CS61A Lecture 30
MapReduce

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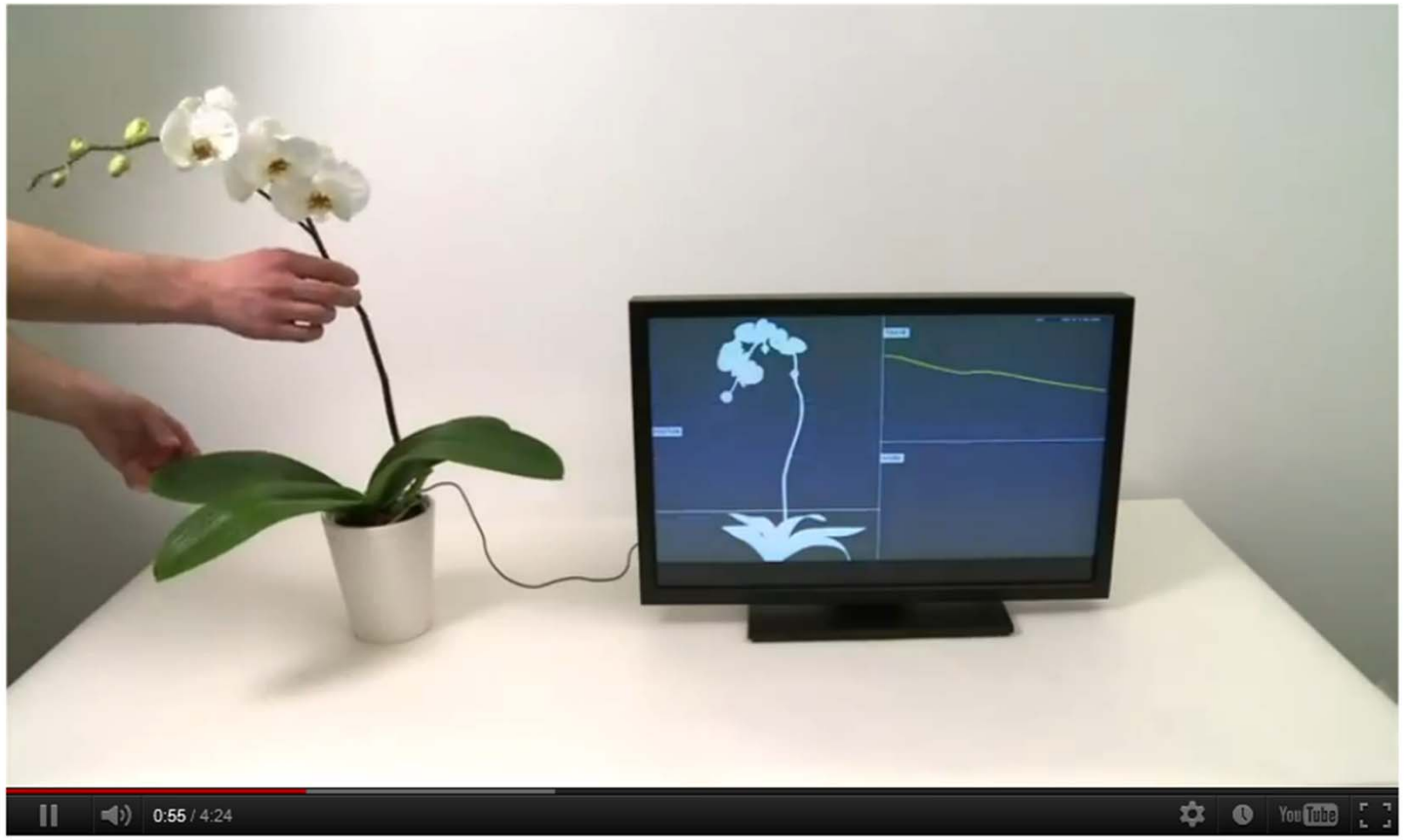
Slides developed from those of John DeNero, Paul Hilfinger, and Eric Tzeng

Computer Science in the News

Touch Your Philodendron and Control Your Computer: Technology Turns Any Plant Into an Interactive Device



http://www.sciencedaily.com/releases/2012/08/120806094053.htm
http://www.disneyresearch.com/research/projects/hci_botanicus_drp.htm

TODAY

- MapReduce
  - Description
  - Examples
- Social implications of Computing
  - Therac-25 case study

RECAP: REDUCE

```
reduce(lambda so_far, elt: so_far * elt,
       [1, 3, 8, 7], 2)

        ((((2 * 1) * 3) * 8) * 7)
```

Map and Reduce

Many problems can be solved by mapping a function over a sequence, and then reducing the new items.

To find the sum of squares of items in a list:

```
from functools import reduce
from operator import add
def sum_squares(list):
    return
    reduce(add,
           map(lambda num: num ** 2,
               list),
           0)
```

2. … and add the squared items together.

1. Square each item in a list…

Map and Reduce: Example

Count the number of letters in the words of a list

```
def count_letters(wordlist):
    return \
    reduce(add,
           map(lambda word: len(word),
               wordlist),
           0)
```

2. … and add the lengths together.

