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Western Digital.

Autonomous Physical Design

Moving Closer Towards Fully Autonomous Design!

Aman Joshi, VP, Design Enablement & Automation

Oct 6,7, 2022

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Western Digital.

WD Corporate Overview

Global Corporate Marketing

April 2022

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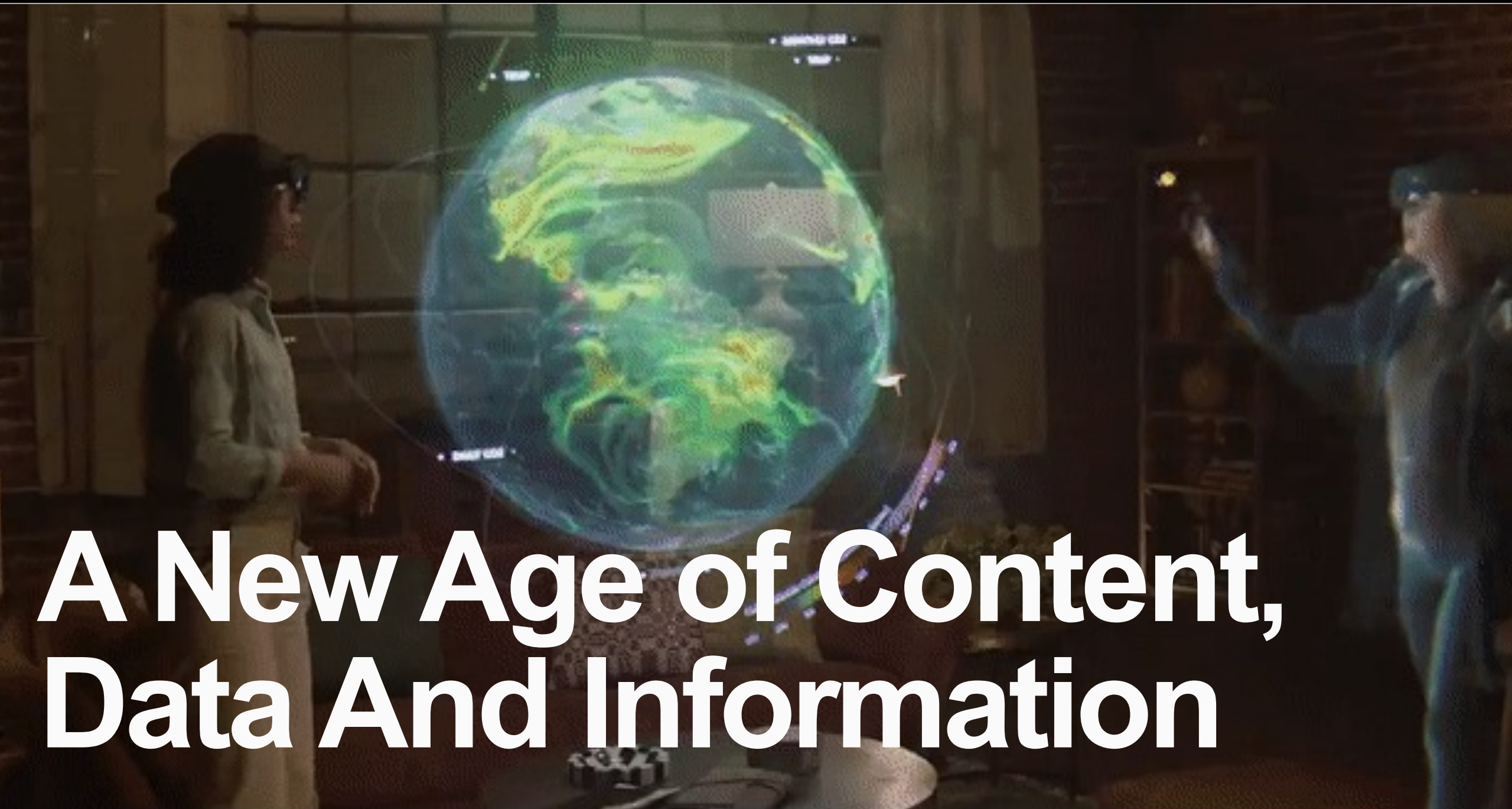

