Smith College
Computer Science

CSC103 How Computers Work

Week 5 — Fall 2017

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Outline

- The von Neumann Bottleneck
- Is Moore's Law dead?

SECTIONS HOME SEARCH

The New York Times

TECHNOLOGY

The Von Neumann model, named after the mathematican John von Neumman has been the template for computing for six decades. It has a processor at the center, surrounded by memory and storage, and it is the basis of computing today. But the "Von Neumann bottleneck" describes the slowdown in performance that comes from that approach, with the processor tightly managing data input and output.

"We're going to have to move from processor-centric computing to data and memory-centric computing with processors sprinkled in it," Mr. Kelly said.

Bits

Bits

Business, Innovation,

Big Data, Speed and the Future of Computing

BY STEVE LOHR OCTOBER 31, 2011 11:24 AM 2

Big data is, yes, about more data — the rising flood from corporate databases, Web browsing trails, sensors and social network communications. But it is just as much about speed.

https://bits.blogs.nytimes.com/2011/10/31/big-data-speed-and-the-future-of-computing/?mcubz=3

From Computer Desktop Encyclopedia
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The von Neumann Bottleneck

John von Neumann

Wikipedia

- 1903-1957
- Hungarian-American
- mathematician, physicist, inventor, computer scientist
- worked on Manhattan Project during WWII
- While at U. Penn., 1945, writes First Draft of a Report on the EDVAC

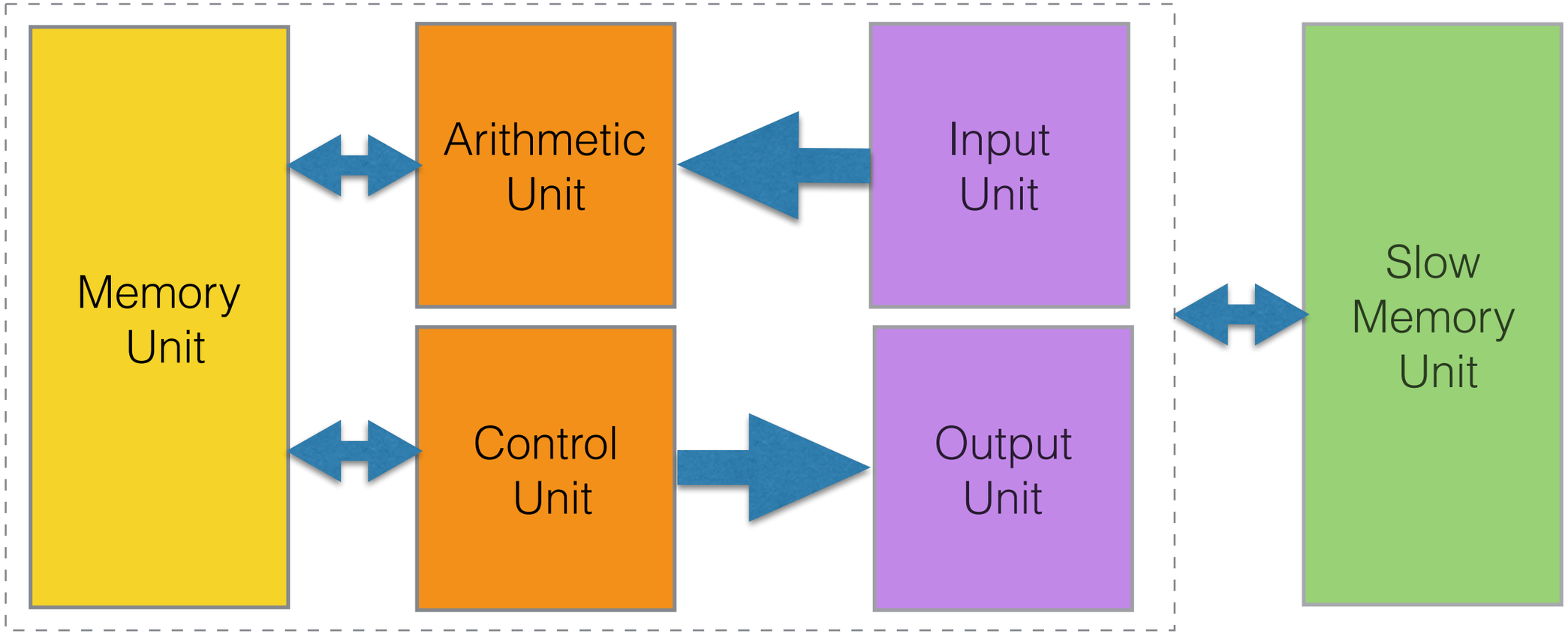
https://en.wikipedia.org/wiki/John_von_Neumann#/media/File:JohnvonNeumann-LosAlamos.gif

Report on the Edvac

Wikipedia

- Detailed the design of a "very high speed automatic digital computing system."

- Proposes an architecture for a computer:

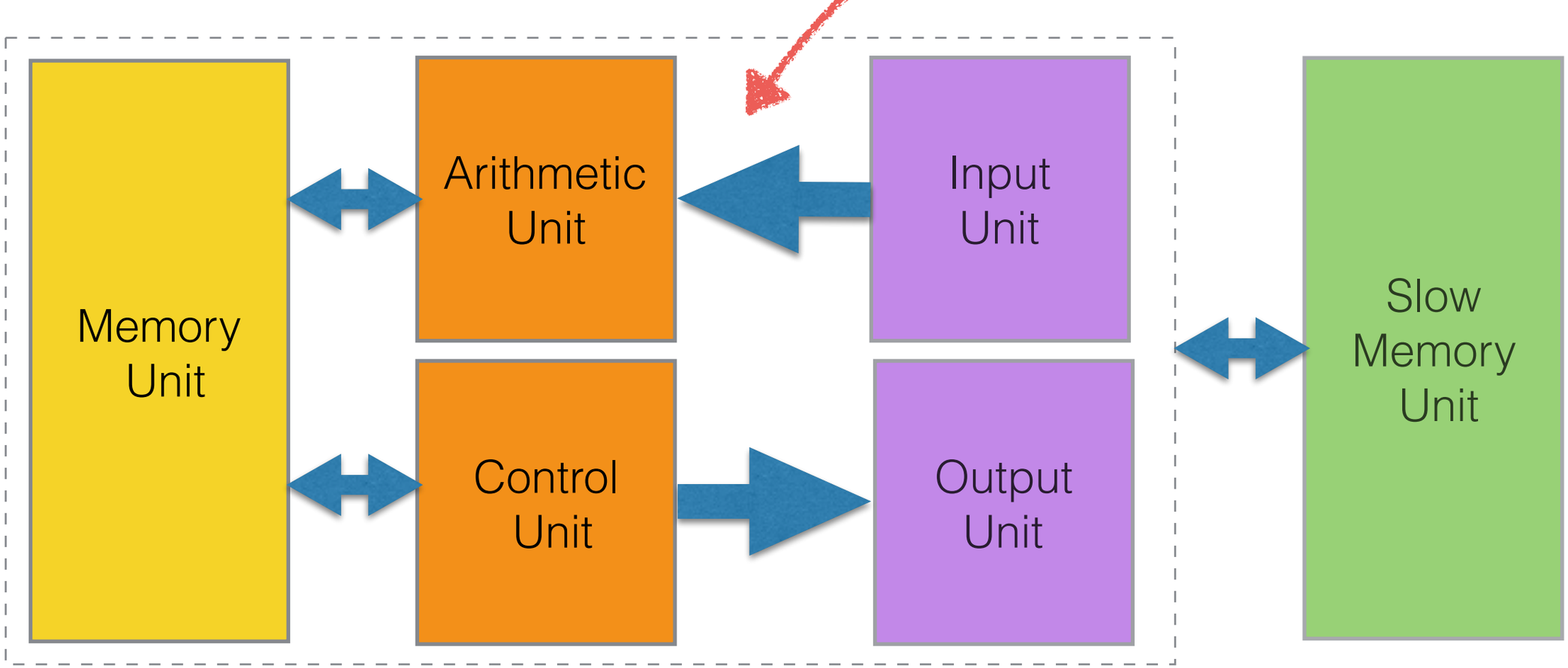


Report on the Edvac

Wikipedia

- Detailed the design of a "very high speed automatic digital computing system."
- Proposes an architecture for a computer:

Operates in Binary

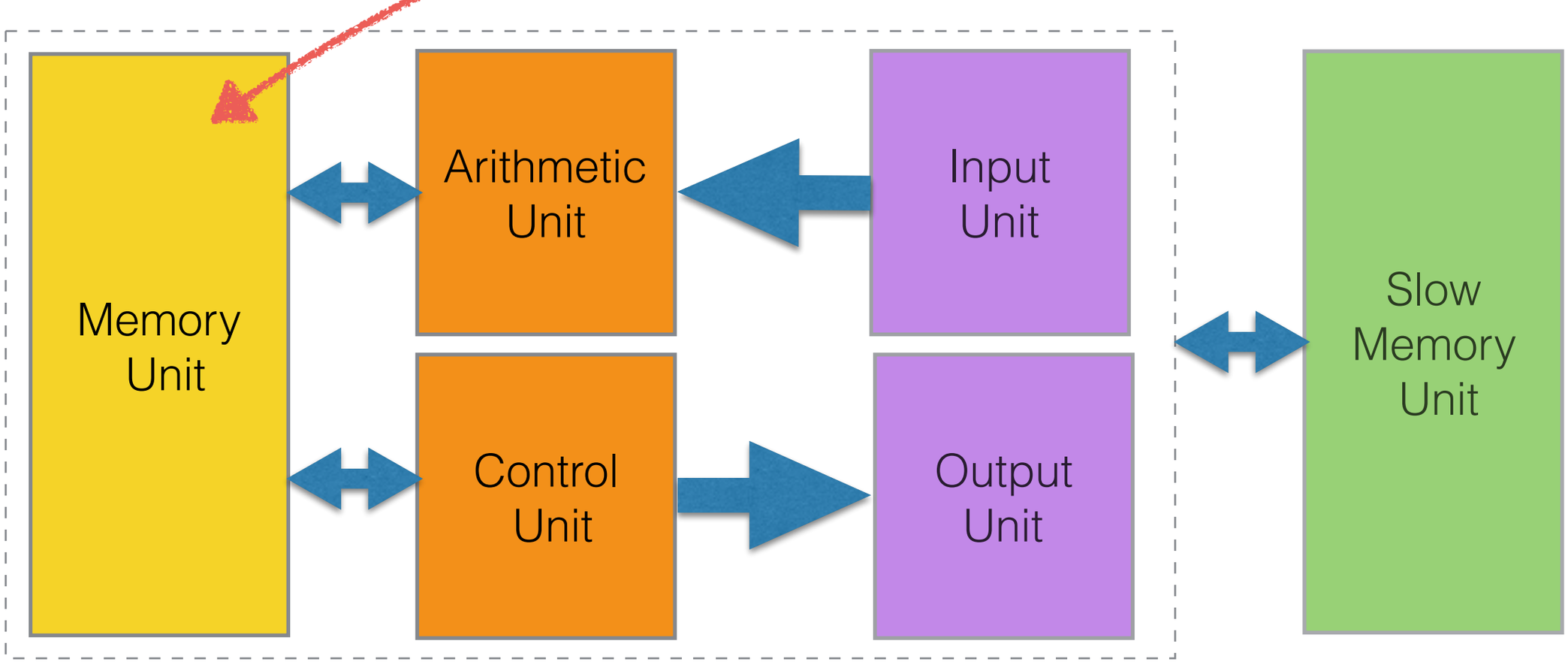


Report on the Edvac

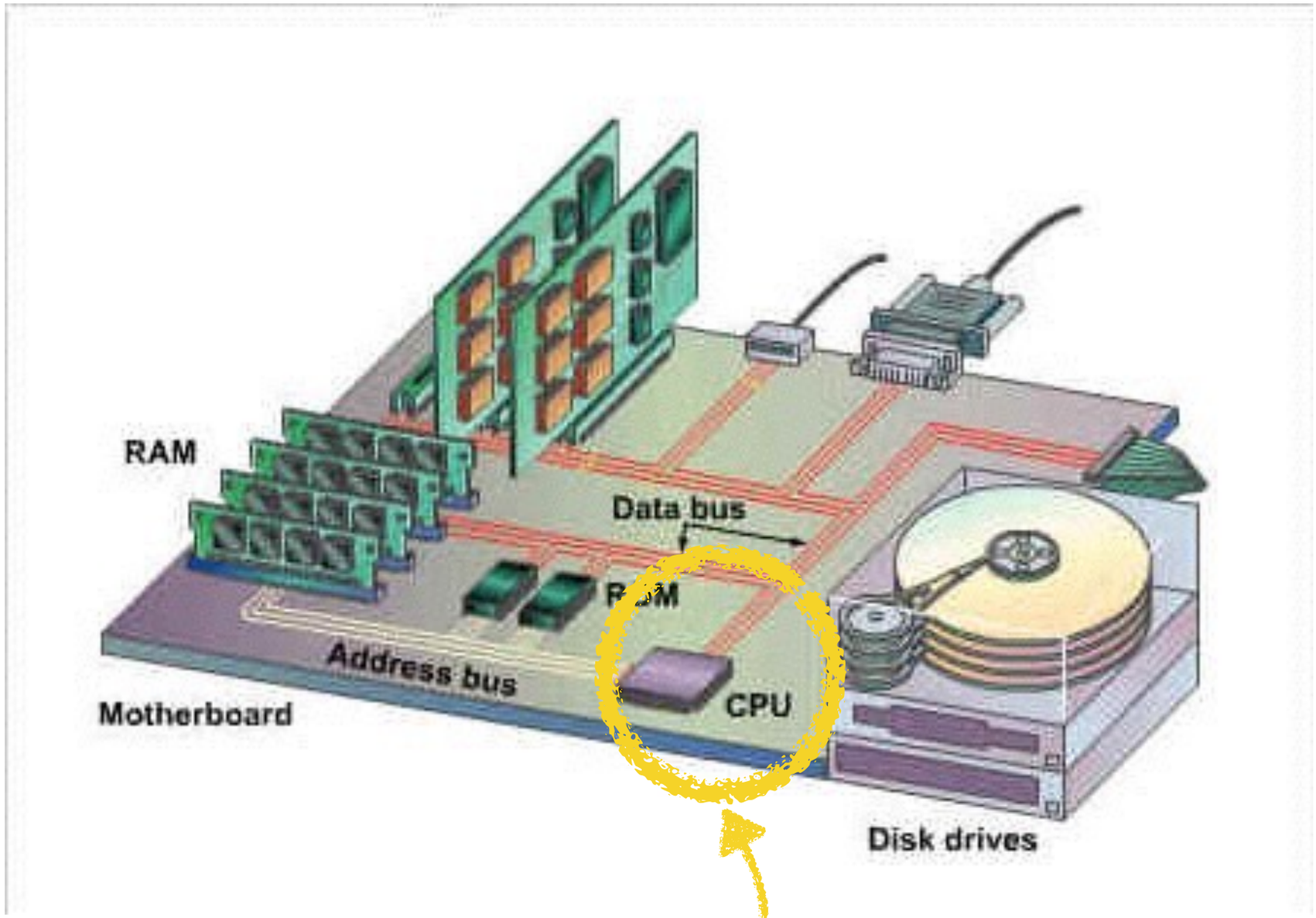
Wikipedia

- Detailed the design of a "very high speed automatic digital computing system."
- Proposes an architecture for a computer:

Contains Code and Data



Today's Computer



Arithmetic & Control Units

photo credits: http://www.alf.sd83.bc.ca/courses/it11/images/proces7.jpg

Today's Computer

Memory

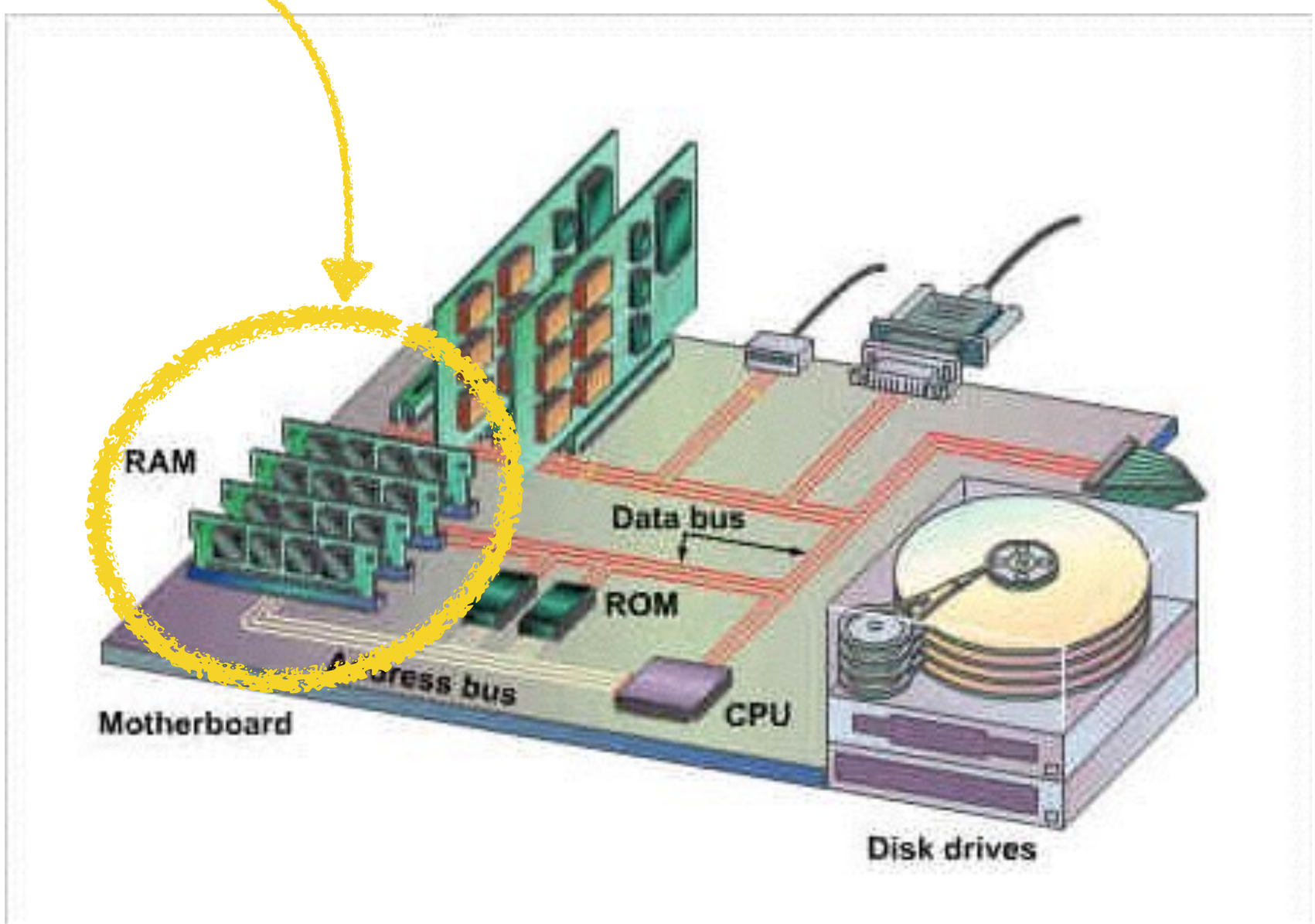


photo credits: http://www.alf.sd83.bc.ca/courses/it11/images/proces7.jpg

Today's Computer

Input/Output Devices (I/O)

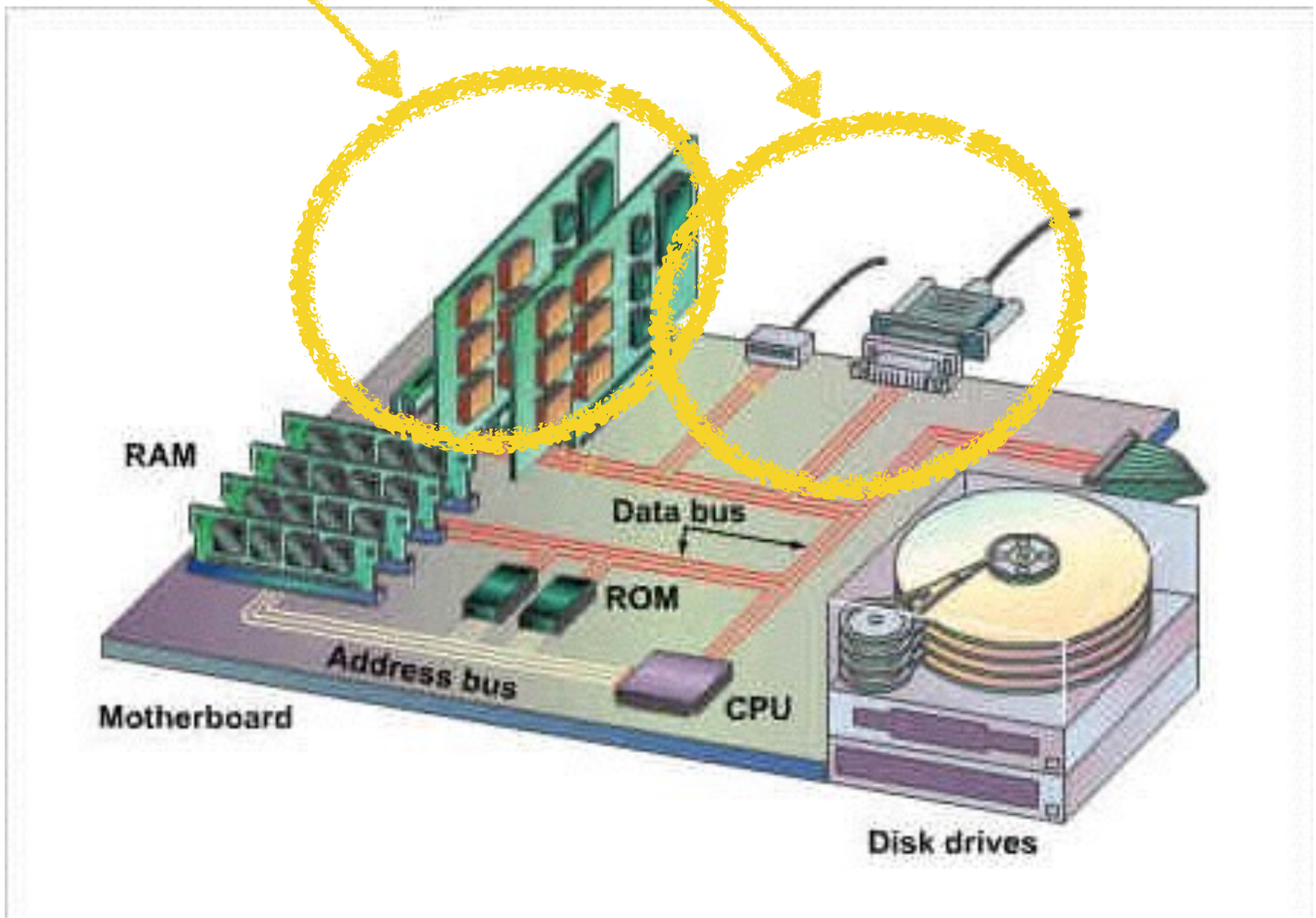


photo credits: http://www.alf.sd83.bc.ca/courses/it11/images/proces7.jpg

Today's Computer

Slow Memory

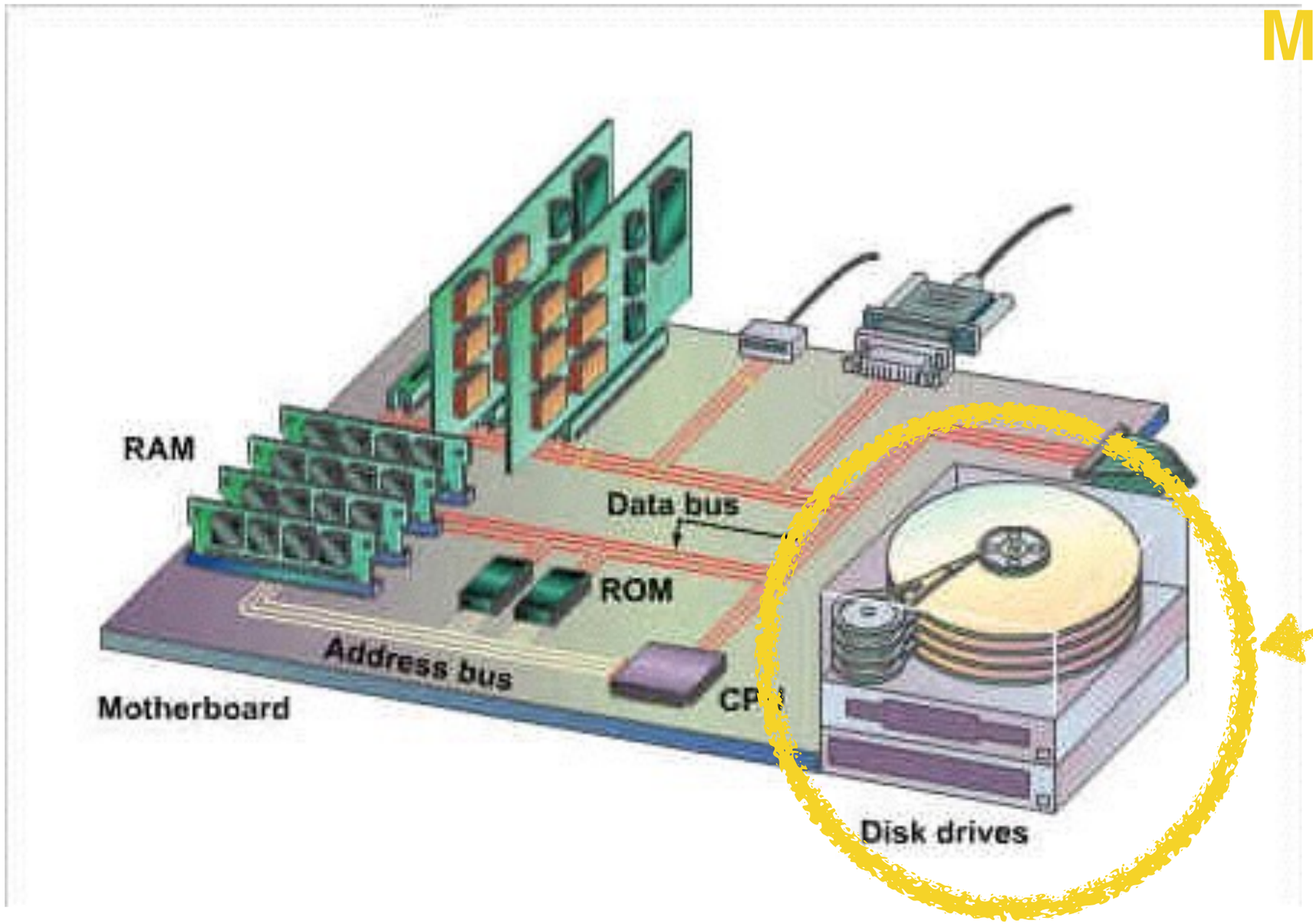
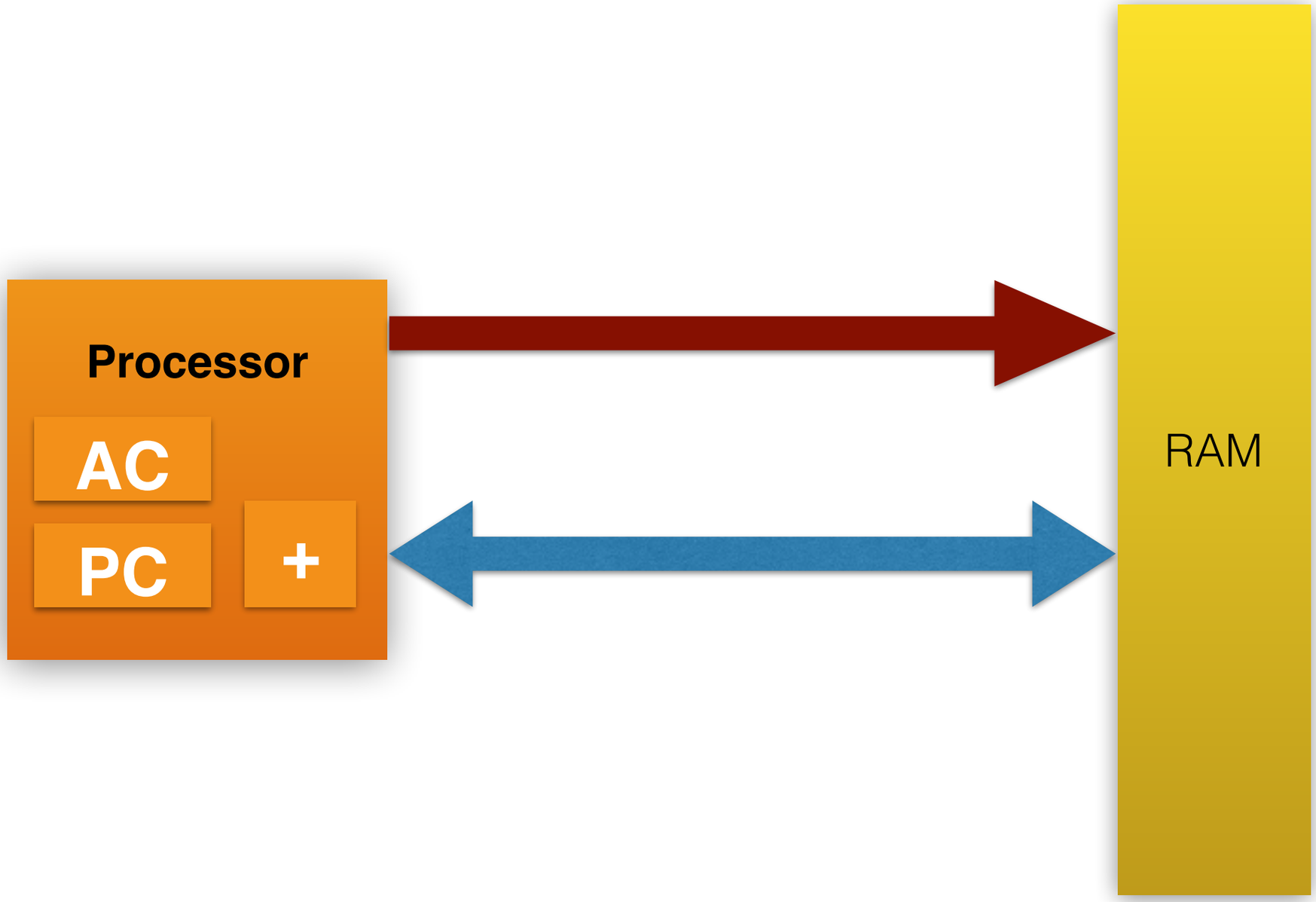


