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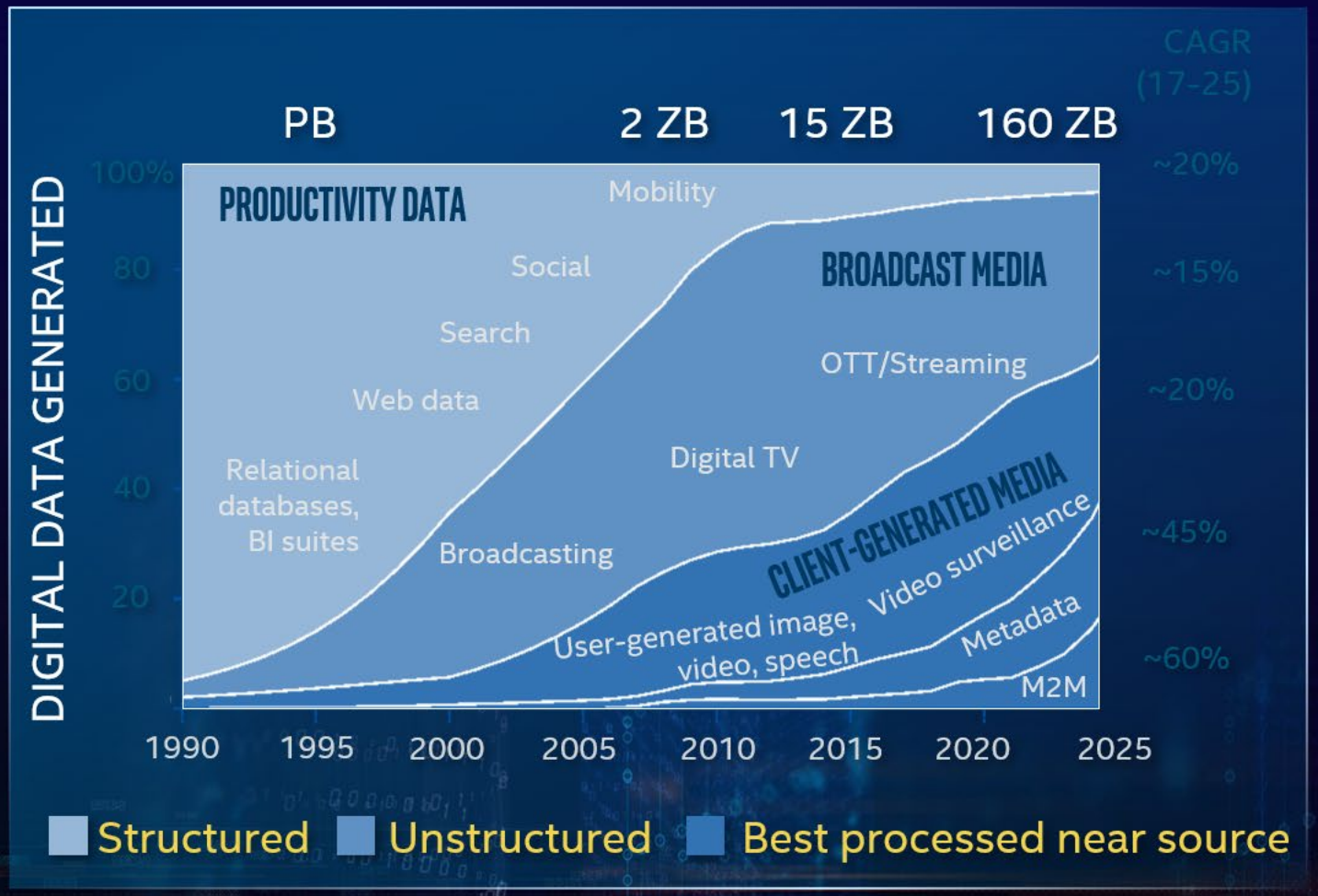
THE SHIFTING NATURE OF DATA…



… MOTIVATES NEW OPTIMIZATIONS

New Forms of Data Parallelism

New Numeric Formats & Precisions

Rethinking Data Compression

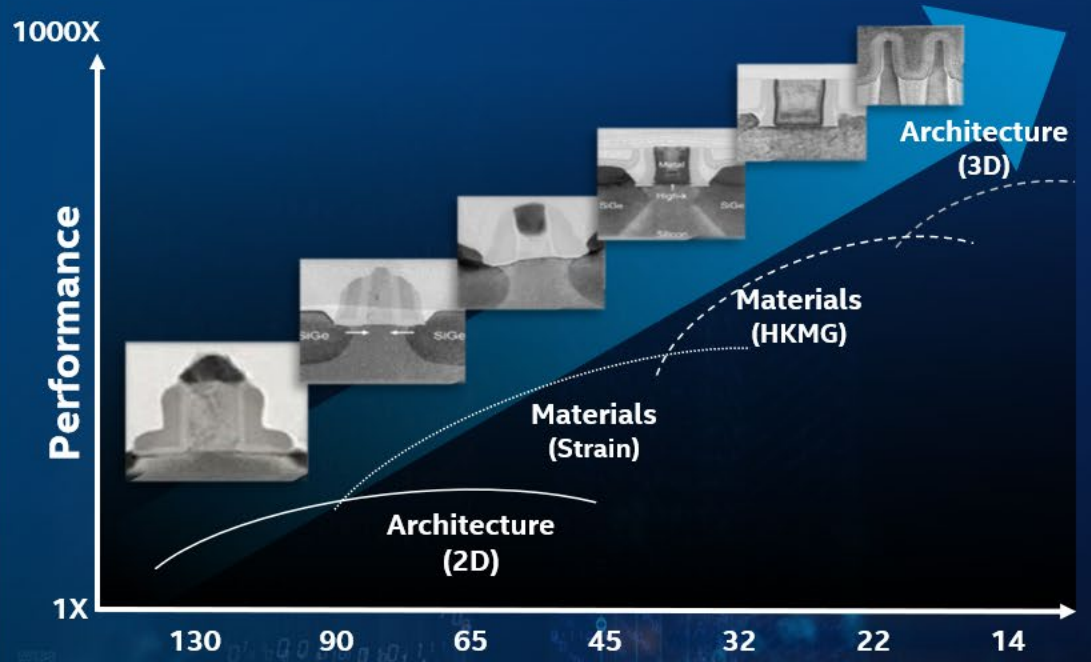
Processing Data at the Source/Edge

Source: Analyst and Intel Data - Oct 2018

MOORE'S LAW EVOLVING…

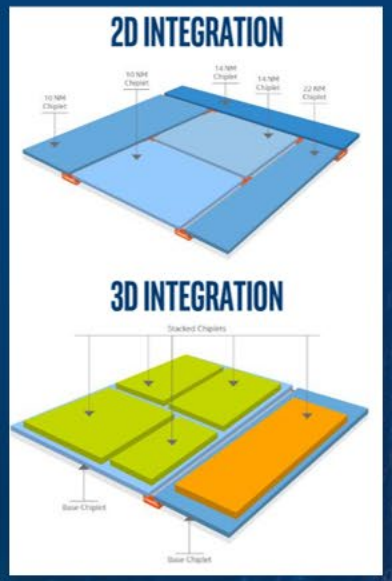
1000X in Reduction in Feature Size

New Materials | New Architecture

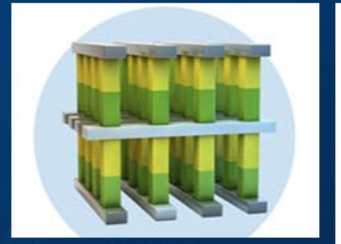


Four Thrusts Along With CMOS Scaling

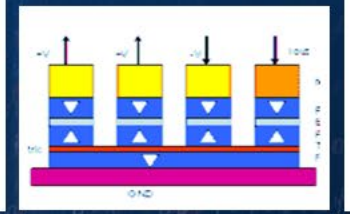
Heterogeneous System Integration



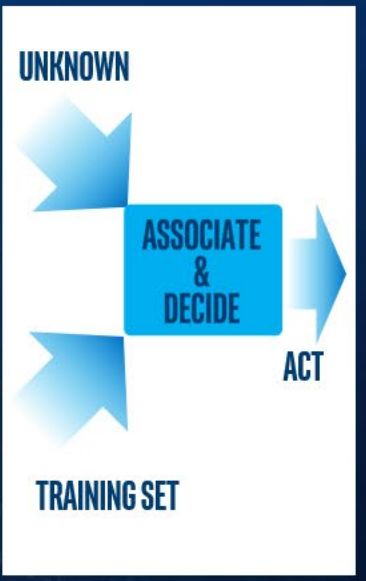
3D Process and Design



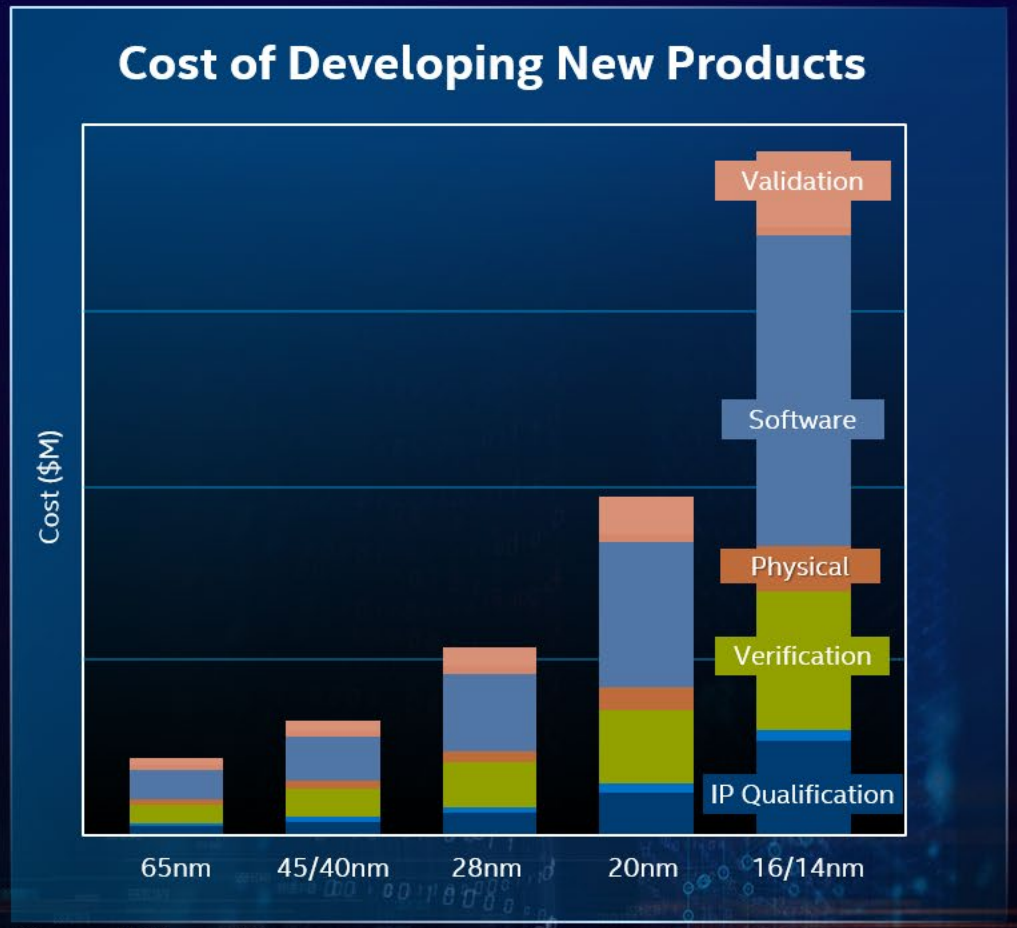
Novel Functions



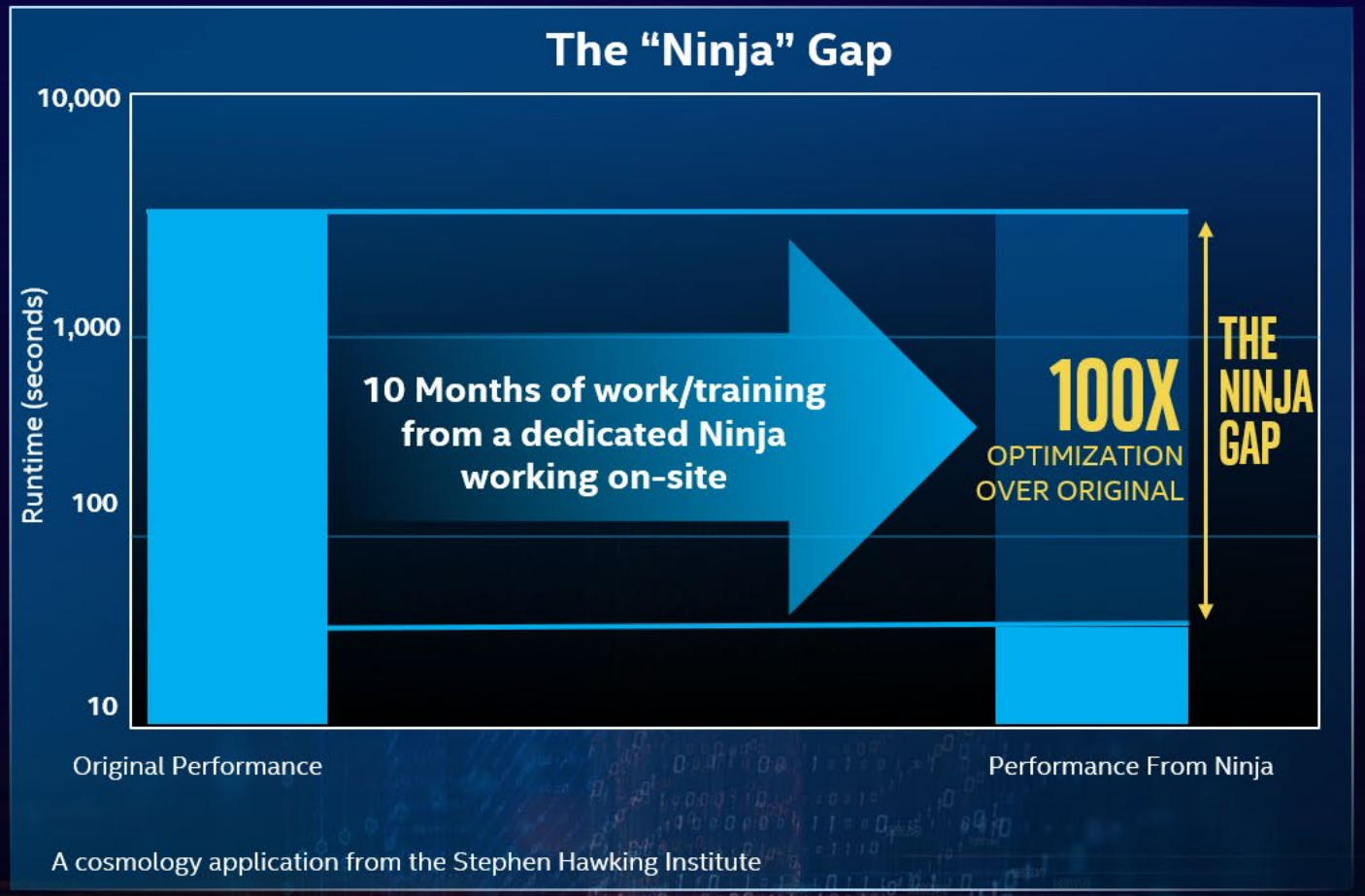
Novel Data Processing Architectures



… INCREASING DESIGN & PROGRAMMING COMPLEXITY



[Source: IBS]



TACKLING THESE CHALLENGES REQUIRES A SYSTEMS VIEW

INTEL LABS

COLLABORATE FOR RESULTS

UNIVERSITIES

GOVERNMENTS

INDUSTRY

KEY RESEARCH FOCUS AREAS

ARTIFICIAL INTELLIGENCE

SECURITY & PRIVACY

AGILE HW/SW CO-DESIGN

FUTURE OF PROGRAMMING

SENSING TECHNOLOGIES

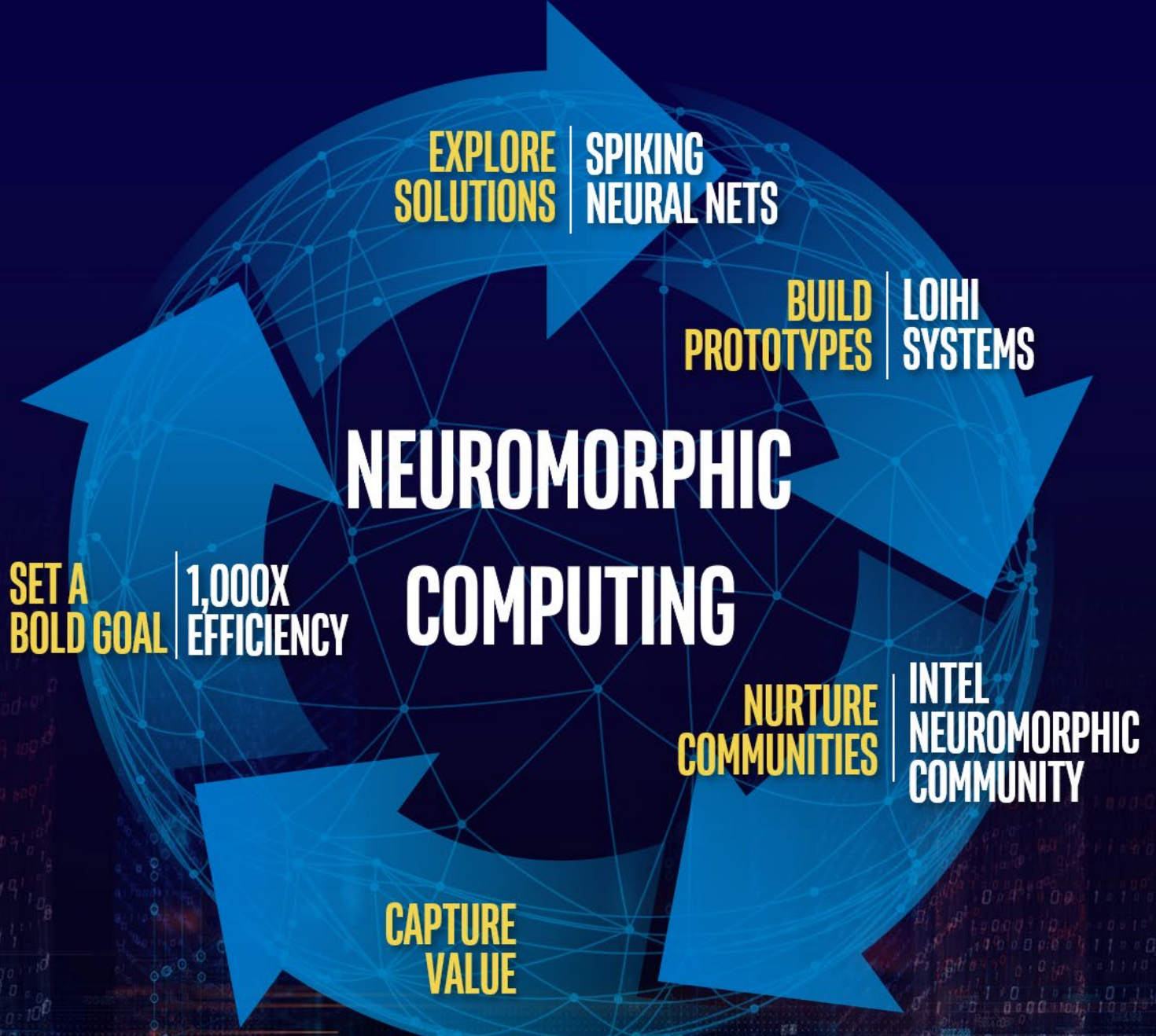
CONNECTIVITY & COMMS

MEMORY & STORAGE ARCHITECTURE

NEW COMPUTE MODELS

INTEL LABS METHODOLOGY

LET'S LOOK AT AN EXAMPLE...


EXPLORE SOLUTIONS
SPIKING NEURAL NETS
BUILD PROTOTYPES
LOIHI SYSTEMS
NEUROMORPHIC COMPUTING
NURTURE COMMUNITIES
INTEL NEUROMORPHIC COMMUNITY
CAPTURE VALUE
SET A BOLD GOAL
1,000X EFFICIENCY

HOW CAN WE ACHIEVE A >1,000X IMPROVEMENT IN COMPUTE EFFICIENCY?

EXPLORE SOLUTIONS

THINKING DIFFERENTLY…

STANDARD COMPUTING

CPU

MEM

if X then
…
else
…

01100
11010
00100

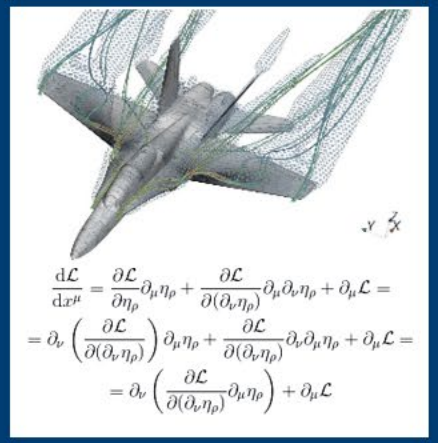
BRAIN INSPIRED COMPUTING

MEM

output layer

NEUROMORPHIC COMPUTING

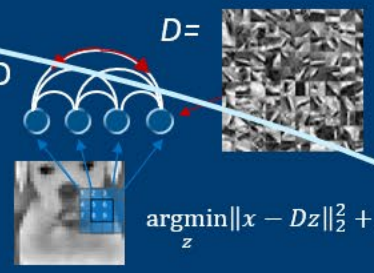
BIOLOGICAL FORM



$$\frac{\mathrm{d}\mathcal{L}}{\mathrm{d}x^{\mu}} = \frac{\partial\mathcal{L}}{\partial\eta_{\rho}}\partial_{\mu}\eta_{\rho} + \frac{\partial\mathcal{L}}{\partial(\partial_{\nu}\eta_{\rho})}\partial_{\mu}\partial_{\nu}\eta_{\rho} + \partial_{\mu}\mathcal{L} =$$
$$= \partial_{\nu}\left(\frac{\partial\mathcal{L}}{\partial(\partial_{\nu}\eta_{\rho})}\right)\partial_{\mu}\eta_{\rho} + \frac{\partial\mathcal{L}}{\partial(\partial_{\nu}\eta_{\rho})}\partial_{\nu}\partial_{\mu}\eta_{\rho} + \partial_{\mu}\mathcal{L} =$$
$$= \partial_{\nu}\left(\frac{\partial\mathcal{L}}{\partial(\partial_{\nu}\eta_{\rho})}\partial_{\mu}\eta_{\rho}\right) + \partial_{\mu}\mathcal{L}$$

$D^{T}D$

$D=$

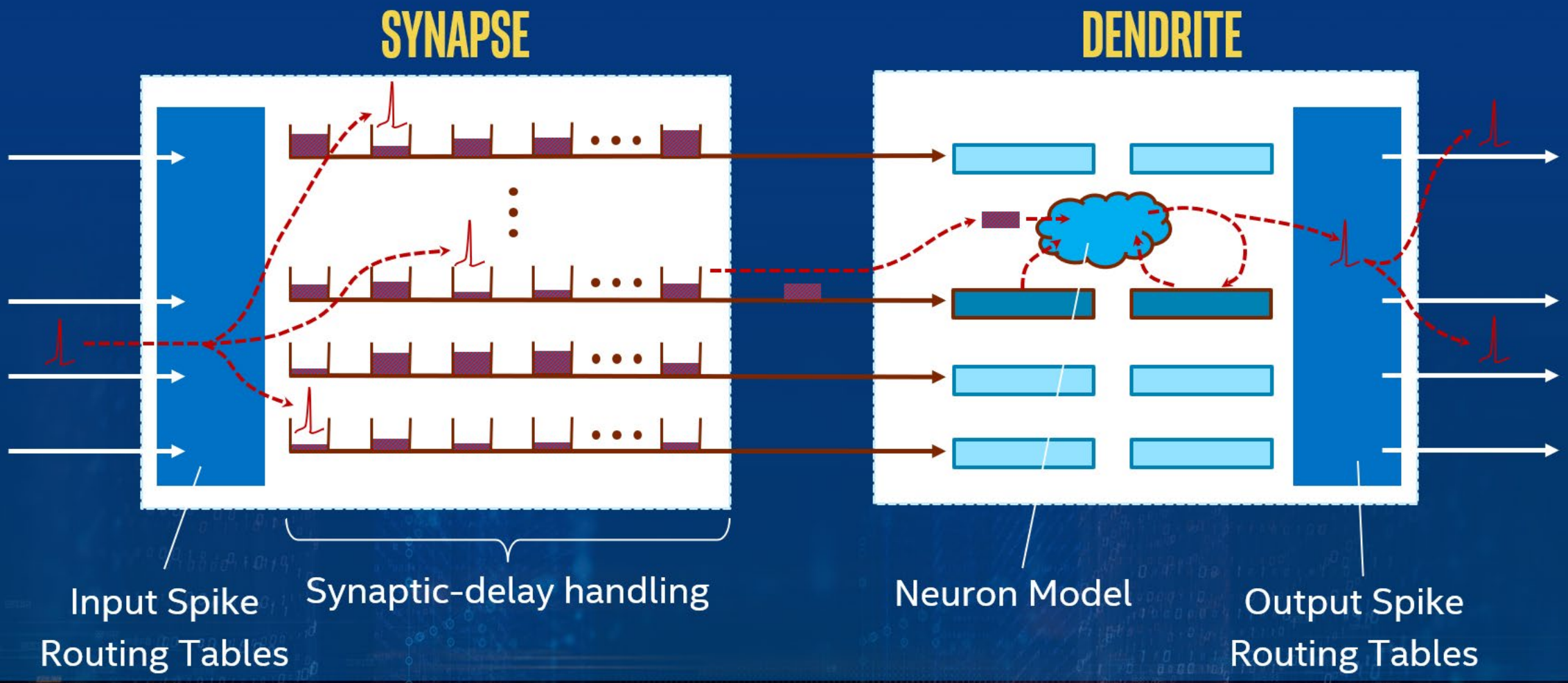


$$\underset{z}{\operatorname{argmin}}\|x - Dz\|_2^2 + \lambda\|z\|_1$$

"INTELLIGENT" APPLICATIONS

SPIKING NEURAL NETWORK (SNN)

