Today’s goal

The goal of this lecture is to connect (some of) the dots between

- What you see in your programming courses, and
- The technology you use in your daily life.
Working With Multiple Processes

- Up until now we have been discussing objects that are in the same Java Virtual Machine (same process, same machine).
- However, almost any significant modern application spans several processes and/or machines.
- How do we communicate between processes?
Network communication

Remember CSC209? How did you communicate between processes?

- Pipes & local files - between processes on the same machine.
- Sockets - Allow you to communicate between machines.
Network communication

- Sockets
  - Essentially a “pipe between machines”
  - Two processes open a socket between them, and read/write data (aka send/receive messages).

- Protocols
  - Sometimes (usually) the data needs context.
  - The format of the data on the wire.
What does foo.f() mean?

- When we see
  - `foo.f();`
- We read
  - "calling" a function f on object foo
- In some OO languages, we say:
  - "Sending the message" f to object foo

Sometimes, it's easier to imagine "sending a message" between machines than "calling a function" across machines.
Distributed Objects

● How should we think about an app that sends data between machines?
  ○ How about a network of “distributed” objects that “send messages” to each other?

● How should we think of the messages?
  ○ The receiver (self or this, depending on language)
  ○ The name of the method
  ○ Arguments to the method
Remote Procedure Call (RPC)

- A remote procedure call is a method call where the callee is on one machine and the caller is on another.
- How do the arguments travel from callee to caller?
Remote Procedure Call (RPC)

● A remote procedure call is a method call where the callee is on one machine and the caller is on another.

● How do the arguments travel from callee to caller?
  ○ Serialization/deserialization to convert arguments (objects) to/from data (bytes)
  ○ Send/receive the resulting data through a socket!
Distributed Applications

● Processes on different machines need to communicate

● At the lowest level, use sockets
  ○ Send/receive bytes
  ○ Control every bit that goes on the wire

● Q: How to get from pushing bytes through a socket to the Internet as we know it?
Protocols

- **Hierarchy** of protocols on top of sockets
  - Agreed-upon standards/conventions
  - Enable communication
  - Each protocol *abstracts a level of details*

- Participants (i.e. processes) know
  - When they should send data
  - What data to send
  - When they should wait for incoming data
  - What incoming data is expected to look like
Examples

● Sending bytes over a socket

● Sending a Java-serialized object over the socket

● Java RMI - Calling a method on a remote object, as if it was local.
  ○ See this hello world example, where the RMI library
    ■ Allows you to bind/lookup objects by name
    ■ Provides you with proxy objects that abstract away all communication details
  ○ RMI depends on agreement/convention between the participants (e.g. client and server)
  ○ Note: RMI is a bit old and is not so popular these days.
    ■ But the same concepts/challenges apply to current libraries/technologies as well.
Basic Communication Protocol

● IP
  ○ The principal communication protocol of the Internet
  ○ All about routing - “Getting data from A to B”

● TCP
  ○ Transport-layer protocol that complements IP
  ○ Reliable data transfer using error detection
Basic Communication Protocol

- TCP/IP is a *transport-layer* protocol
  - Low-level protocol(s), on top of sockets
  - Not much semantics, all about transferring data reliably across the wire.

- If we want to build the Internet, we need ...
  - To think a bit more high-level
  - To abstract away details of moving bytes on a wire

- We need an *application-layer* protocol
Modern Web Applications

- Java-only protocols are no longer an option
- For example, think of Facebook’s system ...
  - iOS app (objective C)
  - Android App (Java)
  - Web client (JavaScript)
  - Web server (PHP)
  - And many (many!) more internal pieces that make up their extremely complex and large system.
Modern Web Applications

- Need a communication protocol that is
  - Application-layer
    - Allow us to focus on building applications, not arranging bits on the wire.
  - Language agnostic
    - Exchange data between applications written in different programming languages
  - Adopted by the industry as a standard!
HTTP

- Application layer protocol
  - On top of reliable transport layer (e.g. TCP/IP).