photo credits: http://www.alf.sd83.bc.ca/courses/it11/images/proces7.jpg

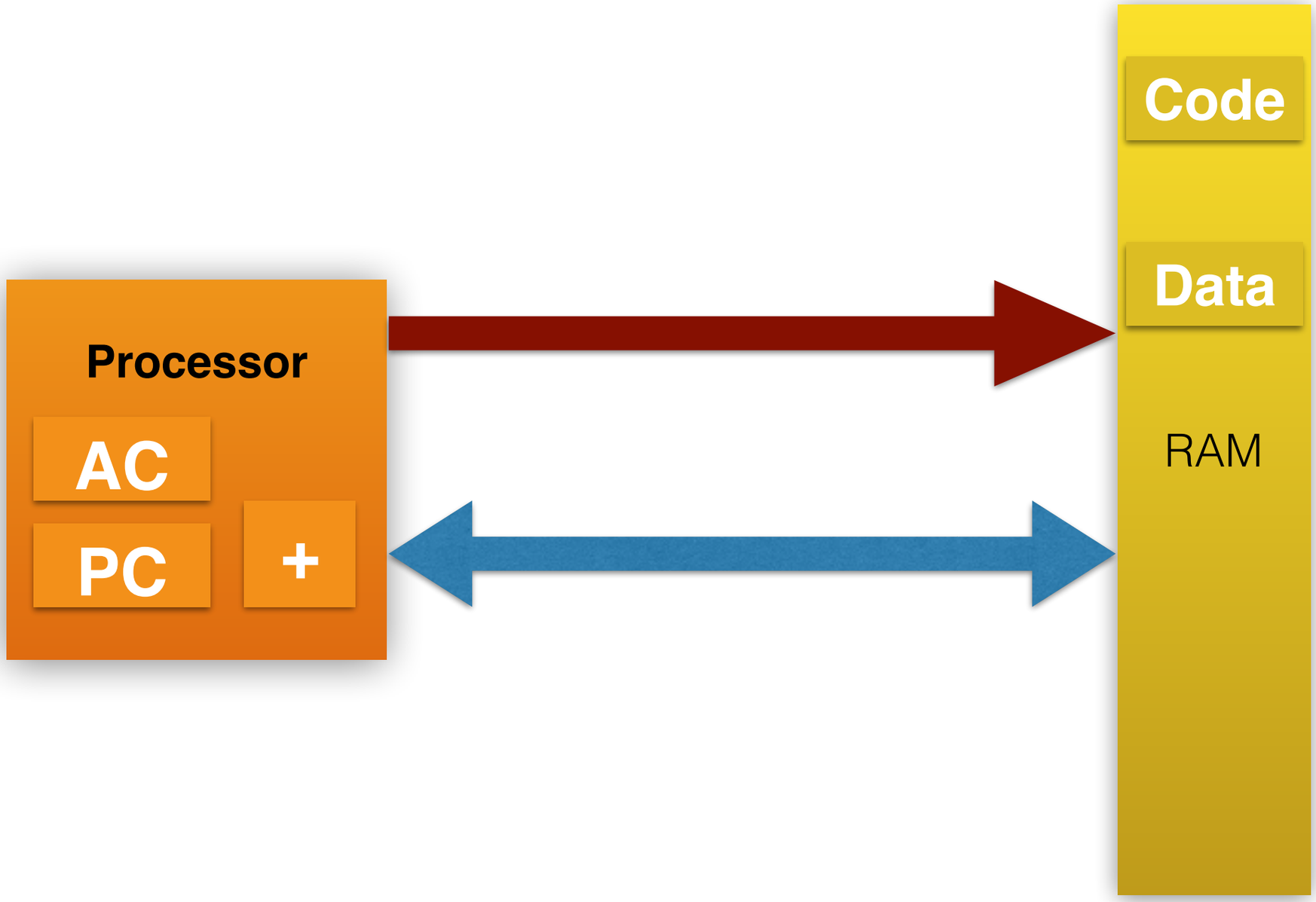
Phone Motherboard

Photo credits: http://www.ebay.com/itm/like/232112848518?chn=ps&dispItem=1

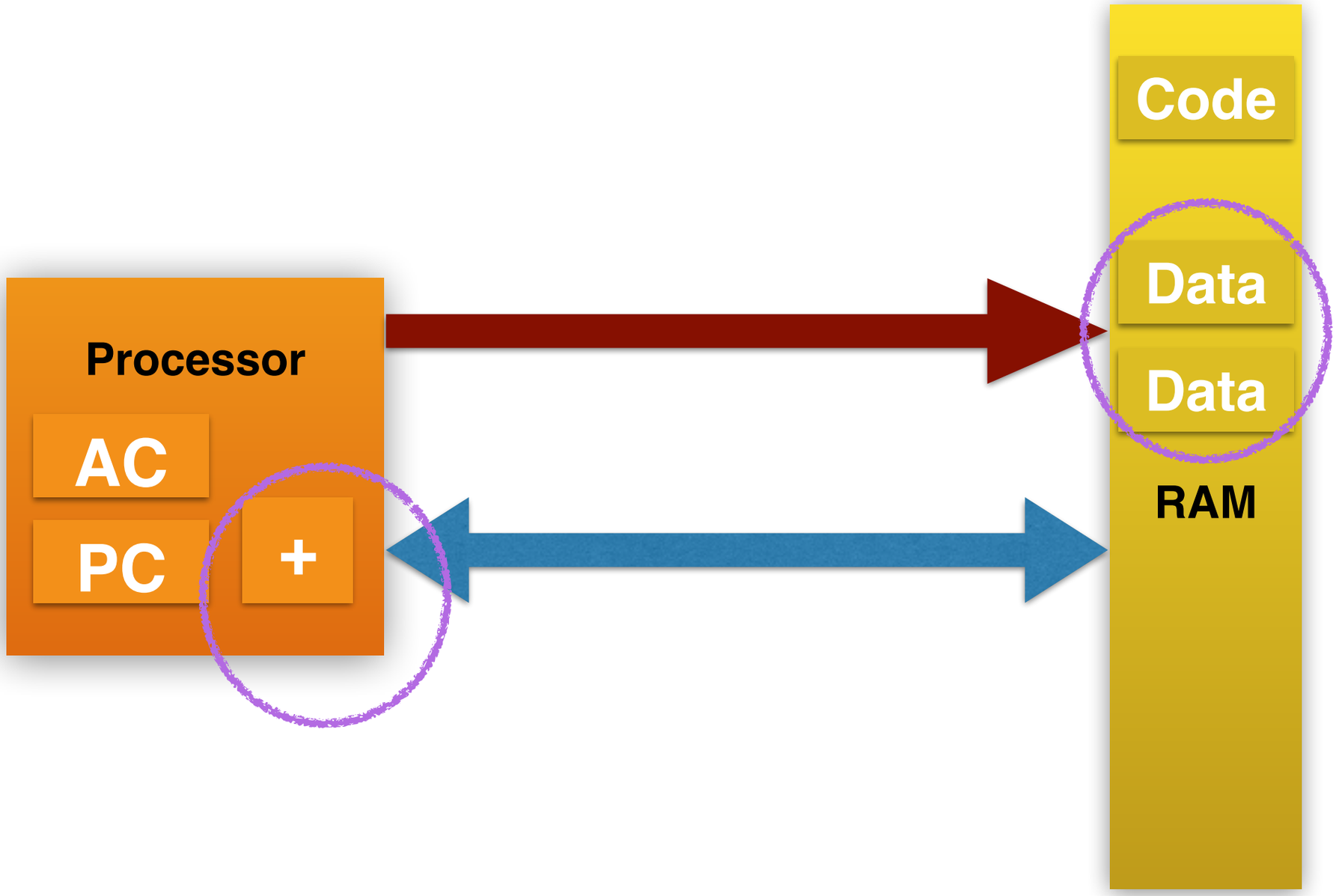
Modern Computer Architecture



Modern Computer Architecture
First Bottleneck

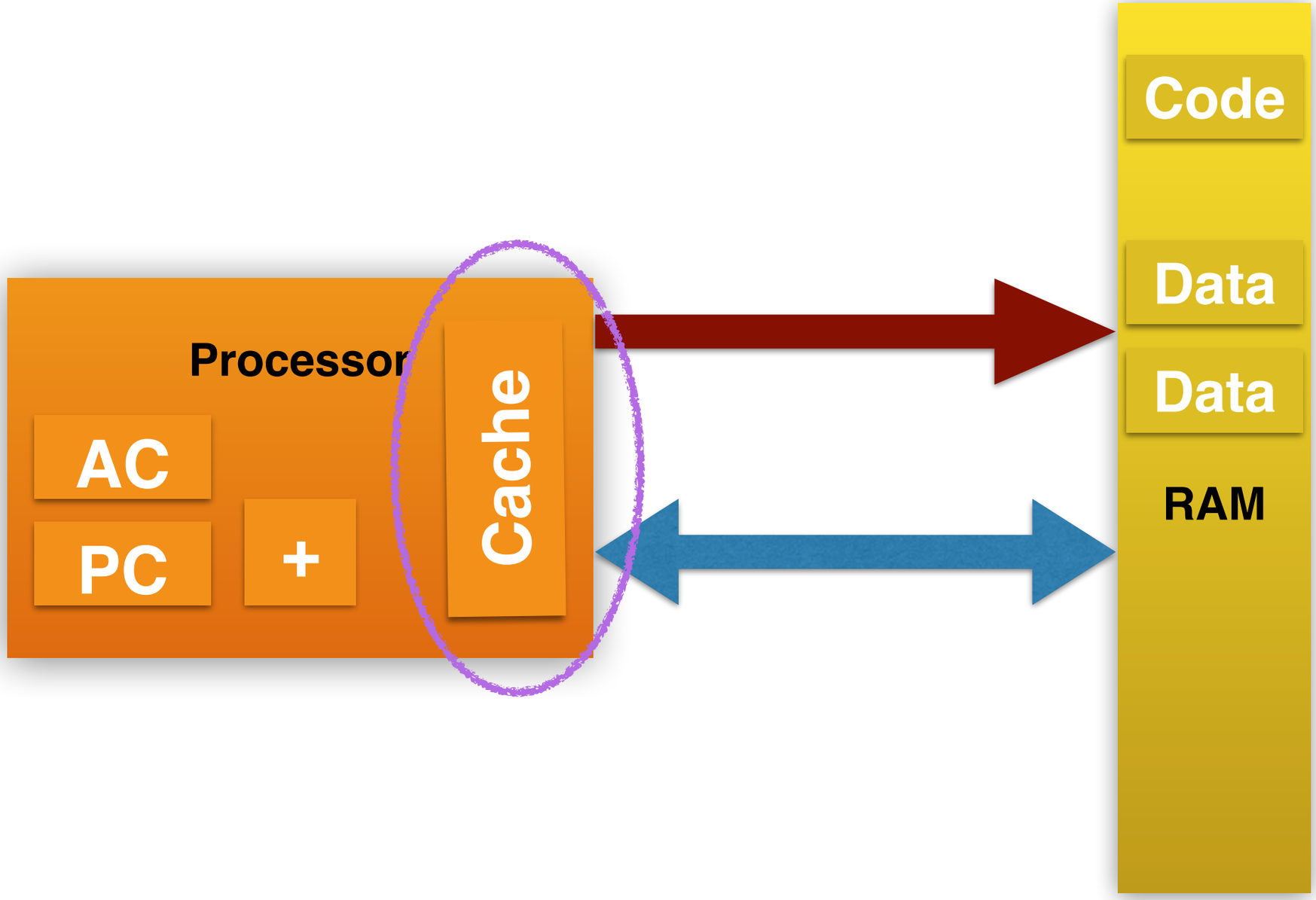


Modern Computer Architecture
Second Bottleneck

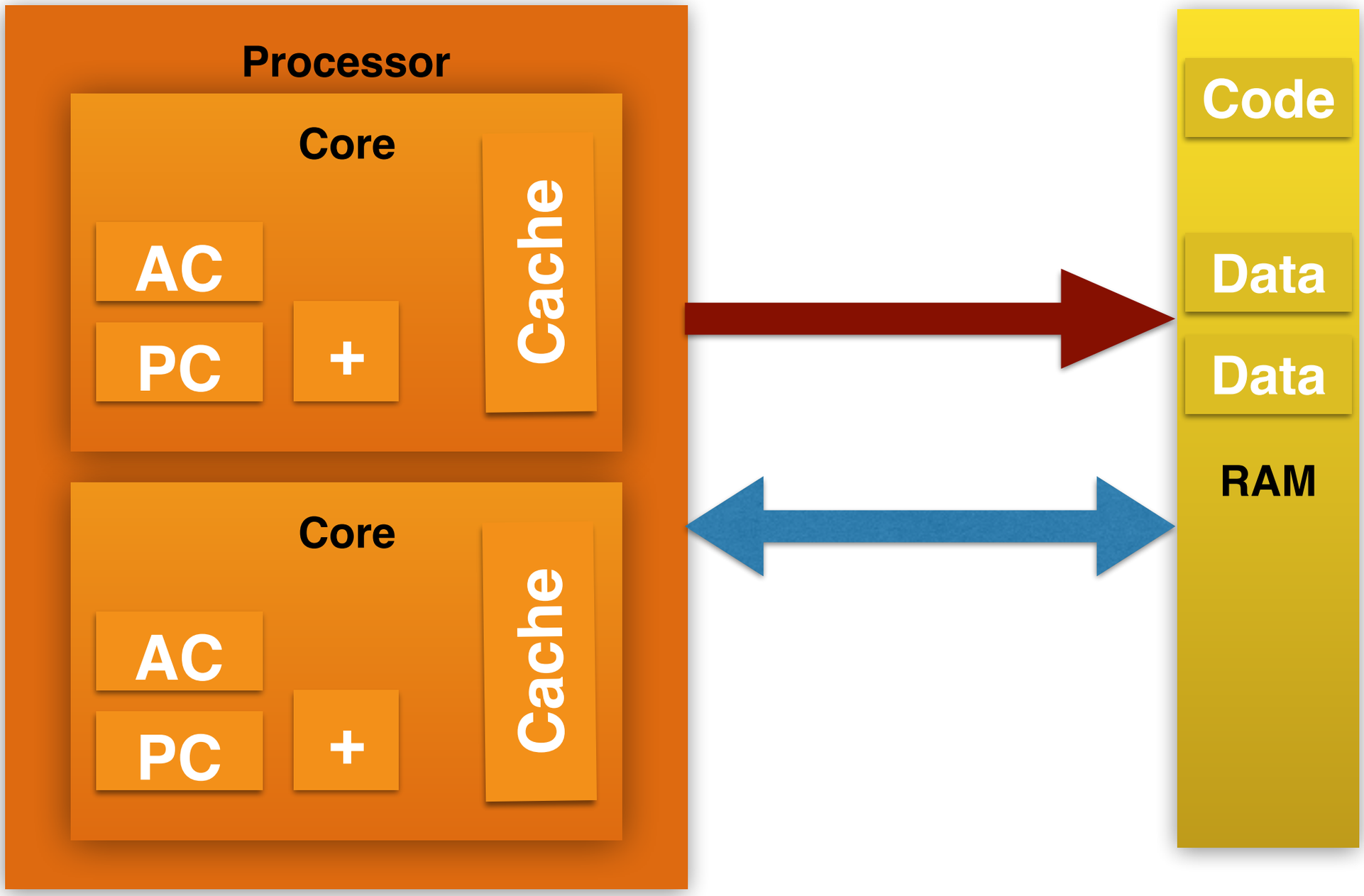


Modern Computer Architecture
Third Bottleneck

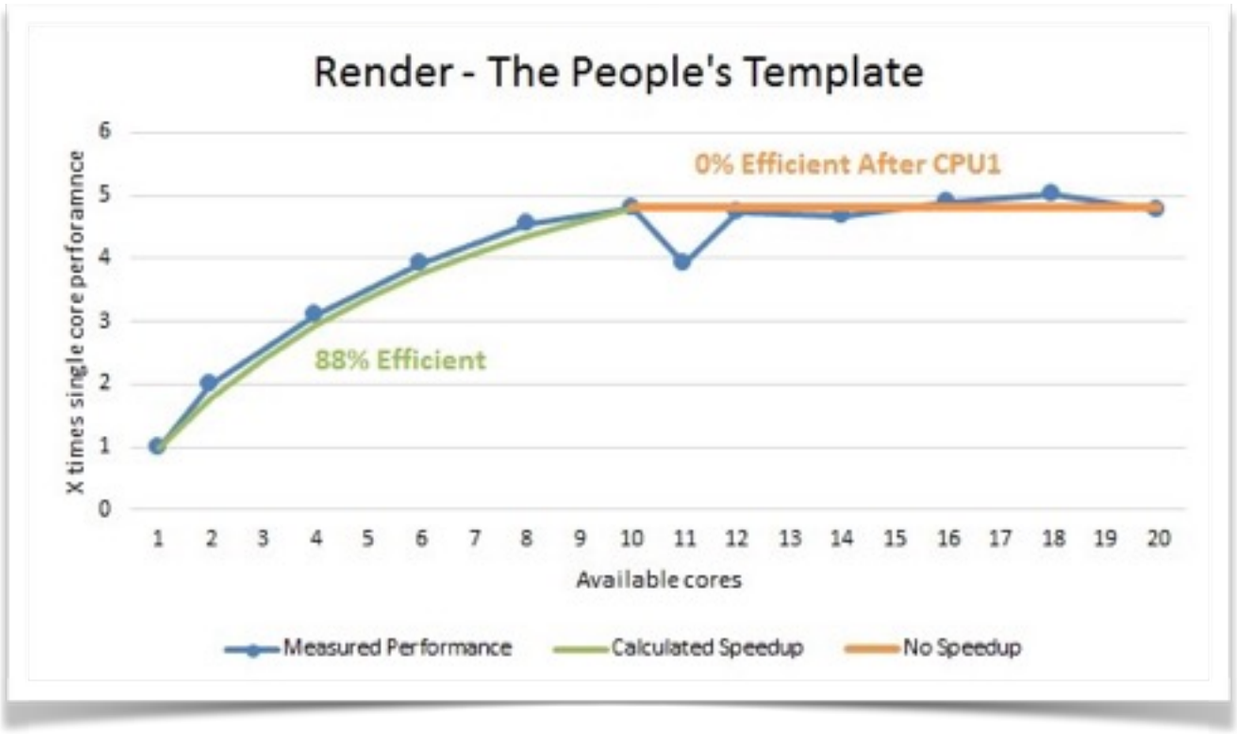
Modern Computer Architecture
A Solution to Bottleneck



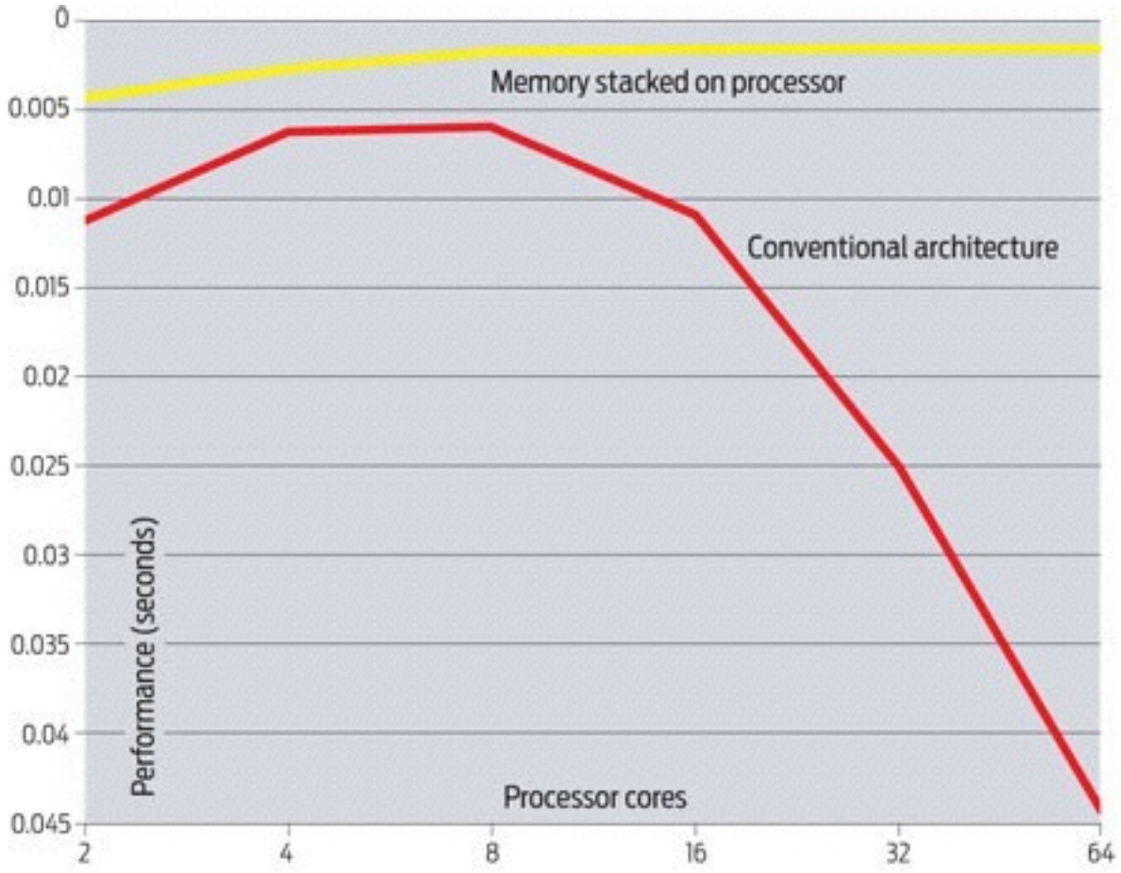
Modern Computer Architecture
Another Solution to Bottleneck



Performance of Multi-Core Systems

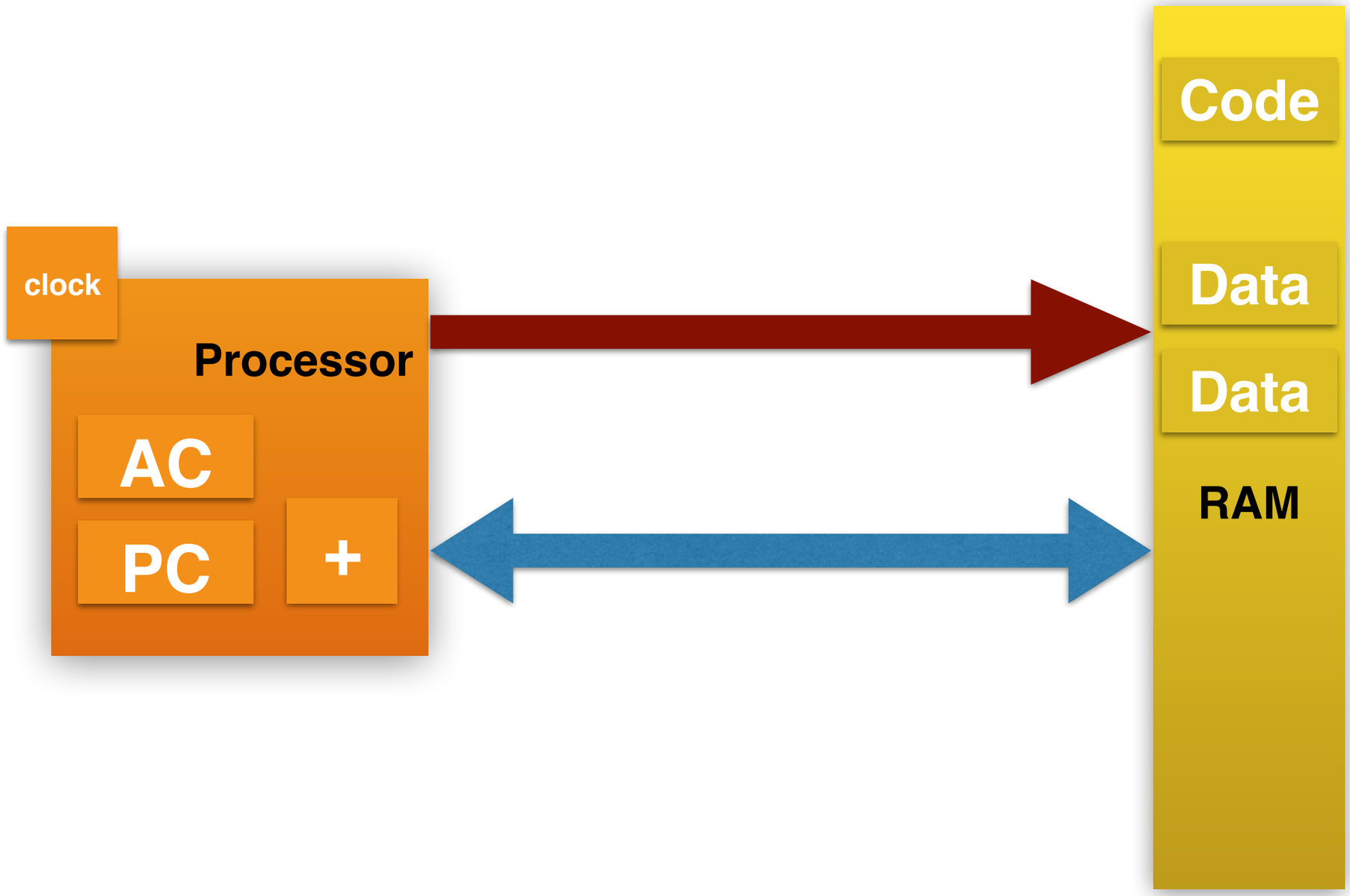


https://www.pugetsystems.com/pic_disp.php?id=37549&width=60



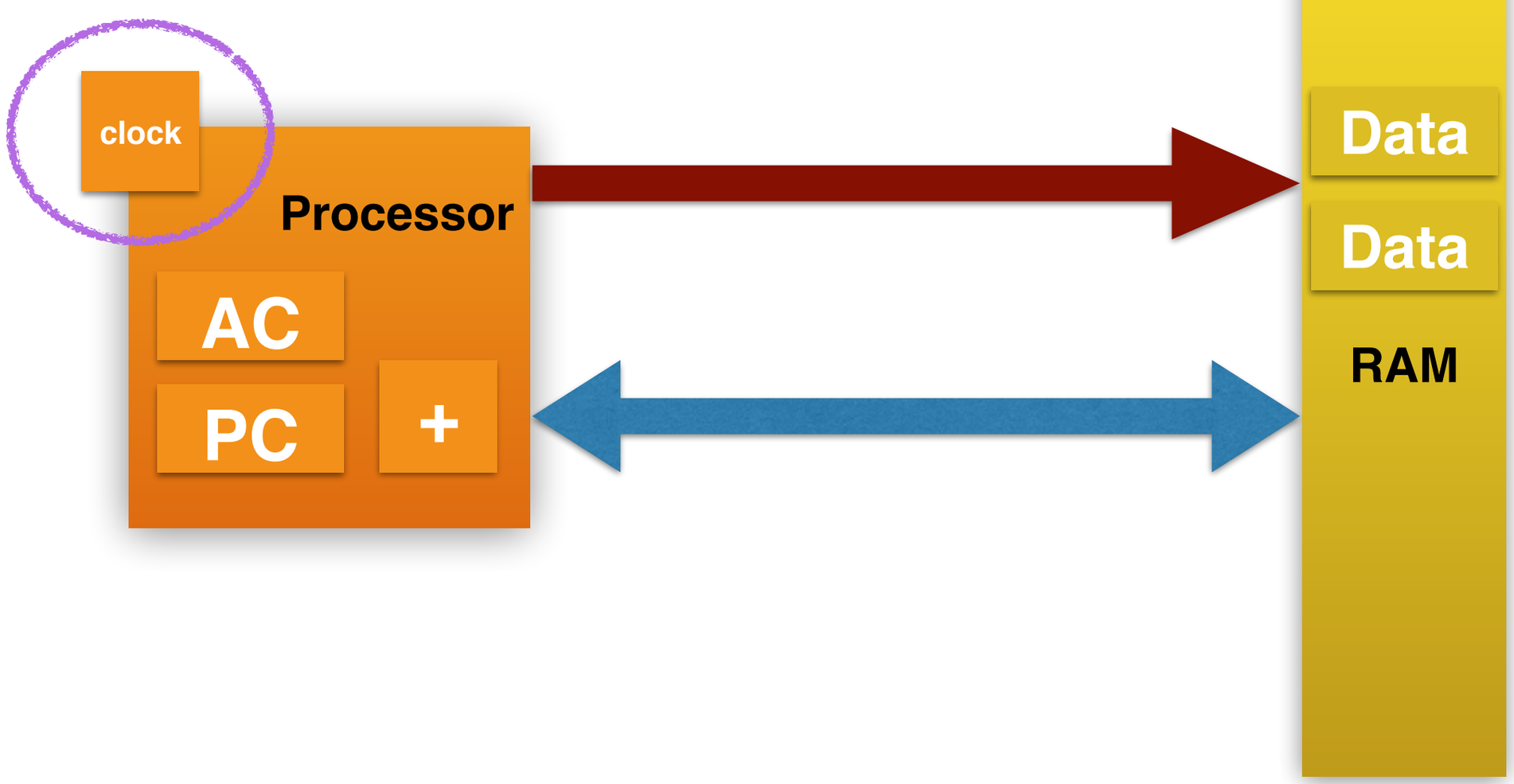
Samual K. Moore, Multicore is bad news for supercomputers, IEEE Spectrum, Nov. 2008.

Modern Computer Architecture
Third Bottleneck



Modern Computer Architecture
Third Bottleneck

Limits:
2 GHz workstations
4 GHz servers



What are the implications?

- The current design of major processors is **frozen**: both architecture and software organization

- **New designs** are investigated to break out of the von Neumann mold

- The main challenge is that programming methods may have to **change**, and remain **compatible** with current **human interfaces**

Outline

- The von Neumann Bottleneck

- Is Moore's Law dead?

Moore

- Gordon Moore, Born 1929. Studied CalTech.
- Worked at Fairchild and co-founded Intel. Chairman emeritus of Intel
- 1965: discovers trend in number of transistors integrated in electronics. Predicts the growth for the next 10 years. **Trend kept going for several decades!**
- Growth rate discovered applies to many areas of technology

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

Understanding Exponential Growth

https://www.bigstockphoto.com/image-143640245/stock-photo-chessboard-with-exponential-growing-heaps-of-rice-grains-legendary-metaphor-of-unlimited-growth

Understanding Exponential Growth

Cell	Rice
1:	1
2:	2
3:	4
4:	8
5:	16
6:	32
7:	64
8:	128

Understanding Exponential Growth

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20:	524,288

Understanding Exponential Growth

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1:	1
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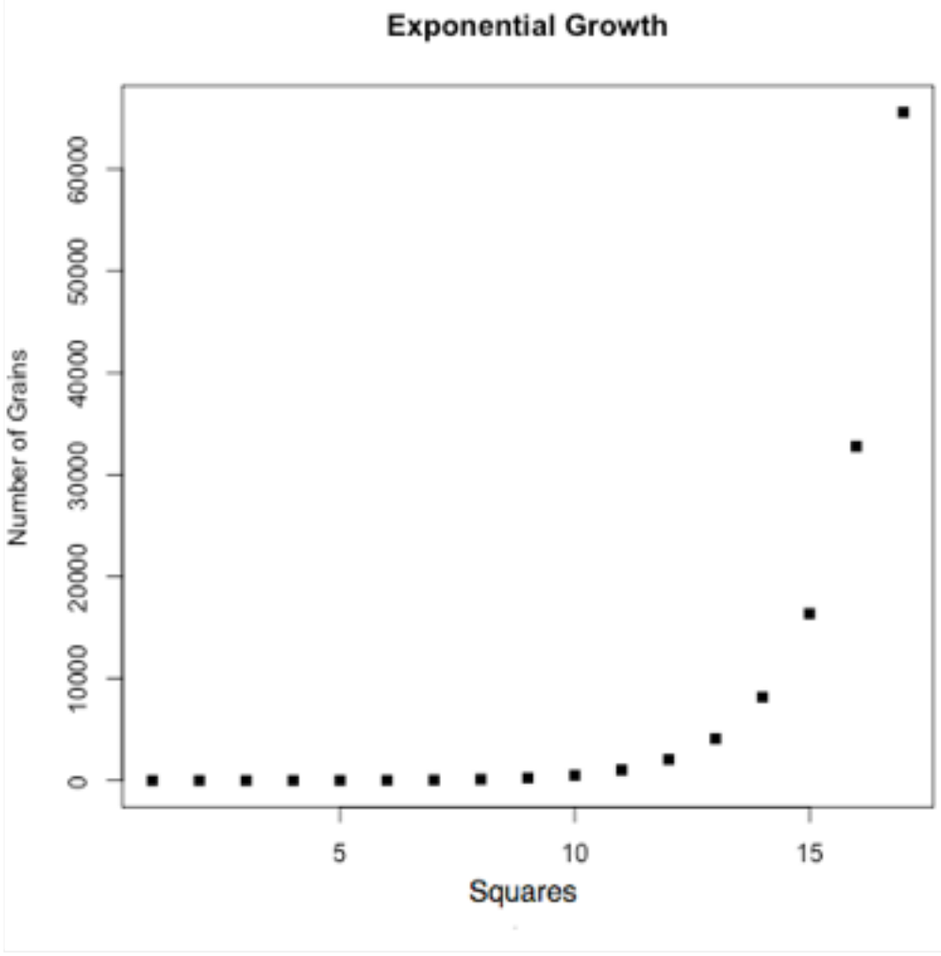
8:	128
20:	524,288
30:	536,870,912

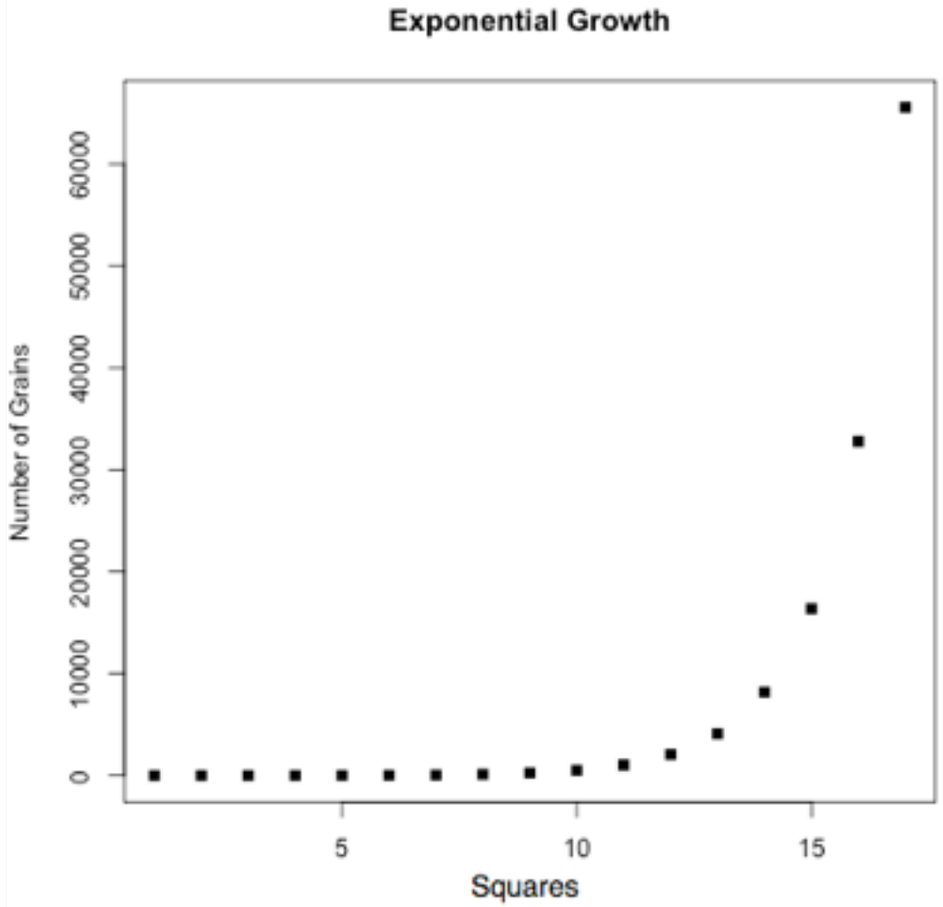
Understanding Exponential Growth

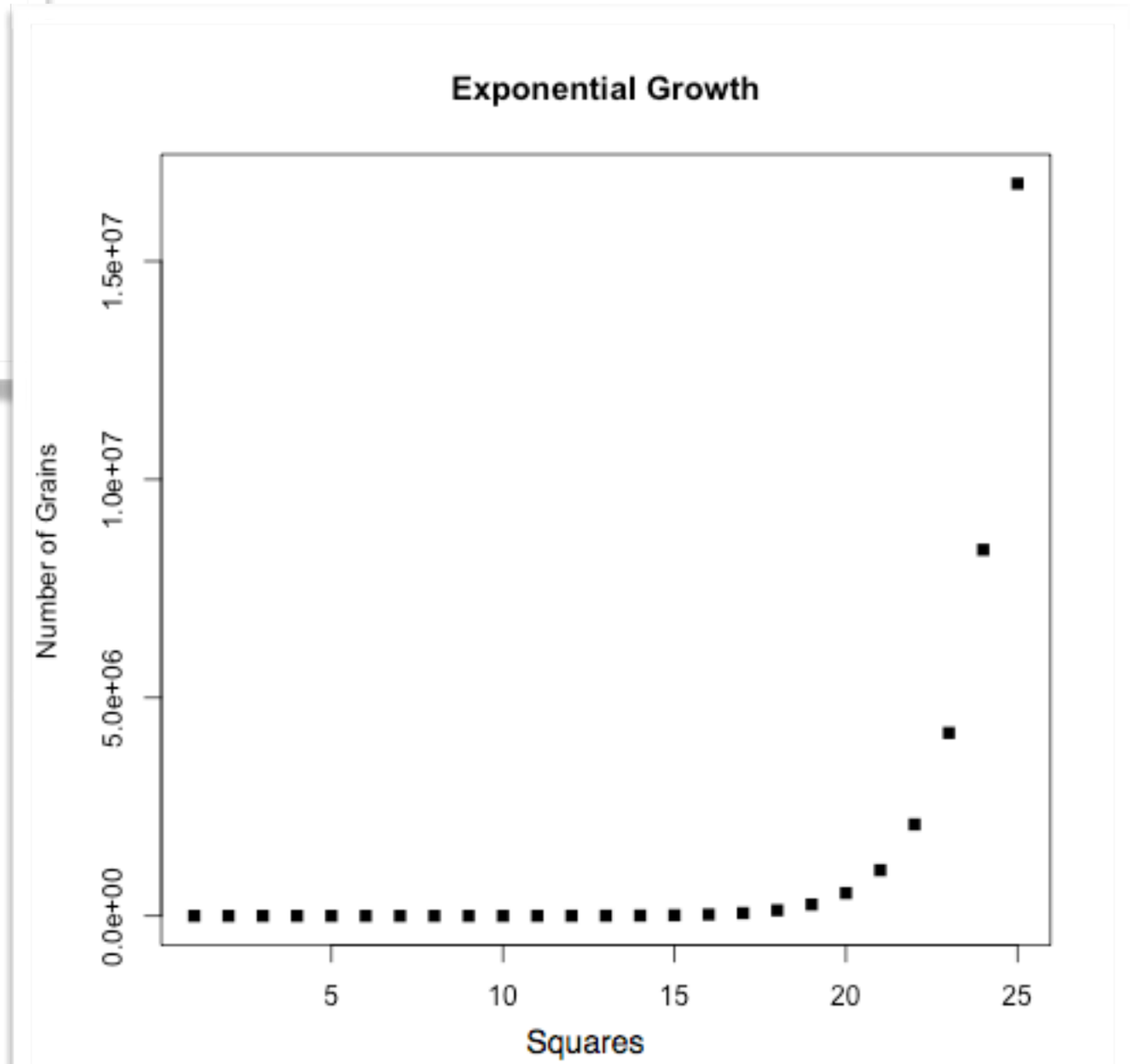
Cell	Rice
1:	1
2:	2
3:	4
4:	8
5:	16
6:	32
7:	64
8:	128
…	
20:	524,288
…	
30:	536,870,912
…	
64:	9,223,372,036,854,775,808