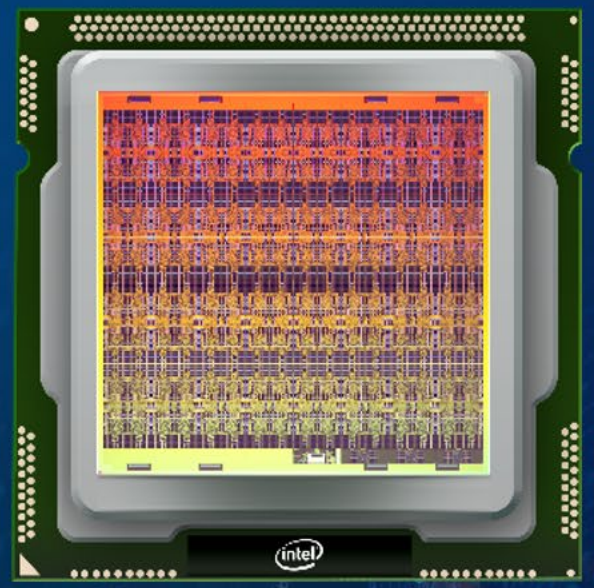
EXPLORE SOLUTIONS



LOIHI ARCHITECTURE

EXPLORE SOLUTIONS

INTEGRATED MEMORY + COMPUTE



- 128 cores | 128k neurons | 128M synapses
- Each neuromorphic core simulates many “logical neurons”
- On-die mesh fabric supports efficient distribution of spiking messages
- Highly-complex neural network topologies
- Scalable on-chip learning capabilities to support a range of learning paradigms

AN EXAMPLE USAGE: SPARSE CODING

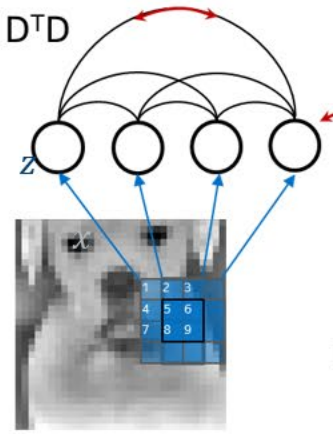
EXPLORE SOLUTIONS

LASSO Sparse Coding

$$\underset{z}{\operatorname{argmin}} \|x - Dz\|_2^2 + \lambda \|z\|_1$$

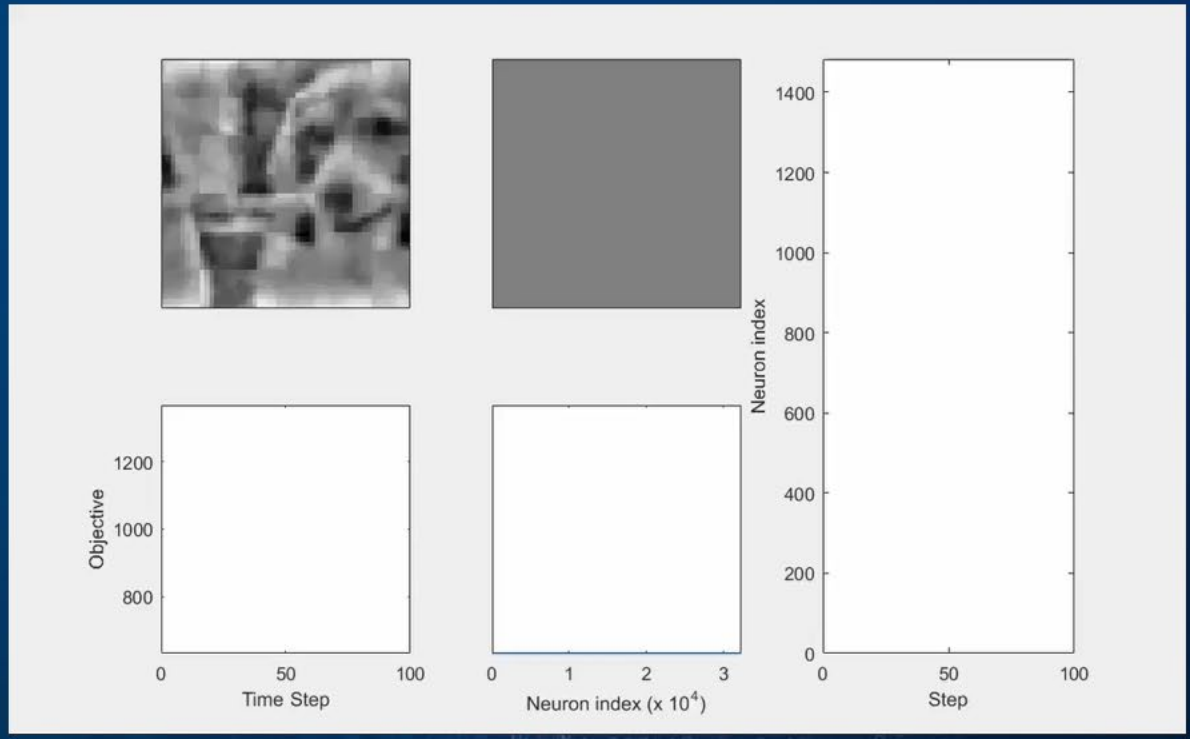
Input Reconstruction | Sparse regularization

$D =$



In the neural network formulation, **feature neurons compete** to reconstruct image with as few contributors as possible

