Algorithms is "Cool"

NUS National University of Singapore
School of Computing

- Where do we use Algorithms
- Analysis of Algorithms & Why it is important
- Sample Computational Problems

Why Algorithm is Cool:

Algorithms is Anywhere & Everywhere.

Where do we need algorithms?

- **Design the next generation CPU/GPU chip**
  - ***how to design optimally (w.r.t. speed, power, area)***
- **Internet (WWW)**
  - ***how to manage, manipulate large volume of data***
- **e-Commerce**
  - ***how to manage transaction (secure, private)***
- **Logistics**
  - ***how to manage transport/transfer of goods, people***
- **Human Genome Project**
  - ***how to analyze huge volume of DNA/protein data***

Motivation (Why algorithms?)

- **Where do we use Algorithms?**
  - **Computer Science, Engineering**
  - **Business, Operations Research**
  - **Finance, Social Sciences, … , Everywhere**
- **Why is Performance Important?**
  - **Exponential-size solution space**
  - **NP-completeness**
- **Problem Size Explosion**
  - **Computer Chip Complexity,**
  - **Database Sizes,**
  - **Human Genome Project, WWW (Google),**

Analysis of algorithms

The theoretical study of program performance and resource usage.

How long does the program run?

* ***Speed / performance***

How much resources does the program use?

* ***Memory/disk space, custom devices,***

Other aspects of software

What are the important aspects of software?

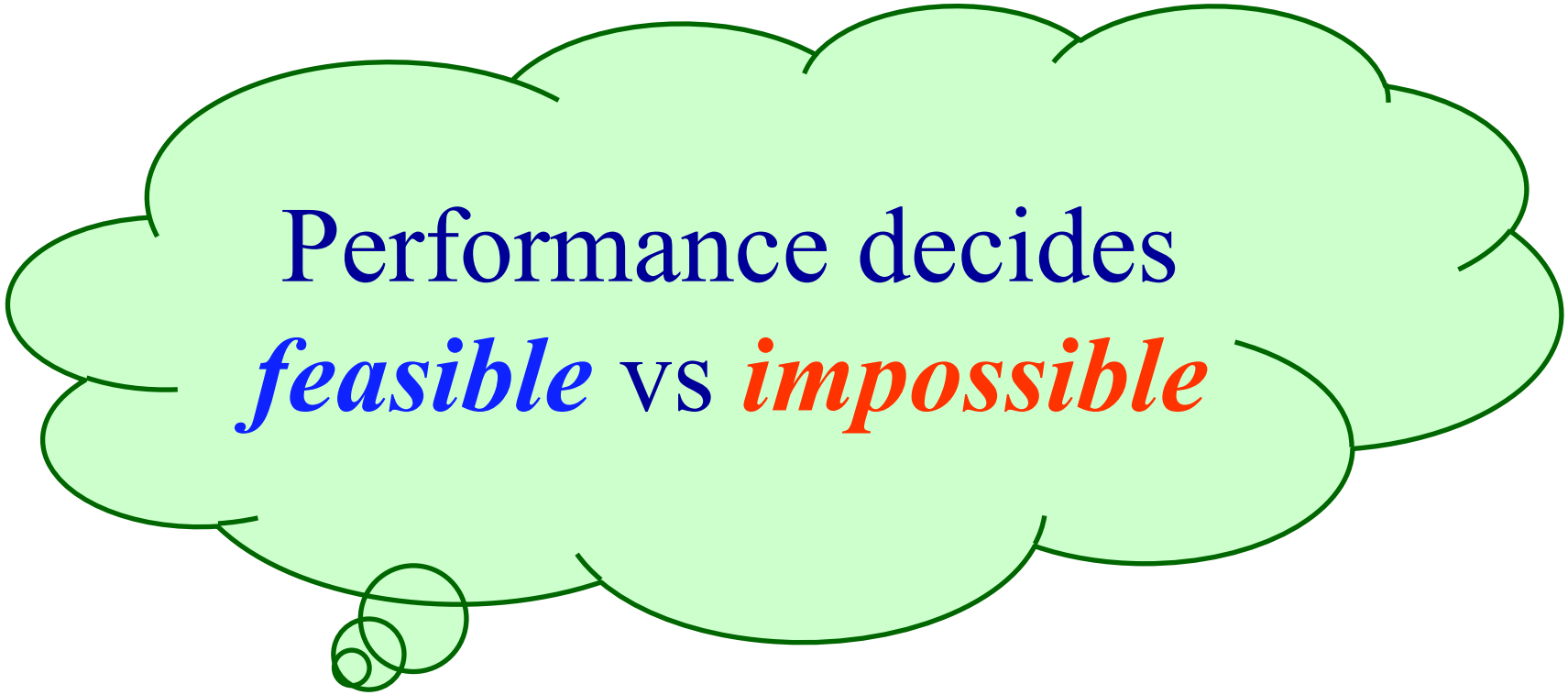
- modularity
- correctness
- maintainability
- functionality
- robustness
- user-friendliness
- programmer time
- simplicity
- extensibility
- reliability

But often, speed / performance is the crucial factor.

