

Lecture 1 – Introduction

Stanford CS343D (Winter 2025)

Fred Kjolstad

Course staff



Fred Kjolstad



Christophe Gyurgyik

Administria

- Syllabus at <https://cs343d.github.io>
- Discussion will happen through Ed in Canvas
- Office Hours
 - Fred: Thursdays 3-4pm in Gates 486
 - Chris: Friday 10-11am Gates 4B common area

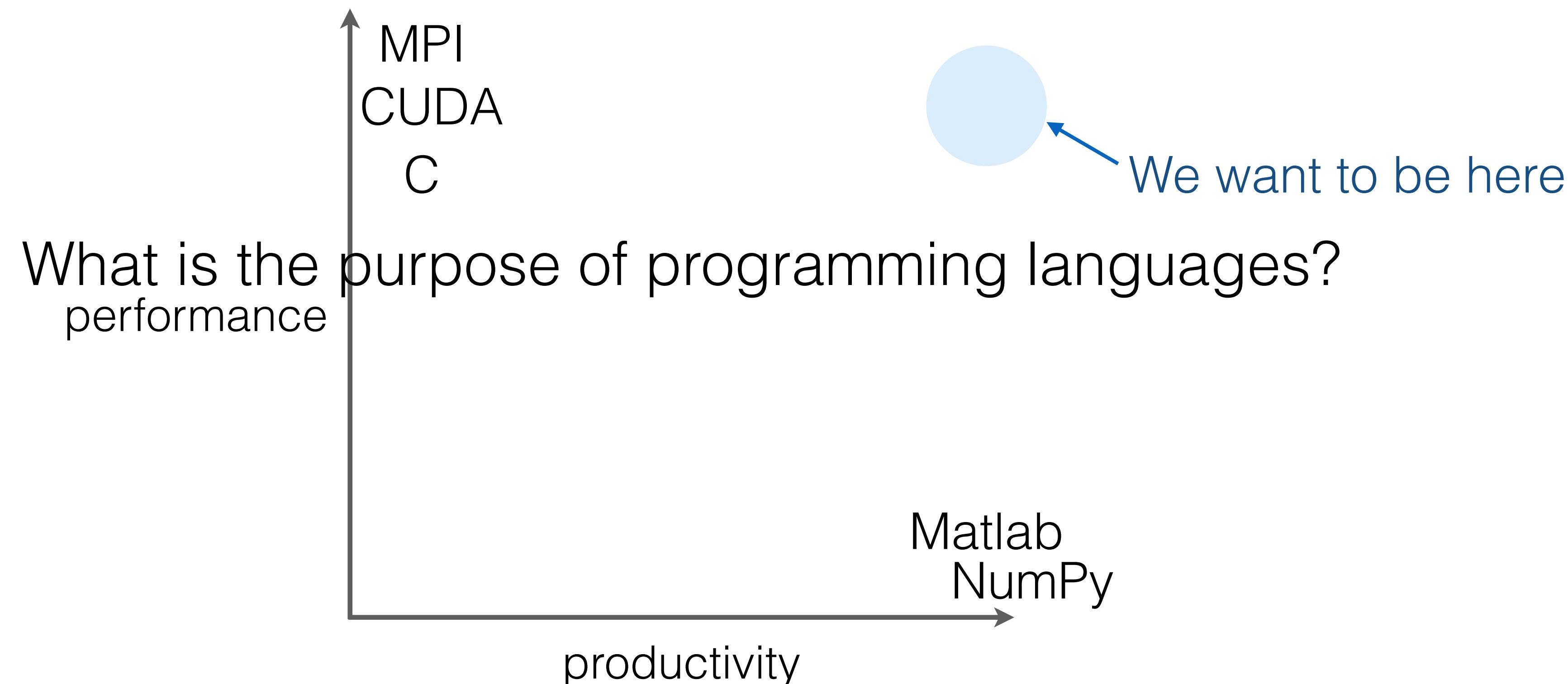
Goals of the Course

- Introduce you to domain-specific and collection-oriented programming languages from the past
- Introduce you to compiler techniques to get good performance for dense and sparse applications
- Bring you to one of the frontiers of PL and compiler research
- Get you thinking about abstractions and semantics
- “What are the three biggest ideas in computer science? Abstraction, abstraction, abstraction.”
-Paul Hudak

Expectations

- Read papers and engage in class (25%)
 - ~2 readings per class
 - Classes will have a lecture followed by paper discussion
 - Everyone will get a chance to lead a discussion
- Two assignments (20%)
 - MiniAPL
 - Sparse Coiteration Code Generation
- Essay (15%)
- Project (40%)

It is all about productivity, performance, and correctness



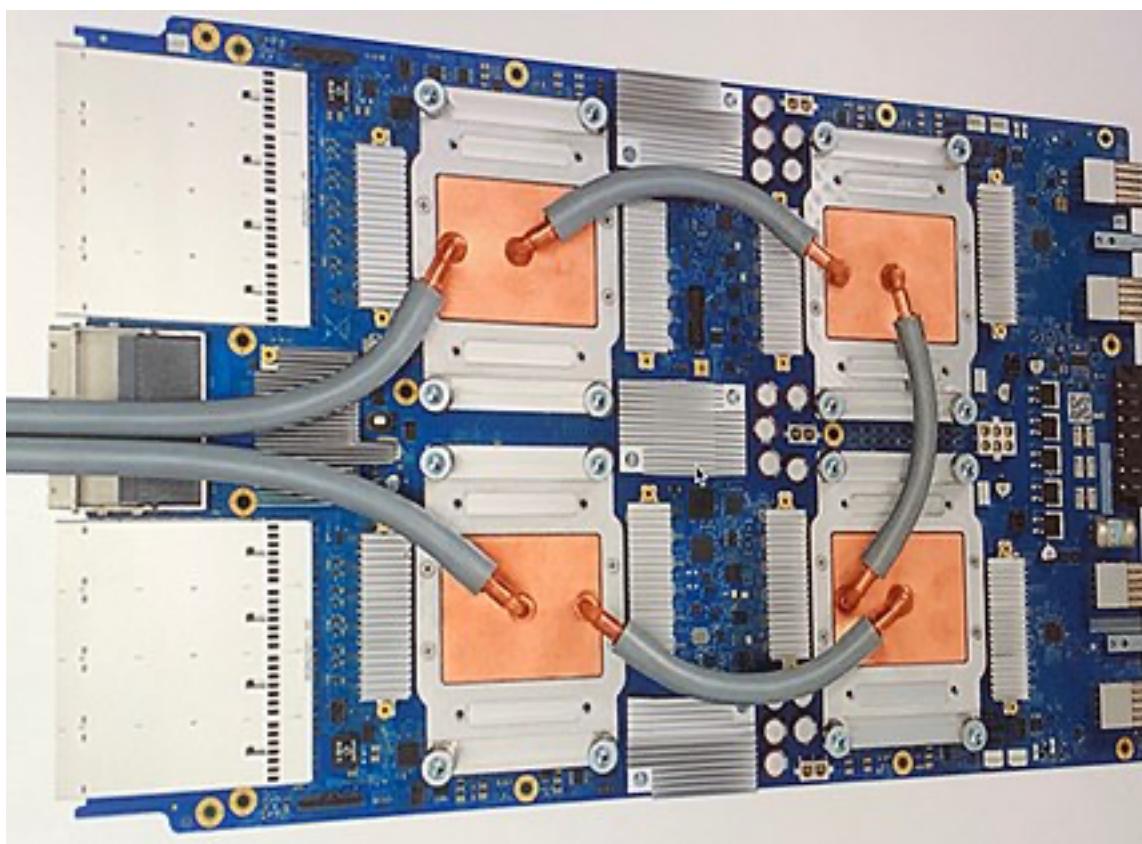
Performance translates to less time and less energy



Data centers



Supercomputers



Tensor Processing Unit



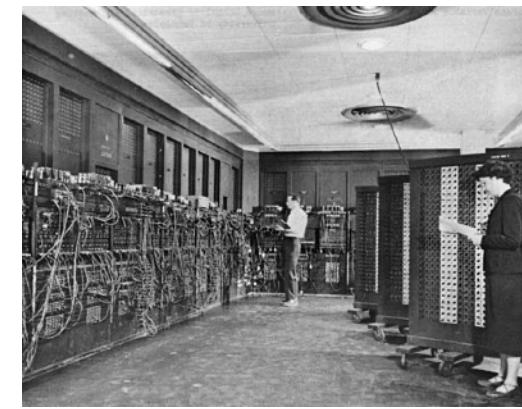
Self-driving cars



Cell-phone batteries

Eras of Computing

Simulation (1945–1965)



Data processing (1965–1984)



Personal Computing (1984–1995)



Communication (1995–2020)

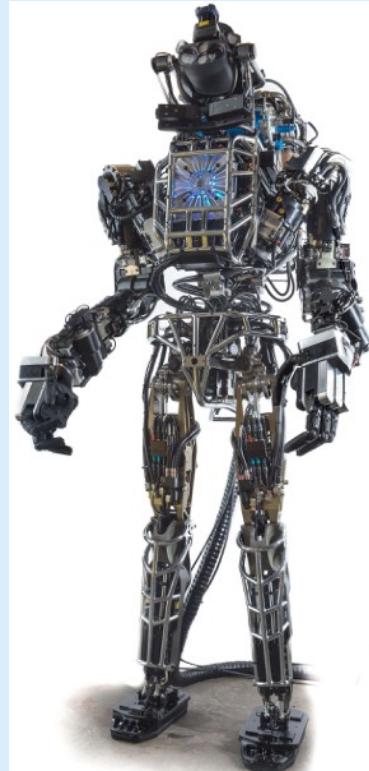


Interaction and AI



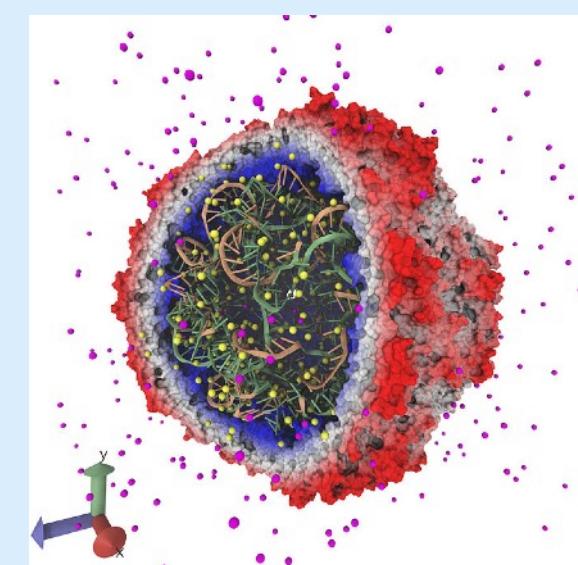
Modern applications are performance hungry