Tang et al., arxiv: 1705:05475

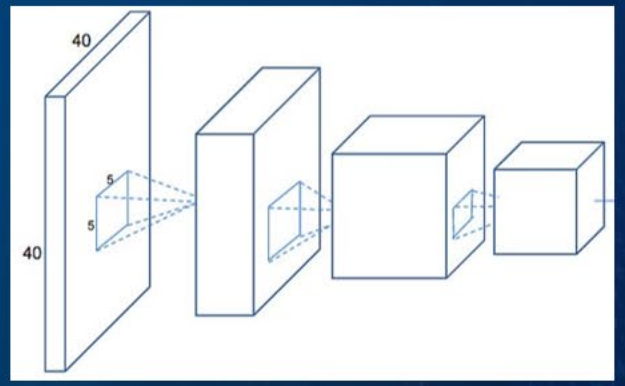


OTHER POTENTIAL ALGORITHMS

EXPLORE SOLUTIONS

DEEP LEARNING

Translating Conventional Deep Networks to SNN Form



Backpropagation for SNNs

OPTIMIZATION

Sparse Coding (LASSO)

$$\underset{z}{\operatorname{argmin}} \|x - Dz\|_2^2 + \lambda \|z\|_1$$

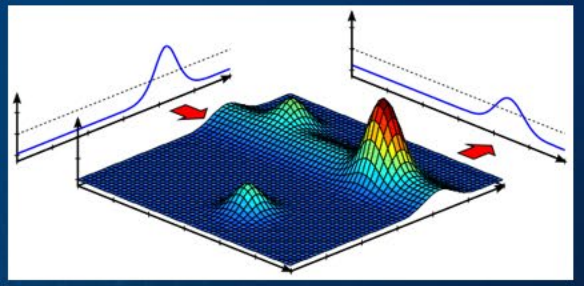
Graph Search
Path Planning

Constraint Satisfaction

Bayesian Computation

DYNAMICS

Novel Programming Paradigms for Dynamical Neural Networks



Adaptive Control for Robot Arm

LOIHI SYSTEMS

BUILD PROTOTYPES

Lady Bug
250K to 500K neurons

Cockroach
1M neurons

Zebra Fish
~10M neurons

Q4 2017

WOLF MOUNTAIN

Remote Access
4 Loihi/Board
(512K neurons)

Q2 2018

NAHUKU

Arria10 Expansion Board
8-32 Loihi/Board
(4M neurons)

Q3 2018

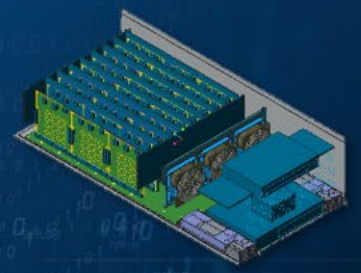
KAPOHO BAY

1-2 Loihi
DVS interface
USB host interface

ANNOUNCING TODAY

POHOIKI BEACH

64 CHIPS SYSTEM
REMOTE ACCESS, 8M NEURONS



INTEL NEUROMORPHIC RESEARCH COMMUNITY

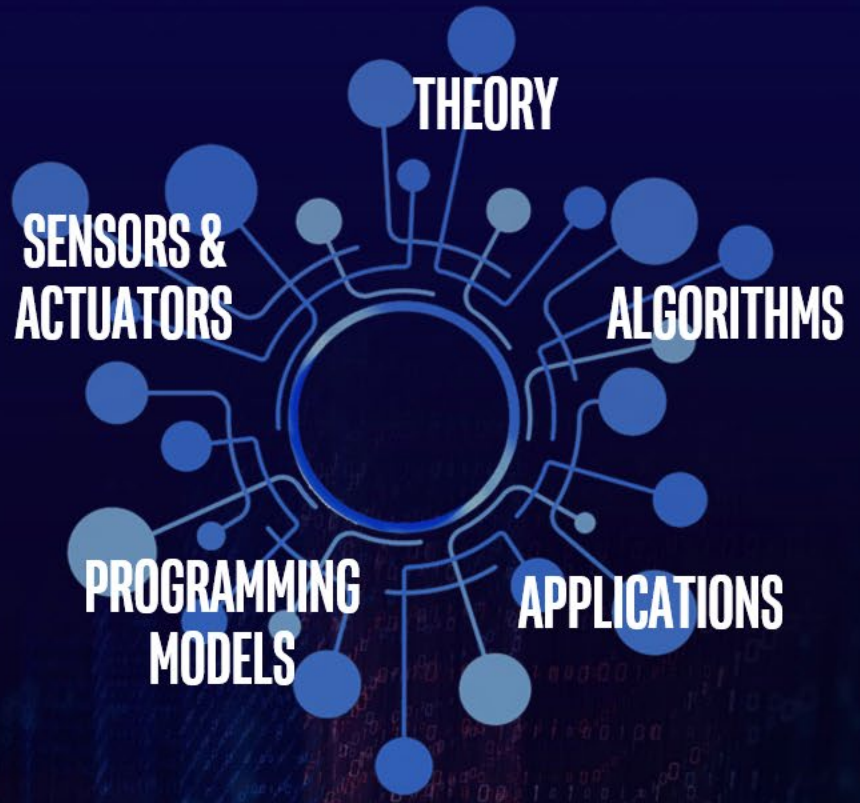
DISCOVERING AND OPTIMIZING APPLICATIONS IN A THRIVING RESEARCH ECOSYSTEM

61 ENGAGED GROUPS

>50 ACTIVE PROJECTS

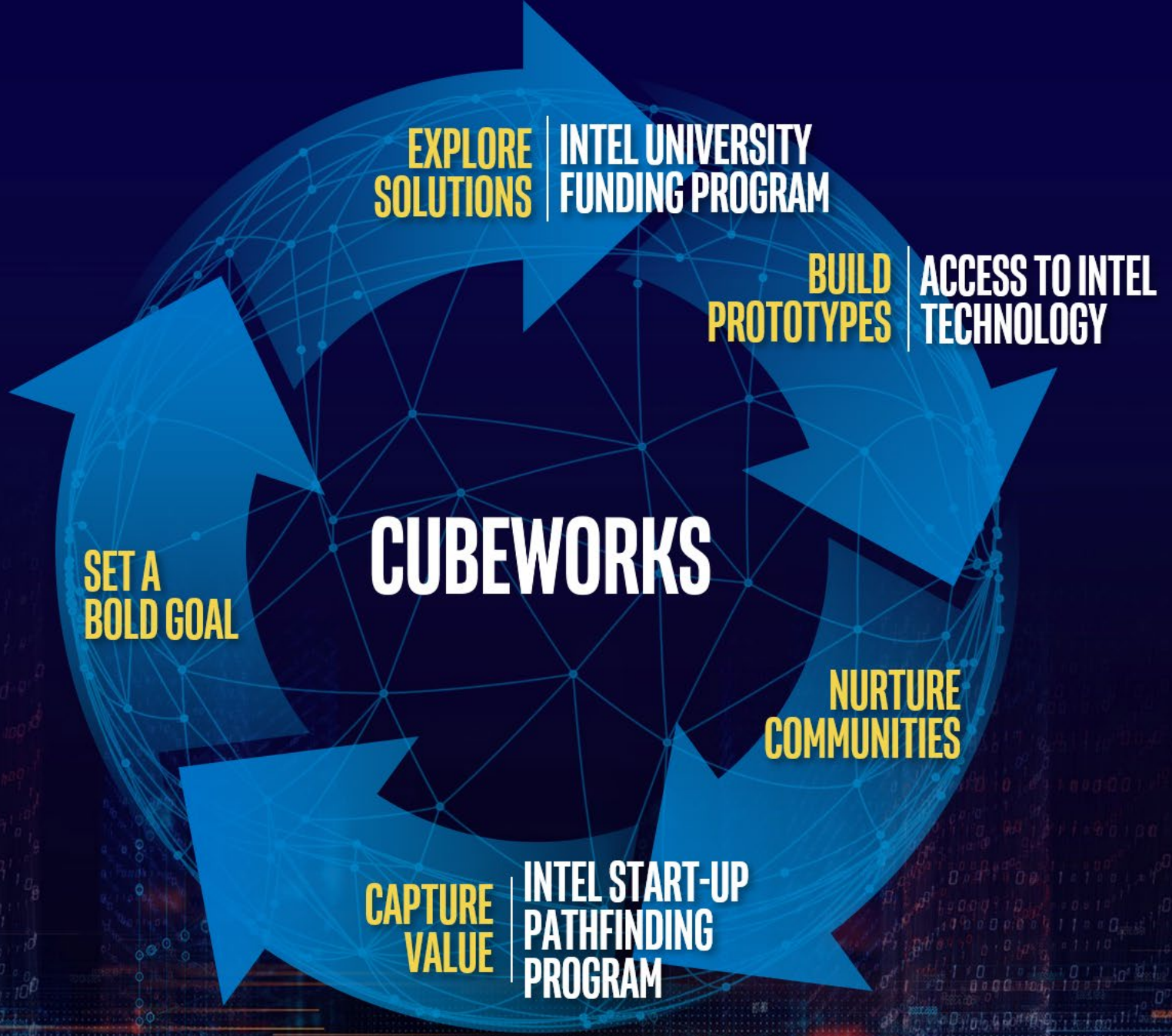
9 WORKSHOPS REACHING OUT TO OVER **400** RESEARCHERS

