Acknowledgement and contacts

- **Credits**
  - *Part of the course material is based on slides provided by the following authors*
    - Pietro Michiardi, Jimmy Lin

- **Contacts**
  - Office hours (Ca’ Vignal 2, 1st floor, #82)
    - Thursday, 11.00 - 13.00 (check the website for last-minute changes)
    - Based on agreement (via email)
  - Email:
    damiano.carra@univr.it
Information and Background

- **Main source of information**
  - course web site
    - Slides
    - Detailed course schedule
      - roughly: 2 hours (theory) + 2 hours (lab) per week
    - *Note that the schedule may change, so keep checking it!*

- **Background**
  - Necessary: Java programming
  - Suggested: Basic Database course

Exam

- **Based on a project**
  - Design and implementation of solutions to analyze different data sets
  - Focus on the efficiency and the performance of the proposed solution

- **The project output will be**
  - The implementation (source code)
  - A technical report with
    - implementation details of the solution
    - results of the analysis of the data sets
    - performance analysis
      - varying cluster size or system parameters
      - The code will probably be used on a real cluster of machines... still working on that, so stay tuned
Course material

- The principal textbooks for this course are:
  - Jimmy Lin, Chris Dyer: “Data-Intensive Text Processing with MapReduce”
    - The pdf can be downloaded here: http://lintool.github.io/MapReduceAlgorithms/ed1n.html
  - Tom White: “Hadoop: The Definitive Guide”
    - A copy will be available at the library
  - A. Rajaraman, J. Leskovec, J.D. Ullman: “Mining of Massive Datasets”
    - Not necessary, it covers many other topics, but some chapters are interesting
    - The pdf can be downloaded here: http://infolab.stanford.edu/~ullman/mmds.html

- Readings from other sources will be pointed during the classes.

- IMPORTANT: The slides are a reference to the topics covered during the course
  - Their content has much less information than the textbooks

Introduction and motivations
A lot of keywords...

- Hadoop
- Big data
- Data center
- NoSql
- Cloud computing
- MapReduce

- After this course, these keywords (and much more) will have, hopefully, a meaning
- Let’s start with... Big data

How much data?

- Google → 20 PB/day (2008)
- Facebook → 90 TB/day (2010)
- LSST → 3 TB/day of image data
- LHC → 10/15 PB/year
- and much more...
  - Amazon, NYT, DNA sequencing

- Is a lot of data enough for big data?
  - Volume, Velocity, Variety
Challenges

- Traditional parallel supercomputers are not the right fit for many problems (given their cost)
  - Optimized for fine-grained parallelism with a lot of communication
  - Cost does not scale linearly with capacity

- Clusters of commodity computers
  - Even more accessible with pay-as-you-go cloud computing

Parallel computing is hard!

Fundamental issues
- scheduling, data distribution, synchronization, inter-process communication, robustness, fault tolerance, ...

Different programming models
- Message passing
- Shared memory

Architectural issues
- Flynn’s taxonomy (SIMD, MIMD, etc.),
- network typology, bisection bandwidth
- UMA vs. NUMA, cache coherence

Common problems
- livelock, deadlock, data starvation, priority inversion...
- dining philosophers, sleeping barbers, cigarette smokers, ...

Different programming constructs
- mutexes, conditional variables, barriers, ...
- masters/slaves, producers/consumers, work queues, ...

The reality: programmer shoulders the burden of managing concurrency...
How to process big data?

- We are looking at newer
  - Programming models
  - Supporting algorithms and data structures
    - More data leads to better accuracy
    - With more data, accuracy of different algorithms converges

NSF refers to it as “data-intensive computing” and industry calls it “big-data” and “cloud computing”

How to process Big-data? Main Ideas

- Scale “out”, not “up”
- Assume failures are common
  - Probability of “no machine down” decreases rapidly with scale...
- Move processing to the data
  - Bandwidth is scarce
- Process data sequentially
  - Seeks are “very” expensive
- Hide system-level details from the application developer
Big-Data: Targeted problems

- Embarrassingly parallel problems
  - Simple definition: independent (shared nothing) computations on fragments of the dataset
  - It’s not easy to decide whether a problem is embarrassingly parallel or not

- Batch processing of data-intensive workloads
  - Involving (mostly) full scans of the dataset
  - Generally not processor demanding
    - E.g., read and process the whole Internet dataset from a crawler
  - Relevant datasets are too large to fit in memory

This course

- We will study current BigData solutions
  - Systems challenges
  - Programming models
  - Dealing with failures

- We will look at some applications
  - Information retrieval, data mining, graph mining, traffic processing, ...

