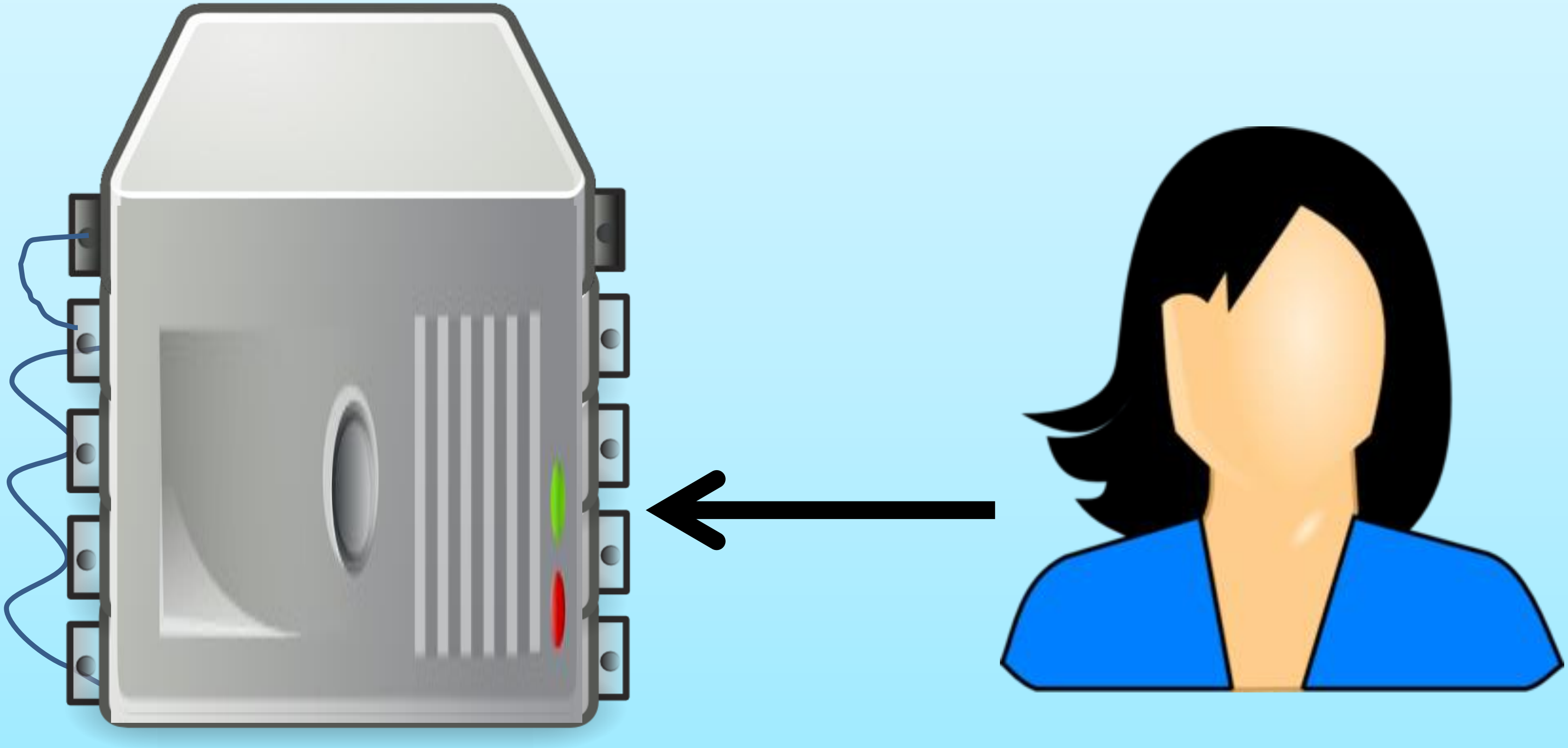
… looks like one system

- Abstract/hide:
  - Access: How different machines are accessed
  - Location: Where the machines are physically
  - Heterogeneity: Different software/hardware
  - Concurrency: Access by several users
  - Etc.
- How?
  - Employ abstract addresses, APIs, etc.

A Good Distributed System …

Flexibility

… can add/remove machines quickly and easily



A Good Distributed System …

Flexibility

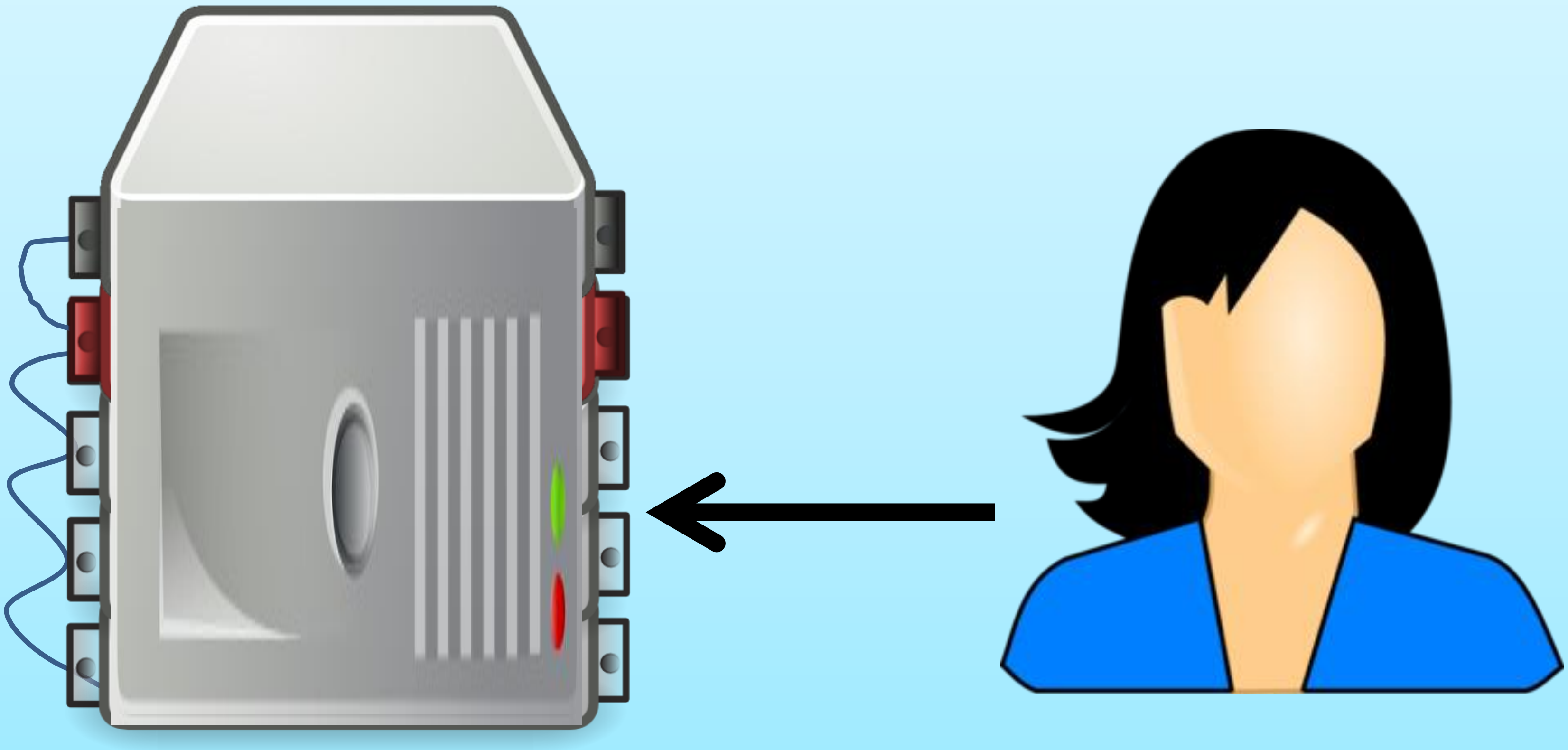
… can add/remove machines quickly and easily

- Avoid:
  - Downtime: Restarting the distributed system
  - Complex Config.: 12 admins working 24/7
  - Specific Requirements: Assumptions of OS/HW
  - Etc.
- How?
  - Employ: replication, platform-independent SW, *bootstrapping*, *heart-beats*

A Good Distributed System …

Reliability

… avoids failure / keeps working in case of failure

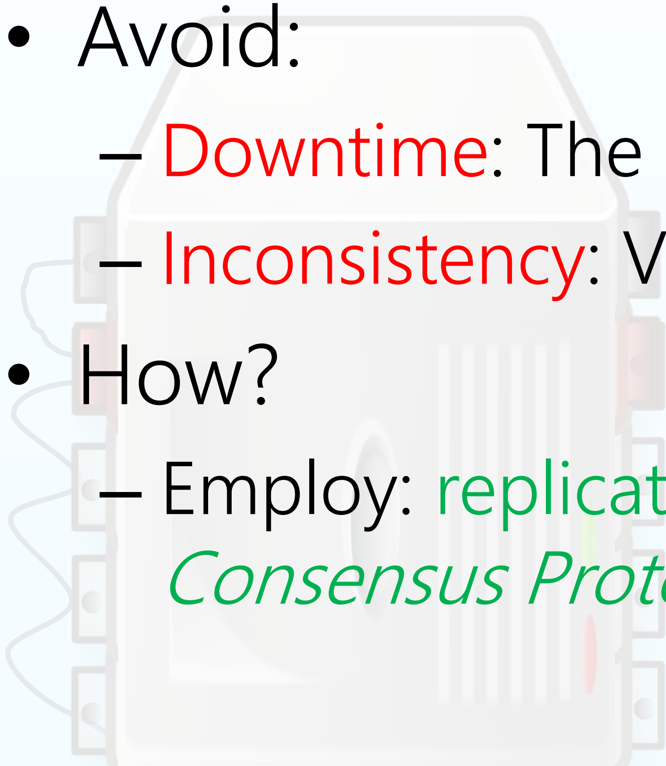


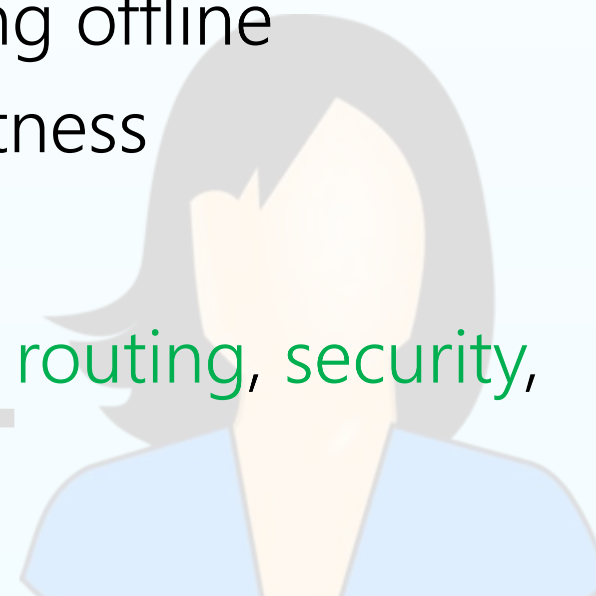
A Good Distributed System …

Reliability

… avoids failure / keeps working in case of failure

- Avoid:
  - Downtime: The system going offline
  - Inconsistency: Verify correctness
- How?
  - Employ: replication, flexible routing, security, *Consensus Protocols*

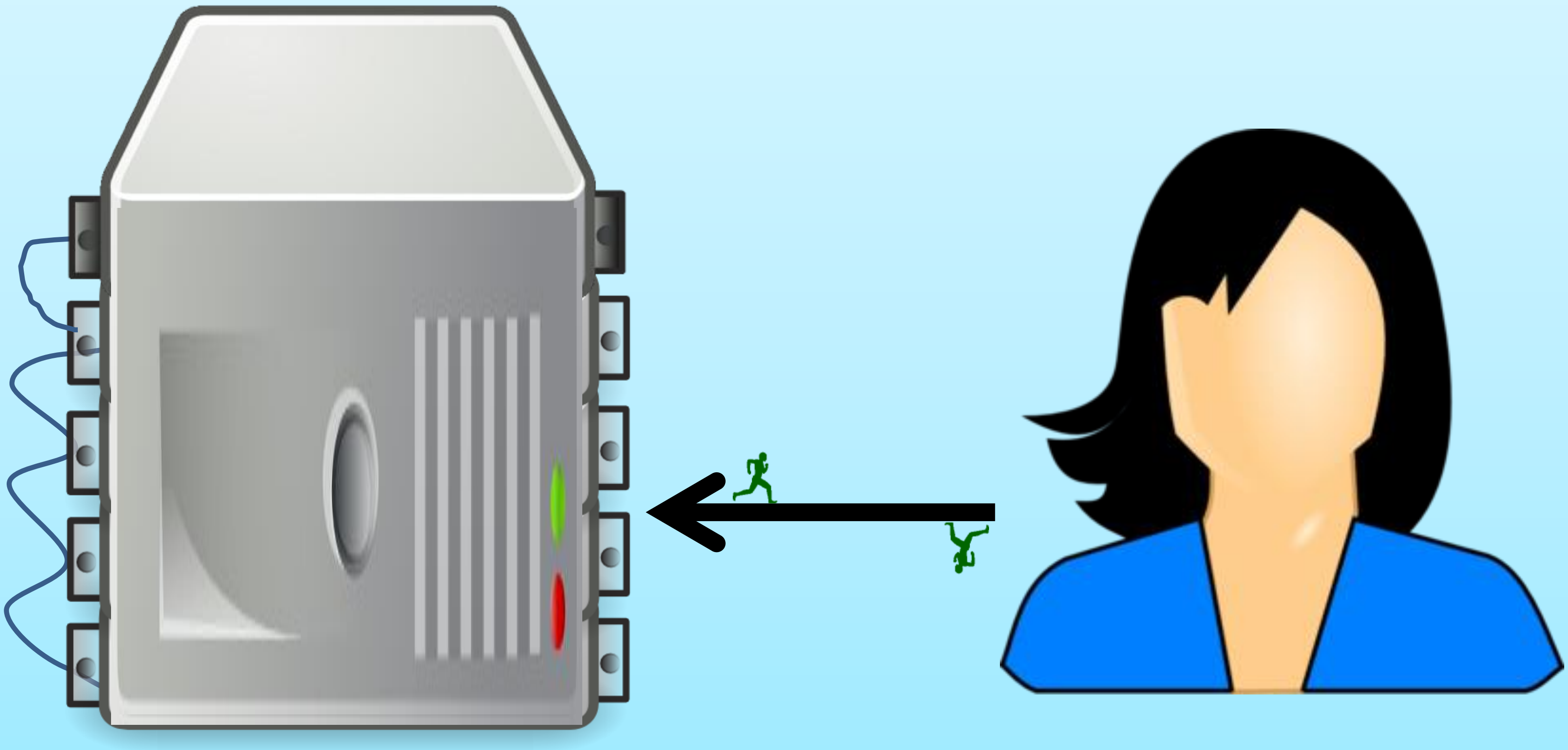




A Good Distributed System …

Performance

… does stuff quickly



A Good Distributed System …

Performance

… does stuff quickly

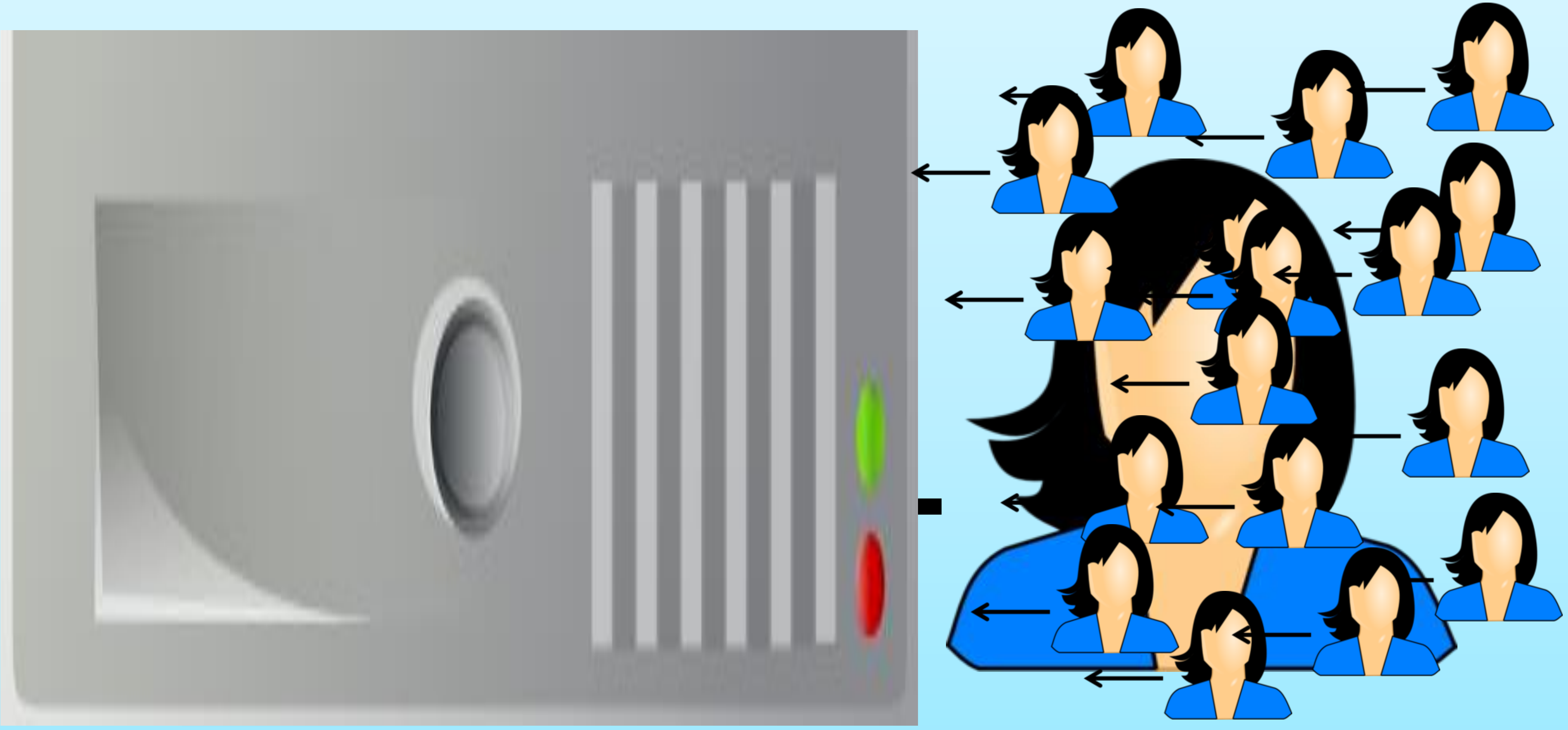
- Avoid:
  - Latency: Time for initial response
  - Long runtime: Time to complete response
  - Well, avoid 

basically
- How?
  - Employ: network optimisation, enough computational resources, etc.

A Good Distributed System …

Scalability

… ensures the infrastructure scales



A Good Distributed System …

Scalability

… ensures the infrastructure scales

- Avoid:
  - Bottlenecks: Relying on one part too much
  - Pair-wise messages: Grows quadratically: $O(n^2)$
- How?
  - Employ: peer-to-peer, direct communication, distributed indexes, etc.

A Good Distributed System …

Transparency
… looks like one system

Flexibility
… can add/remove machines quickly and easily

Reliability
… avoids failure / keeps working in case of failure

Performance
… does stuff quickly

Scalability
… ensures the infrastructure scales

A Good Distributed System …

Transparency

… looks like one system

Flexibility

… can add/remove machines quickly and easily

Why these five in particular?

Reliability

Good question. ¯_(ツ)_/¯

… avoids failure / keeps working in case of failure

Performance

… does stuff quickly

Scalability

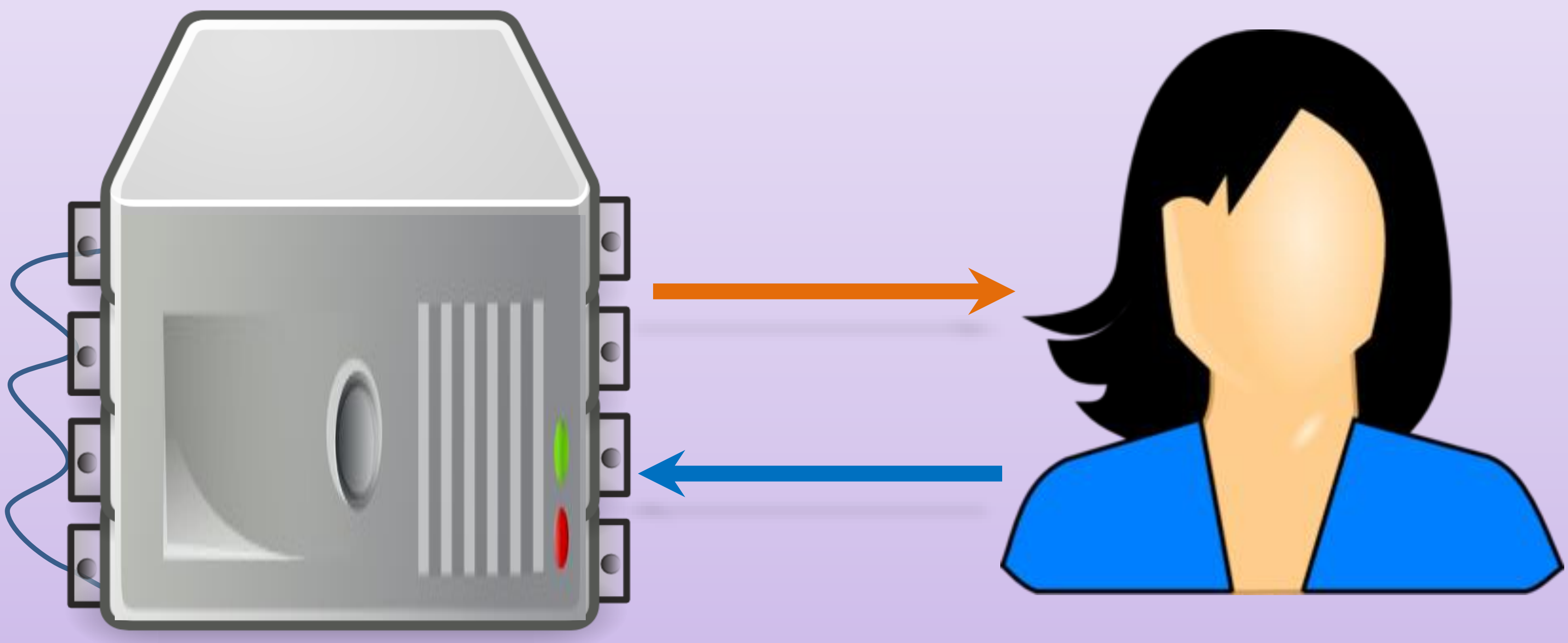
… ensures the infrastructure scales

DISTRIBUTED SYSTEMS: CLIENT–SERVER ARCHITECTURE

Client–Server Model

Client makes request to server

Server acts and responds



For example?