Simulation and Optimization



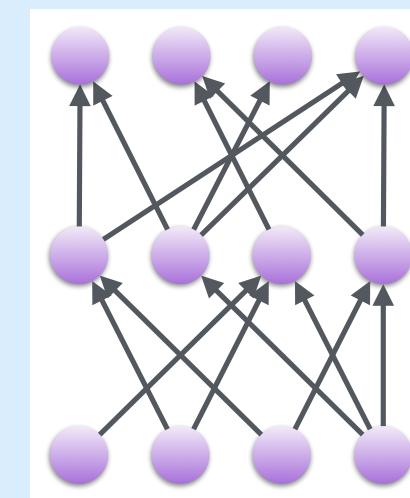
Graphics Simulations

Robotics

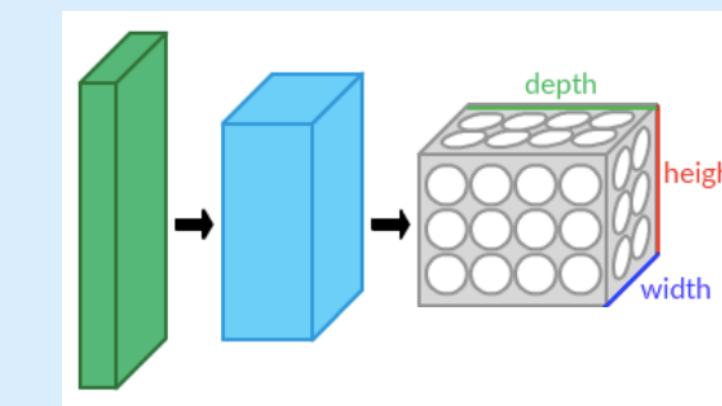


Virus Modelling

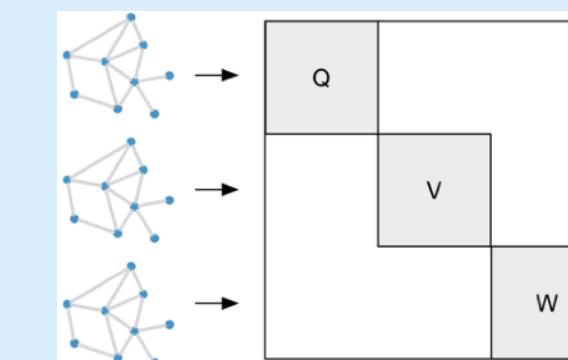
Machine Learning



Neural Networks



Convolutional Networks



Graph Convolutional Network

Data Analytics

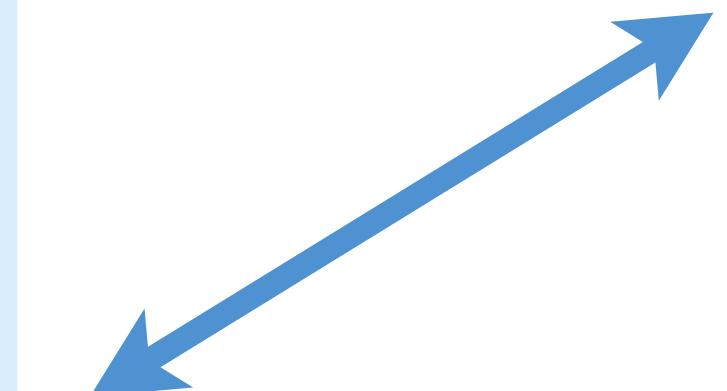


Social Networks

Kristina	★★★★★	Great Product
	March 30, 2017	Color: White Verified Purchase
		Great product. Large enough for all spoons and fits nicely on my stovetop. Would definitely buy it again.
Teresa	★★★★★	Excellent buy
	October 25, 2017	Verified Purchase
		This is a great product for your boy who loves sports! It was a good value as well. Other stores sell for 3x the cost. I bought one for a basketball and football and my 9 year old loves it in his room. Solid item too, not flimsy. Will hold items nicely.
Lisa	★★★★★	I was really disappointed. The spoon holder it self was great and ...
	December 31, 2016	Color: Black Verified Purchase
		This product came with a manufacturer's chips in it. It is not the seller's fault but I do not know how many in this batch this seller may have. I was really disappointed. The spoon holder it self was great and larger than I expected.
Sarah	★★★★★	Malfunctioned within a month. Waste of \$.
	December 5, 2017	Style: Battery Powered Alarm Size: 1 Pack Verified Purchase
		I chose this one because the reviews were good. It malfunctioned within a month. The back of the alarm has a key for the chirps and of course mine was a lemon. It looks like it was just made August 9th, 2017. I received it at the end of October and it died mid-November. It was a waste of money.

