CS10: The Beauty and Joy of Computing

Lecture #20
Distributed Computing

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GOOGLE SCIENCE FAIR WINNER

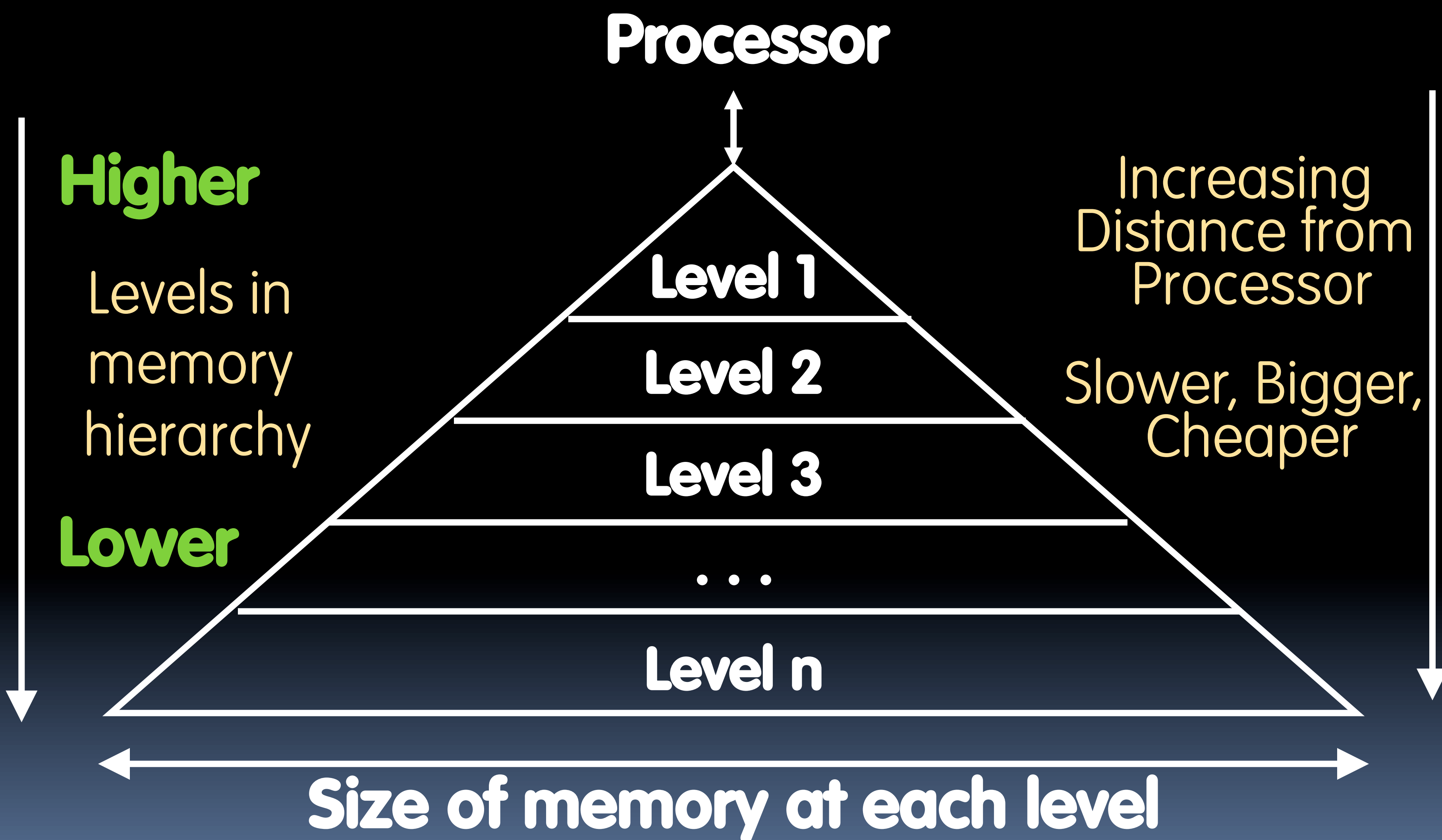
Brittany Wenger wrote a neural net that analyzes diagnostic test data to detect breast cancer – and it performs better than commercial software.

http://bit.ly/NVusUb

Lecture Overview

- **Basics**
  - Memory
  - Network
- **Distributed Computing**
  - Themes
  - Challenges
- **Solution! MapReduce**
  - How it works
  - Our implementation