Web, Email, DropBox, …

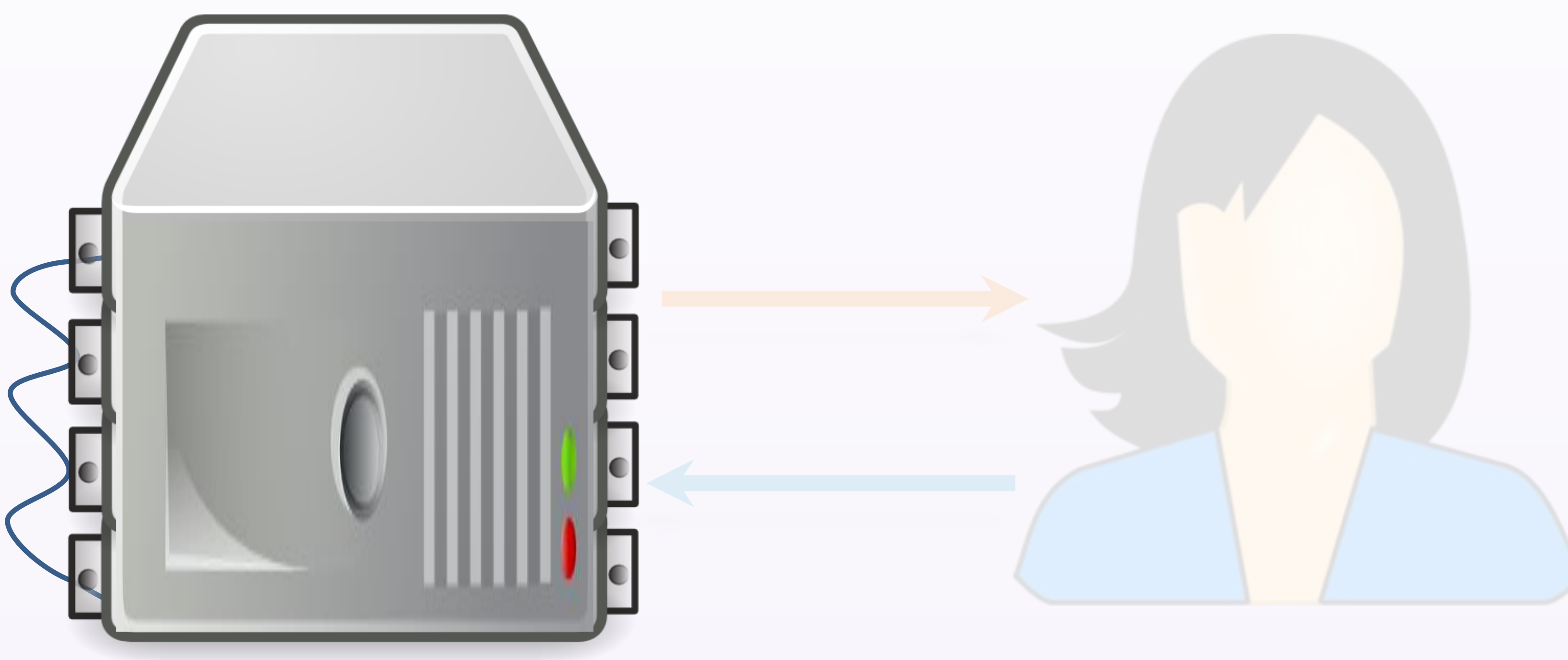
Client–Server Model

Client makes request to server

Server acts and responds

Server can be a distributed system! ⚠

Server ≠ Physical Machine



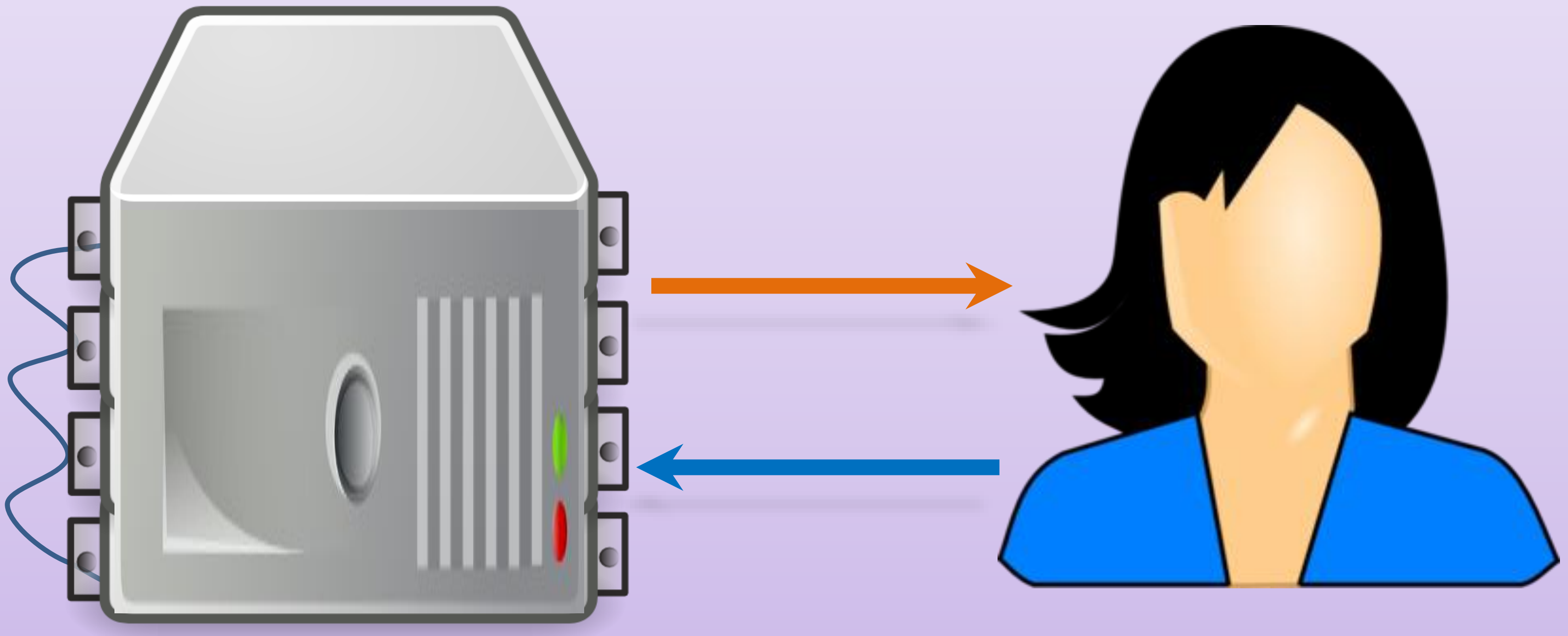
For example?

Web, Email, DropBox, ...

Client–Server: Thin Client

Server does the hard work

(server sends results | client uses few resources)



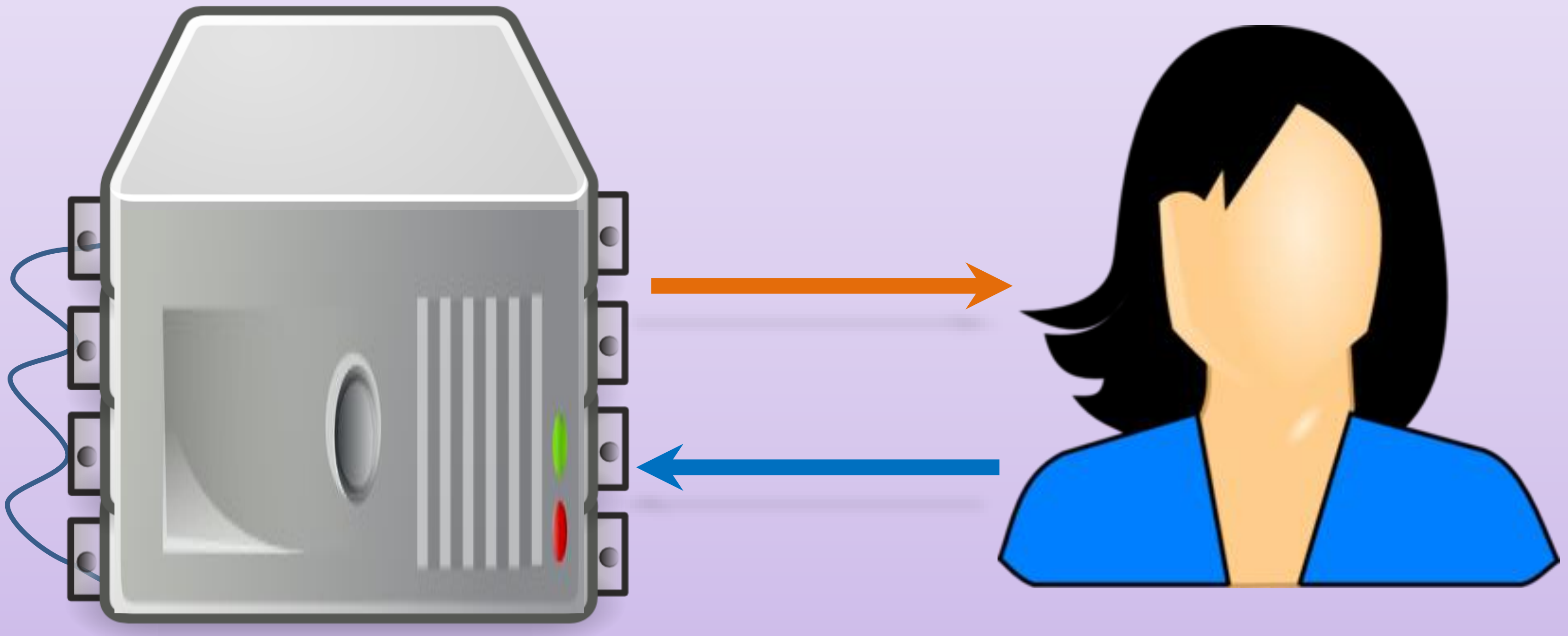
For example?

Email, Early Web (PHP, etc.)

Client–Server: Fat Client

Client does the hard work

(server sends raw data | client uses more resources)



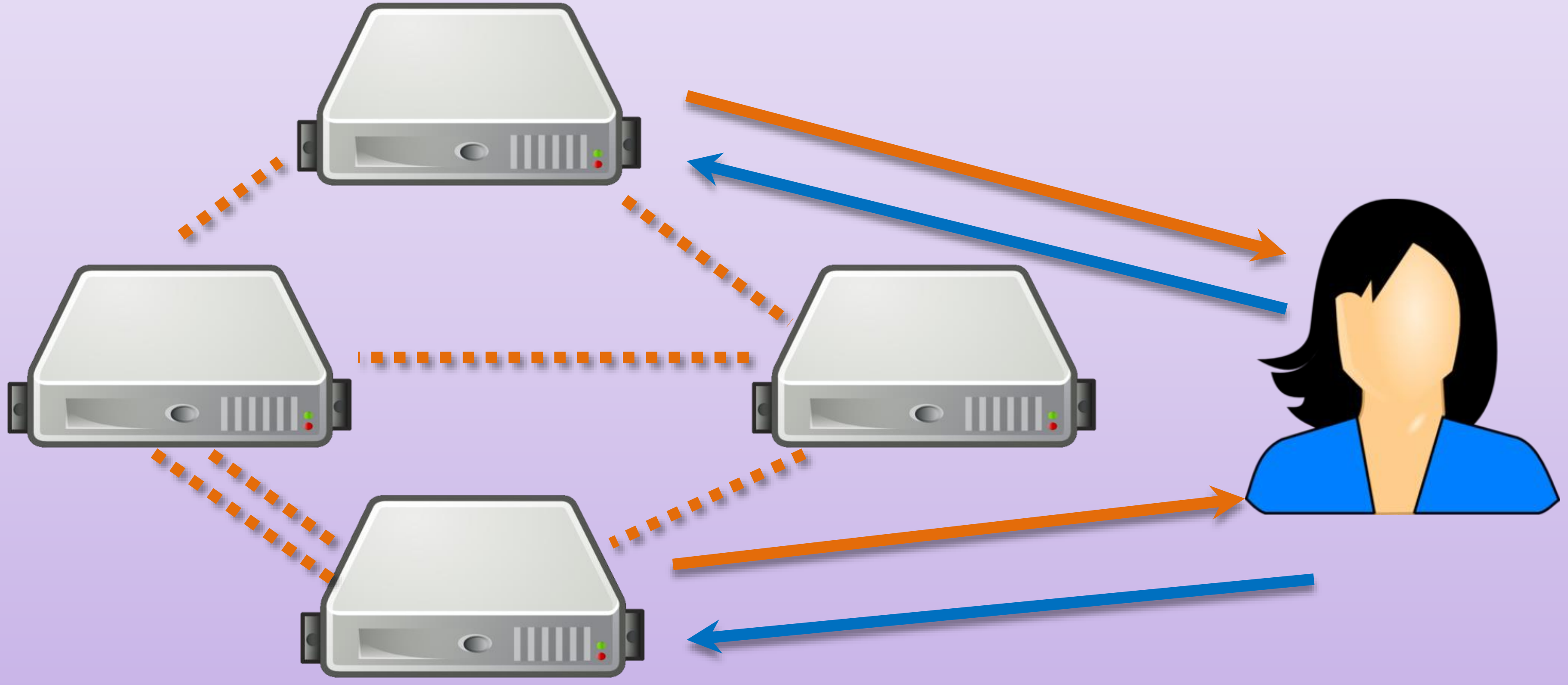
For example?

Javascript, Mobile Apps, Video

Client–Server: Mirror Machine

Client goes to any mirror machine

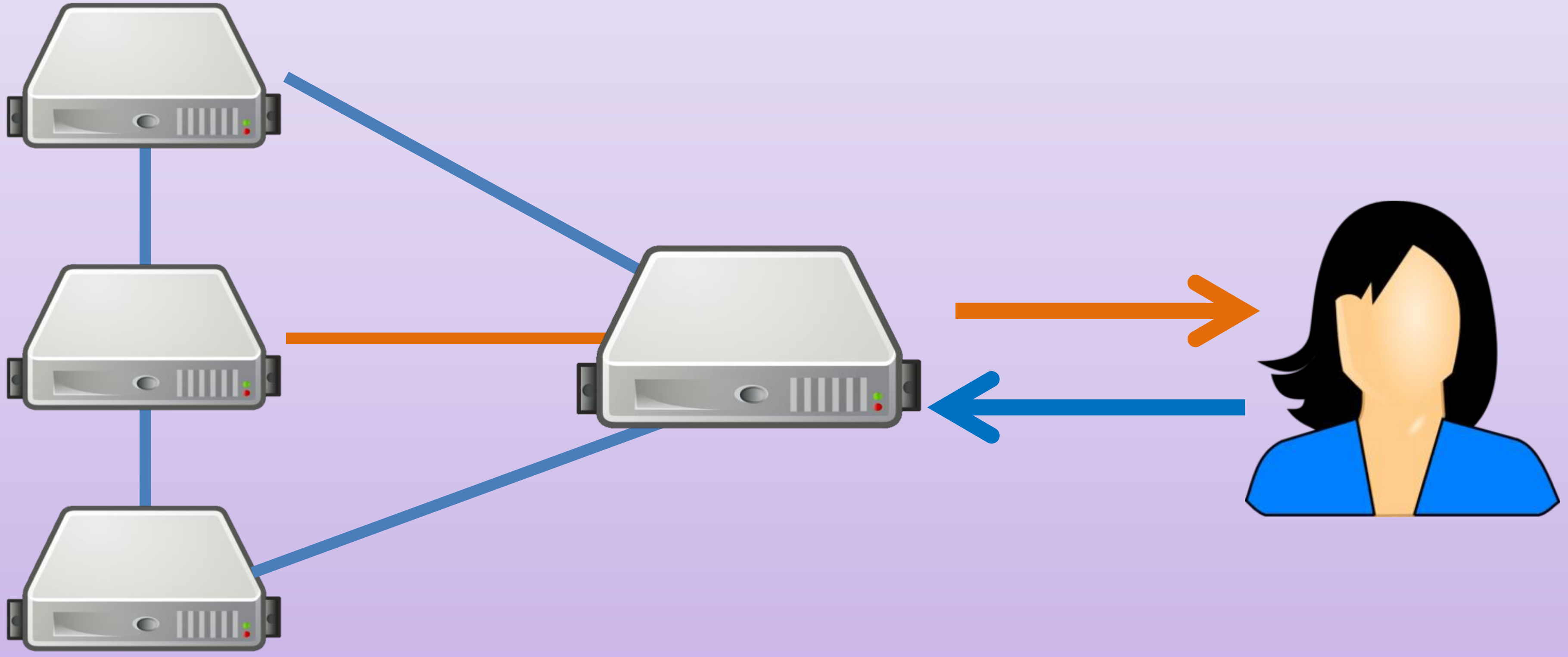
(user-facing services are replicated)



Client–Server: Proxy Machine

Client goes to "proxy" machine

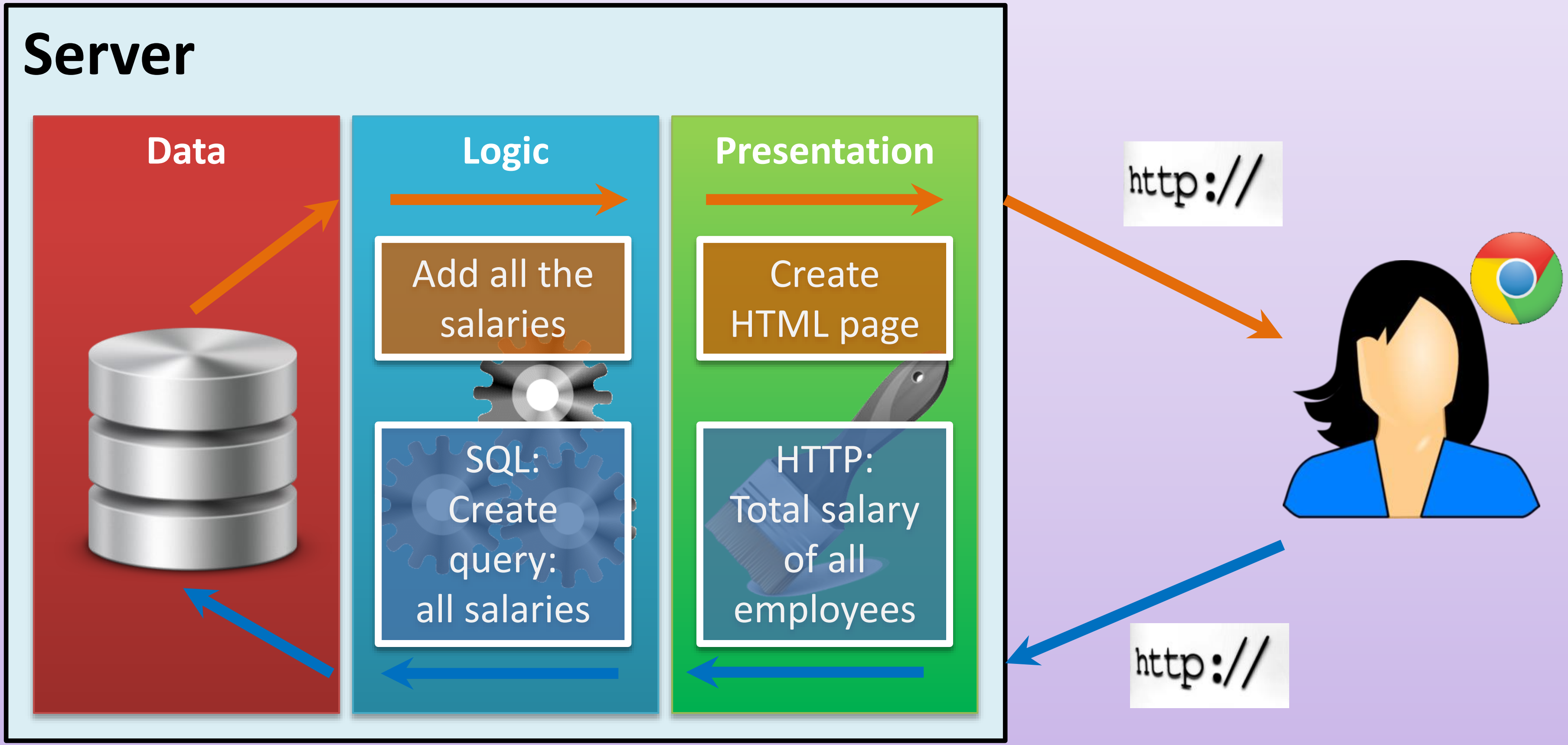
(proxy machine forwards request and response)