Why study algorithms and performance?

- Algorithms help us to understand ***scalability***.
- Performance often draws the line between what is ***feasible*** and what is ***impossible***.
- Performance is the ***currency*** of computing.
- The lessons of program performance ***generalize*** to other computing resources.
- Speed is ***fun***!

Why study program performance?



Q: Can we trust the CPUs in our laptop / iPad / Apple Watch?

Is the MULT(*) operation correct?

Your laptop / iPad / Apple Watch
all have a CPU inside.

The CPU has a MULT operation (*)

1994, Pentium FDIV bug

Pentium FDIV bug

From Wikipedia, the free encyclopedia

The **Pentium FDIV bug** was a computer bug that affected the floating point unit (FPU) of the early Intel Pentium processors. Because of the bug, the processor could return incorrect binary floating point results when dividing a number. Discovered in 1994 by Professor Thomas R. Nicely at Lynchburg College,[1] Intel attributed the error to missing entries in the lookup table used by the floating-point division circuitry.[2]

66 MHz Intel Pentium (sSpec=SX837) with the FDIV bug

The severity of the FDIV bug is debated. Intel, producer of the affected chip, claims that the common user would experience it once every 27,000 years while IBM, manufacturer of a chip competing with Intel's Pentium, claims that the common user would experience it once every 24 days. Though rarely encountered by most users (*Byte* magazine estimated that 1 in 9 billion floating point divides with random parameters would produce inaccurate results),[3] both the flaw and Intel's initial handling of the matter were heavily criticized by the tech community. The man who

https://en.wikipedia.org/wiki/Pentium_FDIV_bug

What if we don't true the CPU?

Q: Can we trust the CPUs in our laptop / iPad / Apple Watch?

Testing the * operation in a CPU

Q: How to test that the "*" operation of your CPU is correct?

A: Check exhaustively. For all a, b
Check $a * b = c$

Q: How long will it take?

A: Any guesses?

Testing the * operation in a CPU

Q: How long will it take?

