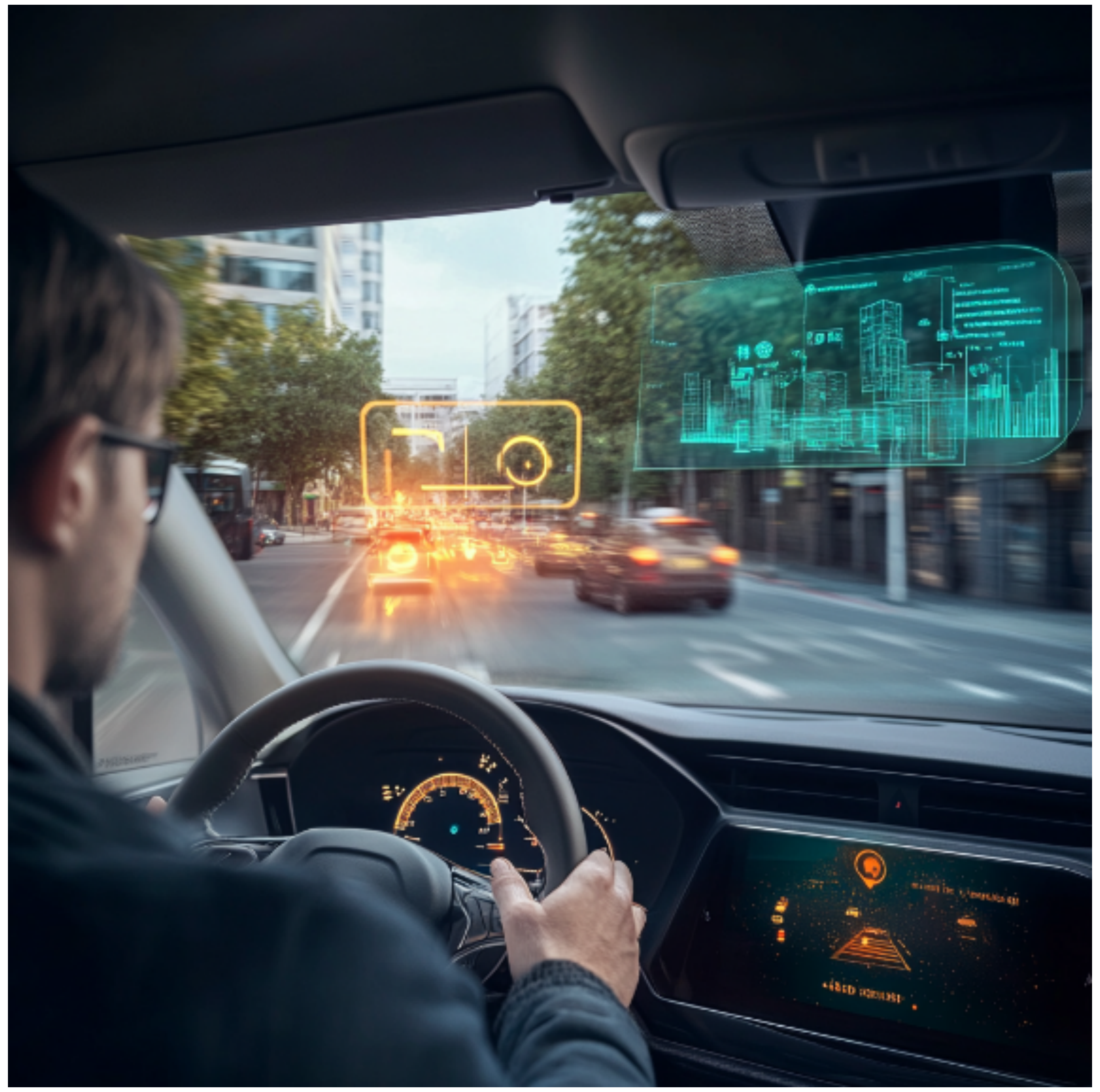
Physical AI (based on XR)

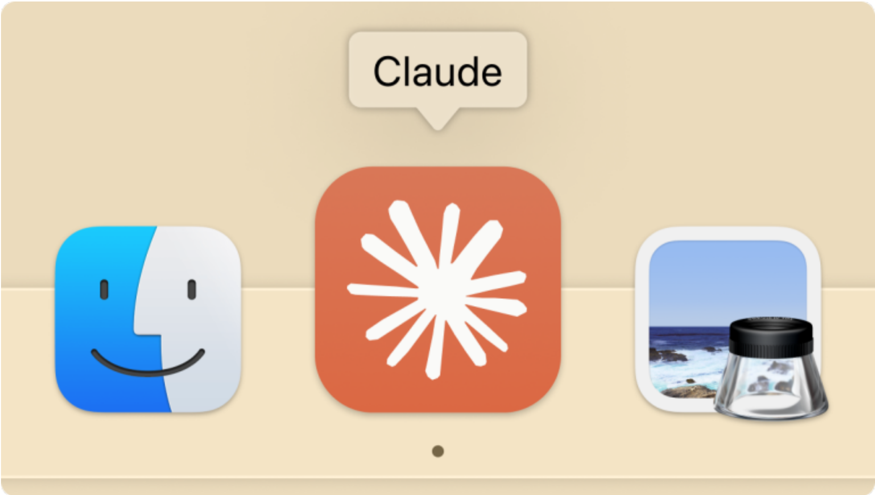
Synthetic Data and related emerging technologies

IITP PM LEE, Junwoo

Background

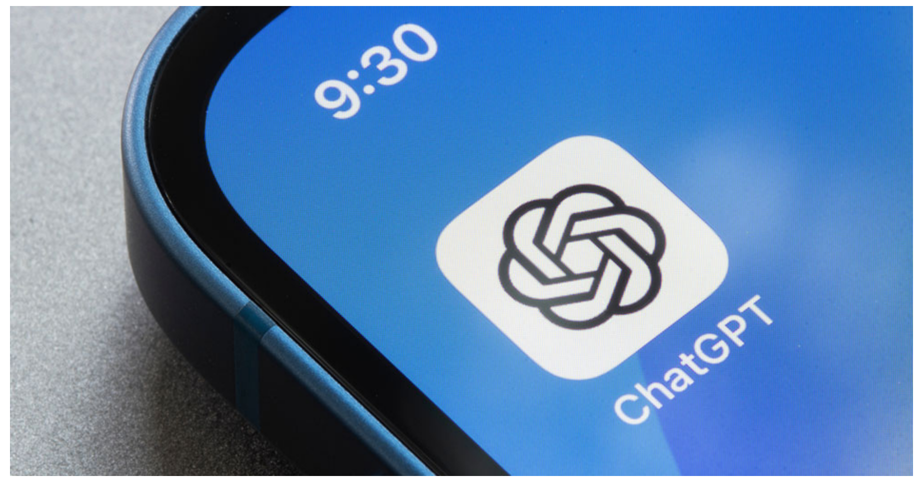


“driver sitting in the car looking at the floating virtual traffic sign over the window shield. Floating traffic sign is the mixed reality object and it is located middle in the street”
– Midjourney, Oct 21, 2024



desktop

"*Claude gets desktop apps and dictation support*"



Mobility & Web integration

"*ChatGPT is officially an AI-powered web search engine*"

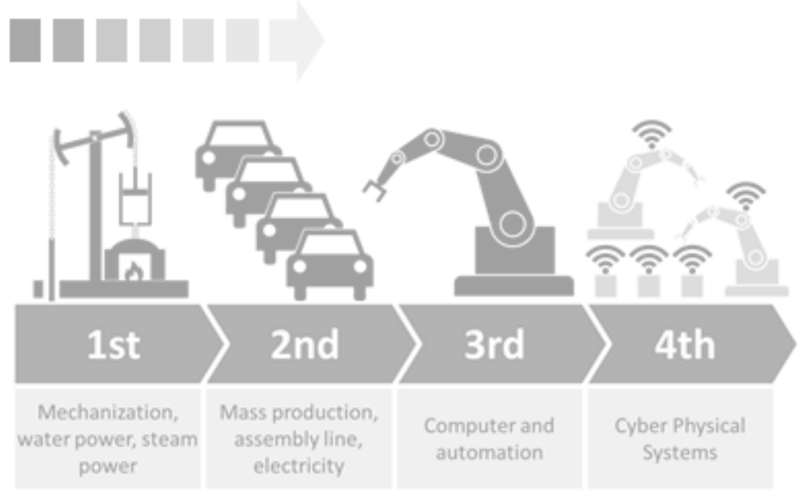
Current digital & AI functions are working within the 2D-display

How to extract digital & AI out of display

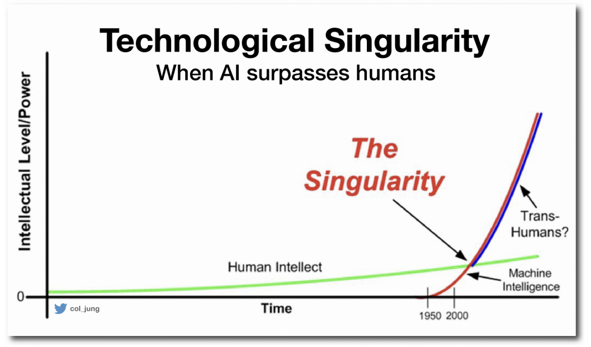
Trends: AI, AI, AI,,,

Meta-Transformation

D Digital
X Transformation


1st
2nd
3rd
4th
Mechanization, water power, steam power
Mass production, assembly line, electricity
Computer and automation
Cyber Physical Systems

A AI
X Transformation



How to deal with “Digital & AI” ?

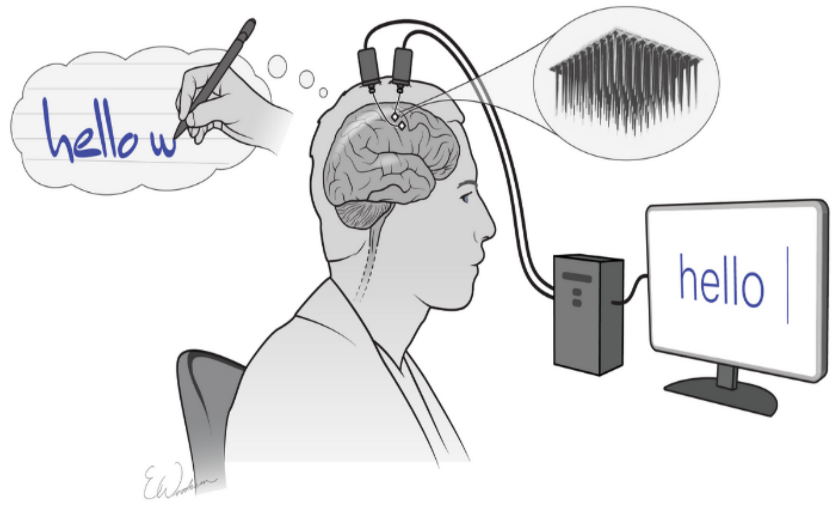
M Meta(verse)
X Transformation

〈 Intuitive digital interaction 〉

“Agentic HCI”

〈 Mixed(real+virtual) env. 〉

“Physical AI”


hello w
hello

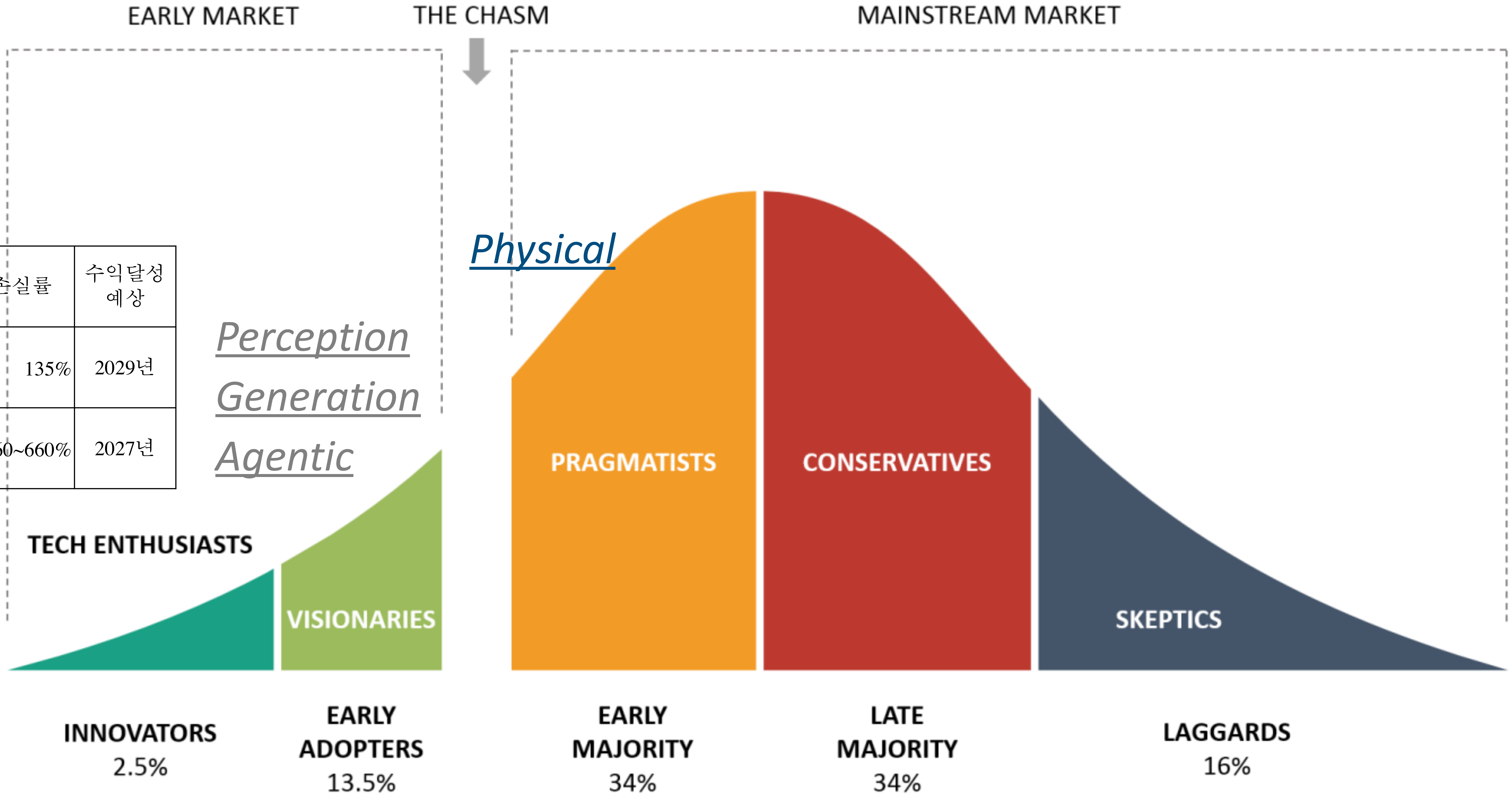
〈 digital sense 〉

“Affection, Emotion, BCI to Neuromorphic”

