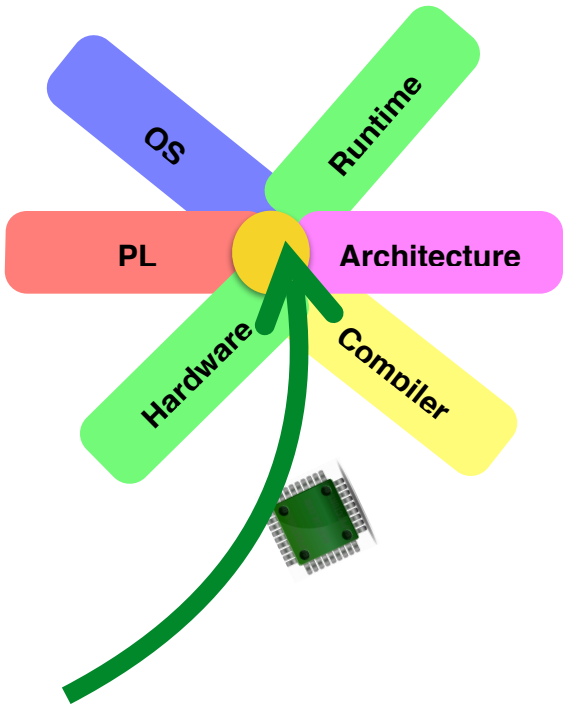
# Imperfection is Beautiful and Efficient

Luis Ceze

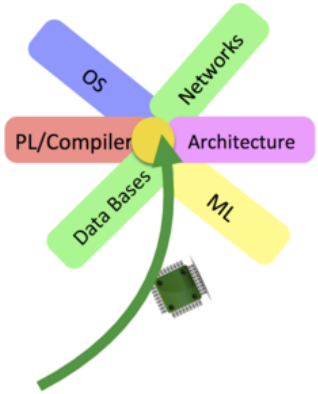
University of Washington



# I do “computer architecture”

## oh, you make computers more beautiful?

## Sort of, I like making them more beautiful and efficient!



# So, what's computer architecture research?

Finding new ways of building computers that are more efficient, faster, can meet new constraints etc…

**core *problems***:

performance

reliability

energy

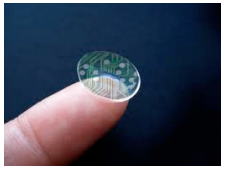

**application domains**:

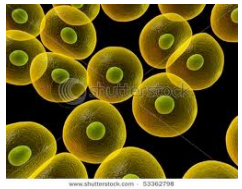
big

small

tiny

nano





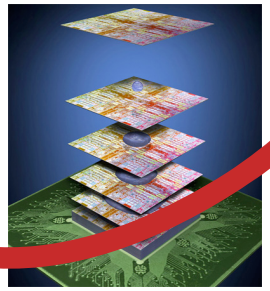
**device technology**:

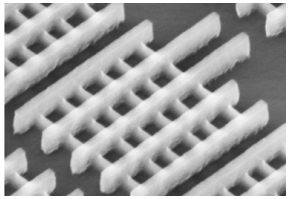
transistors

3d chips

photonics

storage cells





(fast, non-volatile!)

# Facebook Stores 240 Billion Photos And Adds 350 Million More A Day

JULIE BORT

JAN. 30, 2013, 6:48 PM | 1,265 | 1

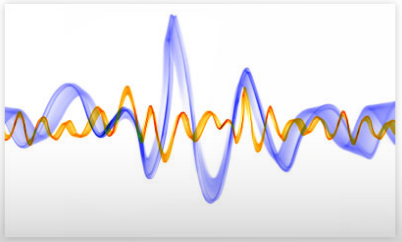
FACEBOOK LINKEDIN TWITTER GOOGLE+

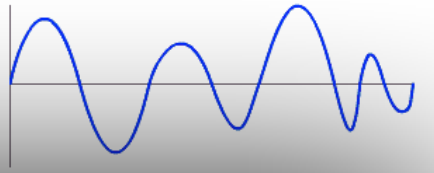
# Netflix Now Accounts for 34 Percent of US Internet Traffic at Peak Times

Associated Press, May 14, 2014


**YouTube**: 100 hours of video uploaded per minute. 4 billion video views a day.

image, sound
and video processing





These applications consume a lot (most?) of our cycles/bytes/bandwidth!

Often input data is inexact by nature (from sensors)

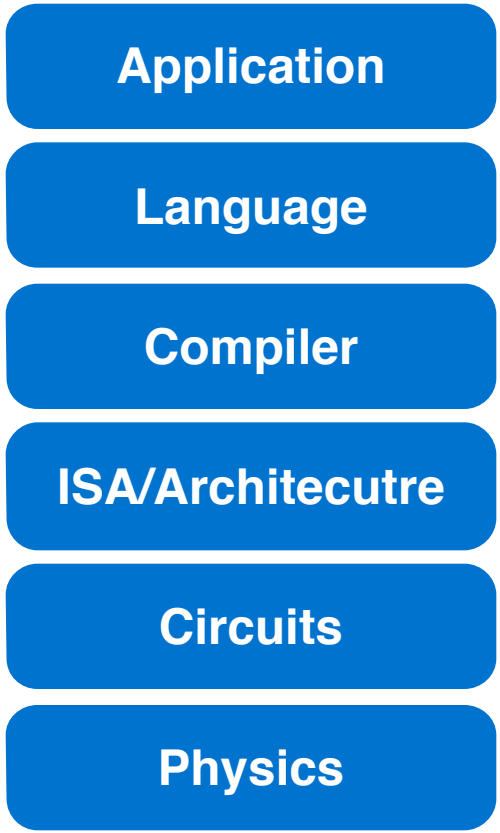
They have multiple acceptable outputs

simulations, games,
search, machine learning

# Yet, we design computer systems like this..

Lower layers work hard to expose a **general, reliable, precise and (mostly) deterministic** interface.

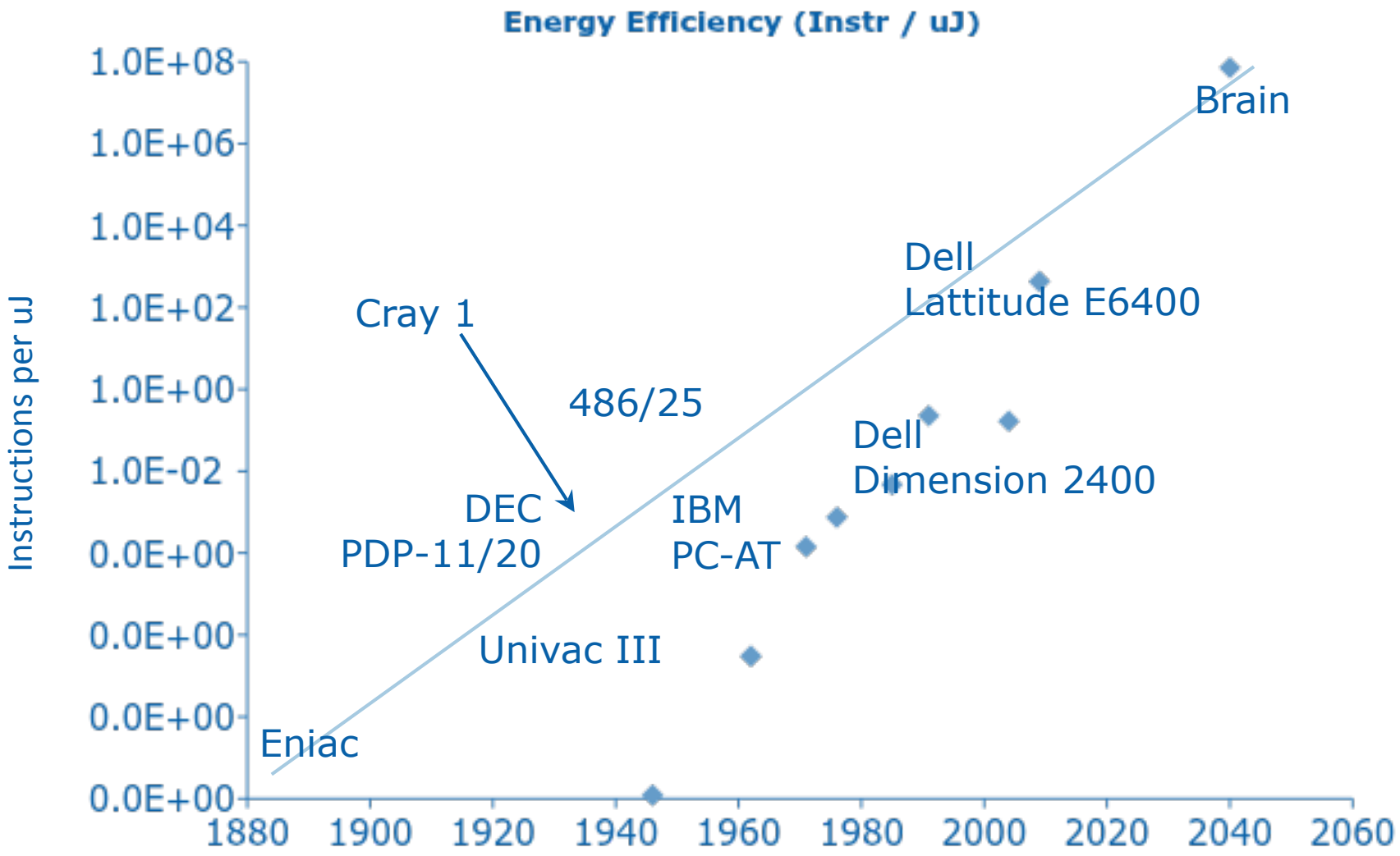
At a **big** efficiency cost!