Understanding Exponential Growth

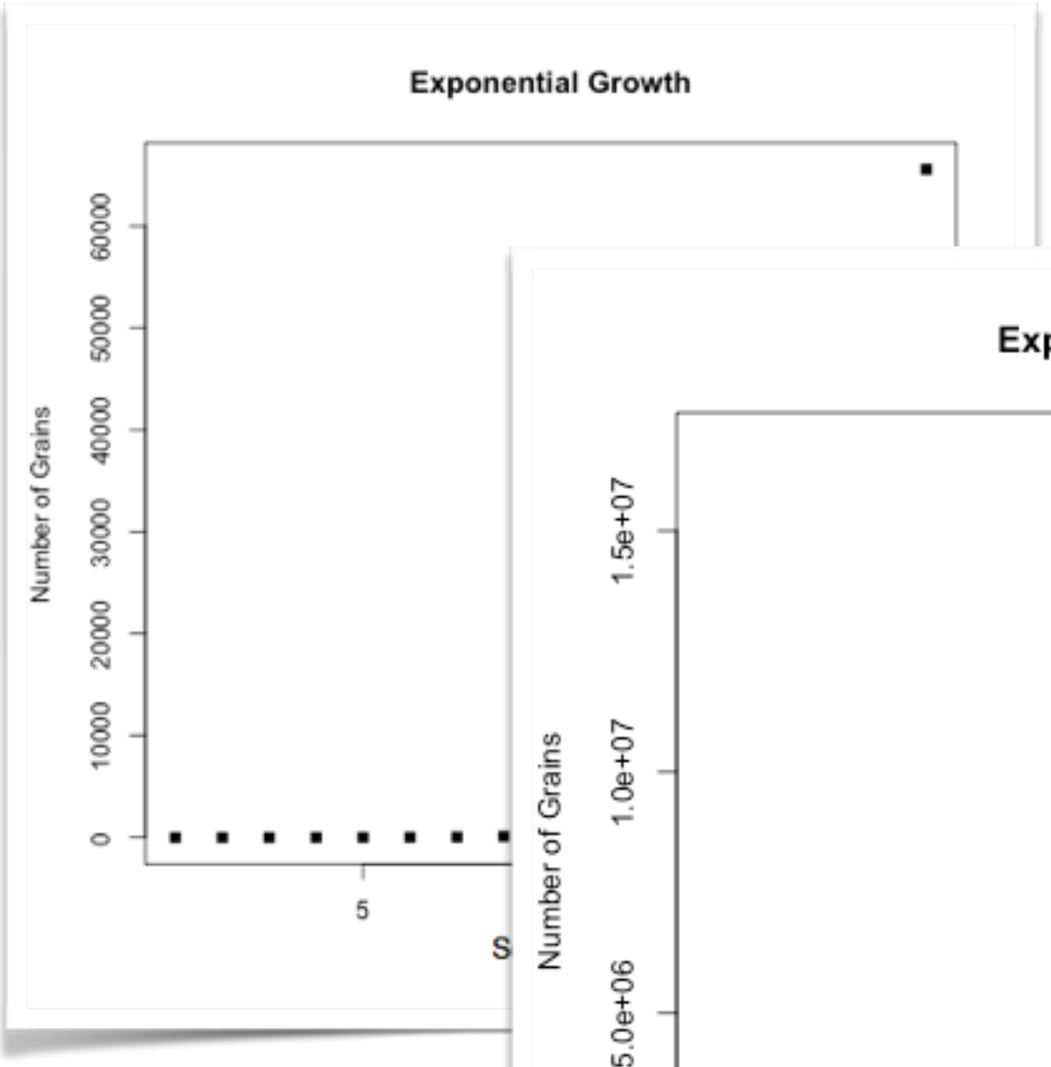


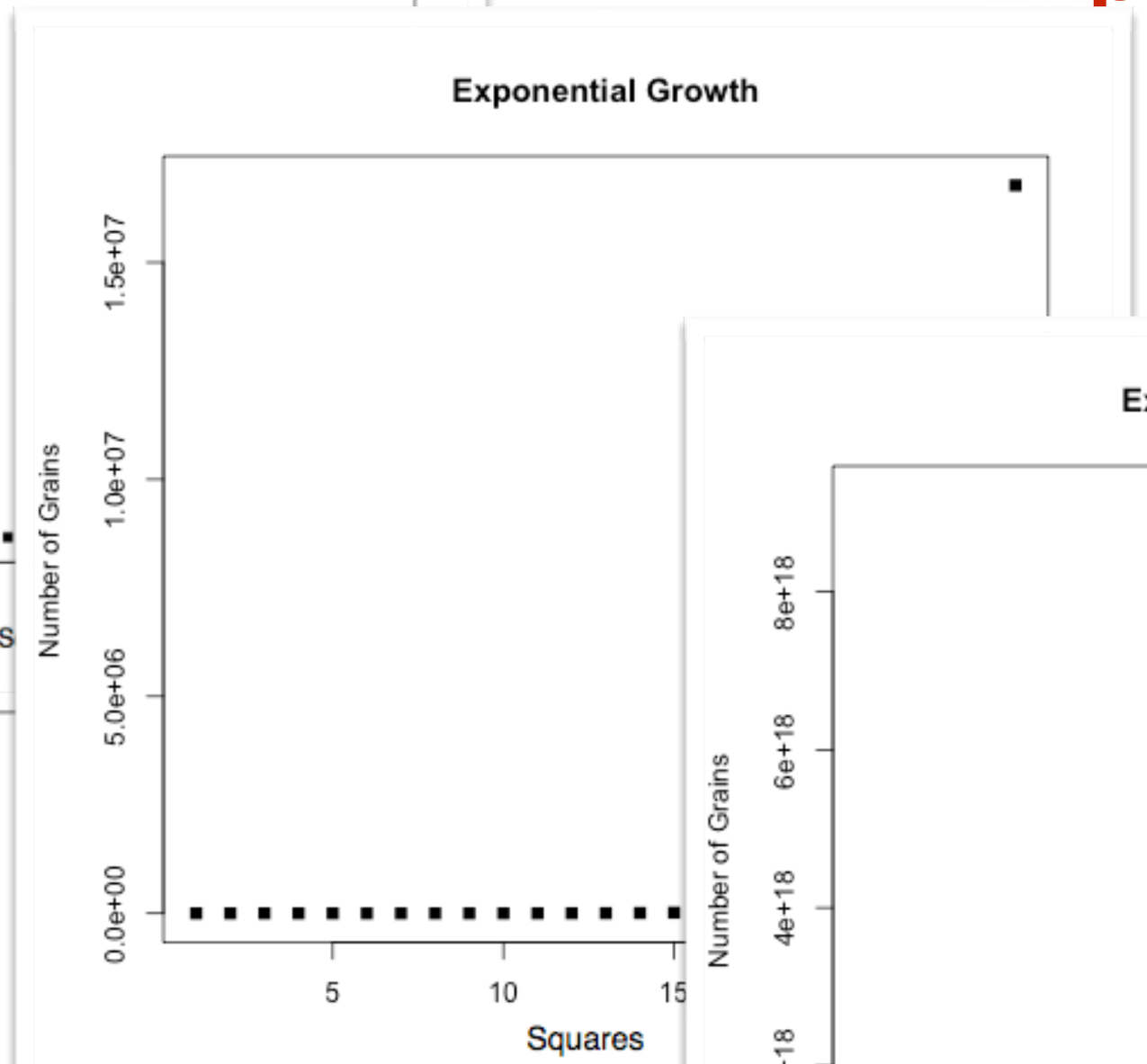
Understanding Exponential Growth

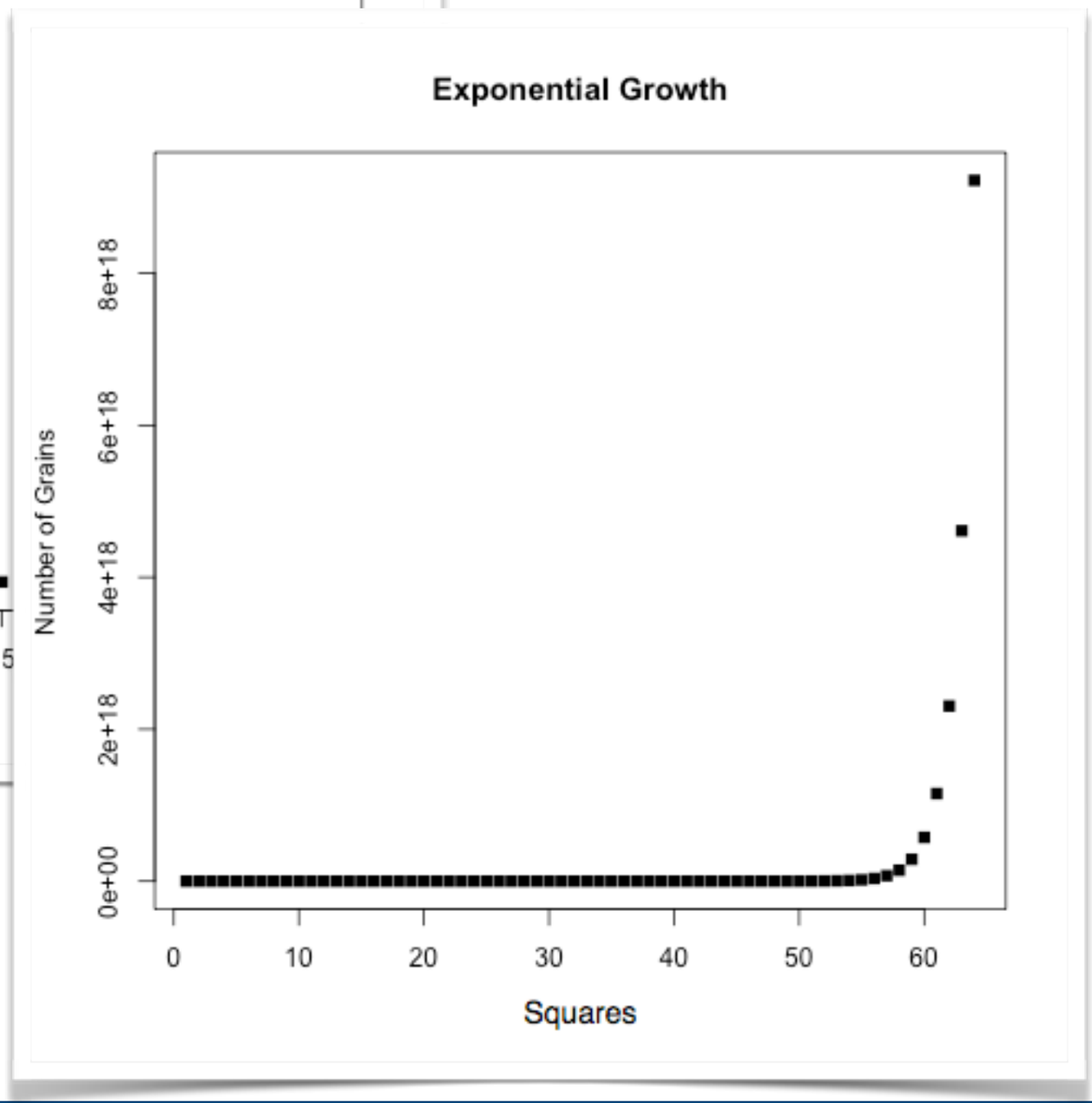




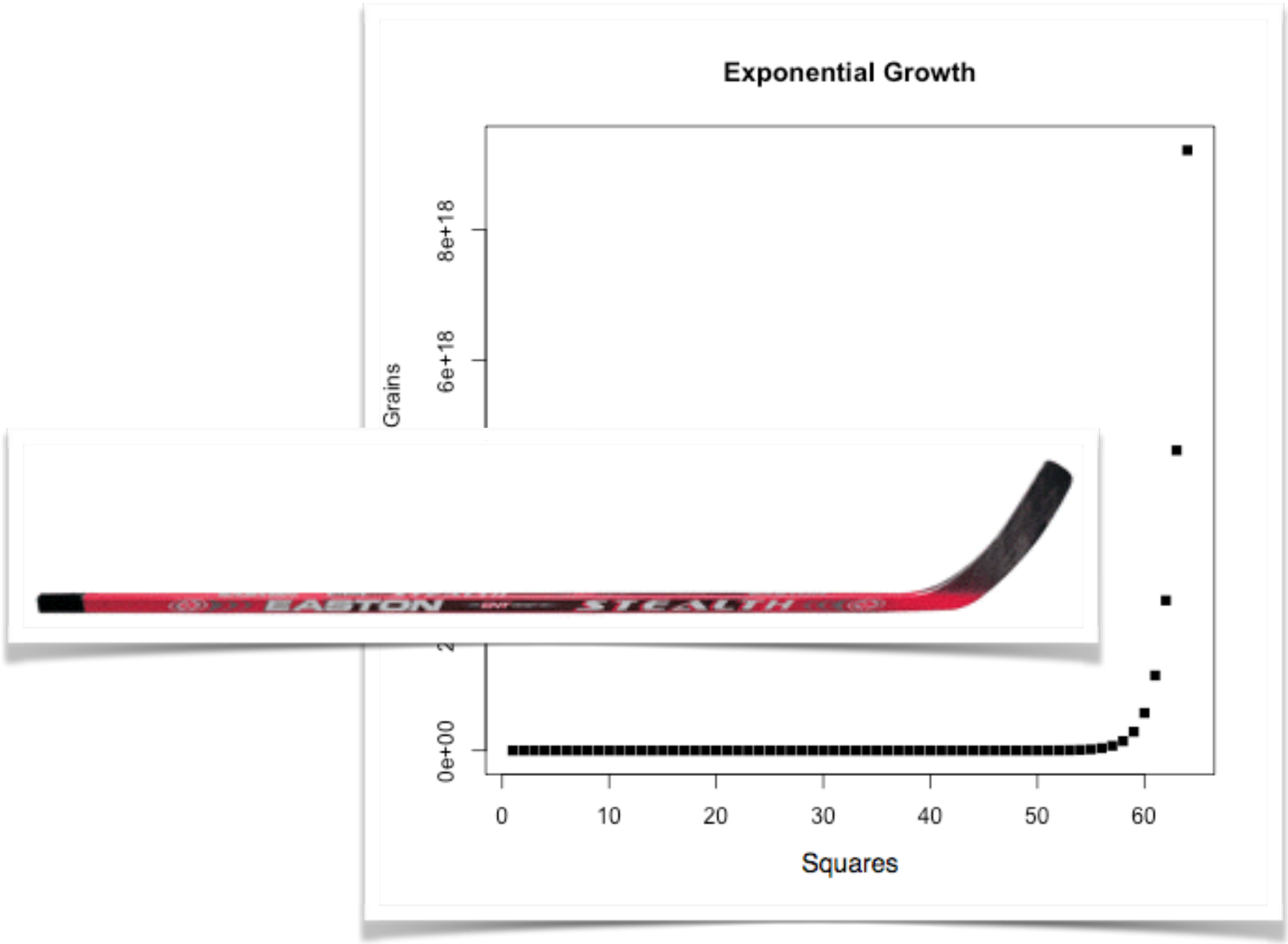
Understanding Exponential Growth



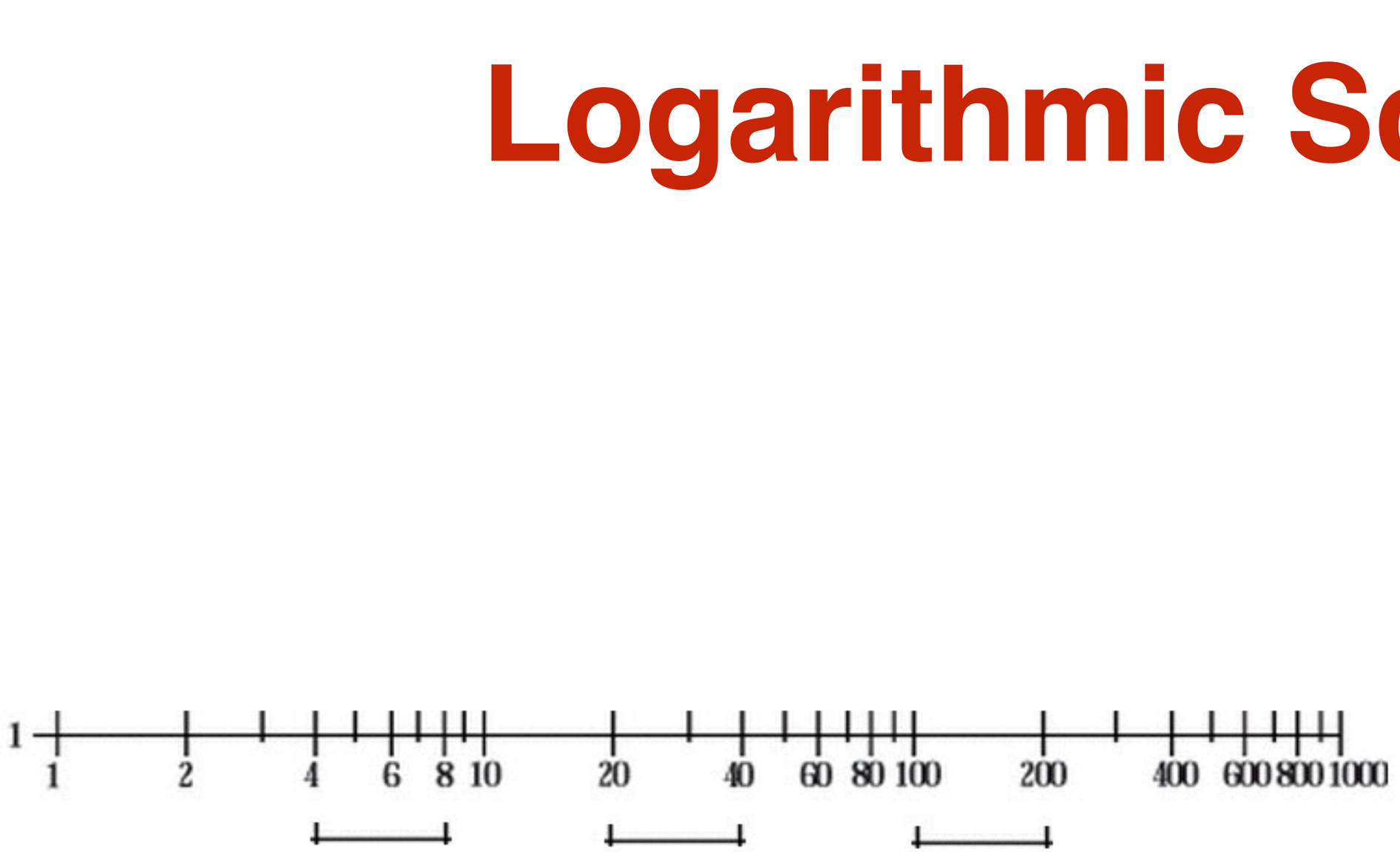




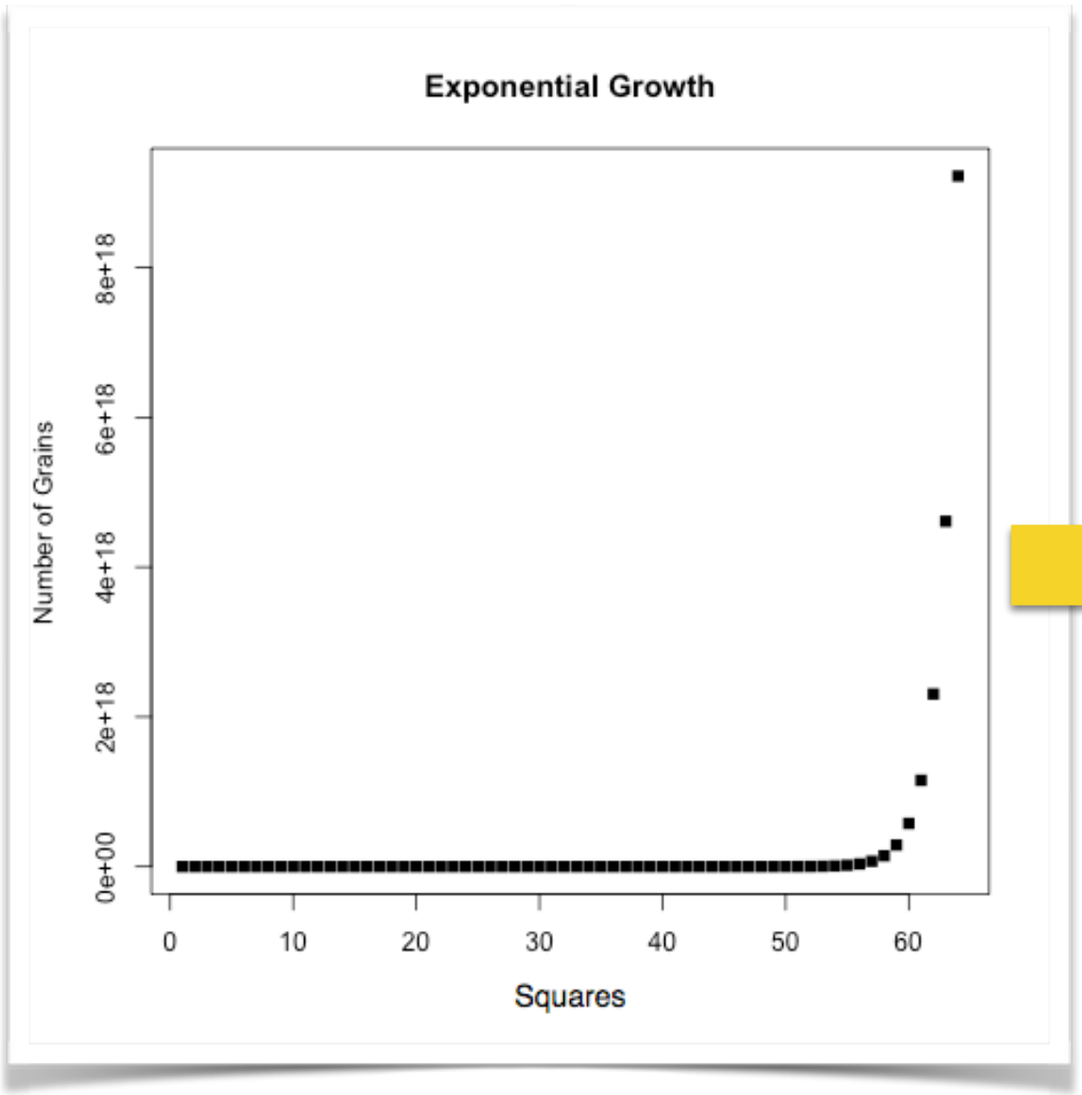
Hockey-Stick Curve!