Client–Server: Three-Tier Server

Three Layer Architecture

1. Data | 2. Logic | 3. Presentation

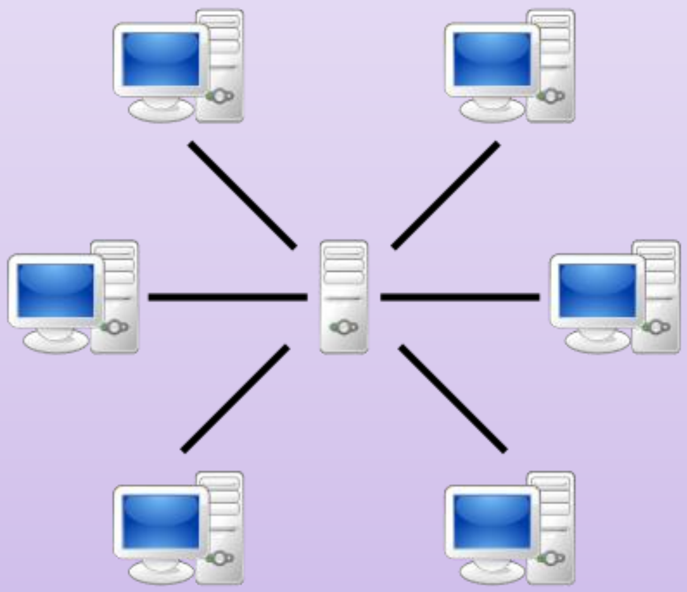


DISTRIBUTED SYSTEMS: PEER-TO-PEER ARCHITECTURE

Peer-to-Peer (P2P)

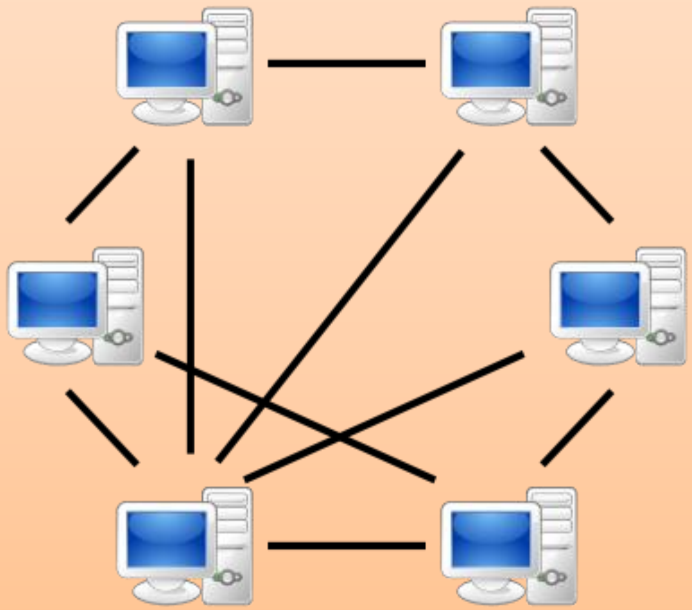
Client–Server

- Client interacts directly with server



Peer-to-Peer (P2)

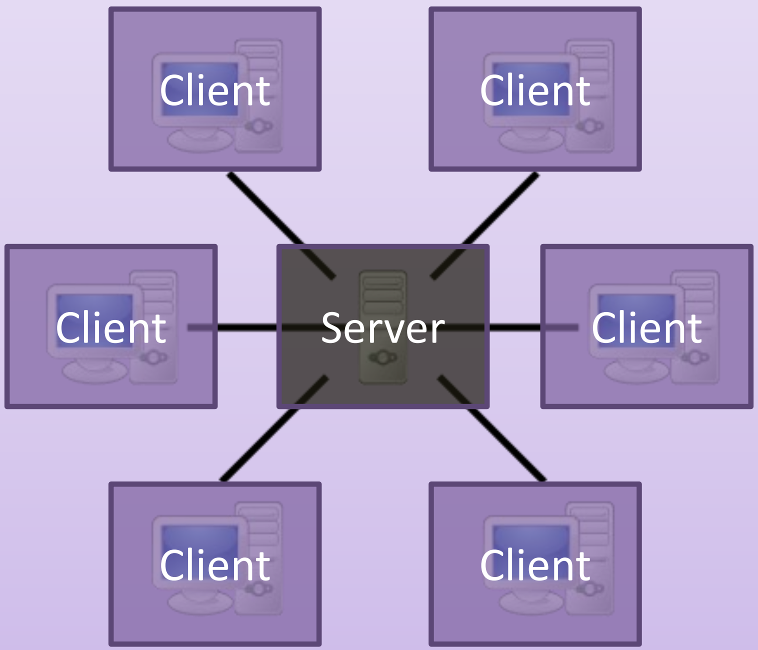
- Peers interact directly with each other



Peer-to-Peer (P2P)

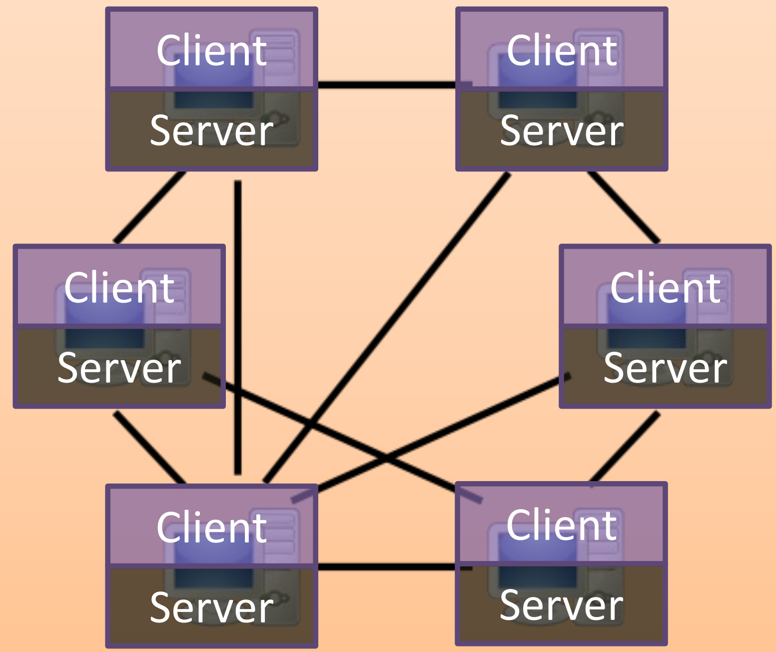
Client–Server

- Client interacts directly with server



Peer-to-Peer (P2)

- Peers interact directly with each other



Peer-to-Peer (P2P)

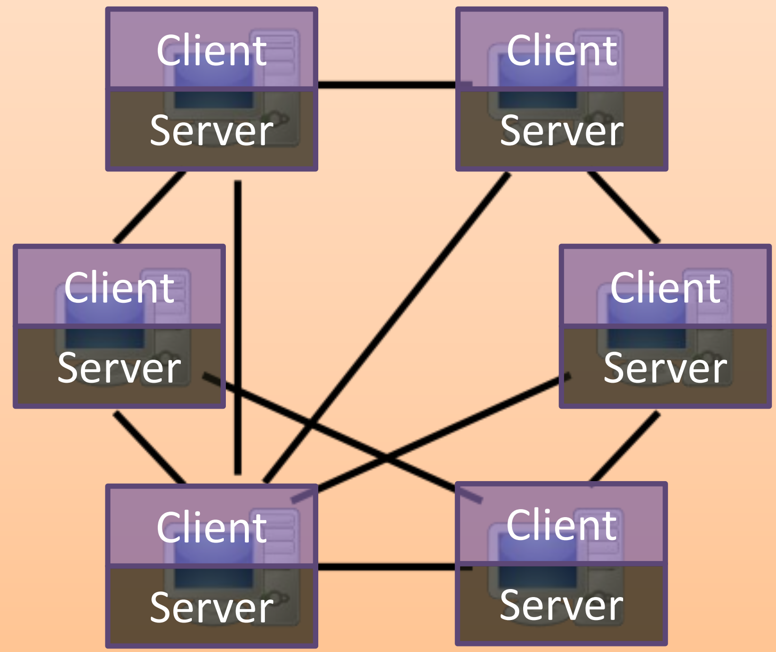
Client–Server

- Client interacts directly with server

Examples of P2P systems?

Peer-to-Peer (P2)

- Peers interact directly with each other



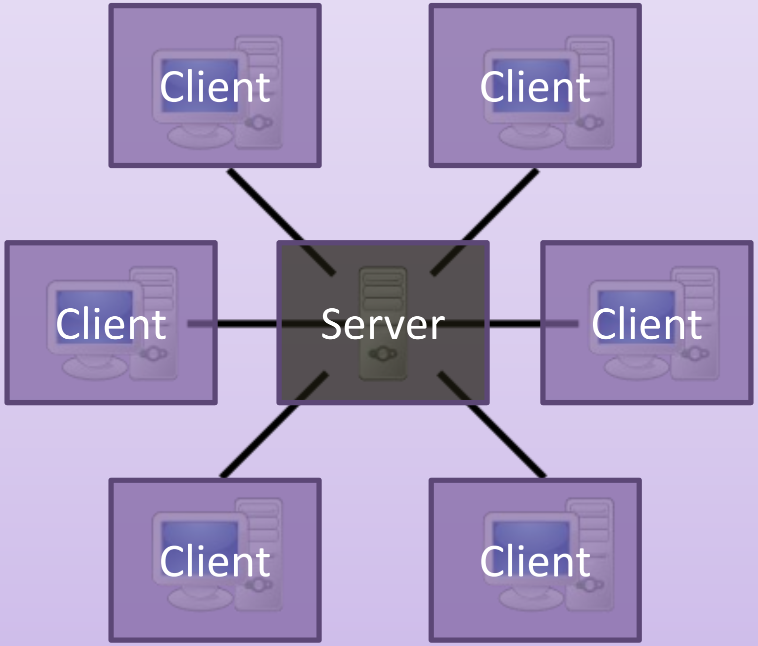
Peer-to-Peer (P2P)

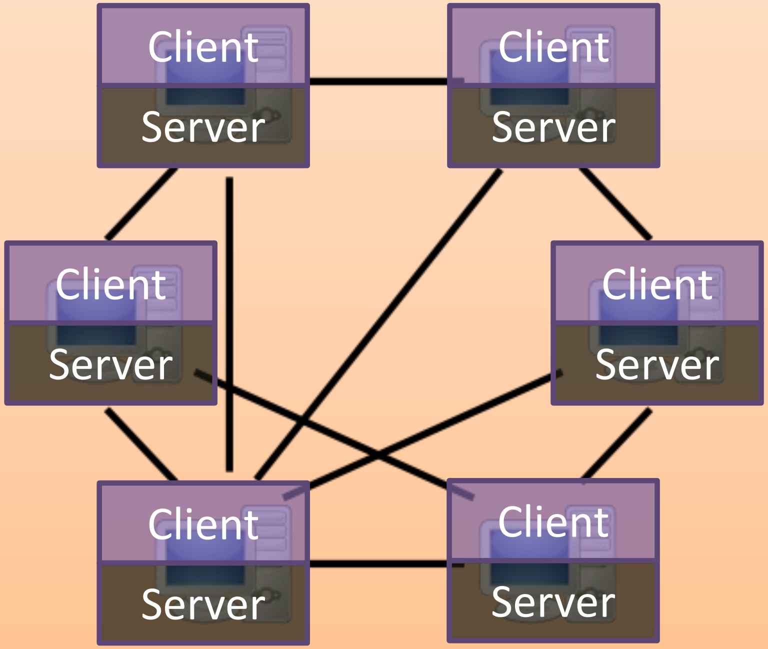
Online Banking:

- Clients interact with a central banking server

Cryptocurrencies (e.g., BitCoin):

- Peers act both as the bank and the client

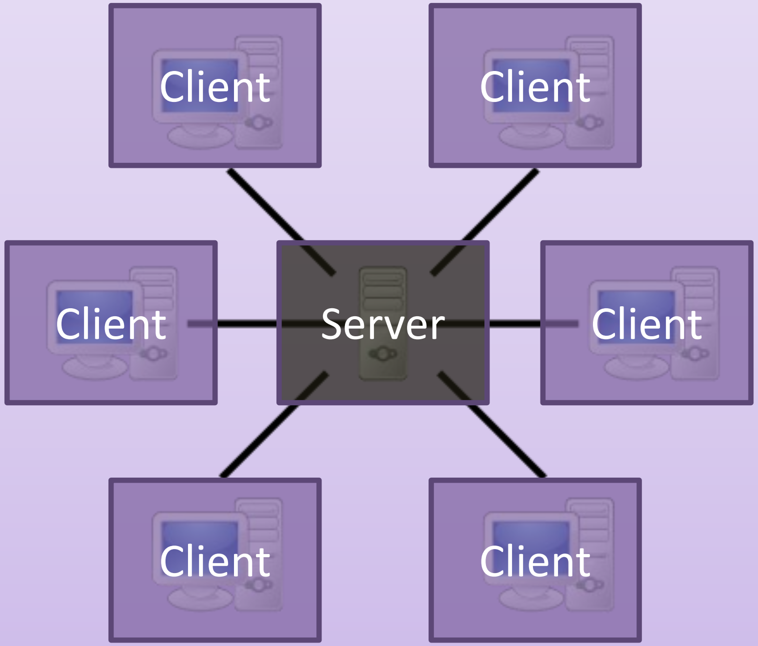




Peer-to-Peer (P2P)

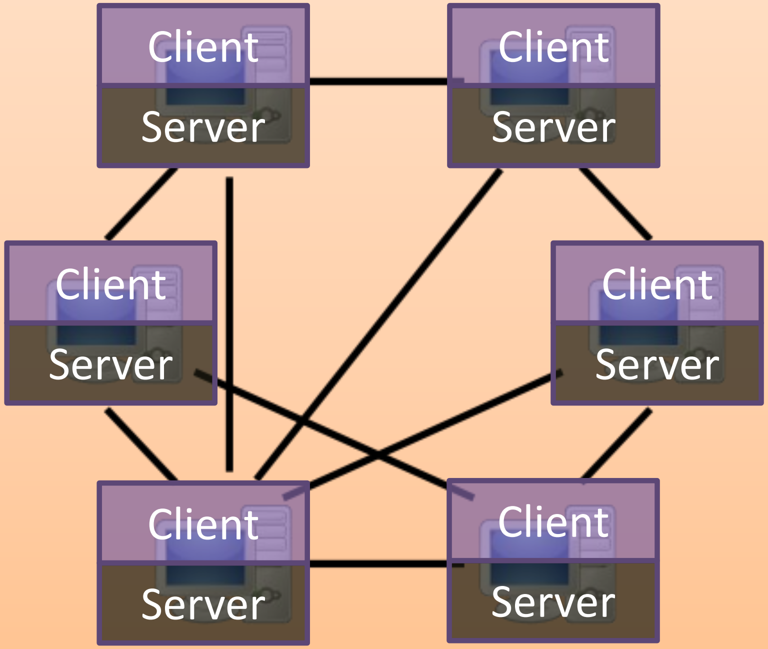
File Servers (DropBox):

- Clients interact with a central file server



P2P File Sharing (e.g., Bittorrent):

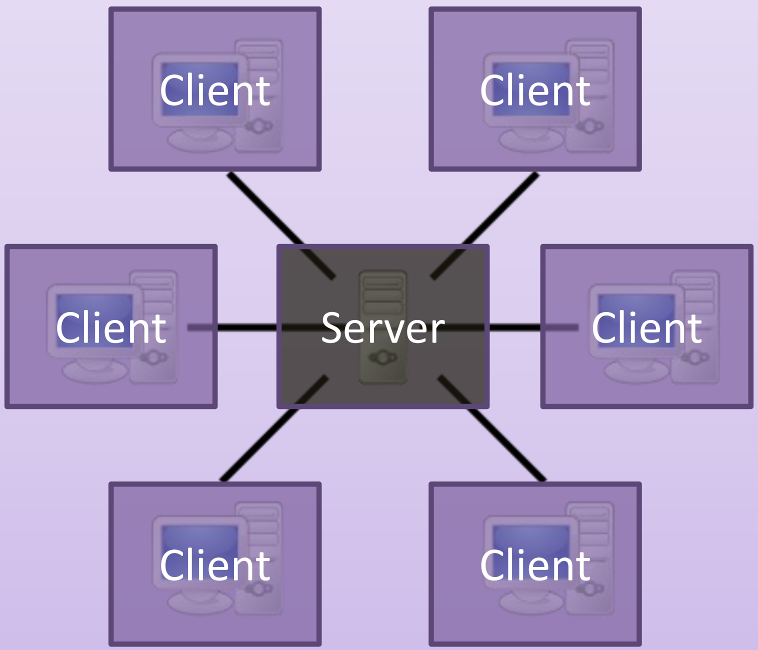
- Peers act both as the file server and the client



Peer-to-Peer (P2P)

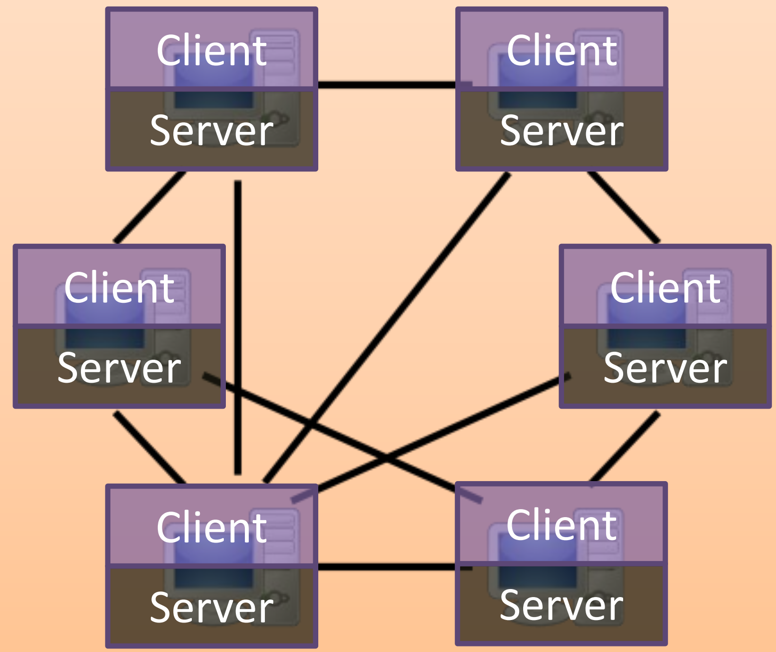
SVN

- Clients interact with a central versioning repository

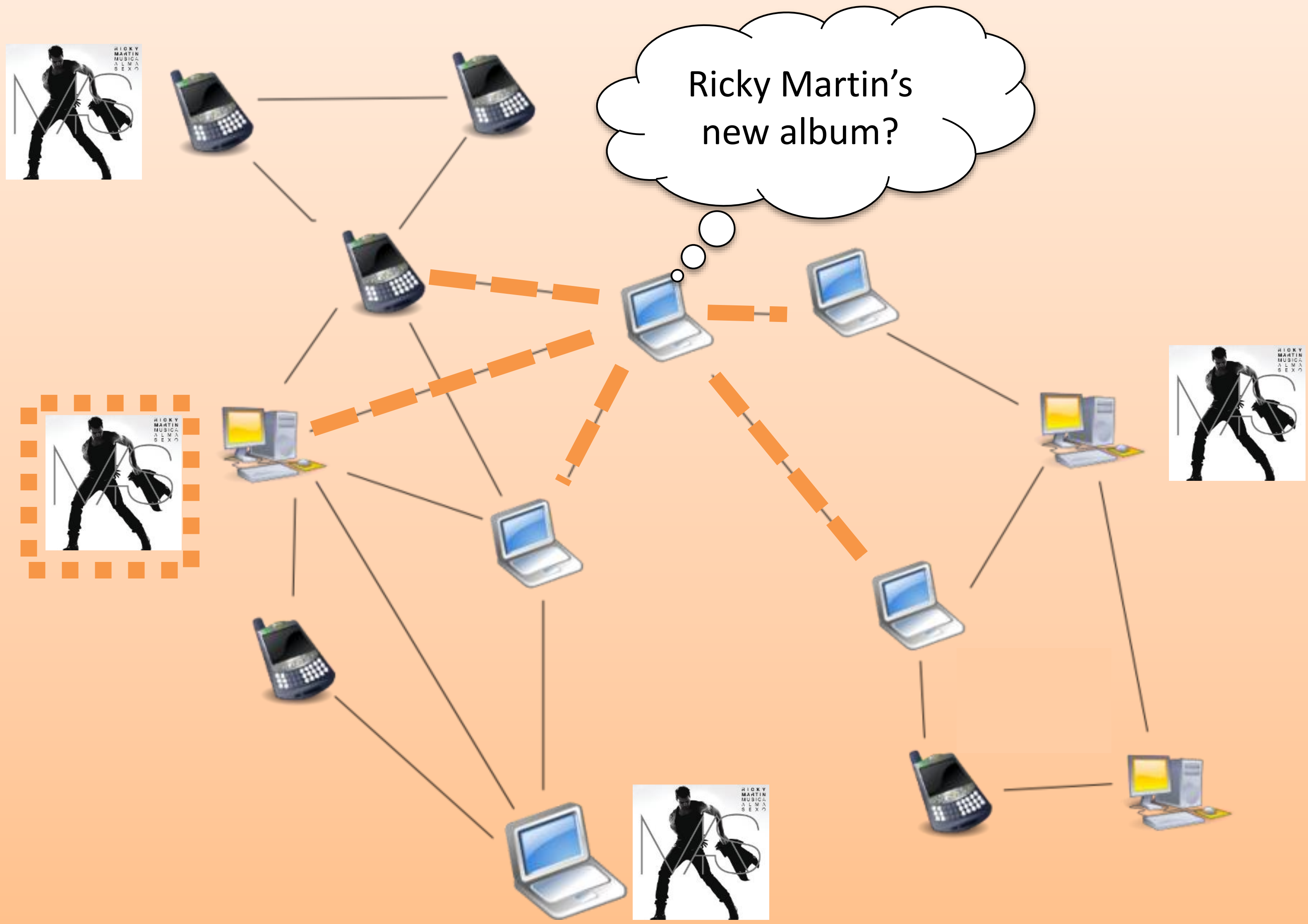


GIT

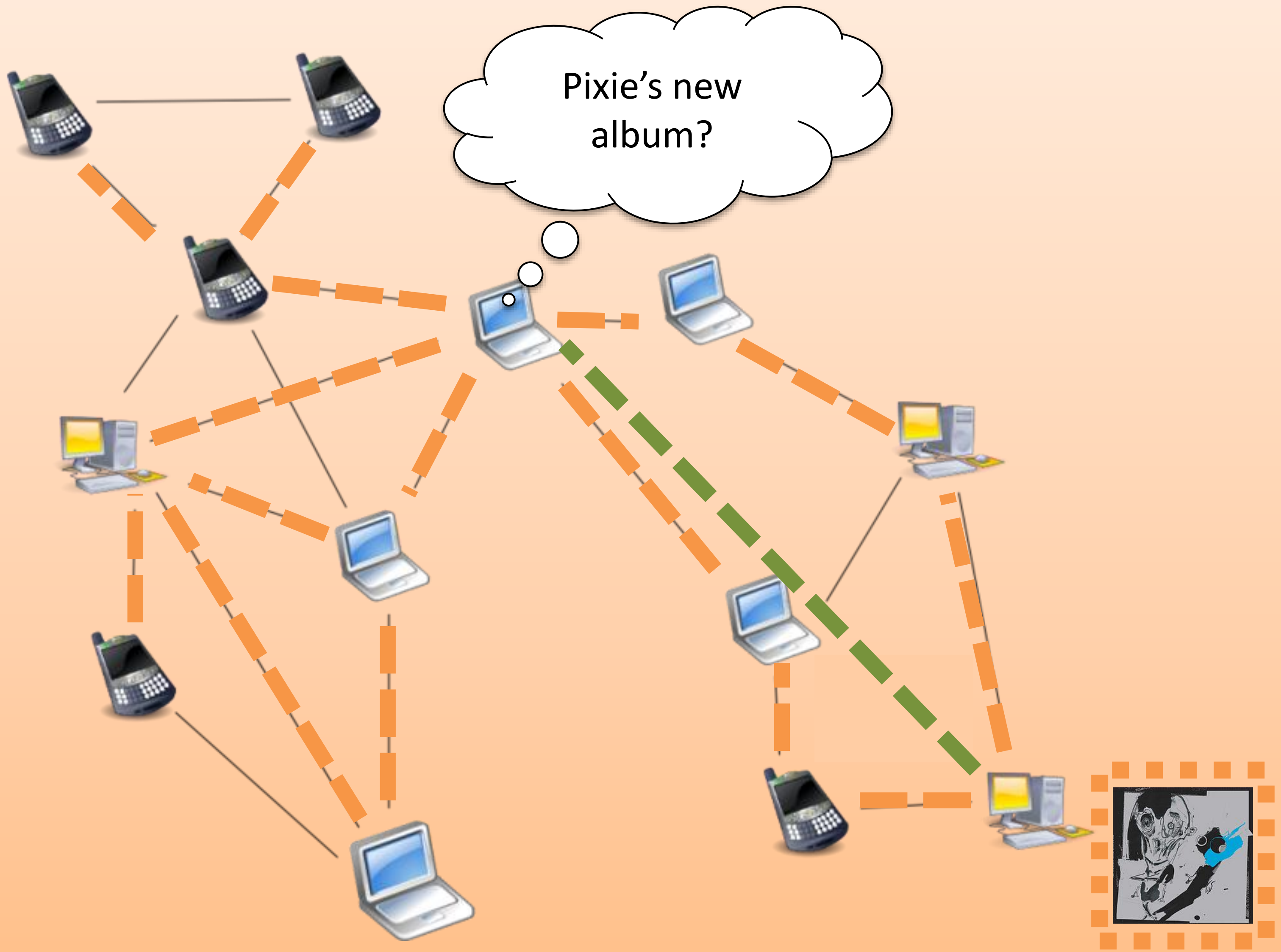
- Peers have their own repositories, which they synch



Peer-to-Peer: Unstructured (flooding)



Peer-to-Peer: Unstructured (flooding)



Peer-to-Peer: Unstructured (flooding)

Transparency?

Flexibility?

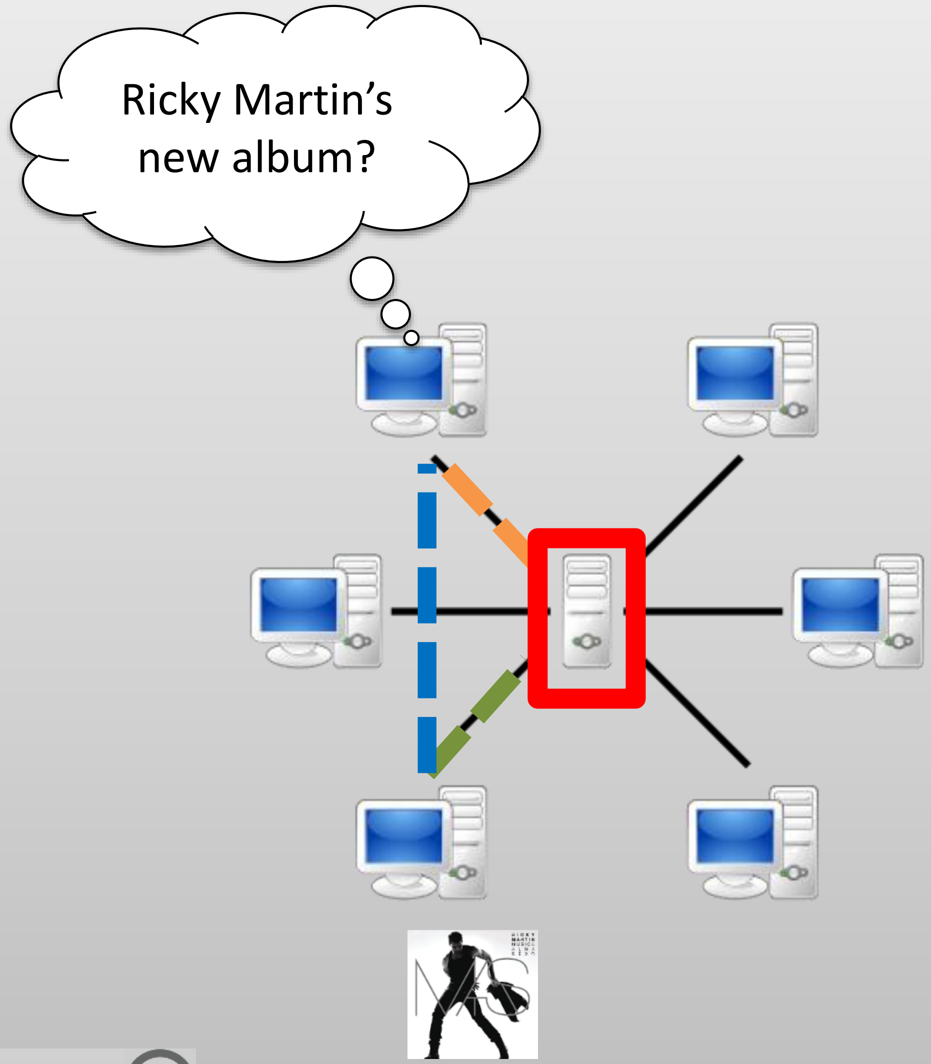
Reliability?

Performance?

Scalability?

Peer-to-Peer: Structured (Central)

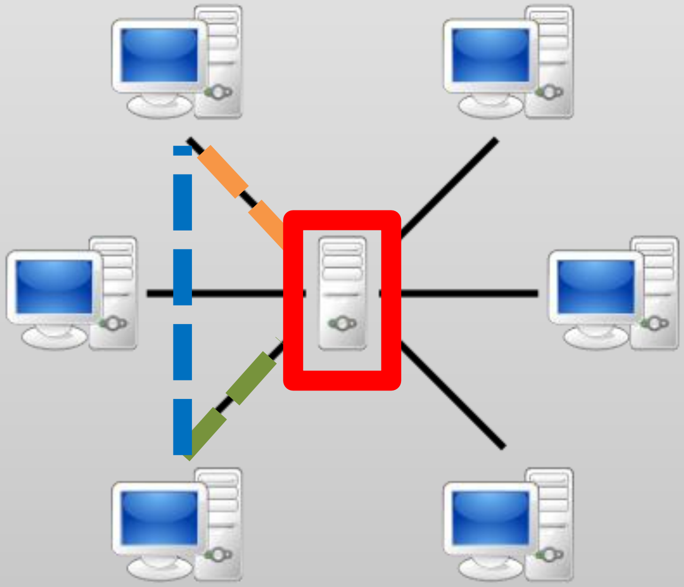
- In central server, each peer registers
  - Content
  - Address
- Peer requests content from server
- Peers connect directly



Advantages / Disadvantages?

Peer-to-Peer: Structured (Central)

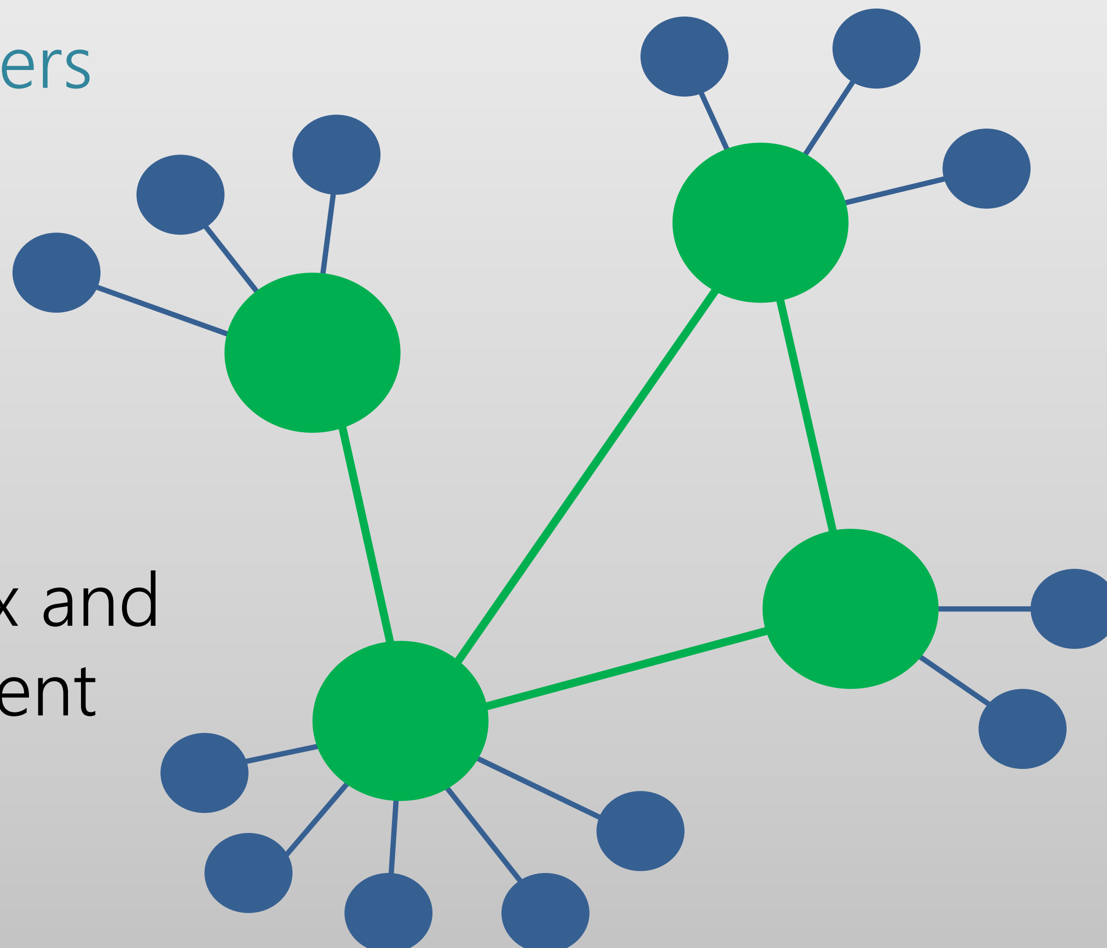
- In central server, each peer registers
  - Content
  - Address
- Peer requests content from server
- Peers connect directly



Advantages / Disadvantages?

Peer-to-Peer: Structured (Hierarchical)

Super-peers and peers



- Super-peers index and organise the content of local peers

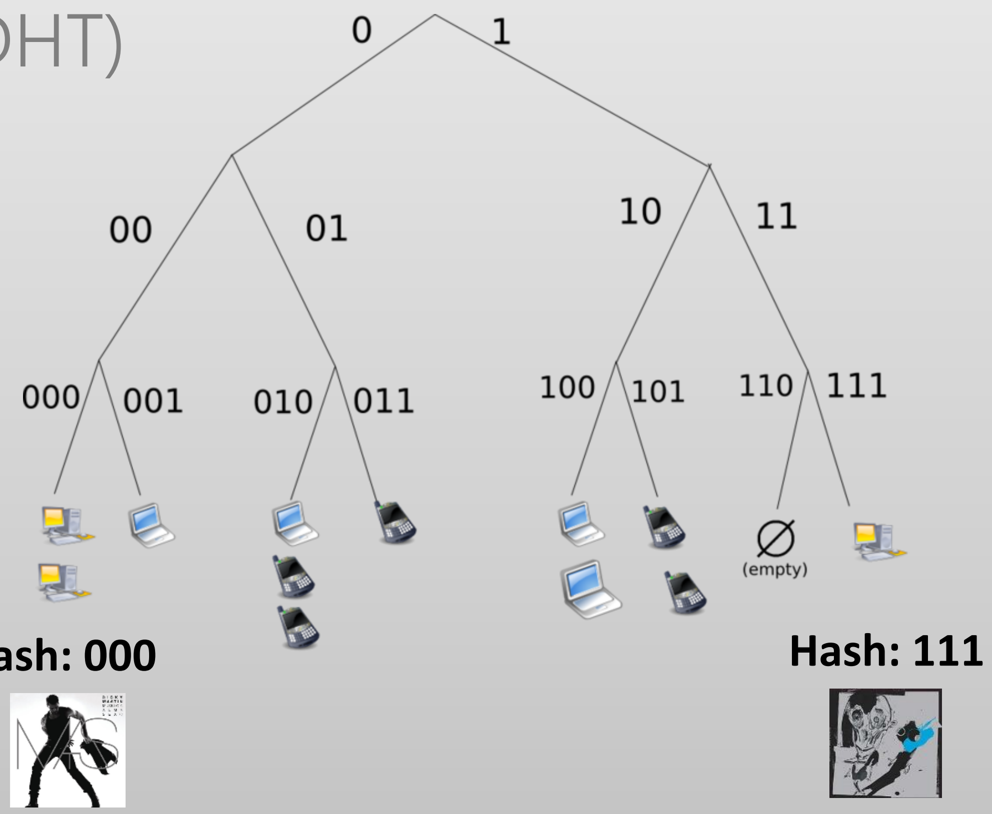
Advantages / Disadvantages?

Peer-to-Peer: Structured (Distributed Index)

Often a:

Distributed Hash Table (DHT)

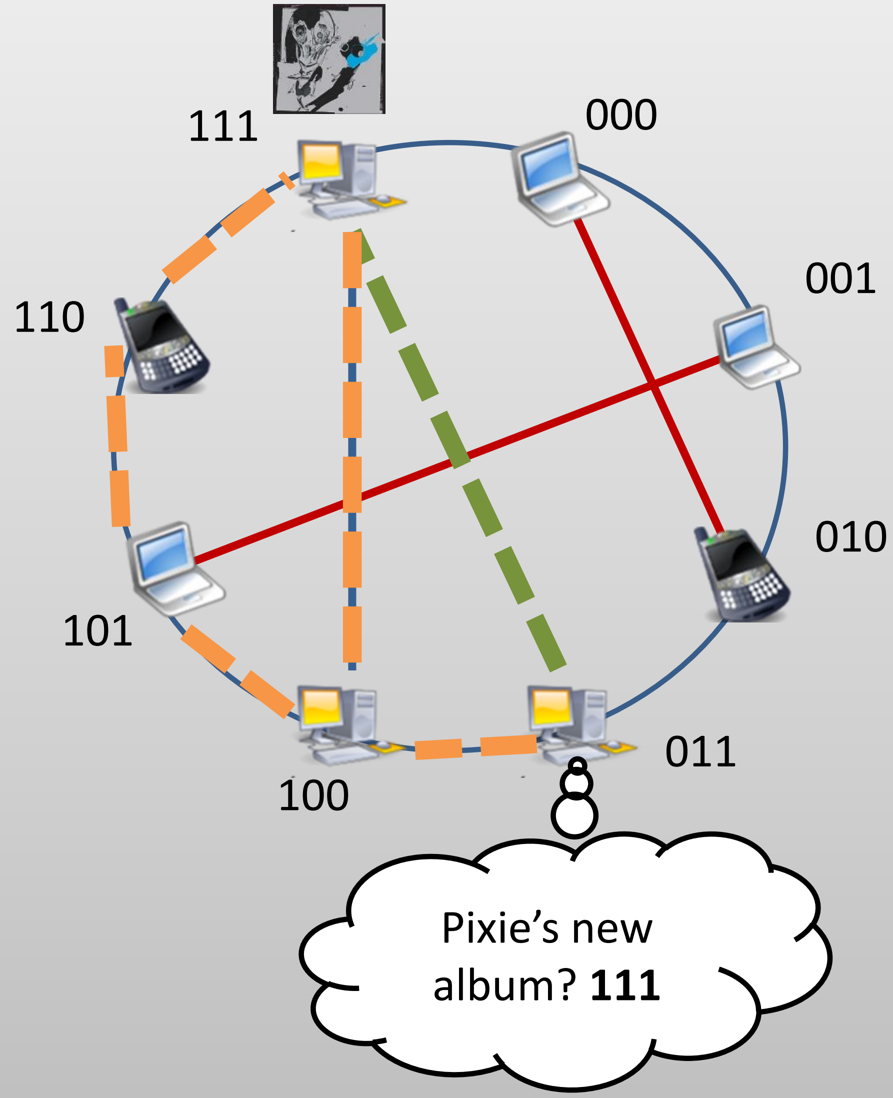
- (*key*, *value*) pairs
- Hash on *key*
- Insert with (*key*, *value*)
- Peer indexes *key* range



Advantages / Disadvantages?

