Principles of Software Construction: Objects, Design, and Concurrency

Distributed System Design, Part 1

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Administrivia

- Homework 5b due tonight
  - Turn in by Thursday, 10 April, 10:00 a.m. to be considered as framework-supporting team
  - Can turn in as late as Thursday, 10 April, 11:59 p.m.
- Homework 5c due next Tuesday
  - 2 late days total for Homework 5
  - Can turn in as late as Thursday, 17 April, 11:59 p.m.
- Homework 2 arena…

Today: Distributed system design

- Java networking fundamentals
- Introduction to distributed systems
  - Motivation: reliability and scalability
  - Failure models
  - Techniques for:
    - Reliability (availability)
    - Scalability
    - Consistency

Recall the java.io.PrintStream

- `java.io.PrintStream`: Allows you to conveniently print common types of data

```
void close();
void flush();
void print(String s);
void print(int i);
void print(boolean b);
void print(Object o);
…
void println(String s);
void println(int i);
void println(boolean b);
void println(Object o);
…
```

The fundamental I/O abstraction: a stream of data

- `java.io.InputStream`

```
void           close();
abstract int   read();
int            read(byte[] b);
```

- `java.io.OutputStream`

```
void           close();
void           flush();
abstract void  write(int b);
void           write(byte[] b);
```

- Aside: If you have an `OutputStream` you can construct a `PrintStream`:

```
PrintStream(OutputStream out);
PrintStream(File file);
PrintStream(String filename);
…
```

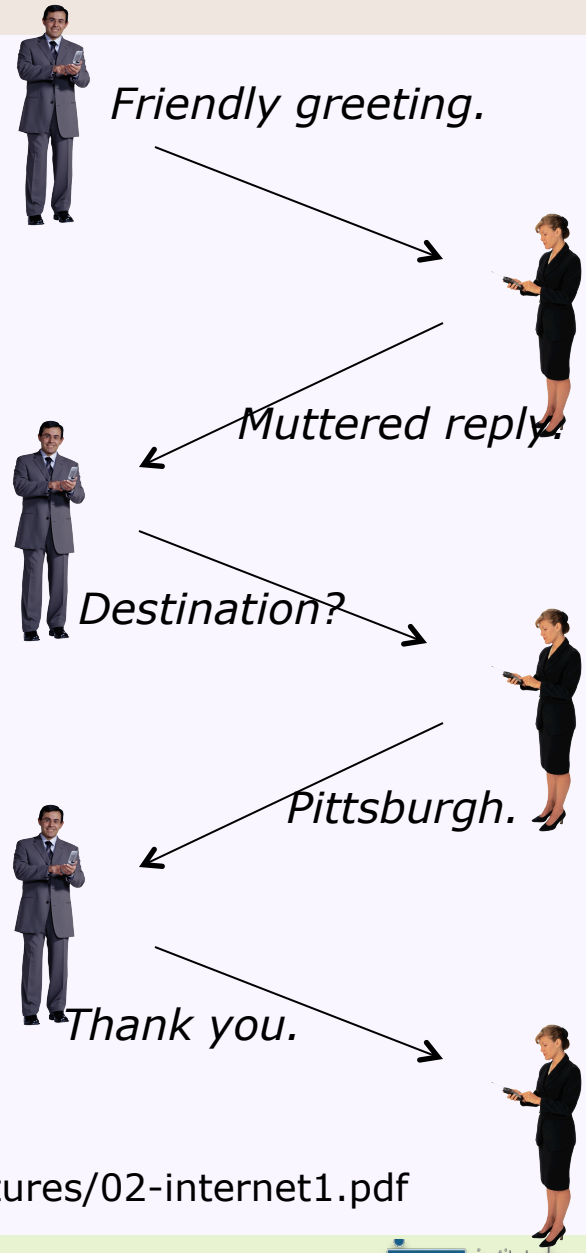
Our destination: Distributed systems

- Multiple system components (computers) communicating via some medium (the network)
- Challenges:
  - Heterogeneity
  - Scale
  - Geography
  - Security
  - Concurrency
  - Failures