**250W**

# The big idea: mimic nature!

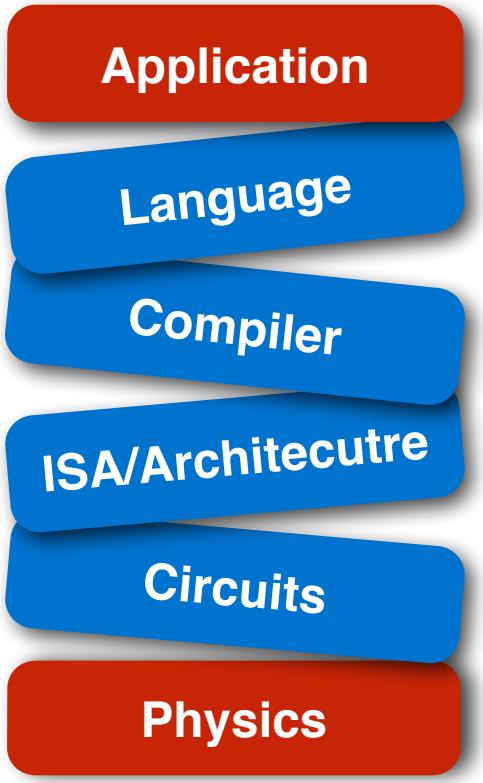
## Energy Efficiency Scaling Joshua Smith, UW



# What is “approximate computing”?

~

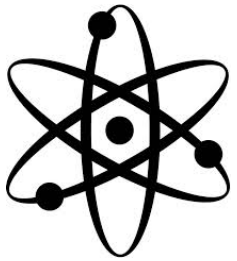
Building acceptable systems out of unreliable/ inaccurate hardware and software components

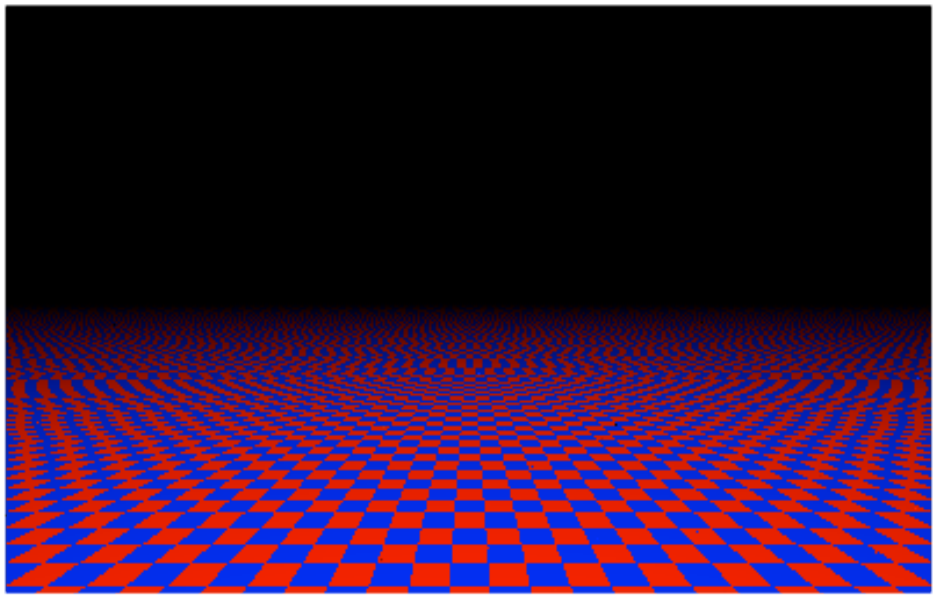


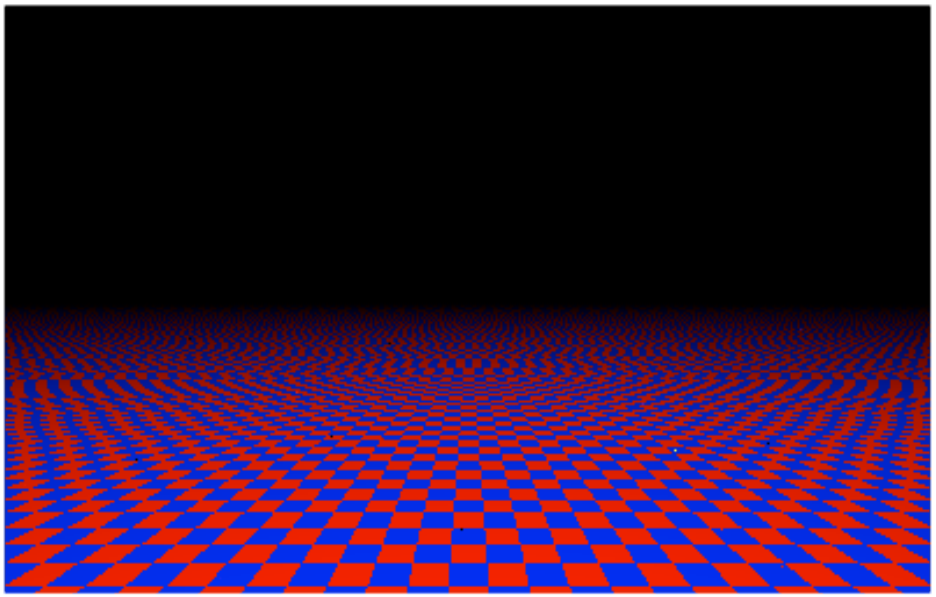

Efficiency and performance

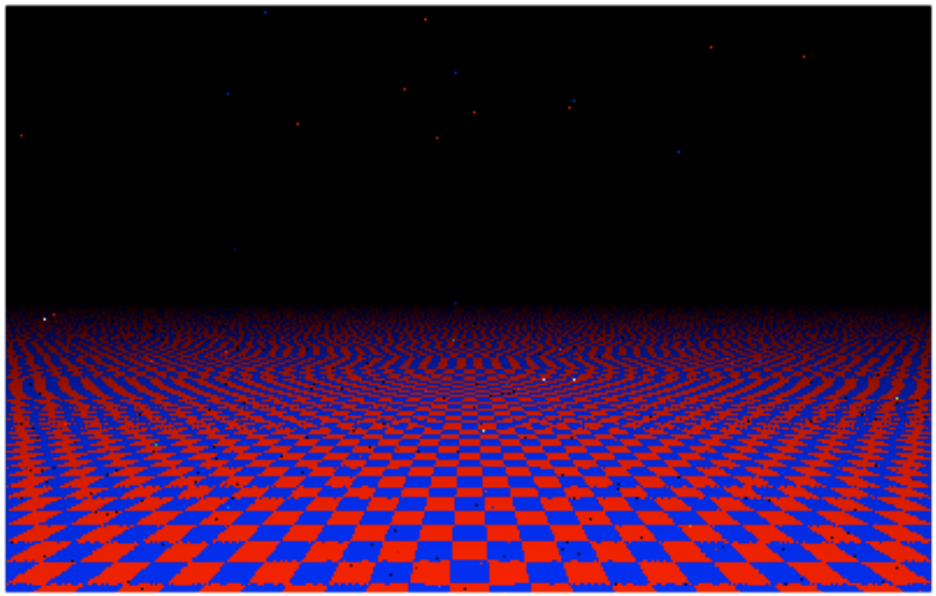
Output accuracy

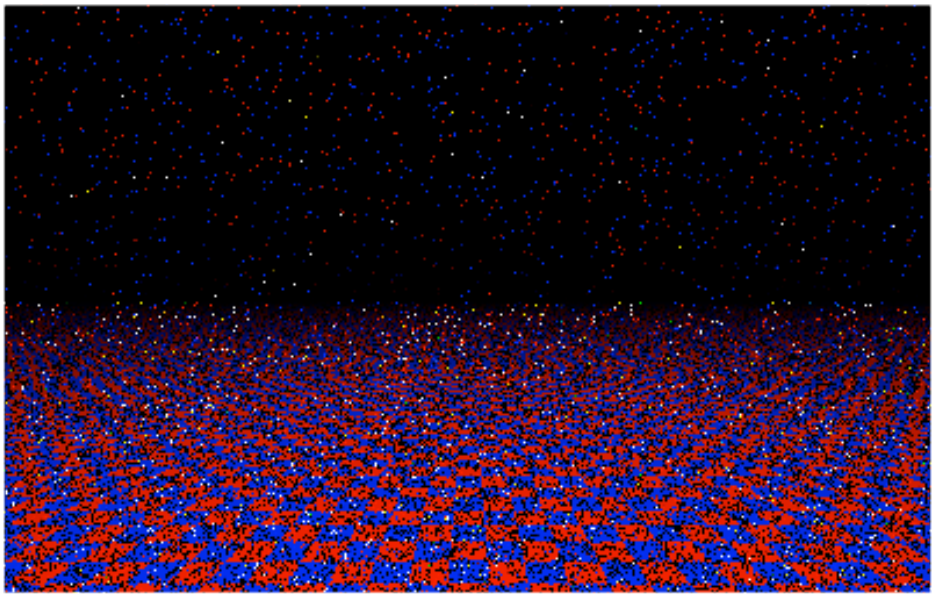
In essence, it is about ***specializing computation, storage and communication*** to properties of the data and the algorithm. Enables better use of underlying substrate.