A New Age of Content, Data And Information

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GROUP: STD LATIN ALPHABET
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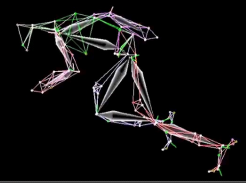
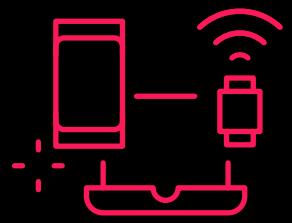
More Technology

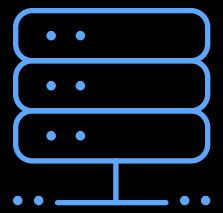
LEADS TO MORE INFORMATION





EVER-INCREASING INTELLIGENT DEVICES

POWERED BY THE CLOUD



CONNECTED BY HIGH-PERFORMANCE NETWORKS

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An Explosion of Digital Information

We will create more than 2x the data in the next 5 years than we have created since the advent of digital storage.

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Innovation With Intent

Across our portfolio, Western Digital is differentiated in its ability to design, tune and optimize solutions purpose-built for customer needs.

HelioSeal® Technology

EAMR / ePMR

Triple Stage Actuator

OptiNAND™ Technology

162-Layer 3D Flash Memory

Circuit Under Array

Multi-Bit Cell Architectures

HDD Innovation

Flash Innovation

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50+ Years of Global Trust

Western Digital is powered by the brightest minds in the industry—
a worldwide team of engineers, inventors, makers and innovators.

OPERATES IN

30+

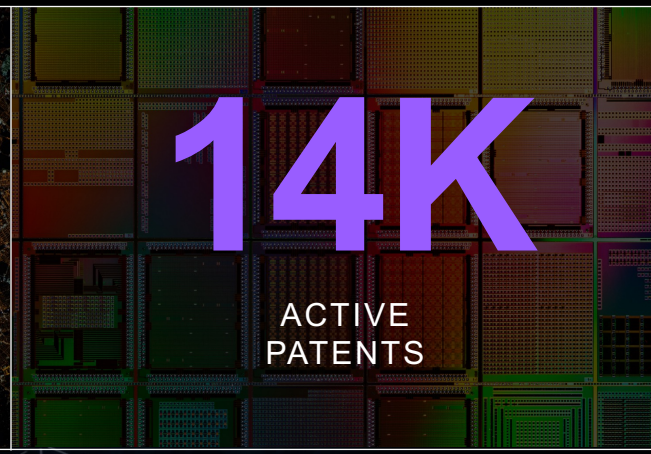
COUNTRIES

12+

MANUFACTURING &
PRODUCT FACILITIES

65K

EMPLOYEES
WORLDWIDE



14K

ACTIVE
PATENTS

RECOGNITIONS:

ETHISPHERE
GOOD. SMART. BUSINESS. PROFIT.