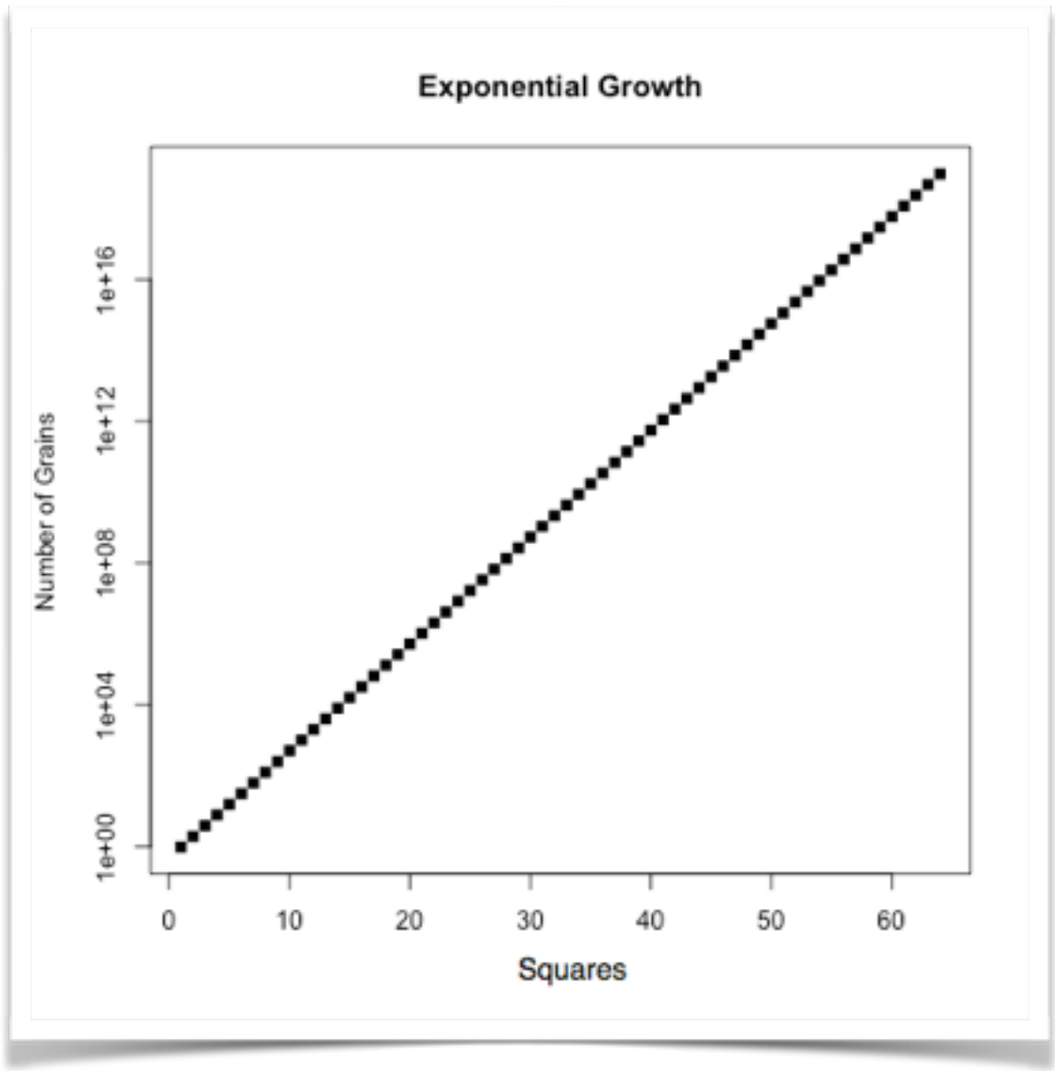


Logarithmic Scale

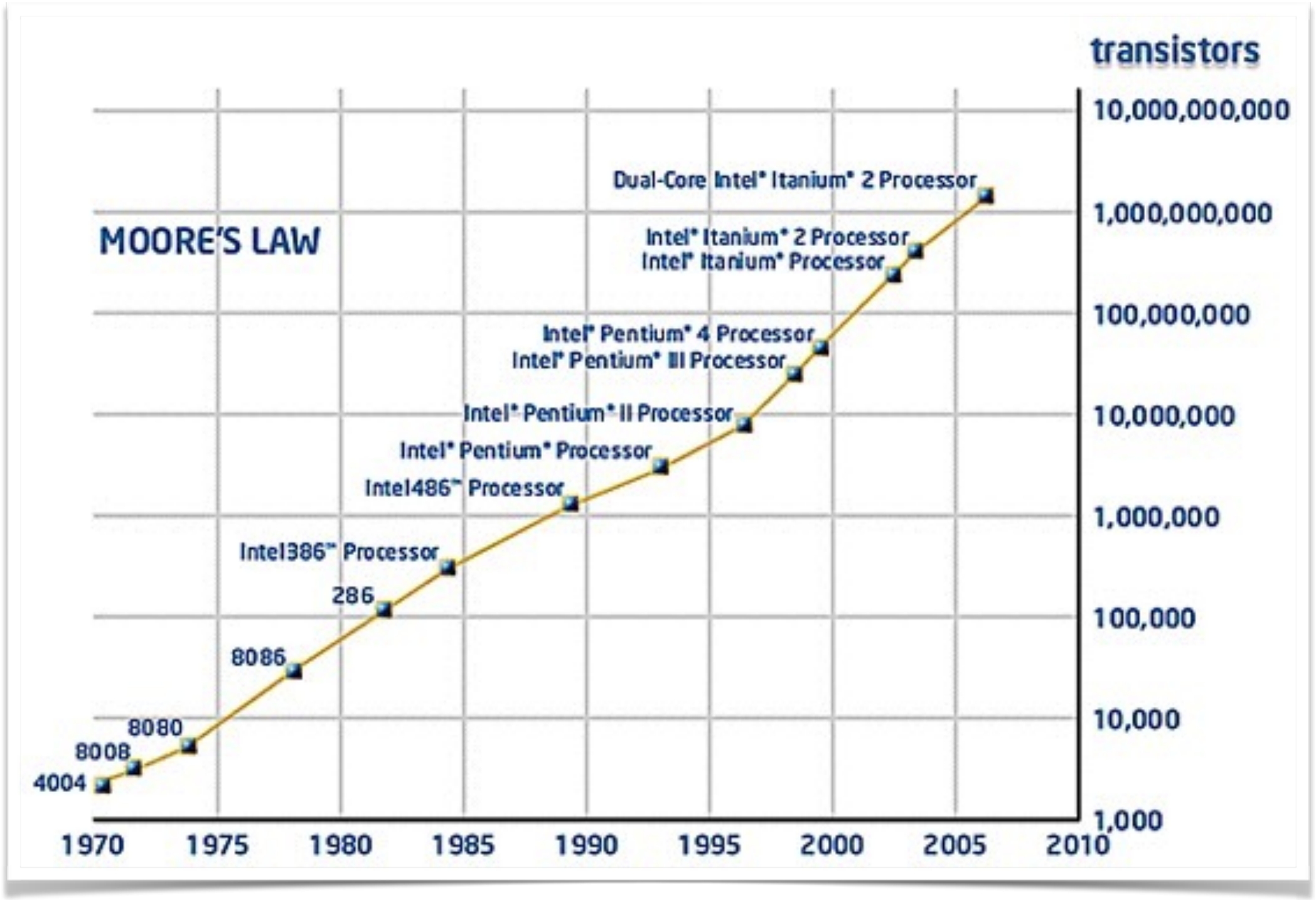


Logarithmic Scale





Moore's Law



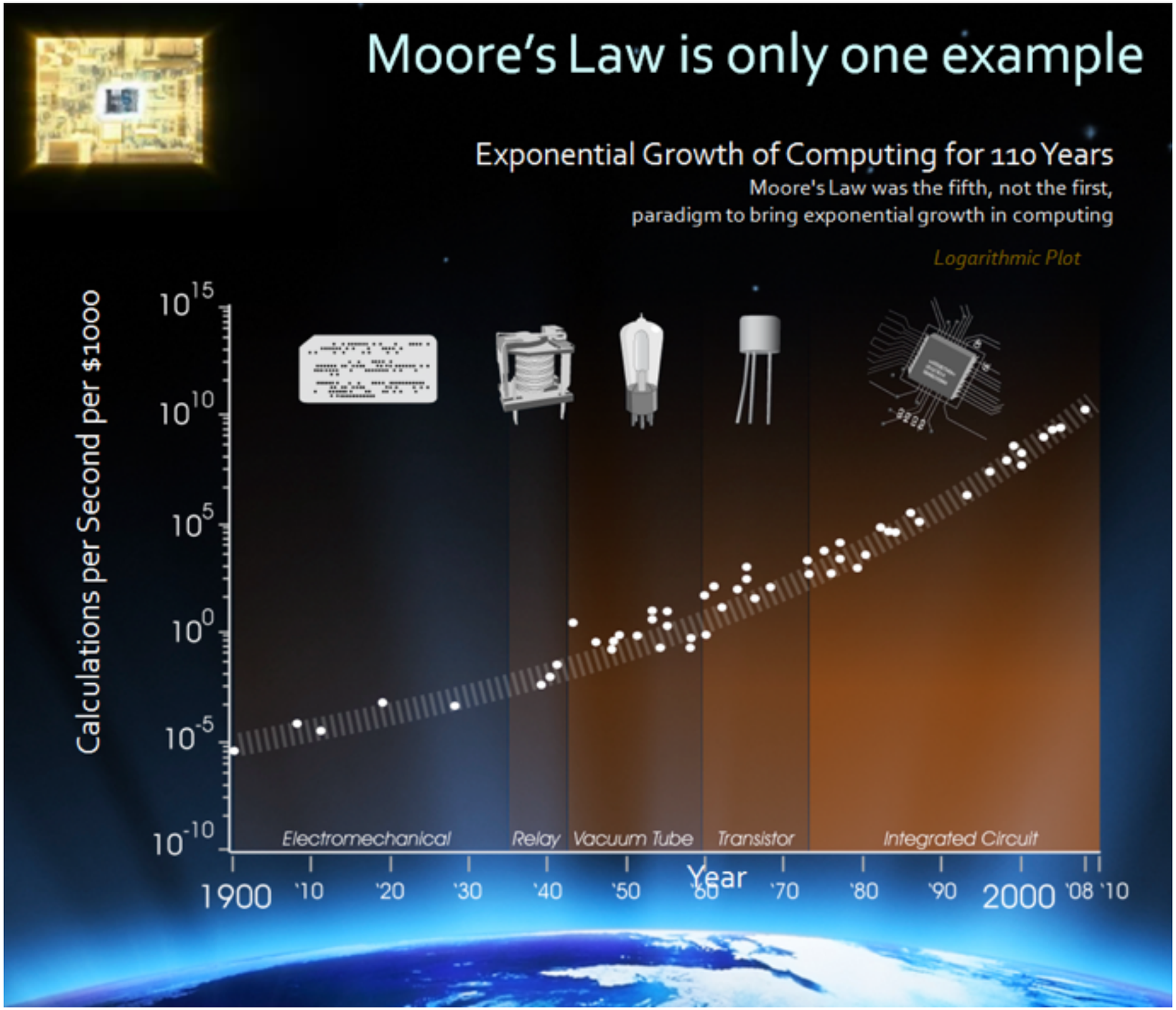
http://www.science.smith.edu/dftwiki/index.php/CSC103_2017:_Instructor%27s_Notes

Moore's Law

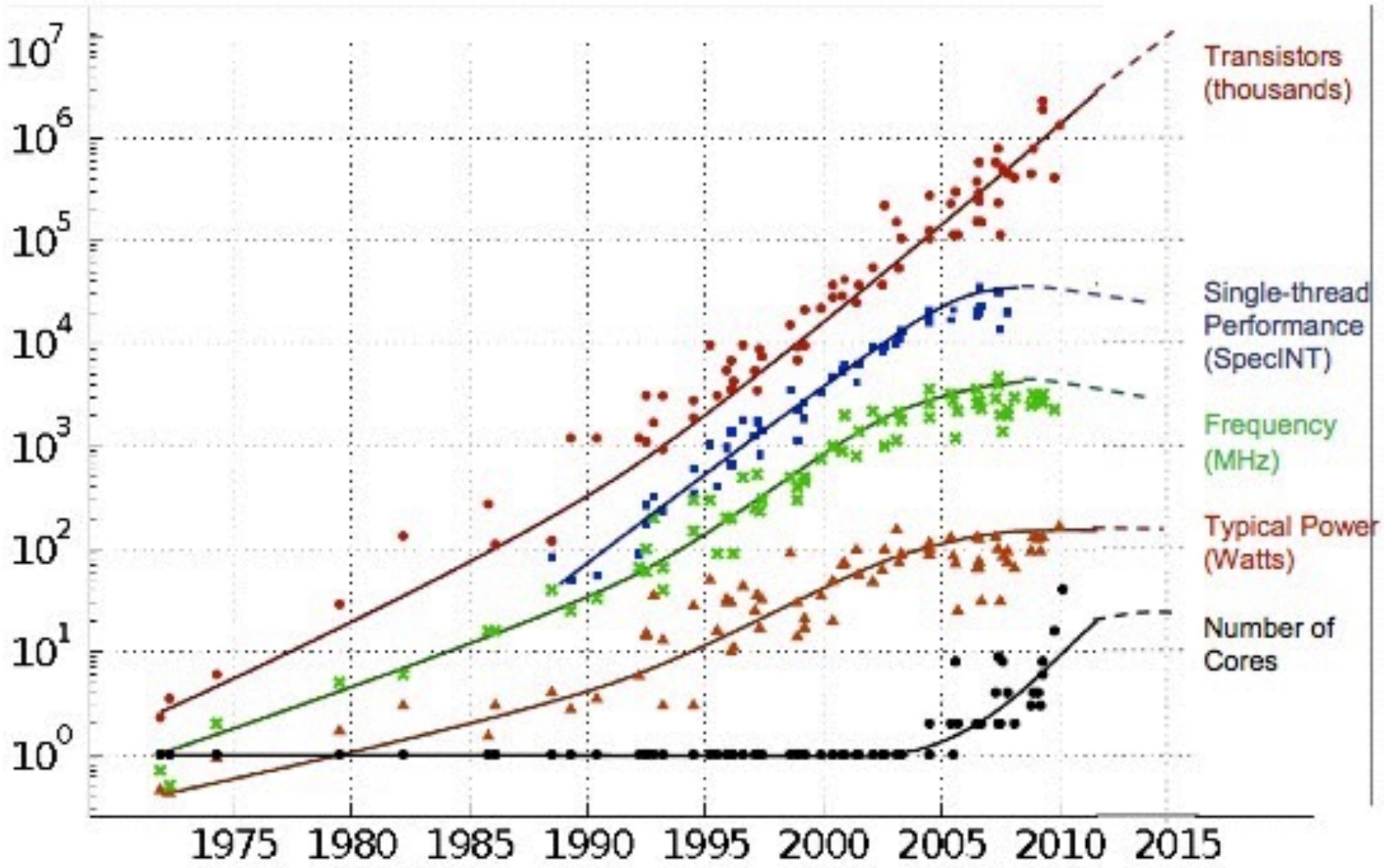
- Moore's Law applies in many areas of technology:
  - Number of transistors in a processor
  - 62 different technologies

https://www.nature.com/news/moore-s-law-is-not-just-for-computers-1.12548

Ray Kurzweil: 130 years of Exponential Growth



Is It Dead?



Original data collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond and C. Batten
Dotted line extrapolations by C. Moore

Implications

- Moore's Law in some ways "rides" the technologies. The technology that displaces other technologies is the one that wins. It is the one that gets implemented, and measured.

- We seem to be at the end of an era in technology, and a slump is appearing in the growth rate of many curves.

- A new technology must be discovered in order to maintain the exponential growth rate we have seen in computers.

- It must be around the corner…

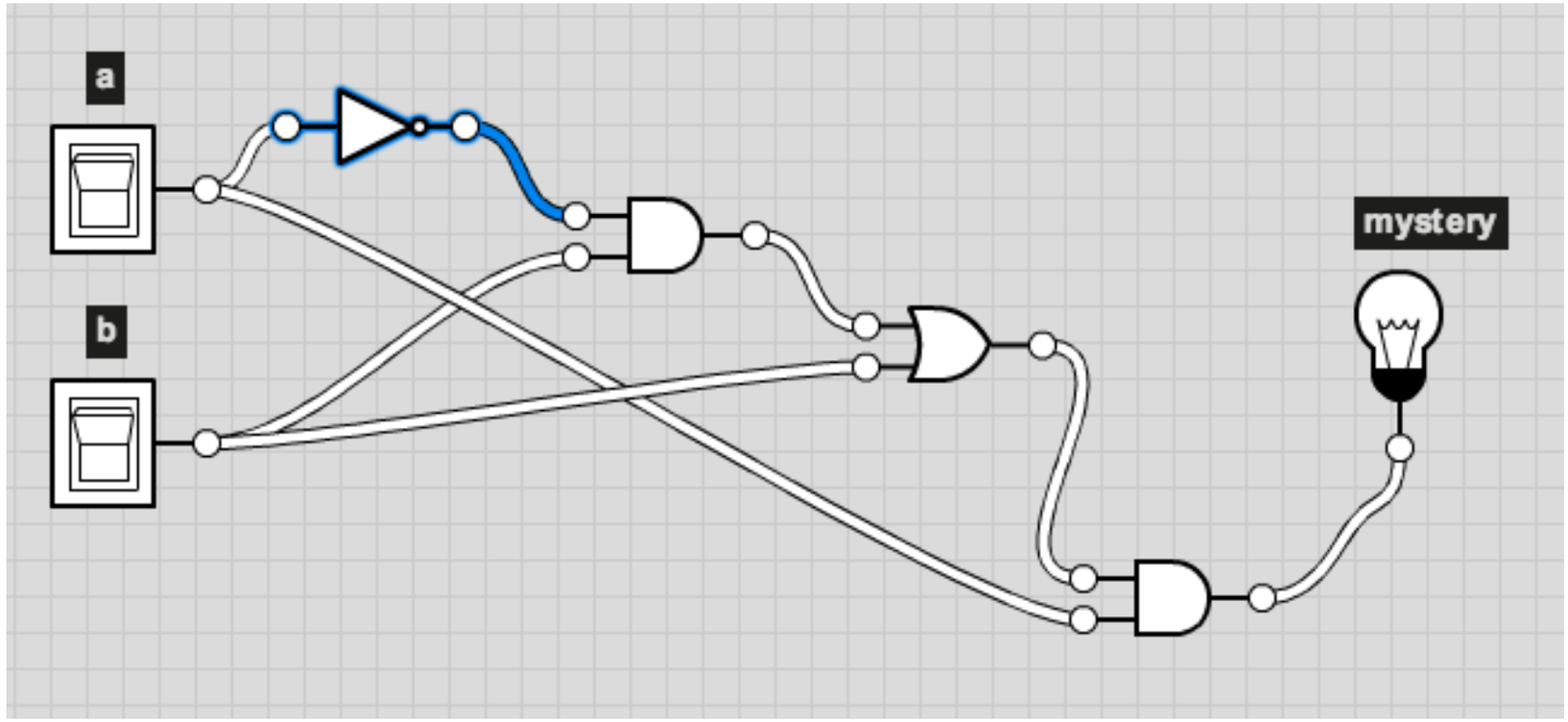
End of Video Lecture

Review Assembly laguage Lab

- Why does the program in the Moodle quiz behave the way it does?

```
0000:    LOAD 126        ;
0002:    ADD 1           ;
0004:    STORE [6]       ;
0006:    JUMP 0          ;
```

Review of Homework 2
Mystery Circuit



Examples of Media mentioning Moore's Law & von Neumann Bottleneck

Moore's Law for Medecine

- MIT Technology Review
  We Need a Moore's Law for Medicine:
  Technology is the primary cause of our skyrocketing health-care costs. It could also be the cure.
  by Antonio Regalado September 3, 2013

- "The more medicine becomes digital, the idea goes, the more productive it will become."

- https://www.technologyreview.com/s/518871/we-need-a-moores-law-for-medicine/

End of Moore's Law

AUG 29, 2013 @ 10:09 AM 4,818

The Little Black Book of Billionaire Secrets

DARPA Bigwig And Intel Fellow: Moore's Law Is Ending Soon

Tim Worstall, CONTRIBUTOR

FULL BIO

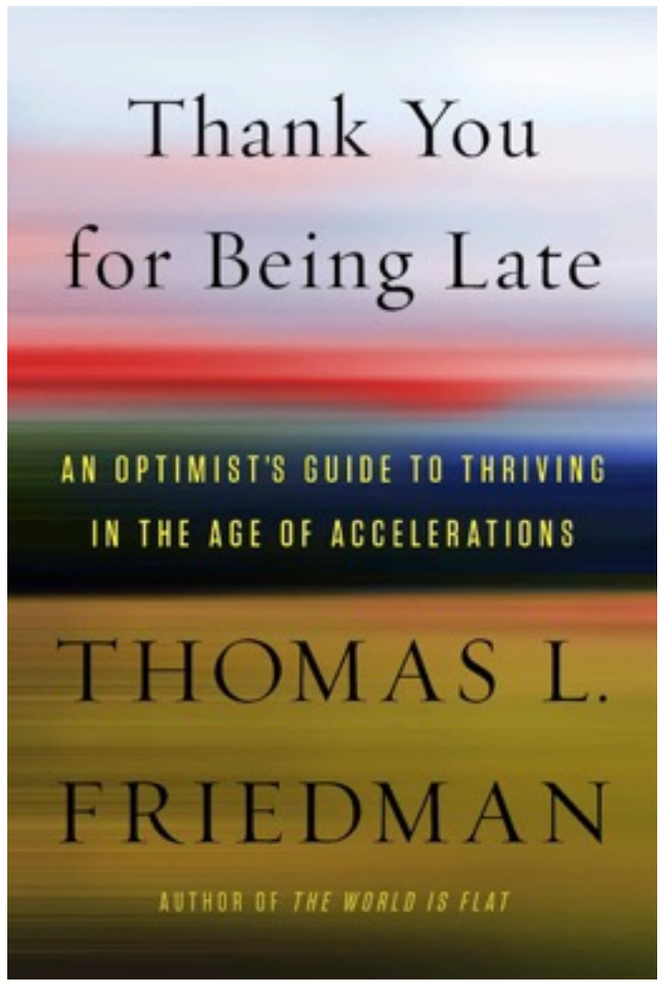
Opinions expressed by Forbes Contributors are their own.

Moore's Law is the empirically true point that the number of transistors on any available piece of silicon will double every 18 months. At first it was just an observation but it's one that has held true for the past half century. That it has done so has led some to believe that it will carry on forever but this almost certainly isn't true:

> According to Colwell, who was Intel INTC +0.8%'s chief chip architect from 1990 to 2001 and an Intel Fellow, there's absolutely no doubt that Moore's Law will eventually be repealed. "Let's at least face the fact that [Moore's Law] is an exponential, and there cannot be an exponential that doesn't end," he said. "You can't have it."

https://www.forbes.com/forbes/welcome/?toURL=https://www.forbes.com/sites/timworstall/2013/08/29/darpa-chief-and-intel-fellow-moores-law-is-ending-soon/&refURL=https://www.google.com/&referrer=https://www.google.com/

Image Credit:http://t2.gstatic.com/images?q=tbn:ANd9GcTOt3D89PSHzk2ozuYG4BFcECDi5A1SGHkFfsQ5TAOjnVuWaSe_

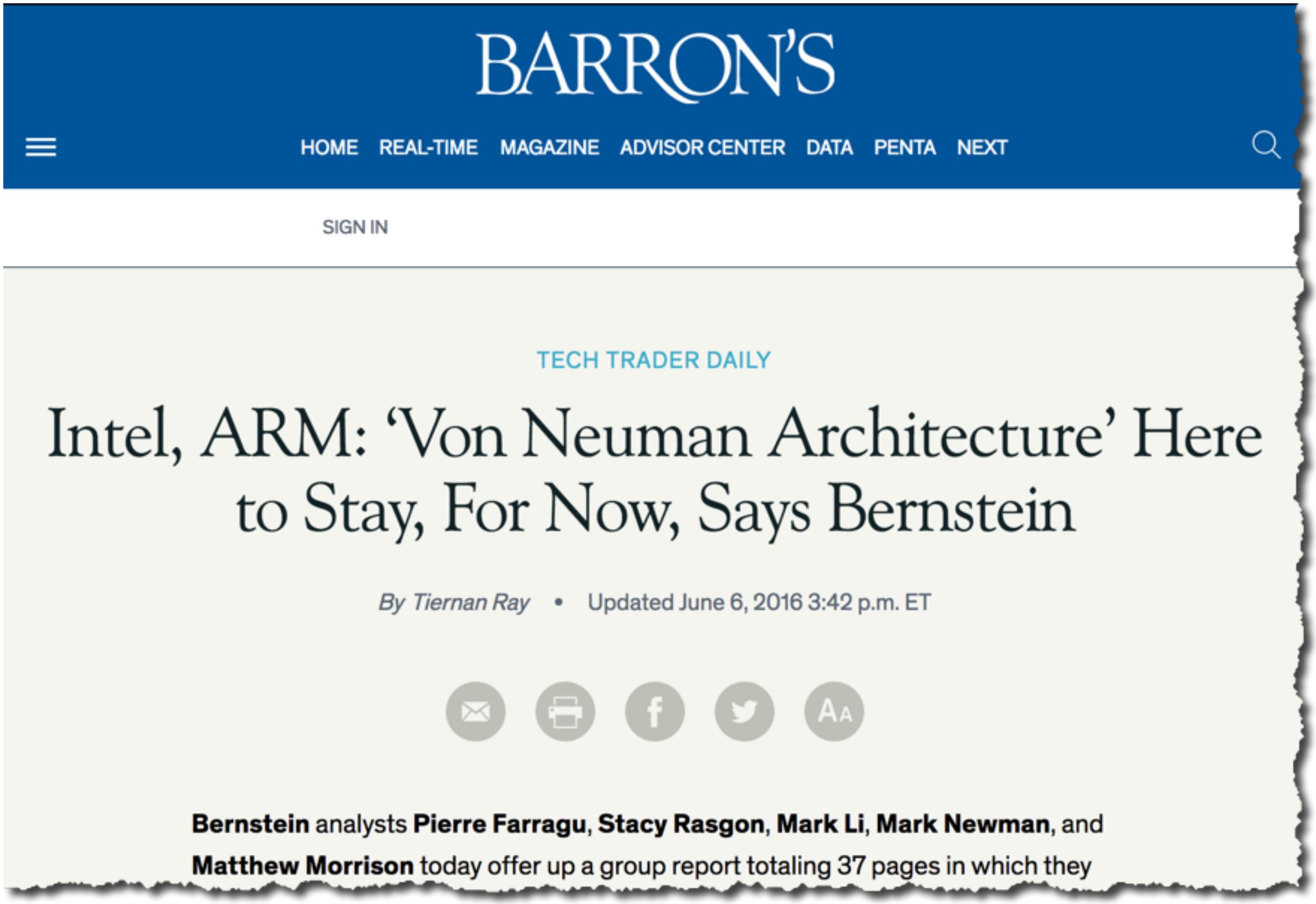


Moore's Law and Economics

Friedman argues that man is actually a fairly adaptable creature. The problem is that our capacity to adapt is being outpaced by a "supernova," built from three ever faster things: **technology, the market and climate change**. That sounds like a predictable list, but Friedman digs cleverly into each one. For instance, on technology he argues convincingly that 2007, which saw the arrival of the iPhone, Android and Kindle, was the year when software began, in the words of Netscape's founder, "eating the world"; he introduces us to vital obscure bits, like GitHub and Hadoop; **he points out that if Moore's law (that the power of microchips would double about every two years) had applied to the capabilities of cars, not computer chips, then the modern descendant of the 1971 Volkswagen Beetle would travel at 300,000 miles per hour, cost 4 cents and use one tank of gasoline in a lifetime.**

https://www.nytimes.com/2016/11/22/books/review/thomas-friedman-thank-you-for-being-late.html?mcubz=3&mtrref=www.google.com&gwh=7707051483C041C71B5CA9FAD8B63F96&gwt=pay

von Neumann Architecture



BARRON'S

HOME REAL-TIME MAGAZINE ADVISOR CENTER DATA PENTA NEXT

SIGN IN

TECH TRADER DAILY

Intel, ARM: 'Von Neuman Architecture' Here to Stay, For Now, Says Bernstein

By Tiernan Ray • Updated June 6, 2016 3:42 p.m. ET

Bernstein analysts **Pierre Farragu**, **Stacy Rasgon**, **Mark Li**, **Mark Newman**, and **Matthew Morrison** today offer up a group report totaling 37 pages in which they

http://www.barrons.com/articles/intel-arm-von-neuman-architecture-here-to-stay-for-now-says-bernstein-1465242162

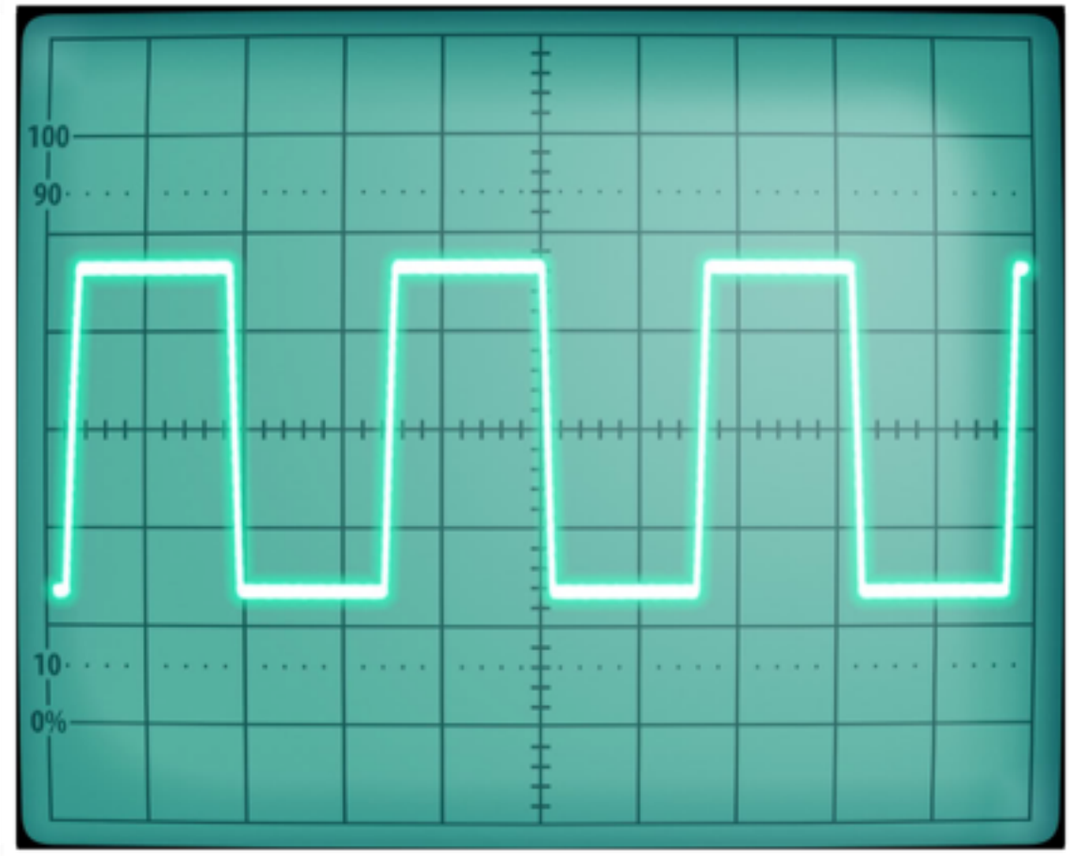
Assembly Language

The Crystal

https://postimg.org/image/3veebzpd5/

The Crystal

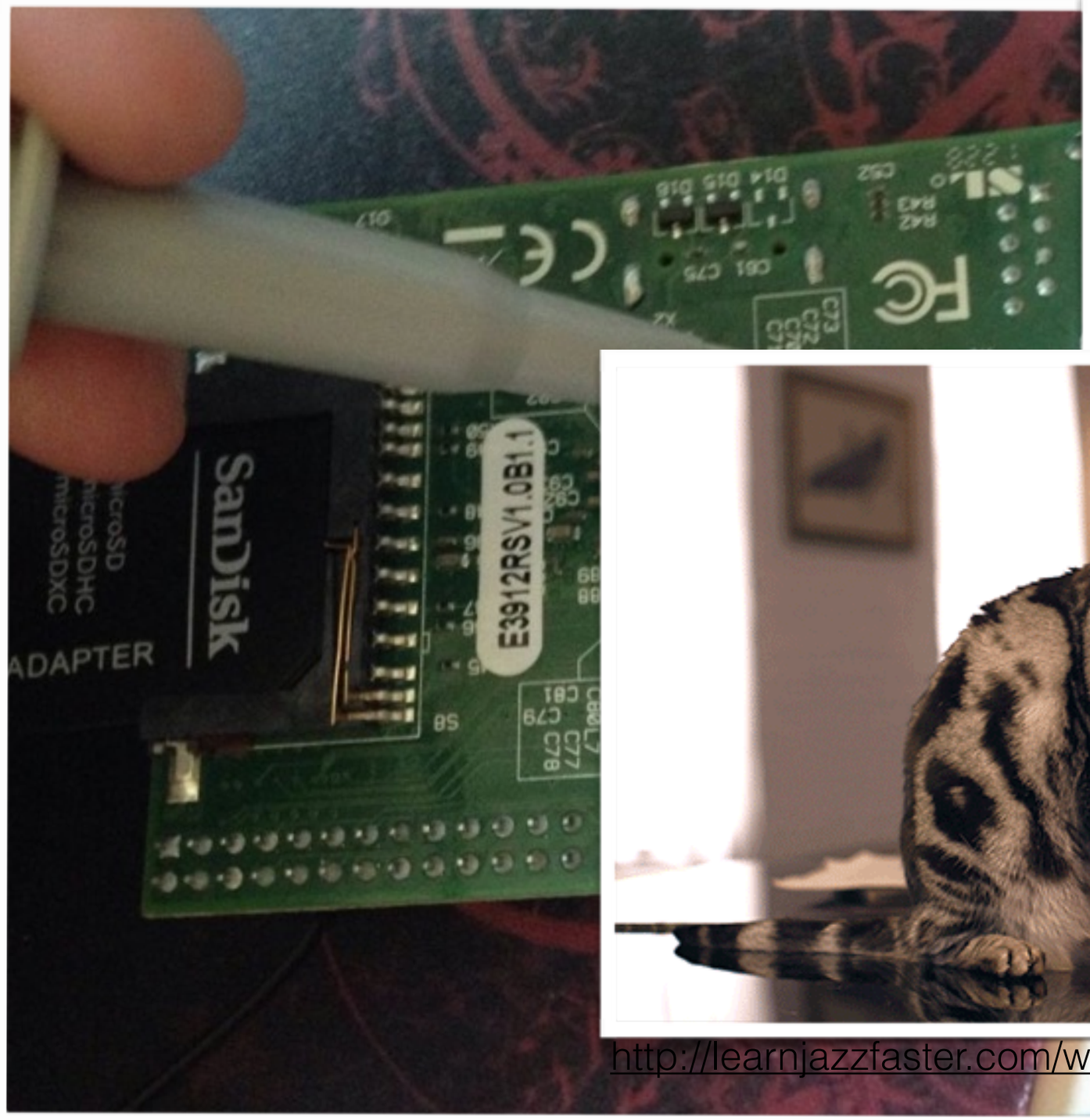
http://photobucket.com/gallery/user/rachjm/media/cGF0aDovT3NjaWxsb3Njb3BlMi0xLmpwZw==/?ref=

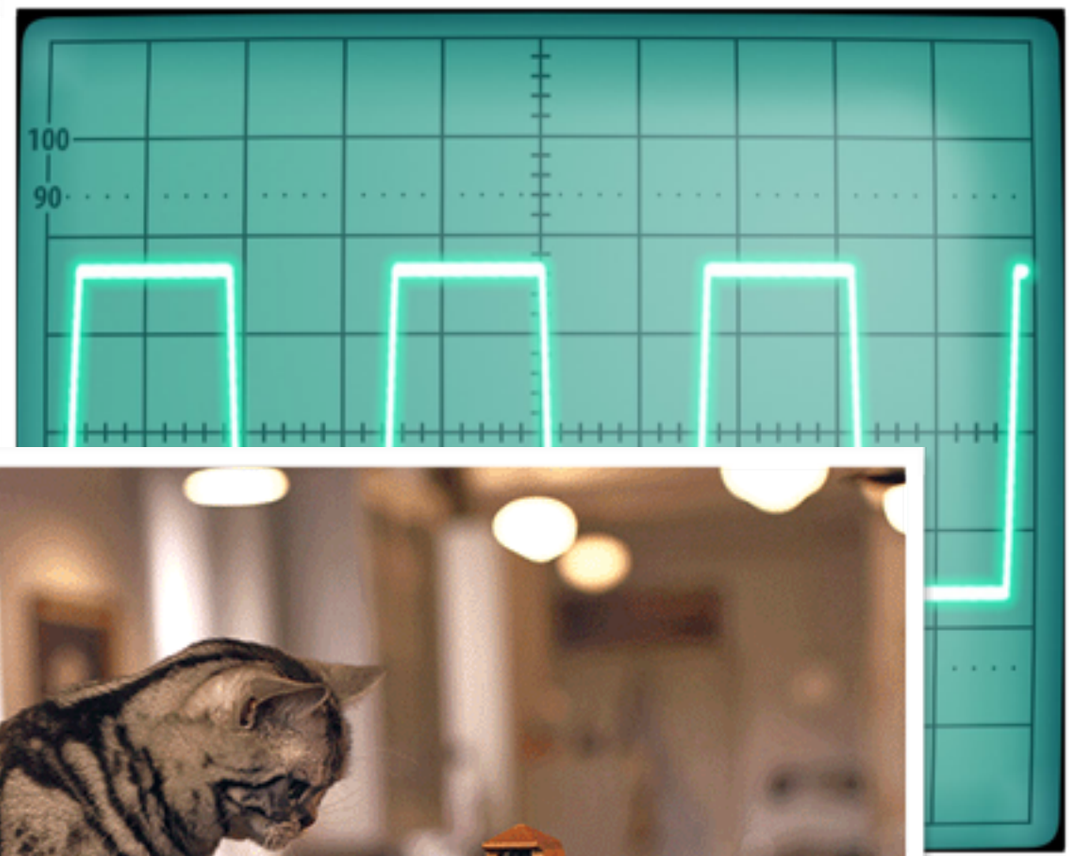


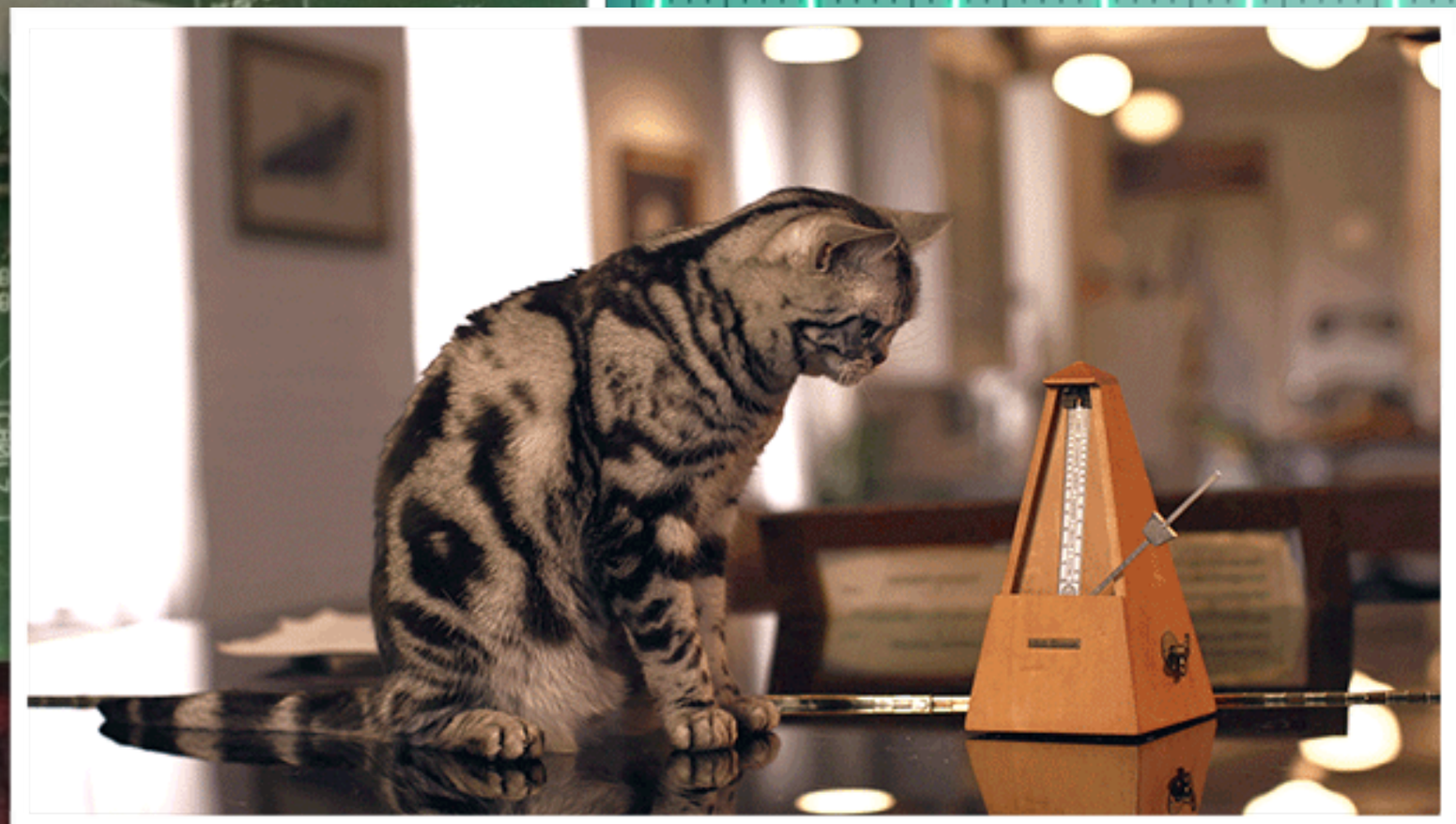
https://postimg.org/image/3veebzpd5/

The Crystal

http://photobucket.com/gallery/user/rachjm/media/cGF0aDovT3NjaWxsb3Njb3BlMi0xLmpwZw==/?ref=





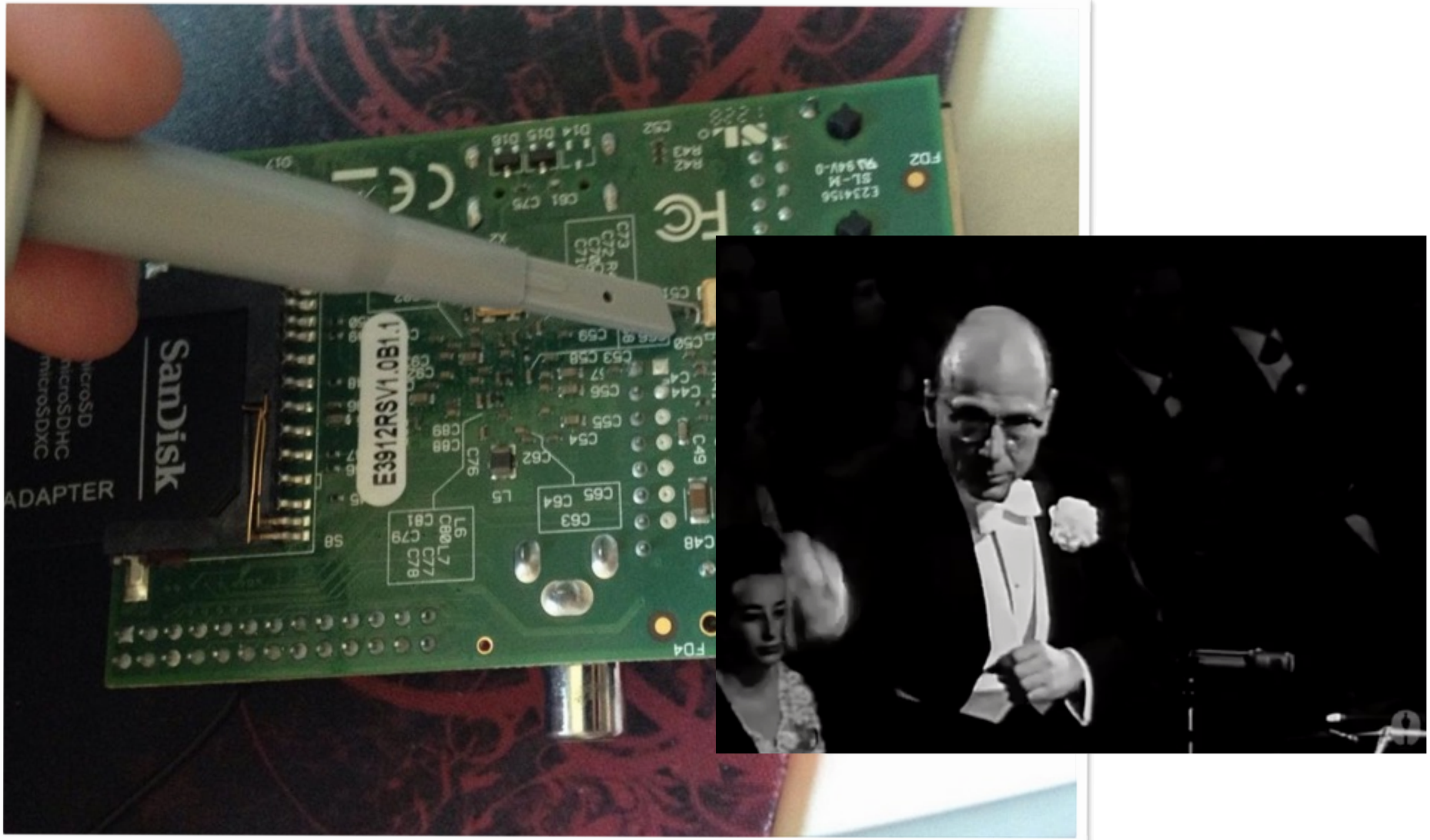


http://learnjazzfaster.com/wp-content/uploads/2017/05/cat-nome.gif

https://postimg.org/image/3veebzpd5/

The Crystal

https://giphy.com/gifs/oscars-academy-awards-1965-26gsnVwDYSK5depi0/download

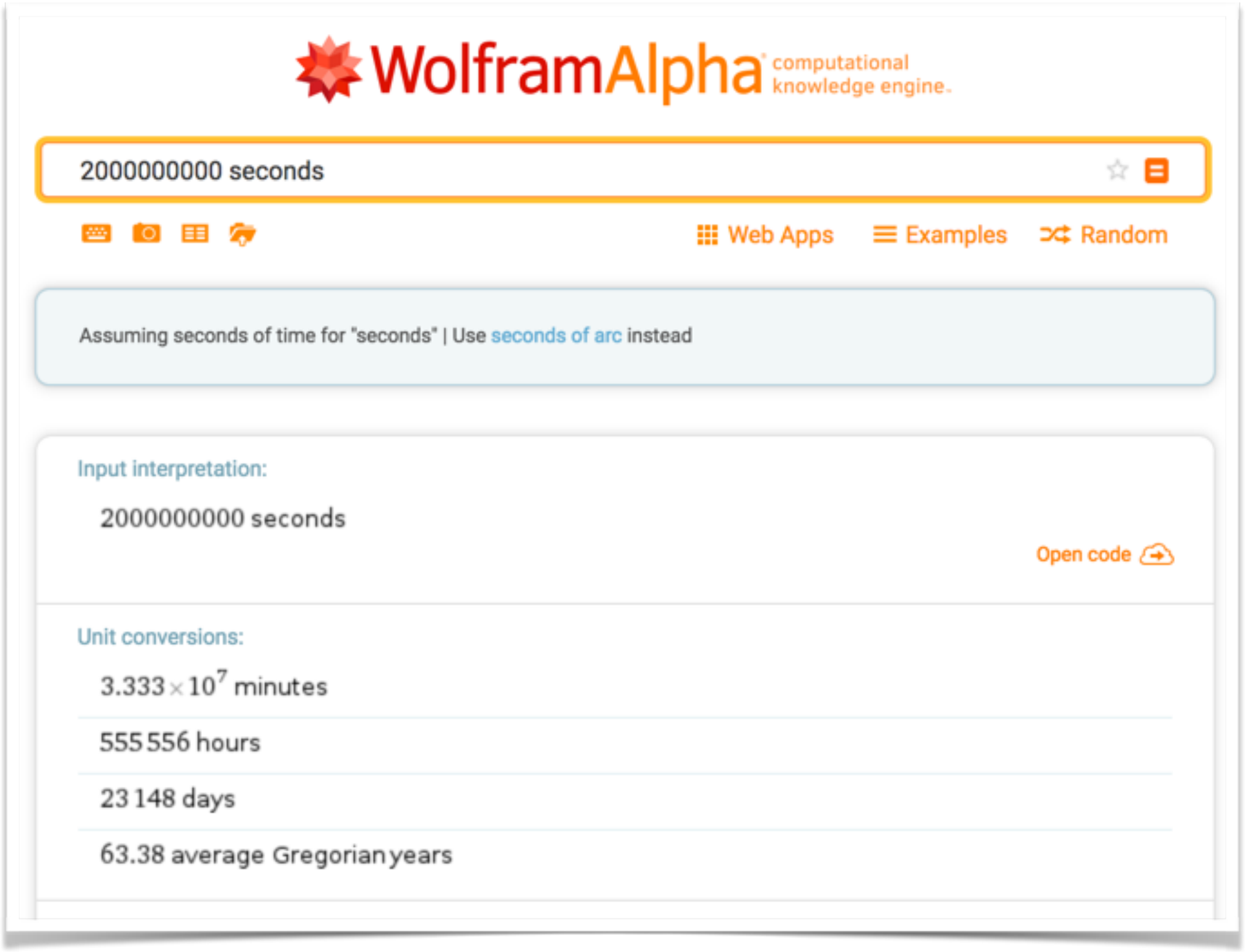


https://postimg.org/image/3veebzpd5/

Getting a Sense of Computer Speed

- Processor executes 1 instruction every tick of the crystal
- Today's processors operate with 2 GHz crystals.
- 2 GHz = 2,000,000,000 ticks / second

How long a concert for music piece with 2,000,000,000 beats?



More Sophisticated Instructions

Study this Program…

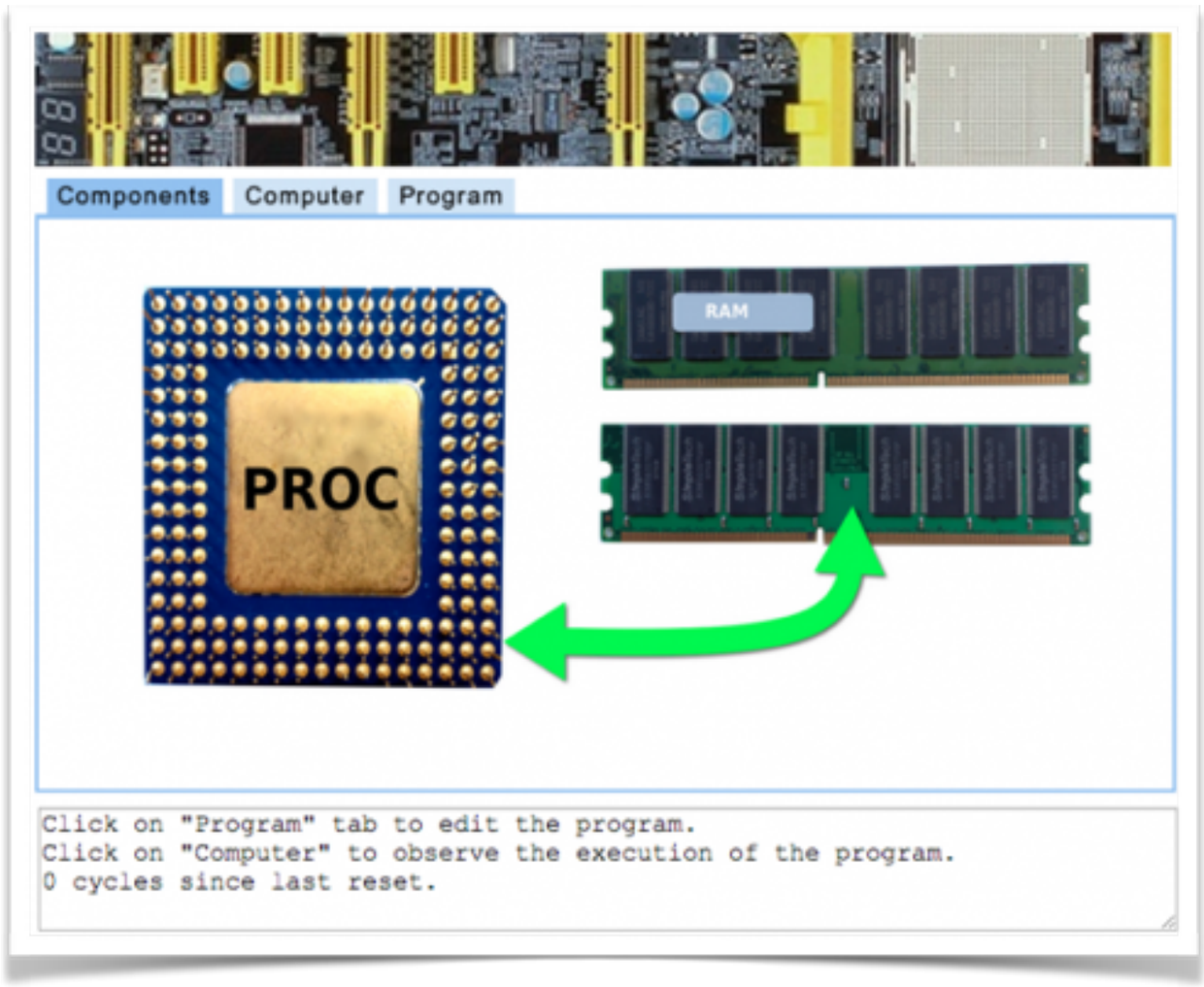
```
0000:     LOAD [12]          ; AC <- counter
0002:     ADD -1             ; decrement AC
0004:     COMP 0             ; is AC equal to 0?
0006:     JEQ 10             ; if so, jump to 10
0008:     JUMP 2             ; jump to 2
0010:     HALT               ; stop program

0012:     15                 ; counter
```

COMP Instruction

- **Compares** the operand to the **AC** register

- If the two binary numbers are the same, the **EQ** bit in the processor is set to 1

- Observe the previous program again, and observe **EQ** every time a **COMP** instruction is executed



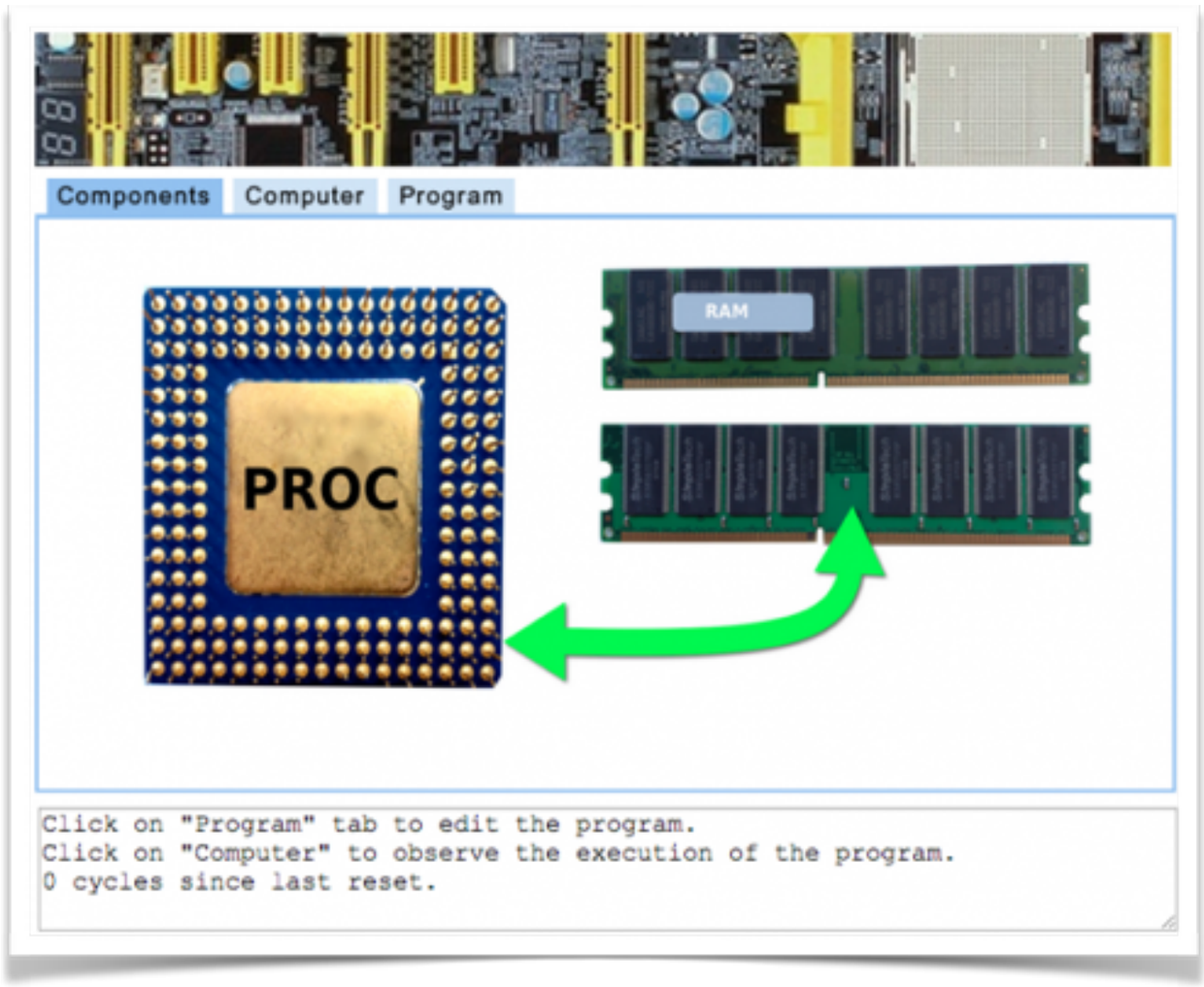
http://bit.ly/2jTJswI

JEQ Instruction

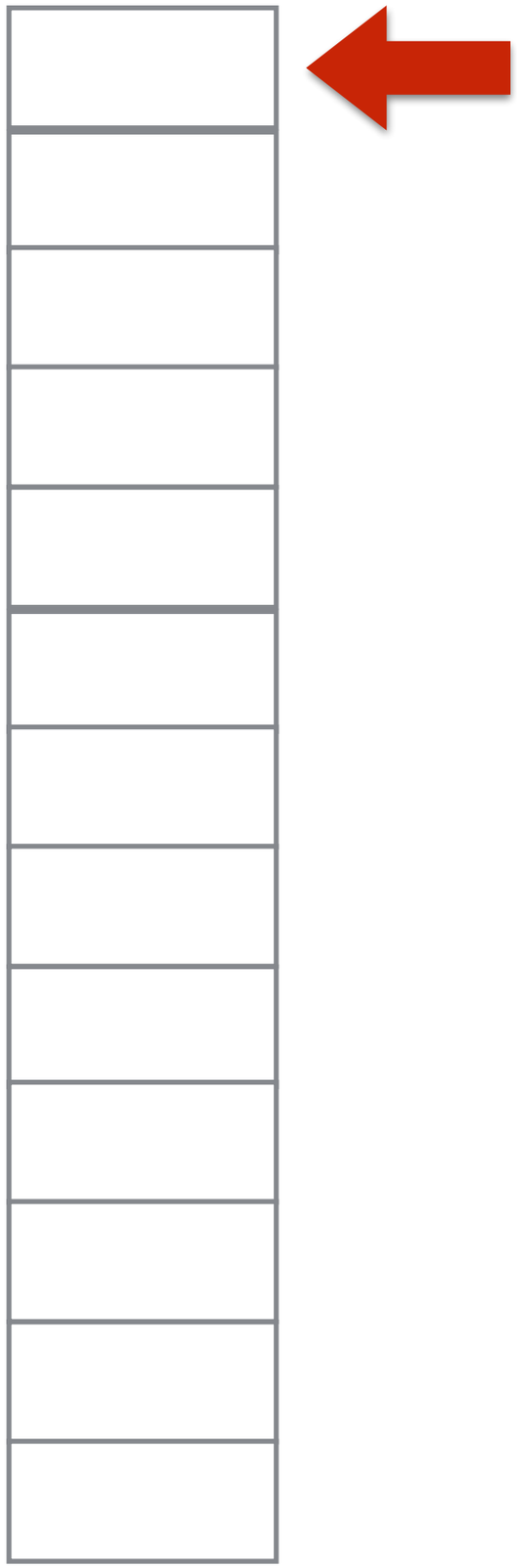
- **Conditional Jump**

- The jump is **taken only if EQ** is equal to **1**.

- Otherwise the execution continues in sequence (Cookie-Monster like)