1. Find the length of each word in a list…

Map and Reduce: Example

Count the number of words in a list

```
def count_words(wordlist):
    return \
    reduce(___,
           map(_______________,
               wordlist),
           0)
```

Map and Reduce: Example

Count the number of words in a list

```
def count_words(wordlist):
    return \
    reduce(add,
           map(lambda word: 1,
               wordlist),
           0)
```

Map and Reduce: Example

Count the number of words in a list of even length

```
def count_words(wordlist):
    return \
    reduce(___,
           map(_____________________________________________,
               wordlist),
           0)
```

Map and Reduce: Example

Count the number of words in a list of even length

```
def count_words(wordlist):
    return \
    reduce(add,
           map(lambda word: 1 if len(word)%2 == 0 else 0,
               wordlist),
           0)
```

Map and Reduce: Example

Count the number of items in a list that satisfy a given predicate

```
def count_pred(pred, list):
    return \
    reduce(___,
           map(_____________________________________,
               list),
           0)
```

Map and Reduce: Example

Count the number of items in a list that satisfy a given predicate

```
def count_pred(pred, list):
    return \
    reduce(add,
           map(lambda item: 1 if pred(item) else 0,
               list),
           0)
```

MAP AND REDUCE: EXAMPLE

Filter out the items in a list that satisfy a given predicate

```
def filter(pred, list):
    return \
    reduce(_____________________________________,
           map(lambda item: ______ if pred(item) \
               else __,
               list),
           __)
```

MAP AND REDUCE: EXAMPLE

Filter out the items in a list that satisfy a given predicate

```
def filter(pred, list):
    return \
    reduce(lambda so_far, sublist: so_far + sublist,
           map(lambda item: [item] if pred(item) \
               else [],
               list),
           [])
```

ANNOUNCEMENTS

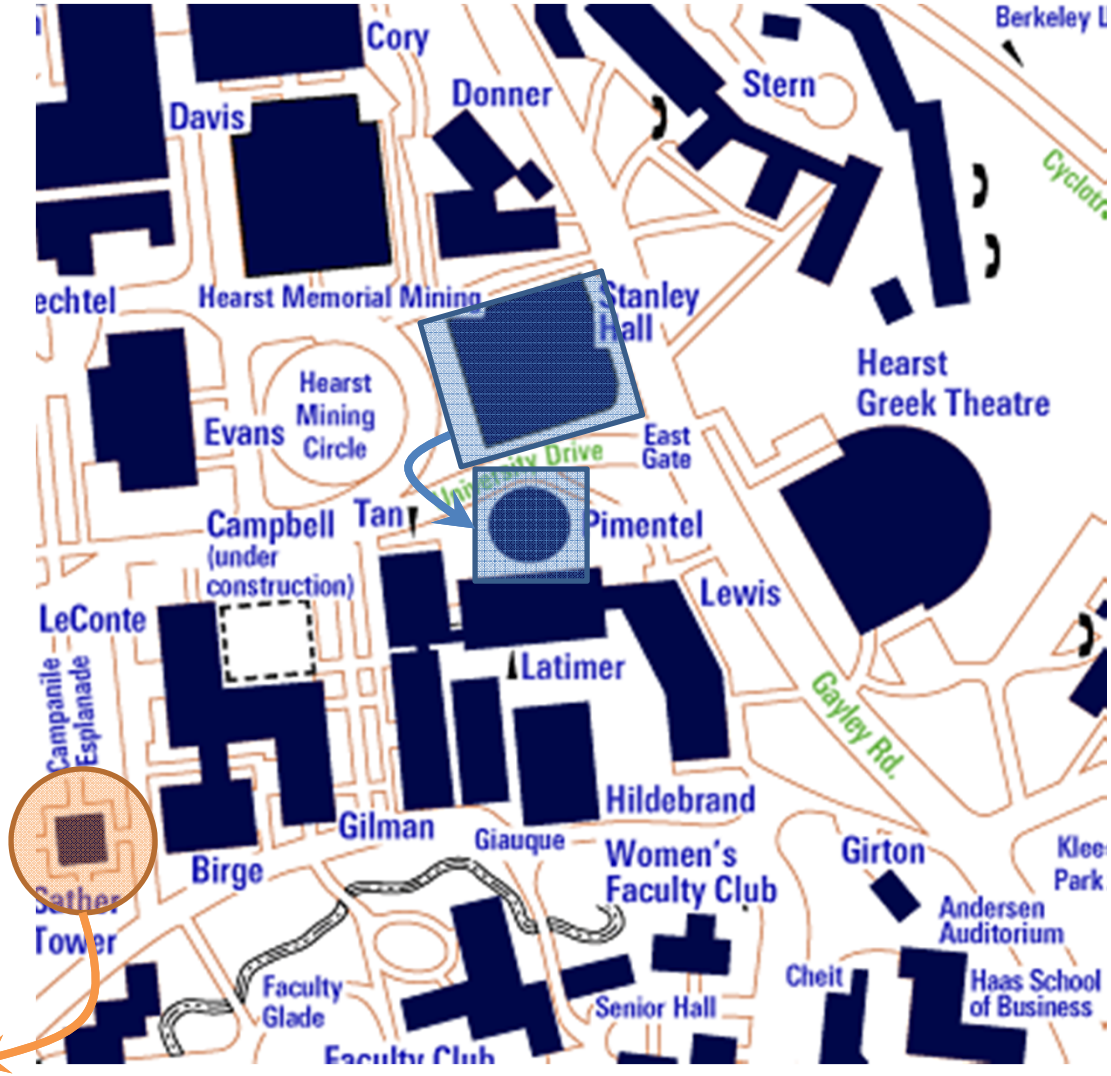
- You are now done with all projects and homework assignments! Congratulations! ☺
- Final lecture: You choose!

  Piazza poll will be sent out today asking for suggestions for tomorrow's lecture.

ANNOUNCEMENTS: FINAL

- Final is **Thursday, August 9**.
  - *Where*? 1 Pimentel.
  - *When*? 6PM to 9PM.
  - *How much*? *All* of the material in the course, from June 18 to August 8, will be tested.
- Closed book and closed electronic devices.
- One 8.5” x 11” ‘cheat sheet’ allowed.
- No group portion.
- Post-final laser tag?

ANNOUNCEMENTS: FINAL



CAMPANILE

http://berkeley.edu/map/maps/BC56.html

How Much Data?

As of 2007, Google processes **20 petabytes** of data per day. Now, they probably process thousands of petabytes per day.

How much is a petabyte?

Source: http://mozy.com/blog/wp-content/uploads/2009/07/whatsapetabyte.gif

How Much Data?