Peer-to-Peer: Structured (DHT)

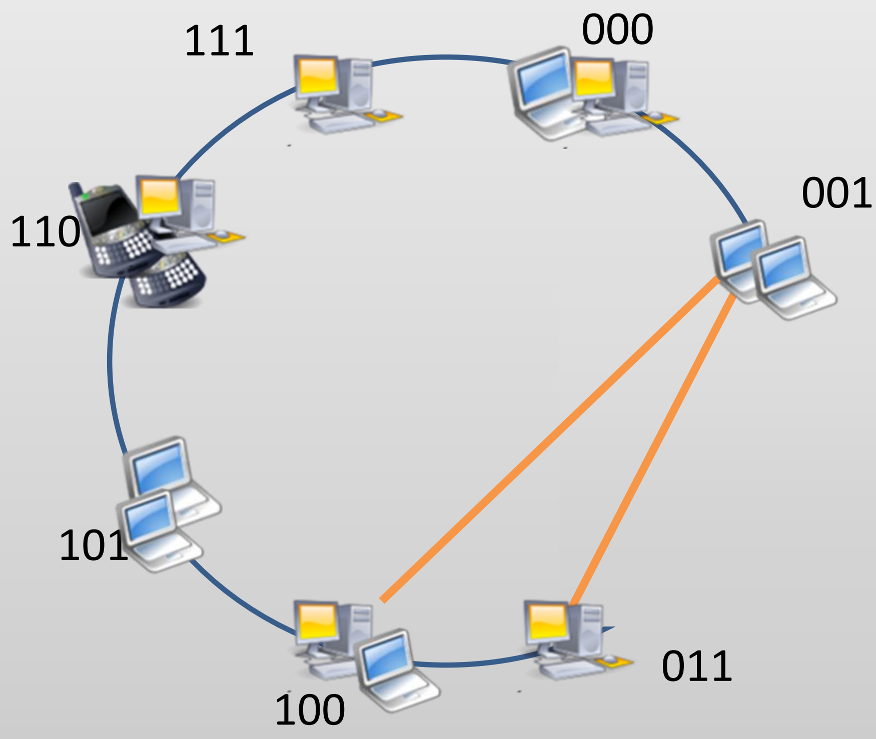
- Circular DHT:
  - Only aware of neighbours
  - O(*n*) *lookups*
- Shortcuts:
  - Skips ahead
  - Enables binary-search-like behaviour
  - O(log(*n*)) *lookups*



Peer-to-Peer: Structured (DHT)

- Handle peers leaving (churn)
  - Keep *n* successors

- New peers
  - Fill gaps
  - Replicate



Comparison of P2P Systems

1) Central Directory

- Search follows directory (1 lookup)
- Connections → $O(n)$
- Single point of failure (SPoF)
- Peers control their data
- No neighbours

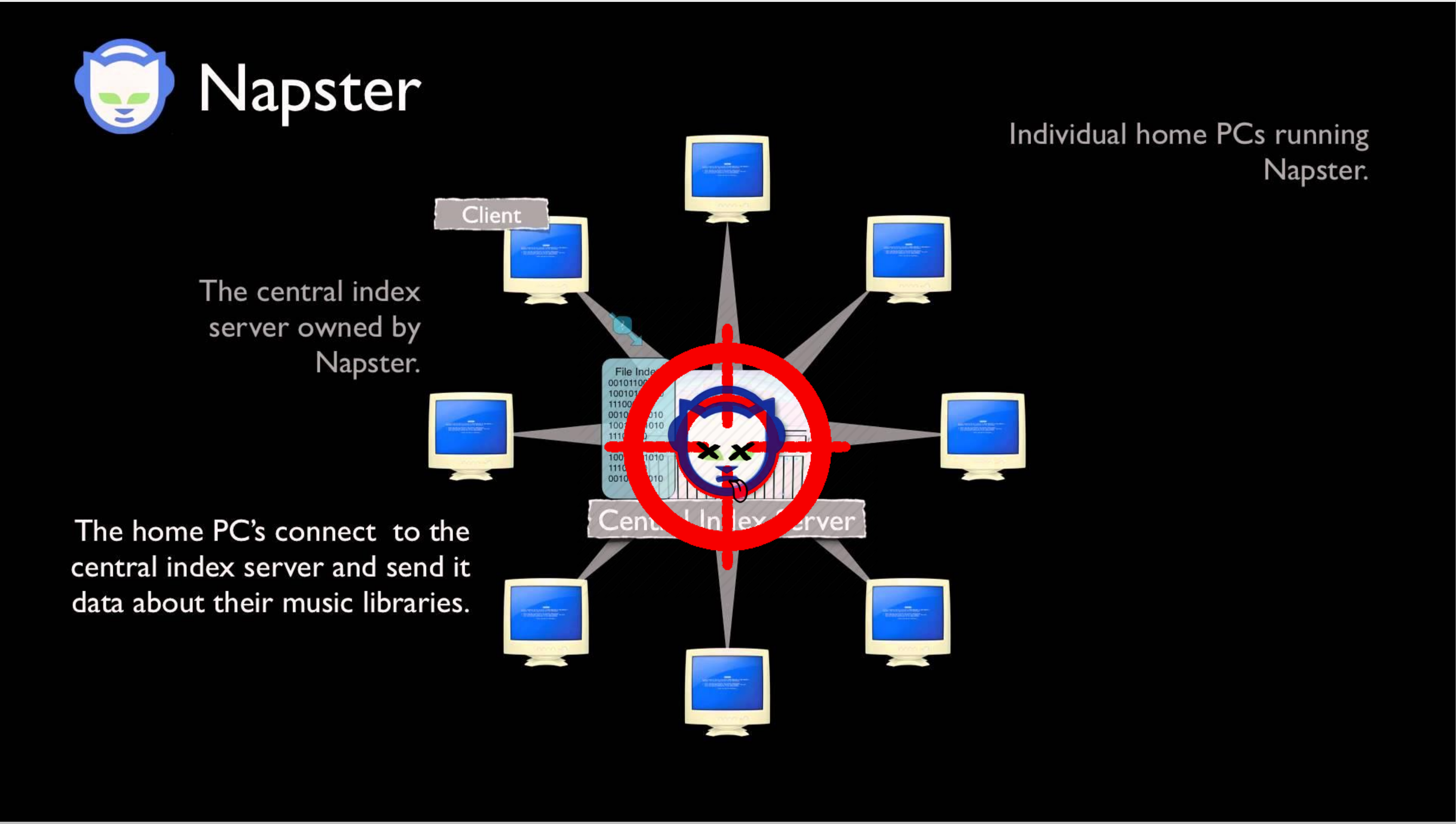
2) Unstructured

- Search requires flooding (n lookups)
- Connections → $O(n^2)$
- No central point of failure
- Peers control their data
- Peers control neighbours

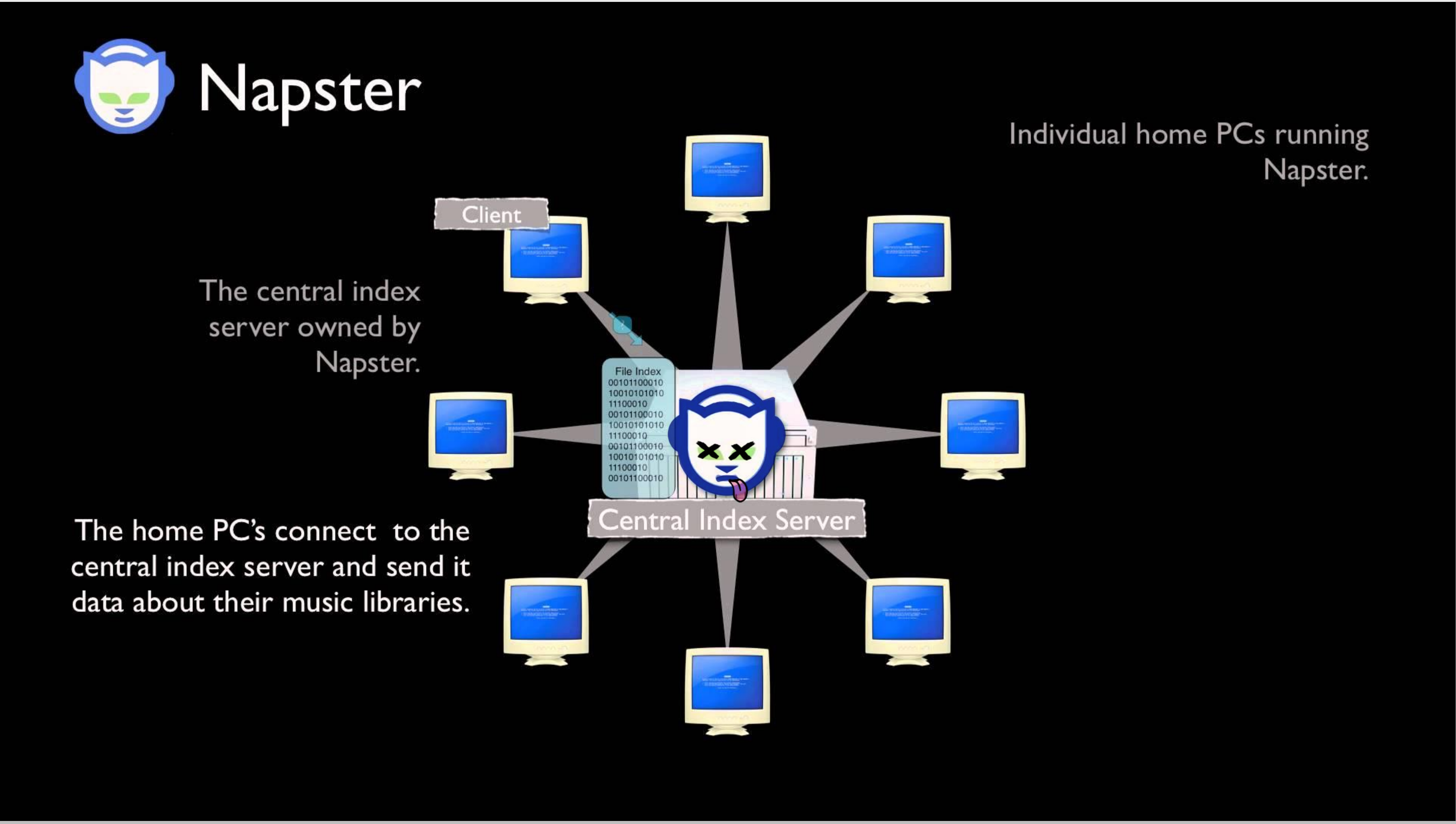
3) Structured

- Search follows structure ($\log(n)$ lookups)
- Connections → $O(n)$
- No central point of failure
- Peers assigned data
- Peers assigned neighbours

Dangers of SPoF: not just technical



Dangers of SPoF: not just technical



P2P vs. Client–Server

Advantages / Disadvantages?

Client–Server

- Data lost in failure/deletes
- Search easier/faster
- Network often faster (to websites on backbones)
- Often central host
  - Data centralised
  - Remote hosts control data
  - Bandwidth centralised
  - Dictatorial
  - Can be taken off-line

Peer-to-Peer

- May lose rare data (churn)
- Search difficult (churn)
- Network often slower (to conventional users)
- Multiple hosts
  - Data decentralised
  - Users (often) control data
  - Bandwidth decentralised
  - Democratic
  - Difficult to take off-line

P2P vs. Client–Server

Advantages / Disadvantages?

Client–Server

- Data lost in failure/deletes
- Search easier/faster
- Network often faster (to websites on backbones)
- Often central host
  - Data centralised
  - Remote hosts control data
  - Bandwidth centralised
  - Dictatorial
  - Can be taken off-line

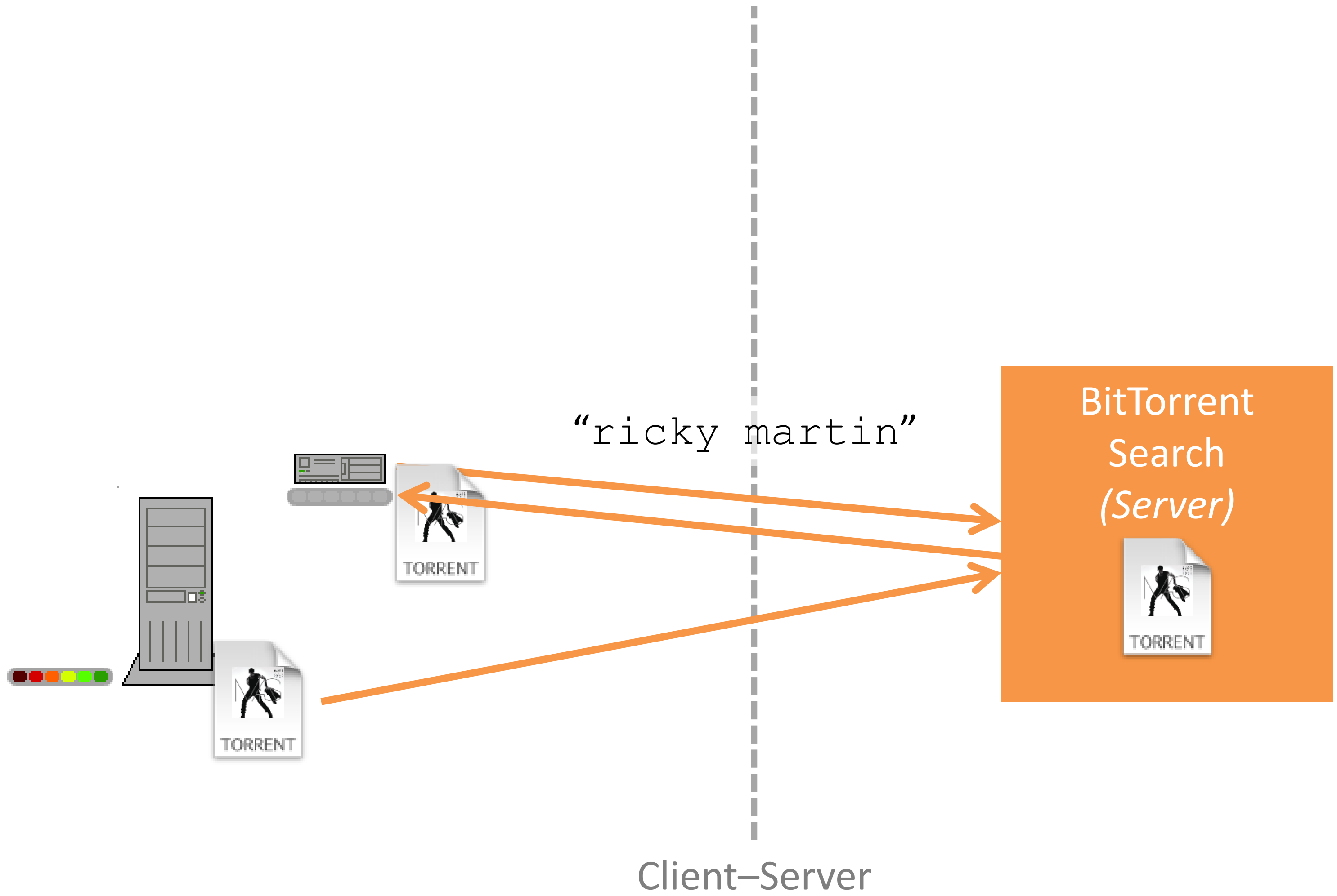
Peer-to-Peer

- May lose rare data (churn)
- Search difficult (churn)
- Network often slower (to conventional users)
- Multiple hosts
  - Data decentralised
  - Users (often) control data
  - Bandwidth decentralised
  - Democratic
  - Difficult to take off-line

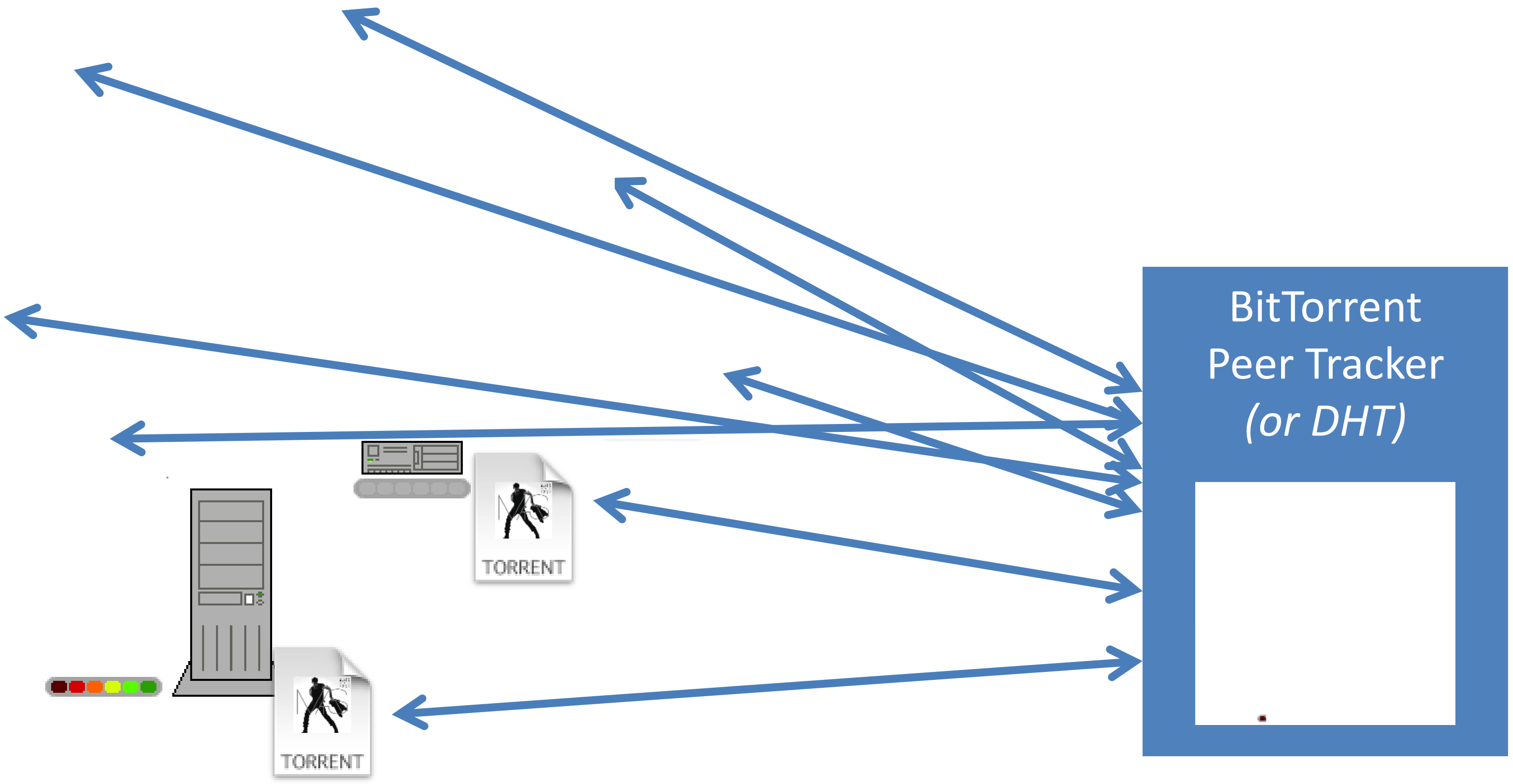
Systems can be hybrid!

DISTRIBUTED SYSTEMS: HYBRID EXAMPLE (BITTORRENT)

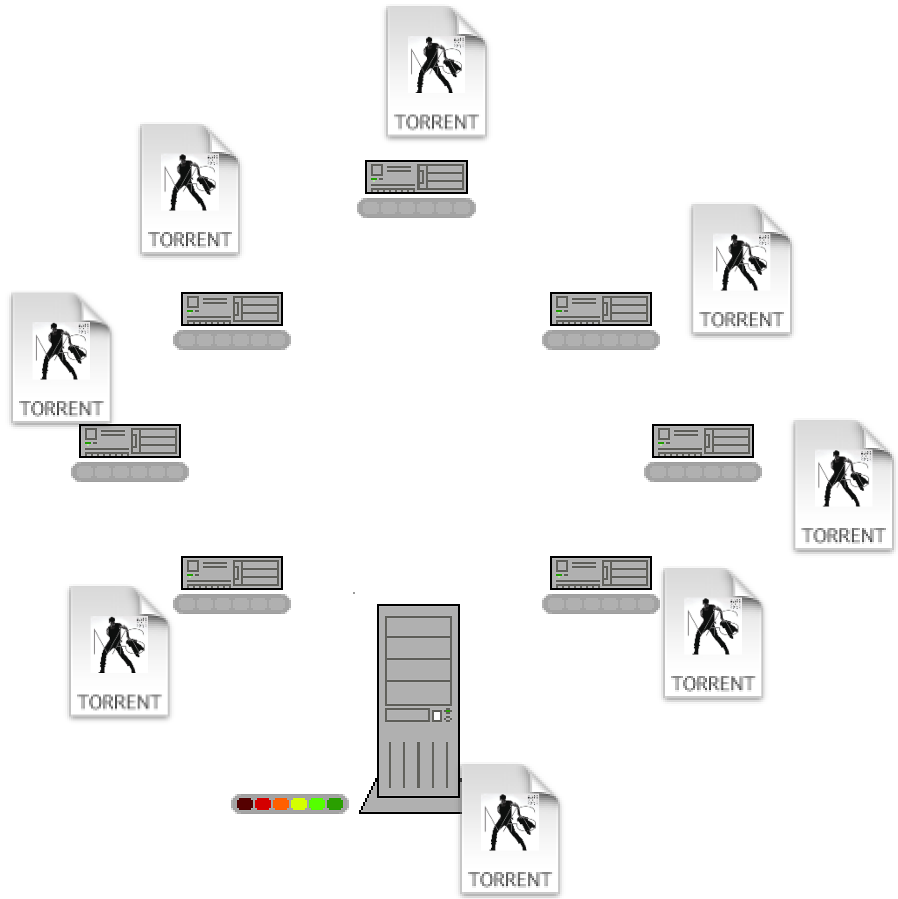
Bittorrent: Search Server



Bittorrent: Tracker



Bittorrent: File-Sharing



Bittorrent: Hybrid

Uploader

1. Creates torrent file
2. Uploads torrent file
3. Announces on tracker
4. Monitors for downloaders
5. Connects to downloaders
6. Sends file parts