11 PUBLICATIONS BY COMMUNITY MEMBERS

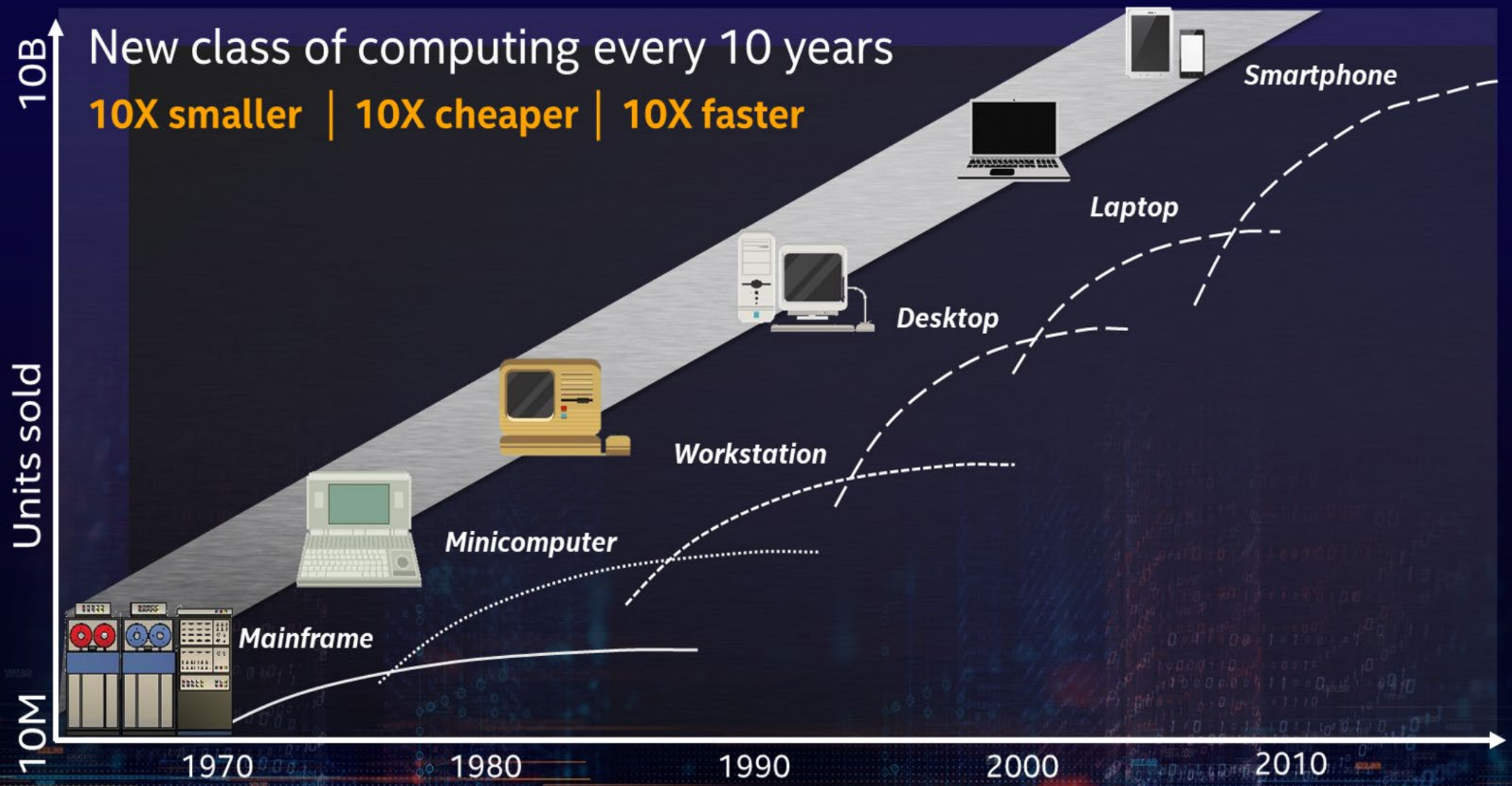


COLLABORATION OPEN TO ACADEMICS, GOVERNMENT AND INDUSTRY

LET'S LOOK AT ANOTHER EXAMPLE...