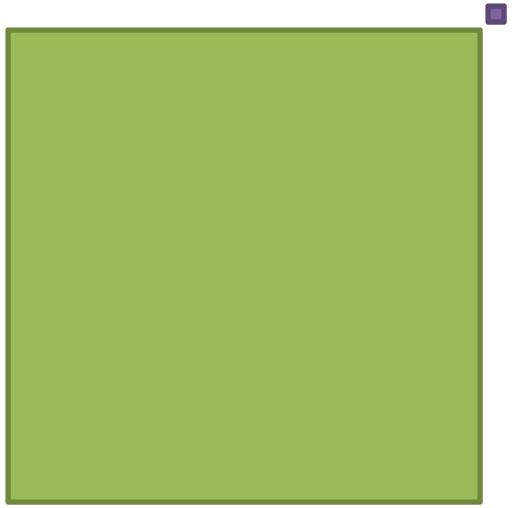
Assume that every 0 or 1 in a file is as large as a pixel on a screen (approx. 100 μm^2).

Then, a homework file, of size (approximately) 5 ***kilo***bytes, is about as big as

How Much Data?

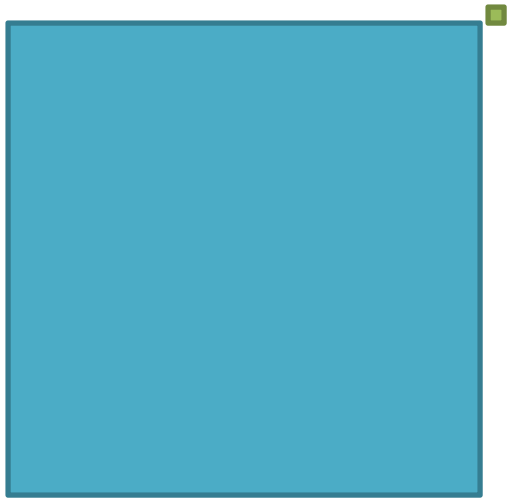
A music file has (approximately) 6 ***mega***bytes.

(1 megabyte = 1024 kilobytes)



How Much Data?

One DVD-R has (approximately) 5 ***giga***bytes.
(1 gigabyte = 1024 megabytes)



This is about as big as the total area of all pages of the *paper* copy of a homework.

How Much Data?

One terabyte is 1024 ***giga***bytes.

One petabyte is 1024 ***tera***bytes.

This is as much information as would fit in:

6 billion photos on Facebook, or

around 13 years of HD video.

Source: http://mozy.com/blog/wp-content/uploads/2009/07/whatsapetabyte.gif

How Much Data?

One petabyte is an **extremely large amount of data**.

We *cannot* process this on one computer alone.

My computer would take around **7 years** to process all of 20 petabytes *exactly once*, and that assumes that all it *ever* does is process data and *never fails*.

Companies like Google do not have this luxury: they need data to be processed as quickly as possible.

Source: http://mozy.com/blog/wp-content/uploads/2009/07/whatsapetabyte.gif

PARALLELISM

Idea: Have a *lot* of computers working at once on different chunks of the same data, *independently* of other chunks and computers.

MapReduce

All data is available at the outset; results are not consumed until processing completes

Framework for **batch processing** of **Big Data**

System used by programmers to build applications

Very large and complex data sets

MapReduce: History

- Developed at Google in 2003.
- Programmers had to consider a lot of details as part of their code: what to do when a computer fails, and how to divide the work up among different computers.
- However, many operations fit neatly into a *map* step, followed by a *reduce* step.

MapReduce

The MapReduce framework is an *abstraction*:

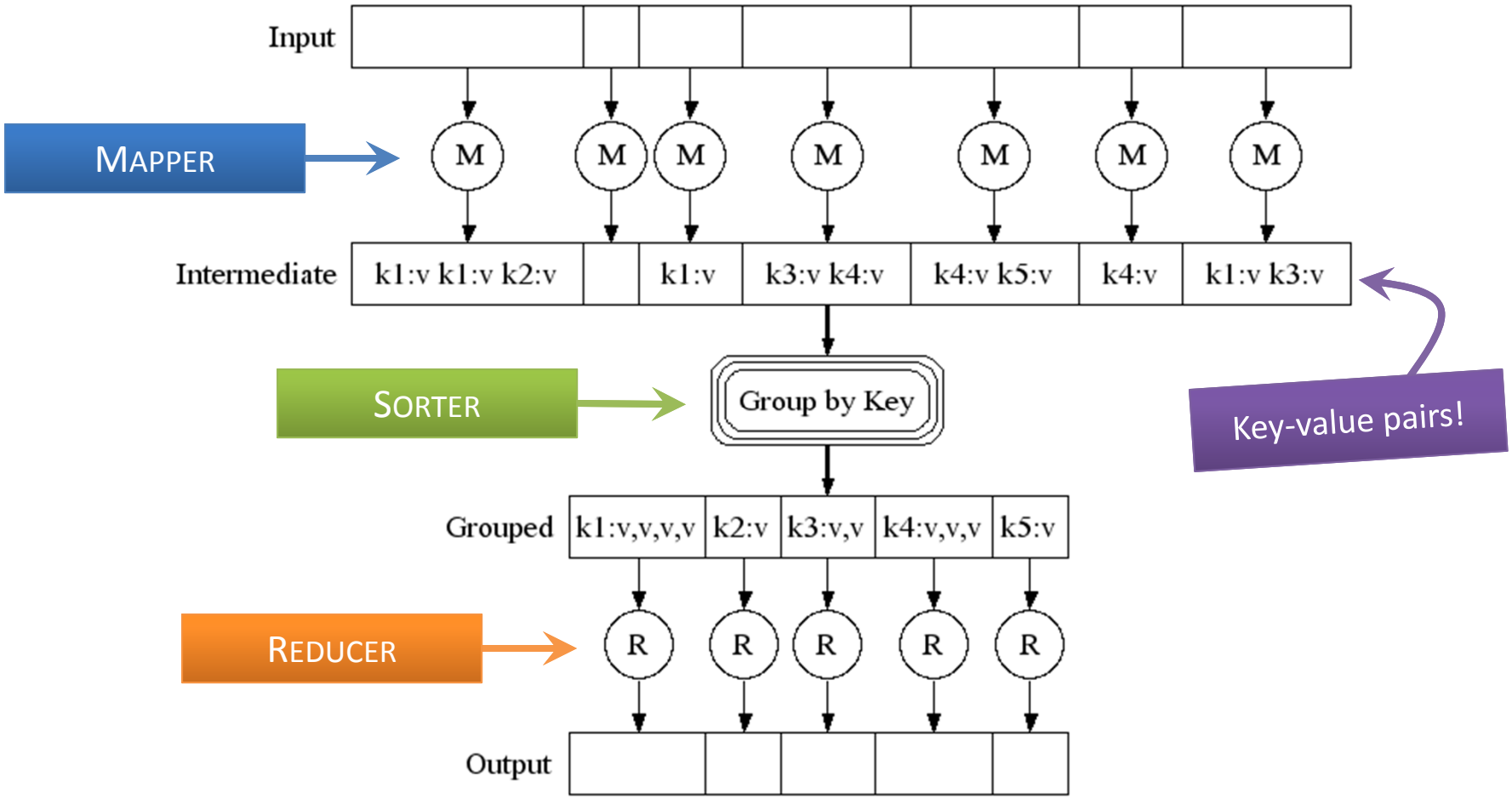
it allows programmers to code, while taking care of the underlying messy details, such as dealing with failure and distributing work across computers.