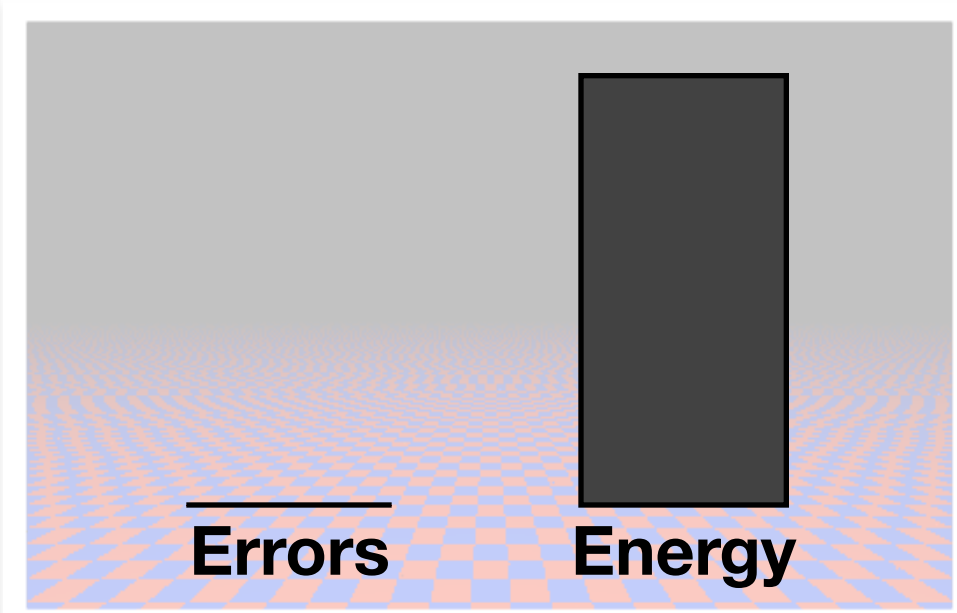


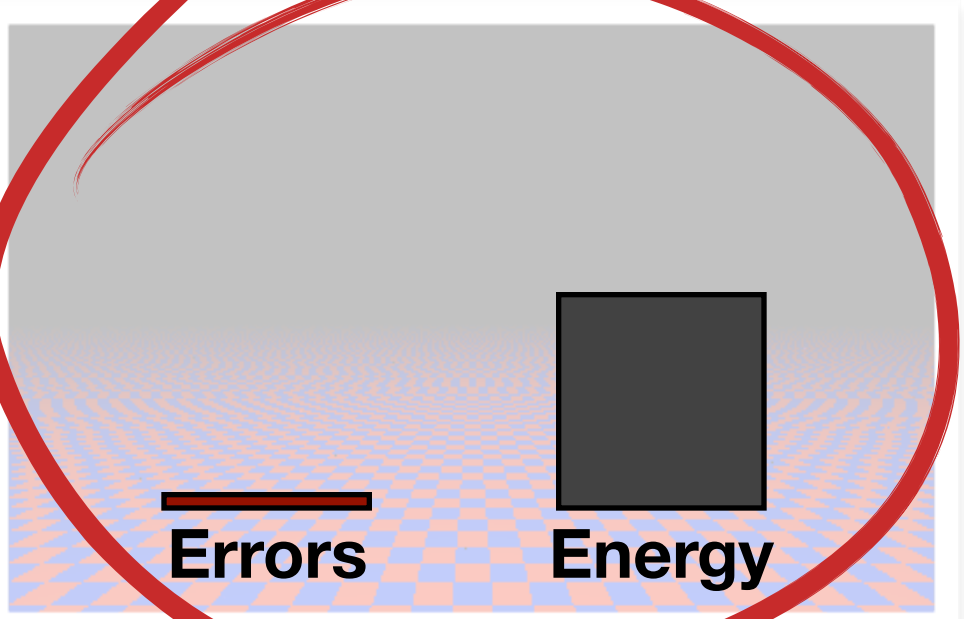









Errors
Energy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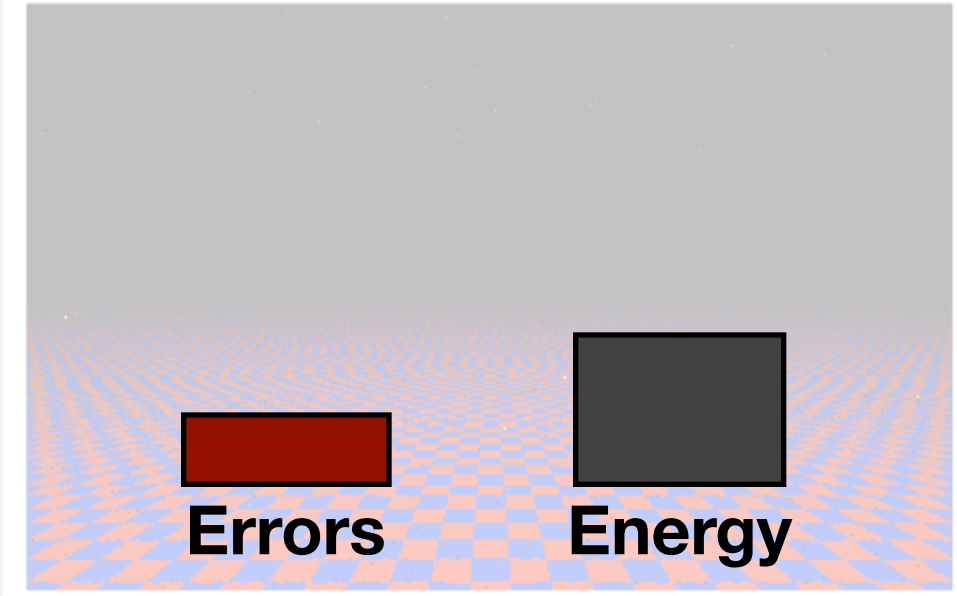
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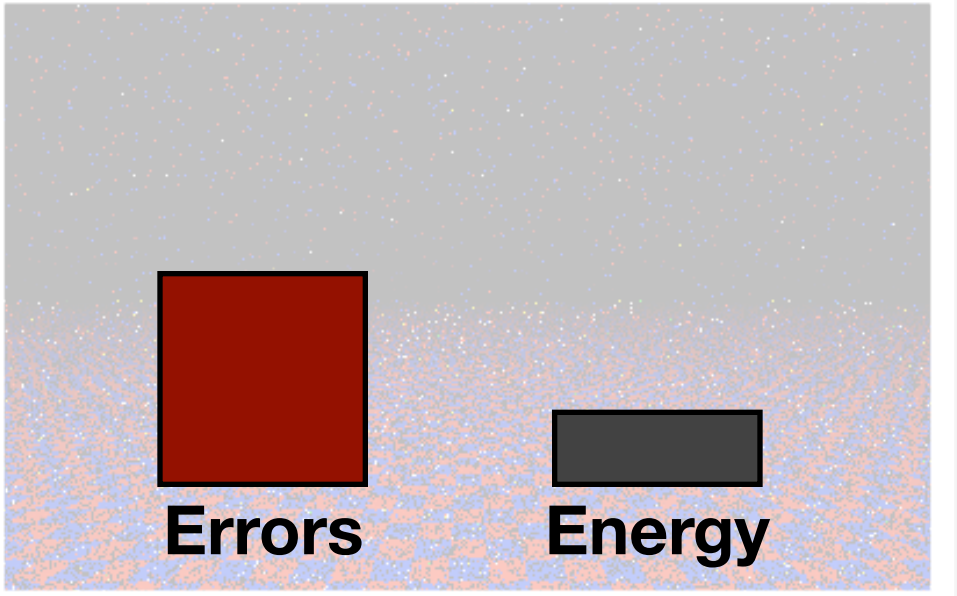
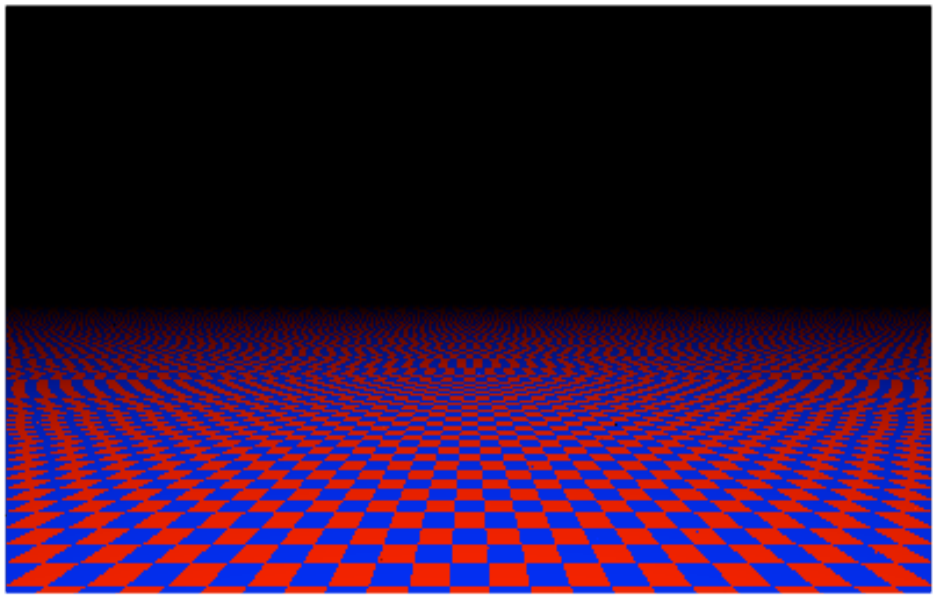
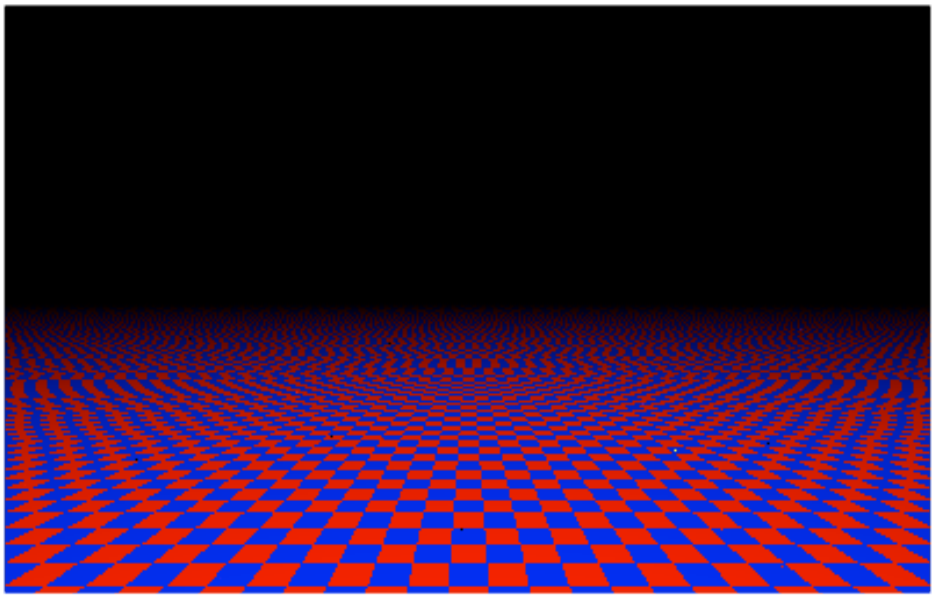
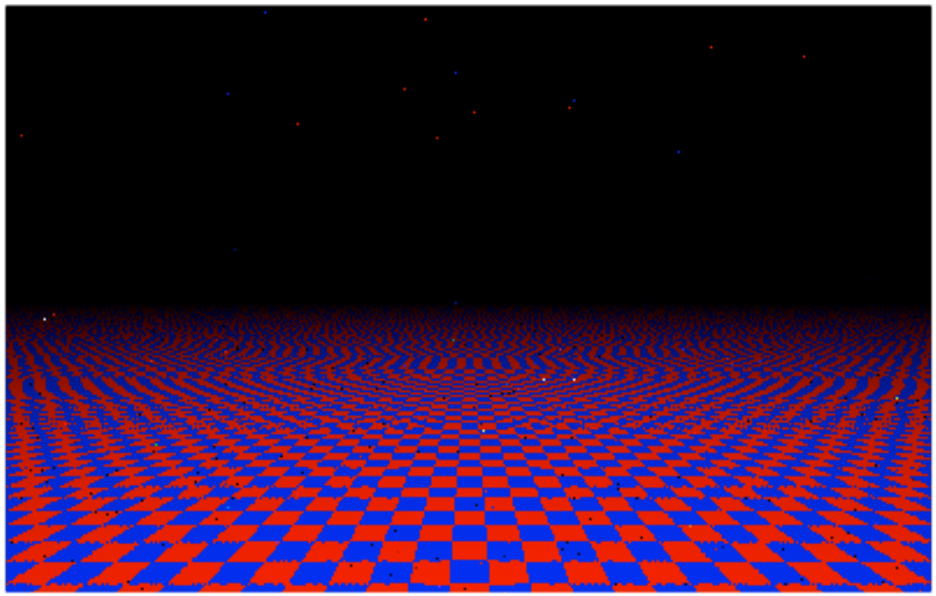
Energy

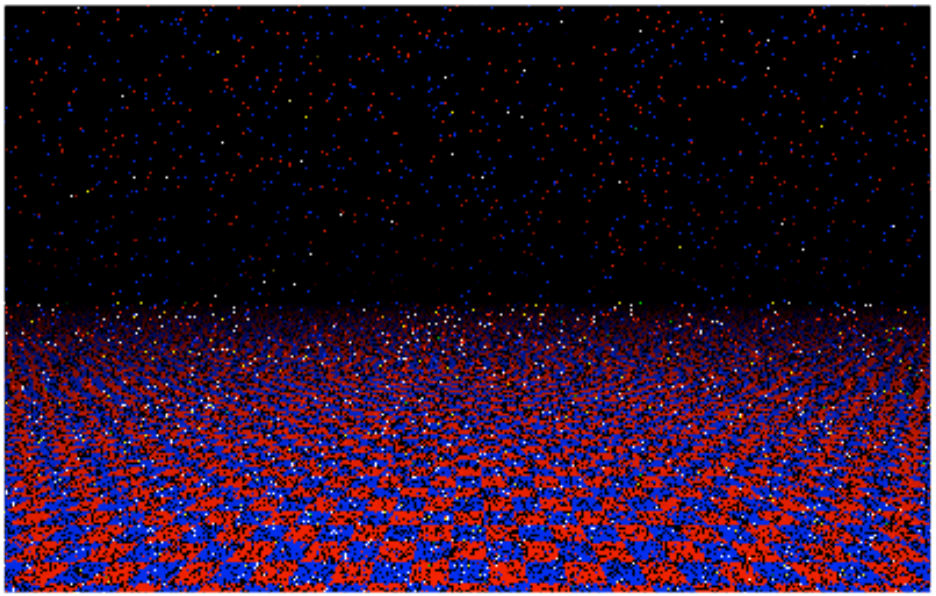

Errors
Energy

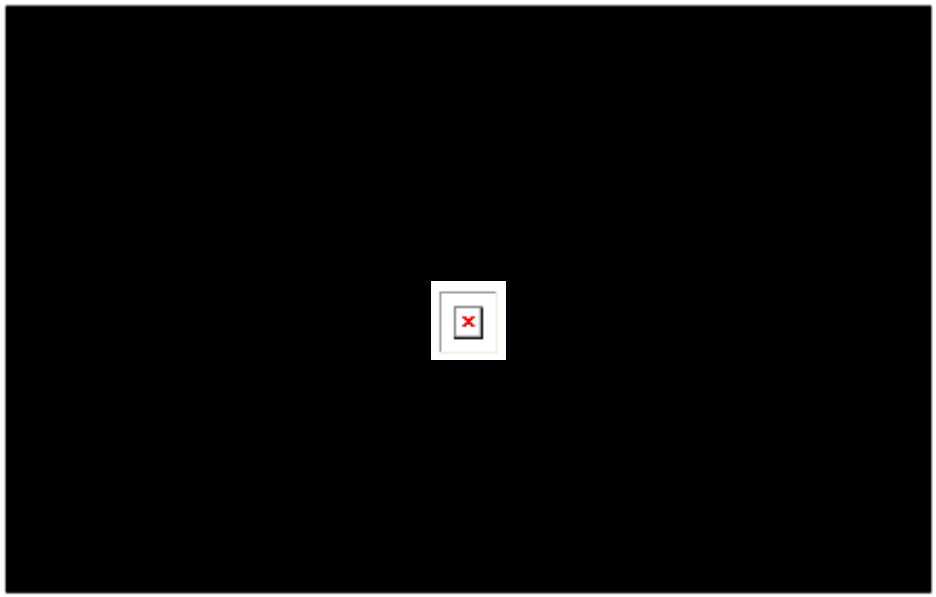
**But approximation needs to be done carefully... or...**