Memory Hierarchy

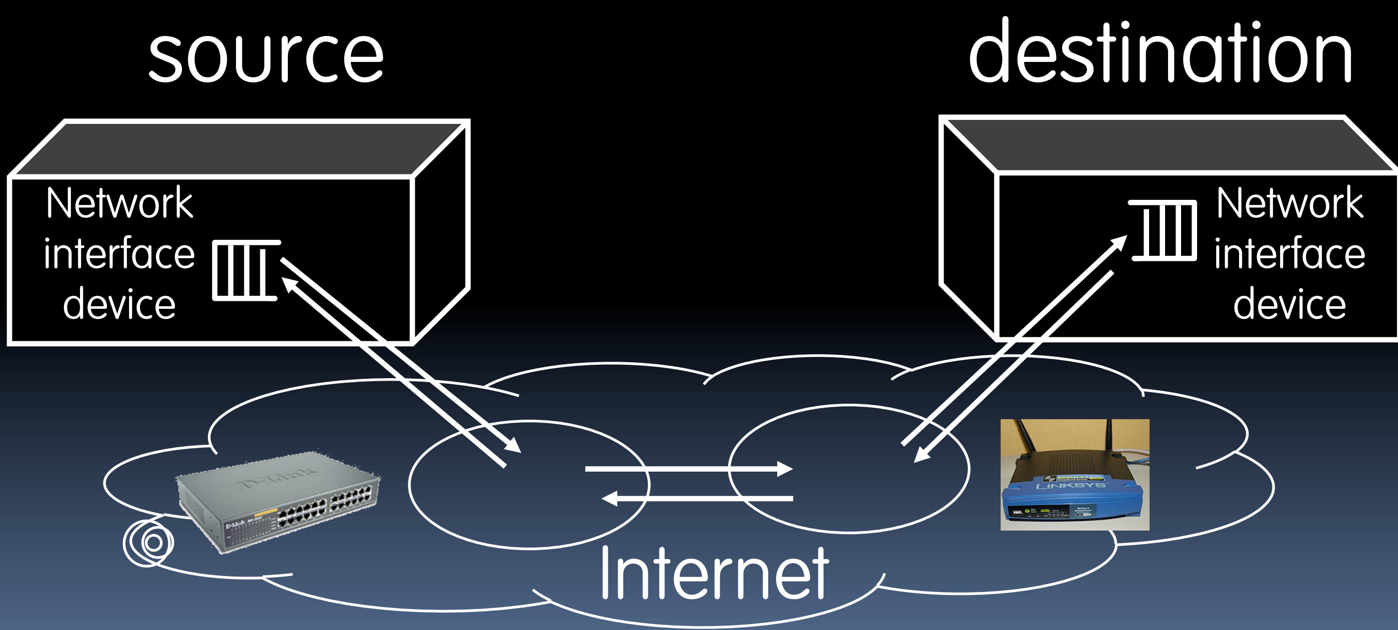


Memory Hierarchy Details

- If level closer to Processor, it is:
  - Smaller
  - Faster
  - More expensive
  - Subset of lower levels
    - …contains most recently used data
- Lowest Level (usually disk) contains all available data (does it go beyond the disk?)
- Memory Hierarchy **Abstraction** presents the processor with the illusion of a very large & fast memory

Networking Basics

- source **encodes** and destination **decodes** content of the message
- **switches** and **routers** use the destination in order to deliver the message, dynamically



Networking Facts and Benefits

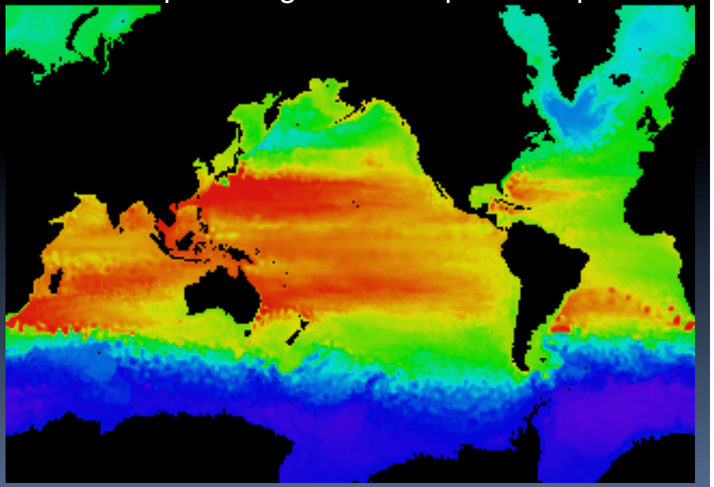
- **Networks connect computers, sub-networks, and other networks.**
  - Networks connect computers all over the world (and in space!)
  - Computer networks...
    - support asynchronous and distributed communication
    - enable new forms of collaboration