All the programmers had to do was create:

a ***mapper*** (the function to map), and

a ***reducer*** (the function to combine mapped results).

MapReduce: Execution Model



http://research.google.com/archive/mapreduce-osdi04-slides/index-auto-0007.html

MapReduce

Map Phase

Apply a *mapper* over inputs, and emit intermediate *key-value pairs*.

Sort Phase

Group the intermediate key-value pairs by *keys*.

Reduce Phase

For each intermediate *key*, apply a *reducer* to "accumulate" all values associated with that key.

MapReduce

Running example

Count all the vowels in Shakespeare's works.

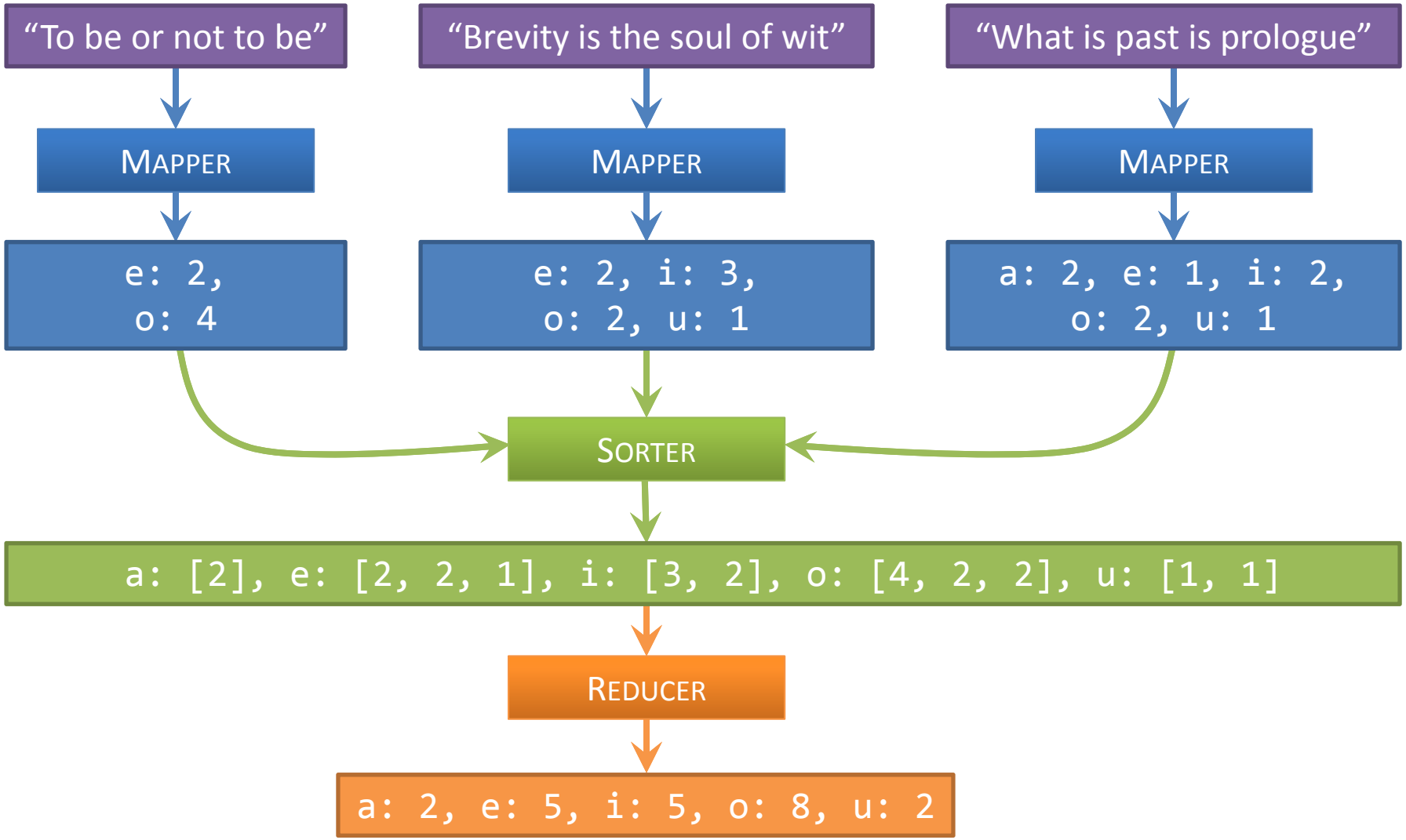
We need a ***mapper*** and a ***reducer***.

Idea:

The mapper will count the number of vowels in each line, for each vowel.

The reducer will take the counts for each vowel from each line and total all the counts.

MapReduce


"To be or not to be"
"Brevity is the soul of wit"
"What is past is prologue"
Mapper
Mapper
Mapper
e: 2, o: 4
e: 2, i: 3, o: 2, u: 1
a: 2, e: 1, i: 2, o: 2, u: 1
Sorter
a: [2], e: [2, 2, 1], i: [3, 2], o: [4, 2, 2], u: [1, 1]
Reducer
a: 2, e: 5, i: 5, o: 8, u: 2

MapReduce: Mapper

```
import sys
from ucb import main
from mr import emit

def emit_vowels(line):
    for vowel in 'aeiou':
        count = line.count(vowel)
        if count > 0:
            emit(vowel, count)

@main
def run():
    for line in sys.stdin:
        emit_vowels(line)
```

2. Check if the line has a vowel.

3. If it does, "emit" – or send to the *standard output* – a key-value pair that associates the vowel with its count.

1. For every line in a file, fed through the *standard input* of this program...

MapReduce: Reducer

Input: Lines of text representing key-value pairs, grouped by key
Output: Iterator over the keys and associated values. The "associated values" are *also* returned using an iterator.

```
import sys
from ucb import main
from mr import emit, values_by_key

@main
def run():
    for key, value_iterator in values_by_key(sys.stdin):
        emit(key, sum(value_iterator))
```

1. Iterate over the keys and associated values, fed through the *standard input*…

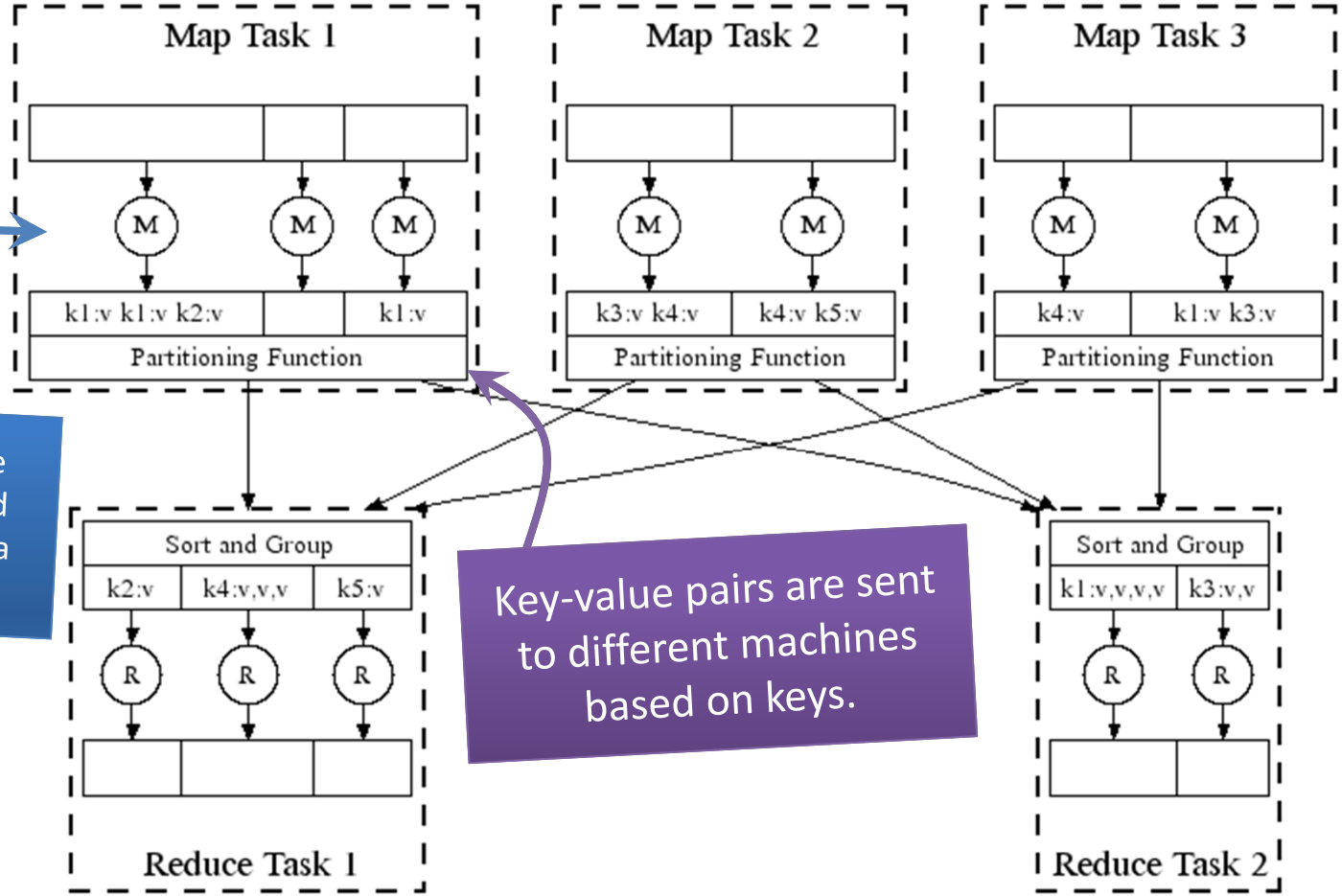
2. … and "emit" each key to the *standard output*, followed by the sum of the associated values.

Standard Input and Output

The *standard input* is where the program receives its input from external sources, such as the user or a file.

The *standard output* is where the program will send its output, such as the screen or another file.

MapReduce: Under-the-Hood



Different computers have copies of the mapper, and work on pieces of the data simultaneously.