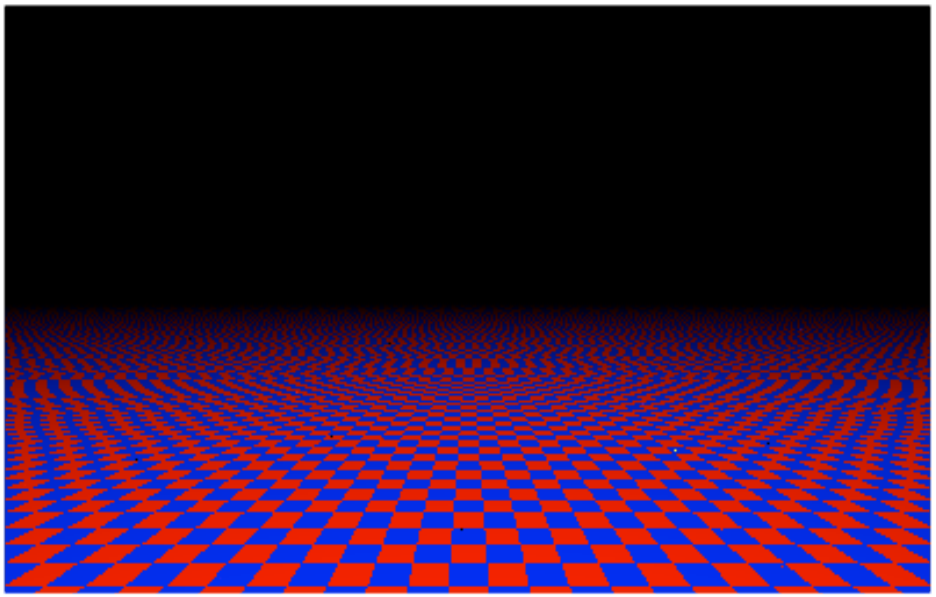


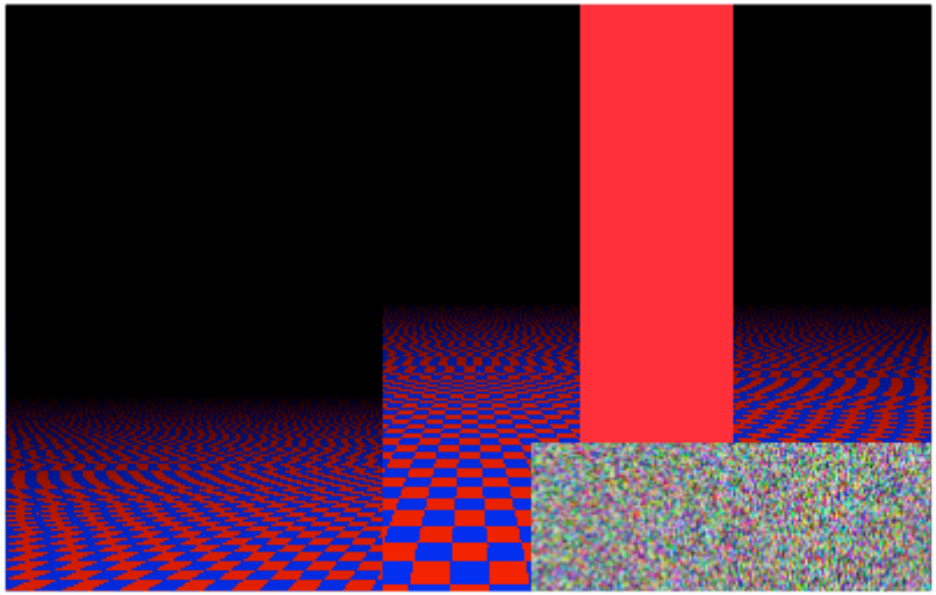








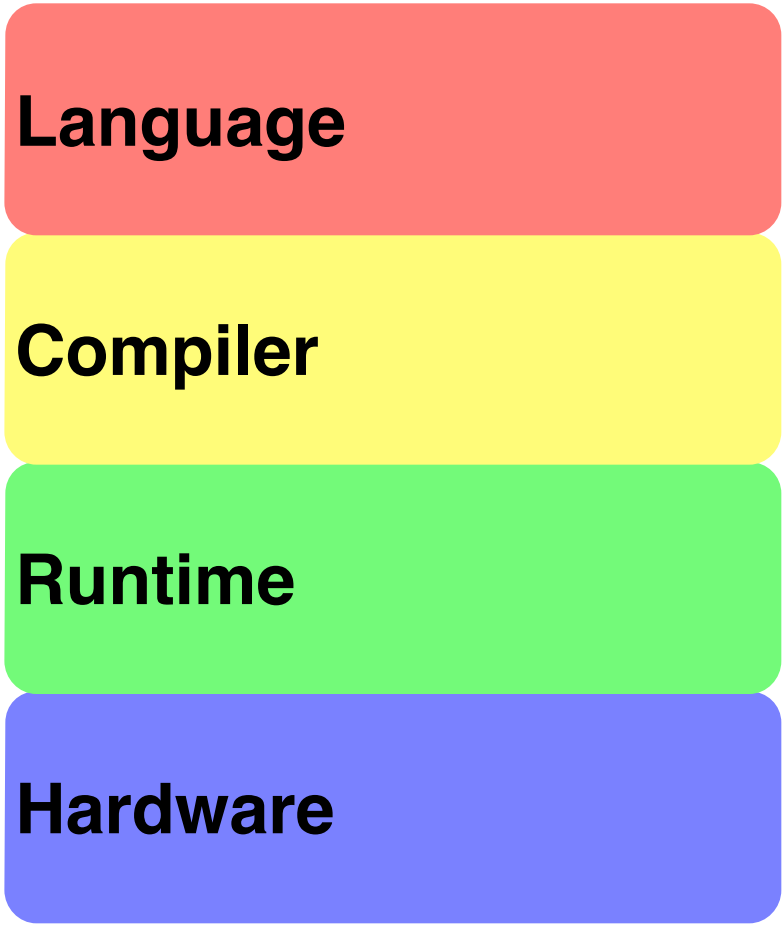




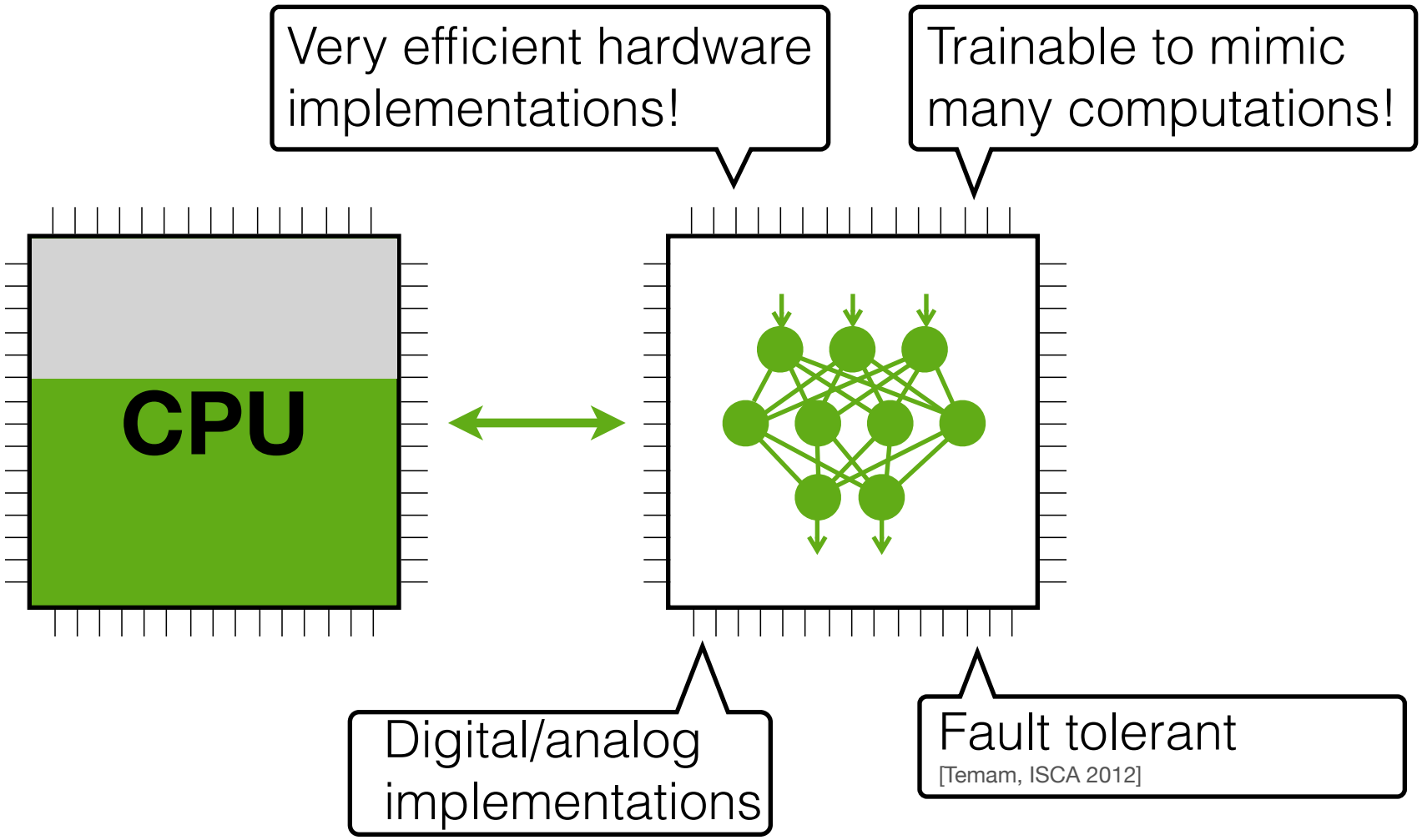

Rapid
A fatal exception 0E has occurred at 0028:C0011E36 in VXD VMM(01) +
00010E36. The current application will be terminated.
* Press any key to terminate the current application.
* Press CTRL+ALT+DEL again to restart your computer. You will
lose any unsaved information in all applications.
Press any key to continue _

# Three important questions

1. What and how to approximate?
2. How good is my output?
3. How to take advantage of it?



# Example: Neural Networks as General Approximate Accelerators



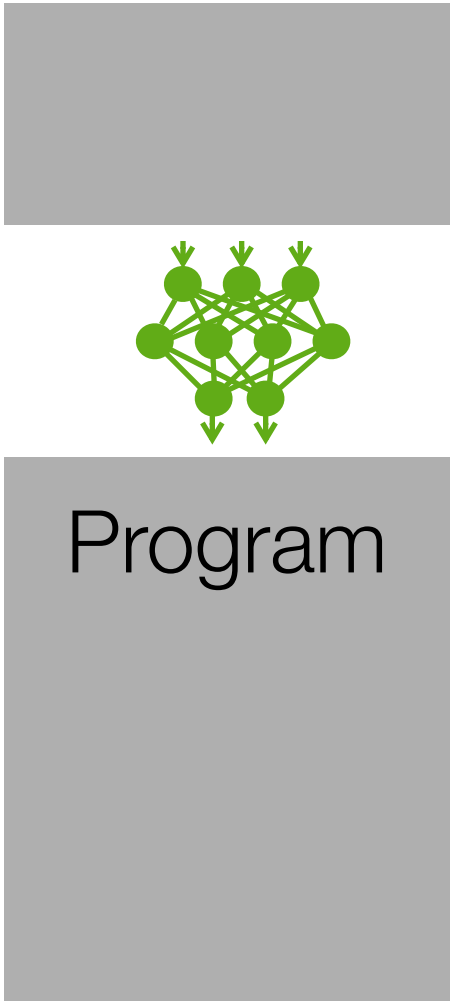

*Neural Acceleration of General-Purpose Approximate Programs, MICRO 2012*
*General-Purpose Code Acceleration with Limited-Precision **Analog** Computation, ISCA 2014*

# Neural acceleration


**Find** an approximate program component

**Compile** the program and train a neural network

# Neural acceleration




**Find** an approximate program component

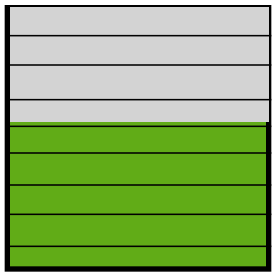
**Compile** the program and train a neural network

**Execute** on a fast Neural Processing Unit (NPU)

**3-20x** performance/efficiency improvement (FPGA SoC prototype).

# Approximation beyond the CPU

## DRAM

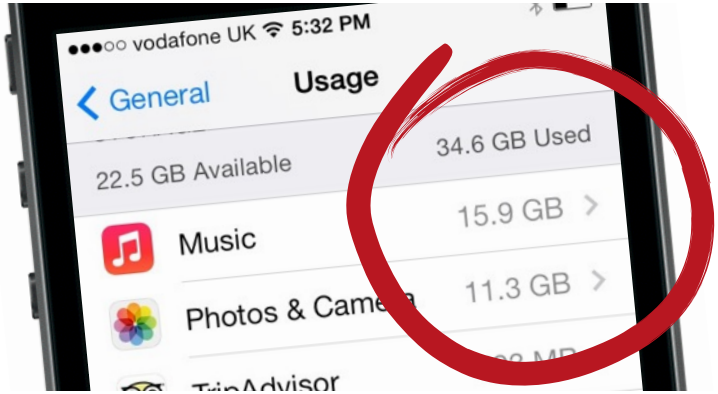


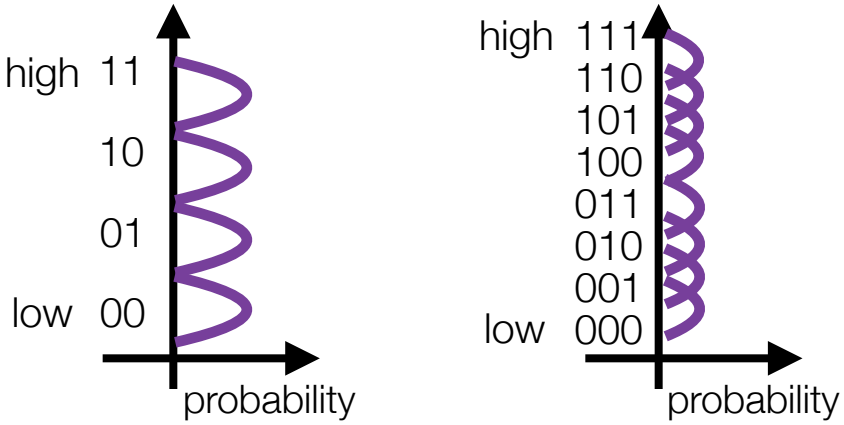
nominal refresh

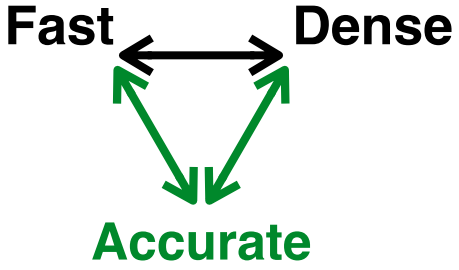
low refresh

## Wireless networking

## Multi-level solid state cells

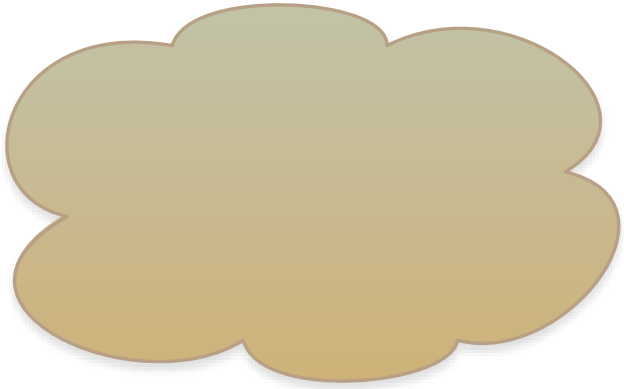


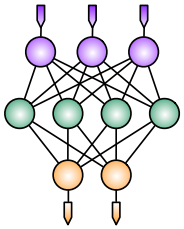



# And end-to-end story

Approximate near-sensor processing



Approximate communication



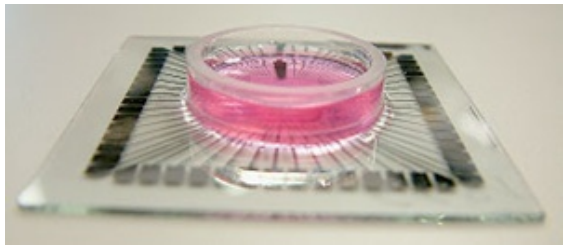
$$o_j = sigmoid(\sum_i w_{ji} x_{ji})$$

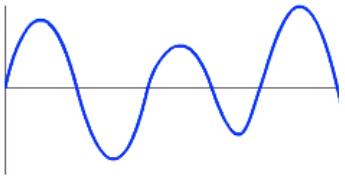
Deep neural nets

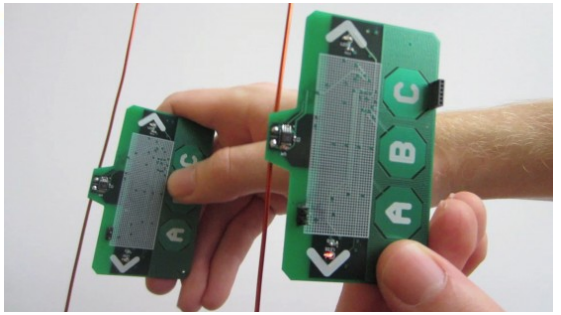
Approximate storage

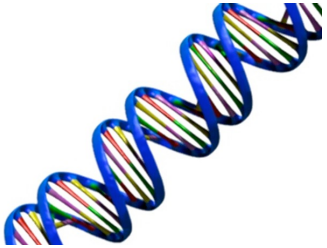
# Beyond CMOS, beyond digital, beyond efficiency