Downloader

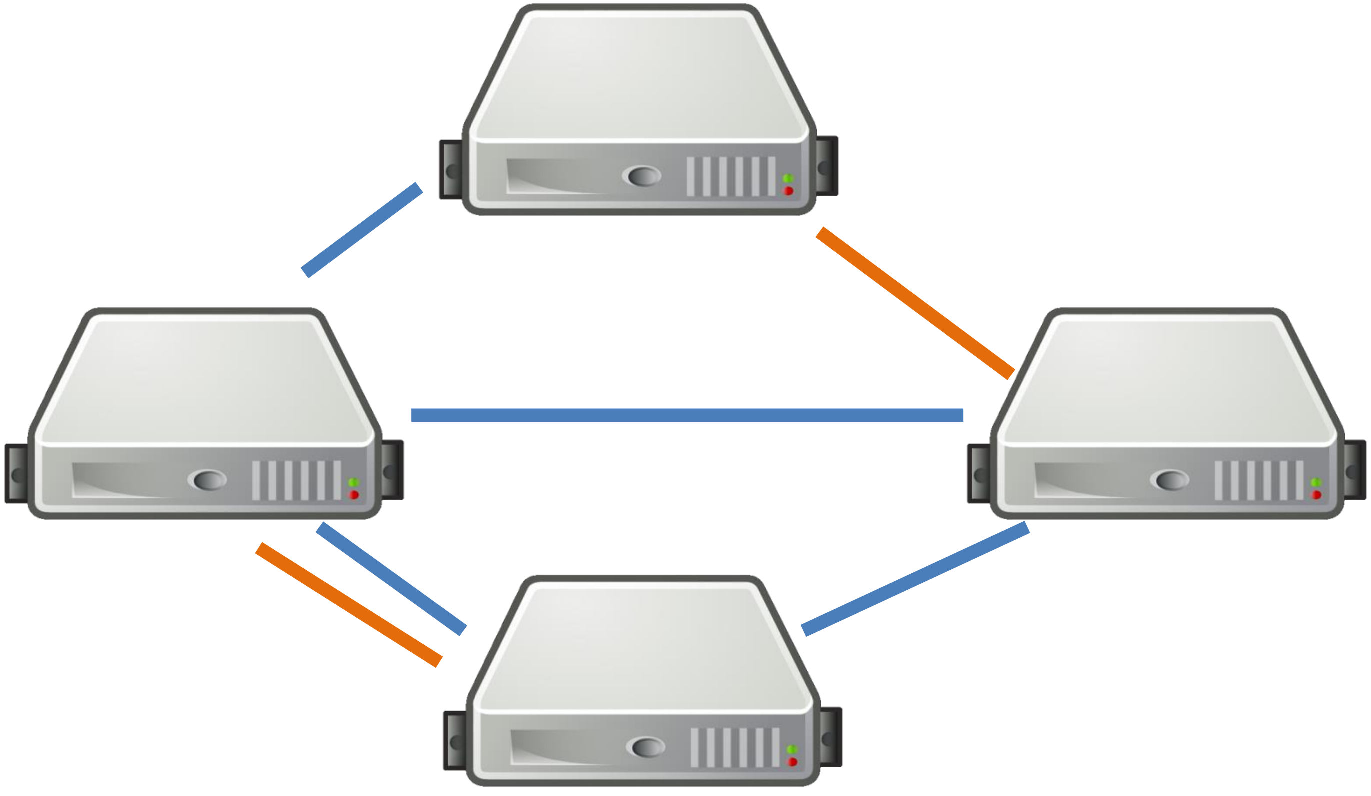
1. Searches torrent file
2. Downloads torrent file
3. Announces to tracker
4. Monitors for peers/seeds
5. Connects to peers/seeds
6. Sends & receives file parts
7. Watches illegal movie

Local / Client–Server / Structured P2P / Direct P2P

DISTRIBUTED SYSTEMS:
IN THE REAL WORLD

Physical Location: Cluster Computing

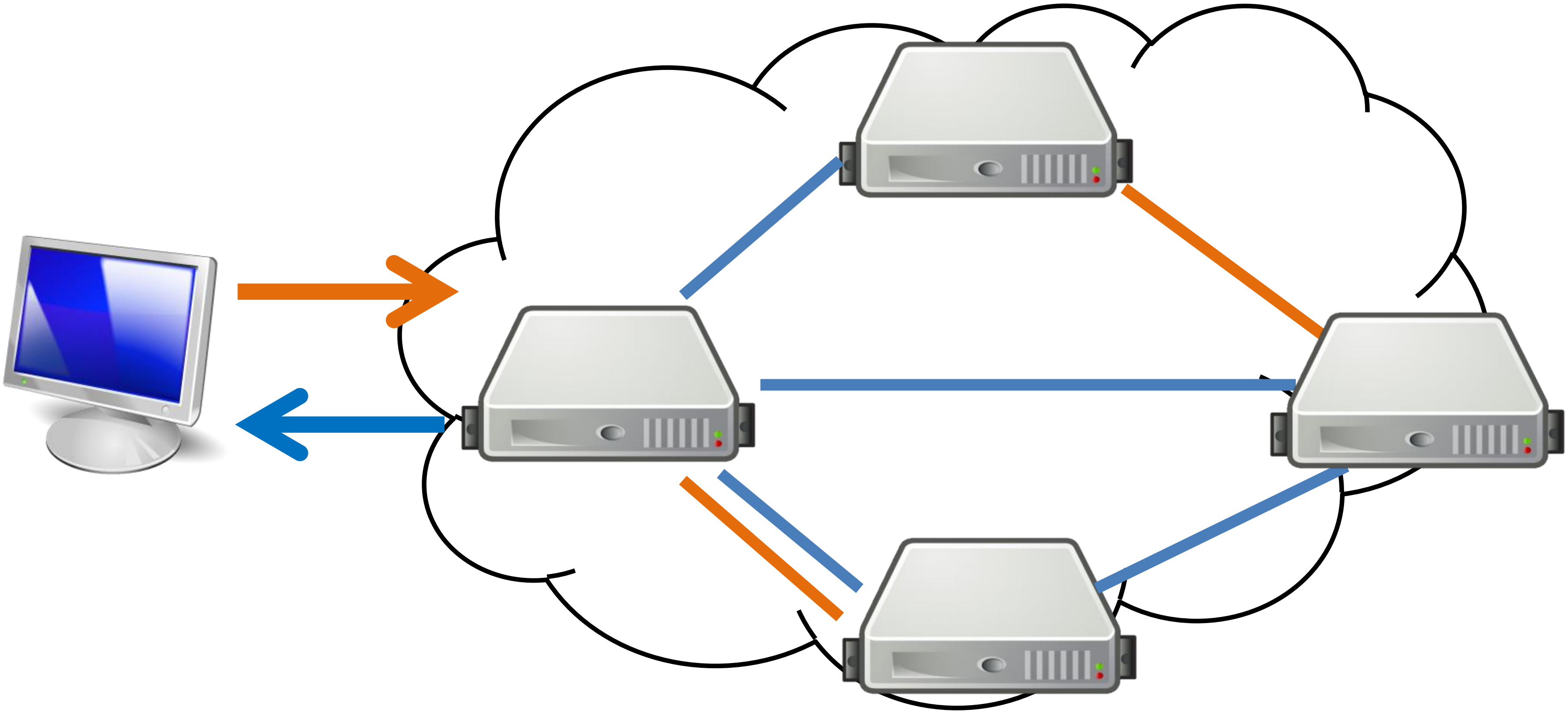
- Machines (typically) in a central, local location; e.g., a local LAN in a server room



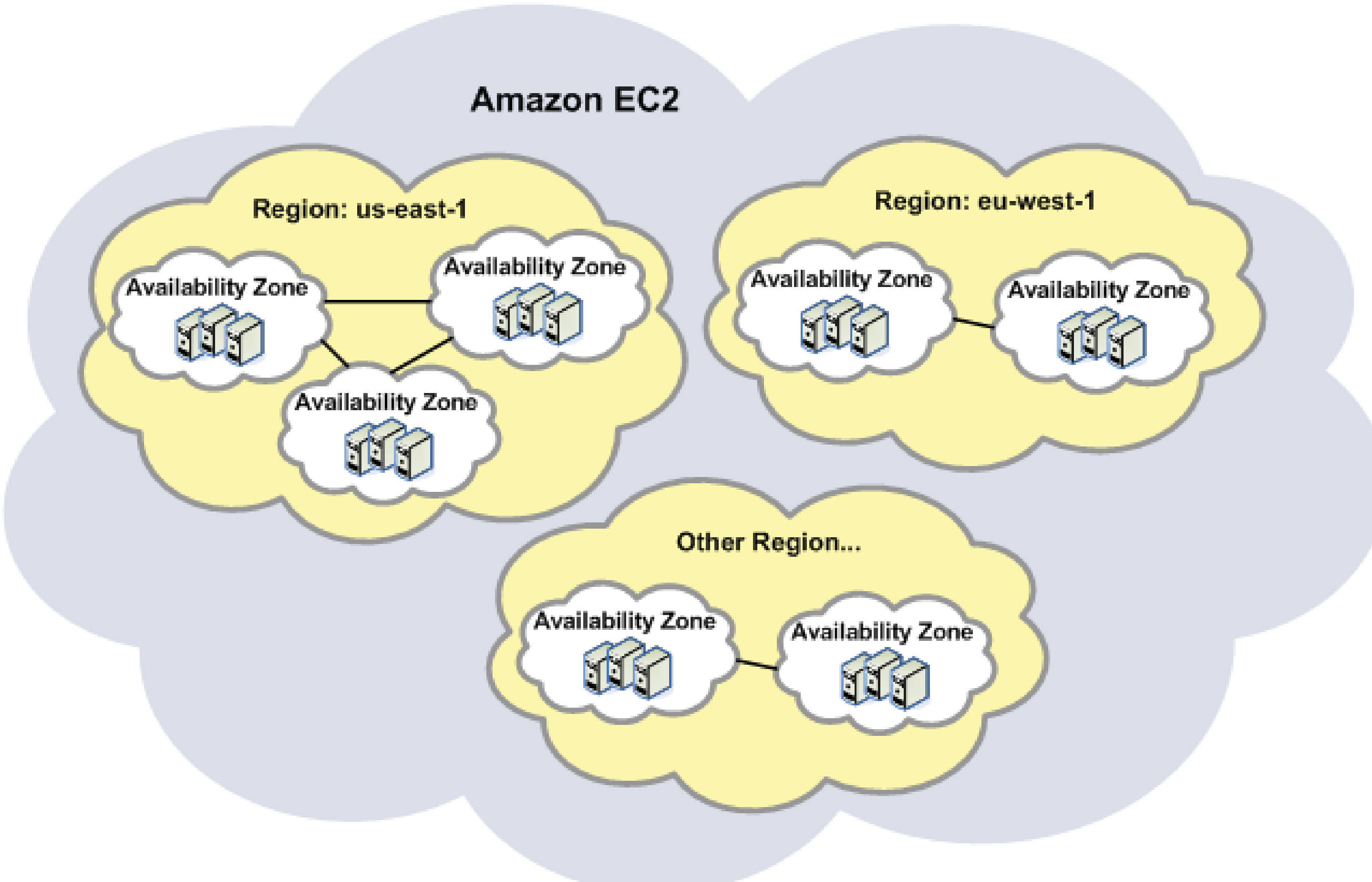
Physical Location: Cluster Computing

Physical Location: Cloud Computing

- Machines (typically) in a central remote location; e.g., Amazon EC2

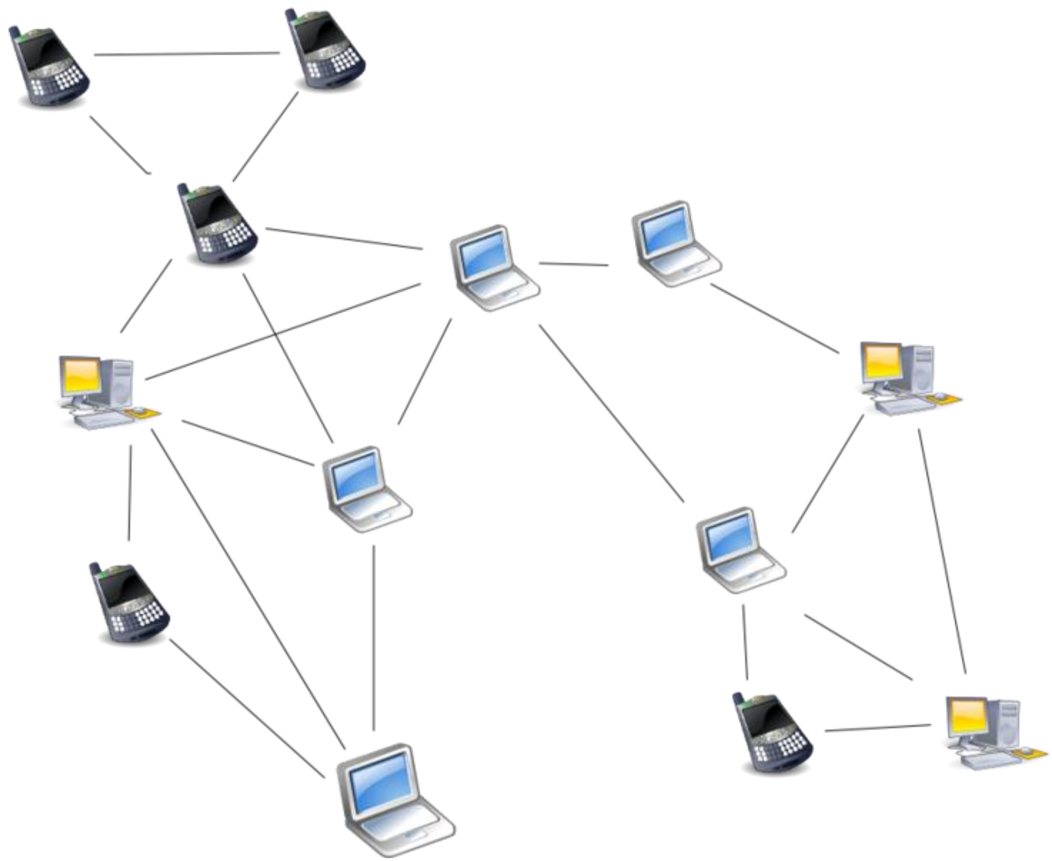


Physical Location: Cloud Computing



Physical Location: Grid Computing

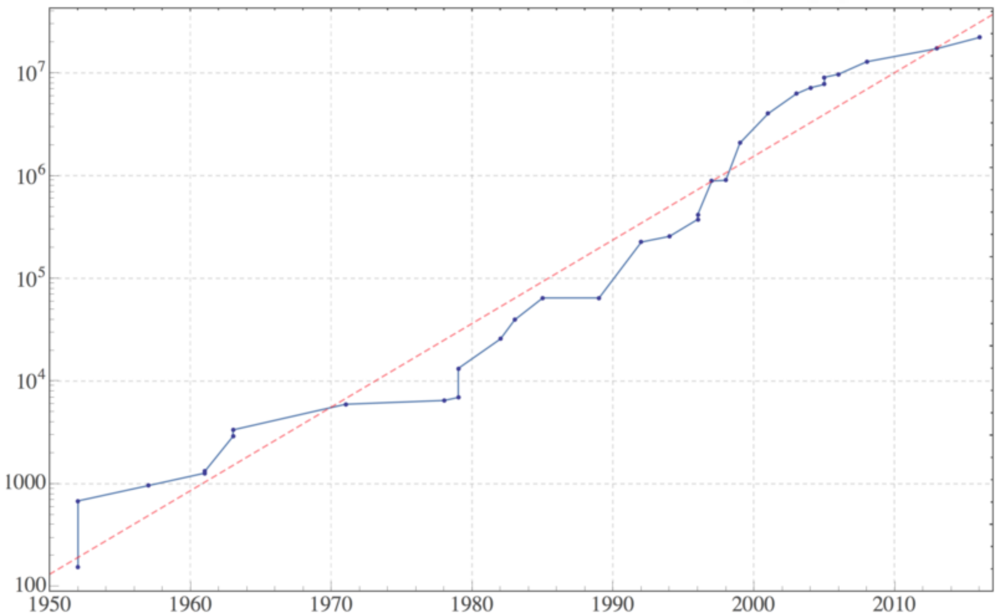
- Machines in diverse locations

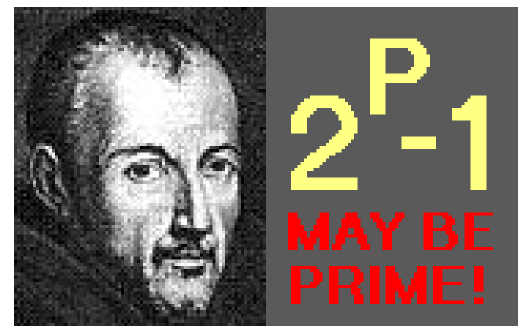


Physical Location: Grid Computing

Physical Location: Grid Computing

$$2^{74,207,281} - 1$$





PrimeGrid

Physical Locations

- Cluster computing:
  - *Typically* centralised, local
- Cloud computing:
  - *Typically* centralised, remote
- Grid computing:
  - *Typically* decentralised, remote

LIMITATIONS OF DISTRIBUTED SYSTEMS: EIGHT FALLACIES

Eight Fallacies

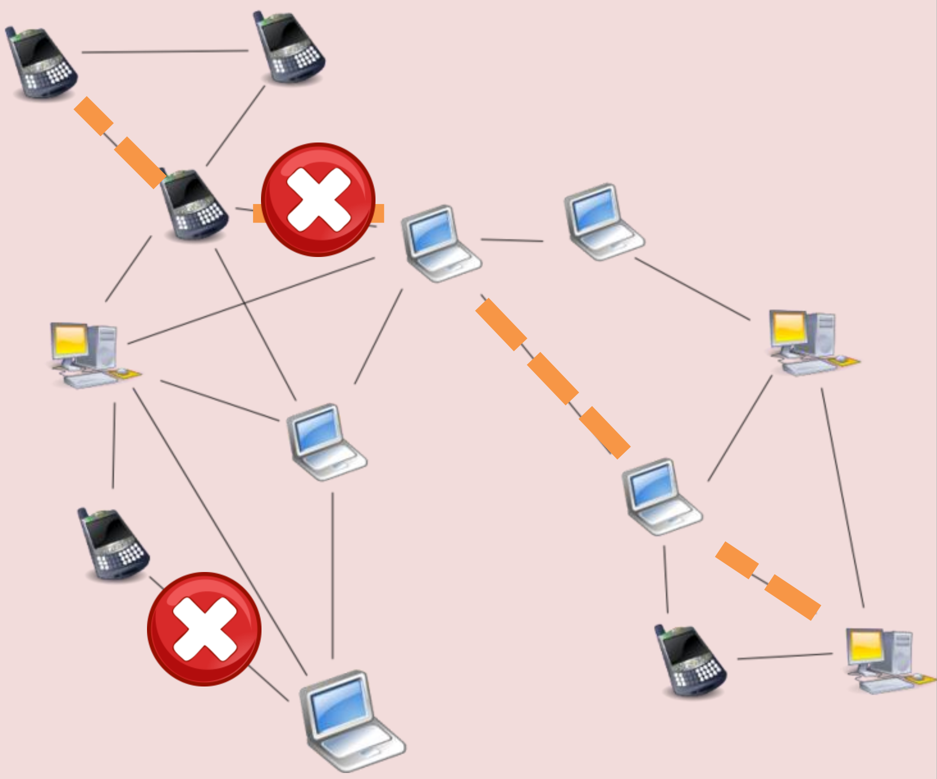
- By L. Peter Deutsch (1994)
  - James Gosling (1997)

"*Essentially everyone, when they first build a distributed application, makes the following eight assumptions. All prove to be false in the long run and all cause big trouble and painful learning experiences.*" — L. Peter Deutsch

- Each fallacy is a false statement!

1. The network is reliable

Machines fail,
connections fail,
firewall eats messages

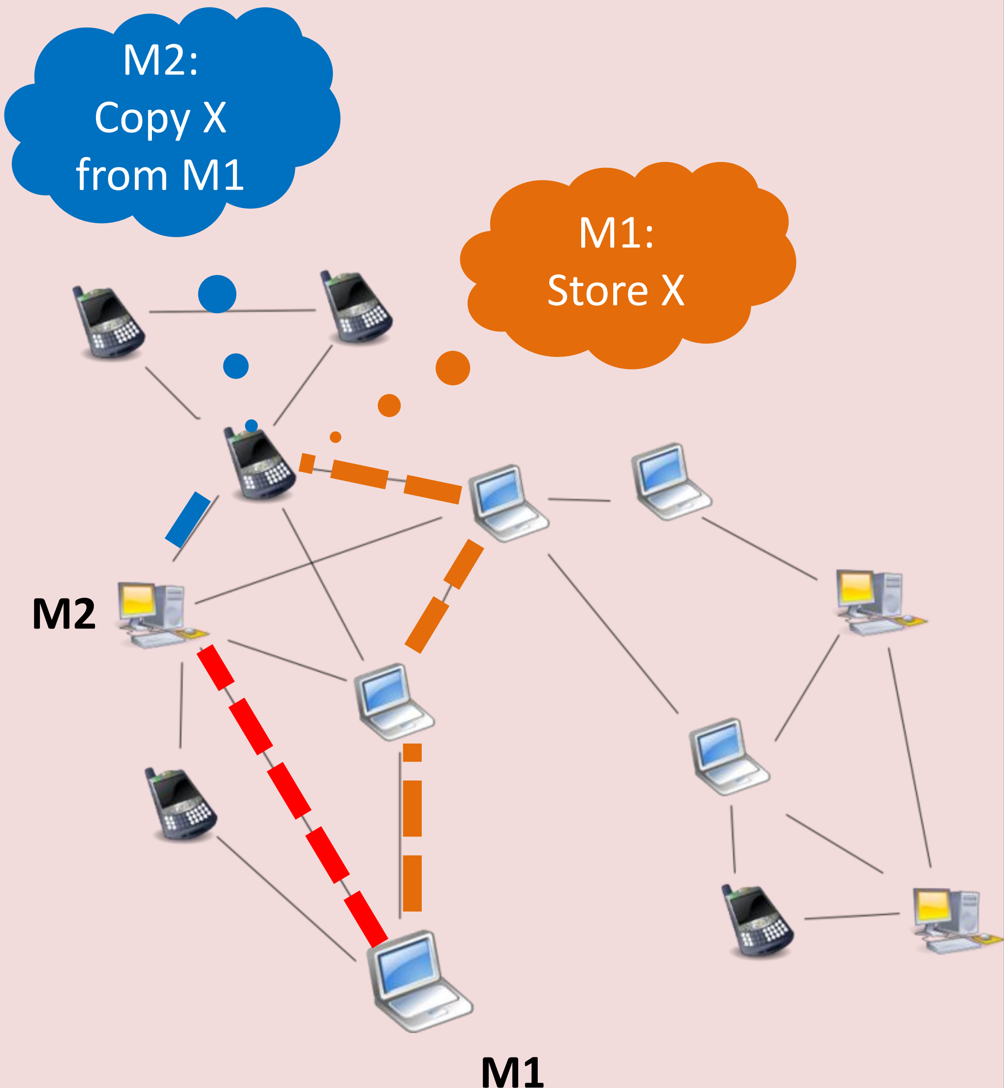


- flexible routing
- retry messages
- acknowledgements!