AI adoption (2024): 74% of Companies

more than expectation. but,

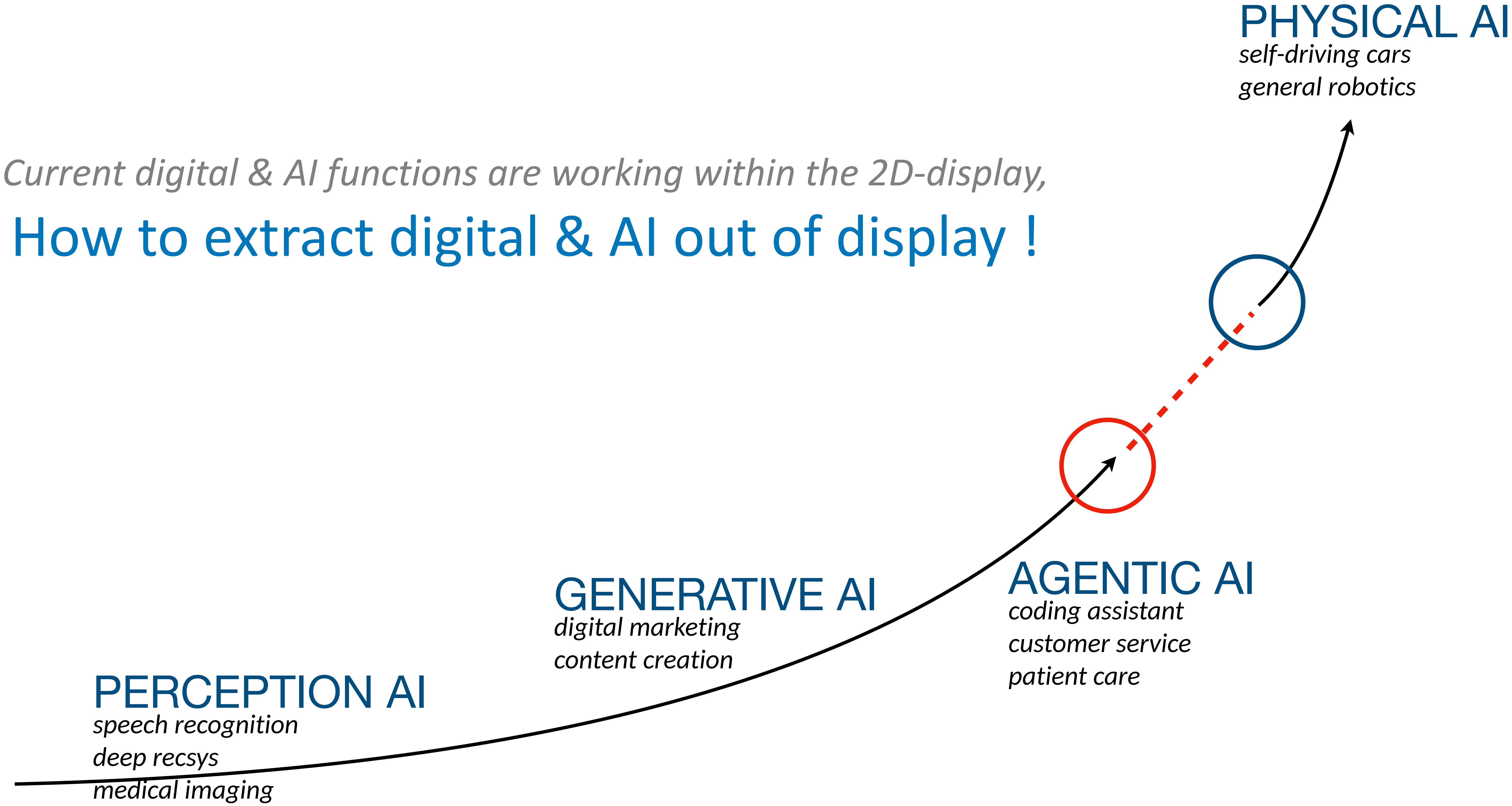
회사	2024년 매출	2024년 손실	손실률	수익달성 예상
OpenAI	37억 달러	50억 달러	135%	2029년
Anthropic	8.5~10억 달러	56억 달러	560~660%	2027년


EARLY MARKET
THE CHASM
MAINSTREAM MARKET
Physical
Perception
Generation
Agentic
TECH ENTHUSIASTS
VISIONARIES
PRAGMATISTS
CONSERVATIVES
SKEPTICS
INNOVATORS 2.5%
EARLY ADOPTERS 13.5%
EARLY MAJORITY 34%
LATE MAJORITY 34%
LAGGARDS 16%

towards physical(real) - digital(virtual) coexistence !

Current digital & AI functions are working within the 2D-display,

How to extract digital & AI out of display !



PHYSICAL AI
self-driving cars
general robotics

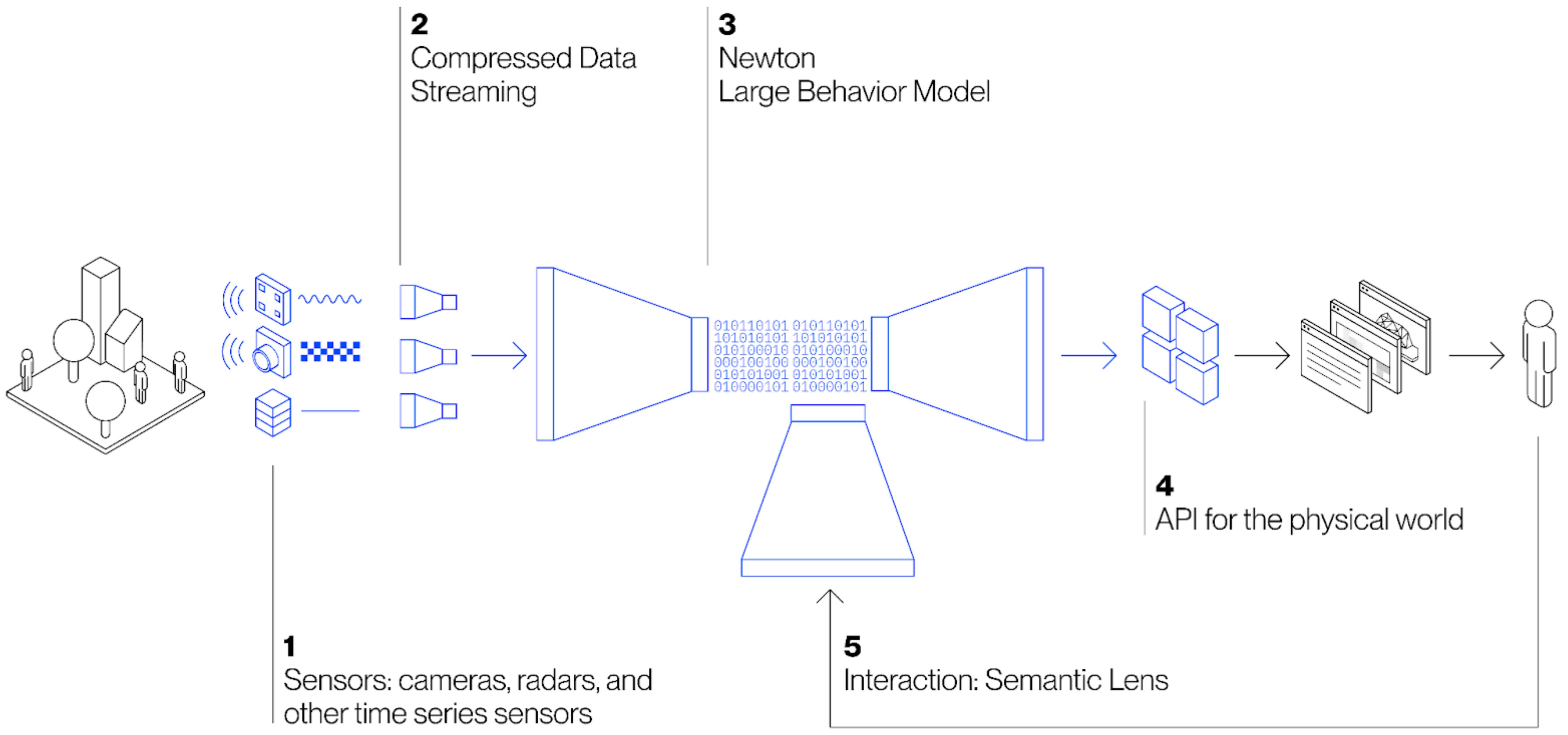
AGENTIC AI
coding assistant
customer service
patient care