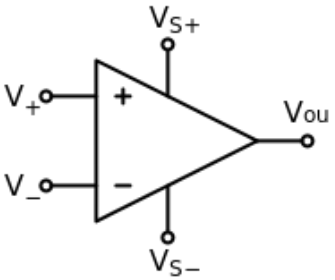
Science of approximate computing





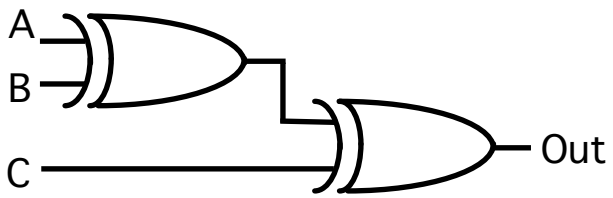



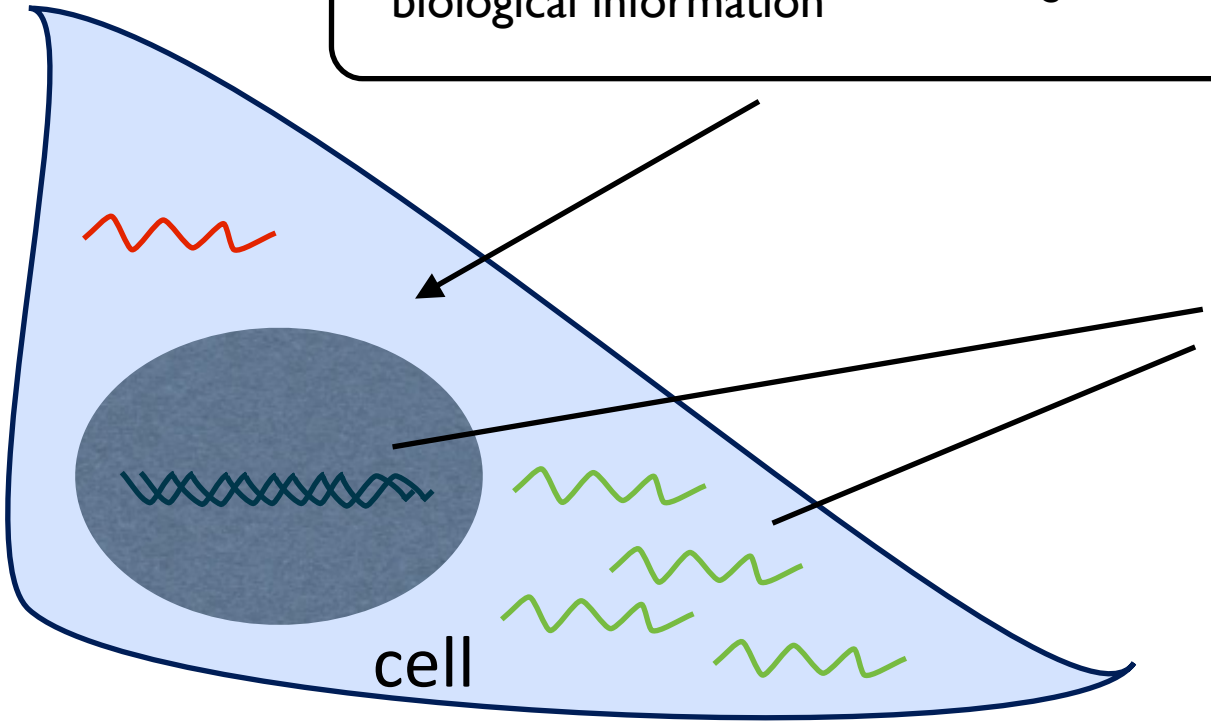





# Embedded controllers for biochemical systems: "smart" therapeutics and diagnostics

A cell-based "computer" needs to be biocompatible, and sense, analyze and act on biological information




Biological Information is encoded in the sequences and amounts of biomolecules (DNA, RNA, proteins, etc.)

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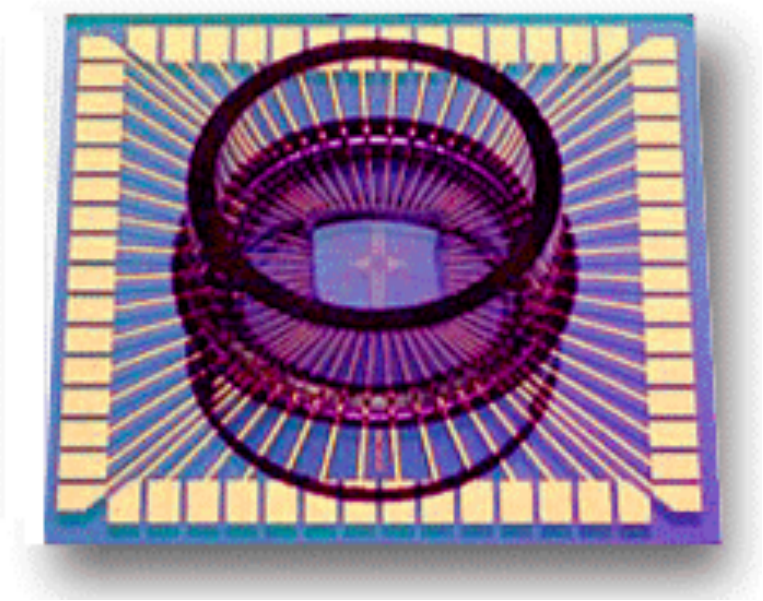
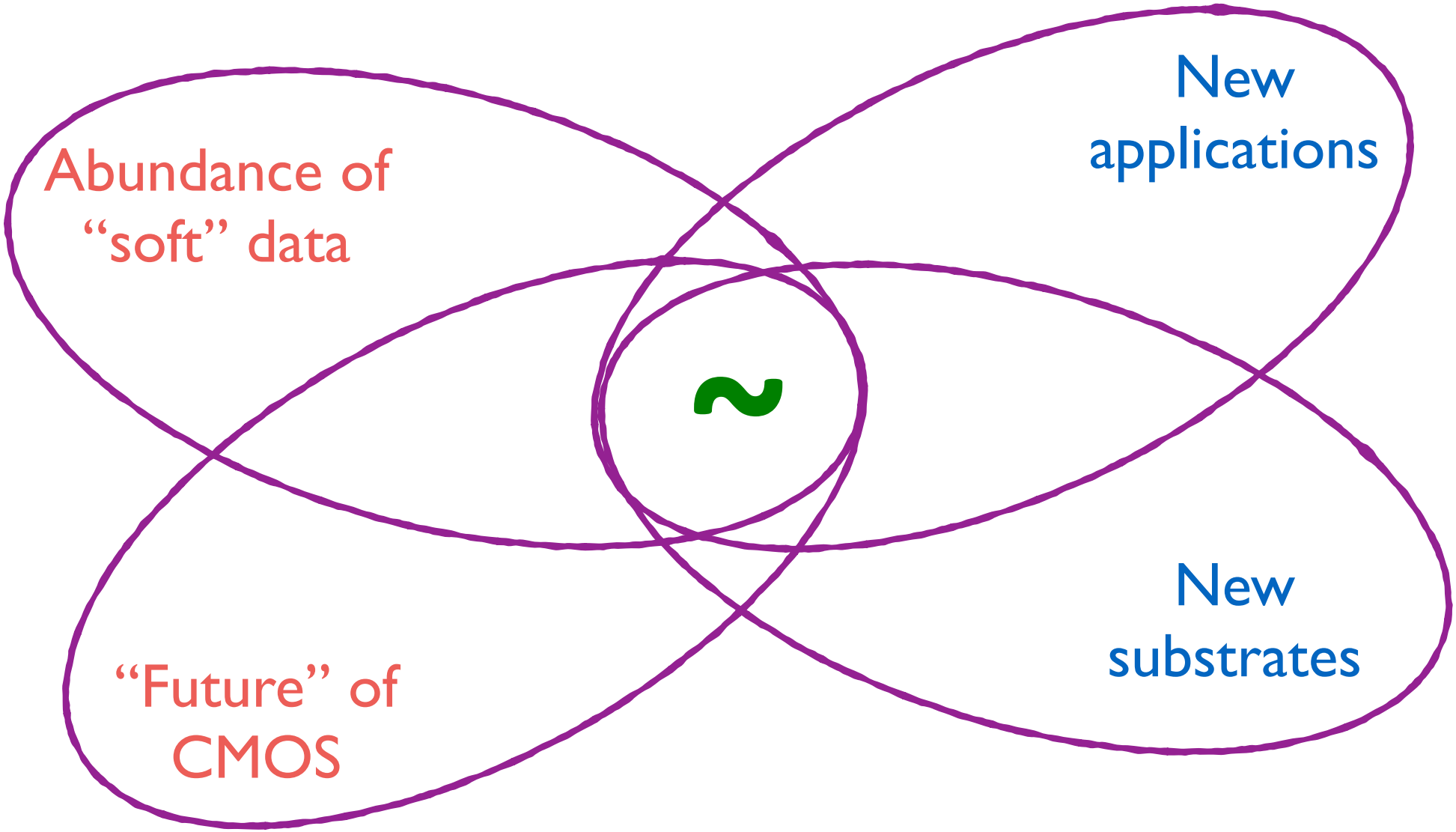
# SIMBIOTECH: Silicon Meets Biotech