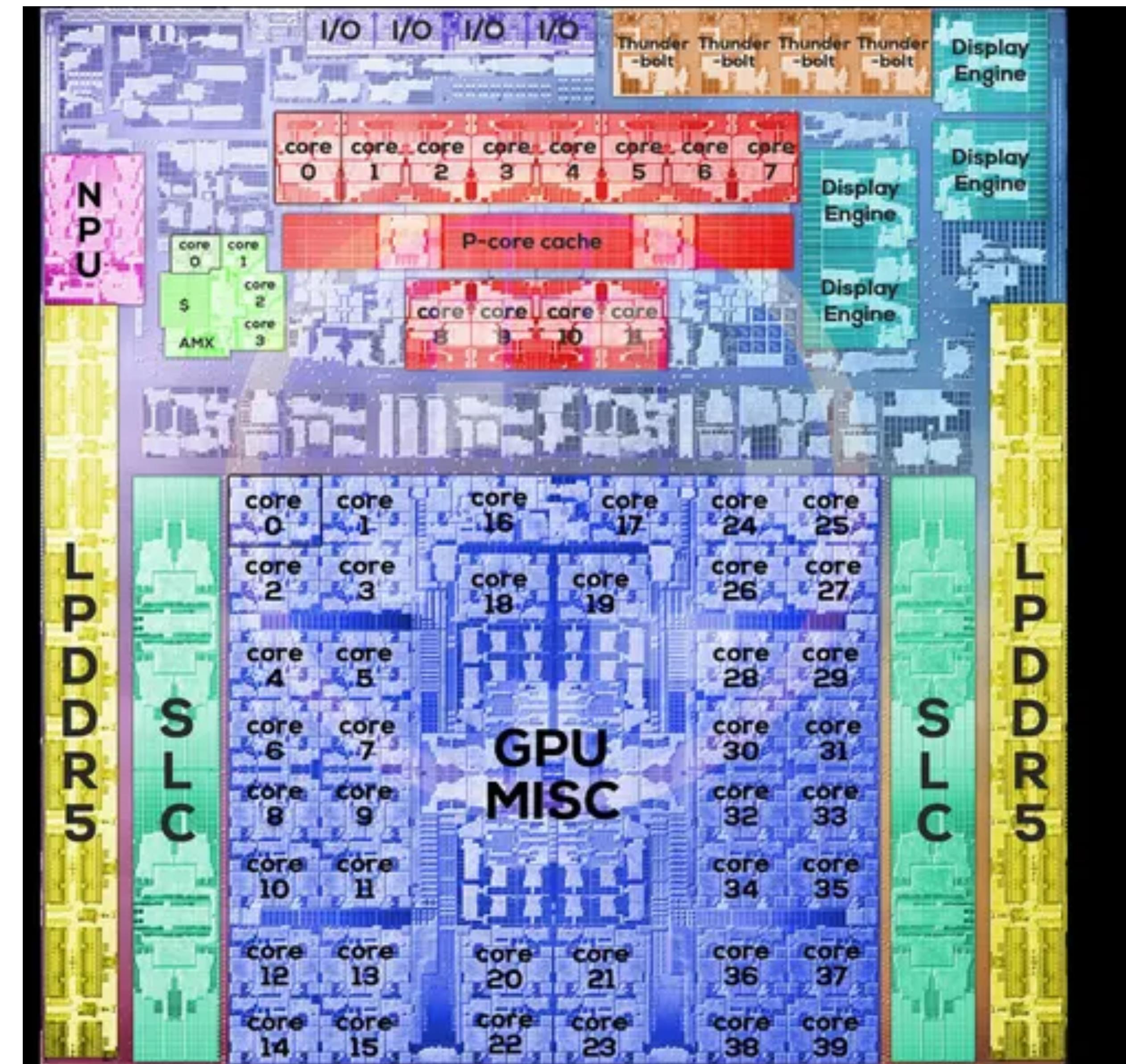
Recommender Systems

Computational Biology

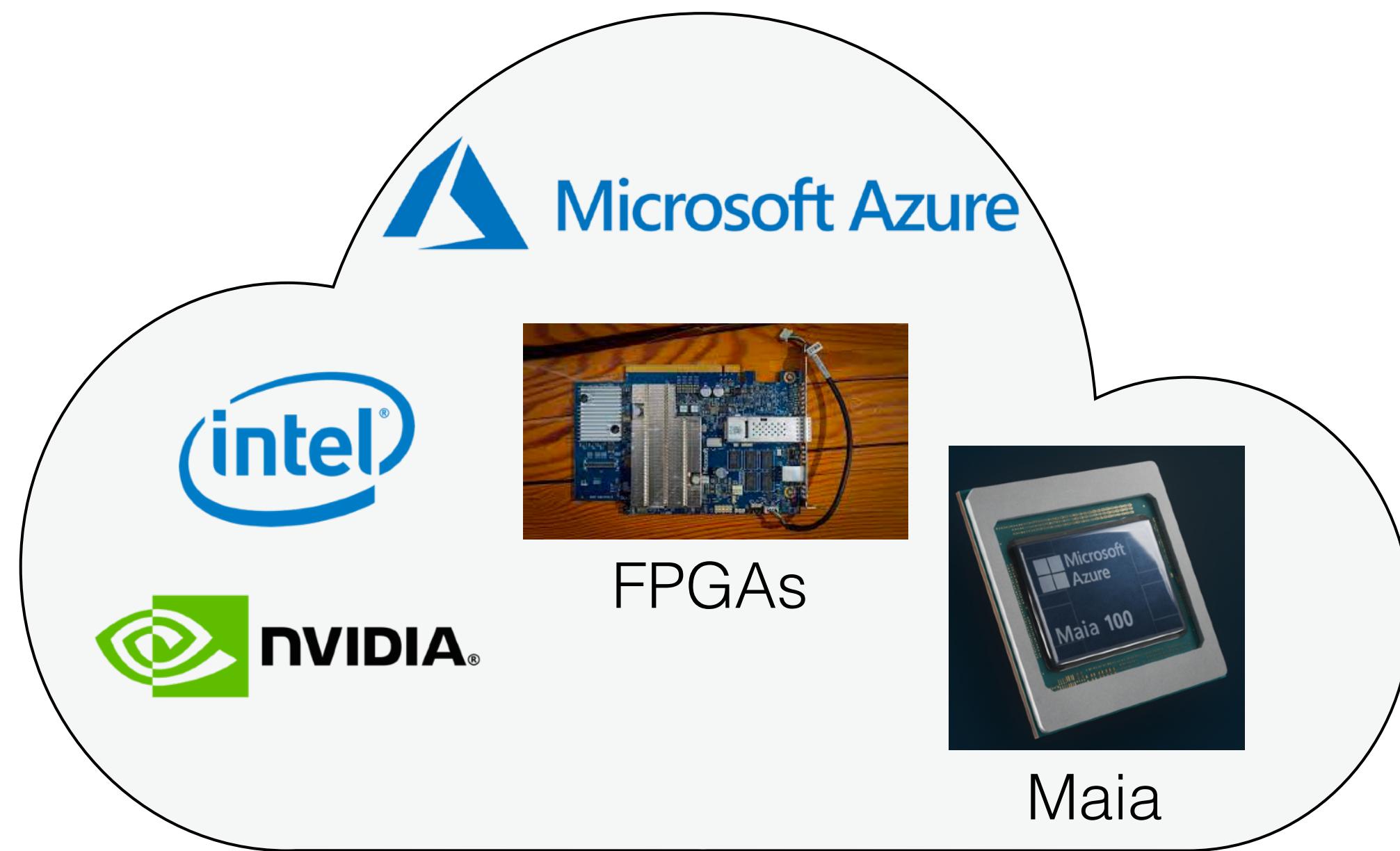
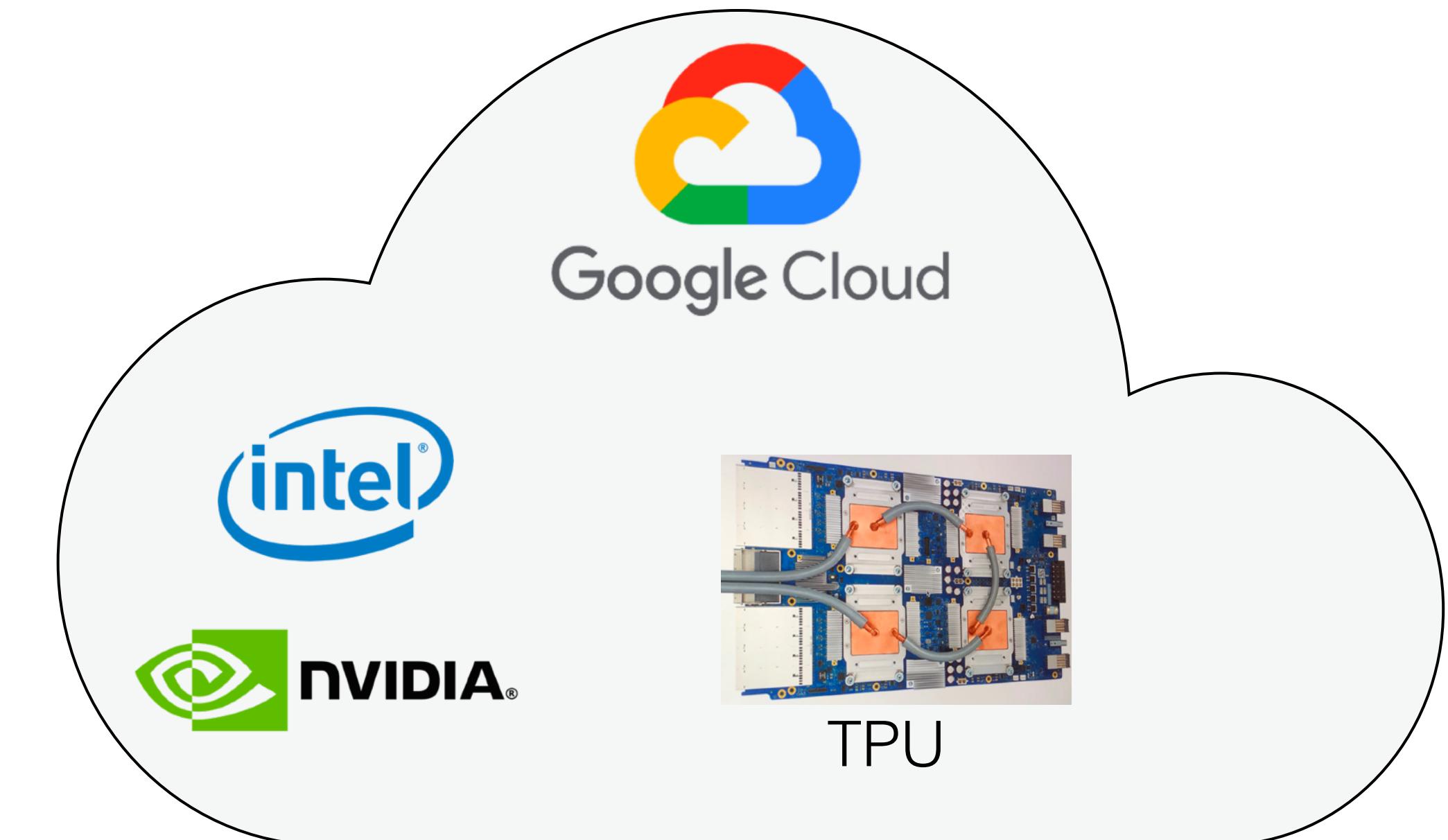
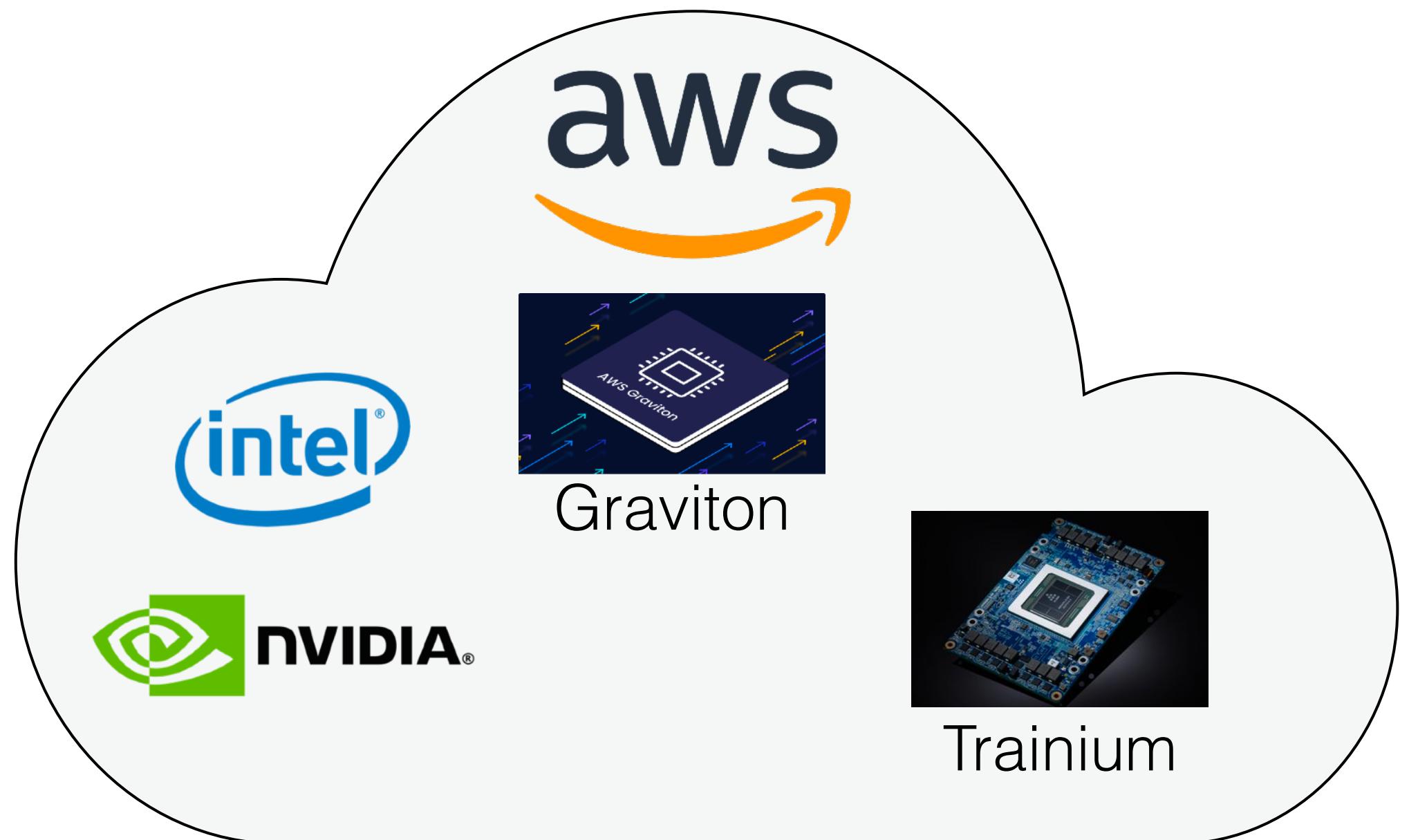


Modern hardware is heterogeneous and programming it is hard

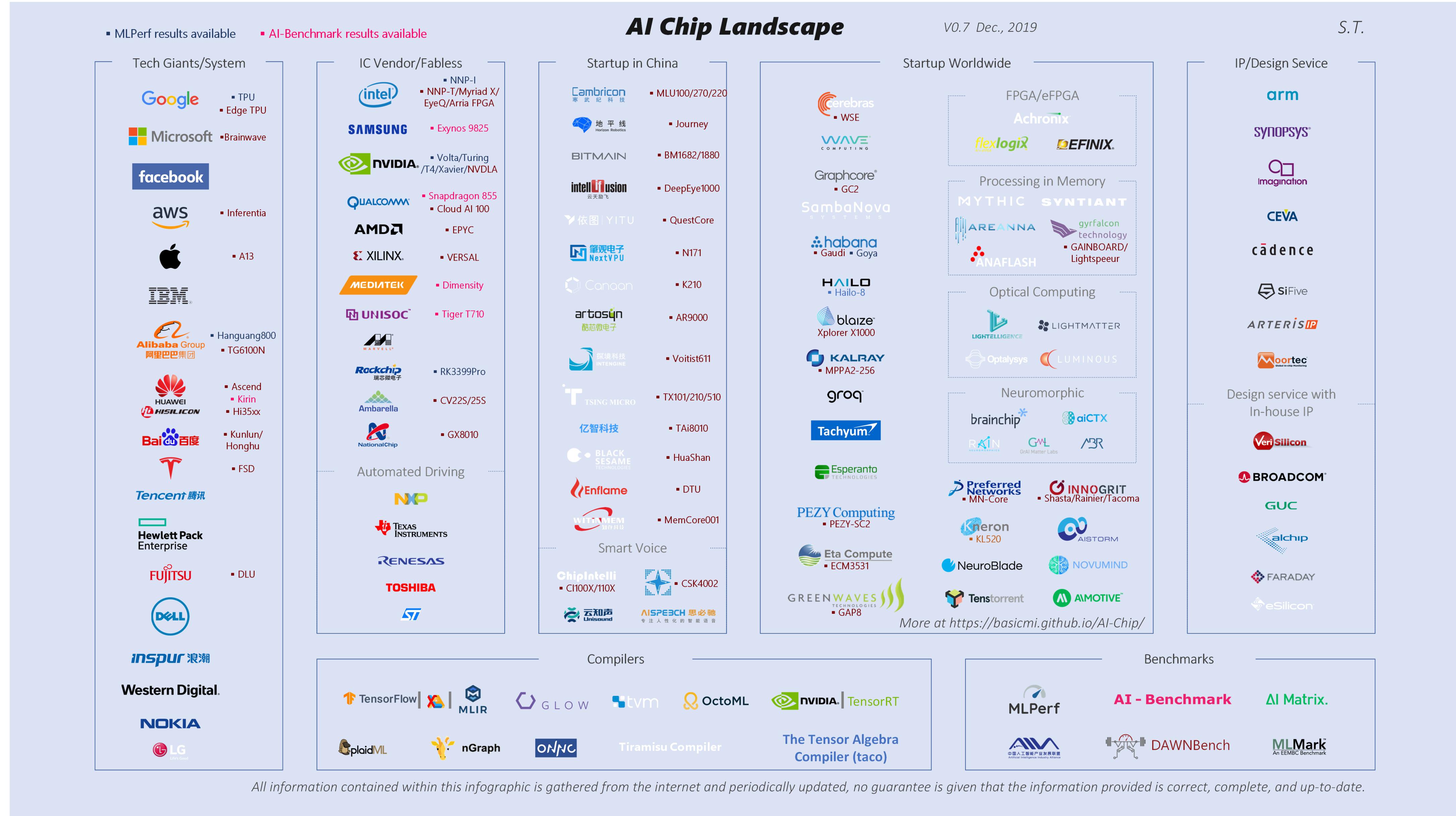
Apple M3 Chip



Hardware in the Clouds



A lot of industry activity (2019 to now)

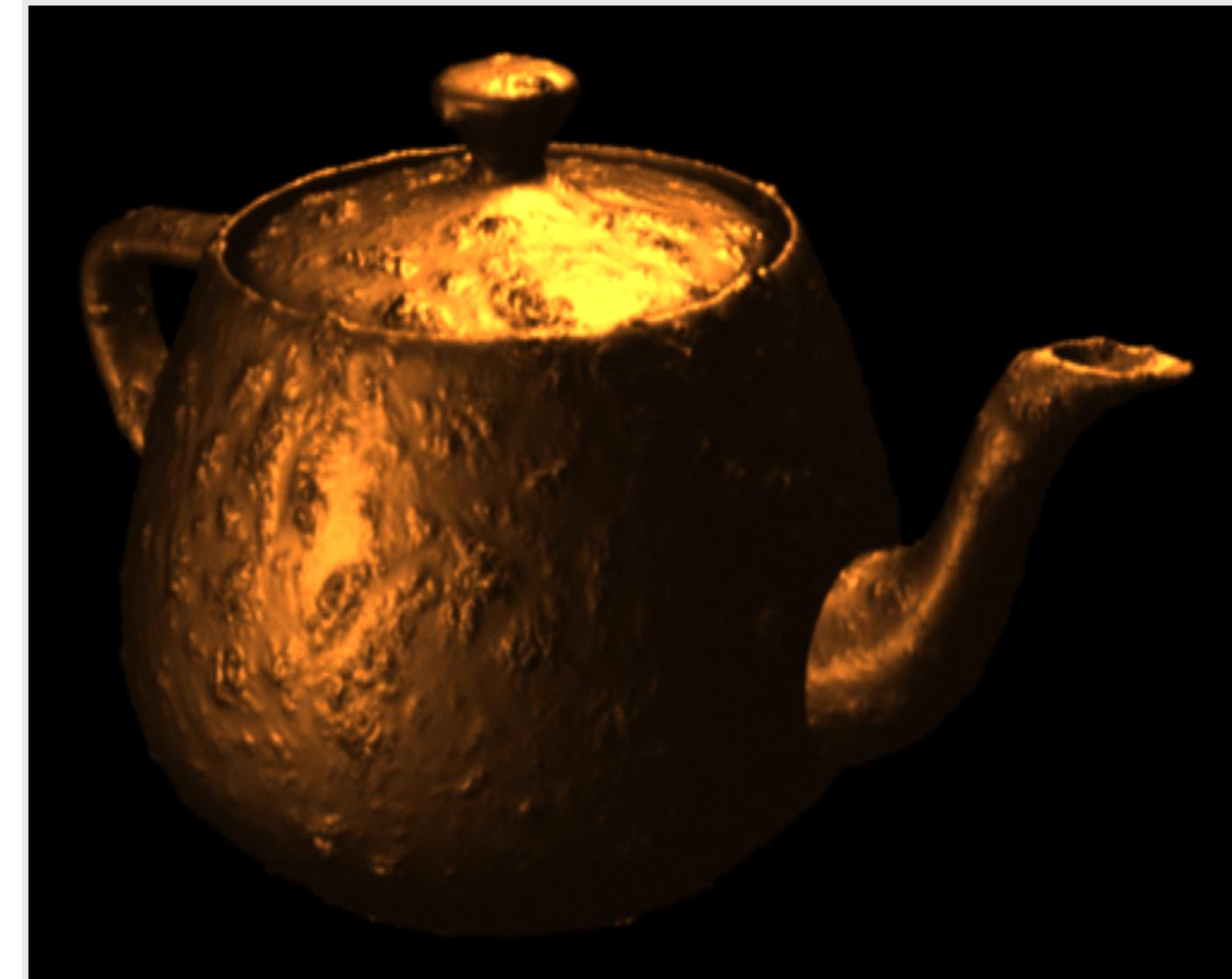


The Road to Point Reyes
Lucasfilm 1984

R.E.Y.E.S = Renders Everything You Ever Saw



```
surface corrode(float Ks=0.4, Ka=0.1, rough=0.25) {  
    float i, freq=1, turb=0;  
  
    // compute fractal texture  
  
    for( i=0; i<6; i++ ) {  
  
        turb+=1/freq*noise(freq*P);  
  
        freq*=2;  
    }  
  
    // perturb surface  
  
    P -= turb * normalize(N);  
  
    N = faceforward(normalize(calculateNormal(P)));  
  
    // compute reflection and final color  
  
    Ci = Cs*(Ka*ambient()+Ks*specular(N,I,rough));  
}
```



Little Languages (DSLs)

Jon Bentley, CACM 29(8), 1986

Defining “little” is harder; it might imply that the first-time user can use this system in an hour or master the language in a day, or perhaps the first implementation took just a few days. In any case, a little language is specialized to a particular problem domain and does not include many features found in conventional languages.

UNIX "DSLs"