Key-value pairs are sent to different machines based on keys.

http://research.google.com/archive/mapreduce-osdi04-slides/index-auto-0008.html

MapReduce: Practice

What is a mapper and reducer that we can use to count the number of times particular words appear in a file?

Mapper: For every line in a file,

emit...

Reducer: For every key,

MapReduce: Practice

What is a mapper and reducer that we can use to count the number of times particular words appear in a file?

Mapper: For every line in a file,

emit a key-value pair that associates a "special" word with the number of times it appears in that line.

Reducer: For every key,

sum up all the values associated with that key.

MapReduce: Practice

What is a mapper and reducer that we can use to count the number of lines in a file?

Mapper: For every line in a file,

emit…

Reducer: For every key,

MapReduce: Practice

What is a mapper and reducer that we can use to count the number of lines in a file?

Mapper: For every line in a file,
emit the key-value pair (“`line`”, `1`).

Reducer: For every key,
sum up all the values associated with that key.

MapReduce

What does the framework provide us?

- ***Fault Tolerance***: A machine or hard drive might crash.

  The framework will automatically re-run failed tasks.

- ***Speed***: Some machine might be slow because it is overloaded.

  The framework can run multiple copies and keep the result of the one that finishes first.

MapReduce

What does the framework provide us?

- ***Network locality***: Data transfer is expensive.

  The framework tries to schedule map tasks on the machines that hold the data to be processed.

- ***Monitoring***: When will my job finish?

  The framework provides a web-based interface describing jobs.

Spelling of Shakespeare's name

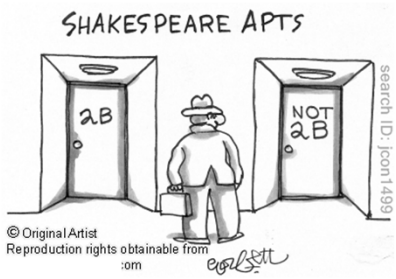
From Wikipedia, the free encyclopedia

The **spelling of William Shakespeare's name** has varied over time. It was not consistently spelled any single way during his lifetime, in manuscript or in printed form. After his death the name was spelled variously by editors of his work and the spelling was not fixed until well into the 20th century.

The standard spelling of the surname as "Shakespeare" was the

lefthandedtoons.com

BREAK



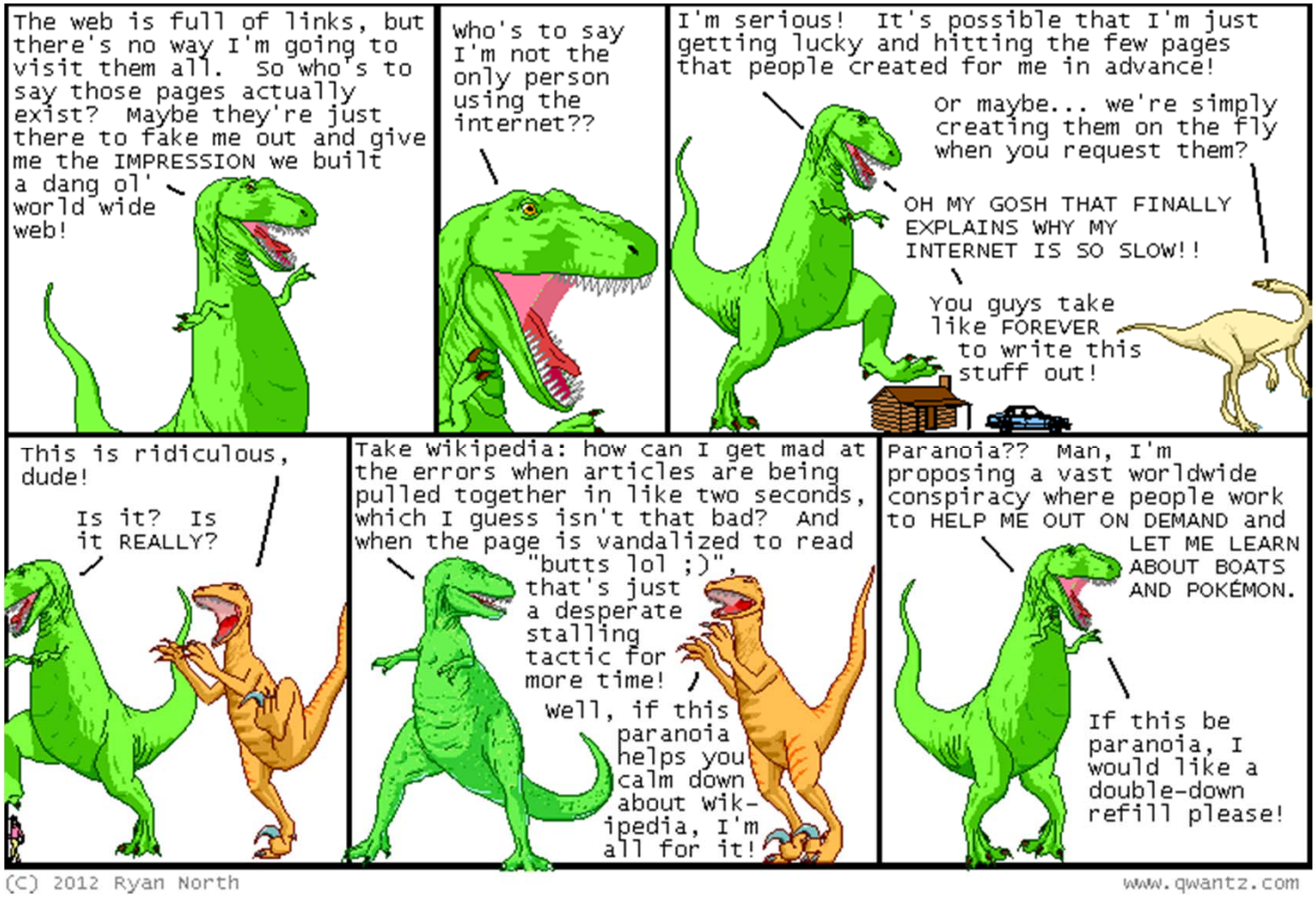
THERE'S BEEN A LOT OF CONFUSION OVER 1024 vs 1000, KBYTE vs KBIT, AND THE CAPITALIZATION FOR EACH.