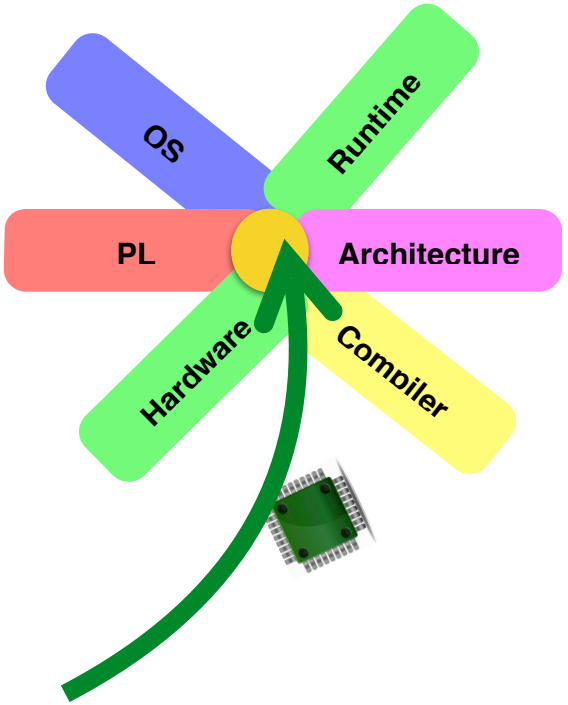
# Take home: confluence of trends points to pervasive approximate computing systems



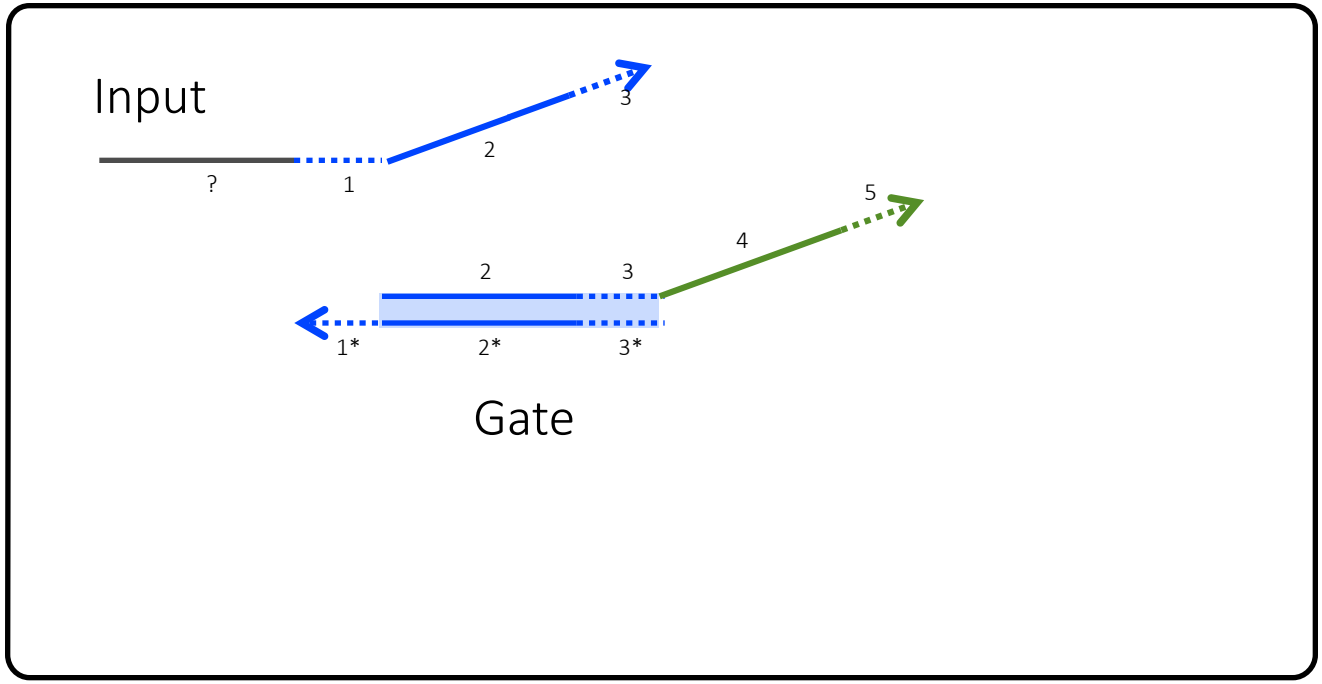
# *Thanks!*

Luis Ceze University of Washington

University of Washington

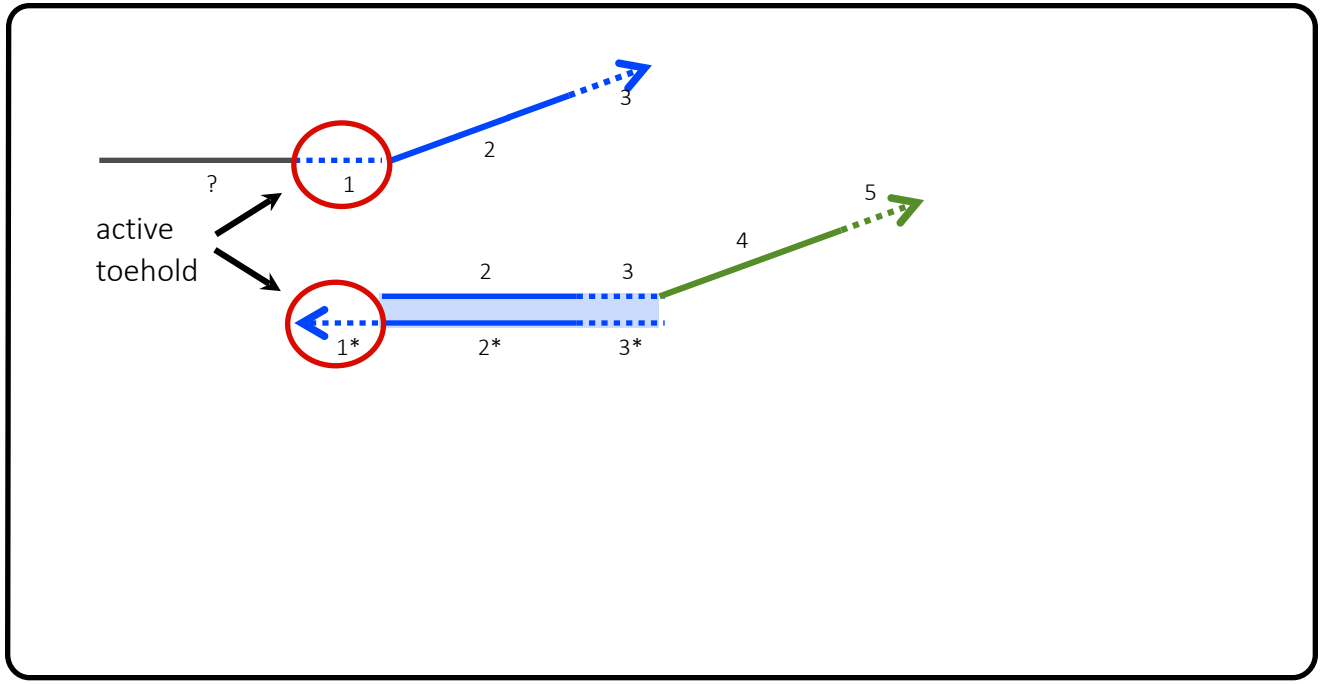


# DNA strand displacement basics




For a review see D. Y. Zhang and G. Seelig, Nature Chemistry (2011)