- Possibly
  - Identify shortcomings, limitations
  - Address these!
Basic example: Word count

- Assume to have a large collection of texts
  - e.g., Web pages from the whole Internet
- We would like to count how many times each word is mentioned all over the collection
  - it represents the basis for more complex computations, such as frequencies, pairings, etc

- Assuming that the collection is distributed among N machines, how would you proceed?

Basic example: Word count

- In a single machine, the solution is trivial
  - final output: [\{(fog, 3), (winter, 2), (and, 4), \ldots\}]
Basic example: Word count

- In a single machine, the solution is trivial
  - final output: [(fog, 3), (winter, 2), (and, 4), ...]

- With multiple machines
  1. Use the solution for the single machine in each machine
     - intermediate output: [(fog, 3), (winter, 2), (and, 4), ...]
  2. Join the results collected from the different machines and produce the final output
     - final output: [(tree, 8), (fog, 13), (cold, 3), (winter, 6), (and, 22), ...]

Divide and Conquer

```
<table>
<thead>
<tr>
<th>Partition</th>
<th>Combine</th>
</tr>
</thead>
<tbody>
<tr>
<td>w_1</td>
<td>worker</td>
</tr>
<tr>
<td>w_2</td>
<td>worker</td>
</tr>
<tr>
<td>w_3</td>
<td>worker</td>
</tr>
</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th>“Work”</th>
<th>“Result”</th>
</tr>
</thead>
</table>
```
Parallelization Challenges

- How do we assign work units to workers?
- What if we have more work units than workers?
- What if workers need to share partial results?
- How do we aggregate partial results?
- How do we know all the workers have finished?
- What if workers die?

What’s the common theme of all of these problems?

Common Theme?

- Parallelization problems arise from:
  - Communication between workers (e.g., to exchange state)
  - Access to shared resources (e.g., data)
- Thus, we need a synchronization mechanism
Managing Multiple Workers

- Difficult because
  - We don’t know the order in which workers run
  - We don’t know when workers interrupt each other
  - We don’t know when workers need to communicate partial results
  - We don’t know the order in which workers access shared data
- Thus, we need:
  - Semaphores (lock, unlock)
  - Conditional variables (wait, notify, broadcast)
  - Barriers
- Still, lots of problems:
  - Deadlock, livelock, race conditions…
  - Dining philosophers, sleeping barbers, cigarette smokers…
- Moral of the story: be careful!

In summary

- Concurrency is difficult to reason about
- Concurrency is even more difficult to reason about
  - At the scale of datacenters and across datacenters
  - In the presence of failures
  - In terms of multiple interacting services
- Not to mention debugging…
- The reality:
  - Lots of one-off solutions, custom code
  - Write you own dedicated library, then program with it
  - Burden on the programmer to explicitly manage everything
Parallel computing: Concerns

- A parallel system needs to provide:
  - Data distribution
  - Computation distribution
  - Fault tolerance
  - Job scheduling

- The execution framework should hide these system-level details
  - Separate the *what* from the *how*
A final thought

Chris Stucchio

Don't use Hadoop - your data isn't that big
Posted: Mon, 16 Sep 2013

"So, how much experience do you have with Big Data and Hadoop?" they asked me. I told them that I use Hadoop all the time, but rarely for jobs larger than a few TB. I'm basically a big data neophyte - I know the concepts, I've written code, but never at scale.

The next question they asked me. "Could you use Hadoop to do a simple group by and sum?" Of course I could, and I just told them I needed to see an example of the file format.

They handed me a flash drive with all 600MB of their data on it (not a sample, everything). For reasons I can't understand, they were unhappy when my solution involved pandas.read_csv rather than Hadoop.

Hadoop is limiting. Hadoop allows you to run one general computation, which I'll illustrate in pseudocode: