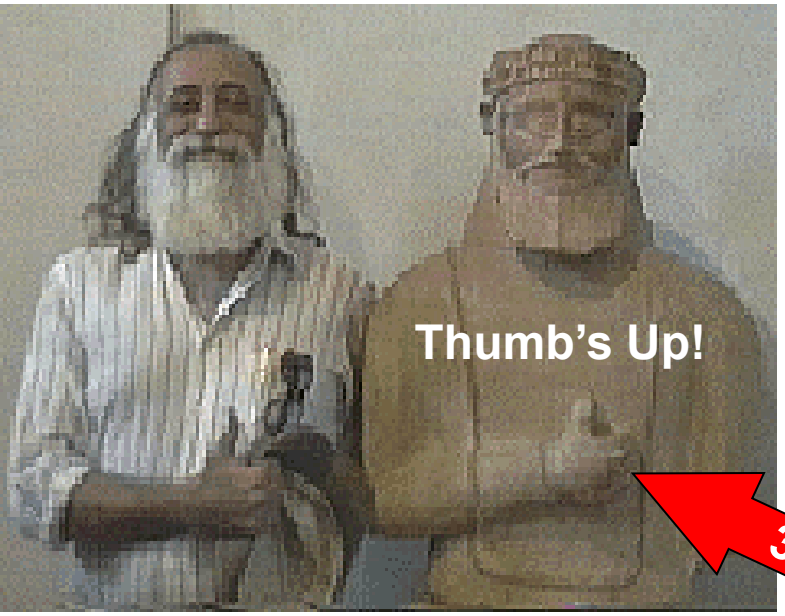
# The Future of Computer Architecture

**Babylonian Dynasty**
**1894-1595 BC**



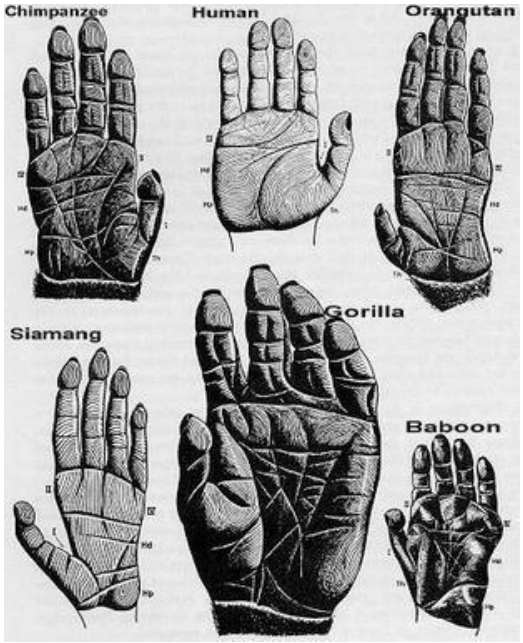

3600 Years

**Space: The Final Frontier**
**1966-1969**

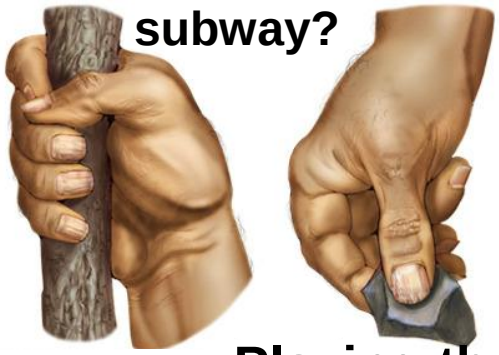

**Phil Emma**
**Chief Scientist**
**IBM TJ Watson Research**
**Sept. 2014**

**In Honor of Yale Patt's**
**Dodranscentennial**
**LXXV**

# Why did God give man opposable thumbs?




Riding the subway?



Playing the guitar?


prosper!
(Vulcans)

Hitch-hiking?