GENERATIVE AI
digital marketing
content creation

PERCEPTION AI
speech recognition
deep recsys
medical imaging

Physical AI

singularity - out of display



2
Compressed Data
Streaming

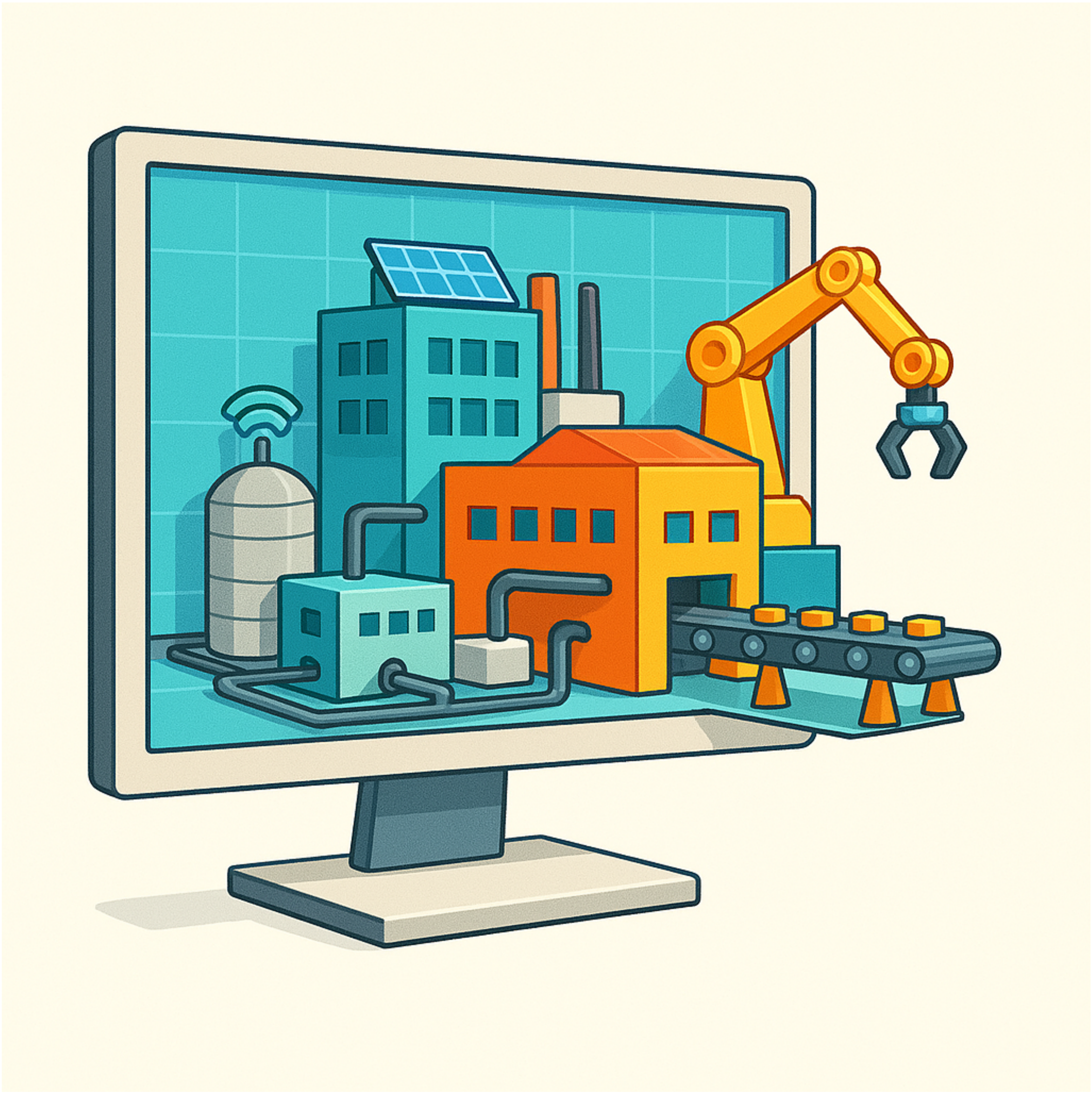
3
Newton
Large Behavior Model

4
API for the physical world

1
Sensors: cameras, radars, and
other time series sensors

5
Interaction: Semantic Lens

< out of display >



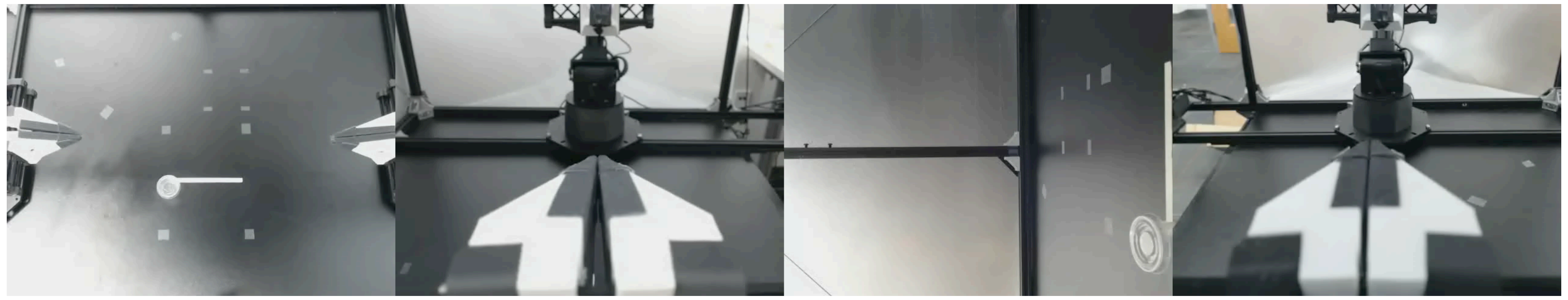
examples: mobile-aloha

Cook Shrimp
(autonomous)
6x speed
Stanford
University

< Mobile ALOHA >

Clean Restroom
(teleop)
10x speed

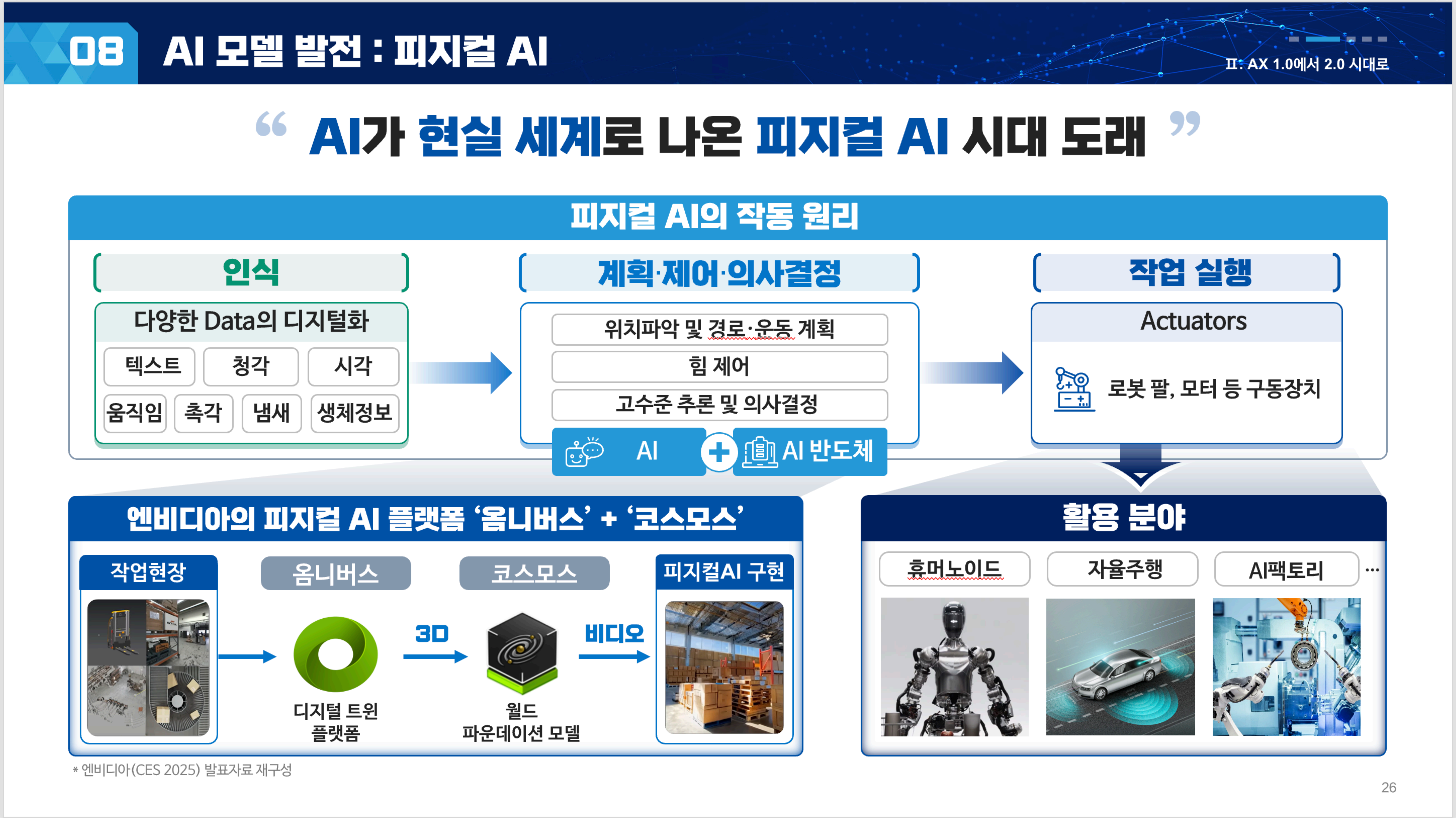
< Mobile ALOHA >



< Dataset >

Physical AI

trends



08 AI 모델 발전 : 피지컬 AI

“ AI가 현실 세계로 나온 피지컬 AI 시대 도래 ”

피지컬 AI의 작동 원리

인식

다양한 Data의 디지털화

- 텍스트
- 청각
- 시각
- 움직임
- 촉각
- 냄새
- 생체정보

계획·제어·의사결정

- 위치파악 및 경로·운동 계획
- 힘 제어
- 고수준 추론 및 의사결정

AI + AI 반도체

작업 실행

Actuators

로봇 팔, 모터 등 구동장치

엔비디아의 피지컬 AI 플랫폼 ‘옴니버스’ + ‘코스모스’

작업현장 → 옴니버스: 디지털 트윈 플랫폼 → 3D → 코스모스: 월드 파운데이션 모델 → 비디오 → 피지컬AI 구현

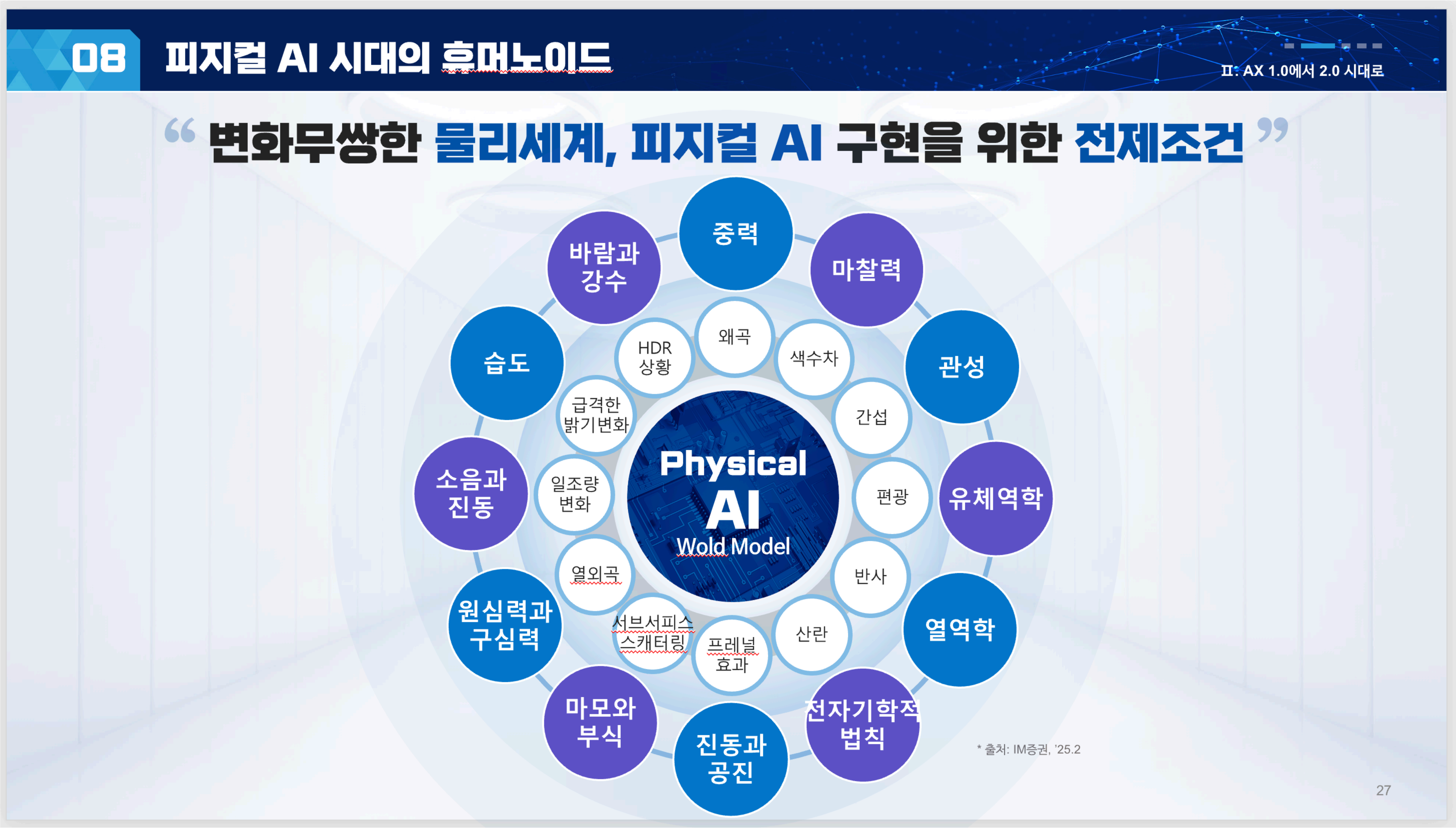
활용 분야

- 휴머노이드
- 자율주행
- AI팩토리
- …

* 엔비디아(CES 2025) 발표자료 재구성

Physical AI

trends



08 피지컬 AI 시대의 휴머노이드

“ 변화무쌍한 물리세계, 피지컬 AI 구현을 위한 전제조건 ”

Physical AI
Wold Model

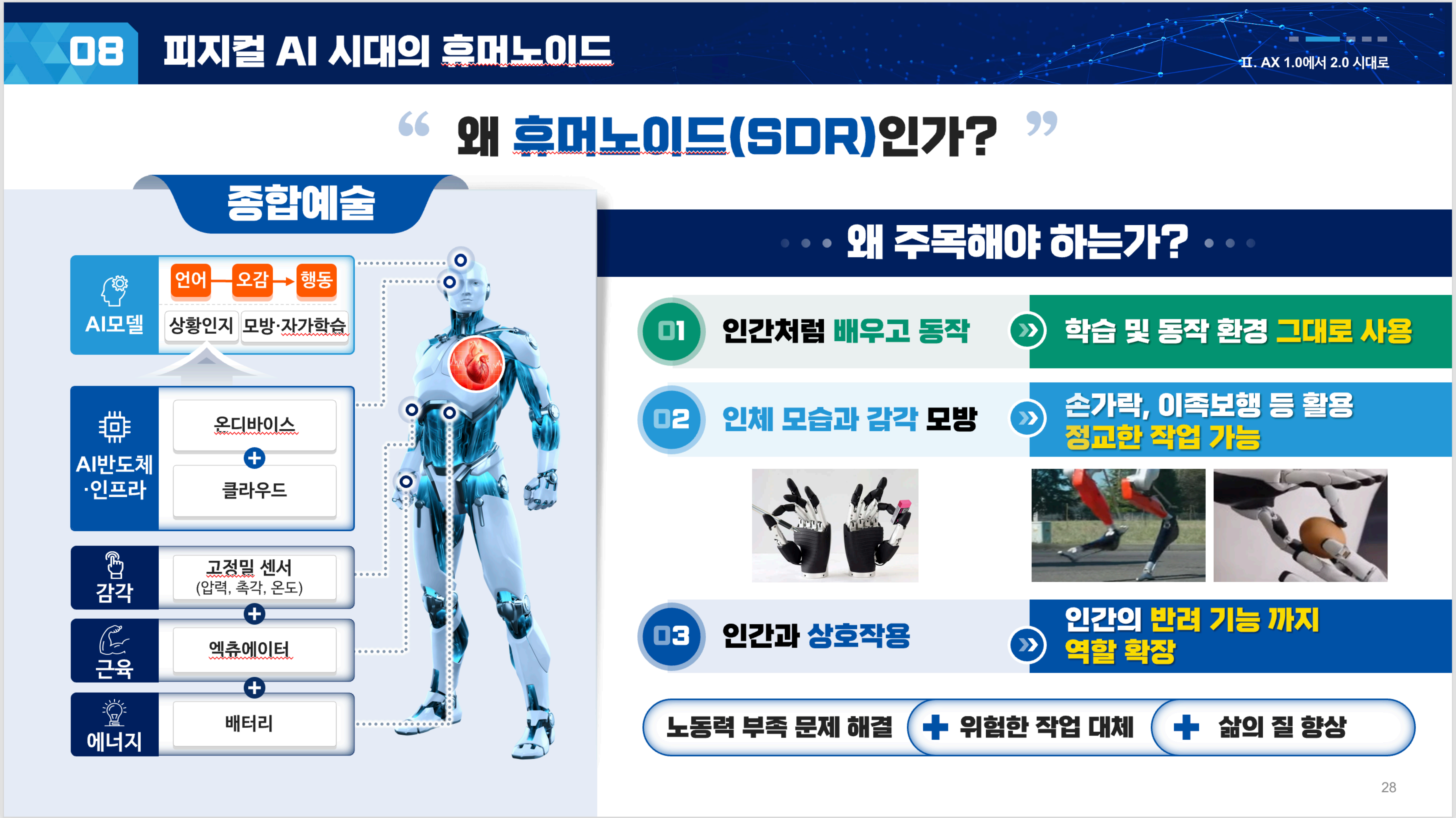
중력
마찰력
관성
유체역학
열역학
전자기학적 법칙
진동과 공진
마모와 부식
원심력과 구심력
소음과 진동
습도
바람과 강수

왜곡
색수차
간섭
편광
반사
산란
프레넬 효과
서브서피스 스캐터링
열외곡
일조량 변화
급격한 밝기변화
HDR 상황

* 출처: IM증권, '25.2

Physical AI

trends



08 피지컬 AI 시대의 휴머노이드

“ 왜 휴머노이드(SDR)인가? ”

종합예술

AI모델: 언어 — 오감 → 행동

상황인지 | 모방·자가학습

AI반도체·인프라: 온디바이스 + 클라우드

감각: 고정밀 센서 (압력, 촉각, 온도)

+

근육: 엑츄에이터

+

에너지: 배터리

왜 주목해야 하는가?

01 인간처럼 배우고 동작 » 학습 및 동작 환경 그대로 사용

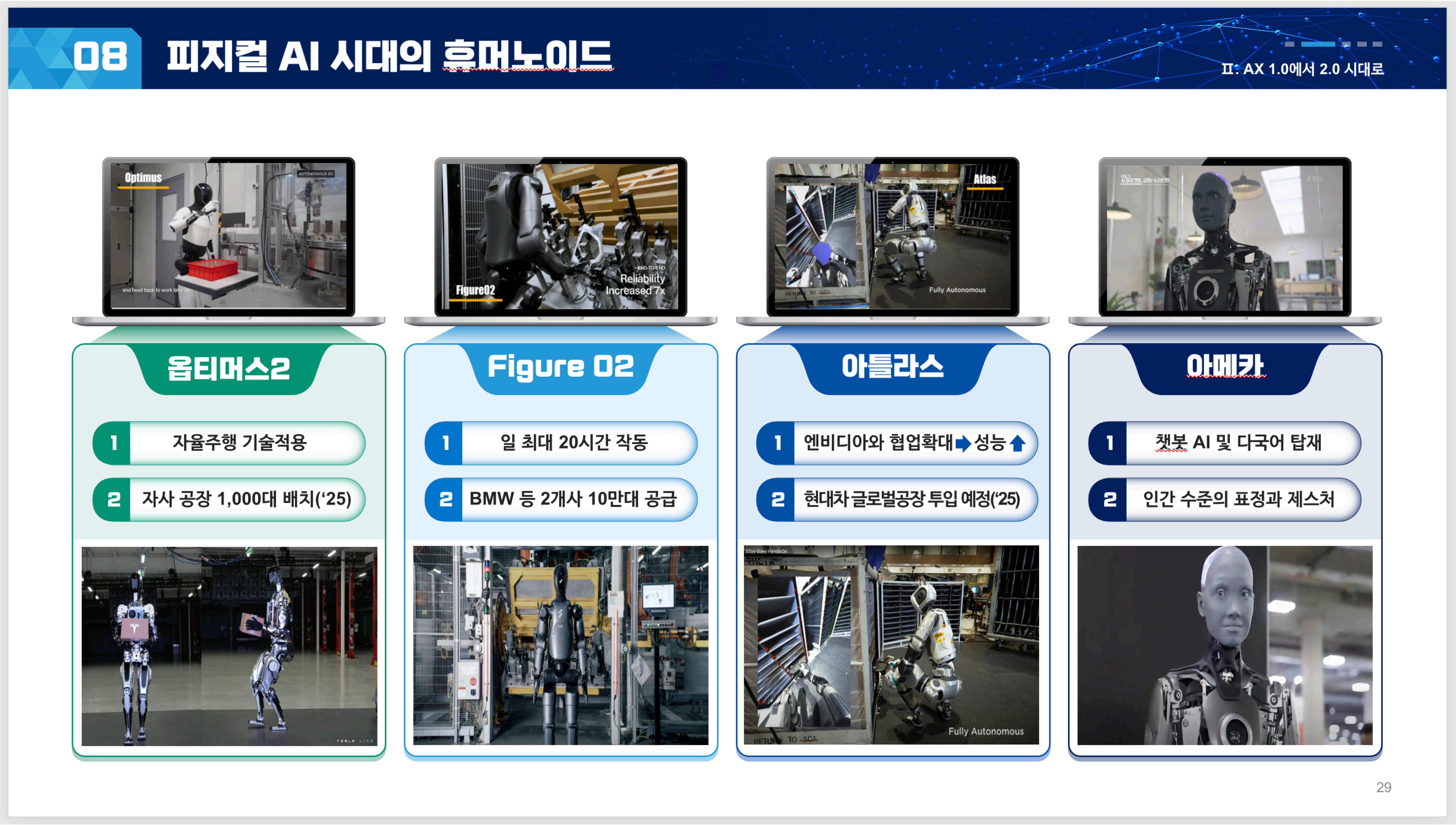
02 인체 모습과 감각 모방 » 손가락, 이족보행 등 활용 정교한 작업 가능

03 인간과 상호작용 » 인간의 반려 기능 까지 역할 확장

노동력 부족 문제 해결 + 위험한 작업 대체 + 삶의 질 향상

Physical AI

trends



08 피지컬 AI 시대의 휴머노이드

옵티머스2

1. 자율주행 기술적용
2. 자사 공장 1,000대 배치('25)

Figure 02

1. 일 최대 20시간 작동
2. BMW 등 2개사 10만대 공급

아틀라스

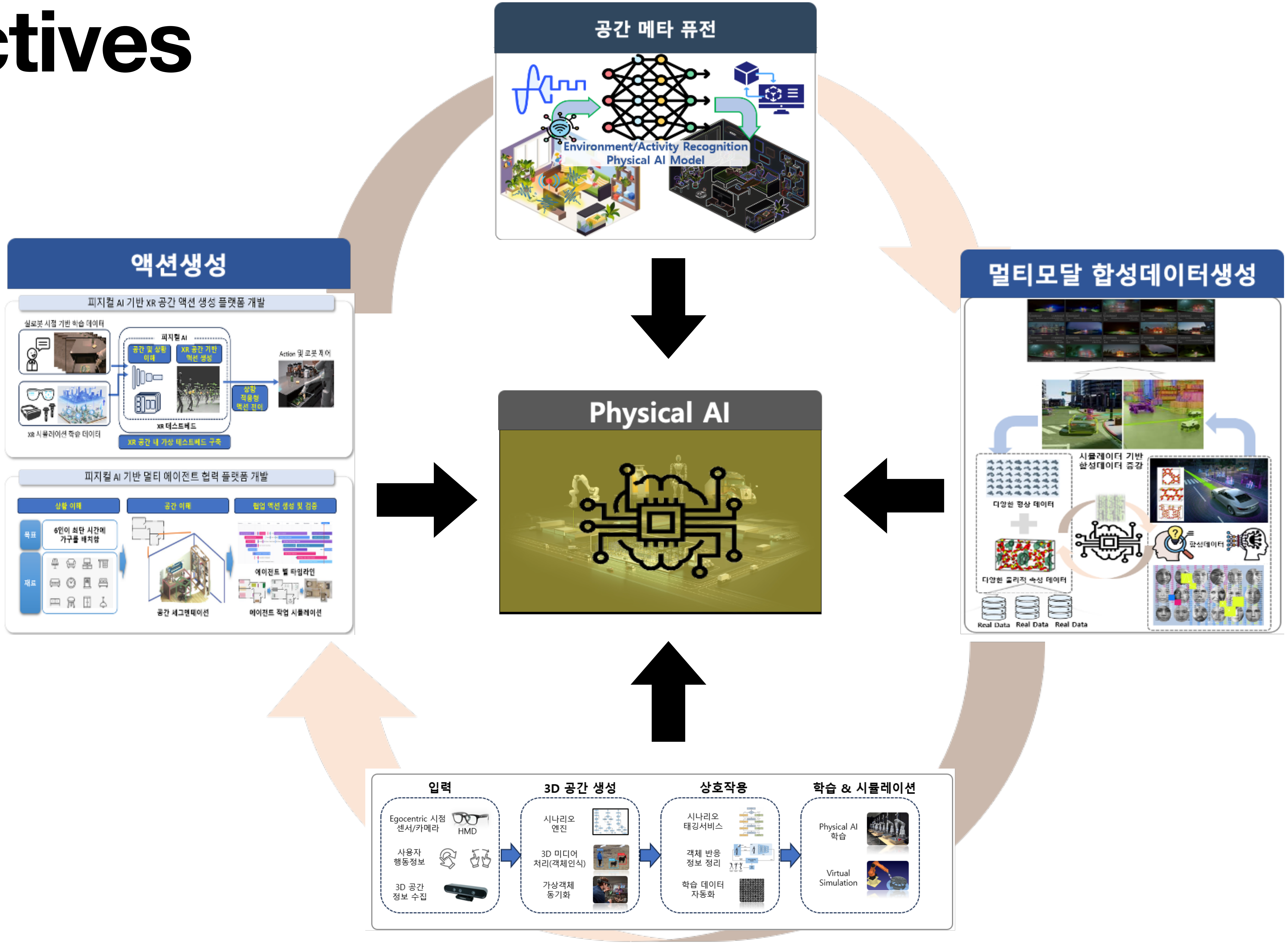
1. 엔비디아와 협업확대 ➡ 성능 ⬆
2. 현대차 글로벌공장 투입 예정('25)

아메카

1. 챗봇 AI 및 다국어 탑재
2. 인간 수준의 표정과 제스처

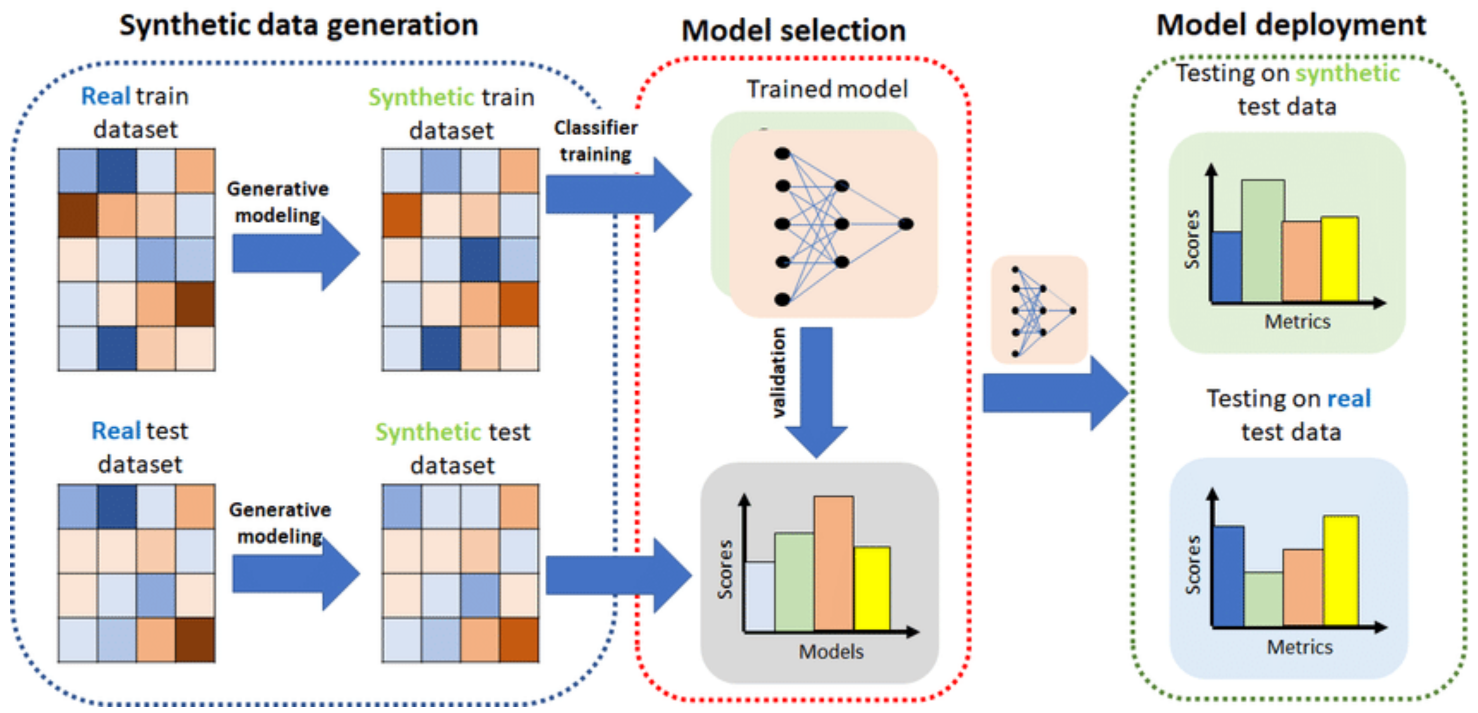
Optimus
Figure02
Reliability Increased 7x
Atlas
Fully Autonomous
Fully Autonomous