bash, csh - shell programming

awk - processing strings

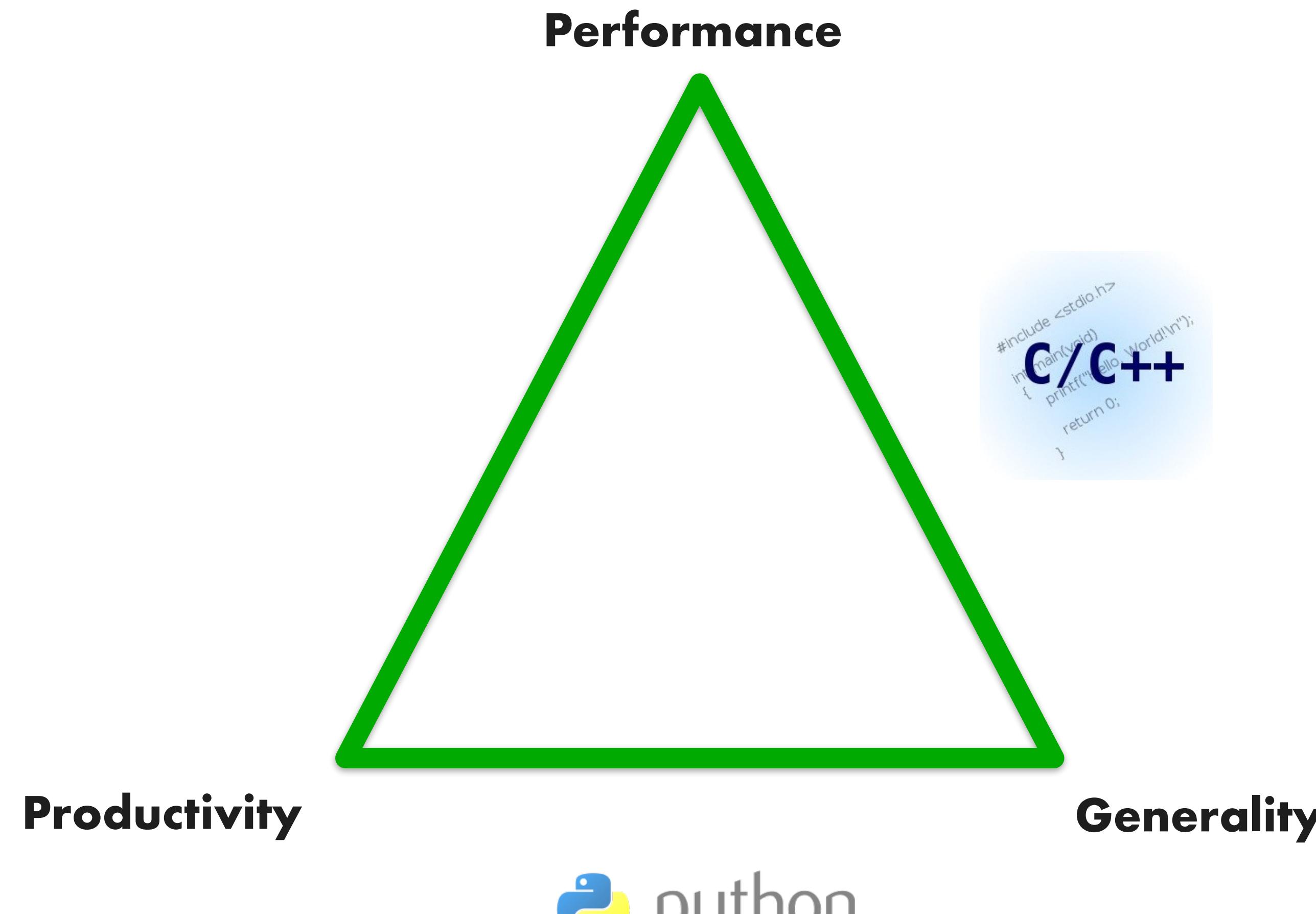
sed - regular expressions

troff, pic, tbl, eqn, ...

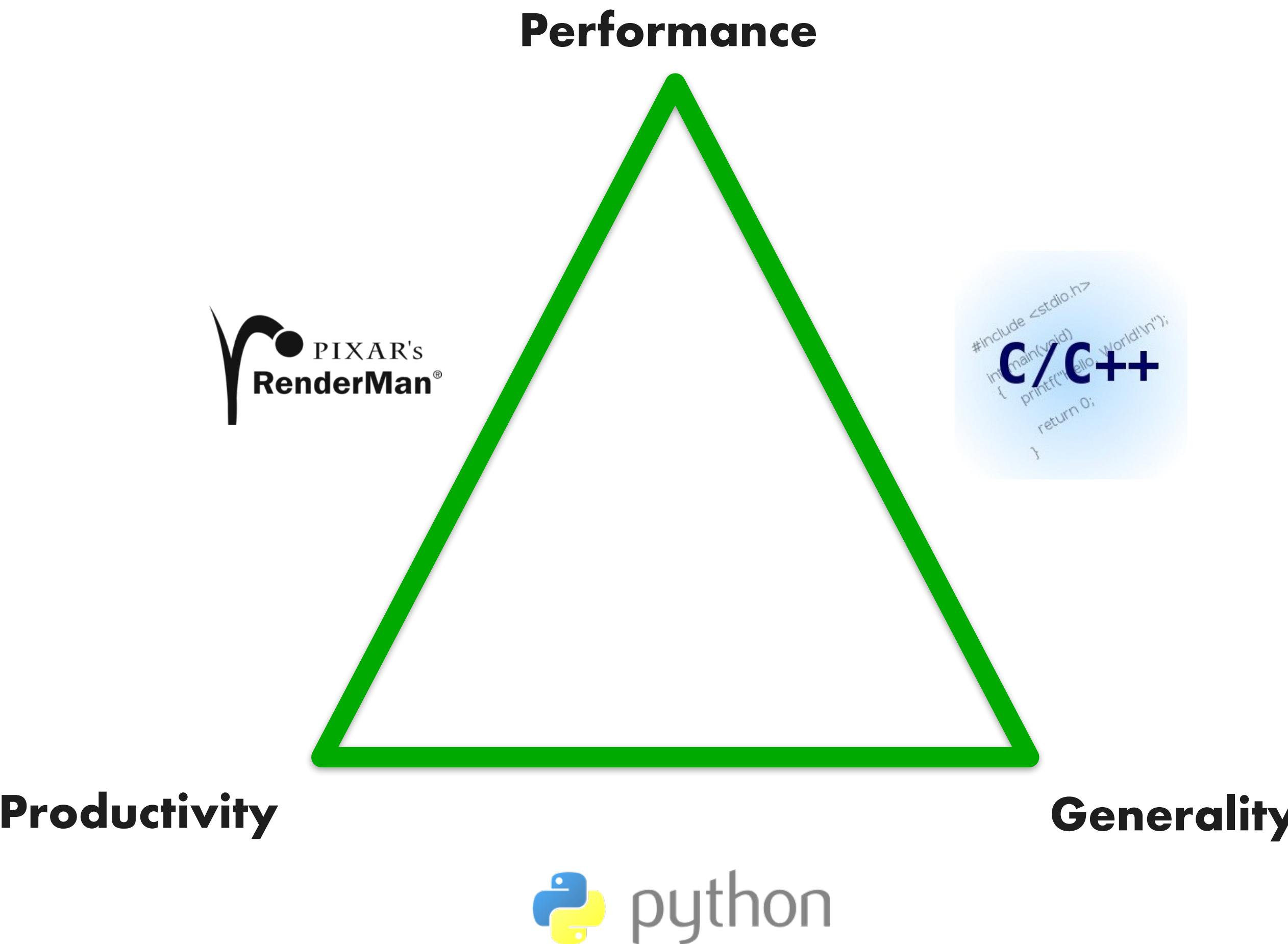
printf formatting

...

Programming Languages



Domain-Specific Languages



Graphics Libraries

```
glPerspective(45.0);
for( ... ) {
    glTranslate(1.0,2.0,3.0);
    glBegin(GL_TRIANGLES);
        glVertex(...);
        glVertex(...);

        ...
    glEnd();
}
glSwapBuffers();
```

OpenGL “Grammar”

`<Scene> = <BeginFrame> <Camera> <World>
<EndFrame>`

`<Camera> = glMatrixMode(GL_PROJECTION)
<View>
<View> = glPerspective | glOrtho`

`<World> = <Objects>*
<Object> = <Transforms>* <Geometry>
<Transforms> = glTranslatef | glRotatef | ...
<Geometry> = glBegin <Vertices> glEnd
<Vertices> = [glColor] [glNormal] glVertex`

Advantages

Productivity

- Graphics library is easy to use

Portability

- Runs on wide range of GPUs

Performance

- Runs in parallel

Restrictions

- Vertices/Fragments are independent
- Rasterization can be done in hardware
- Textures are read-only; texture filtering hw
- Specialized scheduler for pipeline
- ...
- Allows for super-optimized implementations

Abstraction is about restrictions, in order to get useful properties

Advantages

Productivity

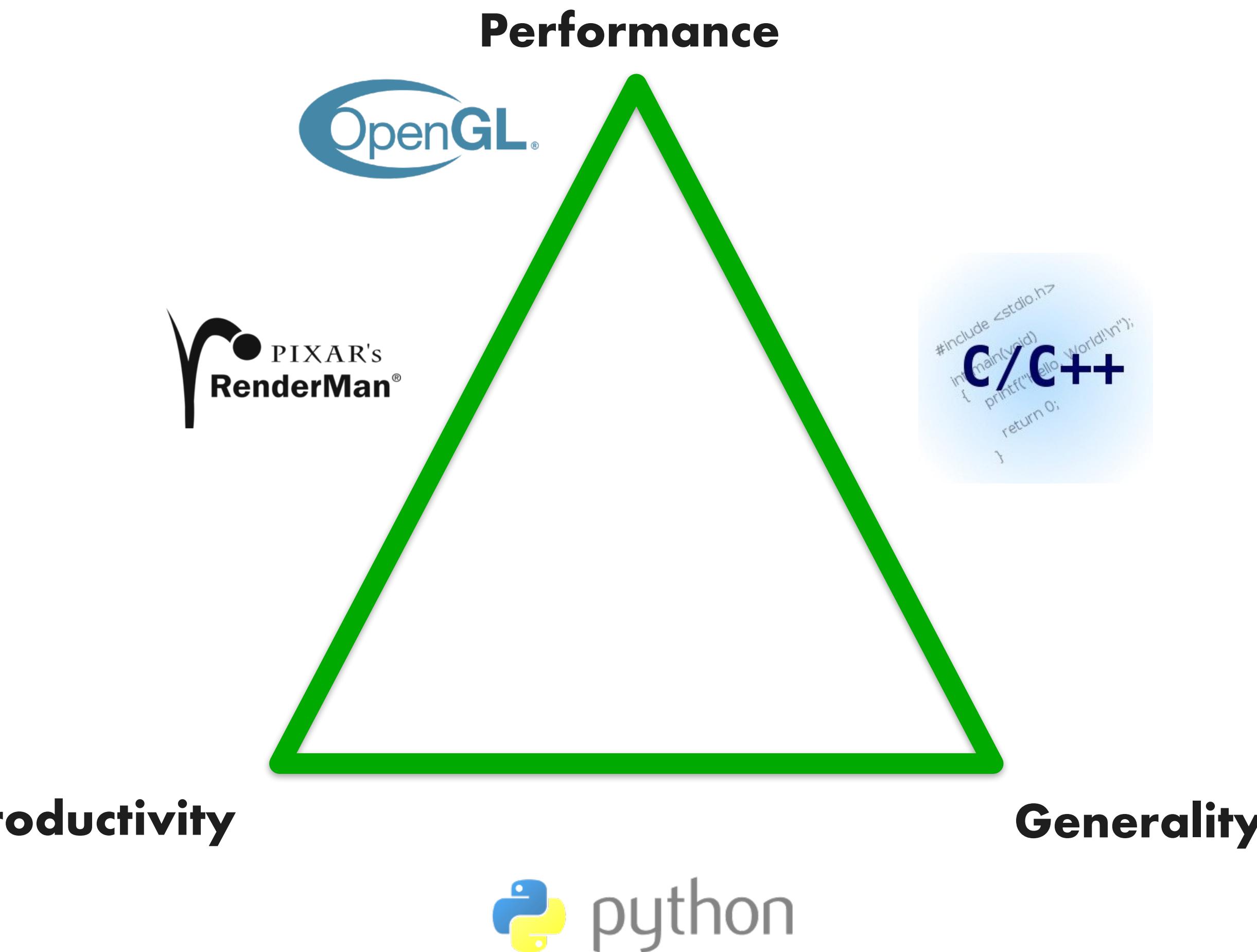
Portability

Performance

Encourage innovation

- Allows vendors to radically optimize hardware architecture to achieve efficiency
- Allows vendors to introduce new low-level programming models and abstractions