2. Latency is zero

There are significant communication delays

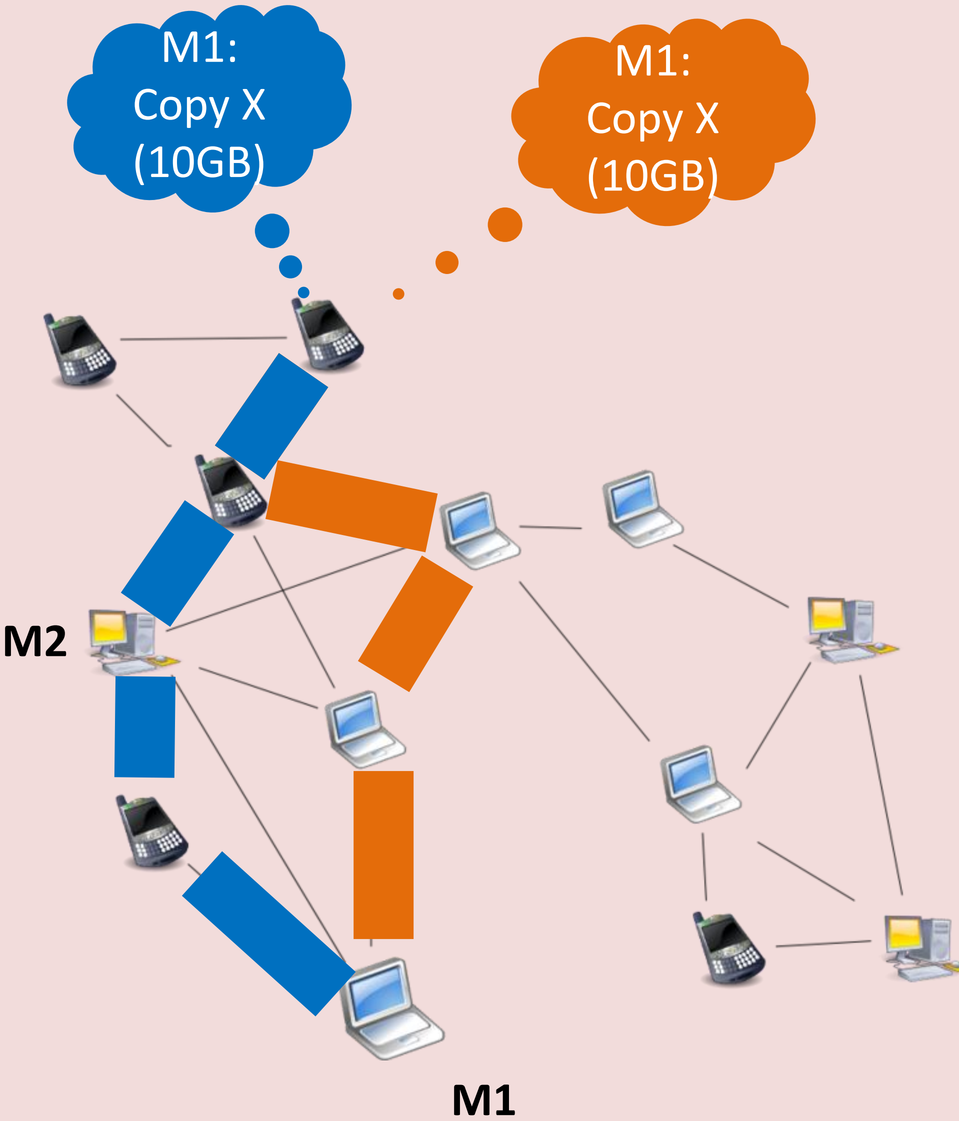
- avoid "races"
- local order ≠ remote order
- acknowledgements
- minimise remote calls
  - batch data!
- avoid waiting
  - multiple-threads



3. Bandwidth is infinite

Limited in amount of data that can be transferred

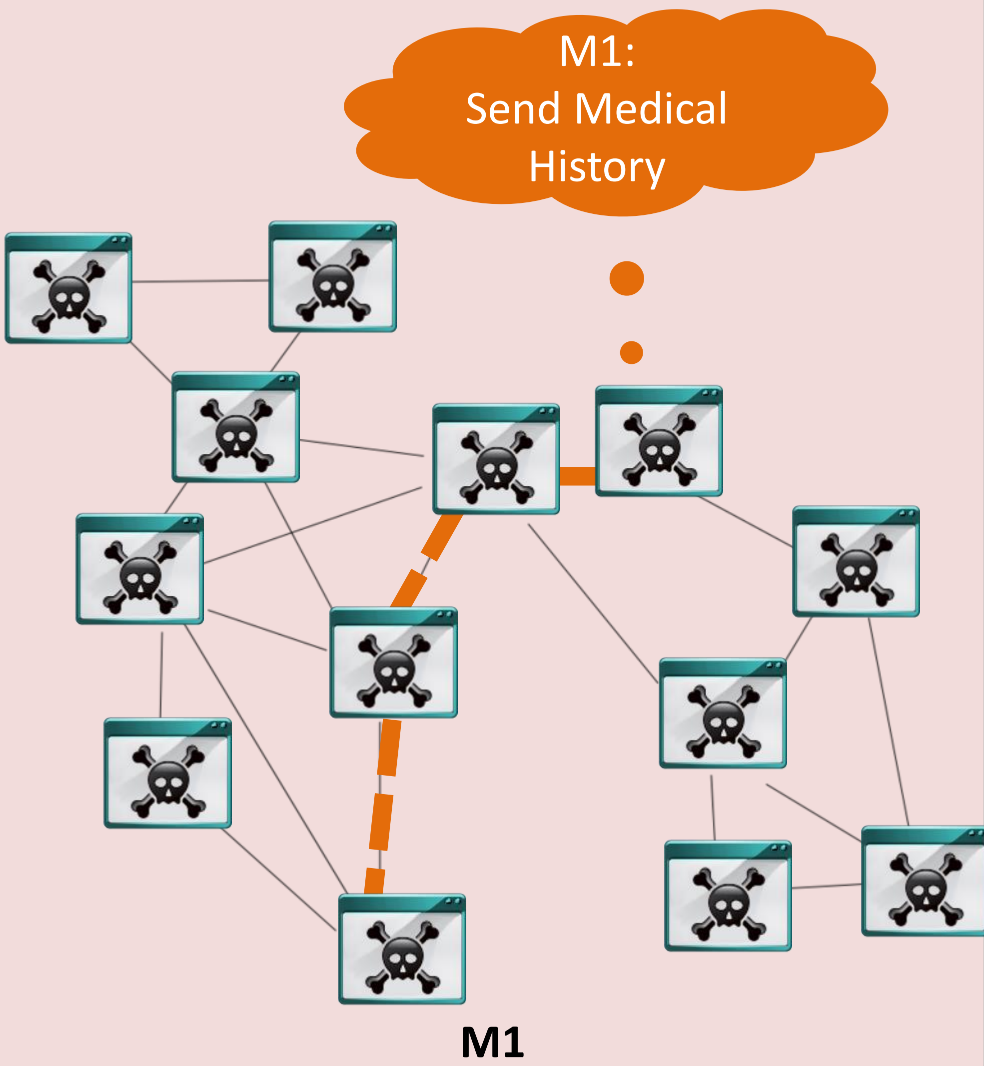
- avoid resending data
- avoid bottlenecks
- direct connections
- caching!!



4. The network is secure

Network is vulnerable to hackers, eavesdropping, viruses, etc.

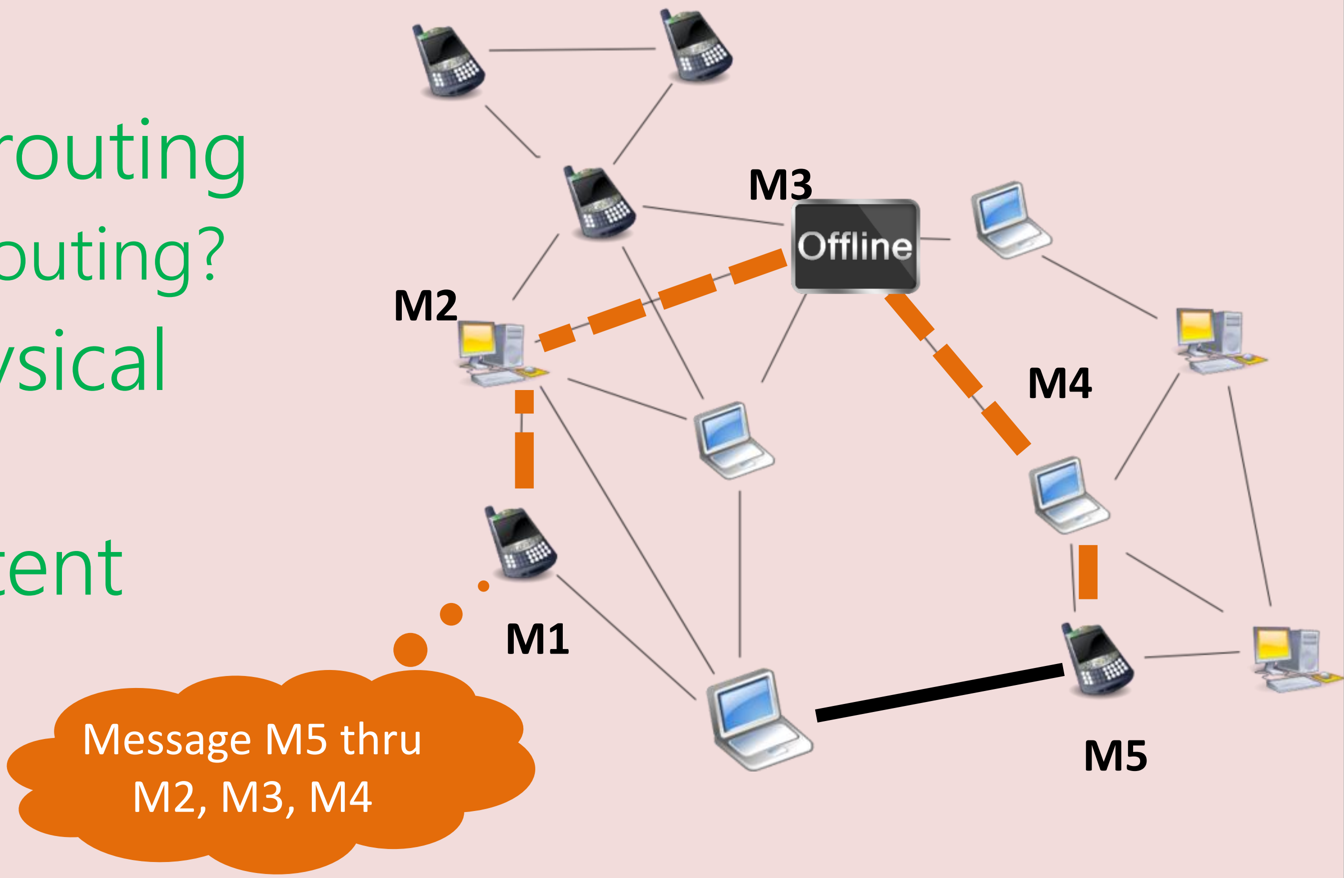
- send sensitive data directly
- isolate hacked nodes
  - hack one node ≠ hack all nodes
- authenticate messages
- secure connections



5. Topology doesn't change

How machines are physically connected may change ("churn")!

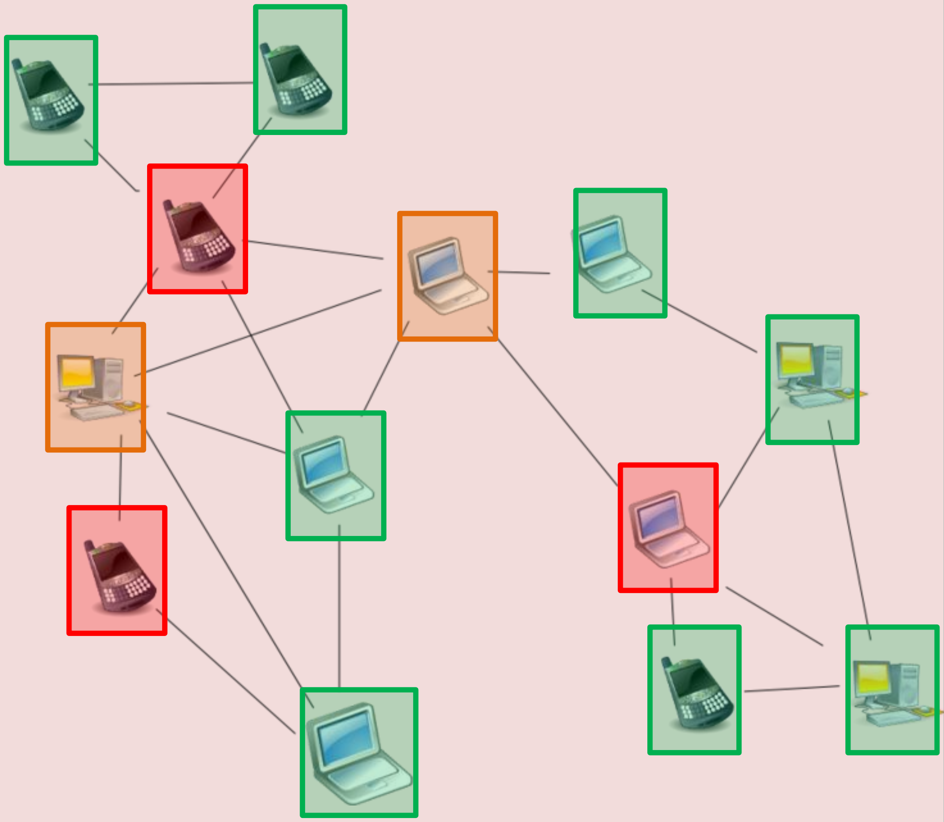
- avoid fixed routing
  - next-hop routing?
- abstract physical addresses
- flexible content structure



6. There is one administrator

Different machines have different policies!

- Beware of firewalls!
- Don't assume most recent version
  - Backwards compat.

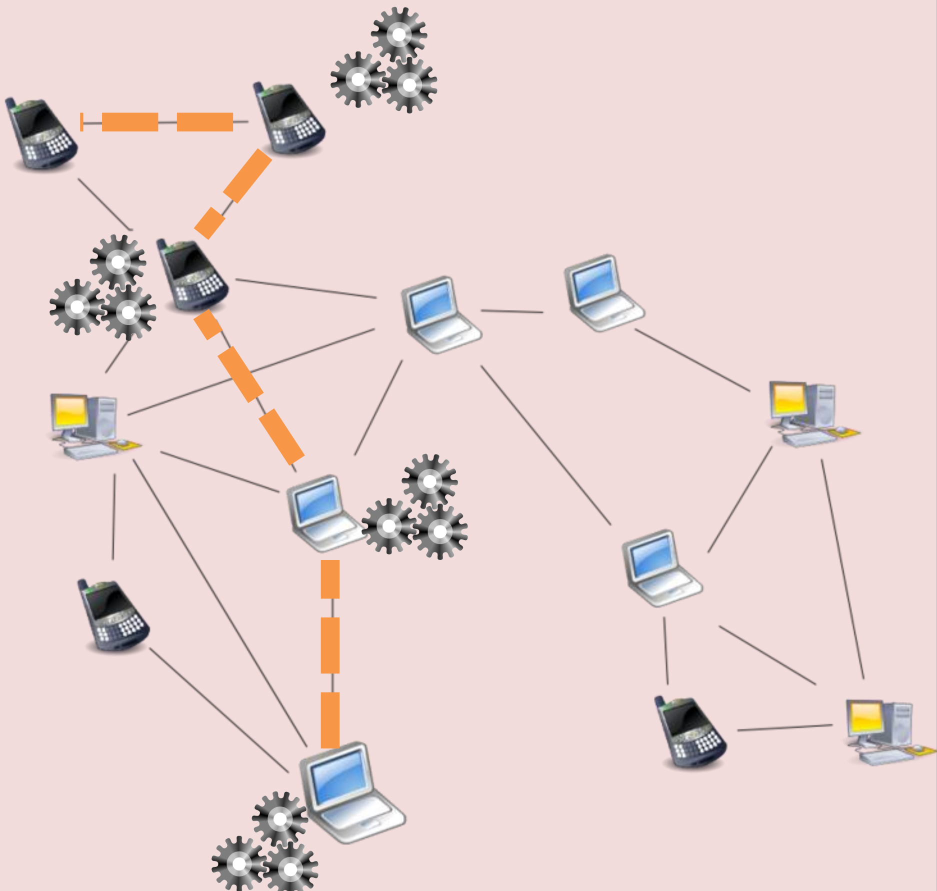


7. Transport cost is zero

It costs time/money to transport data: not just bandwidth

(*Again*)

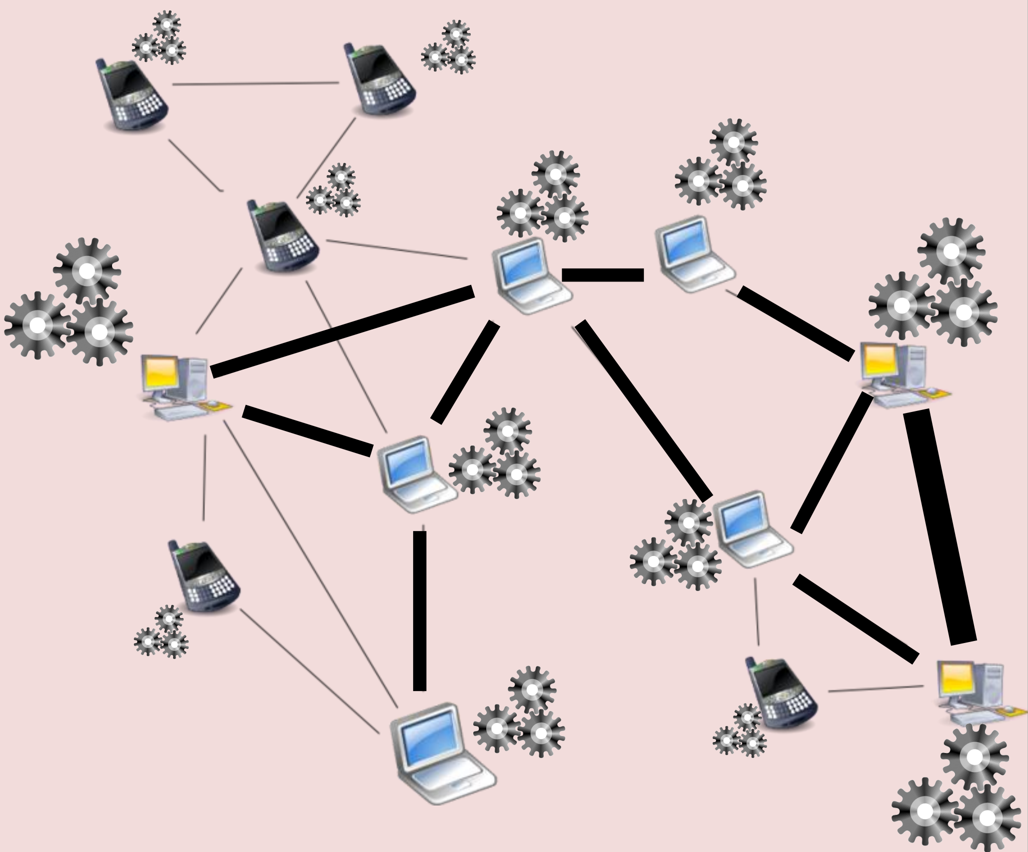
- minimise redundant data transfer
  - avoid shuffling data
  - caching
- direct connection
- compression?