Objectives

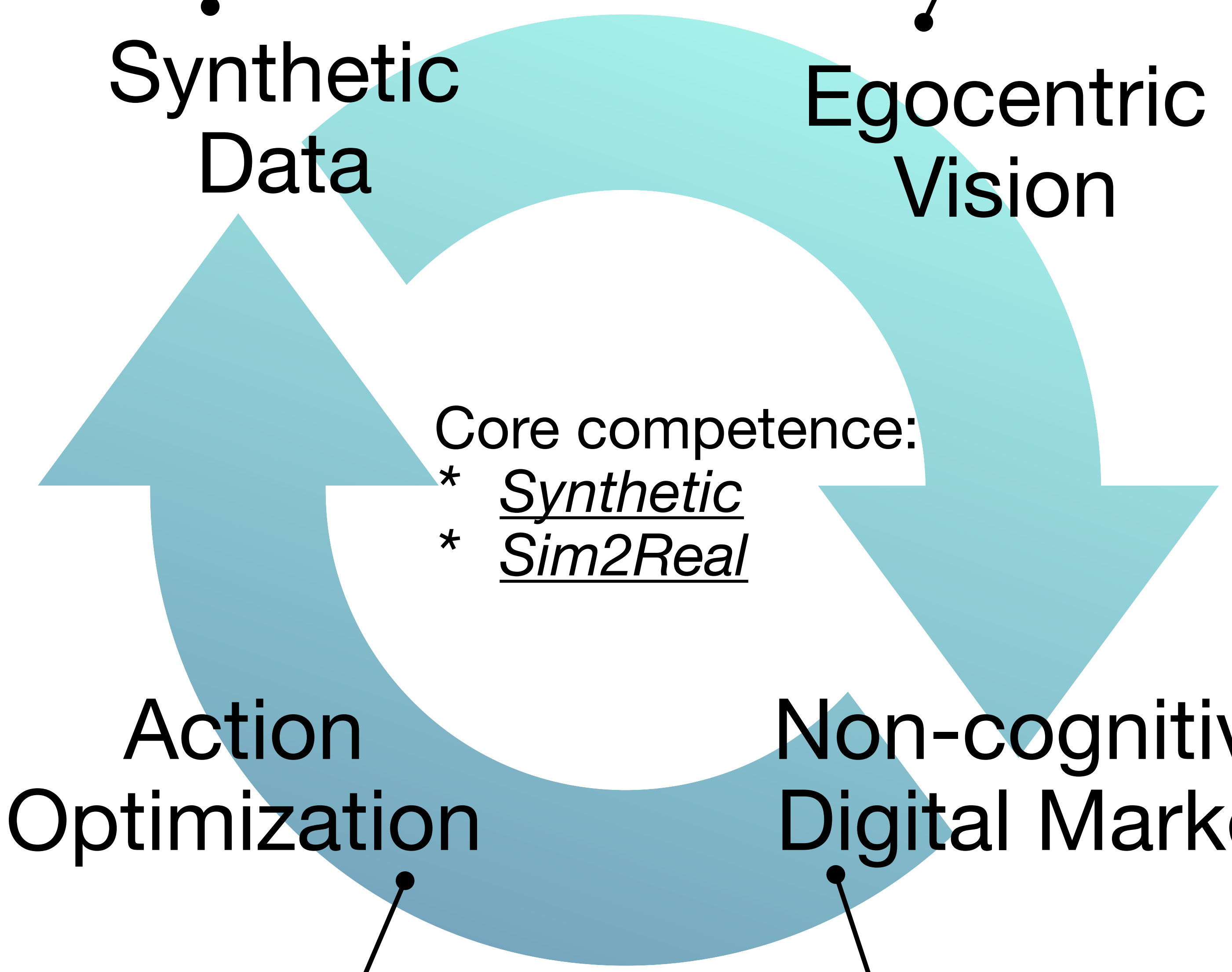

공간 메타 퓨전
Environment/Activity Recognition
Physical AI Model
Physical AI
액션생성
피지컬 AI 기반 XR 공간 액션 생성 플랫폼 개발
실로봇 시점 기반 학습 데이터
피지컬 AI
공간 및 상황 이해
XR 공간 기반 액션 생성
상황 적응형 액션 전이
Action 및 로봇 제어
XR 시뮬레이션 학습 데이터
XR 테스트베드
XR 공간 내 가상 테스트베드 구축
피지컬 AI 기반 멀티 에이전트 협력 플랫폼 개발
상황 이해
공간 이해
협업 액션 생성 및 검증
목표
6인이 최단 시간에 가구를 배치함
재료
공간 세그멘테이션
에이전트 별 타임라인
에이전트 작업 시뮬레이션
멀티모달 합성데이터생성
시뮬레이터 기반 합성데이터 증강
다양한 형상 데이터
다양한 물리적 속성 데이터
Real Data
Real Data
Real Data
합성데이터
입력
Egocentric 시점 센서/카메라
HMD
사용자 행동정보
3D 공간 정보 수집
3D 공간 생성
시나리오 엔진
3D 미디어 처리(객체인식)
가상객체 동기화
상호작용
시나리오 태깅서비스
객체 반응 정보 정리
학습 데이터 자동화
학습 & 시뮬레이션
Physical AI 학습
Virtual Simulation

Physical AI

singularity - out of display


Synthetic data generation
Real train dataset
Synthetic train dataset
Generative modeling
Classifier training
Real test dataset
Synthetic test dataset
Generative modeling
Model selection
Trained model
validation
Scores
Models
Model deployment
Testing on synthetic test data
Scores
Metrics
Testing on real test data
Scores
Metrics

Sim2Real



Synthetic Data

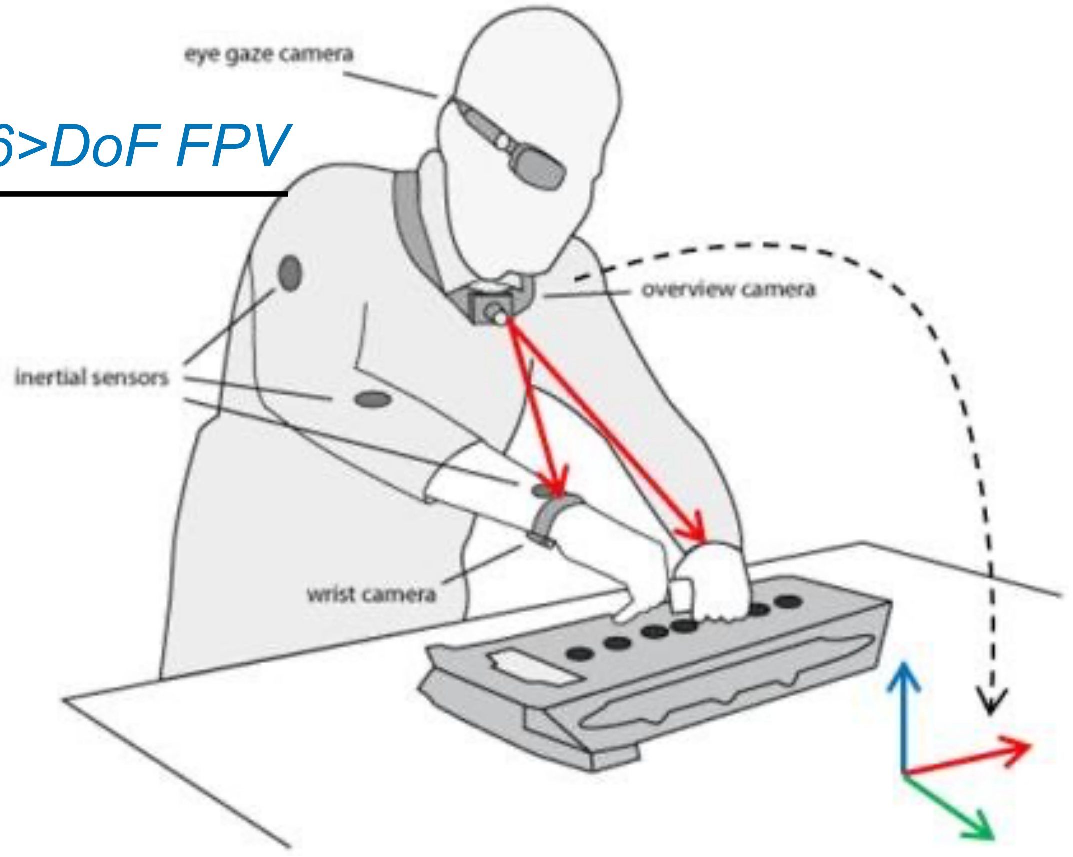
Egocentric Vision

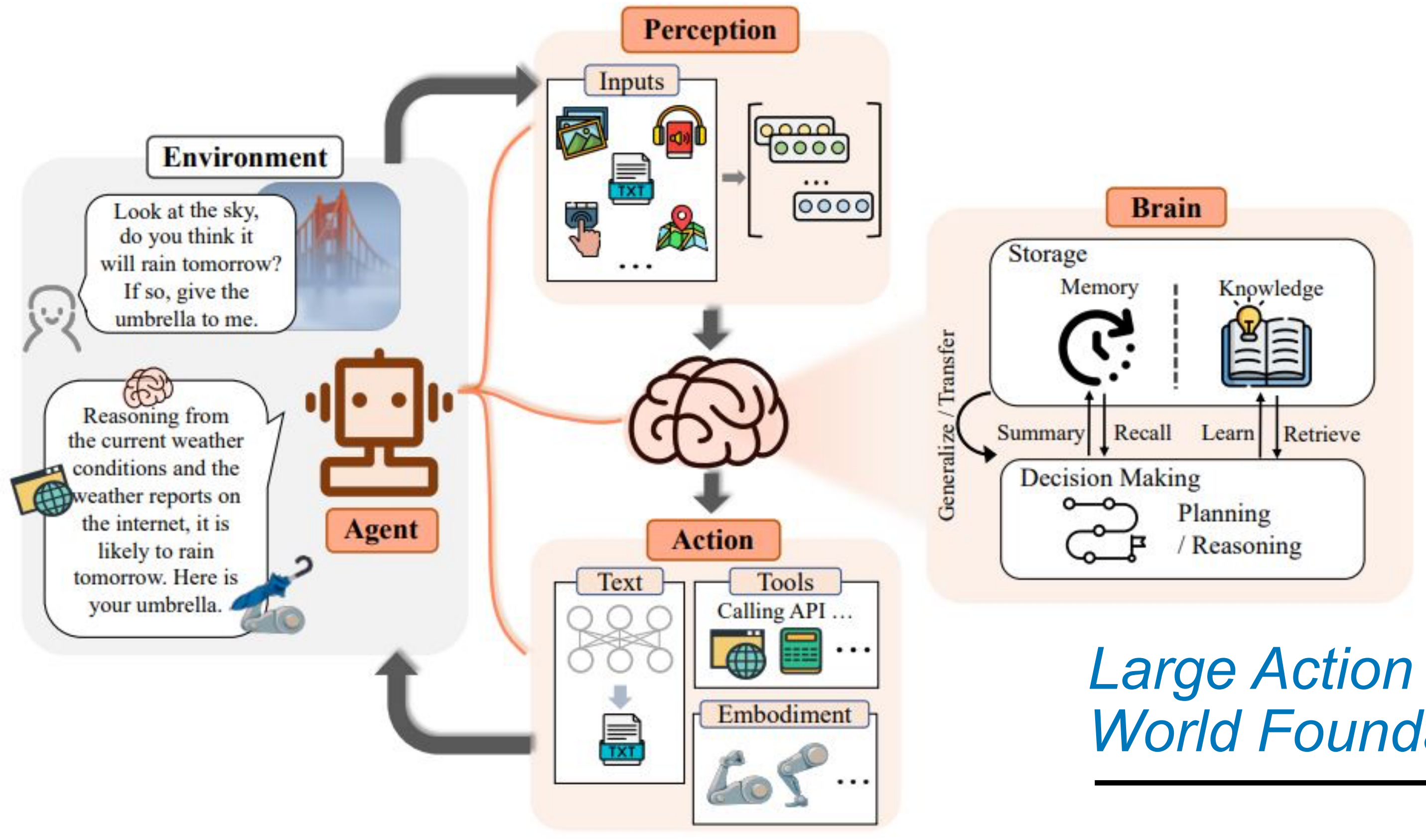
Non-cognitive Digital Marker

Action Optimization

Core competence:
* Synthetic
* Sim2Real

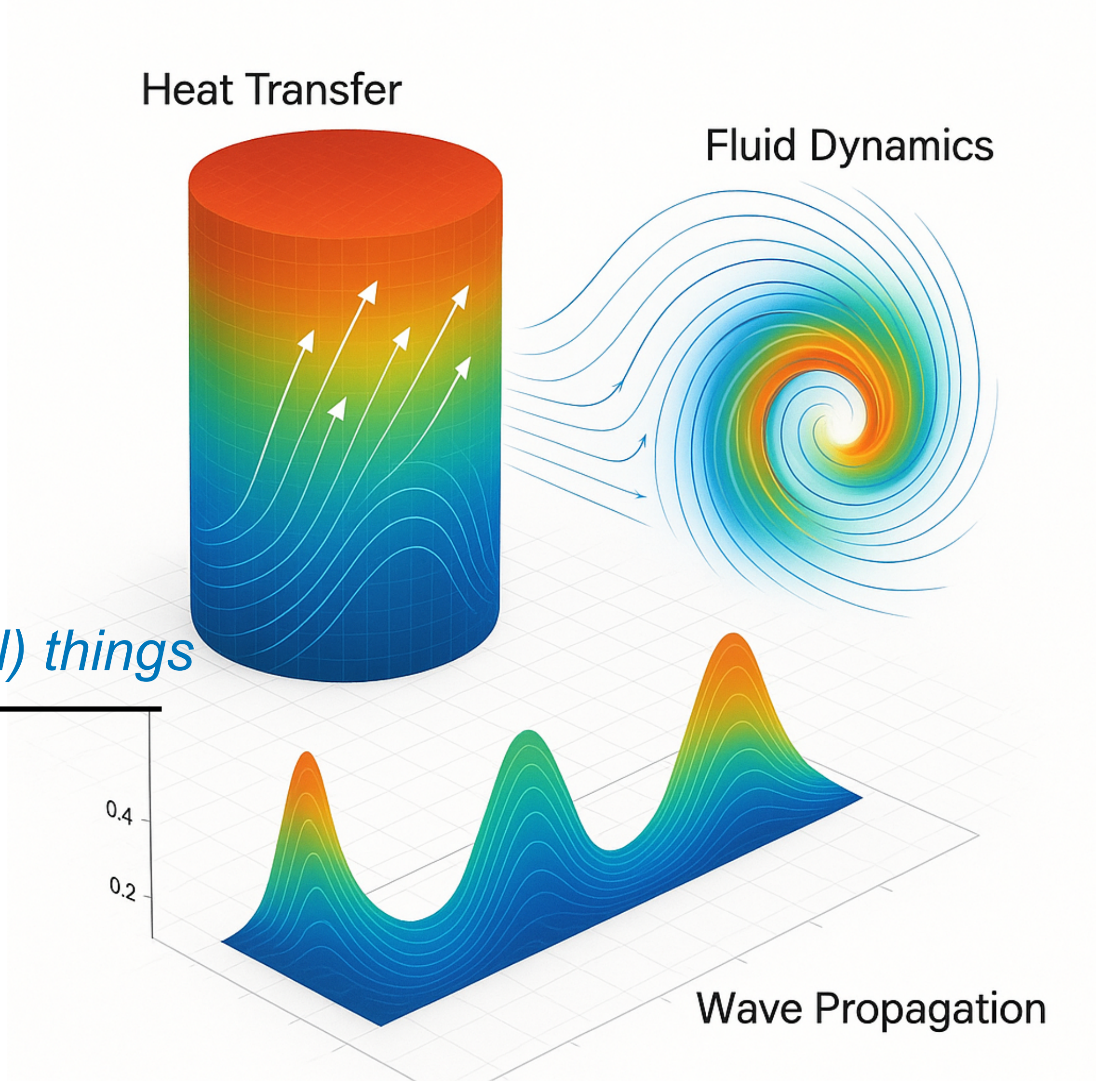
Realtime 6>DoF FPV


eye gaze camera
overview camera
inertial sensors
wrist camera


Environment
Look at the sky, do you think it will rain tomorrow? If so, give the umbrella to me.
Reasoning from the current weather conditions and the weather reports on the internet, it is likely to rain tomorrow. Here is your umbrella.
Agent
Perception
Inputs
TXT
Brain
Storage
Memory
Knowledge
Summary
Recall
Learn
Retrieve
Generalize / Transfer
Decision Making
Planning / Reasoning
Action
Text
Tools
Calling API ...
Embodiment