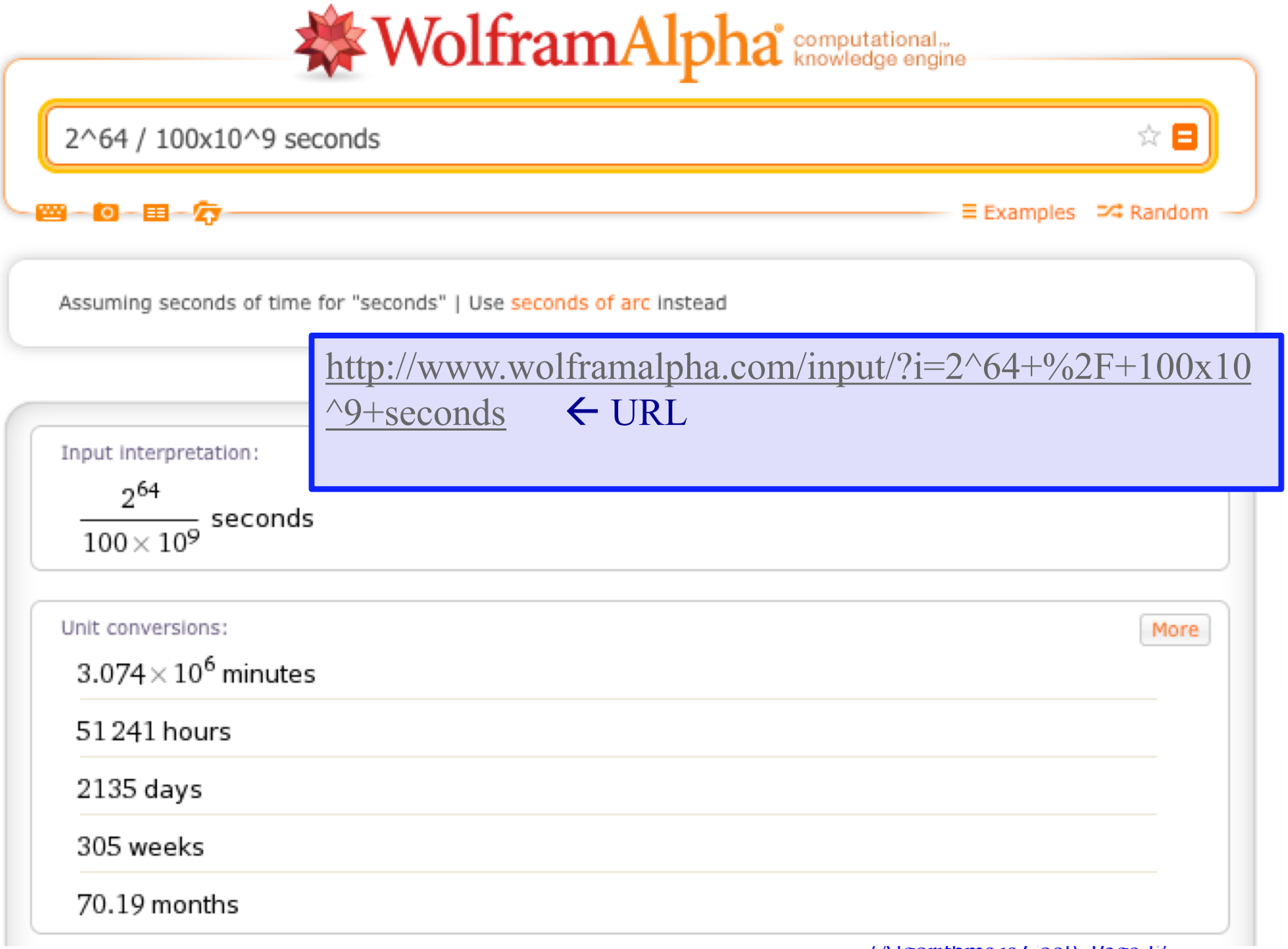
This is very fast.
(most laptops ~3G-Flop)

Assume we use a 100G-Flop CPU
can do 100B operations per sec.

a is a 32-bit number (2^{32} cases)
b is a 32-bit number (2^{32} cases)

So, $(a * b)$ there are (2^{64} cases)

Time taken = $(2^{64} / 100 \times 10^9)$ sec



Testing * operation in a CPU

Q: How long will it take?

Assume we use a 100G-Flop machine can take 100B operations per sec.

a is a 32-bit number $(2^{32}$ cases)

b is a 32-bit number $(2^{32}$ cases)

So, $(a * b)$ there are $(2^{64}$ cases)

Time taken = $(2^{64} / 100 \times 10^9)$ sec

≈ 6 years!

Summary

Testing * operation in a CPU

Q: If we use $O(n^2)$ algorithm?

≈ 6 years!

Impossible.
Not practical

Why study program performance?

The task is seemingly
impossible

Q: What can we do?

A: Of course,
better algorithm.

Testing * operation in a CPU

Q: What if we have (n lg n) algorithm?

Assume we use a 100G-Flop machine can do 100B operations per sec.

a is a 32-bit number (2^{32} cases)
b is a 32-bit number (2^{32} cases)

When $n = 2^{32}$, with (n lg n) algorithm

Time taken = (2^{32} * 32 / 100x10^9) sec

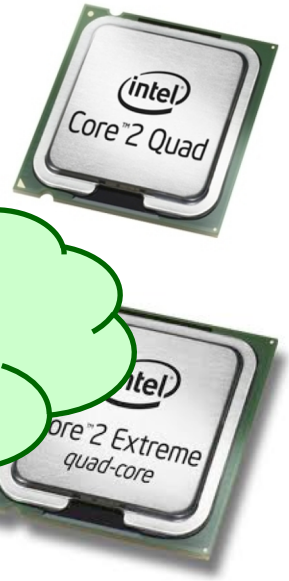
< 2 sec!

Good algorithm makes BIG difference

Testing * operation in a CPU

Q: If we use $O(n^2)$ algorithm?

≈ 6 years!