8. The network is homogeneous

Devices and connections are not uniform

- interoperability!
- route for speed
  - not hops
- load-balancing



Eight Fallacies (to avoid)

1. The network is reliable
2. Latency is zero
3. Bandwidth is infinite
4. The network is secure
5. Topology doesn't change
6. There is one administrator
7. Transport cost is zero
8. The network is homogeneous

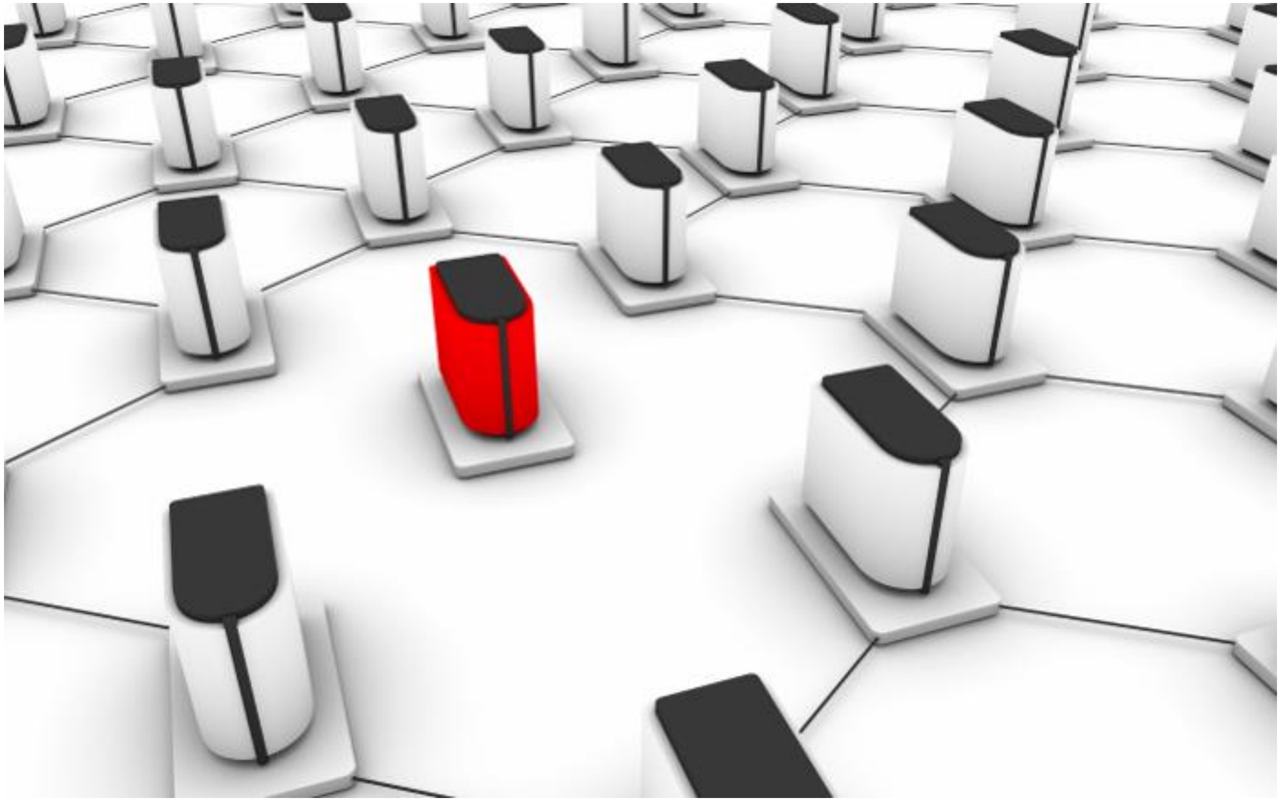
Severity of fallacies vary in different scenarios!

Within Twitter? ?

Web? ?

Bittorrent? ?

Discussed later: Fault Tolerance



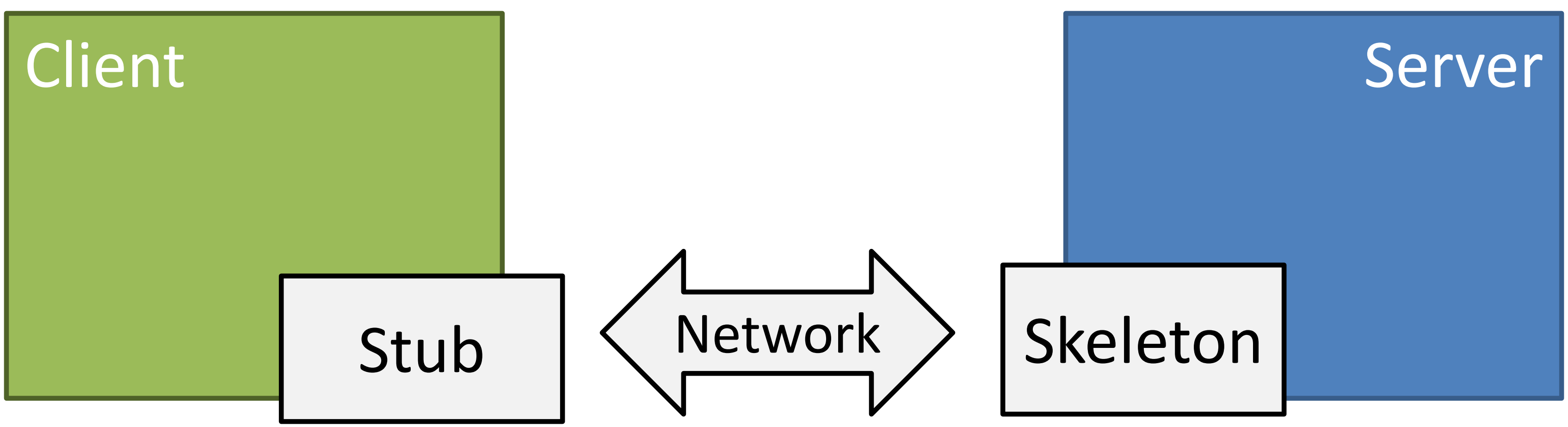
LAB II PREVIEW:
JAVA RMI OVERVIEW

Why is Java RMI Important?

We can use it to quickly build distributed systems using some standard Java skills.

What is Java RMI?

- RMI = Remote Method Invocation
- Remote Procedure Call (RPC) for Java
- Predecessor of CORBA (in Java)
- Stub / Skeleton model (TCP/IP)



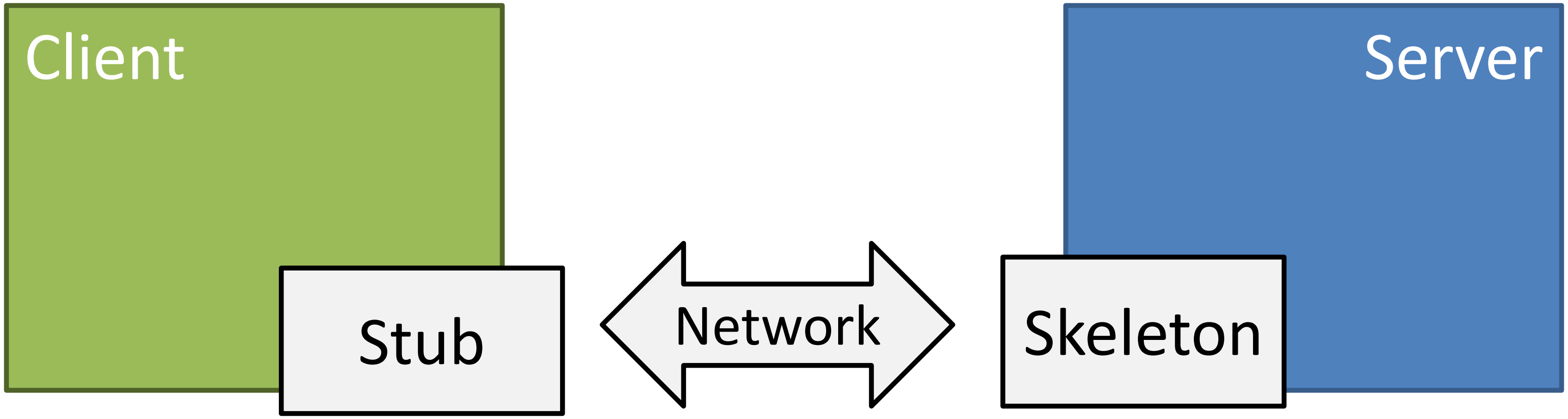
What is Java RMI?

Stub (Client):

- Sends request to skeleton: marshalls/serialises and transfers arguments
- Demarshalls/deserialises response and ends call

Skeleton (Server):

- Passes call from stub onto the server implementation
- Passes the response back to the stub



Stub/Skeleton Same Interface!

```java
package org.mdp.dir;

import java.io.Serializable;

/**
 * This is the interface that will be registered in the server.
 * In RMI, a remote interface is called a stub (on the client-side)
 * or a skeleton (on the server-side).
 *
 * An implementation is created and registered on the server.
 *
 * Remote machines can then call the methods of the interface.
 *
 * Note: every method *must* throw RemoteException!
 *
 * Note: every object passed or returned *must* be Serializable!
 *
 * @author Aidan
 *
 */
public interface UserDirectoryStub extends Remote, Serializable{
    public boolean createUser(User u) throws RemoteException;

    public Map<String,User> getDirectory() throws RemoteException;

    public User removeUserWithName(String un) throws RemoteException;
}
```

Client

Server

Server Implements Skeleton

```java
package org.mdp.dir;

import java.util.HashMap;

 * This is the implementation of UserDirectoryStub.
public class UserDirectoryServer implements UserDirectoryStub {

    private static final long serialVersionUID = -6025896167995177840L;
    private Map<String,User> directory;

    public UserDirectoryServer(){
        directory = new HashMap<String,User>();
    }

     * Return true if successful, false otherwise.
    public boolean createUser(User u) {
        if(u.getUsername()==null)
            return false;

        directory.put(u.getUsername(), u);

        System.out.println("New user registered! Bienvendio a ...\n\t"+u);
        return true;
    }

     * Returns the current directory of users.
    public Map<String, User> getDirectory() {
        return directory;
    }

     * Just an option to clean up if necessary!
    public User removeUserWithName(String un) {
        System.out.println("Removing username '"+un+"'. Chao!");
        return directory.remove(un);
    }
}
```

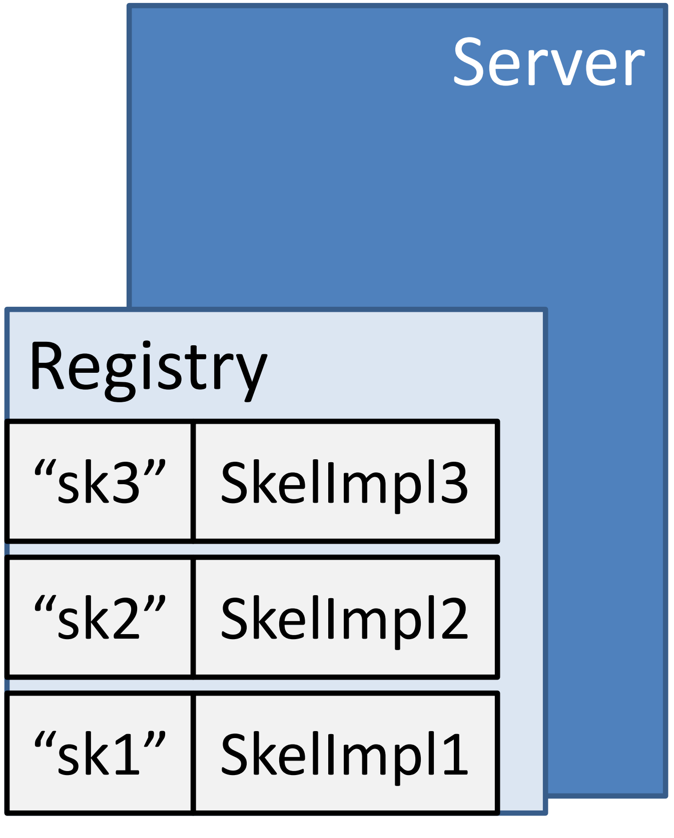
Problem?

Synchronisation:
(e.g., should use ConcurrentHashMap)
[Thanks to Tomas Vera ☺]

Server

Server Registry

- Server (typically) has a Registry: a Map
- Adds skeleton *implementations* with key (a string)



Server Creates/Connects to Registry

```
// create registry
Registry registry = LocateRegistry.createRegistry(port);
```

<u>OR</u>

```
// connect to registry
Registry registry = LocateRegistry.getRegistry(hostname, port);
```

Server

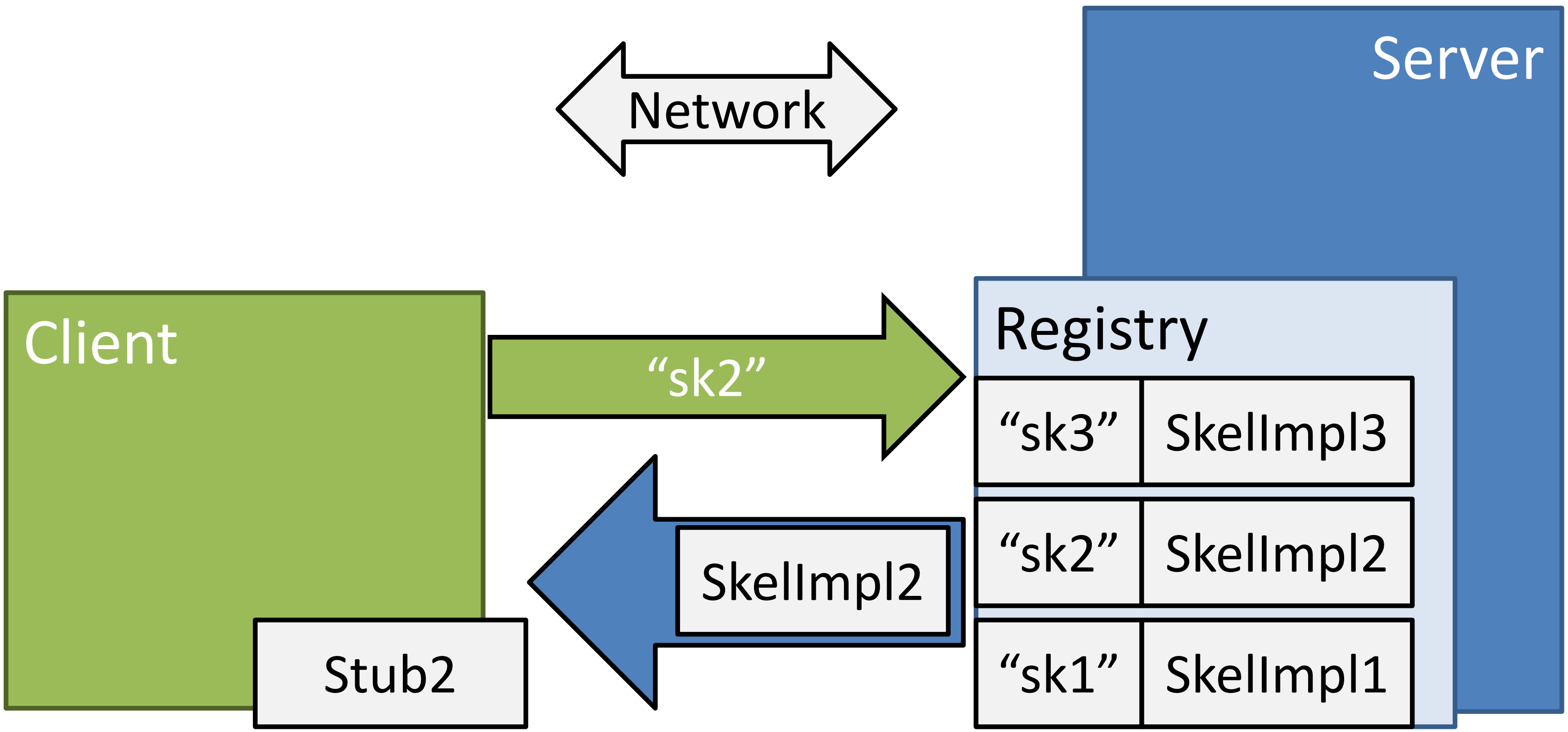
Server Registers Skeleton Implementation As a Stub

```
// create a remote stub to make it
// ready for incoming calls
Remote stub = UnicastRemoteObject.exportObject(new UserDirectoryServer(),0);

// register stub in registry under a key stub-name
String stubname = "mensaje";
registry.bind(stubname, stub);
```

Server

Client Connecting to Registry

- Client connects to registry (port, hostname/IP)!
- Retrieves skeleton/stub with key



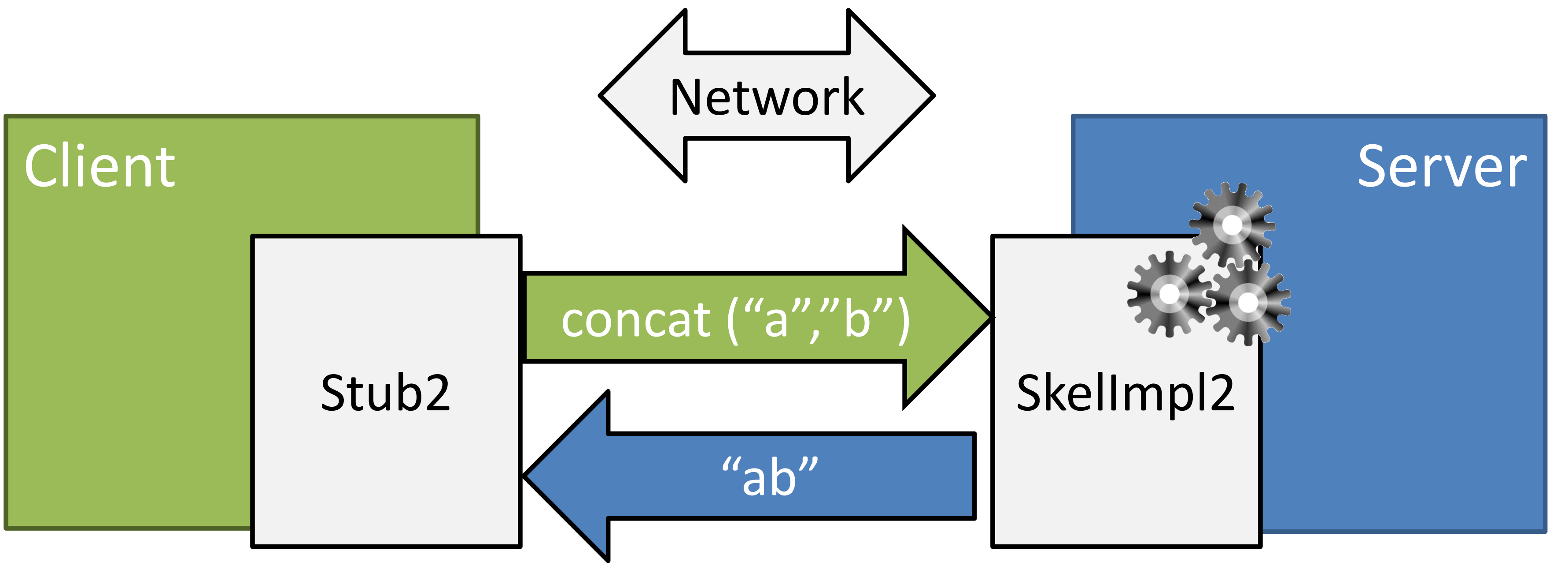
Client Connecting to Registry

```java
String hostname = "server.com";
int port = 1985;
String stubname = "mensaje";

// first need to connect to the remote registry on the given
// IP and port
Registry registry = LocateRegistry.getRegistry(hostname, port);

// then need to find the interface we're looking for
UserDirectoryStub stub = (UserDirectoryStub) registry.lookup(stubname);
```

Client

Client Calls Remote Methods

- Client has stub, calls method, serialises arguments
- Server does processing
- Server returns answer; client deserialises result



Client Calls Remote Methods

```
// now we can use the stub to call remote methods!!
Map<String,User> users = stub.getDirectory();
System.err.println(users.toString());

User u = new User("aidhog", "Aidan Hogan", "10.0.114.59", 1509);
stub.createUser(u);

users = stub.getDirectory();
System.err.println(users.toString());

stub.removeUserWithName("aidhog");

users = stub.getDirectory();
System.err.println(users.toString());
```

Client

Java RMI: Remember …

1. Remote calls are pass-by-value, not pass-by-reference (objects not modified directly)
2. Everything passed and returned must be Serialisable (`implement Serializable`)
3. Every stub/skel method *must* throw a remote exception (`throws RemoteException`)
4. Server implementation can only throw `RemoteException`

RECAP

Topics Covered (Lab)

- External Merge Sorting
  - When it doesn’t fit in memory, use the disk!
  - Split data into batches
  - Sort batches in memory
  - Write batches to disk
  - Merge sorted batches into final output

Topics Covered

- What is a (good) Distributed System?

- Client–Server model
  - Fat/thin client
  - Mirror/proxy servers
  - Three-tier

- Peer-to-Peer (P2P) model
  - Central directory
  - Unstructured
  - Structured (Hierarchical/DHT)
  - BitTorrent

Topics Covered

- Physical locations:
  - Cluster (local, centralised) vs.
  - Cloud (remote, centralised) vs.
  - Grid (remote, decentralised)
- 8 fallacies
  - Network isn’t reliable
  - Latency is not zero
  - Bandwidth not infinite,
  - etc.

Java: Remote Method Invocation

- Java RMI:
  - Remote Method Invocation
  - Stub on Client Side
  - Skeleton on Server Side
  - Registry maps names to skeletons/servers
  - Server registers skeleton with key
  - Client finds skeleton with key, casts to stub
  - Client calls method on stub
  - Server runs method and serialises result to client

Questions?