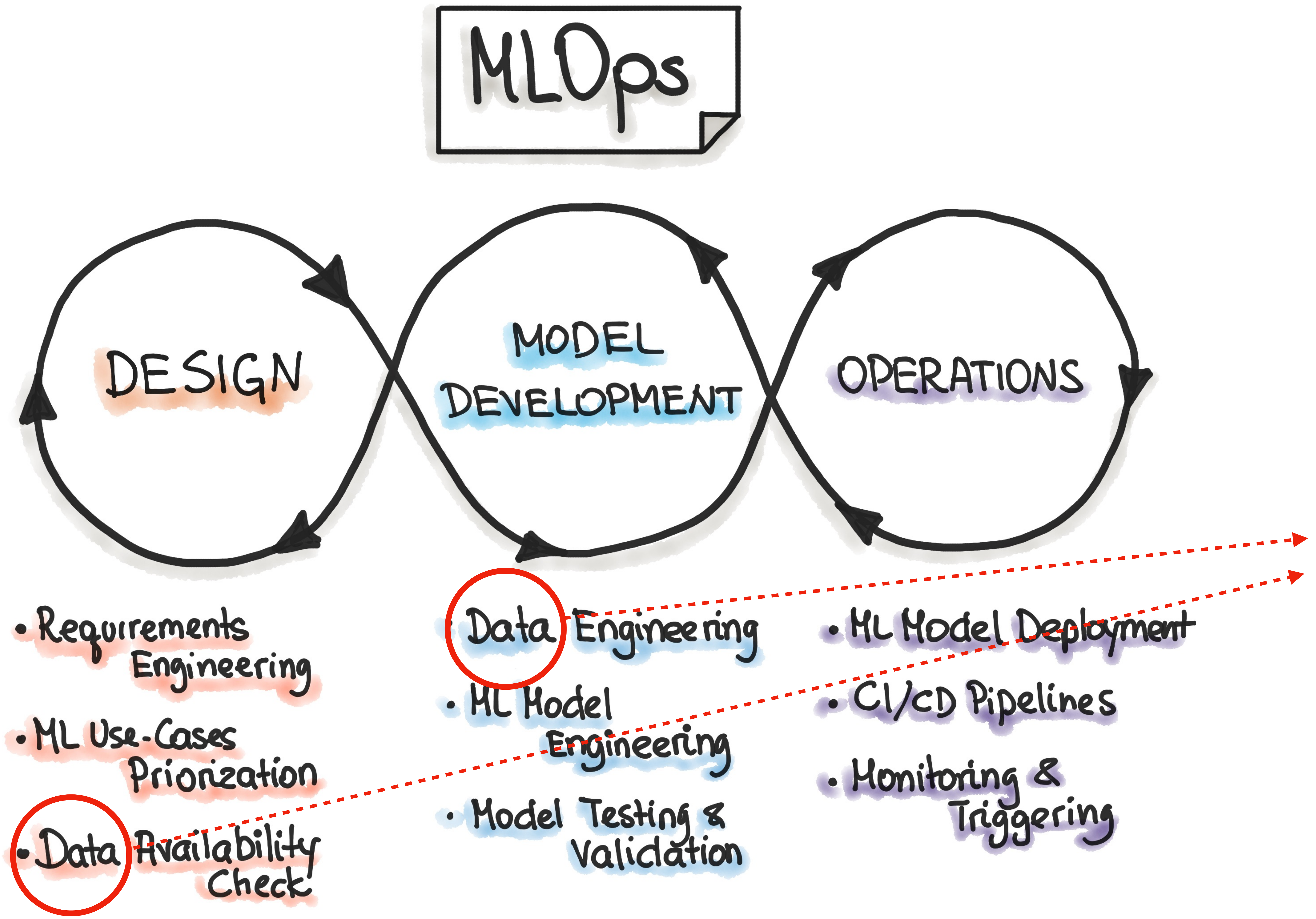
Large Action Model
World Foundation Model

Invisible (physical) things


Heat Transfer
Fluid Dynamics
0.4
0.2
Wave Propagation

MLOps

generic AI model development process



MLOps
DESIGN
MODEL DEVELOPMENT
OPERATIONS
• Requirements Engineering
• ML Use-Cases Priorization
• Data Availability Check
• Data Engineering
• ML Model Engineering
• Model Testing & Validation
• ML Model Deployment
• CI/CD Pipelines
• Monitoring & Triggering

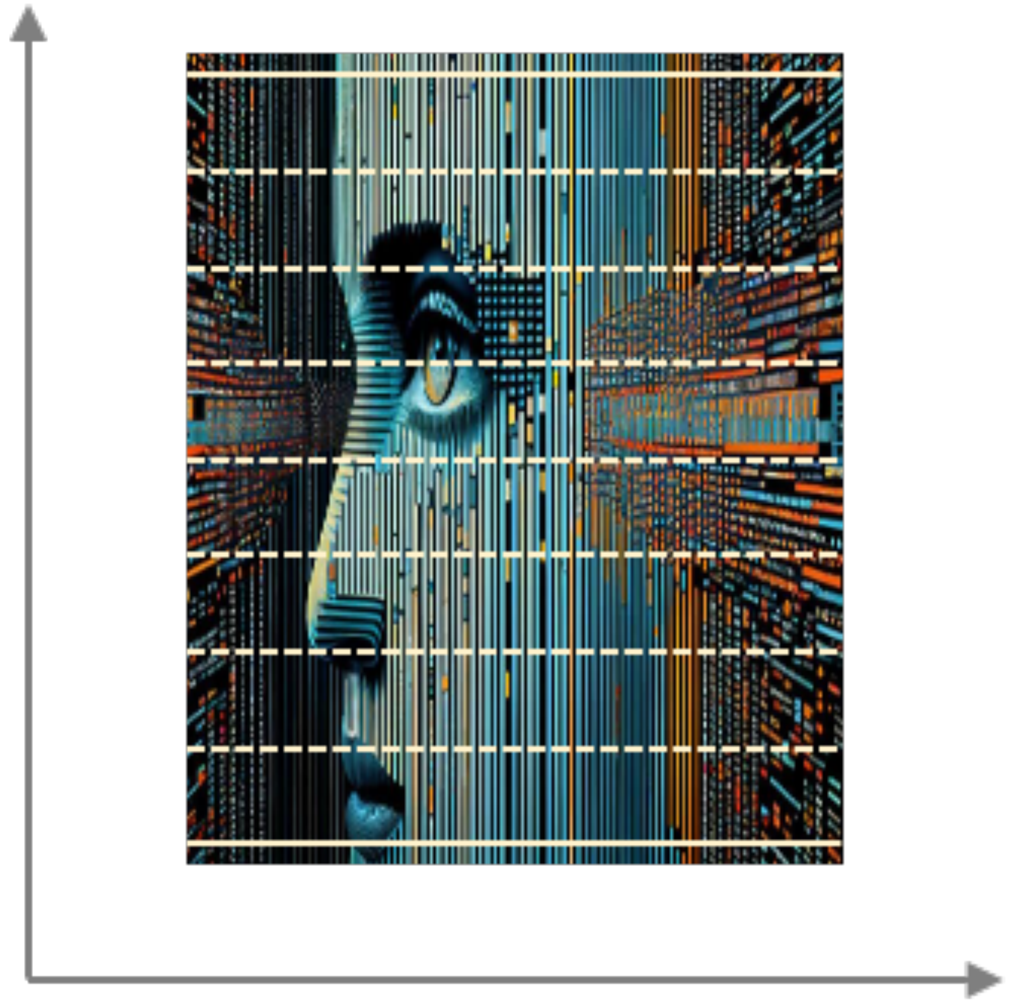
Data !

Physical AI

Increased complexities

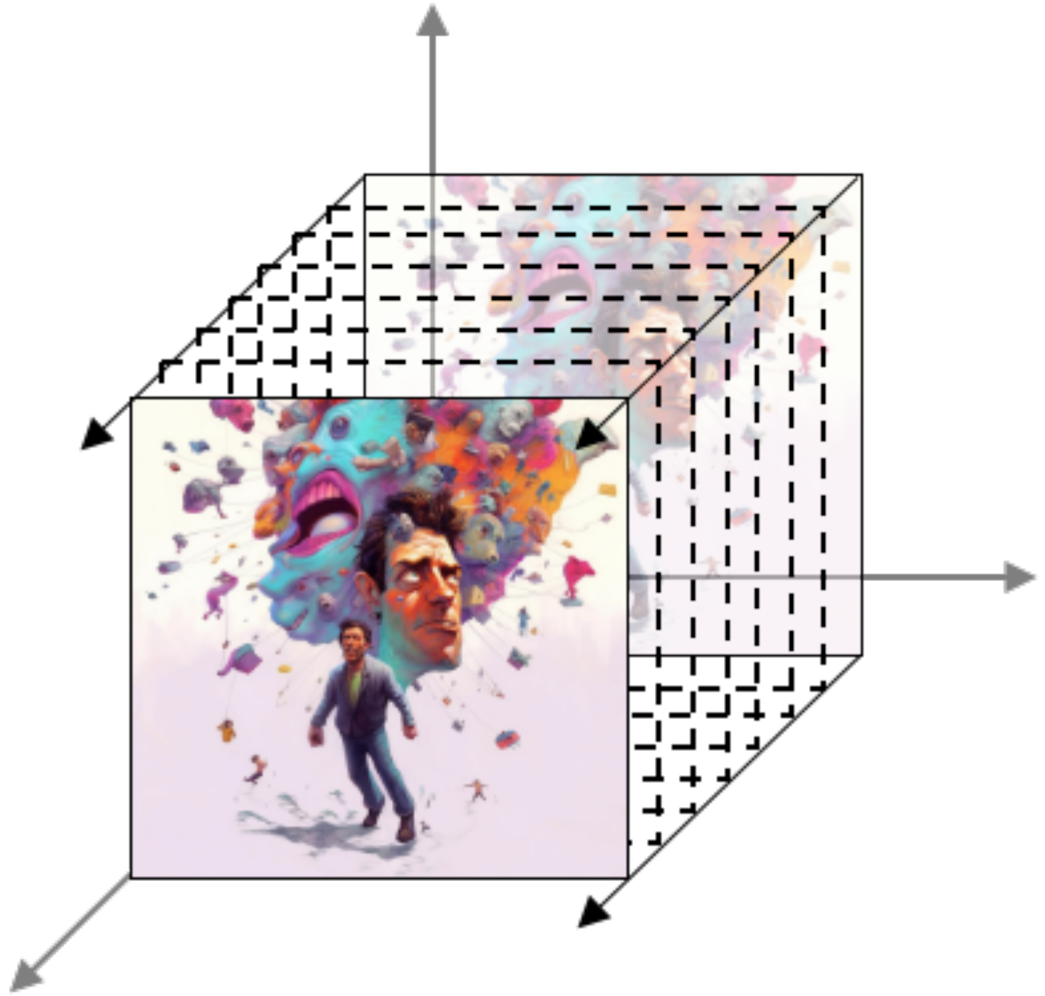
token

- 1 dimension
- Large Language Model



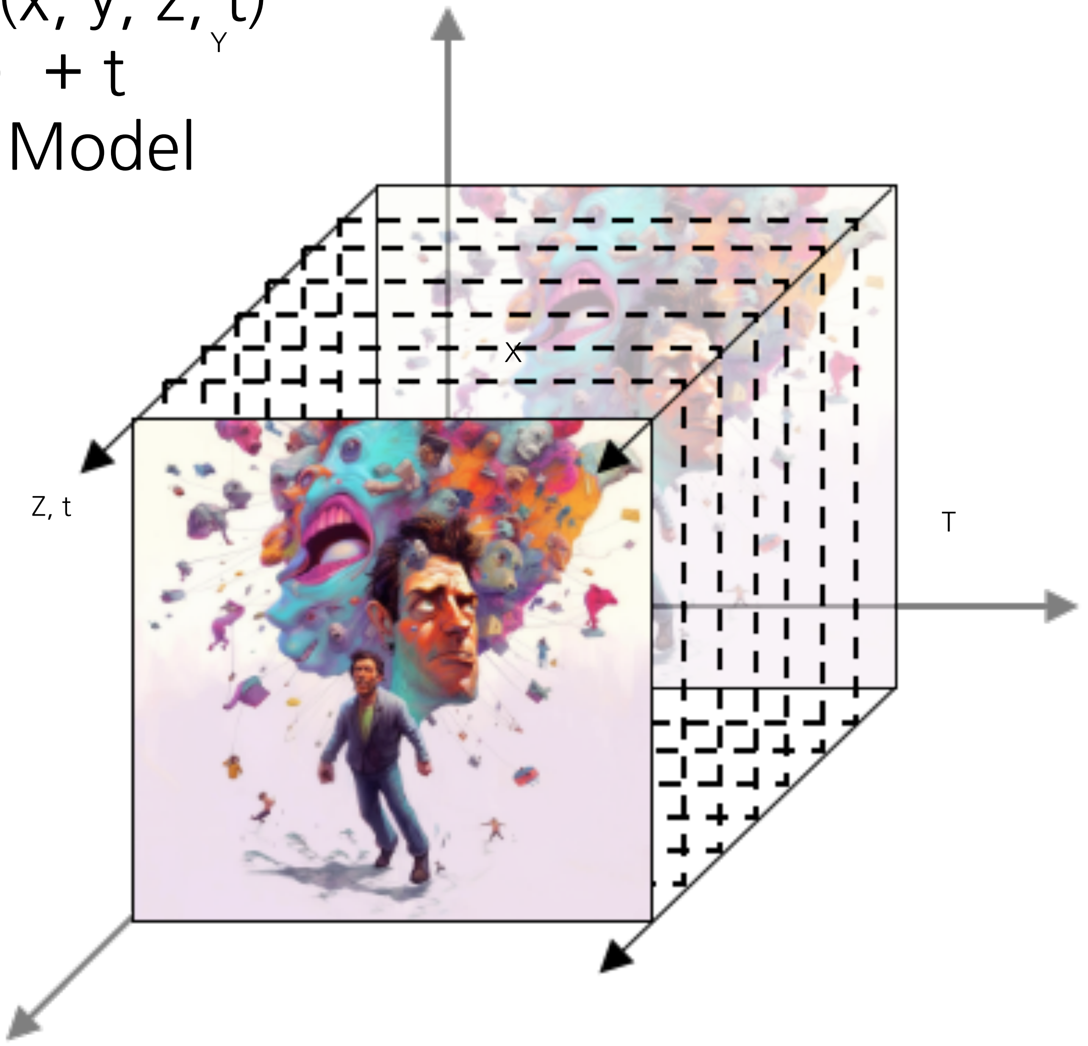
- 2 dimension + frame
- multi-modal
- Large Multimodal Model