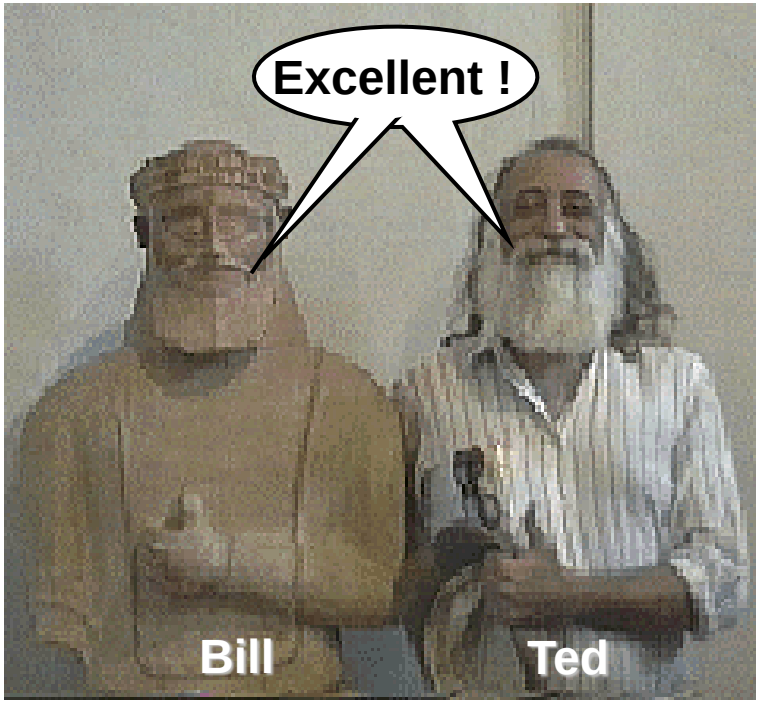

**What can we do because we have thumbs?**

**Give Up?**

# Thumbs are for sports...

## …to hone our hunting skills.


**But we don't USE our thumbs in most sports, and we generally don't use them for hunting!**




**Babylonian Dynasty**
**1894-1595 BC**

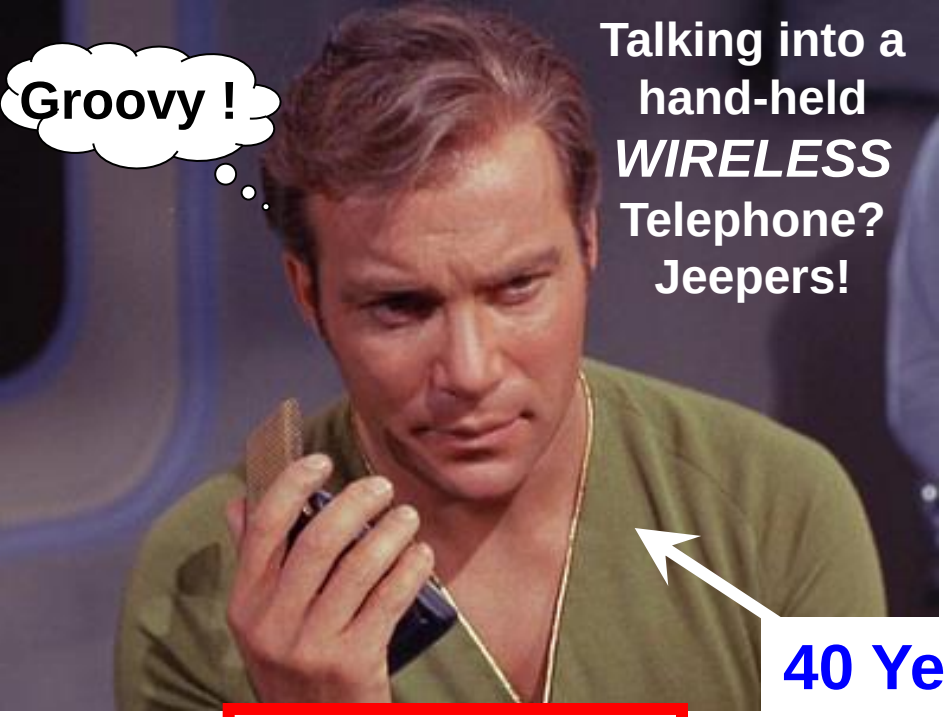

**Space: The Final Frontier**
**1966-1969**

# So what are thumbs for?

# For Texting !!!

# Trends

**1) We are too pessimistic in forecasting when many technologies will happen.**




Kirk: Circa 1970

**40 Years Later…**

Kirk: Circa 2010


**2) And we are almost always wrong about how, exactly, they will manifest.**

**More on thumbs…**

# The Binary Number System & Counting

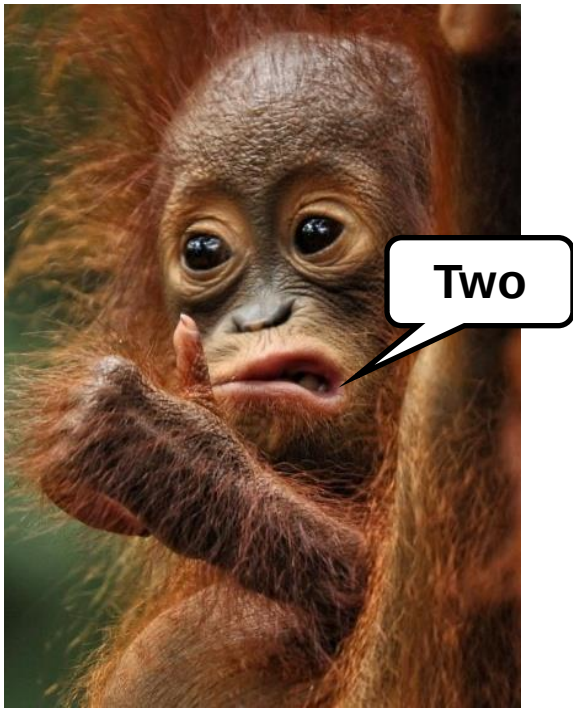
**0** **1** **2** **“Many”**

**Thumbs were first used for counting. That’s why only people and monkeys are known for using Binary.**

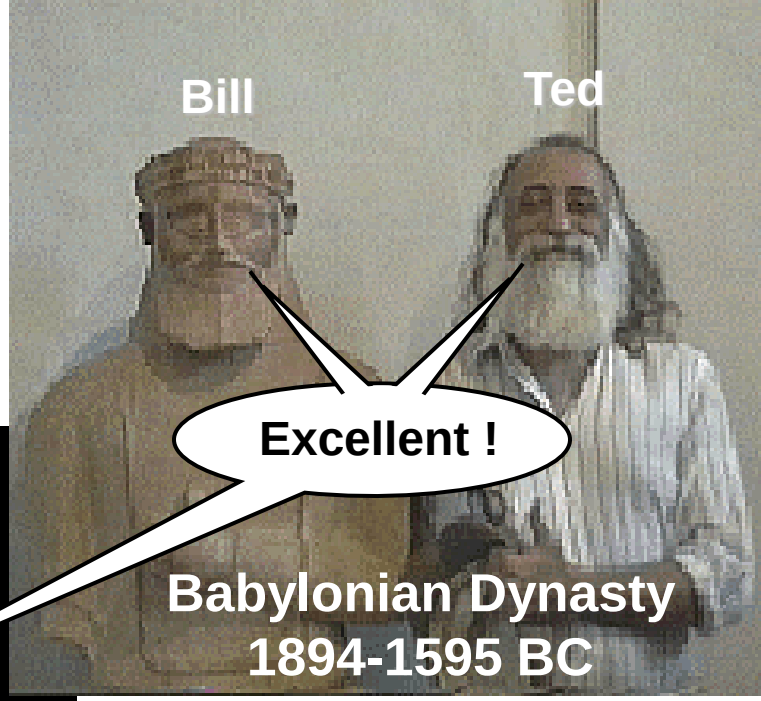
*Aborigines felt no need to count, and while they all had words for “one” and “two,” only some made it to “three.” The Walpiri, for example, only has words for “one,” “two,” and “many.”*

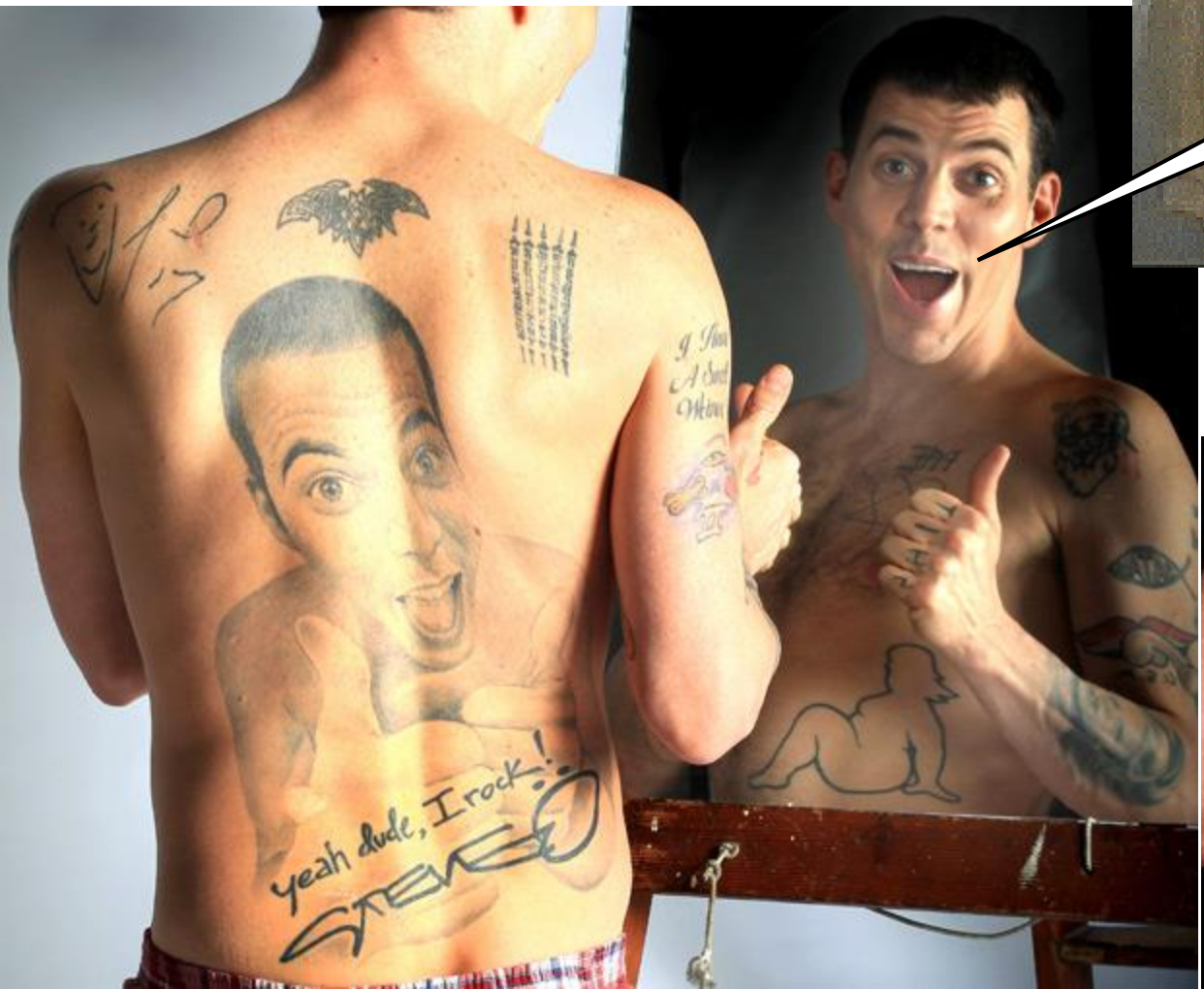
*The Piraha of the Amazon have also been cited as a using a “one-two-many” system of counting.*

**This is why our first few generations of computers have used the Binary number system.**

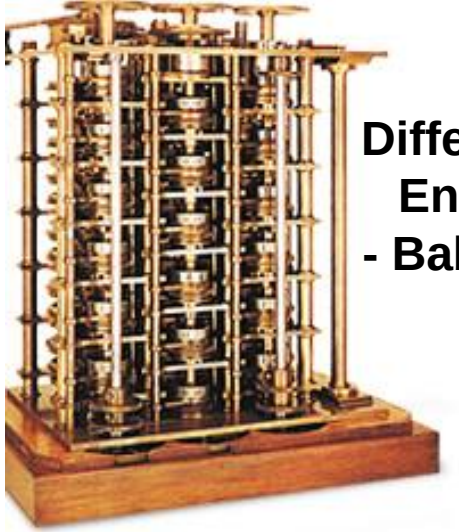


**As we changed to Sexagesimal (Base 60 – used by the Sumerians in the 3rd Millenium BC, and then the Babylonians), Two Thumbs UP, in addition to "Many," was used as a sign of ultimate approval, or of "Excellence;" also it's meaning in Decimal (Base 10) today.**

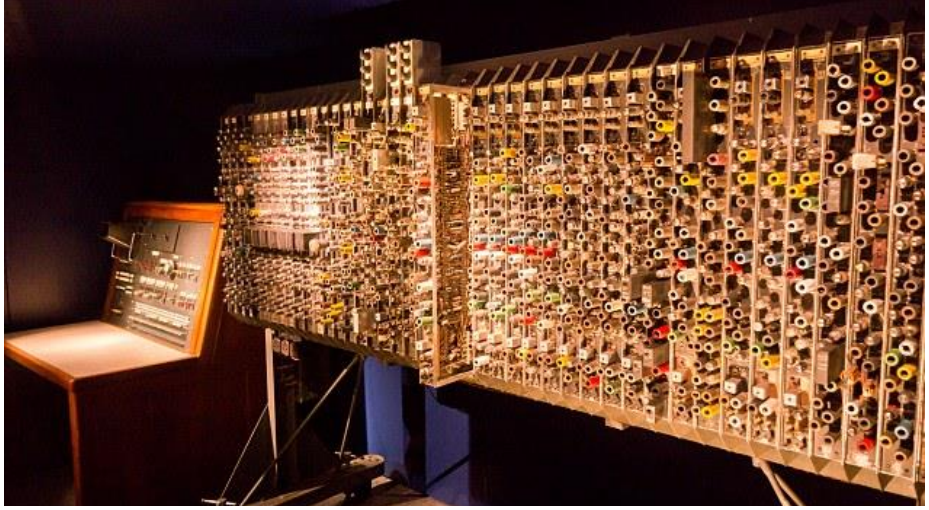


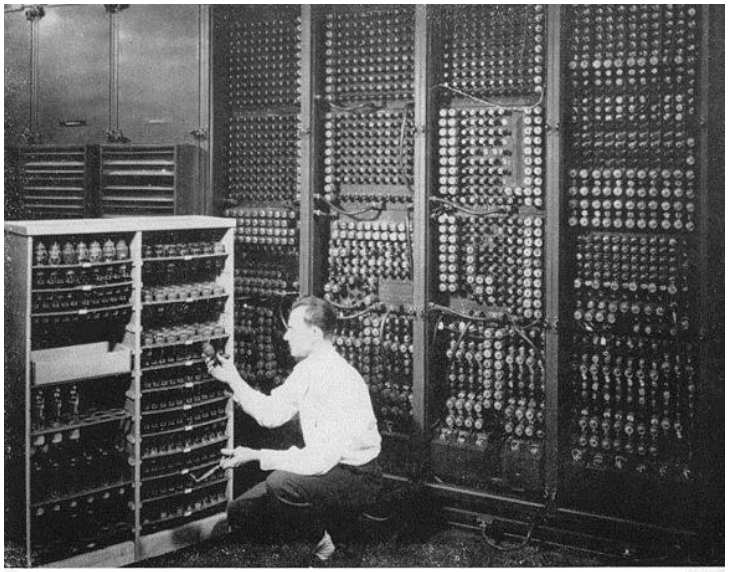

**Steve-O**



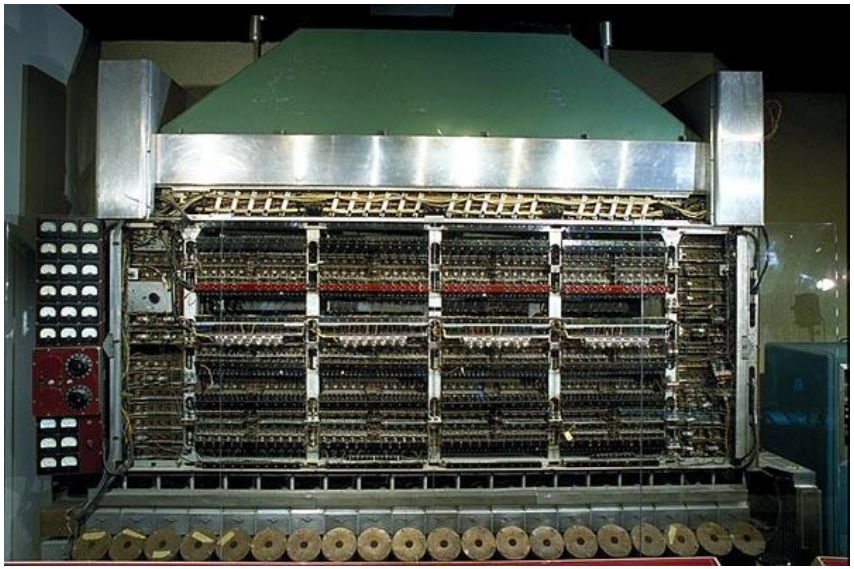
**Difference Engine - Babbage**



**Automatic Computing Engine - Turing**



**ENIAC – Eckert & Mauchley**



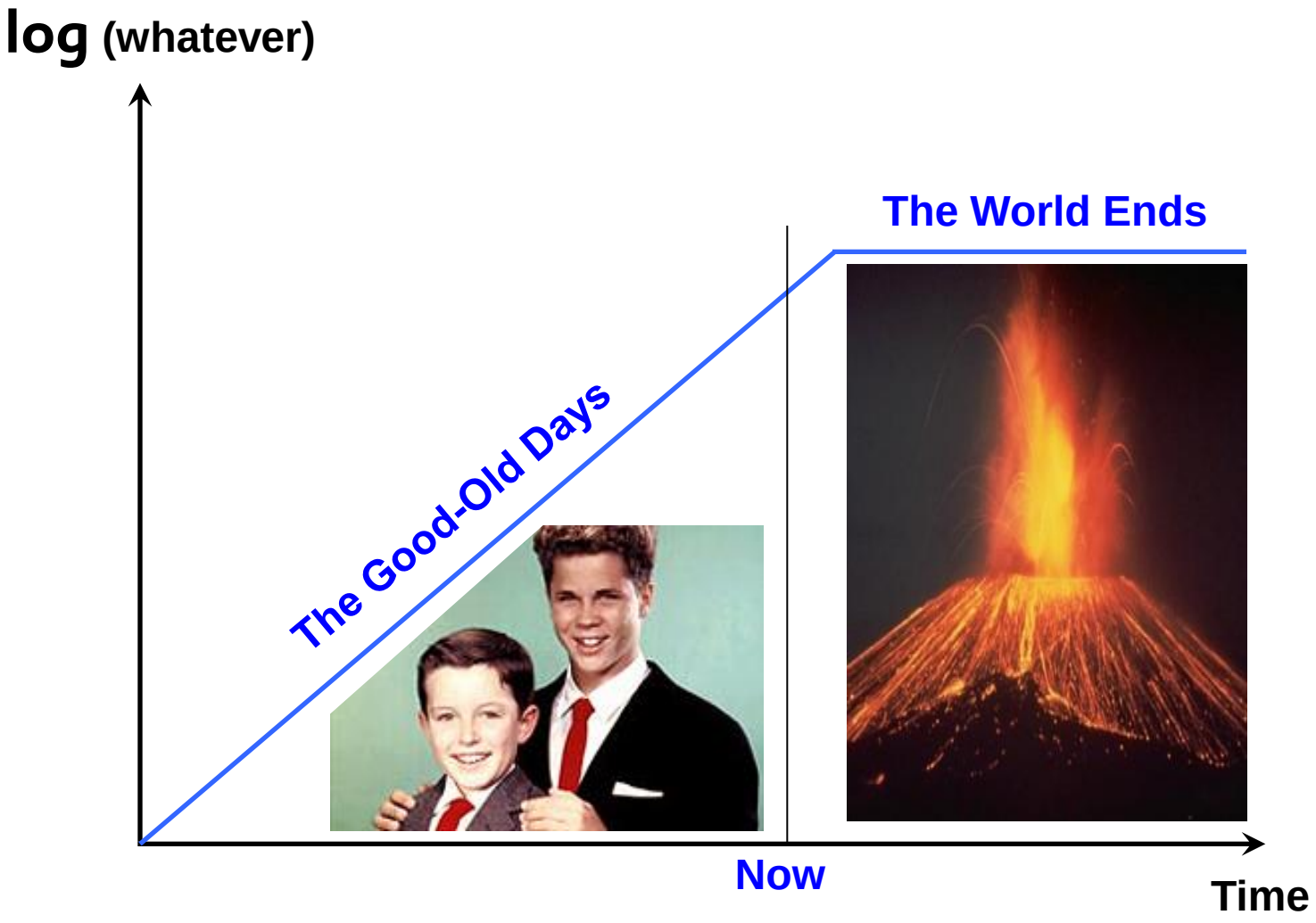
**IAS Machine – von Neumann**

*I am thinking about something much more important than bombs. I am thinking about computers.* **- John von Neumann, 1946**

# Philosophical Breakthroughs

- **Babbage** – *Automatic calculation by machine. Manipulating numbers can be done mechanically – without "thought."*
- **Turing** – *Theory of computation*.
- **Eckert & Mauchley** – *Doing many fast calculations on a very large scale.*
- **von Neumann** – *A stored-program computer. The program can modify itself while running: what the program **does** depends on the data.*

# How Many View Moore's Law

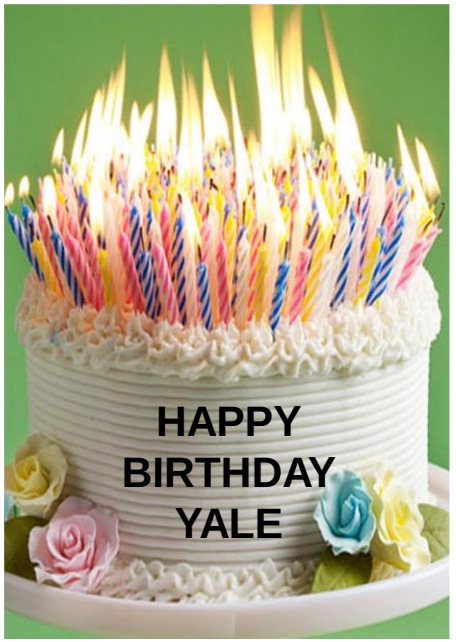


# Moore's Law – My Interpretation

log (whatever)

The Birth of Architectural Innovation !!!

CMOS Roadmap:
No real architectural innovation required.
Keep scaling the Technology!

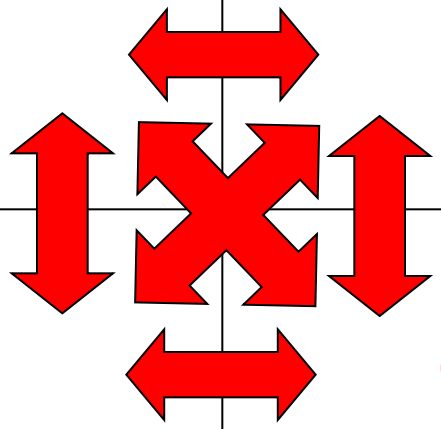

Now

Time

# Where we've been since von Neumann (1946)

## Programming
Binary
Assembly
HLL
Proc.-Oriented
Object-Oriented

## Applications
Calculations
Linear Systems
Text Processing
OS
Database
Transactions

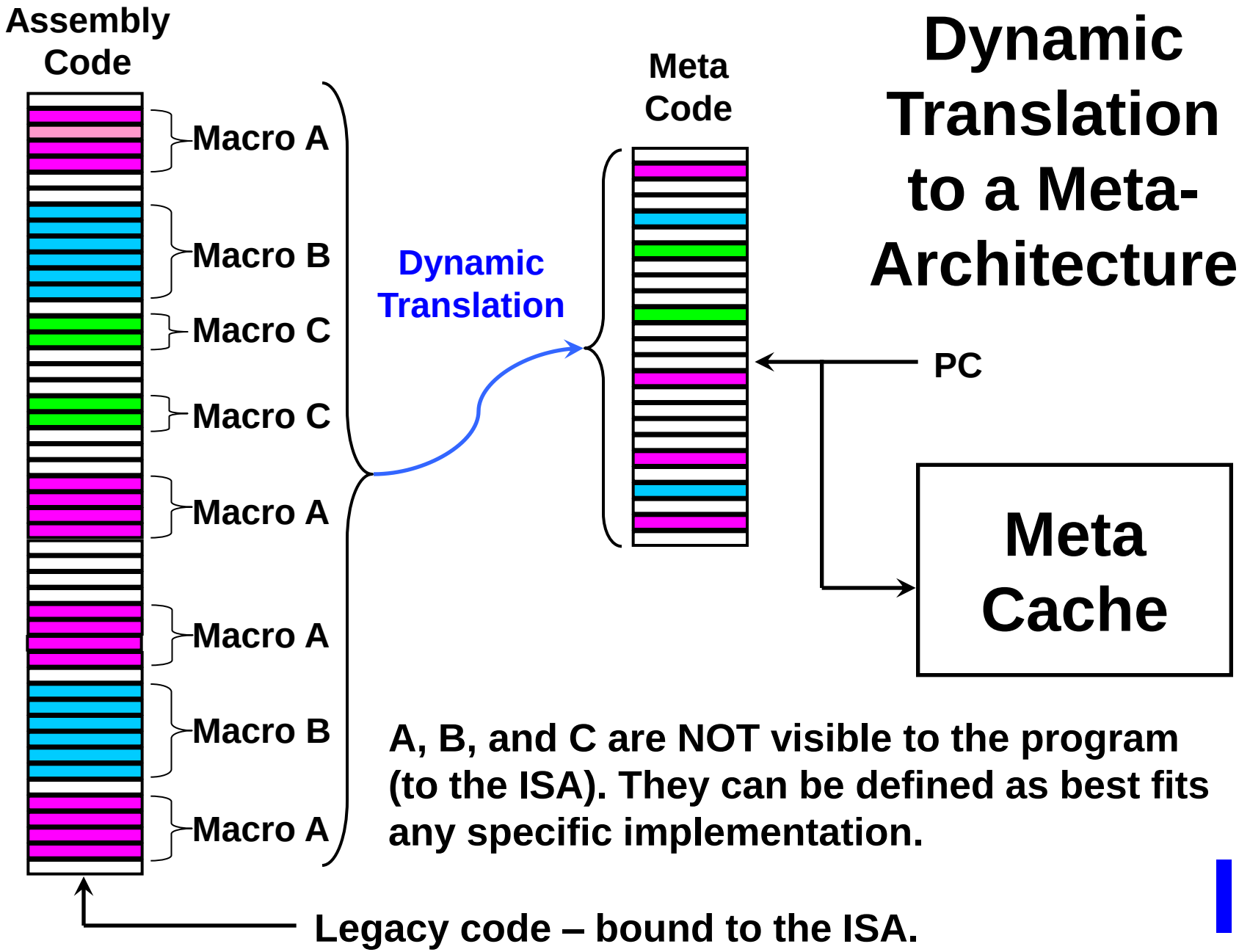


## Architecture
Registers
Stacks
Virtual Machines
VLIW

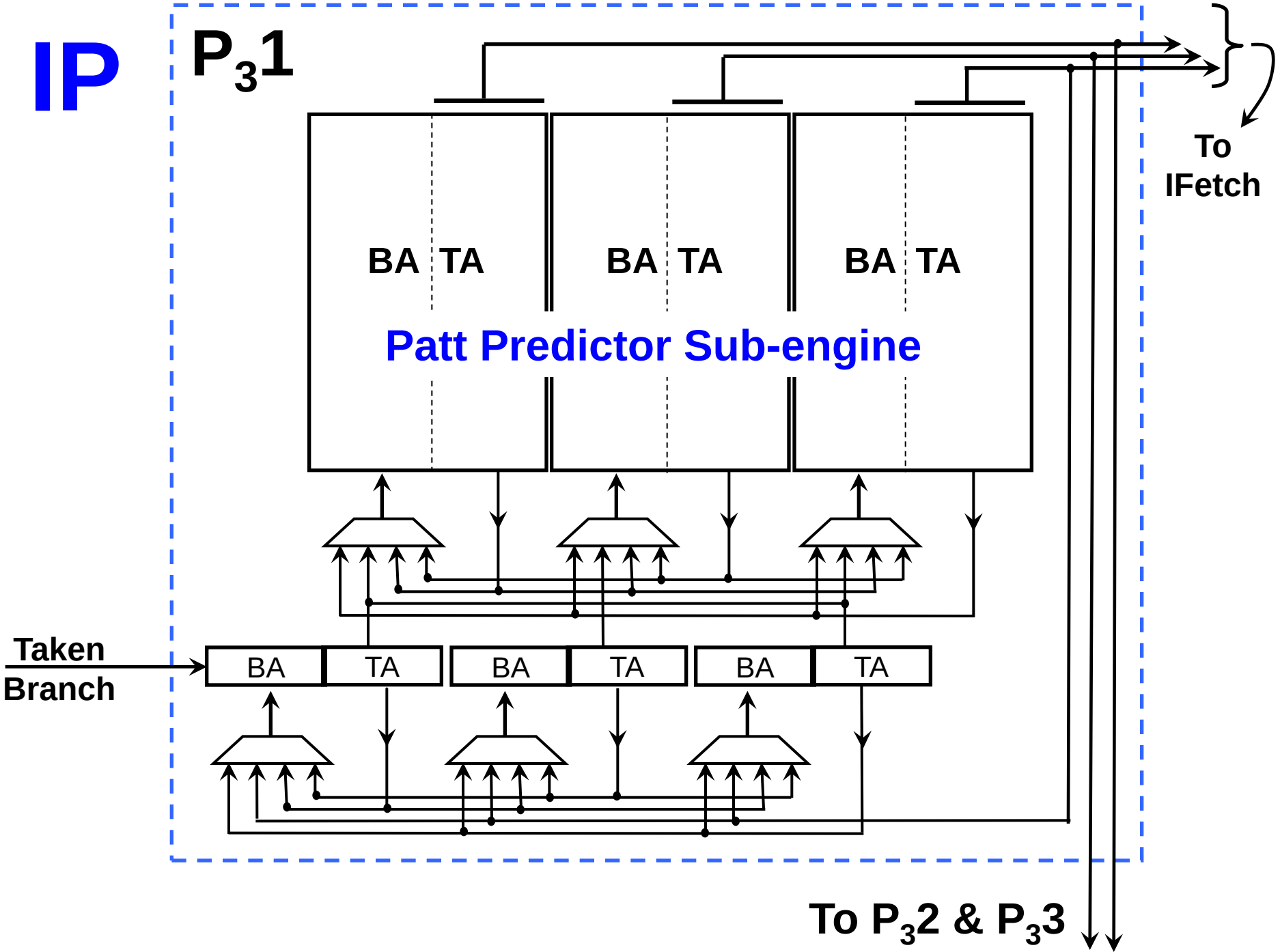
## λArchitecture
Scalar
Cache
Superscalar
Branch Pred.
Multithreading

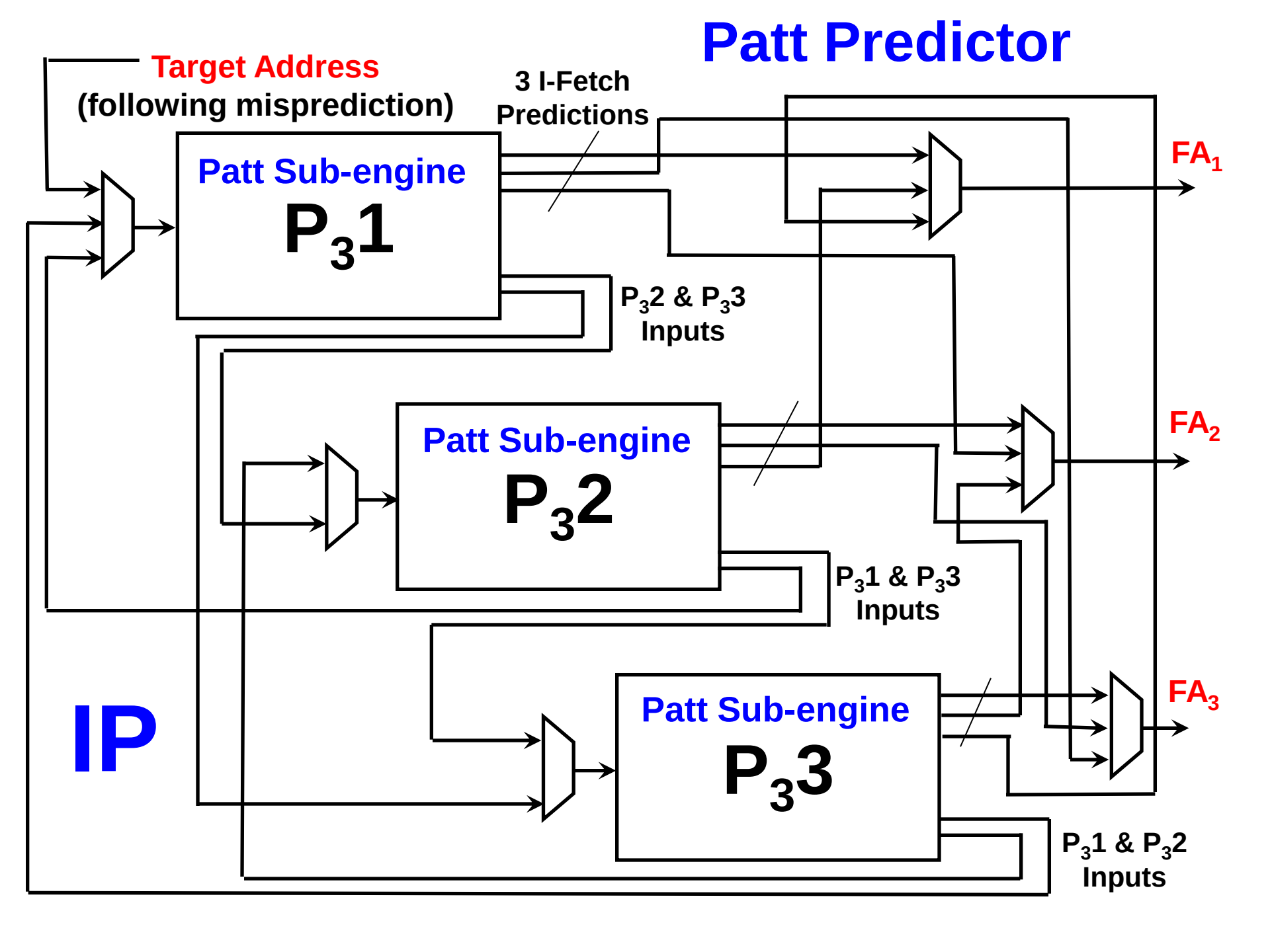
**What dimensions have failed to evolve?**

# Dynamic Translation to a Meta-Architecture




IP


IP
P3 1
BA TA
BA TA
BA TA
Patt Predictor Sub-engine
To
IFetch
Taken
Branch
BA
TA
BA
TA
BA
TA
To P3 2 & P3 3

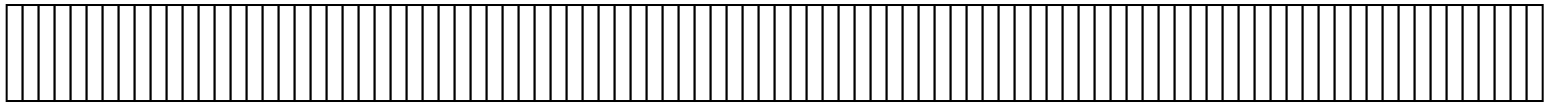

Patt Predictor
Target Address
(following misprediction)
3 I-Fetch
Predictions
Patt Sub-engine
P3 1
FA1
P3 2 & P3 3
Inputs
Patt Sub-engine
P3 2
FA2
P3 1 & P3 3
Inputs
IP
Patt Sub-engine
P3 3
FA3
P3 1 & P3 2
Inputs