(courtesy of http://www.cs.cmu.edu/~dga/15-440/F12/lectures/02-internet1.pdf

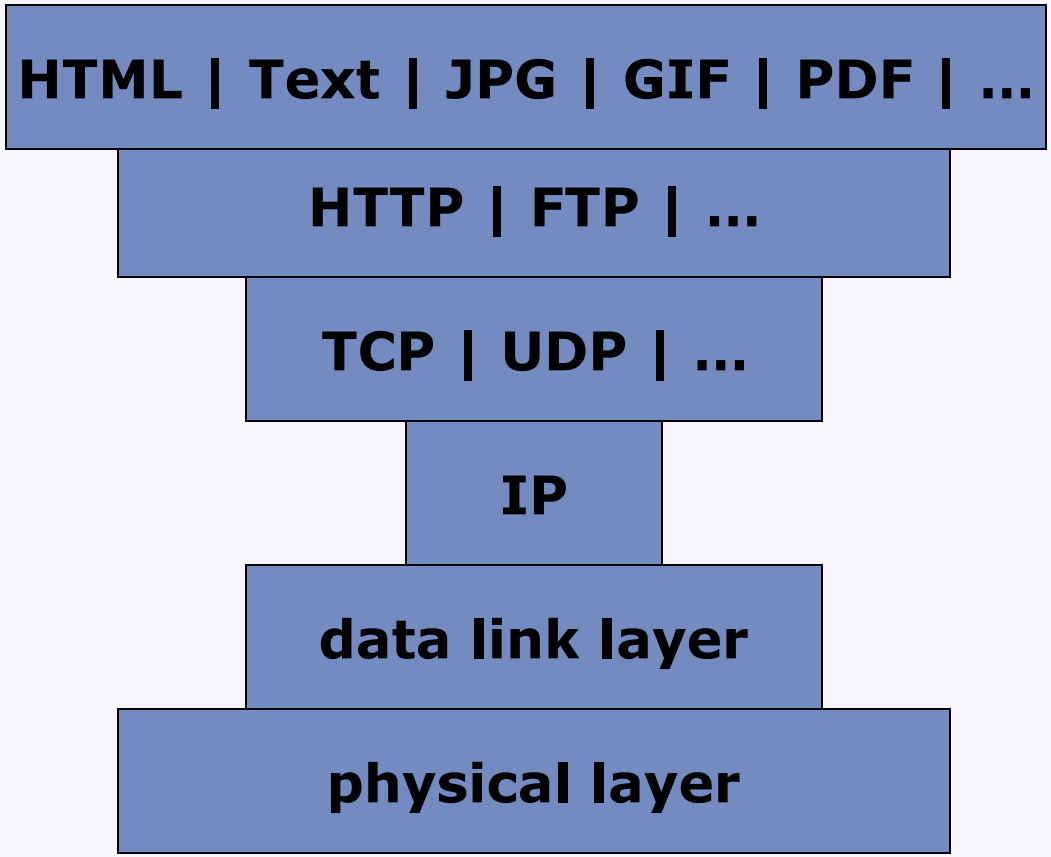
Communication protocols

- Agreement between parties for how communication should take place
  - e.g., buying an airline ticket through a travel agent



(courtesy of http://www.cs.cmu.edu/~dga/15-440/F12/lectures/02-internet1.pdf

Abstractions of a network connection



Packet-oriented and stream-oriented connections

- UDP: User Datagram Protocol
  - Unreliable, discrete packets of data
- TCP: Transmission Control Protocol
  - Reliable data stream