Core competence:
* *Synthetic*
* *Sim2Real*



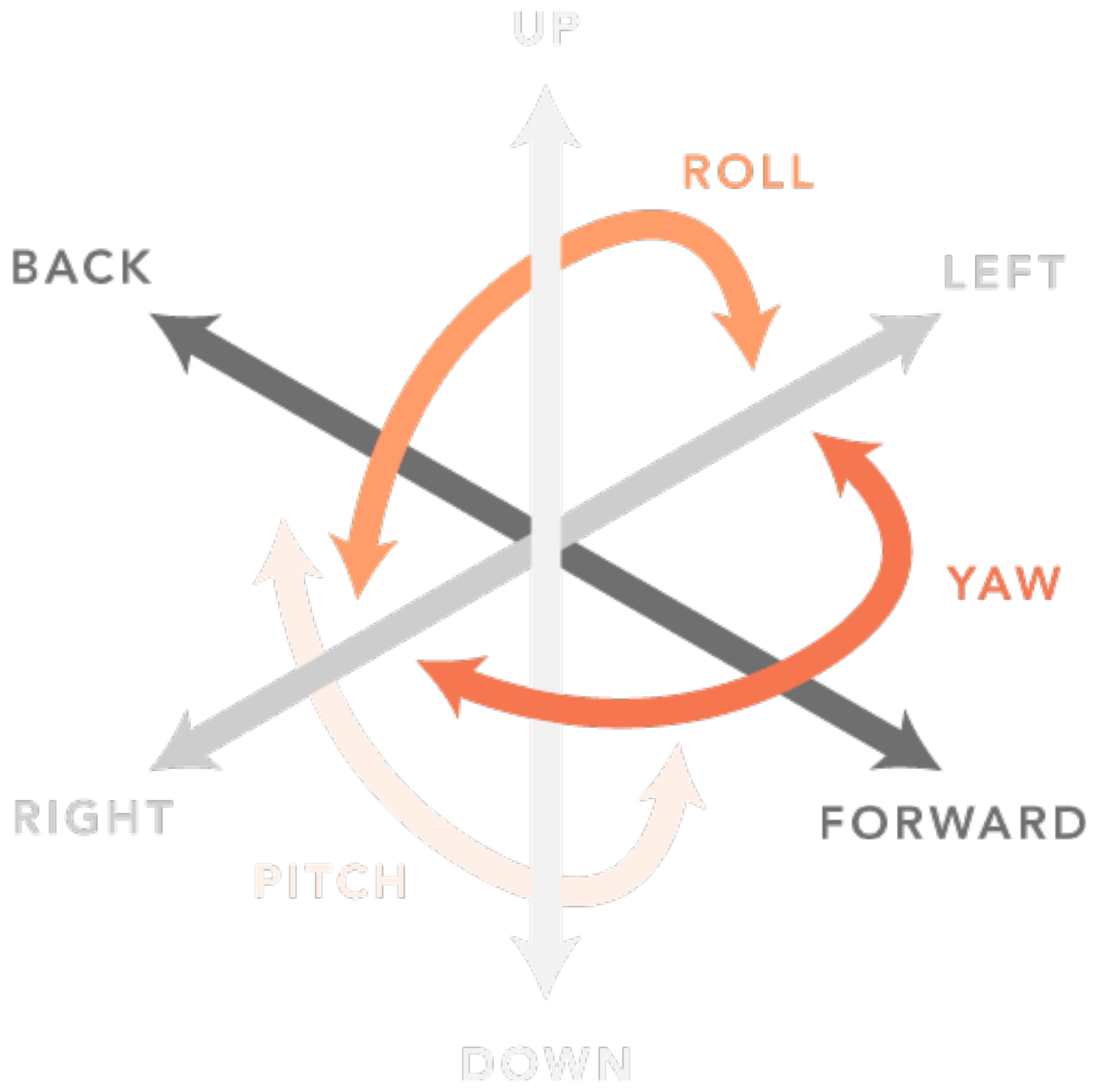
- 3 dimension(volumetric)
- 3DoF + t
- inter-frame consistency

- 4 dimension (x, y, z, t)
- spatial(6DoF) + t
- Large Action Model

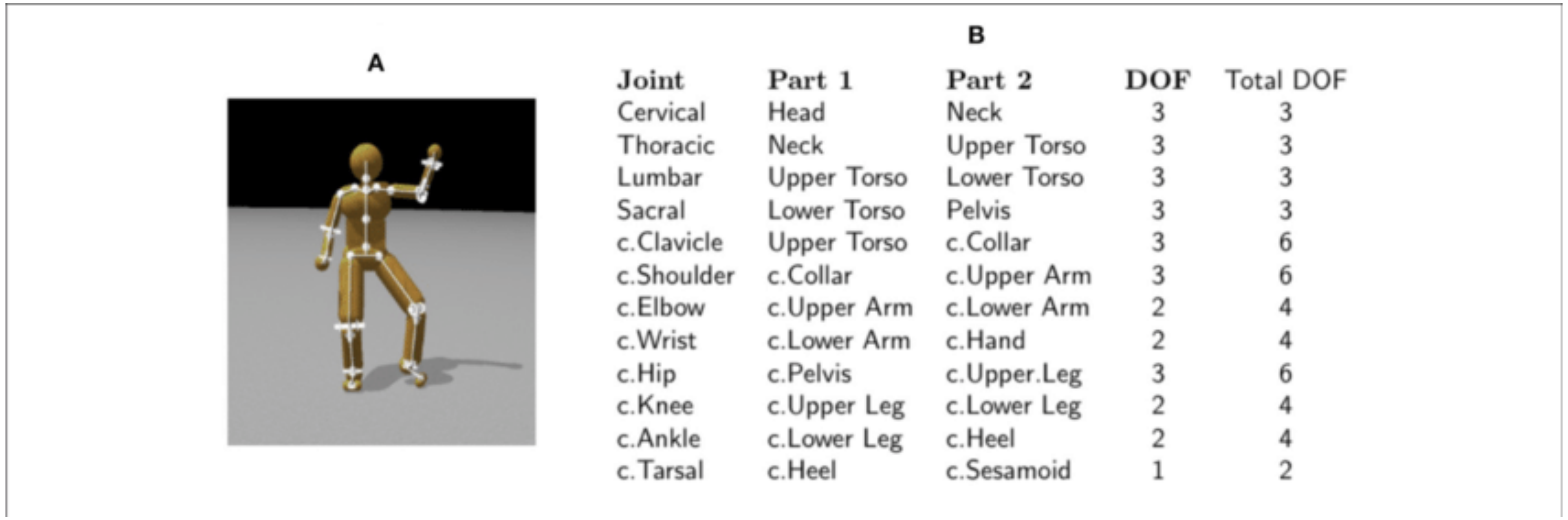


Comparison: DoF

Degrees of Freedom


UP
ROLL
BACK
LEFT
YAW
RIGHT
FORWARD
PITCH
DOWN

< 3/6 DoF >

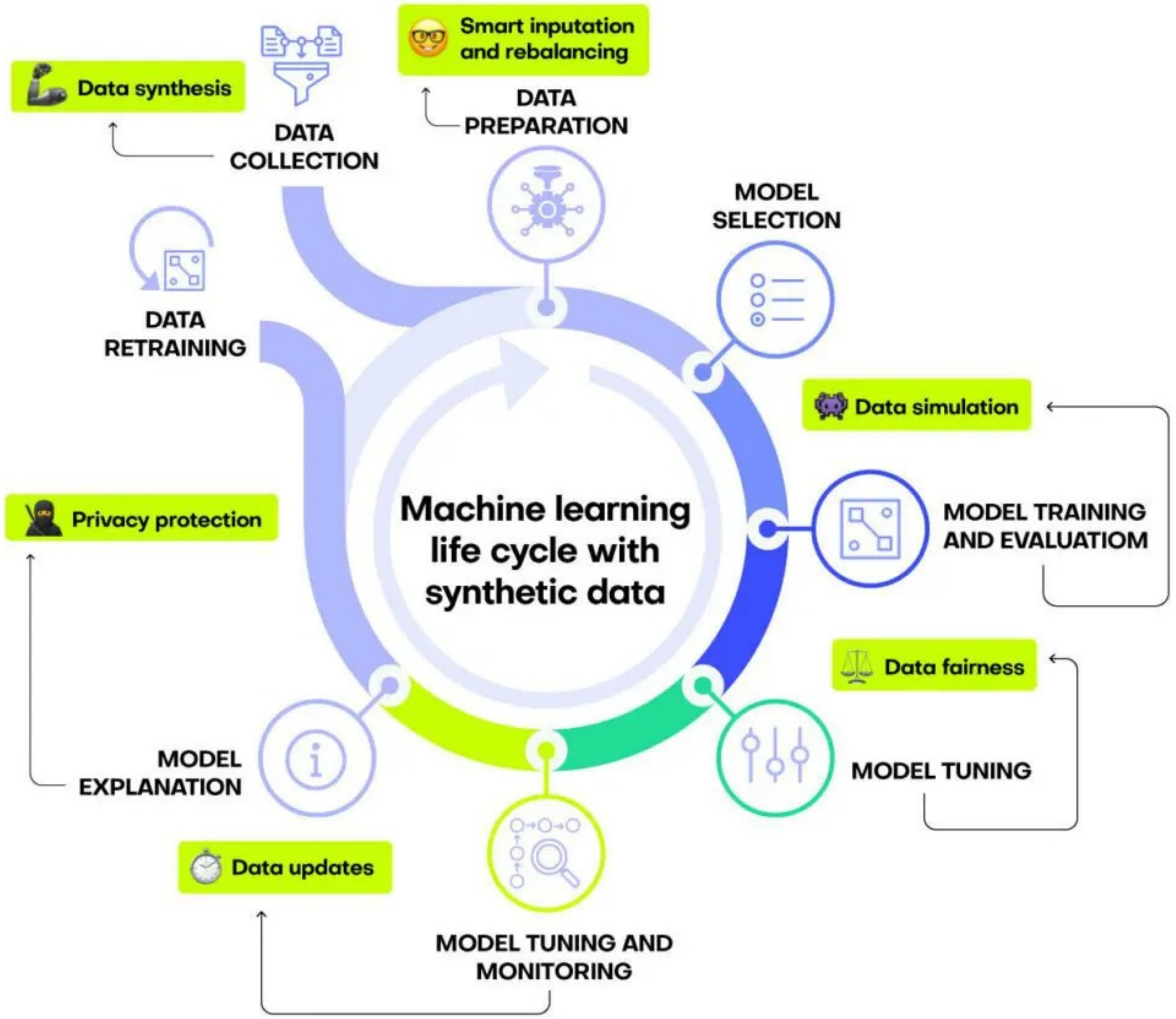


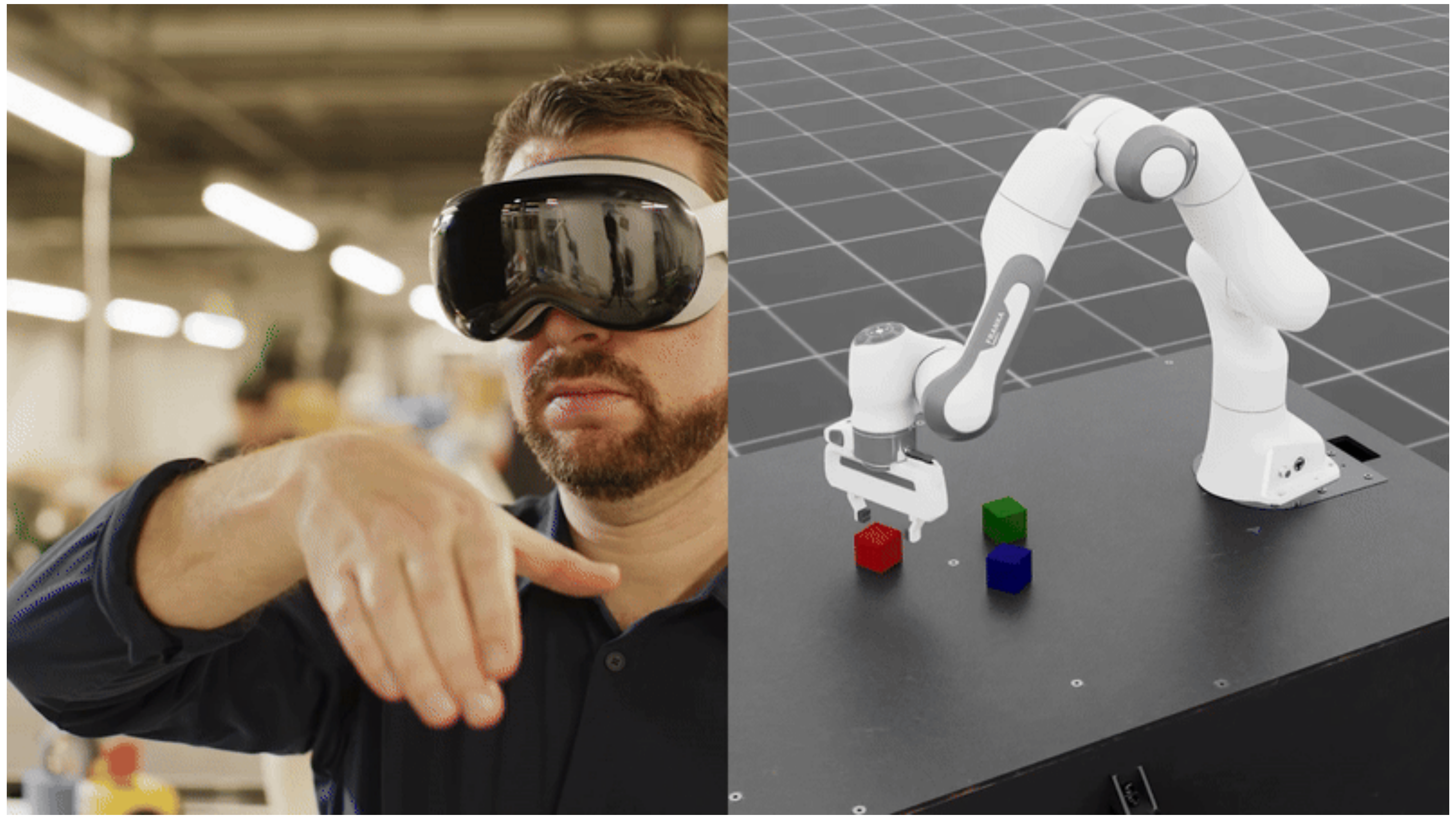
Joint	Part 1	Part 2	DOF	Total DOF
Cervical	Head	Neck	3	3
Thoracic	Neck	Upper Torso	3	3
Lumbar	Upper Torso	Lower Torso	3	3
Sacral	Lower Torso	Pelvis	3	3
c.Clavicle	Upper Torso	c.Collar	3	6
c.Shoulder	c.Collar	c.Upper Arm	3	6
c.Elbow	c.Upper Arm	c.Lower Arm	2	4
c.Wrist	c.Lower Arm	c.Hand	2	4
c.Hip	c.Pelvis	c.Upper.Leg	3	6
c.Knee	c.Upper Leg	c.Lower Leg	2	4
c.Ankle	c.Lower Leg	c.Heel	2	4
c.Tarsal	c.Heel	c.Sesamoid	1	2