# Three Big Ones

- **Environmental**
  - What's the temperature? (Regulate)
  - How much energy & power? (Regulate)
  - What's running with me? (Optimizing)
  - Cost of operation? (Dynamic Adjusting)

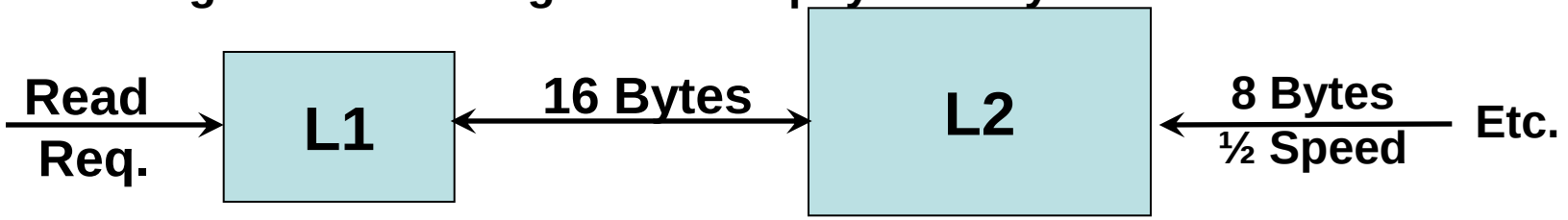
  } **Duh!**
- **Moving Beyond Scalar Operands**
  - Vectors, Matricies
  - Records, Linked Lists
  - Objects
- **Abstract Computing, Acceleration**
  - Direct manipulation of surfaces & objects
  - Sensory operation
    - Hardness & shape
    - Odor & Taste
  - Estimation & approximate computing
  - The Brain???

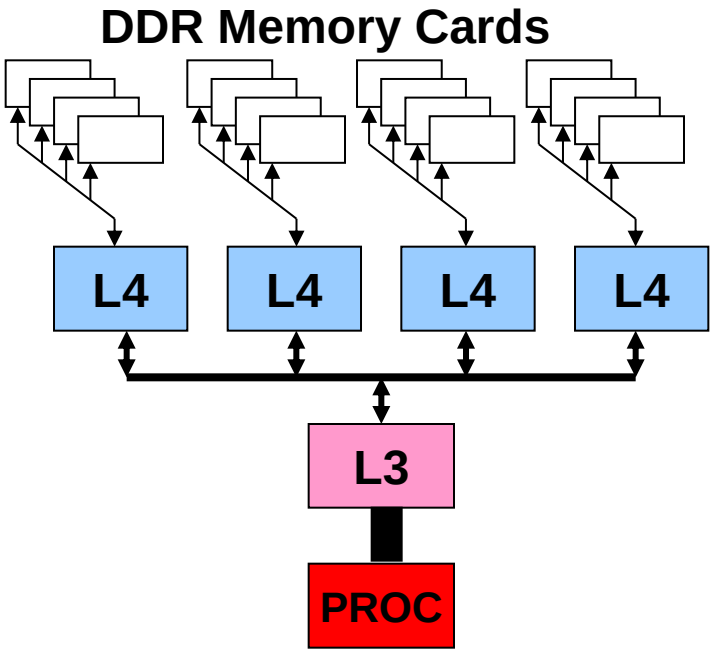
# The NEW Definition of the von Neumann Bottleneck !



0……n

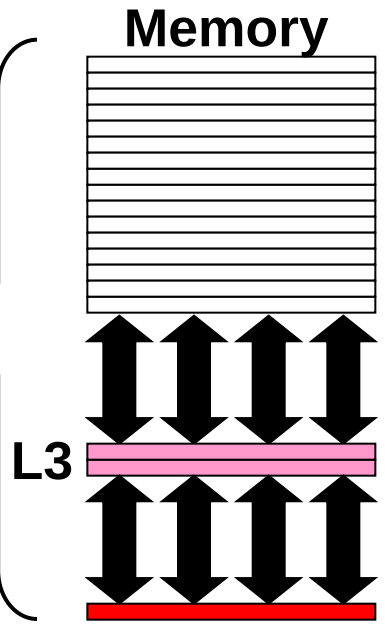
To the program, storage looks like this. Why? Because different levels of storage know nothing about the physical layouts of other levels:



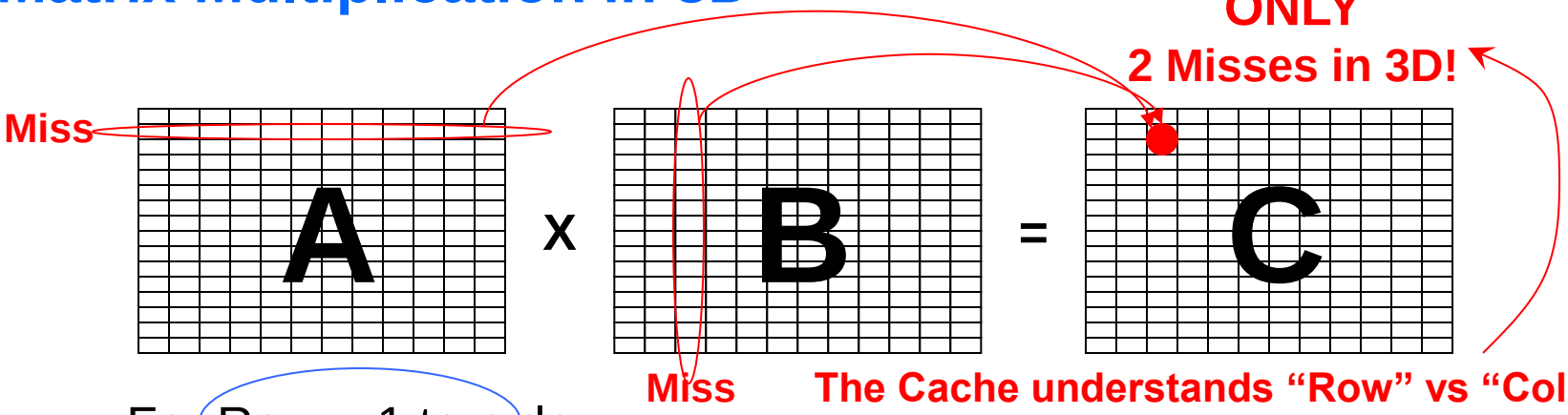

**Why does the OS juggle 100s of jobs today?**

**A physical 3D system like this would *simplify* the OS dramatically.**



# How Could 3D Enrich the ISA?

## Matrix Multiplication in 3D



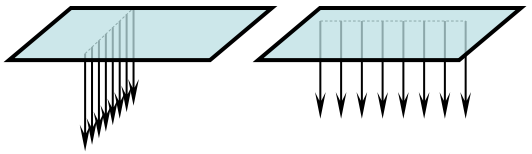

```
For Row = 1 to n do
Begin
    For Col = 1 to n do
    Begin
        C[Row,Col] := A[Row] X B[Col];
    End;
End;
```

Only 2 Registers Required:
They're purely "Structural,"
i.e., it's a 2D structure.

**ALL Scalar Code Is Gone!**

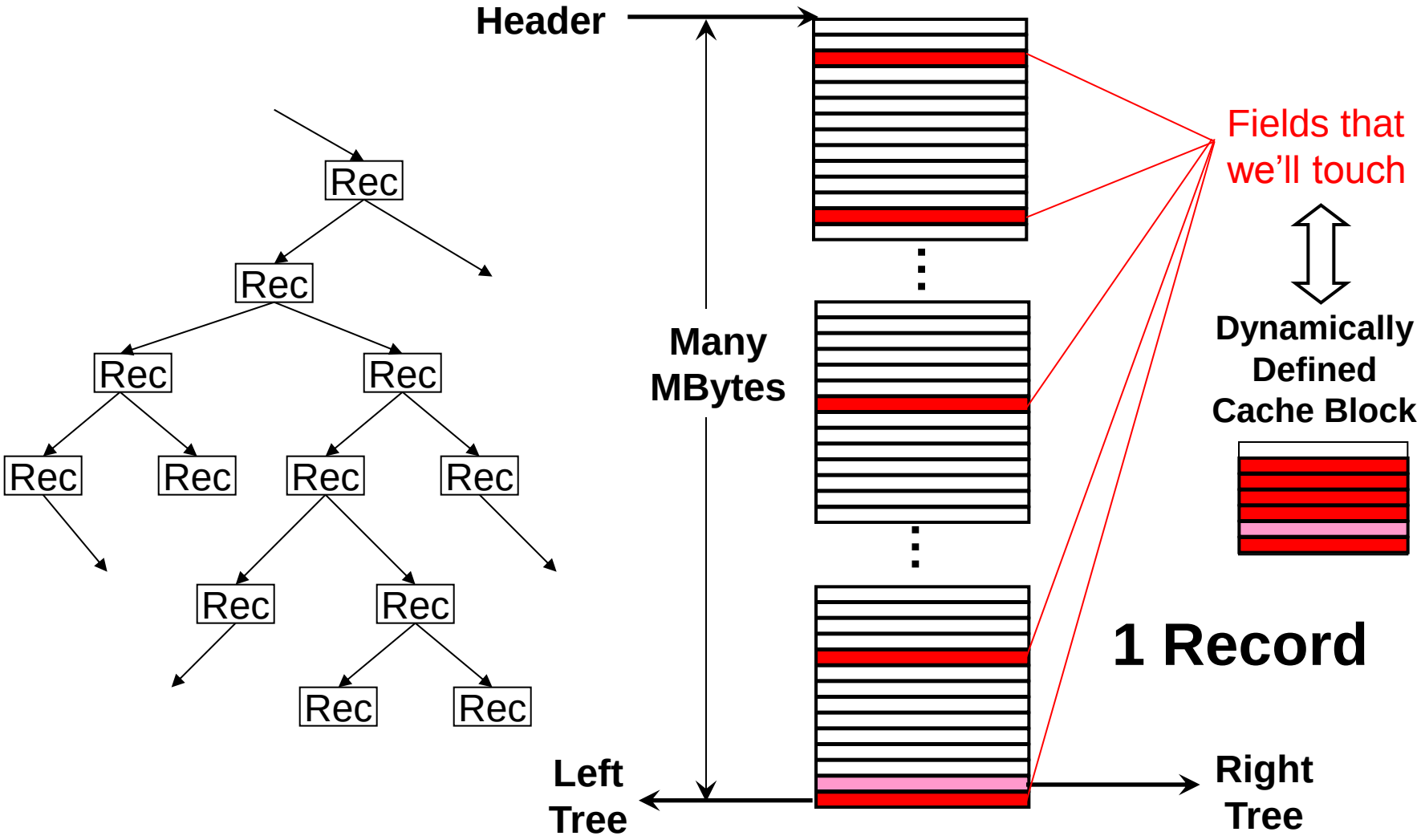
**This is a NEW Machine-level Instruction!**

If I have multiple planes of data (in 3D), I can deal with multidimensional data directly.



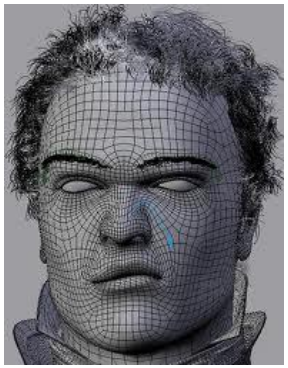
**This is >> Order of Magnitude Speedup, and uses FEWER registers**

# Making the Architecture More Powerful

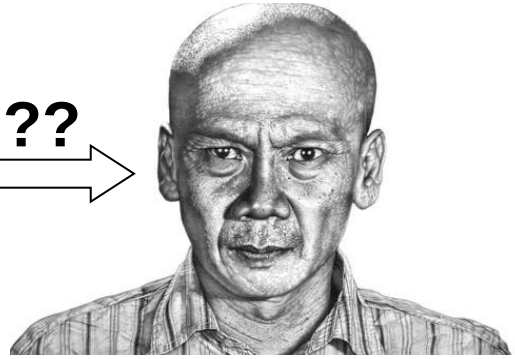



**Why doesn't the ISA or the cache "understand" these structures?**

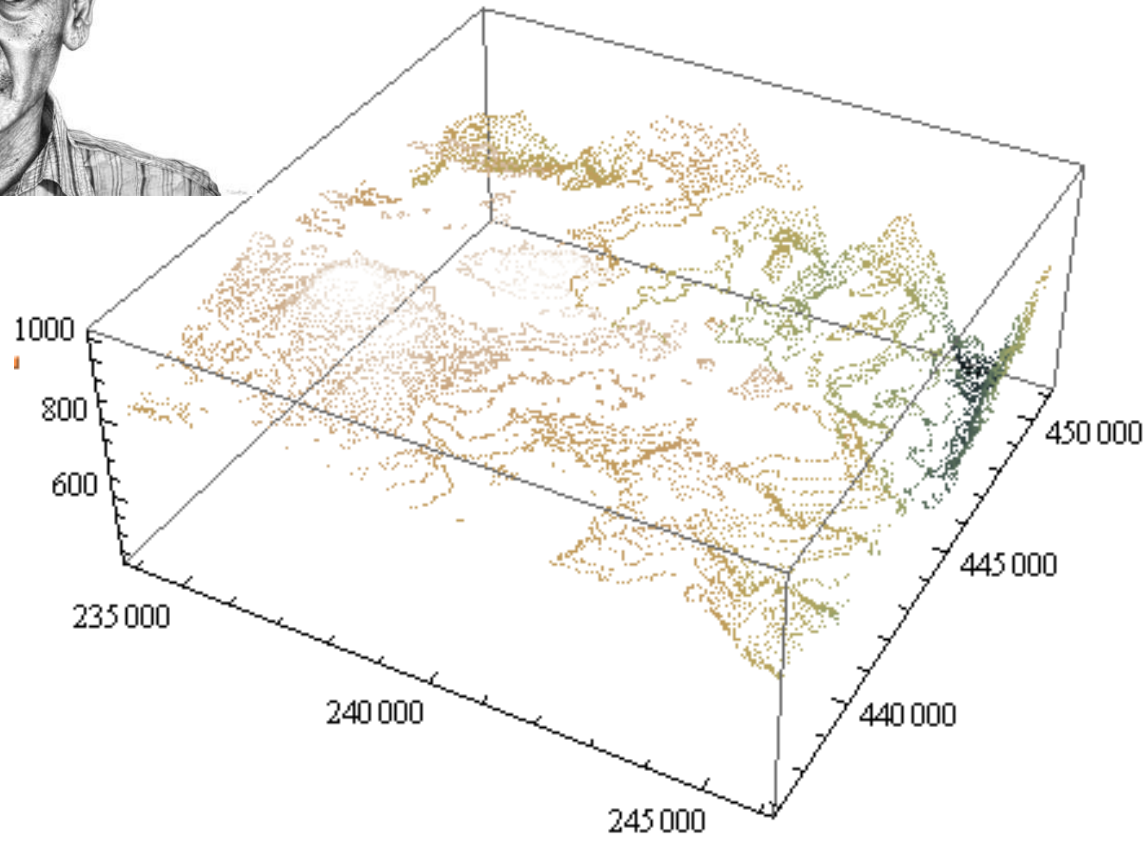
# Manipulation of Topologies

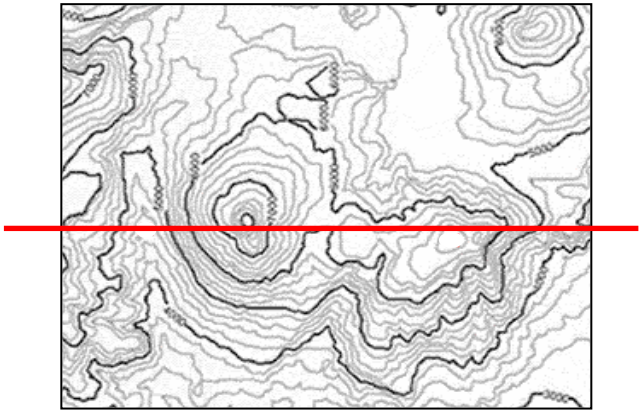


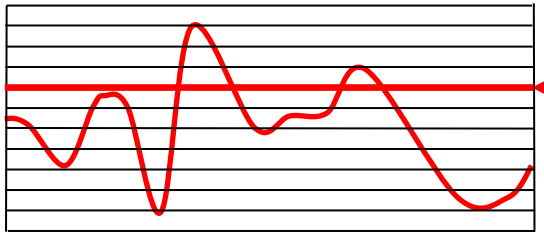
???