- Client-server protocol
  - Client sends a request
  - Server sends back a response

- One of the most commonly-used protocols on the web
HTTP Request

- Request line
  - Indicates which resource the client is requesting
  - Ex: GET /index.html HTTP/1.1

- Request headers
  - Contain metadata
  - Ex: Accept: application/json

- An empty line

- Optional message body (i.e. data)
HTTP Response

- Response line
  - Includes a status code
  - Ex: HTTP/1.1 200 OK

- Response headers
  - Contain metadata
  - Ex: Content-Length: 348

- An empty line

- Optional message body (i.e. data)
Live Demo

1. Open your browser at http://example.com

2. telnet www.example.com 80, and type

```
GET /index.html HTTP/1.1
Host: www.example.com
```

(With an empty line at the end)
Live Demo - Cont’d

● In both cases, you sent HTTP request to a server, and got a response.

● Let’s look at the telnet window
  ○ Save the response body (without the headers) to a local file, test.html.
  ○ And open the file in your web browser.
Another Demo

- Every modern browser has *developer tools*
  - Allow you to inspect what the browser is doing under the hood
  - Different browsers = different menu/shortcut

- Let’s try something ...
  - Open the developer tools in your browser
  - Go to [http://google.com](http://google.com)
Another Demo - Cont’d

● We can see all HTTP requests:

● We only asked for one website, how come there are 25 requests?
Another Demo - Cont’d

● In your browser, keep the *developer tools* open, and start typing a search query in Google.
  ○ The browser sends HTTP request(s),
  ○ Gets a response containing JSON data,
  ○ And updates the screen (i.e. display auto-complete options)

● Notice ... All network communication happened in the background
Sync vs. Async

● Synchronous flow
  ○ Call a function, wait for the result

● Asynchronous flow
  ○ Call a function
  ○ Go do something else (without waiting for the result)
  ○ When the function returns (at some point), do something useful with its result.
Very Quick “History Lesson”

- Early 90’s
  - Browsers were working synchronously
  - User-experience was inferior (in today’s standards)

- During the 90’s
  - Browser vendors gradually added async support

- Early 2000’s
  - Developers realized the potential
  - Emerging standards, conventions, tools and hypes.
AJAX

- Asynchronous JavaScript And XML
- Huge hype around 2004
  - GMail and Yahoo Mail were some of the early notable web apps to offer desktop-like UX
- In time, JSON replaced XML as the standard serialization format
  - Less data to transfer
  - Easier to parse in web browsers (that have an extremely optimized JavaScript engine)
Async Function Call - Review

- When calling f, provide a callback
  - Like Lambda expressions or function pointers
  - Possibly multiple callbacks (e.g. success & error)
- Run f in a background thread
  - Other threads don’t have to wait for f
  - Extremely useful if f makes a network request
- When f returns a result, call the callback function (with the result as an argument)
Software As A Service

- Instead of providing users with software that runs on their machine, provide them with a service that runs on yours.
  - Easier to maintain
  - For many businesses, solves piracy issues
- Client talks to your software over the web
- More standards and conventions ⇒ More powerful tools & libraries
SaaS

- This is how modern web/mobile apps work

- Use remote service(s) to
  - Show weather info
  - Manage comments on articles
  - Display ads
  - etc.
SaaS

● Each service has its own API
  ○ Similar to interfaces in Java

● The API specifies
  ○ Format
    Ex: JSON over HTTP
  ○ Available resources
    Ex: GET /weather?city=Toronto,CA HTTP/1.1
  ○ Expected request/response data
    Ex: {“text” : “hot”, “degrees” : “33c”}
Summary

● Sockets
  ○ Let us transfer bytes *reliably* between machines

● Communication protocols
  ○ Abstract low-level communication details, and used for communicating between applications

● Serialization
  ○ Convert in-memory objects to/from data that can be sent to/from different machines

● Threads
  ○ Allow us to build asynchronous flow
  ○ Async flow enables us to use rich web-services while providing quality UX
  ○ Lambdas (i.e. functions) and promises make async code more elegant and maintainable

● Conventions & Standards
  ○ Ex: By following REST, one can auto-generate server and client code from documentation.