ONE OF THE WORLD'S
MOST **ETHICAL COMPANIES**

Newsweek

ONE OF AMERICA'S MOST
RESPONSIBLE COMPANIES

WORLD ECONOMIC FORUM

GLOBAL
LIGHTHOUSE

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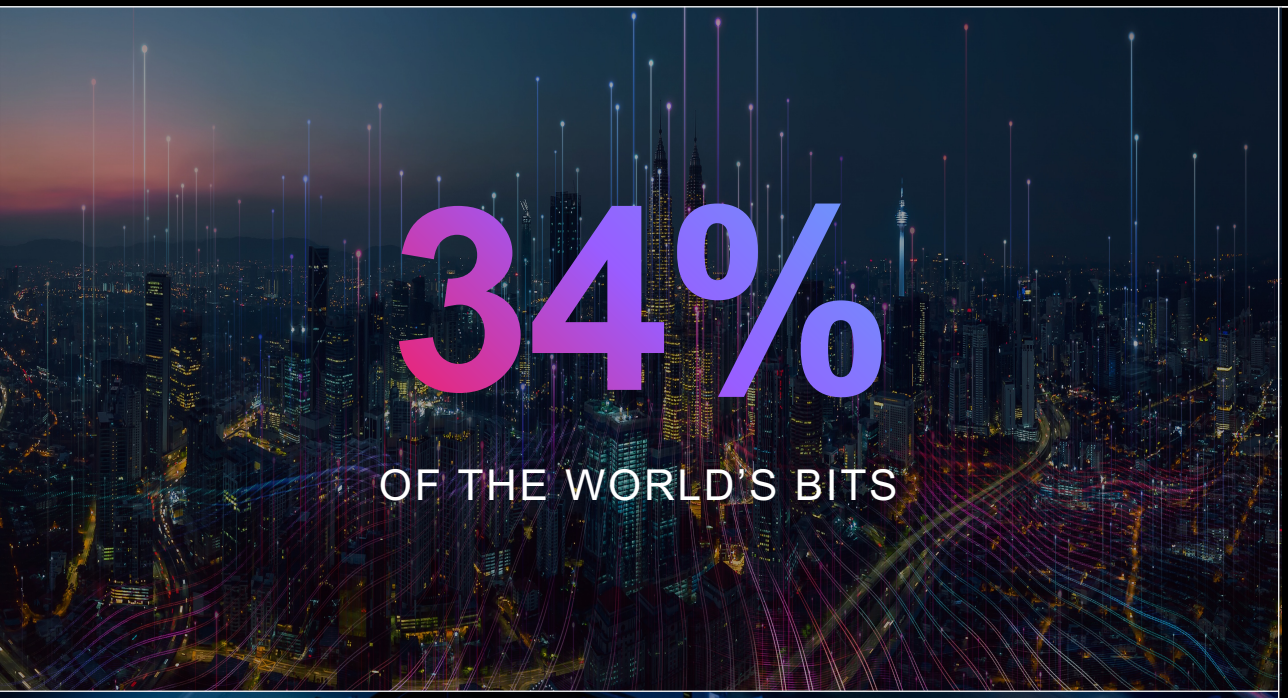

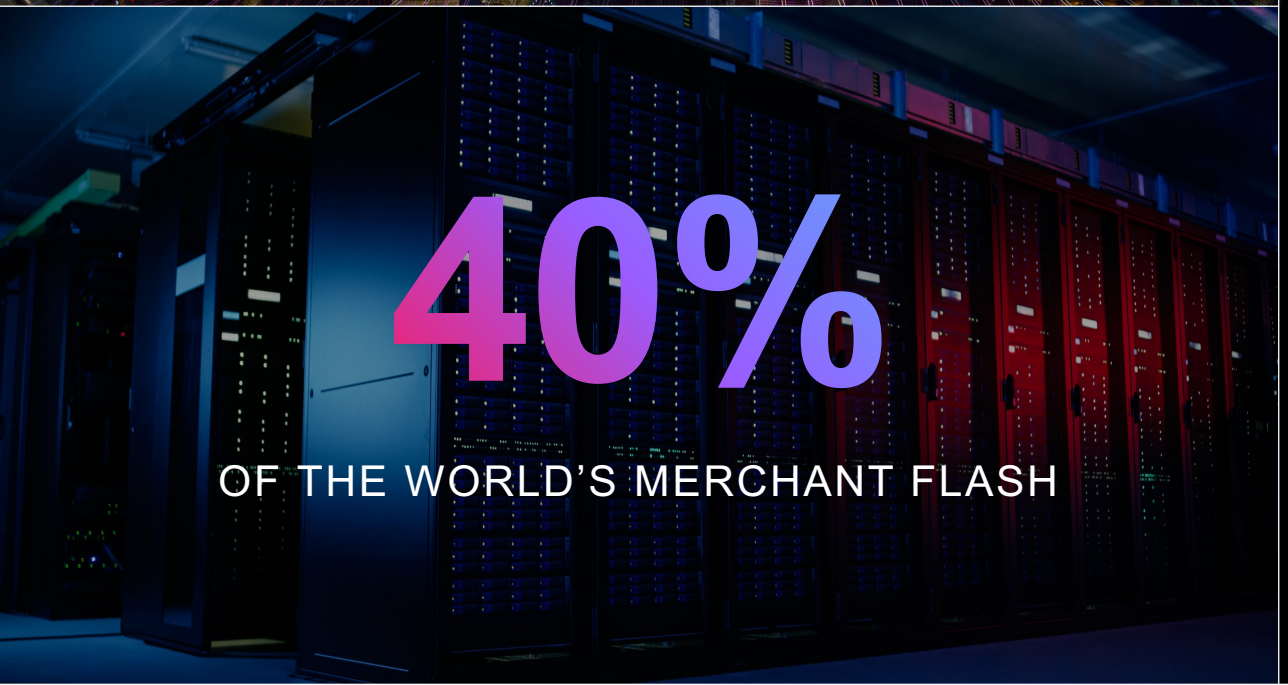

Leading Producer of Flash

For over 20 years we have had a joint R&D and manufacturing partnership with Kioxia—Flash Ventures.

The companies produce greater than 34% of the world's bits and around 40% of of the world's merchant Flash.

Together with Kioxia, Western Digital has spent over $18B in flash R&D over the last ten years.

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HISTORY OF INNOVATION

1956

IBM

Hard Drive (RAMAC)

1963

IBM

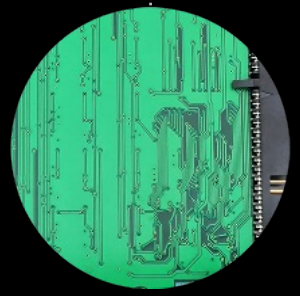
Removable HDD, the 1311

1976

Western Digital

Disk Array Sub-System Patent

1988

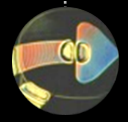


SunDisk*

System Flash

*SunDisk later renamed SanDisk

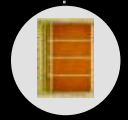
1991



IBM

MR Heads

2000



SanDisk

MLC NAND

2006

HGST

2.5-inch HDD PMR Technology

2008

G-Technology

1TB Portable External HDD

SanDisk

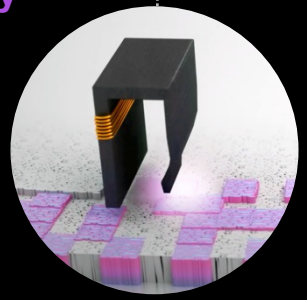
TLC Flash Memory

2009

SanDisk

64GB X4 Flash Memory

2012



Western Digital

Shingled Magnetic Recording (SMR)

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HISTORY OF INNOVATION

2013

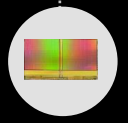
HGST
12Gb/s
SAS SSD

HGST
Helium HDD (6TB)

2015

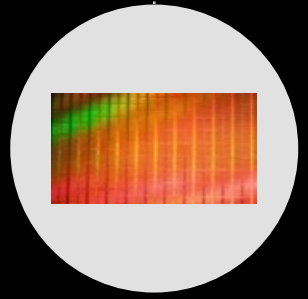
SanDisk
48-layer
3D NAND
Technology

2016



SanDisk
64-layer
3D NAND
Technology

2017



SanDisk
96-layer 3D NAND
Technology

2018

Western Digital
EAMR Technology
Breakthrough
(Energy Assisted
Magnetic Recording)

Western Digital
OpenFlex™

2019

Western Digital
Zoned Storage

2020

Western Digital
Energy-Assisted
Perpendicular
Magnetic Recording
(ePMR)

2021

Western Digital
OptiNAND™
Technology

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Western Digital.

Autonomous Physical Design

Moving Closer Towards Fully Autonomous Design!

Aman Joshi, VP, Design Enablement & Automation

Oct 6,7, 2022

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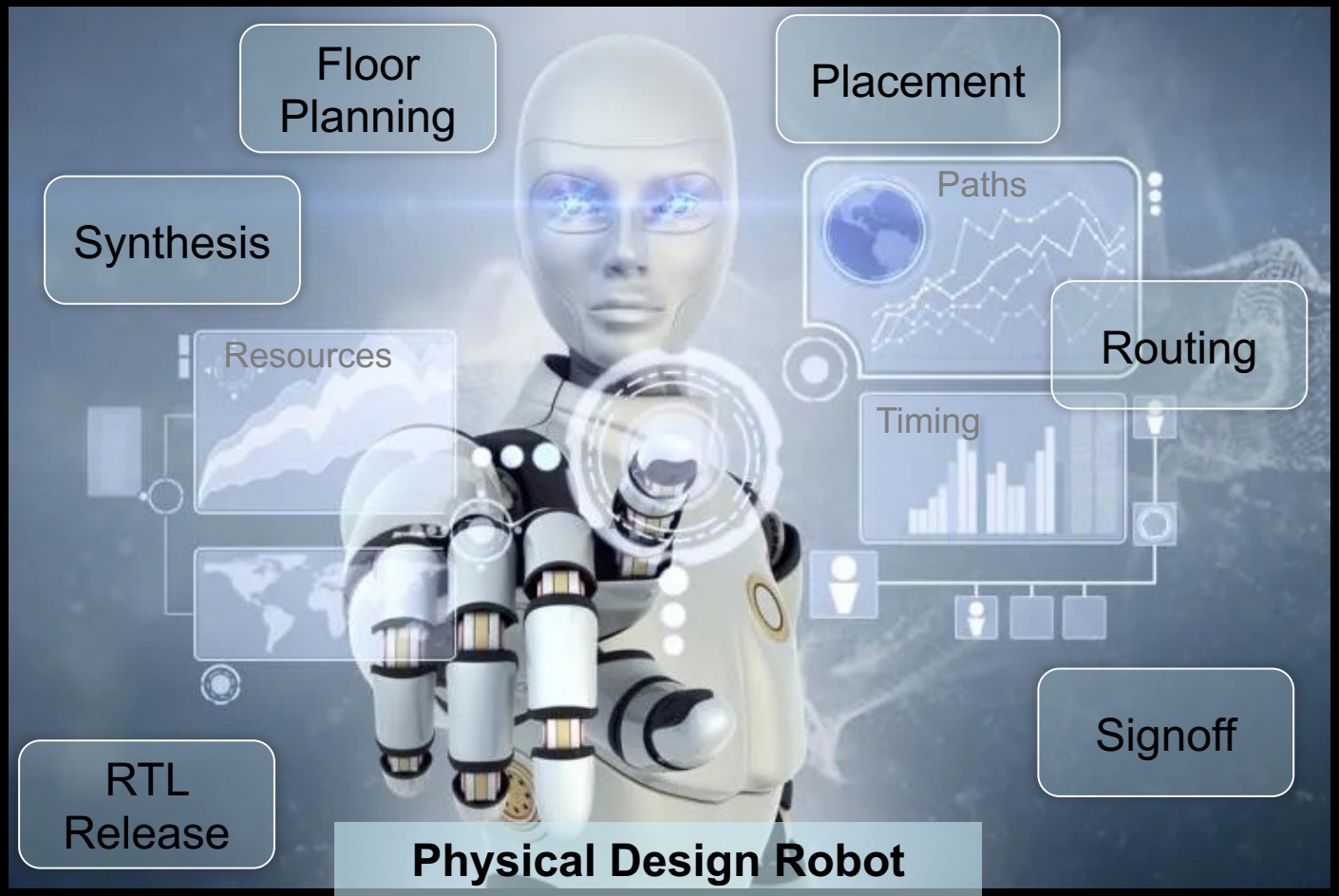
Autonomous Physical Implementation Flows

Goal: Significantly Reduce Typical Physical Design Implementation Time & Cost

Intelligent Robot to autonomously create design implementations per QoR Targets

Learns from years of past PD data across multiple projects and process nodes

+ Continuous Learning from its own autonomous PD execution (RL)



Searches through 1000s of setup variables per tool for optimized setting to achieve QoR target

Predicts results for thousands of designs, narrowing down setup for high probability targets

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Physical Design Exploration Space

Scale and Reduction of Physical Design Flow Problem Space

2^{1000+} ⟶ $\sim 2^{10}$ (1024) ⟶ 0~5

1000+ possible inputs configurable for PD execution

(2^{270} = # atoms in the observable universe!)

