L1: Complexity, Enforced Modularity, and client/server organization

Frans Kaashoek and Dina Katabi

6.033 Spring 2013

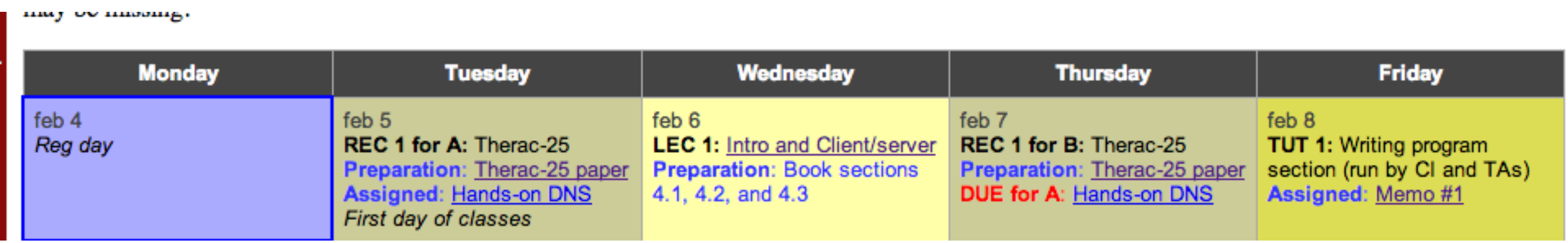
http://web.mit.edu/6.033

MASSACHUSETTS
INSTITUTE OF
TECHNOLOGY

http://web.mit.edu/6.033

- Schedule has all assignments
  - Every meeting has preparation/assignment

- On-line registration form to sign up for section and tutorial times
  - We will post sections assignment Thursday evening



may be missing.

Monday	Tuesday	Wednesday	Thursday	Friday
feb 4 *Reg day*	feb 5 **REC 1 for A:** Therac-25 **Preparation:** Therac-25 paper **Assigned:** Hands-on DNS *First day of classes*	feb 6 **LEC 1:** Intro and Client/server **Preparation:** Book sections 4.1, 4.2, and 4.3	feb 7 **REC 1 for B:** Therac-25 **Preparation:** Therac-25 paper **DUE for A:** Hands-on DNS	feb 8 **TUT 1:** Writing program section (run by CI and TAs) **Assigned:** Memo #1

What is a system?

- 6.033 is about the design of computer systems
- System = *Interacting set of components with a specified behavior at the interface with its environment*
- Examples: Web, Linux
- Much of 6.033 will operate at design level
  - Relationships of components
  - Internals of components that help structure

Challenge: complexity

- Hard to define; symptoms:
  - Large # of components
  - Large # of connections
  - Irregular
  - No short description
  - Many people required to design/maintain
- Complexity limits what we can build
  - Not the underlying technology
  - Limit is usually designers' understanding

Problem Types in Complex Systems

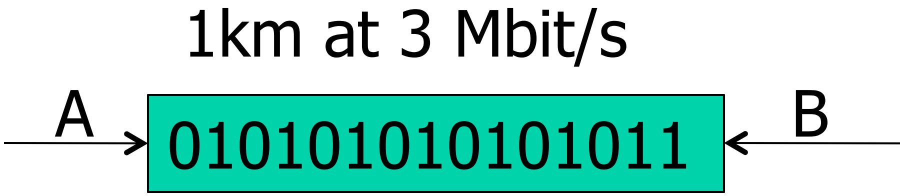
- Emergent properties
  - surprises
- Propagation of effects
  - Small change -> big effect
- [Incommensurate] scaling
  - Design for small model may not scale

- Problems show up in non-computer systems

Emergent Property Example: Ethernet

- All computers share single cable
- Goal is reliable delivery
- Listen while sending to detect collisions

Will listen-while-send detect collisions?