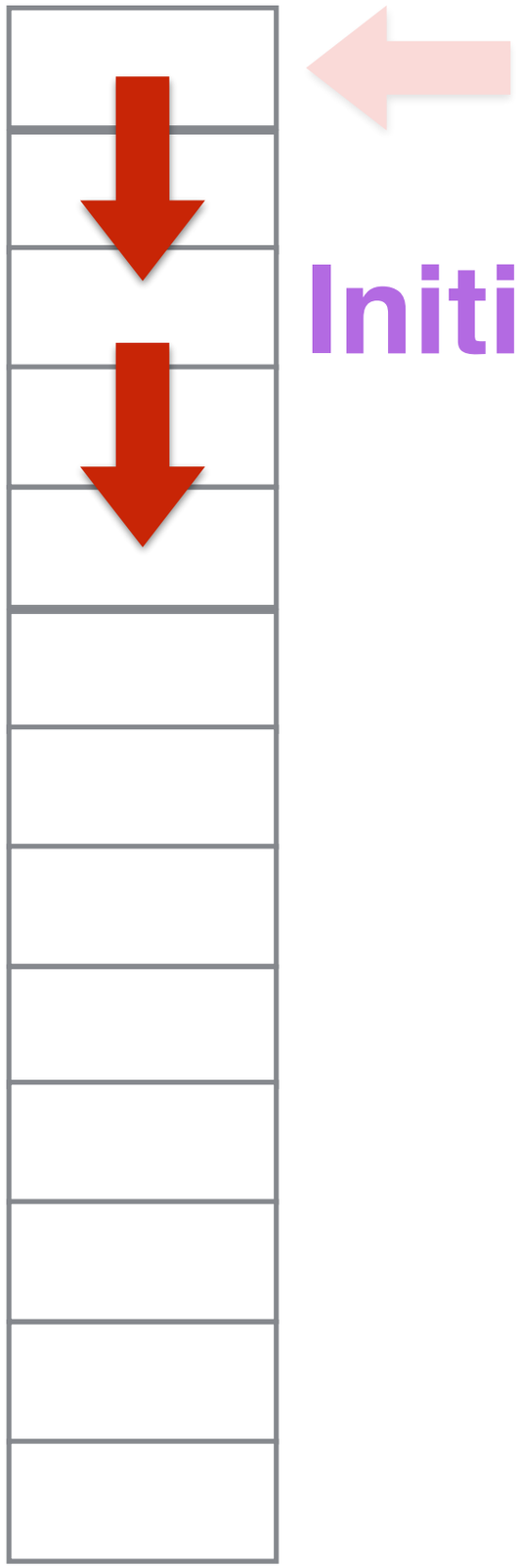
http://bit.ly/2jTJswI



Start

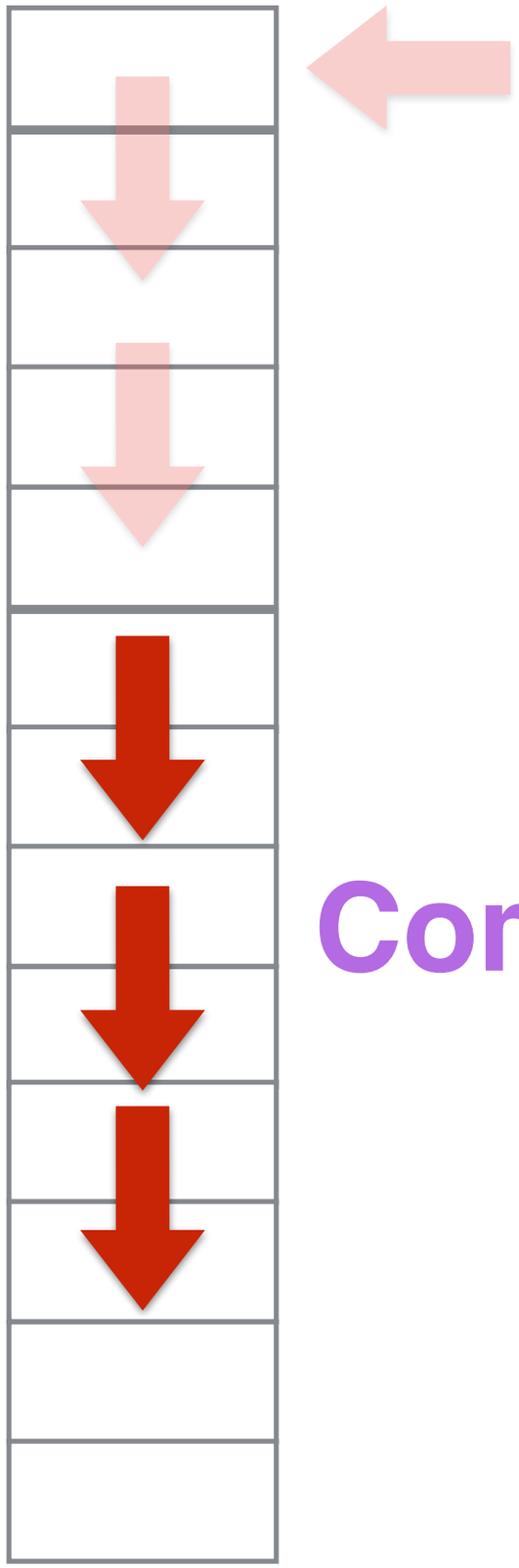
Observations

Observations



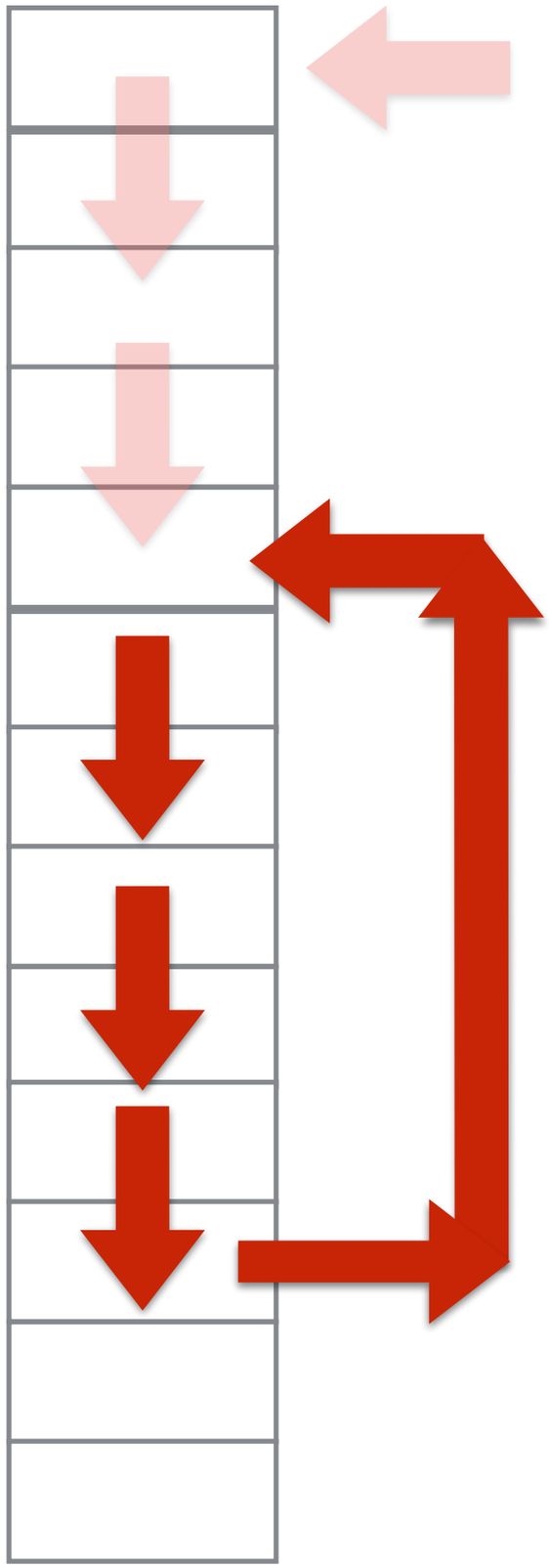
Initialize variables

Observations



Compute intermediate results

Observations



Iterate in a loop

Observations

Finalize the results

Observations

- **Many** programs behave this way
- Computing the sum of 100 numbers requires executing **one addition at a time**, 100 times! The processor can do only 1 **addition at a time**!
- Results get either **printed**, or stored in **files**, or sent over a **network** to some remote destination (cloud)

We stopped here last time…

Exercise

Write an assembly language program that computes sum = 1+2+3+4+…+10

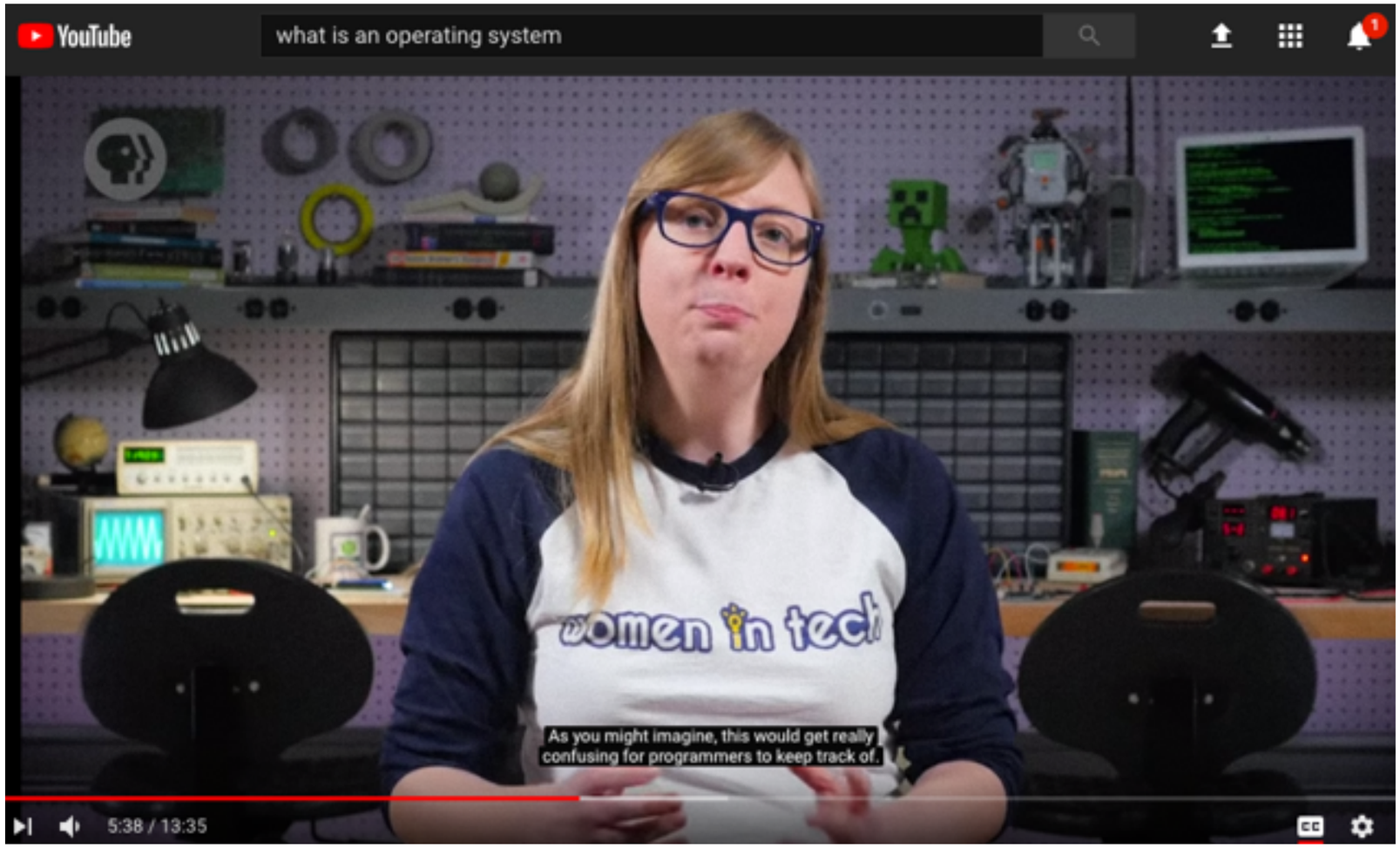
Question

- How long does it take for a 1GHz processor to execute this program?
Note: At a clock speed of **1GHz**, each instruction is executed in **1 nanosecond**, or 10^{-9} seconds.

Solution Program

```
; sum <- 0
; counter <- 10
; loop: sum <- sum + counter
; counter <- counter - 1
; if counter==0 then go to halt
; go back to loop
; halt
0020:    0                  ; sum
0021:    10                 ; counter
0000:    LOAD [20]          ;
0002:    ADD [21]           ; AC <- sum + counter
0004:    STORE [20]         ; sum <- sum + counter
0006:    LOAD [21]          ; AC <- counter
0008:    ADD -1             ; AC <- counter - 1
0010:    STORE [21]         ; counter <- counter -1
0012:    COMP 0             ; counter==0?
0014:    JEQ 18             ;
0016:    JUMP 0             ; loop again
0018:    HALT               ;
```

What is an Operating System?

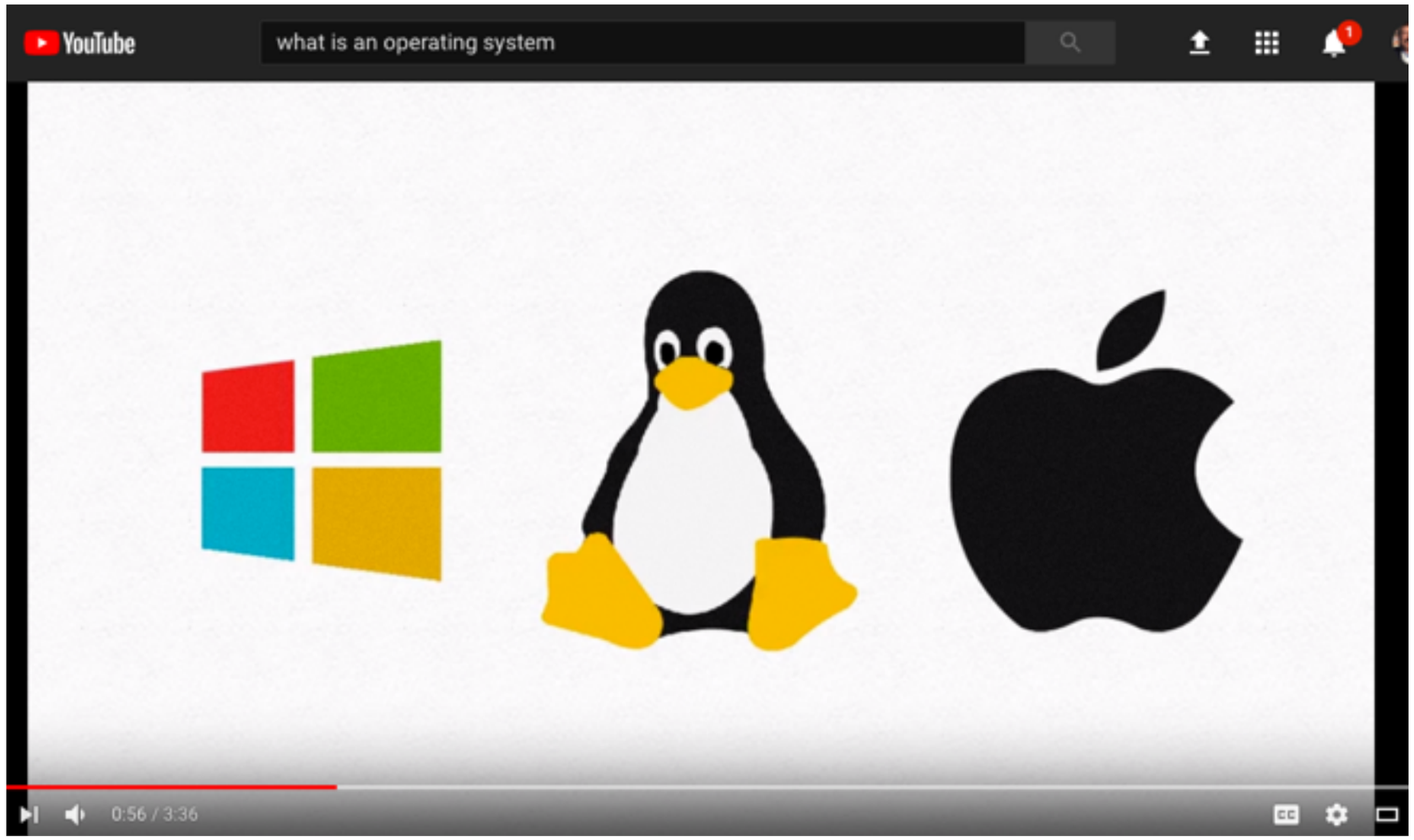


Watch the first 5 min 40 sec

Crash Course Computer Science #18
https://www.hover.com/CrashCourse.

https://www.youtube.com/watch?v=26QPDBe-NB8

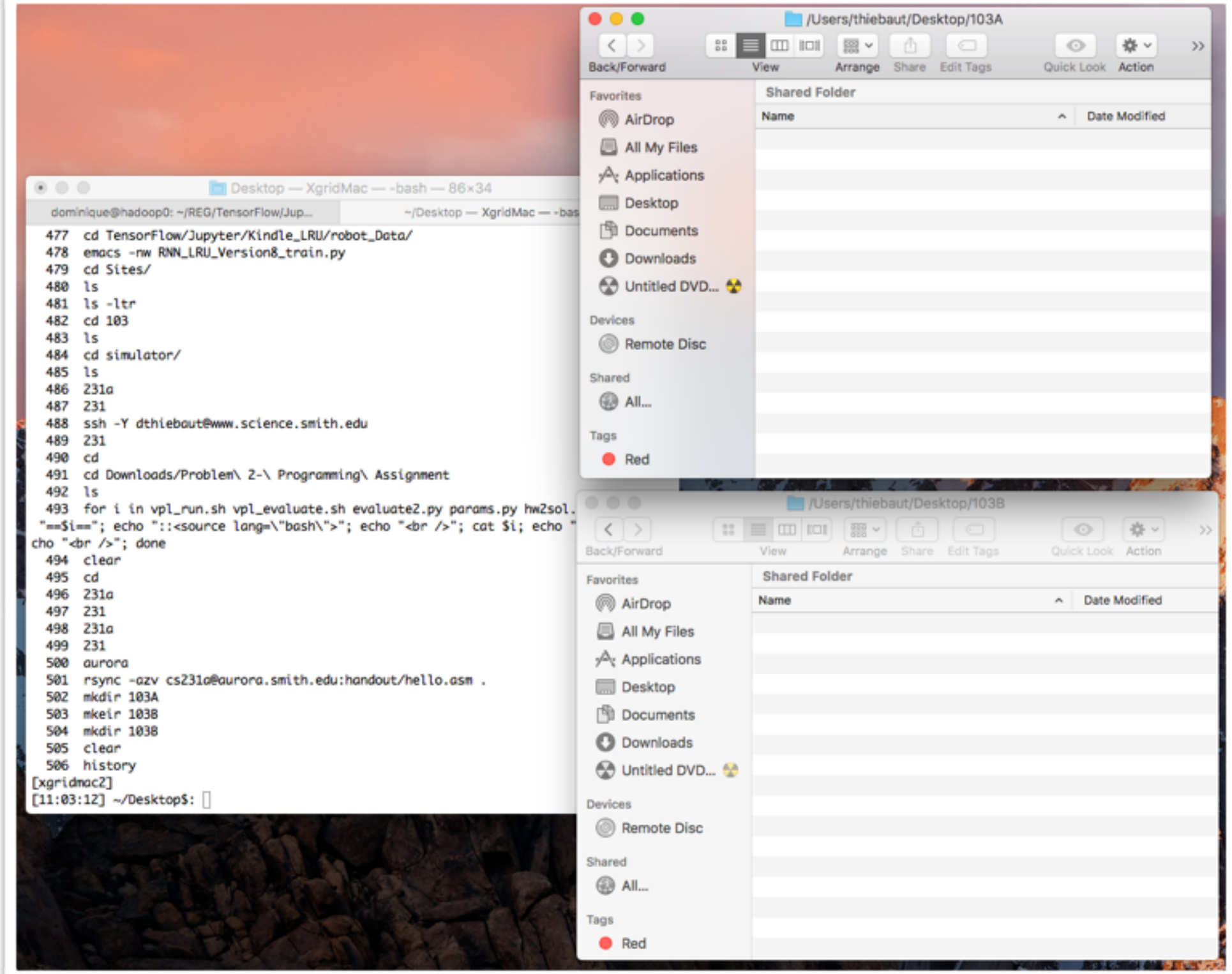
What is an Operating System?



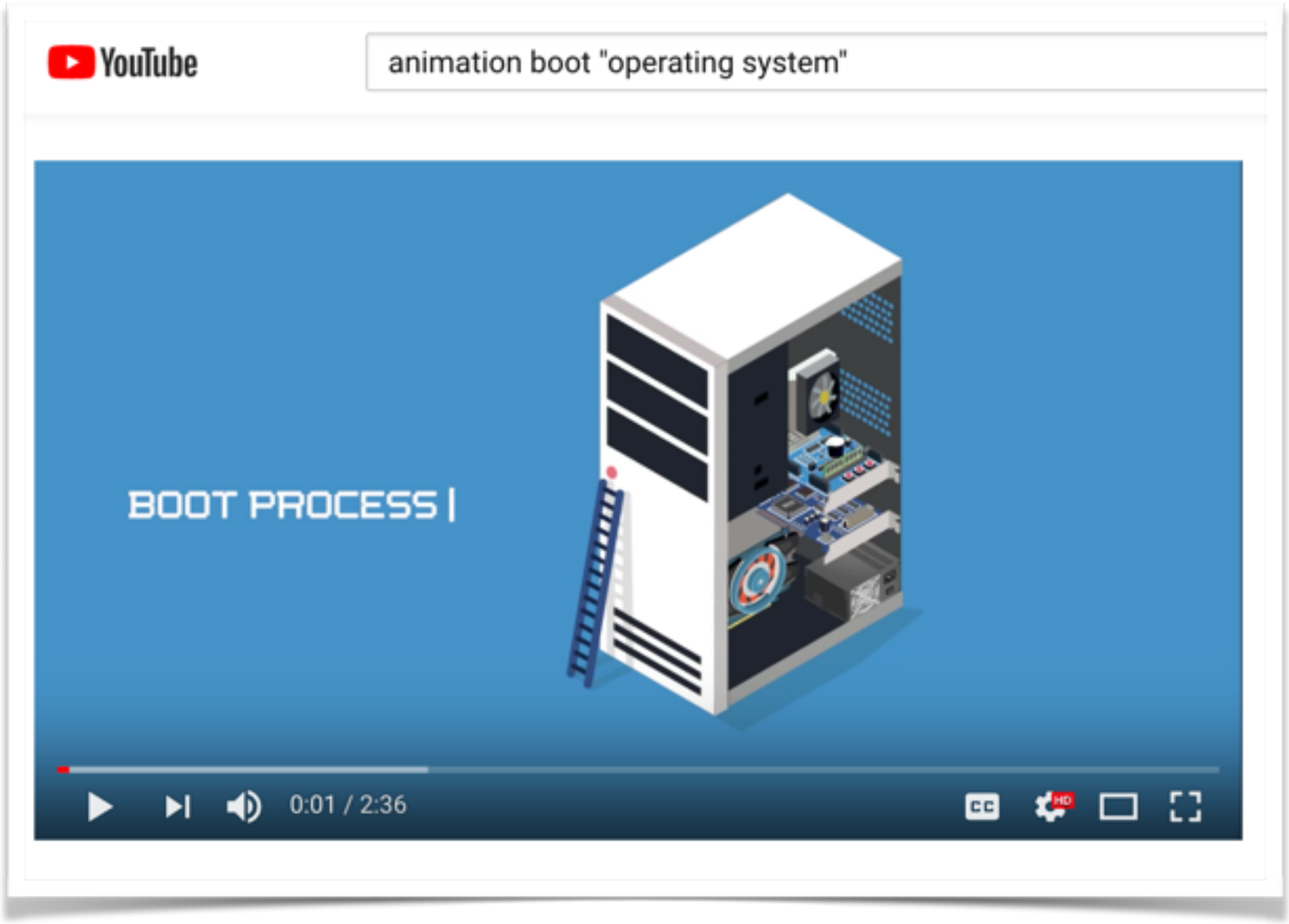
Operating Systems 1 - Introduction
Open Canvas
May 24, 2013

https://www.youtube.com/watch?v=5AjReRMoG3Y

Demo


Desktop — XgridMac — -bash — 86×34
dominique@hadoop0: ~/REG/TensorFlow/Jup...
~/Desktop — XgridMac — -bas
477 cd TensorFlow/Jupyter/Kindle_LRU/robot_Data/
478 emacs -nw RNN_LRU_Version8_train.py
479 cd Sites/
480 ls
481 ls -ltr
482 cd 103
483 ls
484 cd simulator/
485 ls
486 231a
487 231
488 ssh -Y dthiebaut@www.science.smith.edu
489 231
490 cd
491 cd Downloads/Problem\ 2-\ Programming\ Assignment
492 ls
493 for i in vpl_run.sh vpl_evaluate.sh evaluate2.py params.py hw2sol.
"==$i=="; echo "::<source lang=\"bash\">"; echo "
"; cat $i; echo "
cho "
"; done
494 clear
495 cd
496 231a
497 231
498 231a
499 231
500 aurora
501 rsync -azv cs231a@aurora.smith.edu:handout/hello.asm .
502 mkdir 103A
503 mkeir 103B
504 mkdir 103B
505 clear
506 history
[xgridmac2]
[11:03:12] ~/Desktop$:
/Users/thiebaut/Desktop/103A
Back/Forward
View
Arrange
Share
Edit Tags
Quick Look
Action
Favorites
AirDrop
All My Files
Applications
Desktop
Documents
Downloads
Untitled DVD...
Devices
Remote Disc
Shared
All...
Tags
Red
Shared Folder
Name
Date Modified
/Users/thiebaut/Desktop/103B
Back/Forward
View
Arrange
Share
Edit Tags
Quick Look
Action
Favorites
AirDrop
All My Files
Applications
Desktop
Documents
Downloads
Untitled DVD...
Devices
Remote Disc
Shared
All...
Tags
Red
Shared Folder
Name
Date Modified

Boot Process Animated



https://www.youtube.com/watch?v=PSnGuvylWBI