en.wikipedia.org/wiki/FLOPS

Performance Needed for Big Problems

- **Performance terminology**
  - the FLOP: FLoating point OPeration
  - "flops" = # FLOP/second is the standard metric for computing power
- **Example: Global Climate Modeling**
  - Divide the world into a grid (e.g. 10 km spacing)
  - Solve fluid dynamics equations for each point & minute
    - Requires about 100 Flops per grid point per minute
  - Weather Prediction (7 days in 24 hours):
    - 56 Gflops
  - Climate Prediction (50 years in 30 days):
    - 4.8 Tflops
- **Perspective**
  - Intel Core i7 3970X Desktop Processor
    - ~120 Gflops
    - Climate Prediction would take ~3 years

www.epm.ornl.gov/chammp/chammp.html

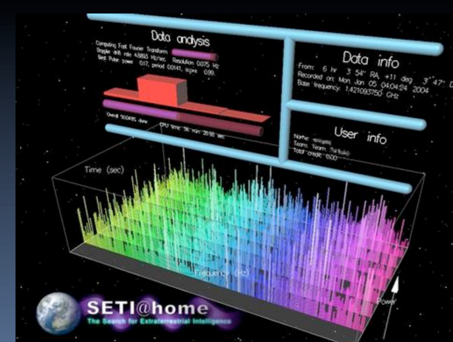


What Can We Do? Use Many CPUs!

- **Supercomputing – like those listed in `top500.org`**
  - Multiple processors "all in one box / room" from one vendor that often communicate through shared memory
  - This is often where you find exotic architectures
- **Distributed computing**
  - Many separate computers (each with independent CPU, RAM, HD, NIC) that communicate through a network
    - Grids (heterogenous computers across Internet)
    - Clusters (mostly homogeneous computers all in one room)
      - Google uses commodity computers to exploit "knee in curve" price/performance sweet spot
  - It's about being able to solve "big" problems, not "small" problems faster
    - These problems can be data (mostly) or CPU intensive

Distributed Computing Themes

- **Let's network many disparate machines into one compute cluster**
- **These could all be the same (easier) or very different machines (harder)**
- **Common themes**
  - "Dispatcher" gives jobs & collects results
  - "Workers" (get, process, return) until done
- **Examples**
  - SETI@Home, BOINC, Render farms
  - Google clusters running MapReduce



Peer Instruction

1. Writing & managing SETI@Home is relatively straightforward; just hand out & gather data
2. The majority of the world's computing power lives in supercomputer centers

	12
a)	FF
b)	FT
c)	TF
d)	TT

Peer Instruction Answer

1. The heterogeneity of the machines, handling machines that fail, falsify data. FALSE
2. Have you considered how many PCs + game devices exist? Not even close. FALSE

1. Writing & managing SETI@Home is relatively straightforward; just hand out & gather data
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en.wikipedia.org/wiki/Embarrassingly_parallel

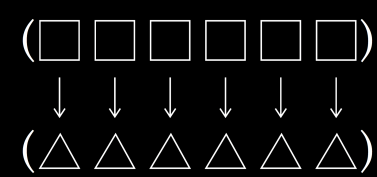
Distributed Computing Challenges

- **Communication is fundamental difficulty**
  - Distributing data, updating shared resource, communicating results, handling failures
  - Machines have separate memories, so need network
  - Introduces inefficiencies: overhead, waiting, etc.
- **Need to parallelize algorithms, data structures**
  - Must look at problems from parallel standpoint
  - Best for problems whose compute times >> overhead

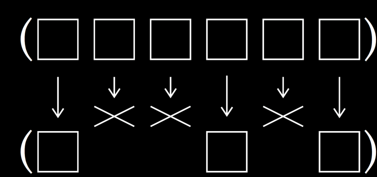
"UP" (L- R) Dug, Russell, Carl Fredricksen ©Disney/Pixar. All Rights Reserved.

Review

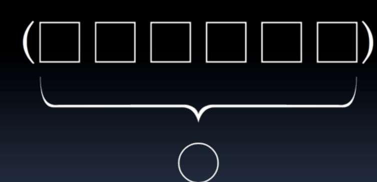
- Functions as Data
- Higher-Order Functions
- Useful HOFs (you can build your own!)
  - map <u>`Reporter`</u> over <u>`List`</u>
    - Report a new list, every element `E` of `List` becoming `Reporter(E)`



  - keep items such that <u>`Predicate`</u> from <u>`List`</u>
    - Report a new list, keeping only elements `E` of `List` if `Predicate(E)`



  - combine with <u>`Reporter`</u> over <u>`List`</u>
    - Combine all the elements of `List` with `Reporter(E)`
    - This is also known as "reduce"



- Acronym example
  - keep → map → combine

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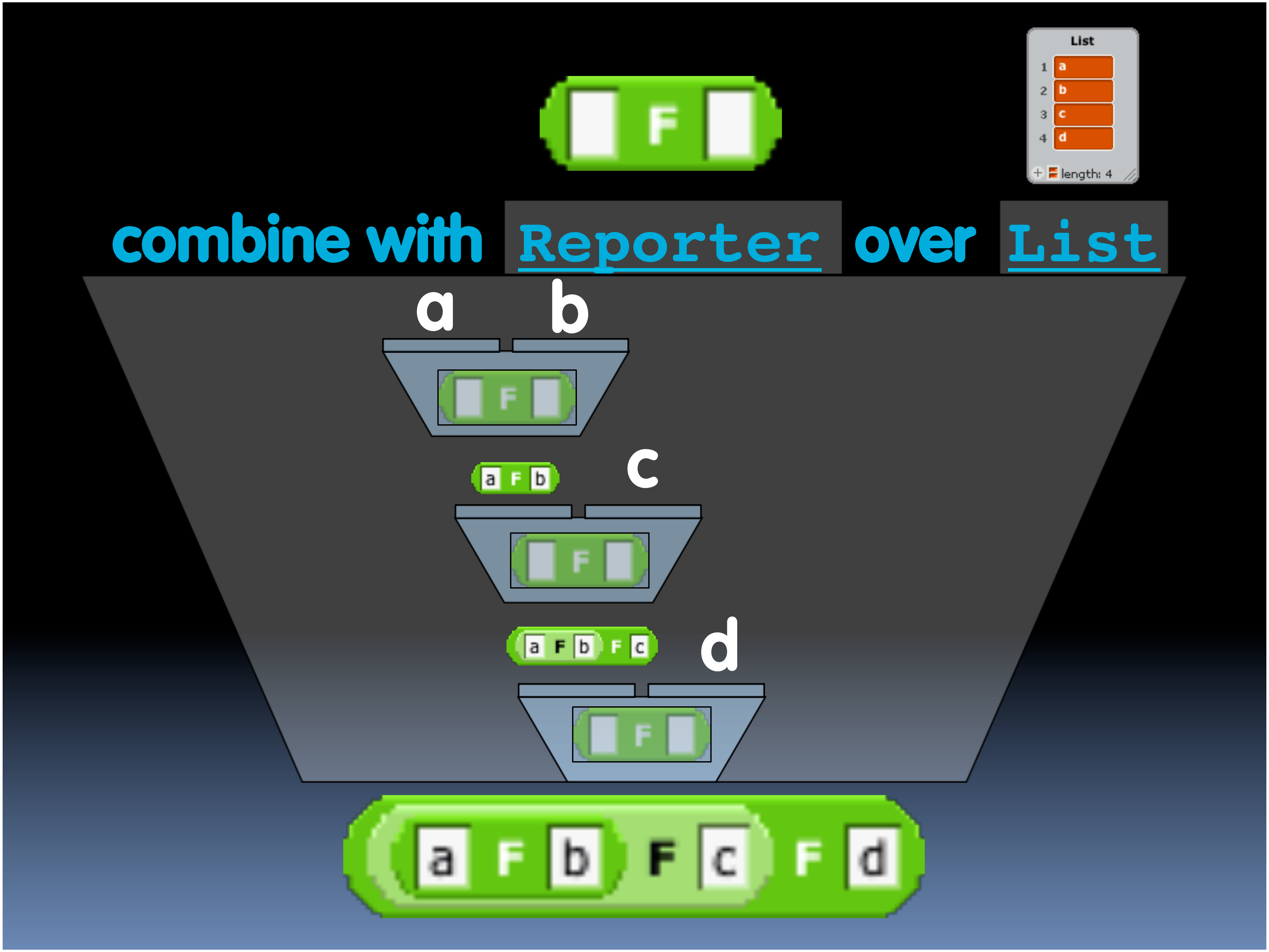
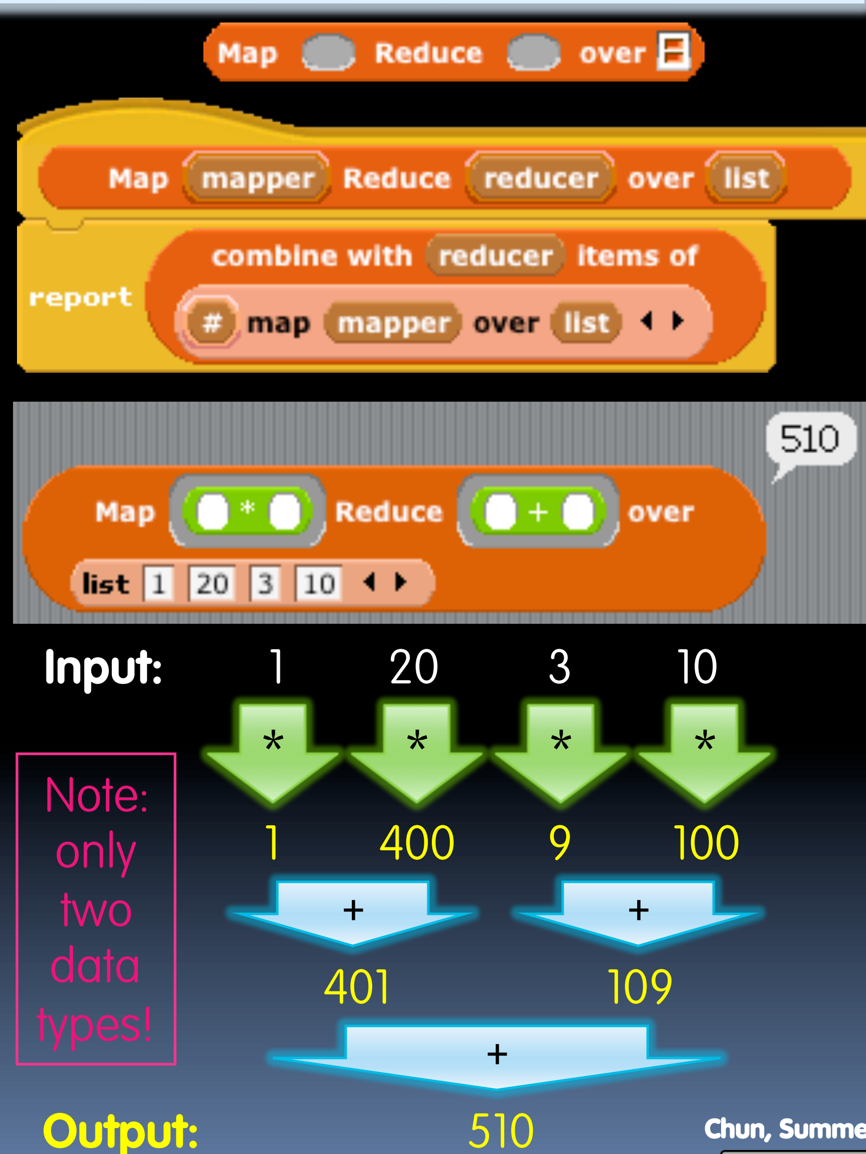