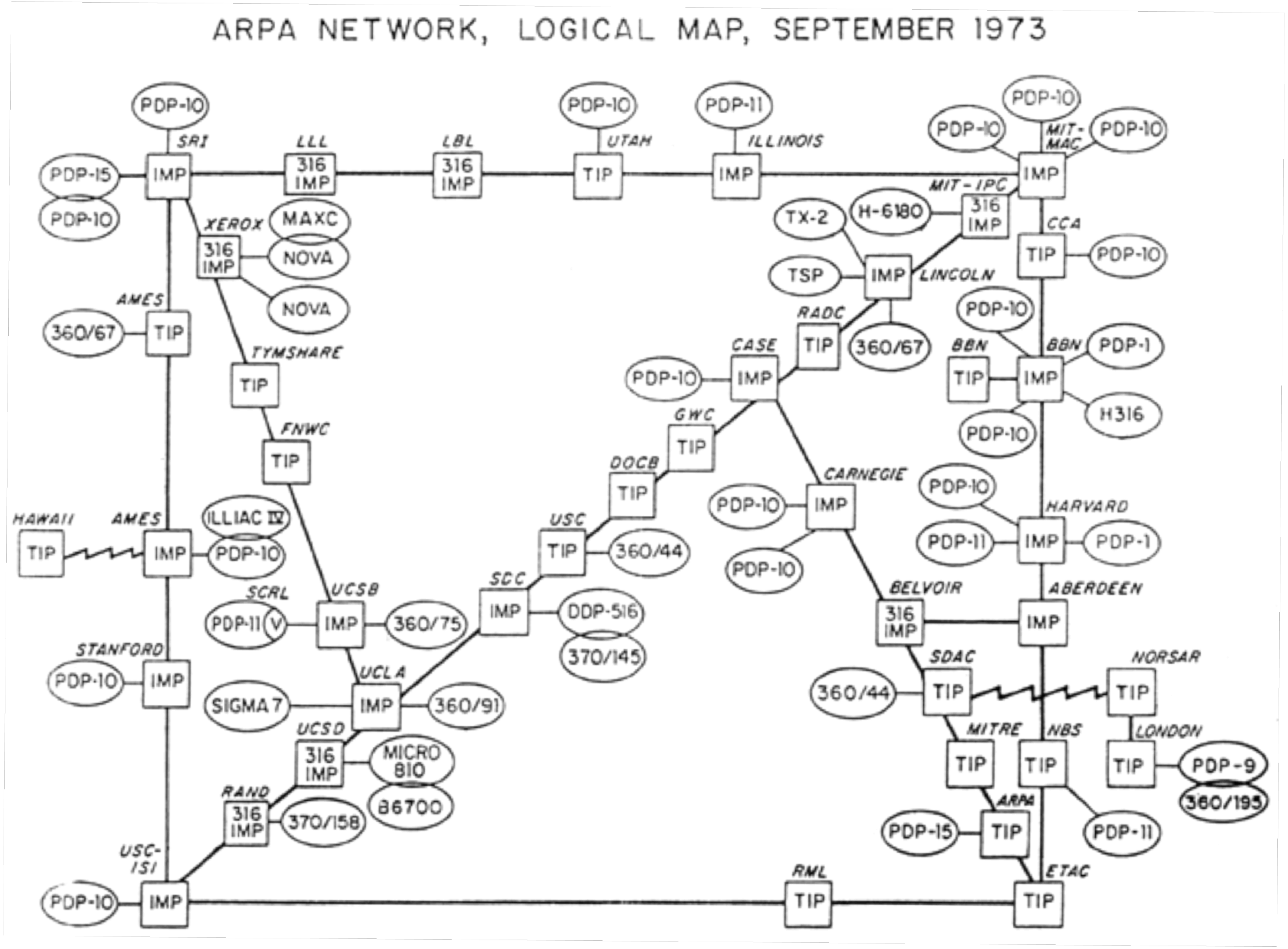
- 1 km at 60% speed of light = 5 microseconds
  - A can send 15 bits before bit 1 arrives at B
- A must keep sending for 2 * 5 microseconds
  - To detect collision if B sends when bit 1 arrives
- Minimum packet size is 5* 2 * 3 = 30 bits

3 Mbit/s -> 10 Mbit/s

- Experimental Ethernet design: 3Mbit/s
  - Default header is: 5 bytes = 40 bits
  - No problem with detecting collisions
- First Ethernet standard: 10 Mbit/s
  - Must send for 2*20 μseconds = 400 bits
  - But header is 14 bytes
  - ➢ Need to pad packets to at least 50 bytes

➢ Minimum packet size!

A computer system scaling example



ARPA NETWORK, LOGICAL MAP, SEPTEMBER 1973

Scaling the Internet

- Size routing tables (for shortest paths): O(n^2)
  - Hierarchical routing on network numbers
  - Address is 16 bit network # and 16 bit host #
- Limited networks (2^{16})
- Network Address Translators and IPv6

Sources of Complexity

- Many goals/requirements
- Interaction of features
- Performance

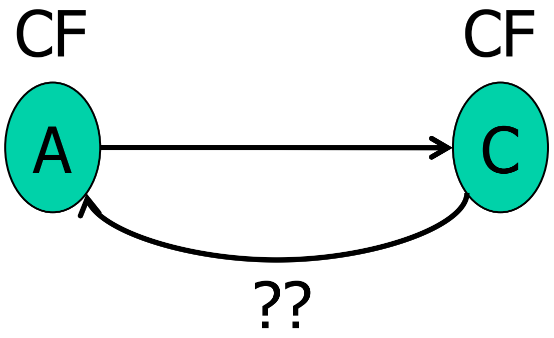
Example: more goals, more complexity

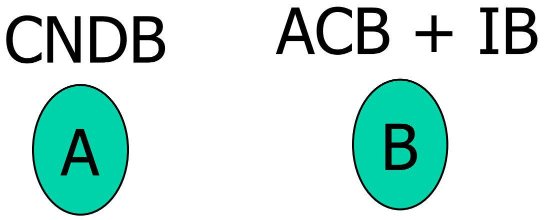
- 1975 Unix kernel: 10,500 lines of code
- 2008 Linux 2.6.24 line counts:

85,000	processes
430,000	sound drivers
490,000	network protocols
710,000	file systems
1,000,000	different CPU architectures
4,000,000	drivers
7,800,000	Total

Example: interacting features, more complexity

- Call Forwarding
- Call Number Delivery Blocking
- Automatic Call Back
- Itemized Billing





- A calls B, B is busy
- Once B is done, B calls A
- A’s number on appears on B’s bill

Interacting Features hidden

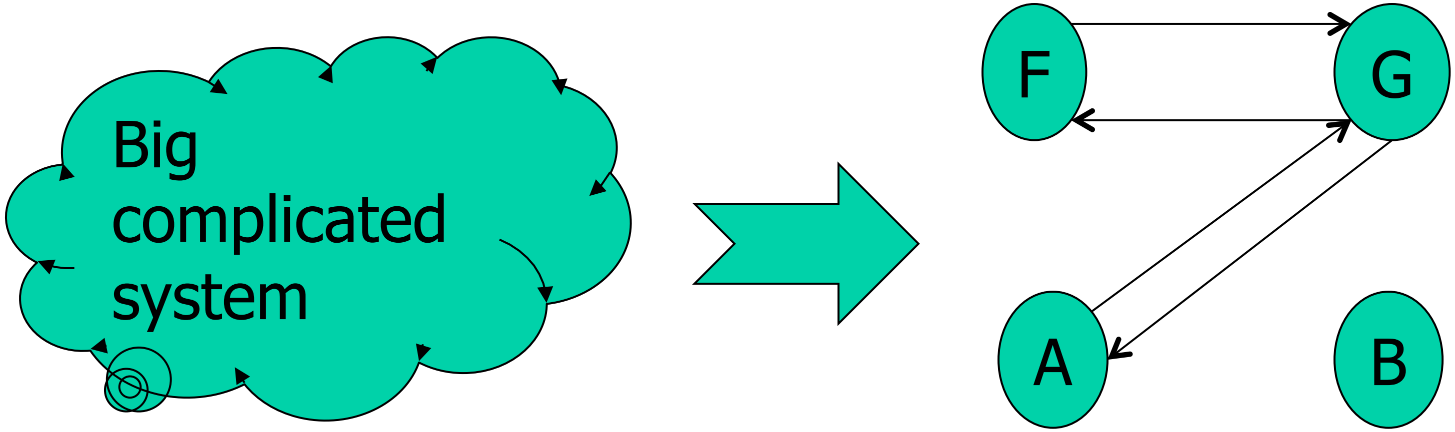
- Each feature has a spec.
- An interaction is bad if feature X breaks feature Y.
- …
- The point is not that these bad interactions can’t be fixed.
- The point is that there are so many interactions that have to be considered: they are a huge source of complexity.
- Perhaps more than n^2 interactions, e.g. triples.
- Cost of thinking about / fixing interaction gradually grows to dominate s/w costs.
- The point: Complexity is super-linear