~10 inputs affecting QoR metrics selected using ML methods

Only up to 5 combos are executed as predicted by Robot to match target QoR

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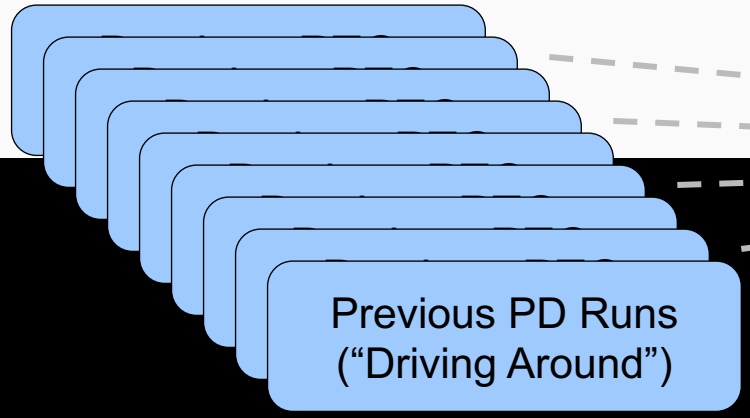
Architecture of Robot for Autonomous PD

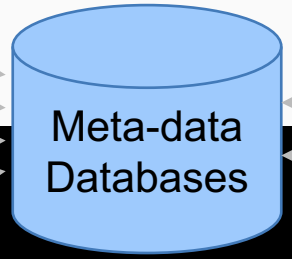
Previous PD Runs: *Learning phase*

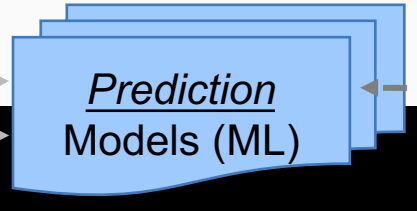
Capture past PD data across multiple projects

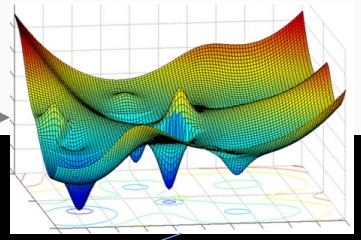
Create ML models to predict end results

Maps QoR* to Multi-Dimensional Matrices









New PD Runs: *Executing ("Inference" based)*

Human: Design Target "Destination" (i.e. PPA)

Physical Design Robot

Robot: Predicts tool variables using past result matrices

Robot: Quickly cycles through ranges using *Prediction*

Target PPA met?

Yes

No

Robot: Runs through PD flows

Other Human Inputs

Benefits:

- High accuracy *Predicted* results save a lot of $ & time
- Robotic operator minimizes human intervention
- Faster convergence to target QoR* ('shift left')

*QoR = Quality of Results, like picking a destination on Google Maps

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Sample Results

Improvements from PD-Robot compared to recent human-execution

Design Name /Project	Design A/Project X	Design B/Project Y	Design C /Project Y
Release Version	v1	v2	V3 (tapeout version)
Instance Count	Small	Medium	Large
Area	Medium	Medium	Large

Metric	Improvement	Improvement	Improvement
Total Execution Time improvement for design	29X	21X	12X
Total License Usage for design (less runs to get same/better QoR)	30X	20X	15X
Disk Footprint for design (less runs to get same/better QoR)	30X	20X	15X
Timing QoR improvements for design	Up to 97% better	Up to 18% better	Up to 24% better

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QoR – Robot vs Human (Early Results)

RouteOpt	Instcount		Area		Utilization	DRV			DRC Count
Execution Type	Stdcell	Blocks	Stdcell	Blocks	Stdcell	MaxCap	MaxTran	MaxLength	Total
Manual	xxxx	xx	xxxx	xxxx	xxxx	xx	xx	xx	xxxx
Robot	xxxx	xx	xxxx	xxxx	xxxx	xx	xx	xxx	xxxx
% Difference	~0.5%	0.00%	~4%	0.00%	~6%	~ -400%	~ 2%	~ -170%	~21%

RouteOpt	Setup Timing						Hold Timing					
		Total		reg2reg			Total			reg2reg		
Execution Type	WNS	TNS	# Paths	WNS	TNS	# Paths	WNS	TNS	# Paths	WNS	TNS	# Paths
Manual	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Robot	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
% Difference	~11%	~70%	~50%	~85%	~100%	~55%	~55%	~35%	~35%	~43%	~26%	~41%