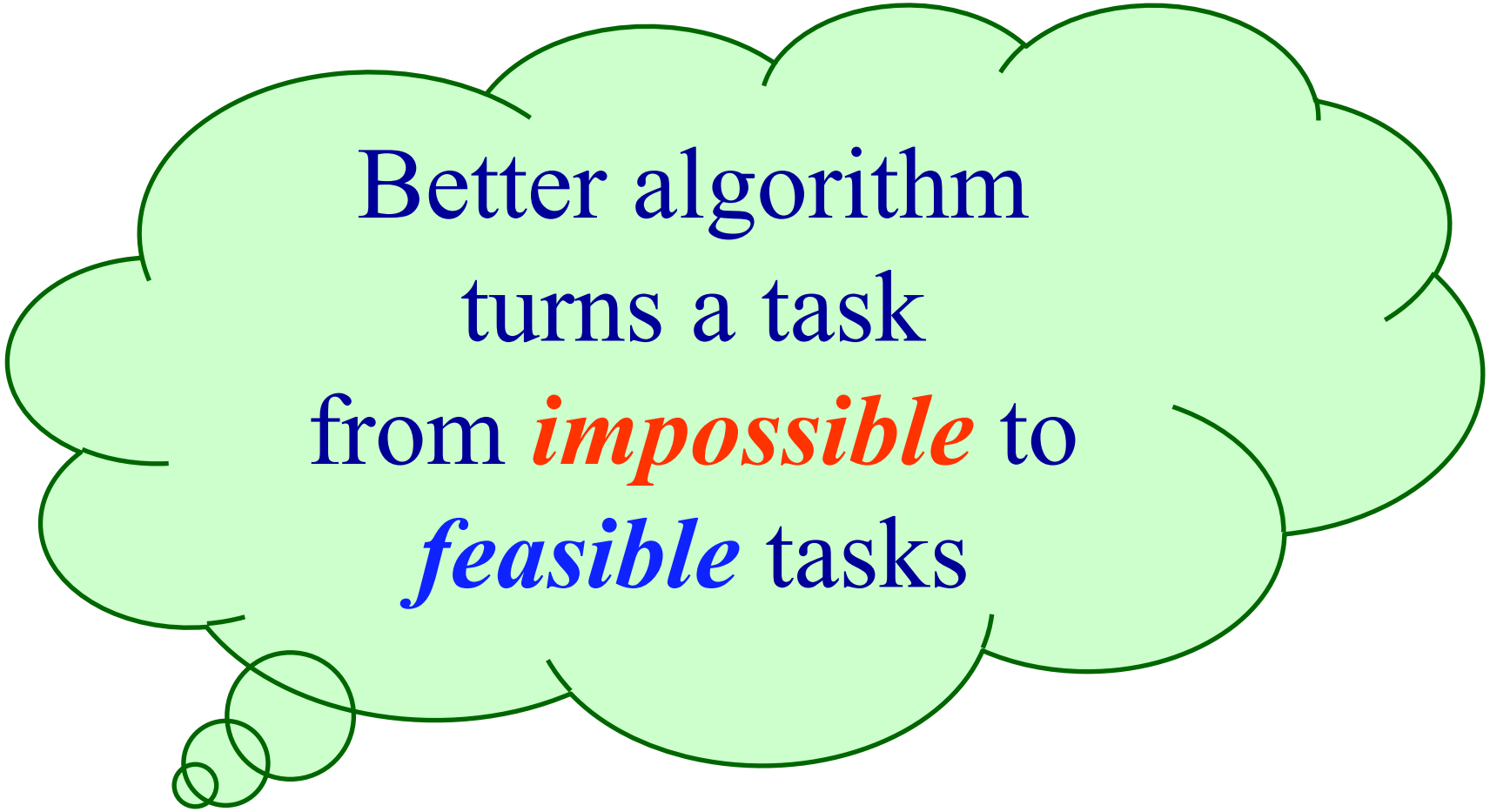
Impossible. Not practical

Q: If we use $O(n \lg n)$ algorithm?