Coping with Complexity

- Simplifying design principles
  - E.g., “Avoid excessive generality”

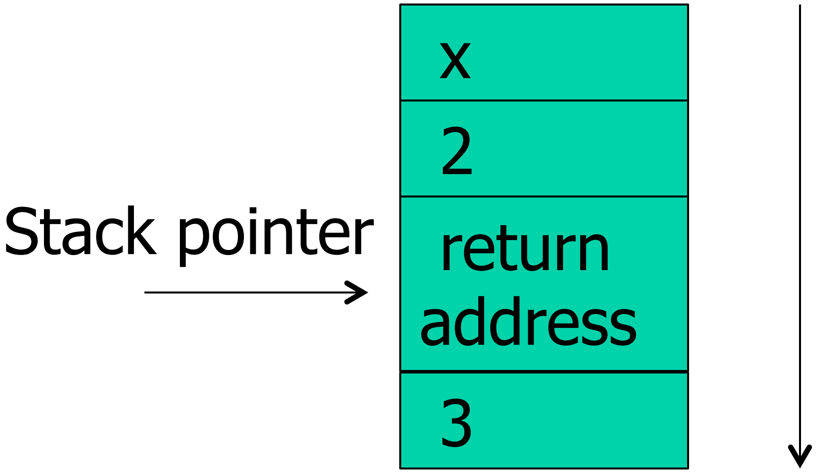
- Modularity
  - Split up system, consider separately
- Abstraction (e.g., RPC, Transactions)
  - Interfaces/hiding
  - Helps avoid propagation of effects
- Hierarchy (e.g., DNS)
- Layering (e.g., Internet)

A modularity tool: procedure call



- Defines interaction between F and G
- F and G don’t expose internals
- How well does this enforce modularity?