Internet addresses and sockets

- For IP version 4 (IPv4) host address is a 4-byte number
  - e.g. 127.0.0.1
  - Hostnames mapped to host IP addresses via DNS
  - ~4 billion distinct addresses
- Port is a 16-bit number (0-65535)
  - Assigned conventionally
    - e.g., port 80 is the standard port for web servers
- In Java:
  - `java.net.InetAddress`
  - `java.net.Inet4Address`
  - `java.net.Inet6Address`
  - `java.net.Socket`
  - `java.net.InetSocket`

Networking in Java

- The java.net.InetAddress:

```
static InetAddress getByName(String host);
static InetAddress getByAddress(byte[] b);
static InetAddress getLocalHost();
```

- The java.net.Socket:

```
Socket(InetAddress addr, int port);
boolean       isConnected();
boolean       isClosed();
void          close();
InputStream   getInputStream();
OutputStream  getOutputStream();
```

- The java.net.ServerSocket:

```
ServerSocket(int port);
Socket        accept();
void          close();
…
```

Simple sockets demos

- NetworkServer.java
- A basic chat system:
  - TransferThread.java
  - TextSocketClient.java
  - TextSocketServer.java

Higher levels of abstraction

- Application-level communication protocols
- Frameworks for simple distributed computation
  - Remote Procedure Call (RPC)
  - Java Remote Method Invocation (RMI)
- Common patterns of distributed system design
- Complex computational frameworks
  - e.g., distributed map-reduce