# DNA strand displacement basics

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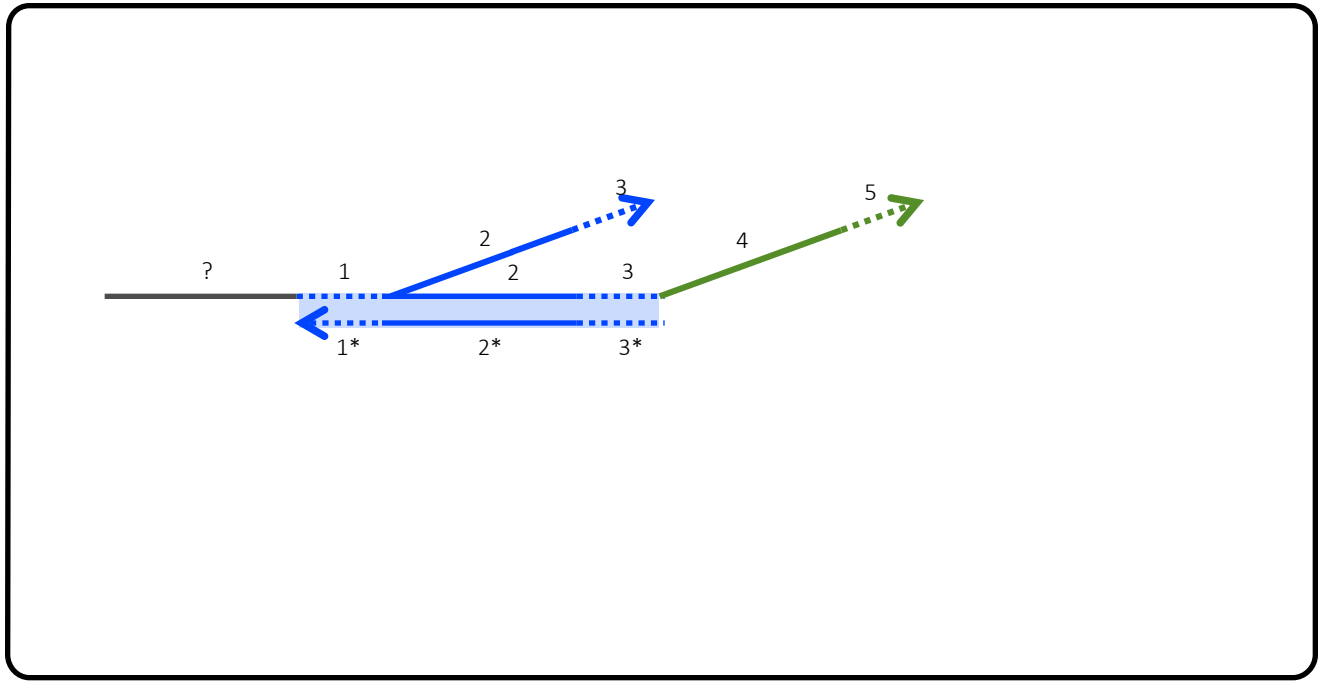
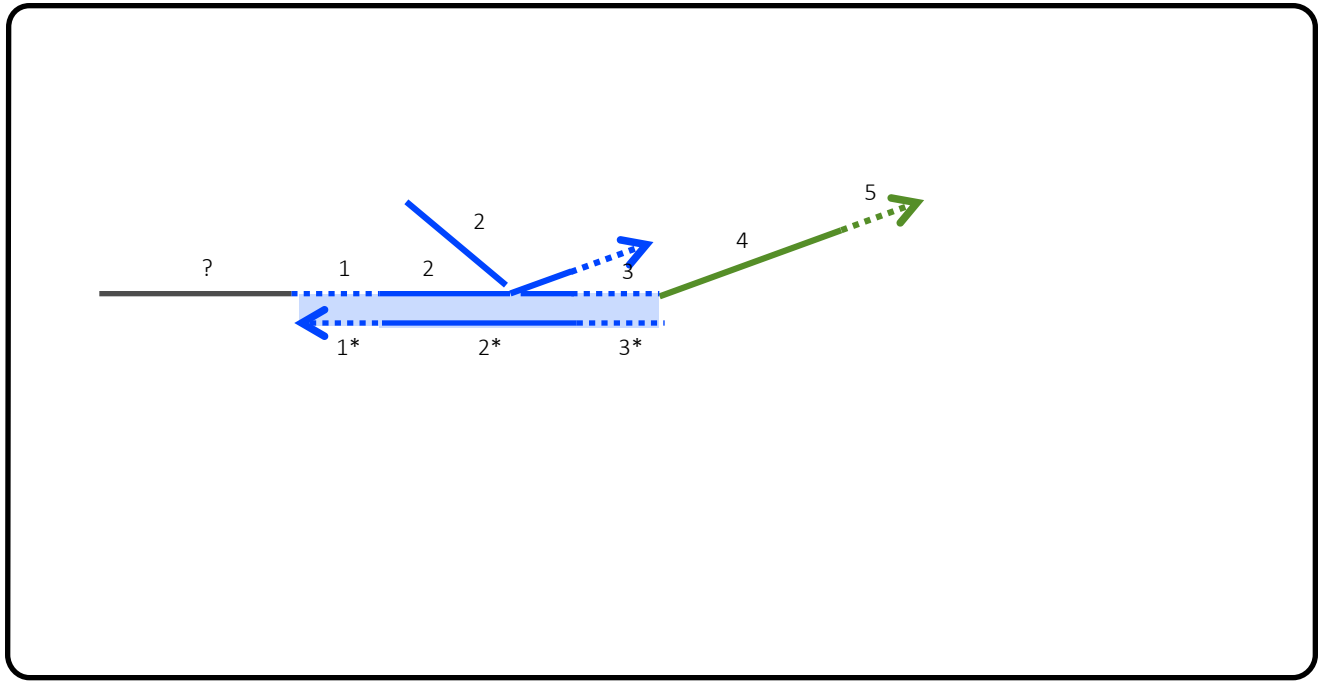
# DNA strand displacement basics



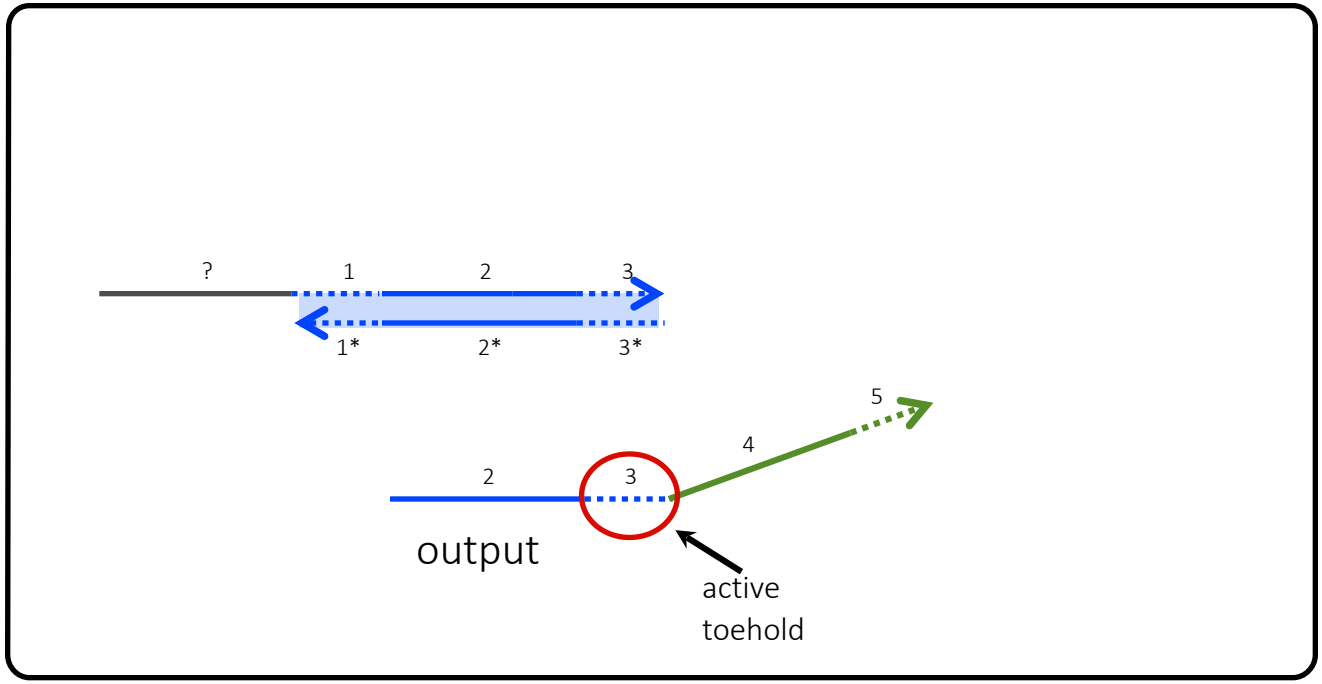

Strand displacement is initiated at the single-stranded toeholds. Toehold binding is a reversible process.

# DNA strand displacement basics



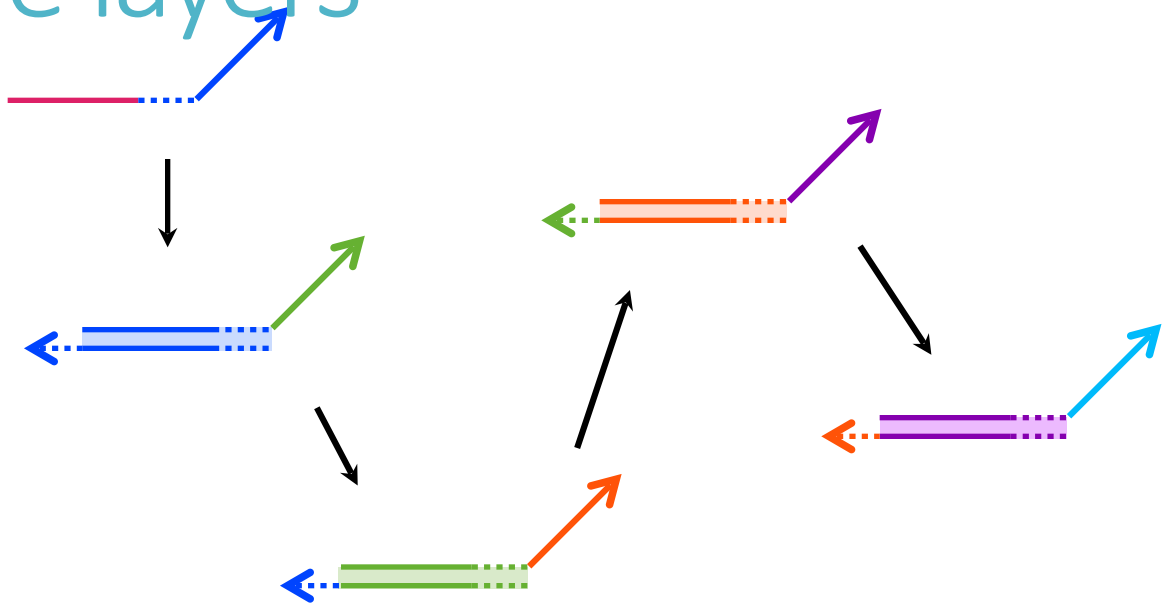

Strand displacement proceeds through a branch migration. Branch migration is a random walk.

# DNA strand displacement basics




Release of the output strand is (almost) irreversible in the absence of a toehold for the reverse reaction.

# Signals can propagate through multiple layers

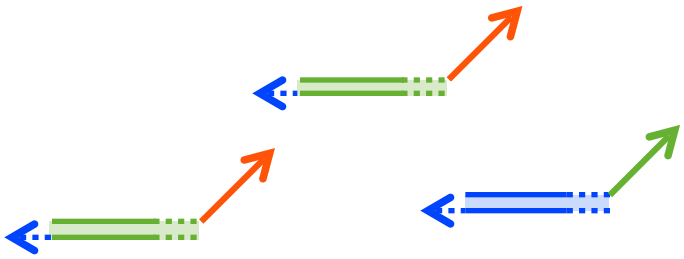


Sequence determines interactions: The chemical specificity determines the “wiring diagram.” There are $4^{20}=10^{12}$ different 20-mers but most sequences can’t be used.

# Take away message

We can build simple logic gates and circuits using DNA.

DNA strand displacement circuits are the largest engineered molecular circuits built so far. But they are still really small.

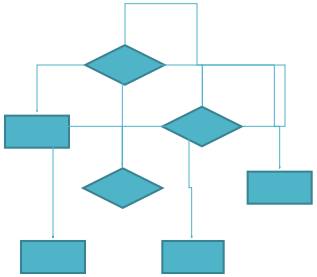
# Classifier Generation Pipeline

target condition/state

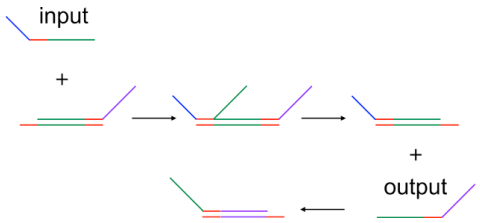
+

cell multi-omics database

automated classifier design



minimize circuit




synthesis and testing

Abnormal state

uses

blood
urine
algae
etc

...

<type>