Implementation using stack



Stack pointer

x

2

return address

3

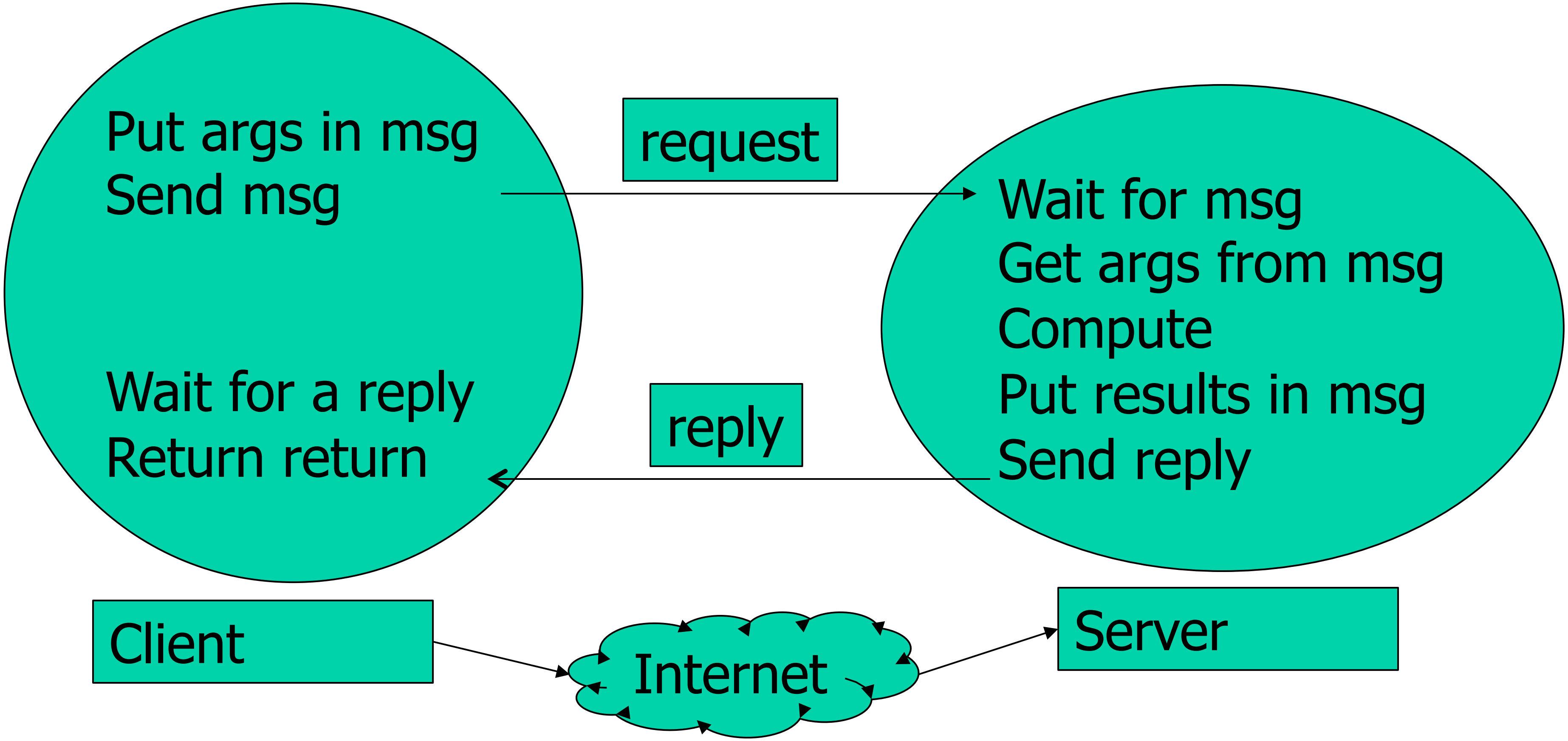
- Calling contract between F and G
  - F sets stack pointer for G
  - G doesn’t modify F’s variables
  - G returns
  - G doesn’t wedge environment
    - Use all heap memory, crash, etc.

Is calling contract enforced?

- C, C++: No
  - Callee can overwrite anything
- Java, C#, Haskell, Go: Somewhat
  - Callee may run computer out of resources
- Python: No
  - A type error in callee can fail caller

- Can we do more?

Client/server organization



Put args in msg
Send msg

Wait for a reply
Return return

request

reply

Wait for msg
Get args from msg
Compute
Put results in msg
Send reply

Client

Internet

Server

- Modules interact through messages

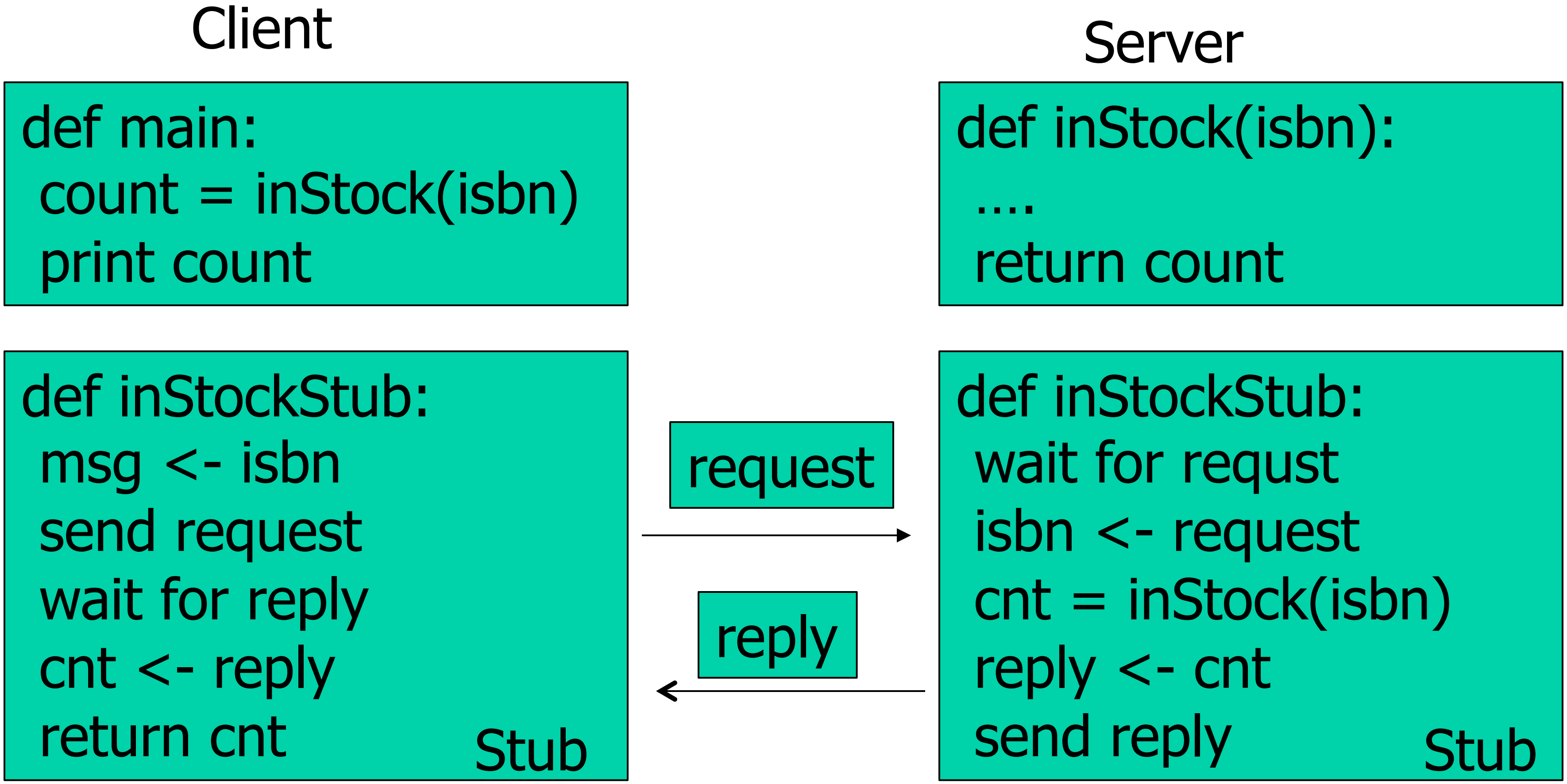
C/S enforced modularity

- Protects memory content
- Separates resources
  - Heap, cpu, disk, etc.
- No fate sharing
  - But, client might not get a response
- Forces a narrow spec, but:
  - Bugs can still propagate through messages
  - Programmer must implement spec correctly

Usages of client/server

- Allows computers to share data
  - AFS, Web
- Allows remote access
  - Two banks transferring money
- Allows trusted third party
  - E-bay provides controlled sharing of auction data

Simplifying C/S with remote procedure call



Client

```
def main:
  count = inStock(isbn)
  print count
```

```
def inStockStub:
  msg <- isbn
  send request
  wait for reply
  cnt <- reply
  return cnt
```

Stub

Server

```
def inStock(isbn):
  ....
  return count
```

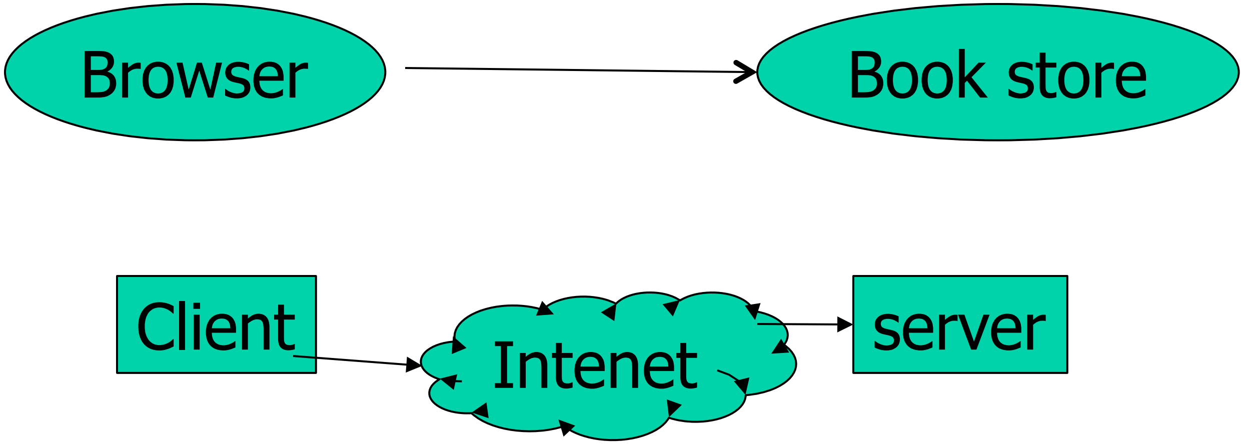
```
def inStockStub:
  wait for requst
  isbn <- request
  cnt = inStock(isbn)
  reply <- cnt
  send reply
```

Stub

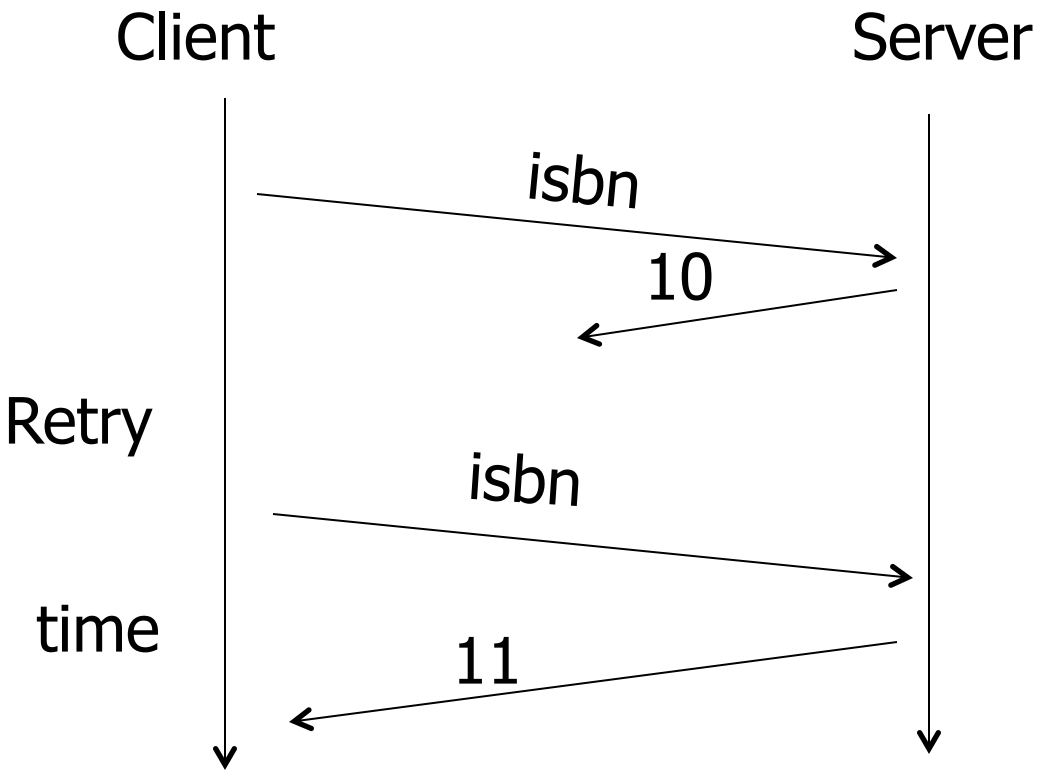
- Stubs make C/S look like an ordinary PC

RPC != PC

InStock(isbn) -> count
Ship(isbn, address)