HERE, AT LAST, IS A SINGLE, DEFINITIVE STANDARD:

SYMBOL	NAME	SIZE	NOTES
kB	KILOBYTE	1024 BYTES OR 1000 BYTES	1000 BYTES DURING LEAP YEARS, 1024 OTHERWISE
KB	KELLY-BOOTLE STANDARD UNIT	1012 BYTES	COMPROMISE BETWEEN 1000 AND 1024 BYTES
KiB	IMAGINARY KILOBYTE	1024 $\sqrt{-1}$ BYTES	USED IN QUANTUM COMPUTING
kb	INTEL KILOBYTE	1023.937528 BYTES	CALCULATED ON PENTIUM F.P.U.
Kb	DRIVEMAKER'S KILOBYTE	CURRENTLY 908 BYTES	SHRINKS BY 4 BYTES EACH YEAR FOR MARKETING REASONS
KBa	BAKER'S KILOBYTE	1152 BYTES	9 BITS TO THE BYTE SINCE YOU'RE SUCH A GOOD CUSTOMER

http://www.lefthandedtoons.com/1271/
http://xkcd.com/394/
http://www.cartoonstock.com/newscartoons/cartoonists/jco/lowres/jcon1499l.jpg

BREAK



http://www.qwantz.com/index.php?comic=2258

THERAC-25

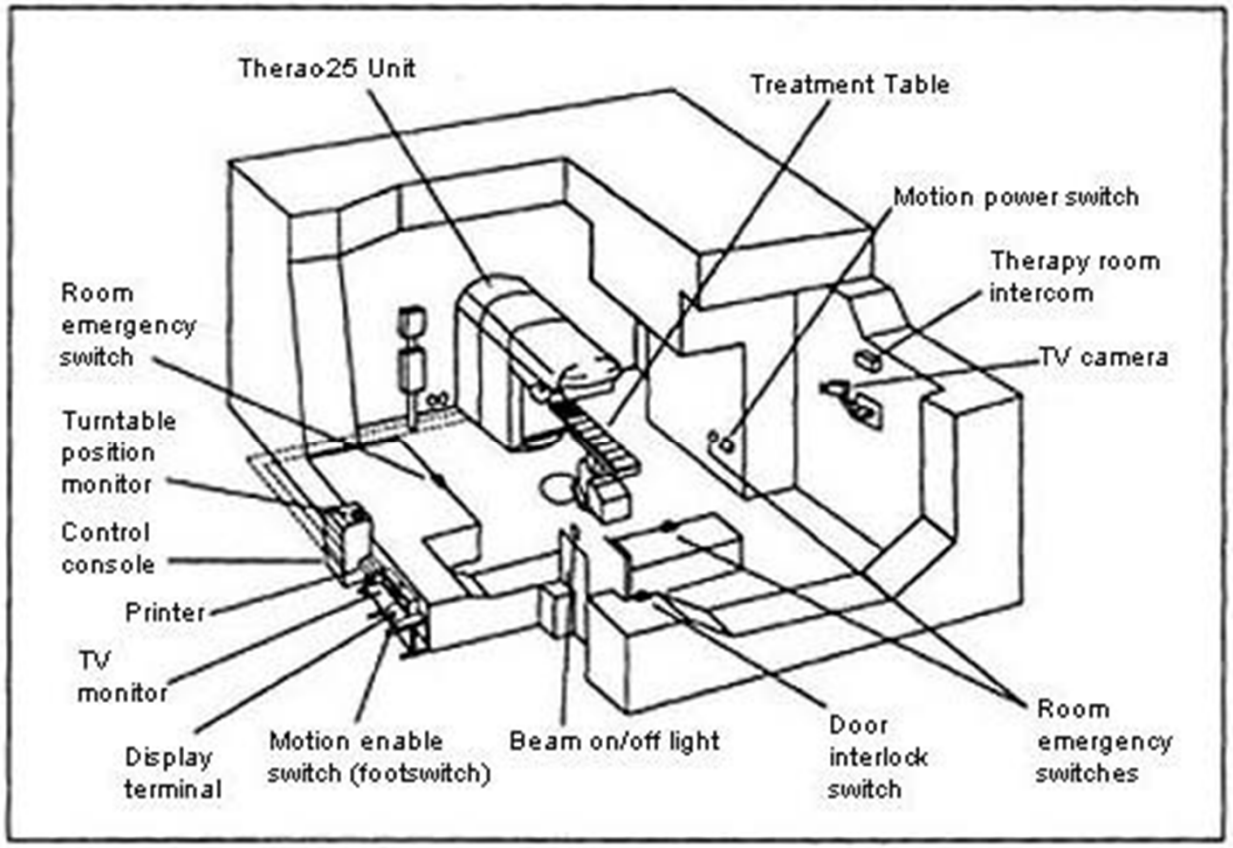


Figure 1. Typical Therac-25 facility

http://computingcases.org/images/therac/therac_facility.jpg

THERAC-25

- Built by AECL (Atomic Energy of Canada Limited)
- Dual-mode machine:
  - Treat using low-energy electron beams.
  - Treat using high-energy X-ray beams.
- Turntable with items for each mode placed on it: rotates to the correct position before a beam is started up.

Sources:
http://computingcases.org/case_materials/therac/supporting_docs/therac_case_narr/Machine_Design.html
http://en.wikipedia.org/wiki/Therac-25

THERAC-25

What happened?

- High-power beam activated instead of the low-power beam.
- High-power beam had approximately 100 times the intended dose of radiation.
- Six accidents between 1985 and 1987.
- Three deaths from radiation poisoning.