Domain-Specific Languages



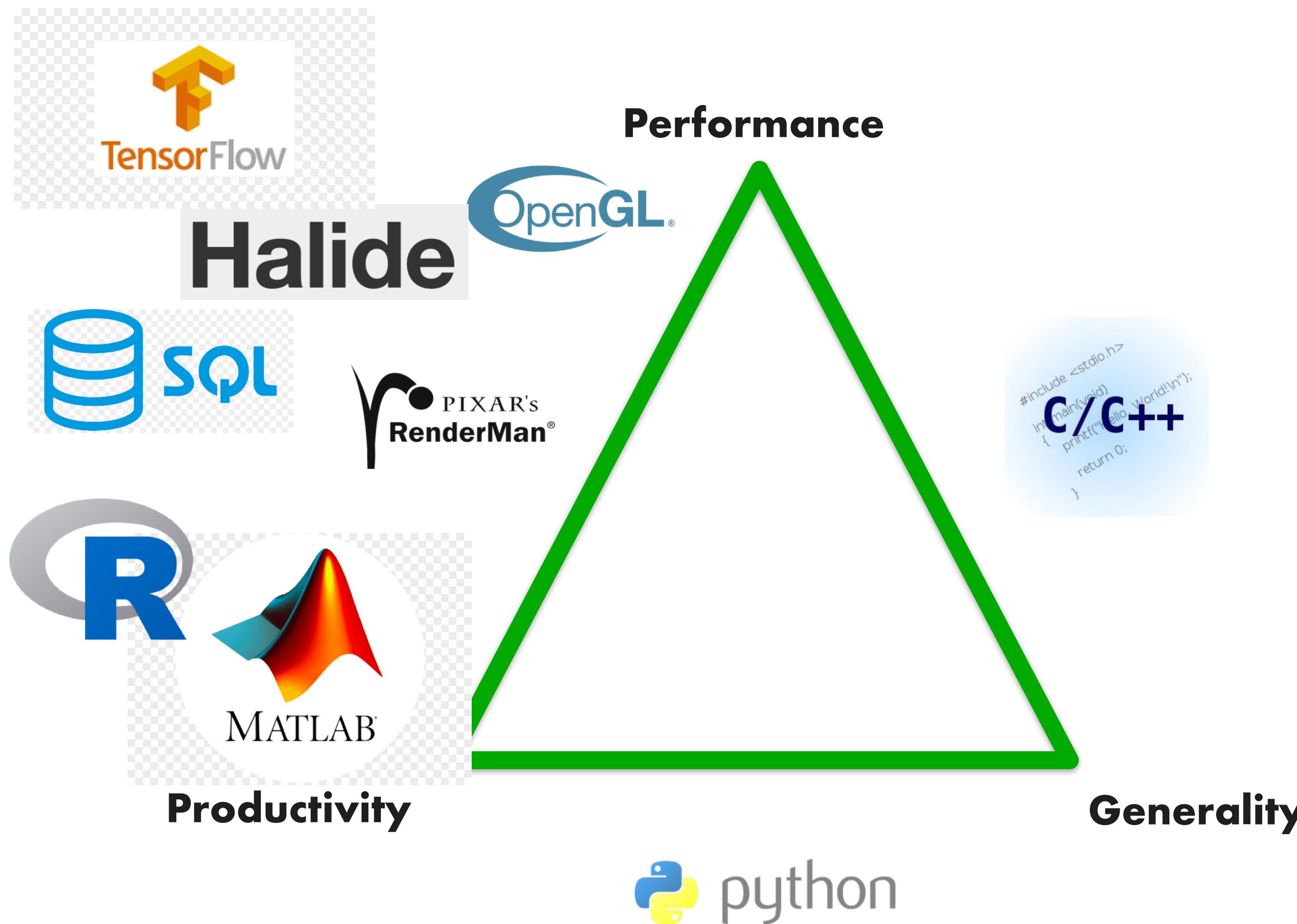
Domain-Specific

A language or library that exploits domain knowledge for productivity and performance

Widely used in many application areas

- matlab / R
- SQL / map-reduce / Microsoft's LINQ
- TensorFlow, pytorch

Domain-Specific Languages



Why DSLs Work

Advantages

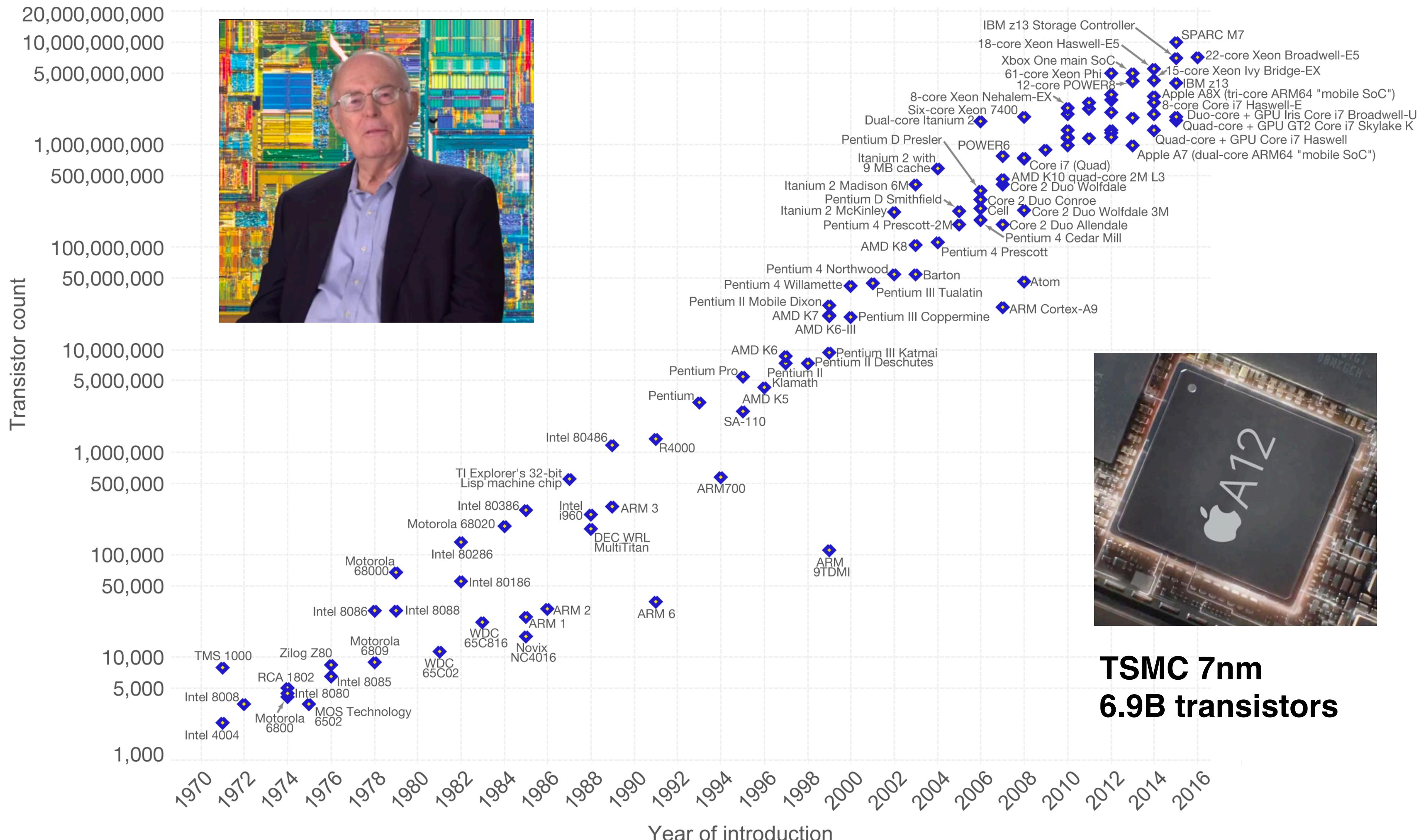
- Add the semantics of the domain
 - High-level program transformations
 - Restrict programming language
 - Less-general computations
 - Guarantee static analysis
- Known parallelization strategies
 - Someone has shown how to robustly do it

=> Tractable

Moore's Law – The number of transistors on integrated circuit chips (1971-2016)

Our World in Data

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are strongly linked to Moore's law.