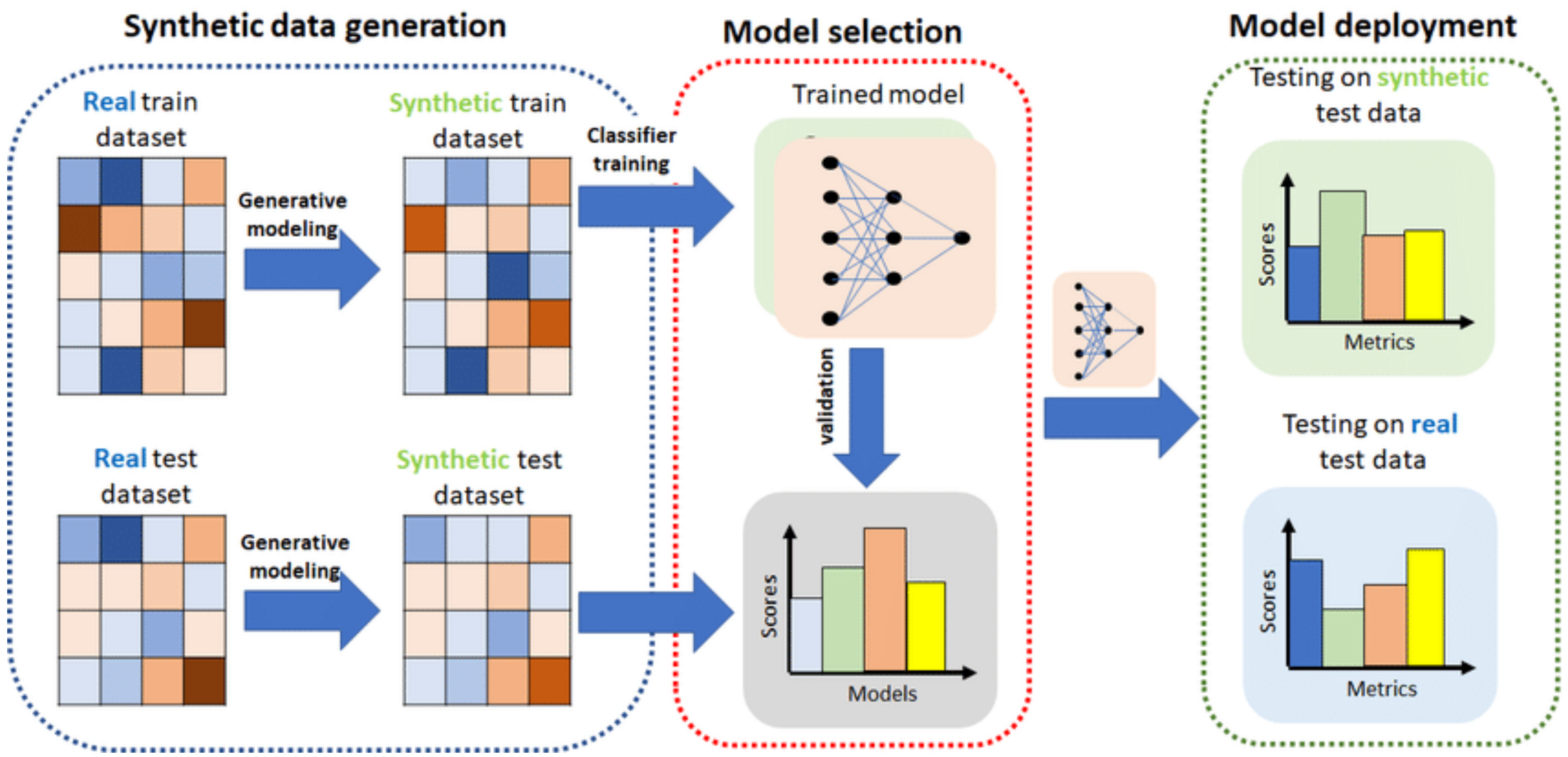
< 48 DoF >

Synthetic Data

rack of real data

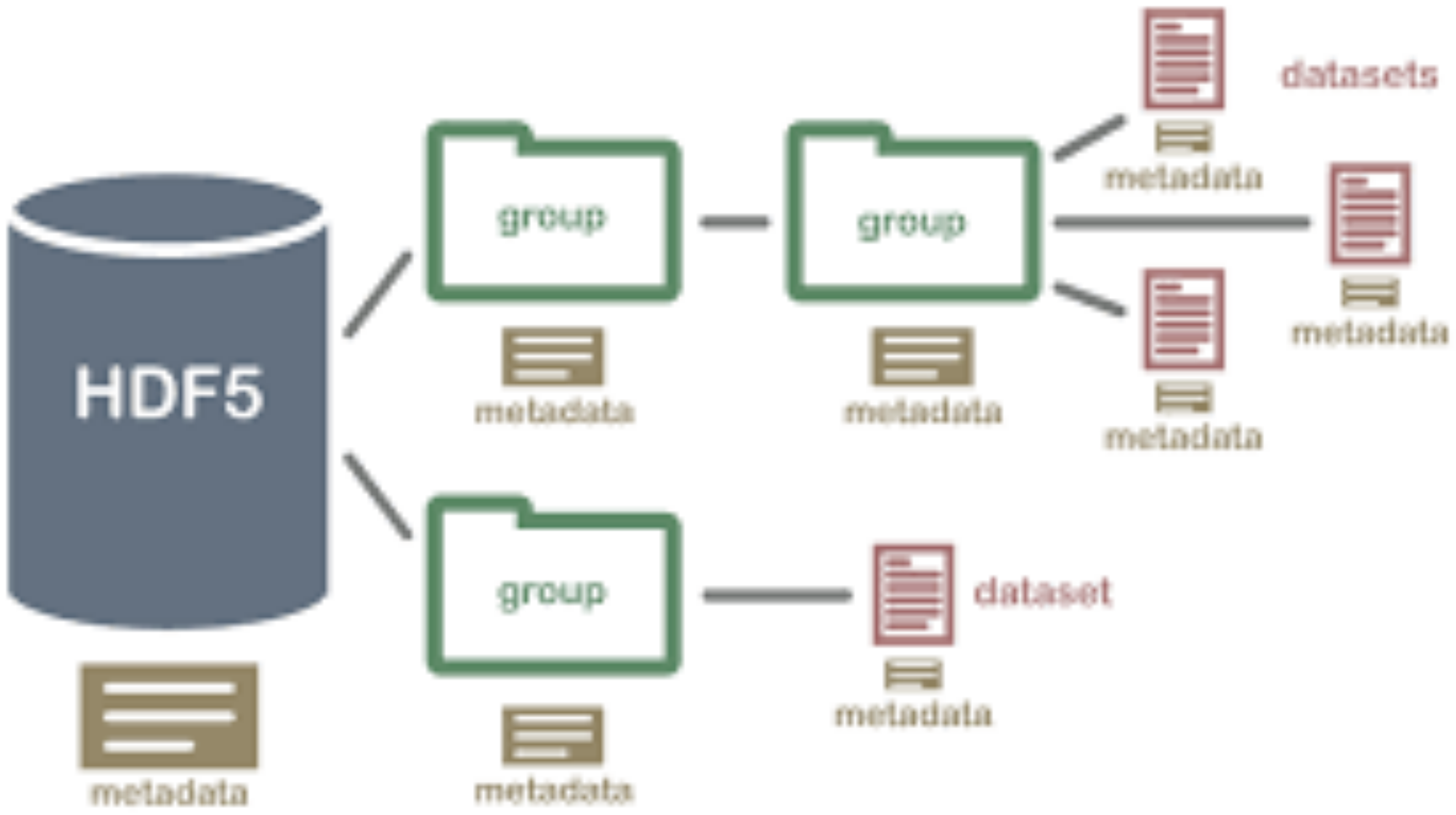

Data synthesis
DATA COLLECTION
Smart inputation and rebalancing
DATA PREPARATION
MODEL SELECTION
DATA RETRAINING
Data simulation
MODEL TRAINING AND EVALUATIOM
Privacy protection
Machine learning life cycle with synthetic data
Data fairness
MODEL TUNING
MODEL EXPLANATION
Data updates
MODEL TUNING AND MONITORING




Synthetic data generation
Model selection
Model deployment
Real train dataset
Synthetic train dataset
Generative modeling
Classifier training
Trained model
Testing on synthetic test data
Scores
Metrics
validation
Real test dataset
Synthetic test dataset
Generative modeling
Testing on real test data
Scores
Models
Scores
Metrics

Sim2Real

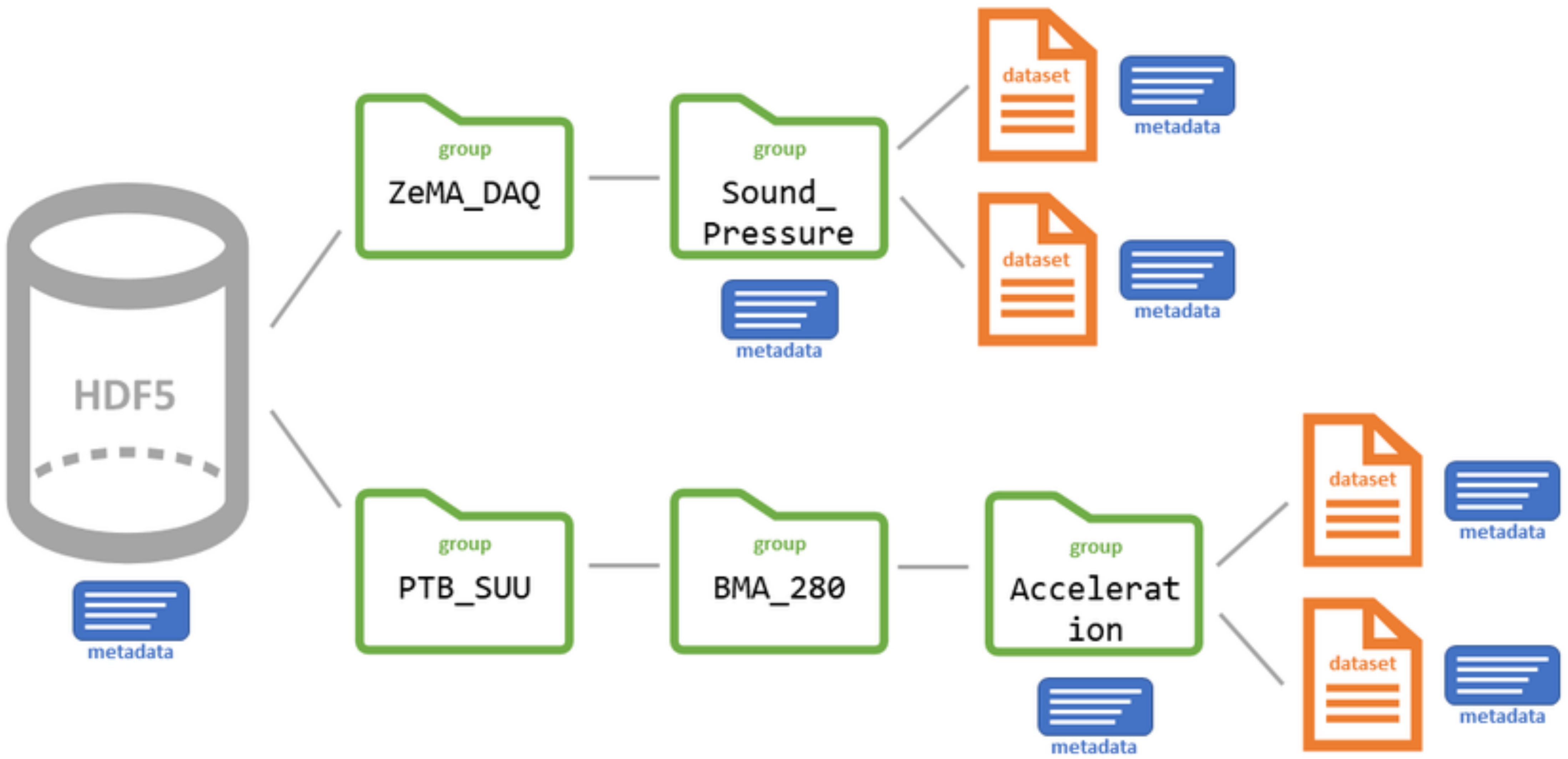
How to reduce Sim2Real Gap


HDF5
metadata
group
metadata
group
metadata
datasets
metadata
metadata
metadata
group
metadata
dataset
metadata

- find out optimal embedding space
- optimize loss function

includes inertia, acceleration, elasticity, friction,,,

and substance, temperature,


HDF5
metadata
group
ZeMA_DAQ
group
Sound_ Pressure
metadata
dataset
metadata
dataset
metadata
group
PTB_SUU
group
BMA_280
group
Accelerat ion
metadata
dataset
metadata
dataset
metadata

E.O.D