Sources:
http://computingcases.org/case_materials/therac/supporting_docs/therac_case_narr/Machine_Design.html
http://en.wikipedia.org/wiki/Therac-25

THERAC-25

Why? Software bugs and user interface issues.

- A one-byte counter frequently "overflowed", or got too big for the memory allocated to it.

  If an operator provided manual input at the same time as the overflow, the interlock would fail.

- Failure only occurred during a nonstandard sequence of keystrokes: this went unnoticed for a long time.

Sources:
http://computingcases.org/case_materials/therac/supporting_docs/therac_case_narr/Machine_Design.html
http://en.wikipedia.org/wiki/Therac-25

THERAC-25

Why? Software bugs and user interface issues.

- Therac-25 did *not* have the hardware interlocks that its predecessors had, to prevent the wrong beam from activating.
- The developers relied on software interlocks, which were incorrectly coded.
- The code reused software from older models, where the hardware interlocks could not report that they were triggered.

Sources:
http://computingcases.org/case_materials/therac/supporting_docs/therac_case_narr/Machine_Design.html
http://en.wikipedia.org/wiki/Therac-25

THERAC-25

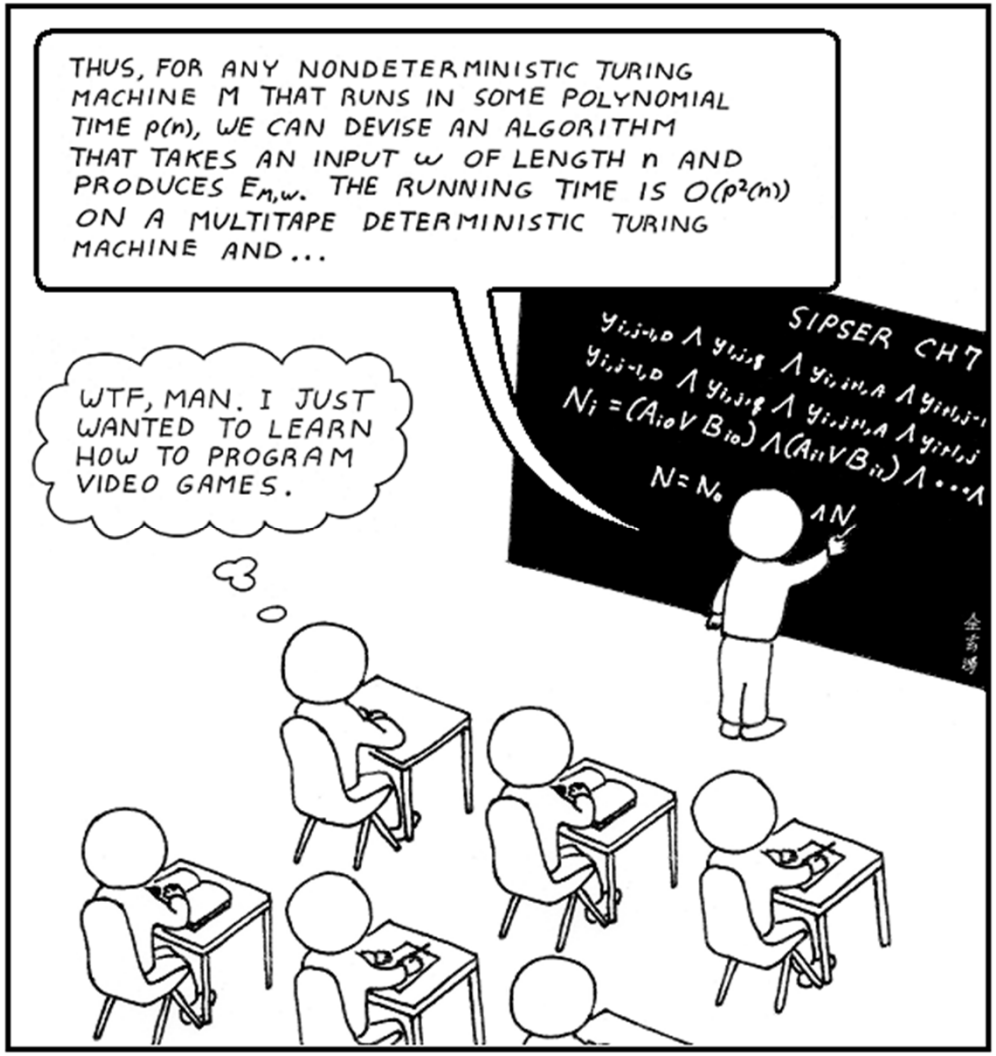
Why? Software bugs and user interface issues.

- The combination of hardware and software was never tested until at the hospital.
- If the system noticed that something was wrong, it would halt the X-ray beam and display the word "MALFUNCTION", followed by an unhelpful error code.

  The operator could override the warning and proceed anyway.
- Complaints were not believed initially.

Sources:
http://computingcases.org/case_materials/therac/supporting_docs/therac_case_narr/Machine_Design.html
http://en.wikipedia.org/wiki/Therac-25

THERAC-25



http://abstrusegoose.com/206

THERAC-25

What can we learn?

- Computers are *everywhere*: this means that the code you write can potentially be used in a life-or-death situation.
- In a complex codebase, software bugs can be *really hard* to catch and fix.
- This can be ameliorated significantly with *proper design* and *frequent testing*.

THERAC-25

What can we learn?

- Test not just the software, but how it interacts with hardware *and even the user*.
- The user is *not your enemy*.
  - A significantly large project will account for many possible erroneous inputs from the user.
  - The user should be provided useful output to understand the cause for error.

CONCLUSION

- MapReduce is a framework that allows programmers to process large amounts of data in parallel, without having to concern themselves with details such as computer failure and task assignment.
- Proper design and test of software is becoming increasingly essential, especially in a world where computing is ubiquitous.