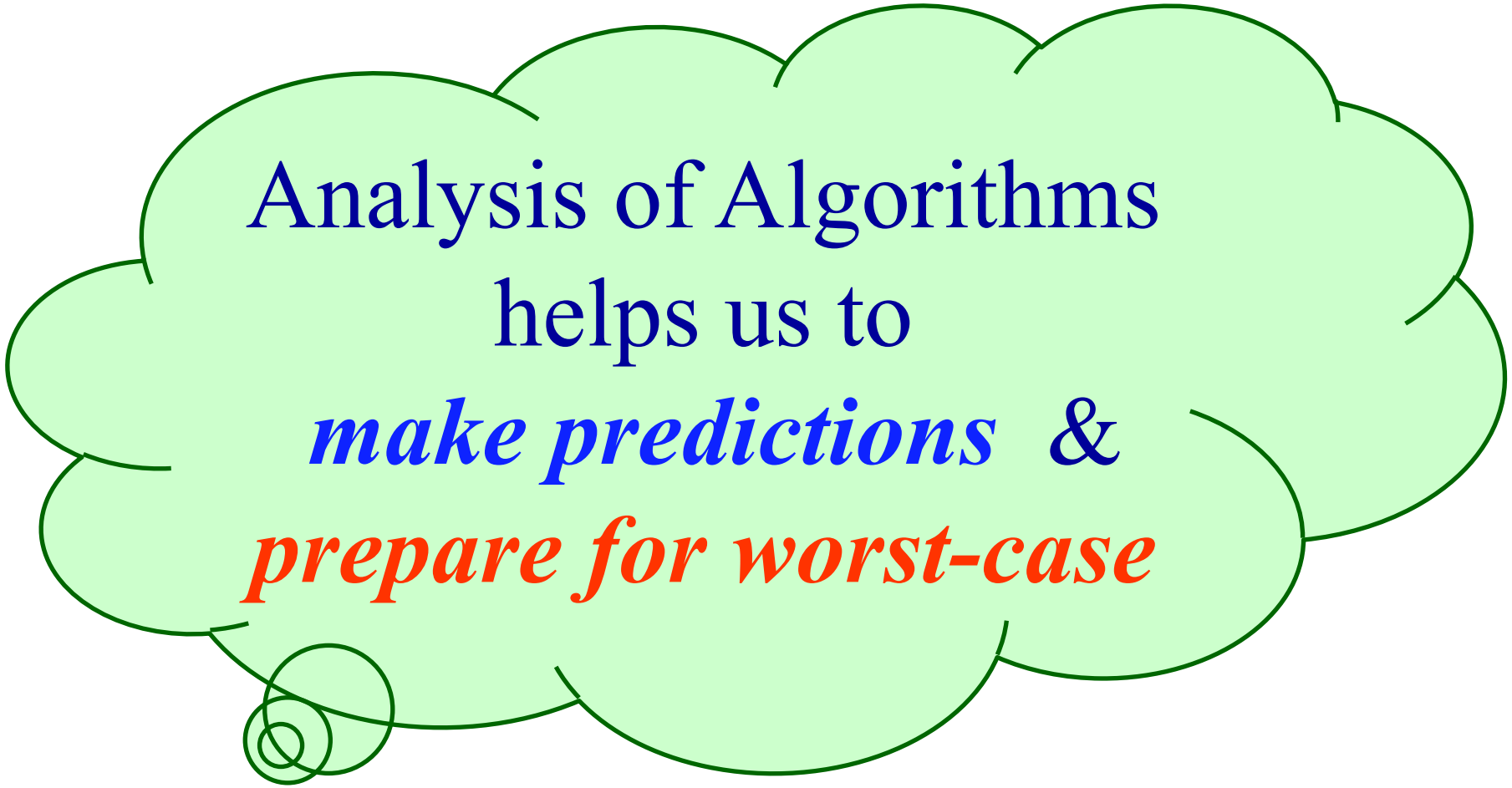
< 2 sec!

Fast & Practical

Conclusion 1:



Another Story…



Application in Web-Service

Suppose you code up a new web-service – *CoolApp*

- you debugged your code, and after some time.
- you got it *working*, you *tested it* a little bit
- it is quite fast.

Can you release *CoolApp*?
Will it work? Or will it bomb?

If dream come true & *CoolApp*'s wildly popular?
How fast is "quite fast", will server die? When?

Making predictions, for worst-case

Your app is ***quite fast***…

One operation takes 0.02sec ("***quite fast***")