Today

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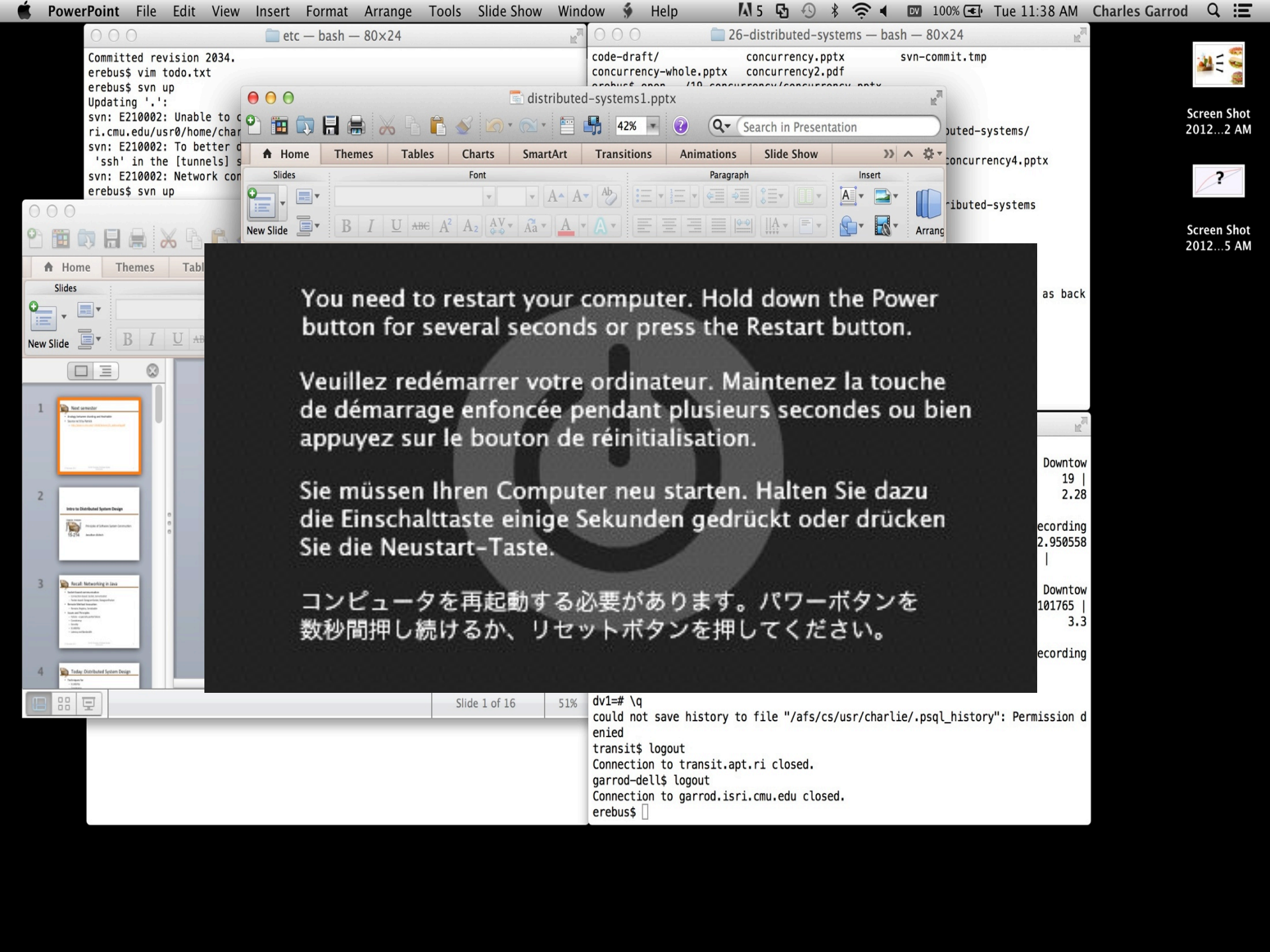
PowerPoint File Edit View Insert Format Arrange Tools Slide Show Window Help
Tue 11:38 AM Charles Garrod
etc — bash — 80×24
Committed revision 2034.
erebus$ vim todo.txt
erebus$ svn up
Updating '.':
svn: E210002: Unable to c
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svn: E210002: To better d
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svn: E210002: Network con
erebus$ svn up
26-distributed-systems — bash — 80×24
code-draft/ concurrency.pptx svn-commit.tmp
concurrency-whole.pptx concurrency2.pdf
distributed-systems1.pptx
42%
Search in Presentation
Home Themes Tables Charts SmartArt Transitions Animations Slide Show
Slides Font Paragraph Insert
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New Slide
You need to restart your computer. Hold down the Power button for several seconds or press the Restart button.
Veuillez redémarrer votre ordinateur. Maintenez la touche de démarrage enfoncée pendant plusieurs secondes ou bien appuyez sur le bouton de réinitialisation.
Sie müssen Ihren Computer neu starten. Halten Sie dazu die Einschalttaste einige Sekunden gedrückt oder drücken Sie die Neustart-Taste.
コンピュータを再起動する必要があります。パワーボタンを数秒間押し続けるか、リセットボタンを押してください。
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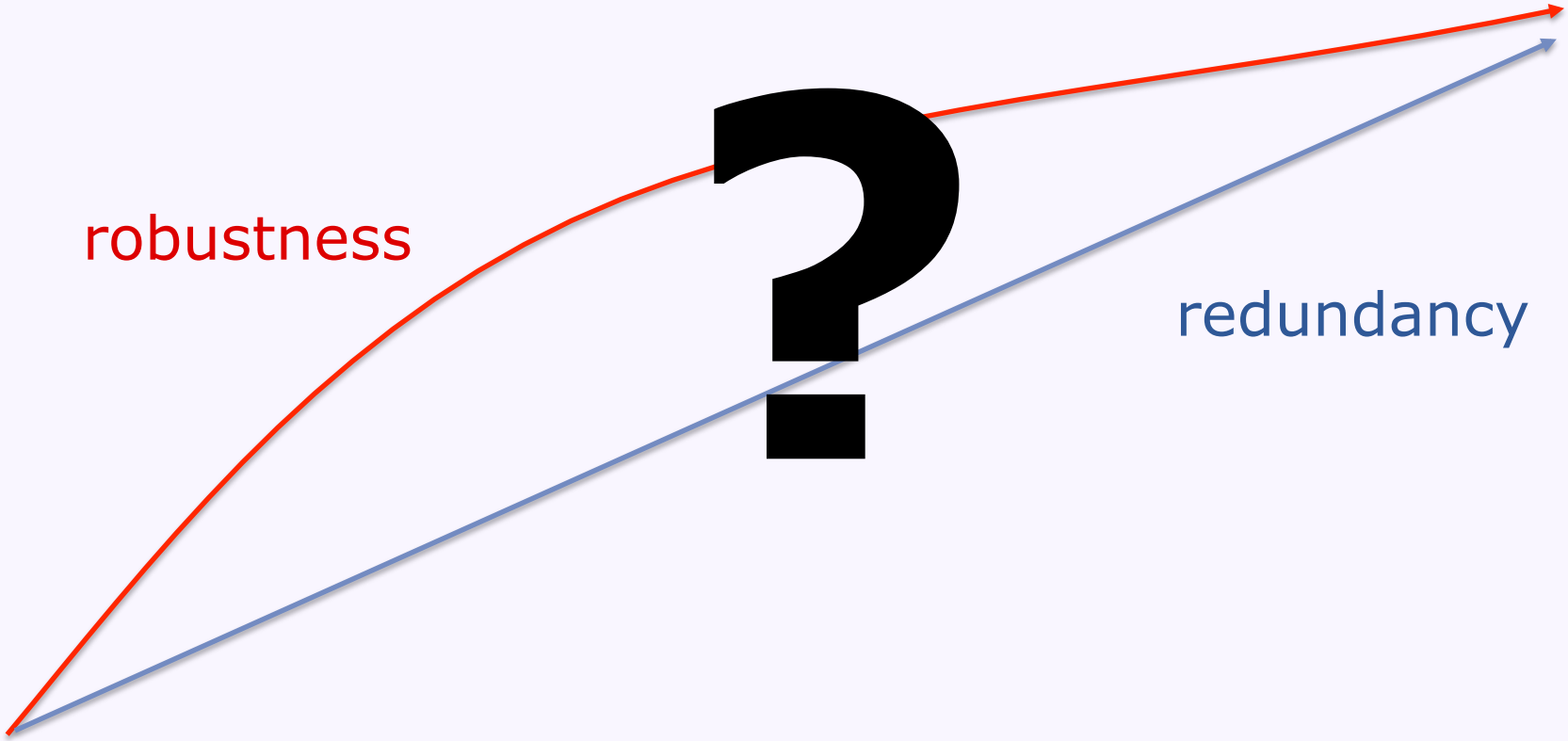
51%
dv1=# \q
could not save history to file "/afs/cs/usr/charlie/.psql_history": Permission denied
transit$ logout
Connection to transit.apt.ri closed.
garrod-dell$ logout
Connection to garrod.isri.cmu.edu closed.
erebus$
Screen Shot 2012...2 AM
Screen Shot 2012...5 AM

Aside: The robustness vs. redundancy curve

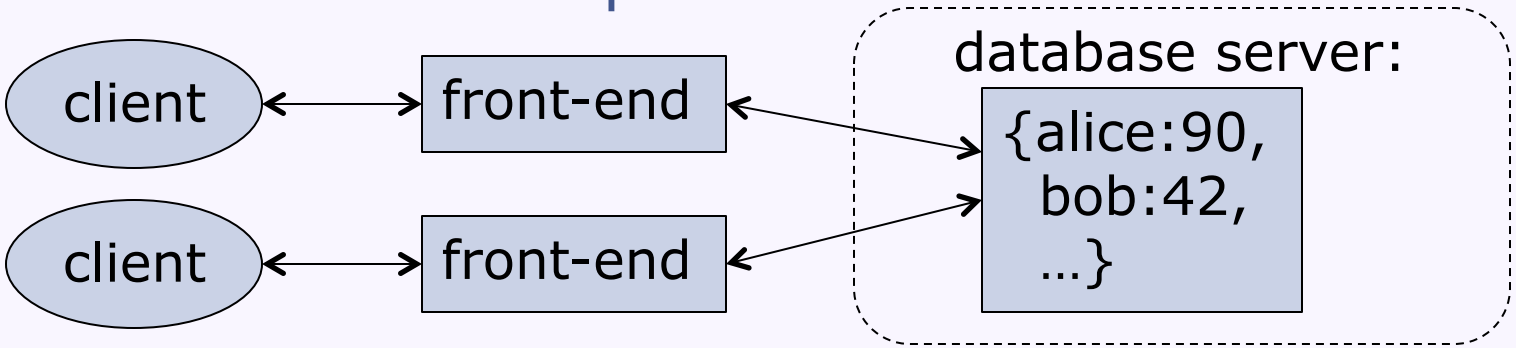


Metrics of success

- Reliability
  - Often in terms of availability: fraction of time system is working
    - 99.999% available is "5 nines of availability"
- Scalability
  - Ability to handle workload growth

A case study: Passive primary-backup replication

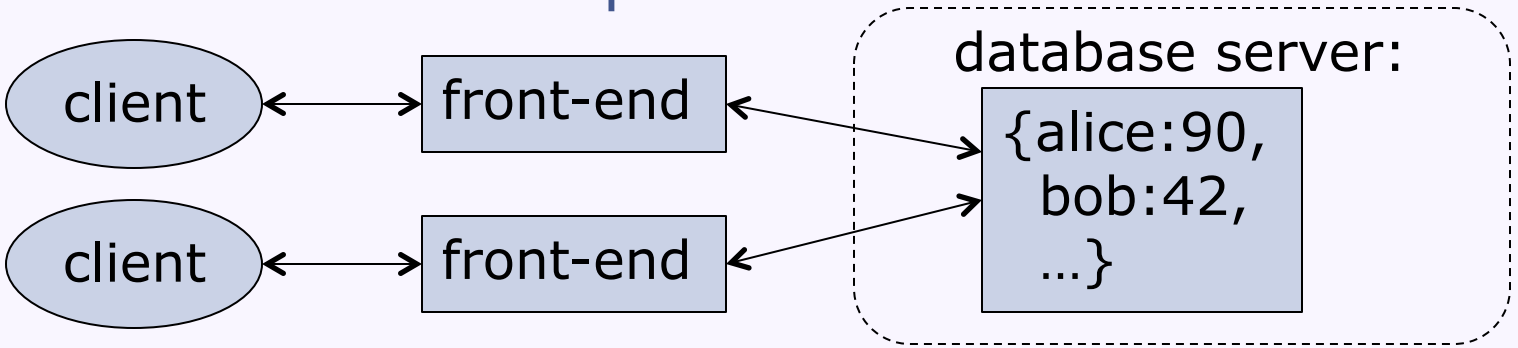
- Architecture before replication:



  - Problem: Database server might fail

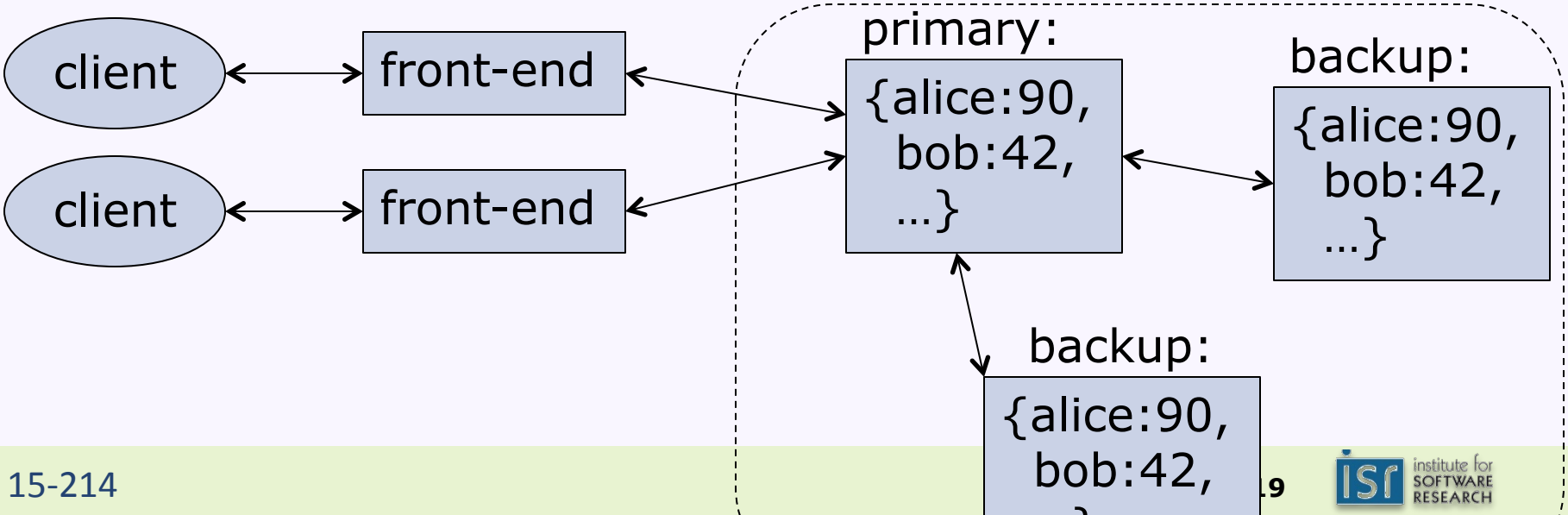
A case study: Passive primary-backup replication

- Architecture before replication:



  - Problem: Database server might fail

- Solution: Replicate data onto multiple servers



Passive primary-backup replication protocol

1. Front-end issues request with unique ID to primary DB
2. Primary checks request ID
   - If already executed request, re-send response and exit protocol
3. Primary executes request and stores response
4. If request is an update, primary DB sends updated state, ID, and response to all backups
   - Each backup sends an acknowledgement
5. After receiving all acknowledgements, primary DB sends response to front-end

Issues with passive primary-backup replication

- If primary DB crashes, front-ends need to agree upon which unique backup is new primary DB
  - Primary failure vs. network failure?
- If backup DB becomes new primary, surviving replicas must agree on current DB state
- If backup DB crashes, primary must detect failure to remove the backup from the cluster
  - Backup failure vs. network failure?
- If replica fails* and recovers, it must detect that it previously failed
- Many subtle issues with partial failures
- …

More issues…

- Concurrency problems?
  - Out of order message delivery?
    - Time…
- Performance problems?
  - 2n messages for n replicas
  - Failure of any replica can delay response
  - Routine network problems can delay response
- Scalability problems?
  - All replicas are written for each update, but primary DB responds to every request

Types of failure behaviors

- Fail-stop
- Other halting failures
- Communication failures
  - Send/receive omissions
  - Network partitions
  - Message corruption
- Performance failures
  - High packet loss rate
  - Low throughput
  - High latency
- Data corruption
- Byzantine failures

Common assumptions about failures

- Behavior of others is fail-stop (ugh)
- Network is reliable (ugh)
- Network is semi-reliable but asynchronous
- Network is lossy but messages are not corrupt
- Network failures are transitive
- Failures are independent
- Local data is not corrupt
- Failures are reliably detectable
- Failures are unreliably detectable

Some distributed system design goals

- The end-to-end principle
  - When possible, implement functionality at the end nodes (rather than the middle nodes) of a distributed system
- The robustness principle
  - Be strict in what you send, but be liberal in what you accept from others
    - Protocols
    - Failure behaviors
- Benefit from incremental changes
- Be redundant
  - Data replication
  - Checks for correctness

Next time…

- MapReduce