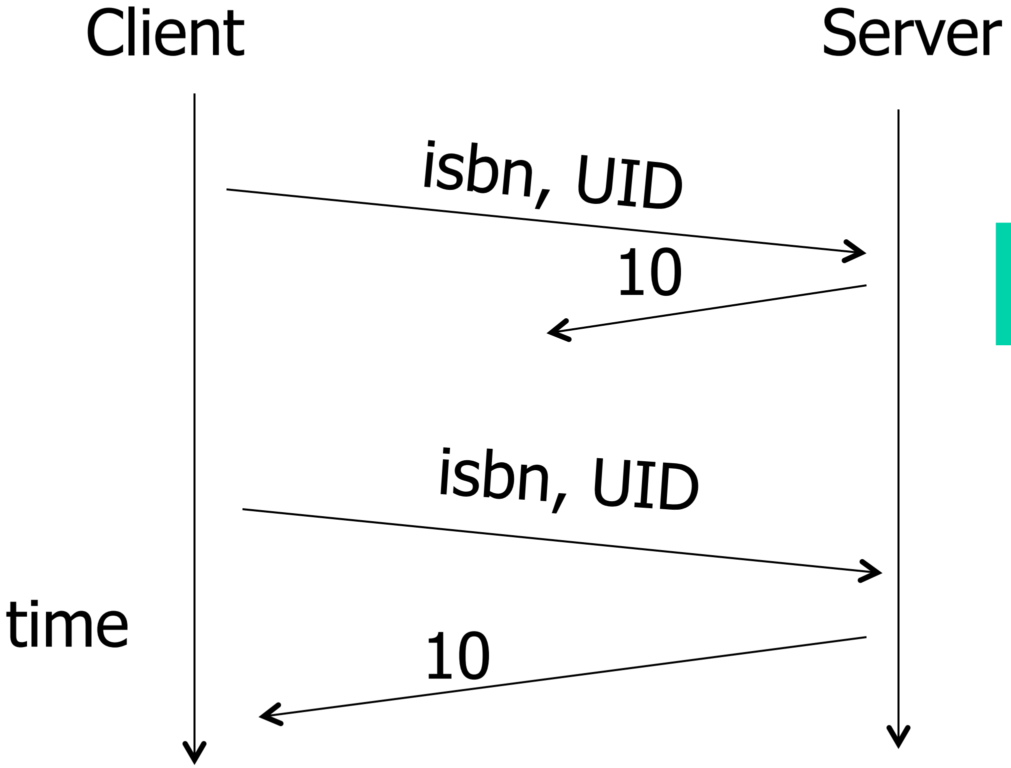


Challenge 1: network looses requests



- Approach: Retry after time out
- Doesn’t work for Ship()

Filter duplicate requests



Client	UID	Reply

- What if server plus table fail?

Challenge 2: server fails

- “Unknown” outcome for ship(isbn):
  - If server fails before sending reply
- Removing “unknown” outcome requires heavy-duty techniques
  - Check back in April
- Practical solution: RPC != PC
  - Users can check account later
  - Amazon can correct by crediting account

```
public interface ShipInterface extends Remote {
  public String ship(Integer) throws RemoteException;
}
```

```
public static void main (String[] argv) {
    try {
      ShipInterface srvr = (ShipInterface)
           Naming.lookup("//amazon.com/Ship");
      shipped = srvr.ship(“123”);
      System.out.println(shipped);
    } catch (Exception e) {
      System.out.println (”ShipClient exception: " + e);
    }
  }
```

Summary so far

- Designing systems is difficult
- Systems fail due to complexity
- New abstractions for system design
  - Enforced modularity through client/server
  - Remote procedure call
  - But, RPC != PC
- Failures will be a central challenge in 6.033
- No algorithm for successful system design

6.033 Approach to system design

- Lectures/book: big ideas and examples
- Hands-ons: play with successful systems
- Recitations: papers describing successful systems
- Design projects: you practice designing and writing
    - Design: choose problem, tradeoffs, structure
    - Writing: explain core ideas concisely
- Exams: focus on reasoning about system design
- Ex-6.033 students: papers and design projects

Example 6.033 systems

- Therac-25

  bad design, at many levels. detailed post-mortem
- UNIX
- MapReduce
- System R

Class plan

- Client/server: Naming
- Operating systems:
  - Enforced modularity within a machine
- Networks:
  - Enforced modularity between machines
- Reliability and transactions:
  - Handing hardware failures
- Security: handling malicious failures