Resources	PrePlace			Place Opt			CTS			CTS Opt			Routing			Route Opt		
Execution Type	Total Time (h)	Total Jobs Count	Disk Use (GB)	Total Time (h)	Total Jobs Count	Disk Use (GB)	Total Time (h)	Total Jobs Count	Disk Use (GB)	Total Time (h)	Total Jobs Count	Disk Use (GB)	Total Time (h)	Total Jobs Count	Disk Use (GB)	Total Time (h)	Total Jobs Count	Disk Use (GB)
Manual	>150	>40	>20	>350	>70	>50	>80	>70	>50	>150	>70	>60	>110	>70	>70	>300	>70	>90
Robot	2	3	1.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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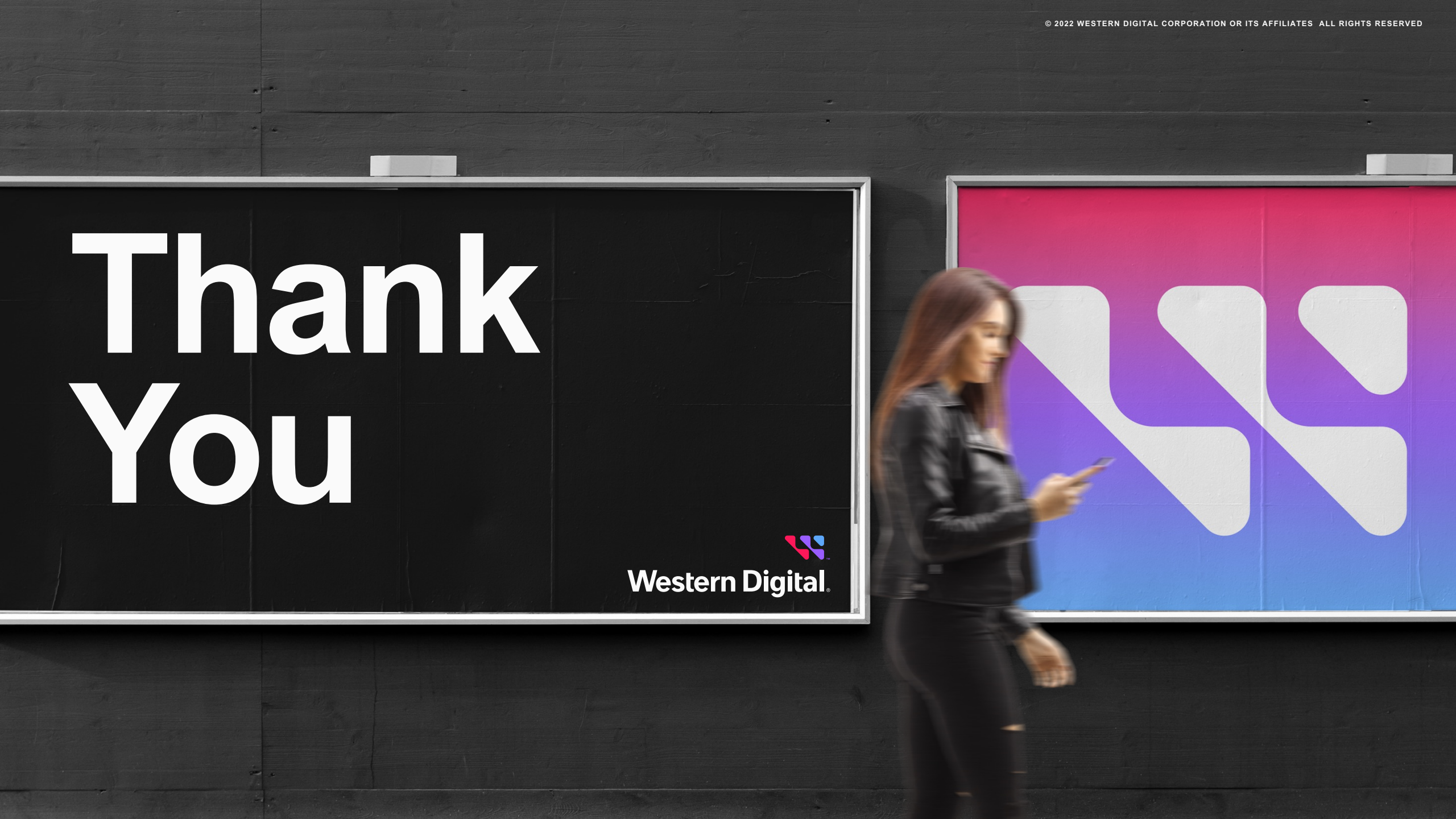

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