F
List
1 a
2 b
3 c
4 d
length: 4
combine with Reporter over List
a
b
F
a F b
c
F
a F b F c
d
F
a F b F c F d

Google's MapReduce Simplified

- **We told you "the beauty of pure functional programming is that it's easily parallelizable"**
  - Do you see how you could parallelize this?
  - Reducer should be associative and commutative
- **Imagine 10,000 machines ready to help you compute anything you could cast as a MapReduce problem!**
  - This is the abstraction Google is famous for authoring
  - It hides LOTS of difficulty of writing parallel code!
  - The system takes care of load balancing, dead machines, etc.



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MapReduce Advantages/Disadvantages

- **Now it's easy to program for many CPUs**
  - Communication management effectively gone
  - Fault tolerance, monitoring
    - machine failures, suddenly-slow machines, etc are handled
  - Can be much easier to design and program!
  - Can cascade several (many?) MapReduce tasks
- **But … it might restrict solvable problems**
  - Might be hard to express problem in MapReduce
  - Data parallelism is key
    - Need to be able to break up a problem by data chunks
  - Full MapReduce is closed-source (to Google) C++
    - Hadoop is open-source Java-based rewrite

Summary

- Systems and networks enable and foster computational problem solving
- MapReduce is a great distributed computing abstraction
  - It removes the onus of worrying about load balancing, failed machines, data distribution from the programmer of the problem
  - (and puts it on the authors of the MapReduce framework)