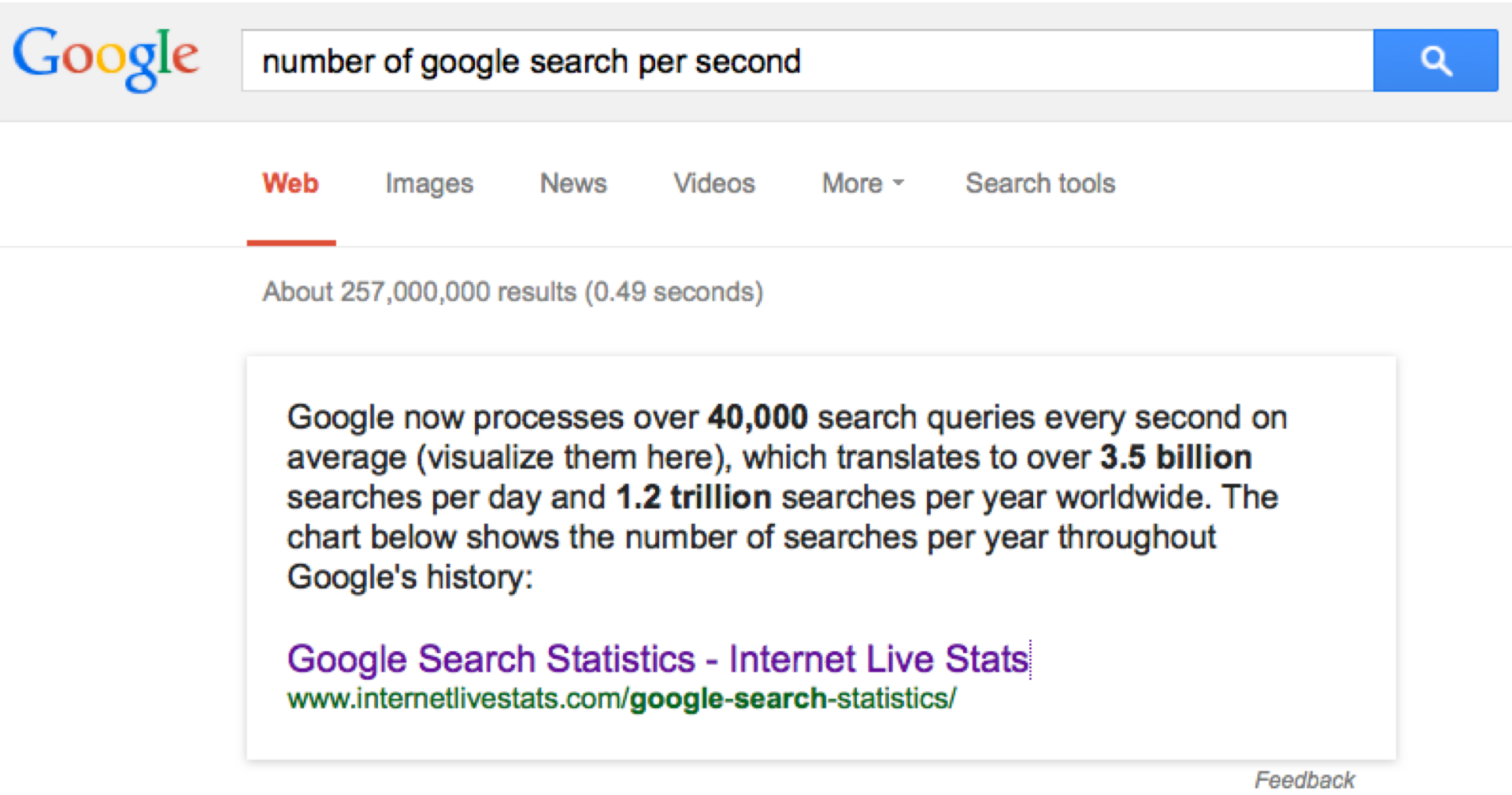
But is it fast ***enough***?

10,000 clicks/sec will take 3min
40,000 clicks/sec will take 12min

Too long to wait.
App is *NOT Cool.*

Q: How big a load, before server dies?

40,000 clicks per seconds (July 2015)



Story of Algorithms in Action

Credit card processing centre in SG (Sci Park):

- monitors showing servers load for diff. countries,
- Blue, Green, Yellow, Orange (send SMS alert),
  RED (URGENT Alert! ➔ deploy more servers!)

Note: ***Picture is NOT the real thing.***
But it gives the rough idea
and "demos" my point.

Note to Self:
Picture is NOT very good.
Will find a better one.

This is simple case (linear)

- **We had assume algorithm is linear**
  - **Running time is $O(n)$, n is size of problem**
- **Why if algorithm is quadratic: $O(n^2)$?**
  - **OK, when $n = 10^5$;**
  - **Slow when n is in the millions**
- **Why if algorithm is exponential: $O(2^n)$?**
  - **Impossibly slow, even small n, like $n = 100$.**

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How to make Algorithms relevant, interesting, FUN?

- **Learn and *really* understand algorithms**
- **Reflect and relate lessons learnt**
  - To the bigger picture of your **major/job**
  - To so**ftware development / app development**
  - To things **in your everyday life**

- How much does a Google Search cost?

Thank you.

Q & A