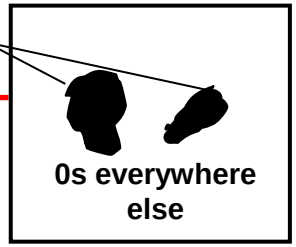
Facial Recognition



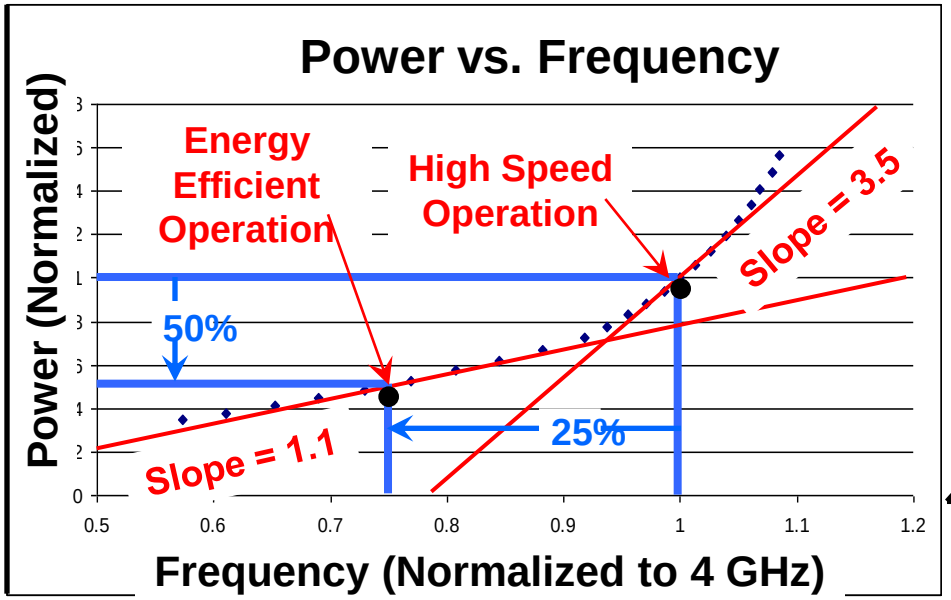


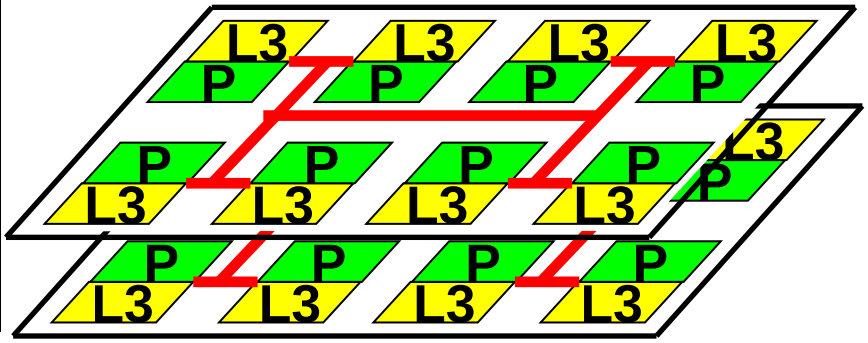
1s
ss

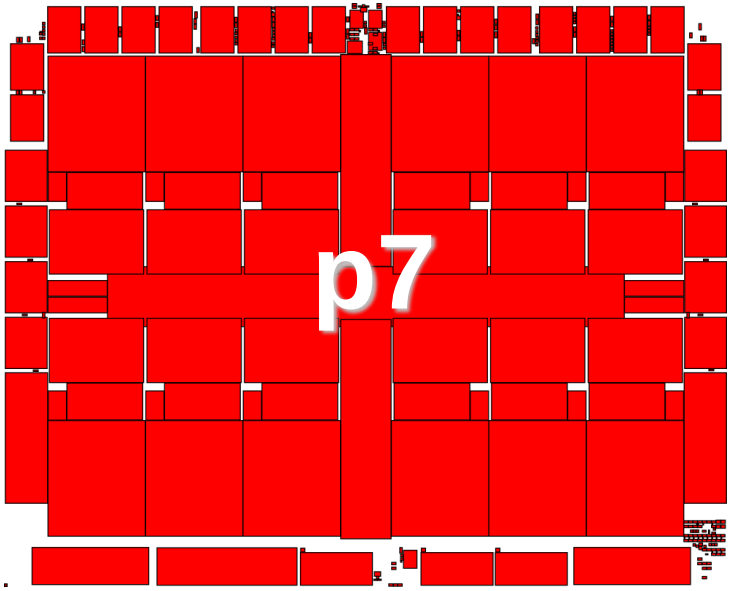


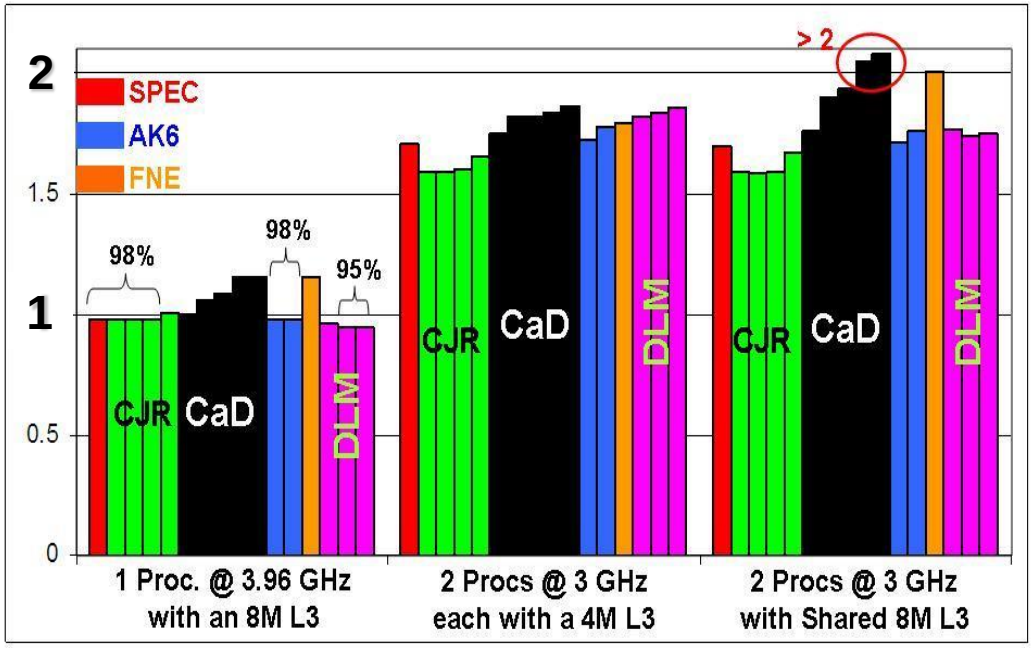

Topographical Maps

# 3D Core-on-Core Study



# What is "*Architecture*" ?

***The purpose of "Architecture" is to create a good interface between applications and technology*** – with a classical understanding of applications, and a contemporary grasp of the technology.

***Both evolve. And each drives the other.***

***Architecture requires broad technical knowledge, coupled to a lively imagination, and what I'll call an "Artistic Sense."*** You can calculate parts of what you need, but sheer "facts" are insufficient.

**Success: Is it a Blessing or a Curse?**

# Academia

## What Kind of Research Should we Do?

***"A great building must begin with the immeasurable, must go through measurable means when being designed, but in the end must be unmeasured."*** **– Louis Kahn**

***"Architecture should have little to do with problem solving - rather it should create desirable conditions and opportunities hitherto thought impossible."*** **– Cedric Price**

***"If you want to get rich from writing, then write the sort of thing that's read by persons who move their lips when reading to themselves."*** **– Don Marquis**

***"I want a man who is kind and understanding. Is that too much to ask for in a millionaire?"*** **– Zsa Zsa Gabor**