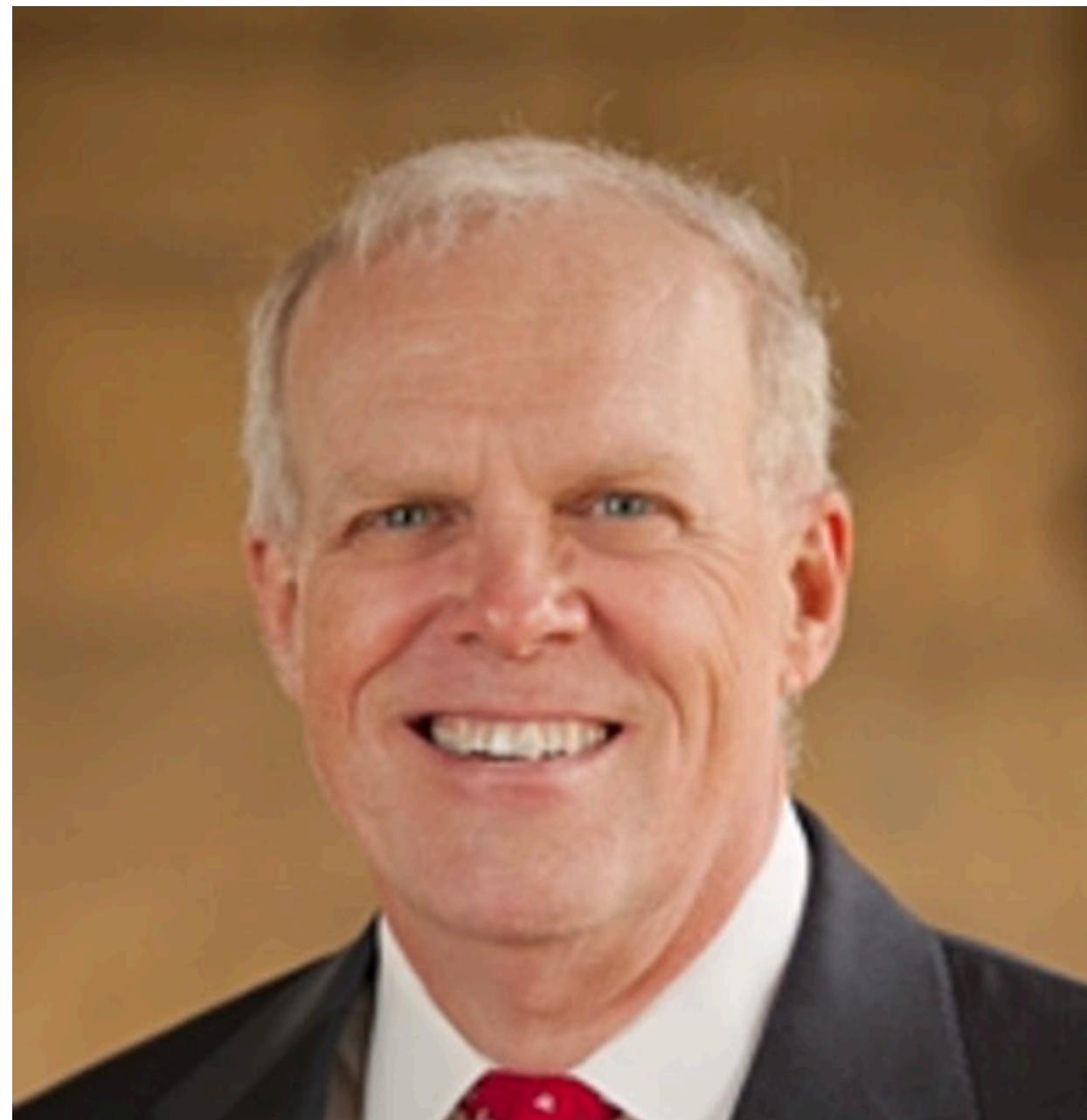


Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_court)

The data visualization is available at OurWorldInData.org. There you find more visualizations and research on this topic.

Licensed under CC-BY-SA by the author Max Roser.

A New Golden Age for Computer Architecture: Domain-Specific Hardware/Software Co-Design