EXPLORE SOLUTIONS
INTEL UNIVERSITY FUNDING PROGRAM
BUILD PROTOTYPES
ACCESS TO INTEL TECHNOLOGY
CUBEWORKS
SET A BOLD GOAL
NURTURE COMMUNITIES
CAPTURE VALUE
INTEL START-UP PATHFINDING PROGRAM

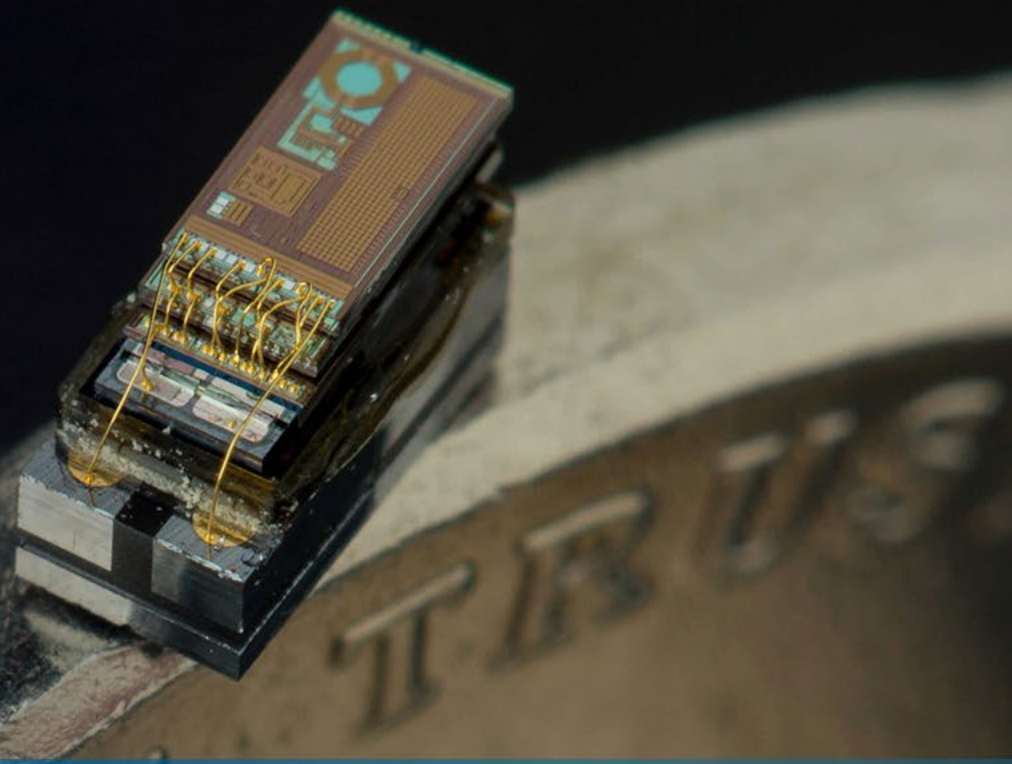
BELL'S LAW


New class of computing every 10 years
10X smaller | 10X cheaper | 10X faster
10B
Units sold
10M
1970
1980
1990
2000
2010
Smartphone
Laptop
Desktop
Workstation
Minicomputer
Mainframe

MICHIGAN MICRO MOTE (M3)

EXPLORE SOLUTIONS

HIGH-VALUE ASSET TRACKING



OTHER APPLICATIONS:

ENVIRONMENTAL
Precision Farming
Air & Water Quality
Asset Assurance

INDUSTRIAL
Personalized Retail
Smart Homes/Cities
Process Monitoring

MILITARY
Surveillance
Soldier Vitals

BIOMEDICAL
Wireless Monitors
Intraocular Pressure
Smart Surgical Tools

2006

2013

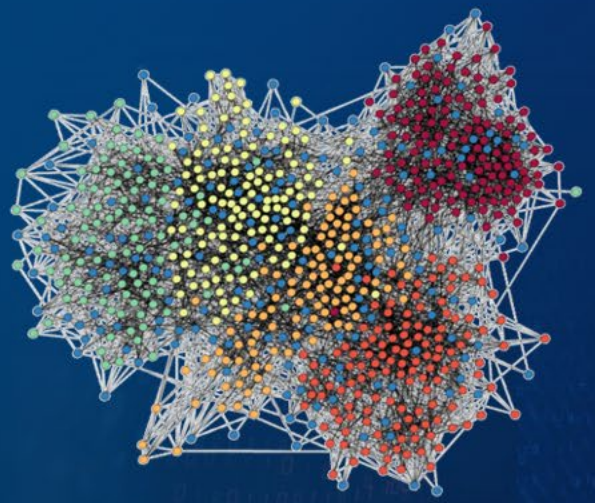
2019

*Other names and brands may be claimed as the property of others.

FUTURE OUTLOOK
INTEL COMMUNITY ENGAGEMENT

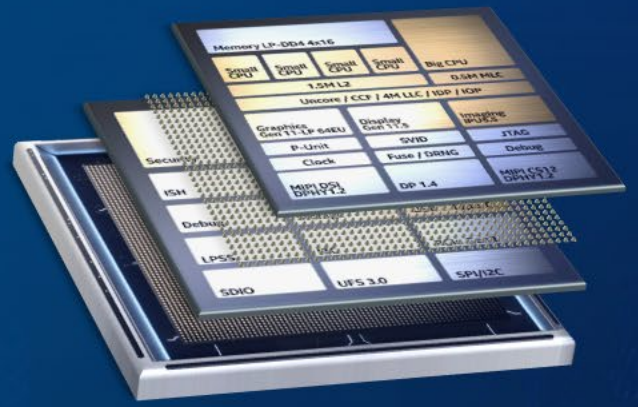
INTEL AND DARPA WORKING TOGETHER

HIVE/SDH



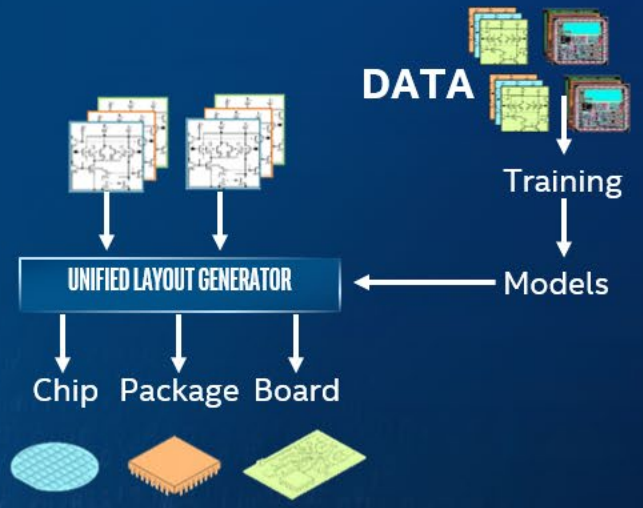
1,000X ENERGY EFFICIENCY FOR GRAPH ANALYTICS

CHIPS



3X REDUCTION IN NRE & TTM THROUGH MODULAR DESIGN

IDEA



AUTOMATED TRANSLATION TO LAYOUT (< 24 HOURS)

“Don't be encumbered by history. Go off and do something wonderful.”

- Robert Noyce

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