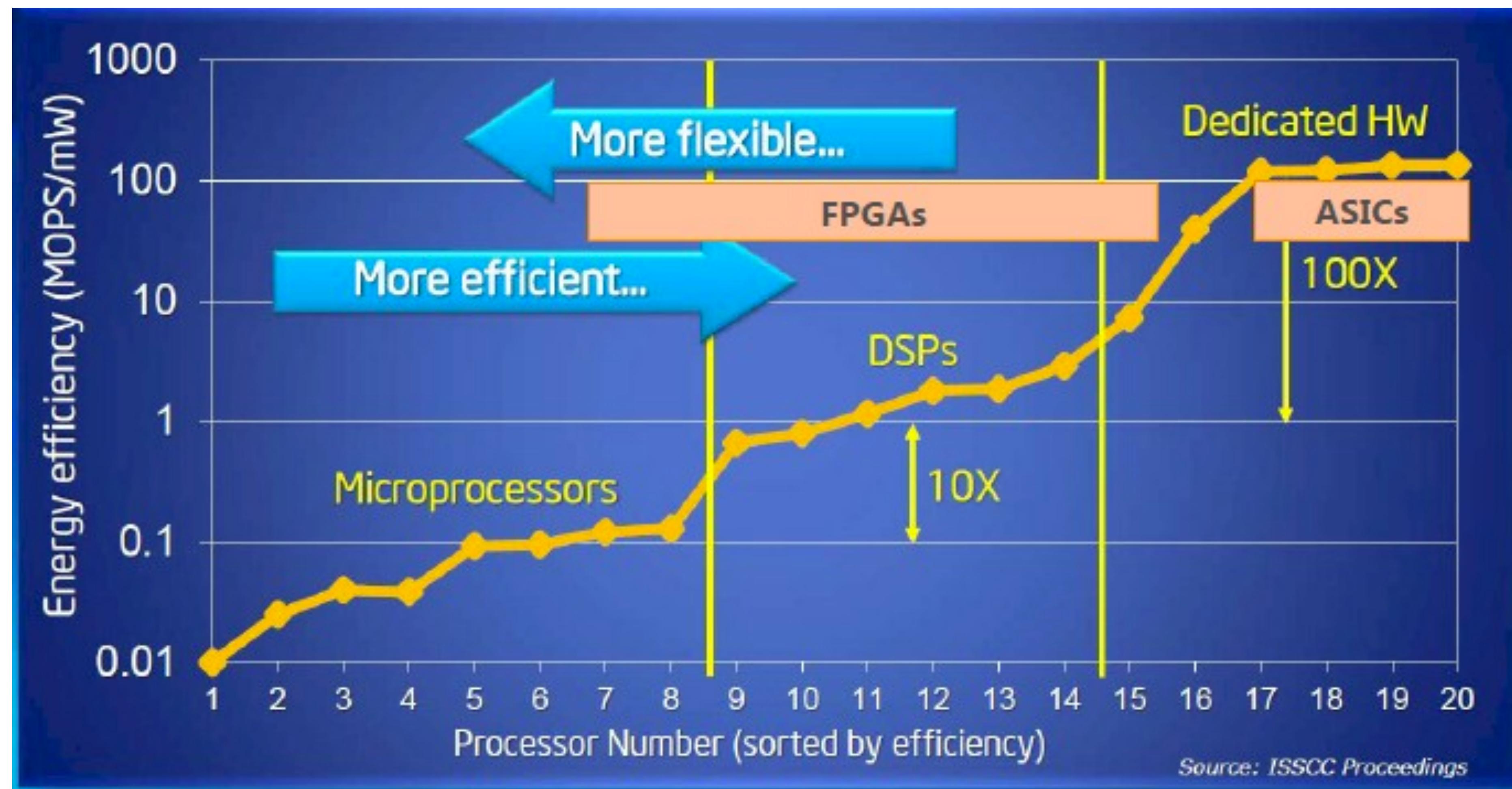
John Hennessy



David Patterson

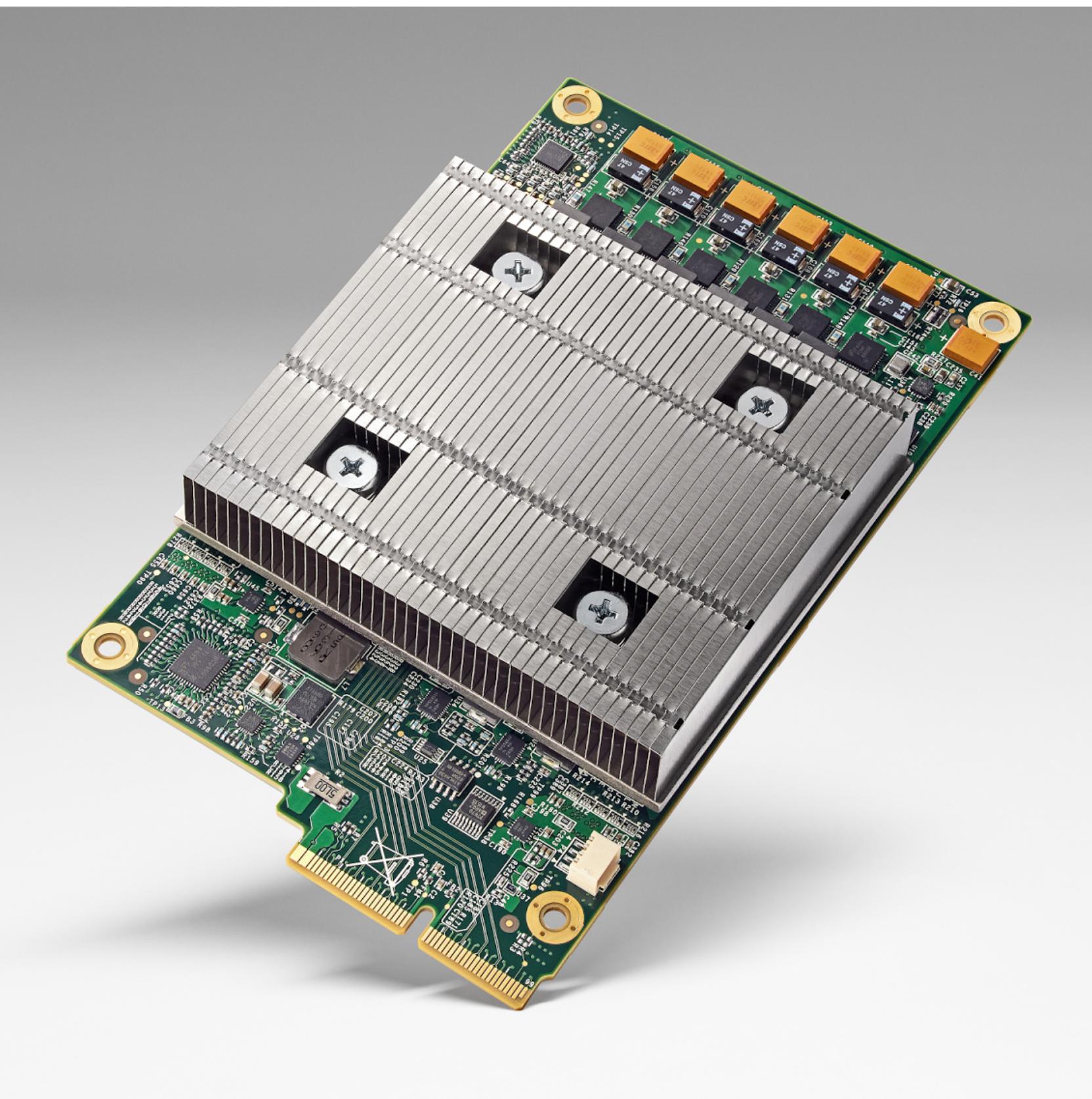
2017 Turing Award

Large efficiency gains with domain-specific architectures

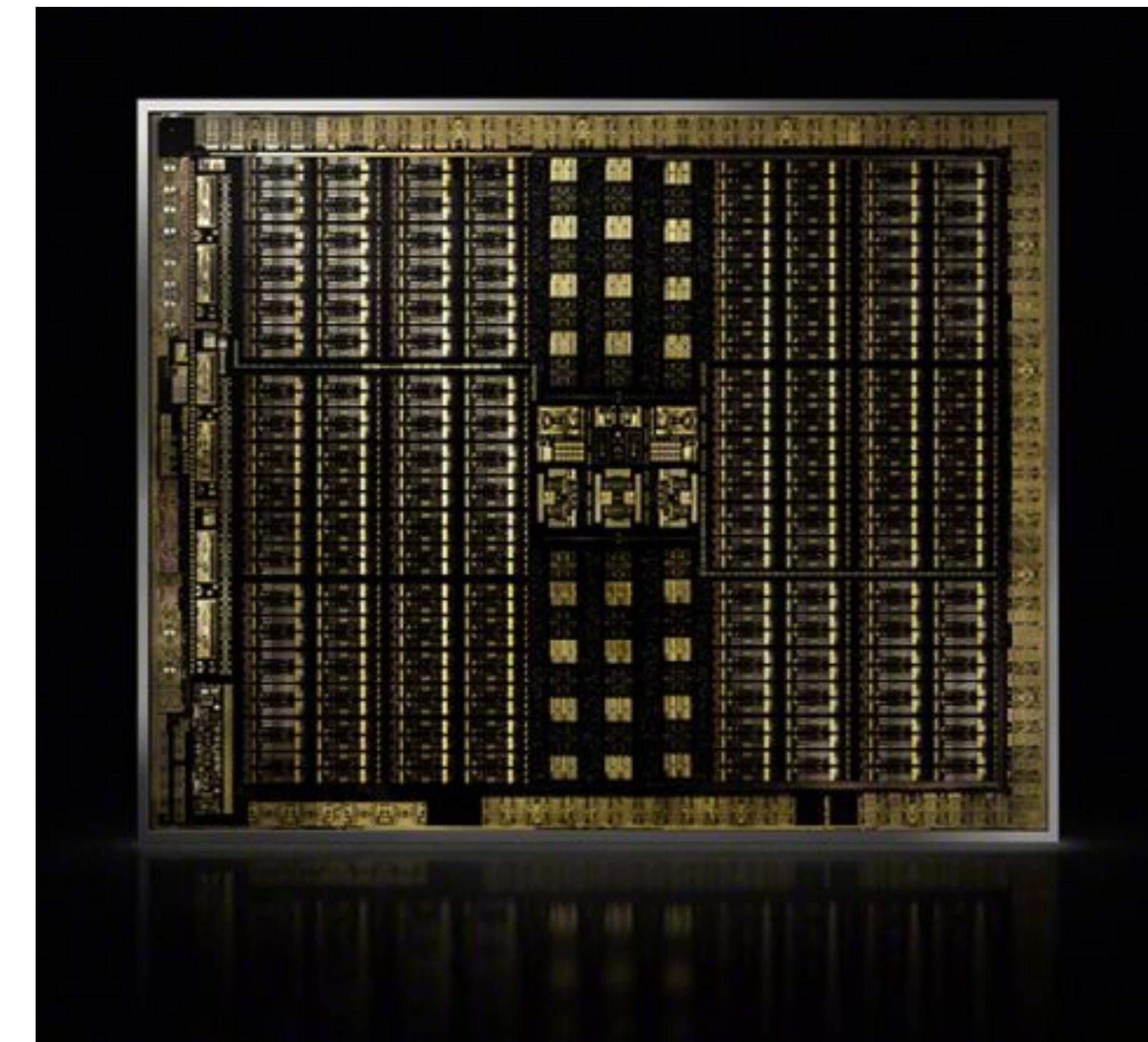


Source: Bob Broderson, Berkeley Wireless group

Domain-Specific Architectures



**Google
Tensor Processing Unit**



**NVIDIA
Turing Architecture**

Collection-Oriented Languages

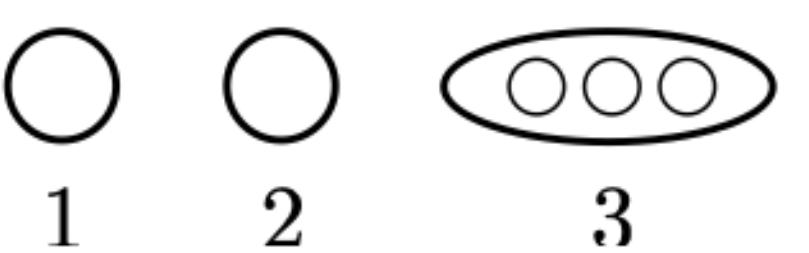
Lists
Lisp M58



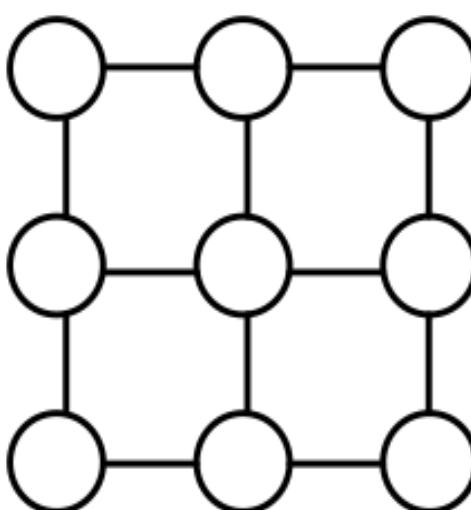
Sets
SETL S70



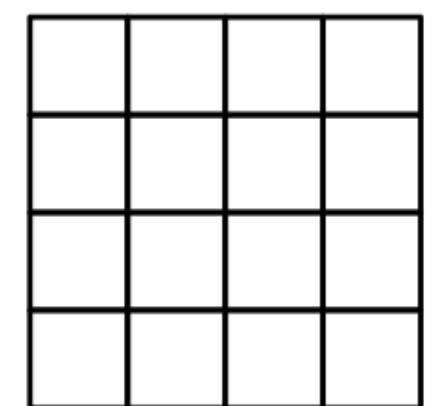
Nested Sequences
NESL B94



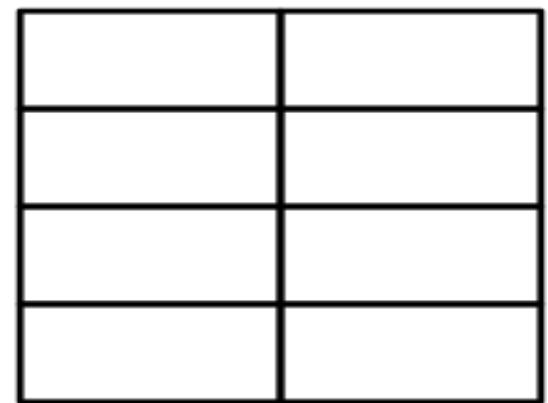
Grids
Sejits S09, Halide



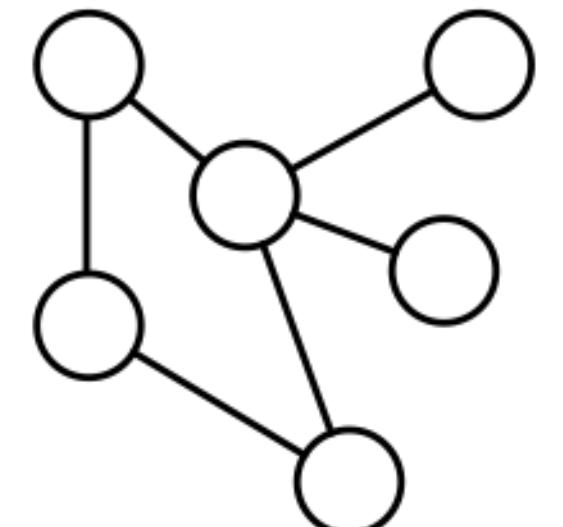
Arrays
APL I62



Relations
Relational Algebra C70,



Graphs
GraphLab L10



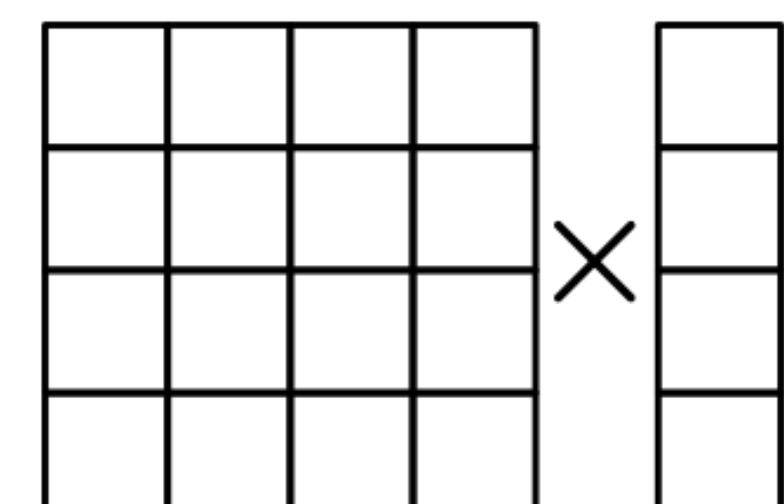
Meshes
Liszt D11



Vectors
Vector Model B90



Matrices and Tensors
Matlab M79, taco K17



A collection-oriented programming model provides collective operations on some collection/abstract data structure

Modern Domain-Specific Languages/Compilers



Halide

