南方科技大学
SOUTHERN UNIVERSITY OF SCIENCE AND TECHNOLOGY

Robot Modeling & Control ME331

Section 1：Introduction

Chenglong Fu（付成龙）
Department of Mechanical and Energy Engineering

Instructor's Information

Chenglong Fu（付成龙）

Professor， Dept. of MEE， SUSTech

Education

1998~2002, B.S. ME, Tongji University, Shanghai, China

2002~2007, Ph.D. ME, Tsinghua University, Beijing, China

Work Experience

2007~2010	Assistant Professor, Dept. of ME , Tsinghua University
2010~2017	Associate Professor, Dept. of ME, Tsinghua University
2011~2012	Visiting Scholar, Dept. of ME, University of Michigan
2017~2020	Associate Professor, Dept. of MEE, SUSTech
2020~present	Professor, Dept. of MEE, SUSTech

1998~2002 2002~2017 2011~2012 2017~present

Instructor's Information

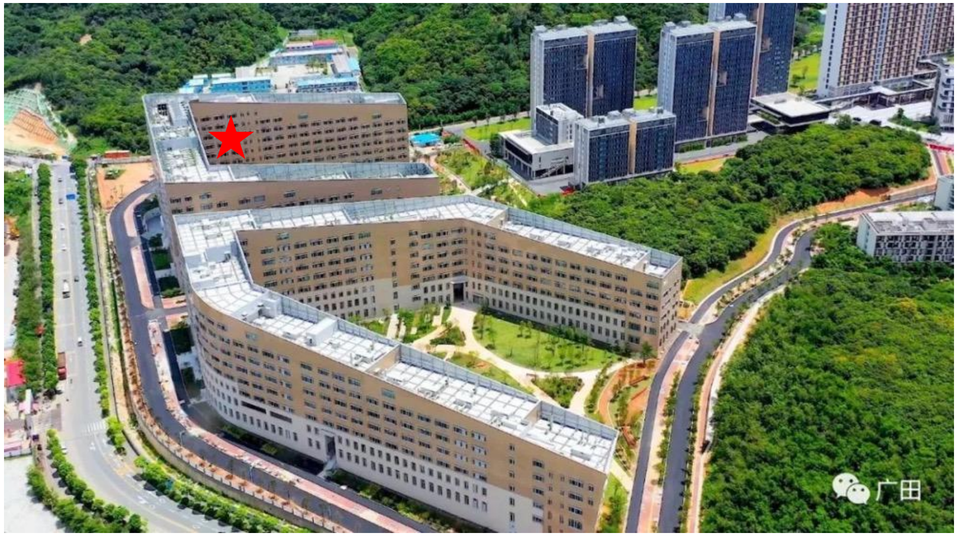
Chenglong Fu（付成龙）

Professor， Dept. of MEE， SUSTech

E-mail: fucl@sustech.edu.cn **Office**: N221, College of Engineering

Phone (M) : 13466686964. **Phone (O)** : 0755-88015355

Office Hour : Monday, (4:00-6:00pm)，**reservation in advance**



TA 1：Xinying Li (李心颖) SID：12432384 Phone: 17876674012

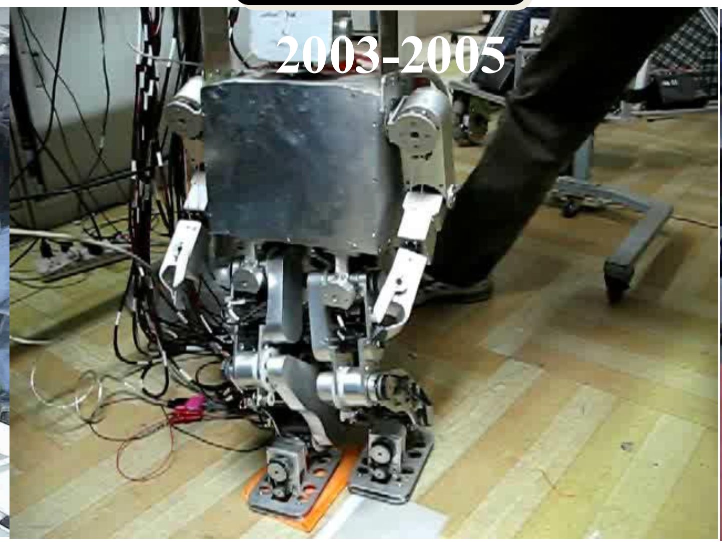
TA 2：Jie Guo (郭杰) SID：12432829 Phone: 15960505903

Course Logistics

Research Interest 1: Biped Robots

THBIP-I

THBIP-II



THR-I

THR-II

M2V2

Course Logistics

Research Interest 2: Human Augmented Robotics

Prostheses

Centaur Robot

Exoskeletons

Healthcare Robots

Course Logistics

Class Schedule

- **Time**: Monday 10:20 - 12:10 (week 1 2 3 … 16)
  Wednesday 8:00 - 9:50 (week 1 3 5… 15)
- **Location:** Room 326, Lecture Hall 1 (一教326)
- **Grading Policy**

  ① **Homework: 40%**

  ② **Initiative project: 30%**

  ③ **Midterm test: 25%**

  ④ **Participation: 5%**

Course Logistics

Class Schedule

- **Grading Policy (cont.)**

① Homework: 40%

There will be weekly homework sets. Homework is due at the *next week*. Late homework will be accepted with a *20% late penalty*.

② Initiative project: 30%

A final *group* project is required for this course. The project will be *selected by students*, with assistance from the instructor and TA. Projects should employ methods studied in the course, and should explore *novel* concepts.

Course Logistics

Class Schedule

- **Grading Policy (cont.)**

③ Midterm test: 25%

A 25% portion of the final grade will be determined by a partially open book examination in the midterm.

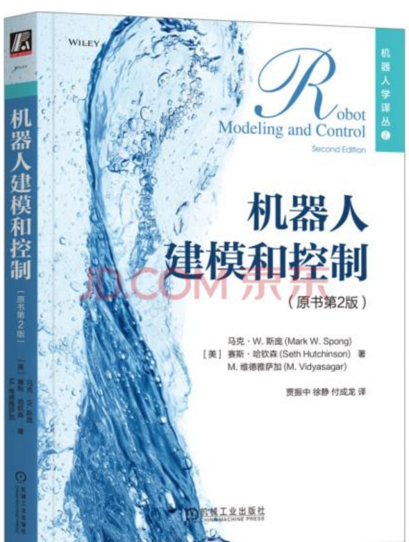
④ Participation: 5%

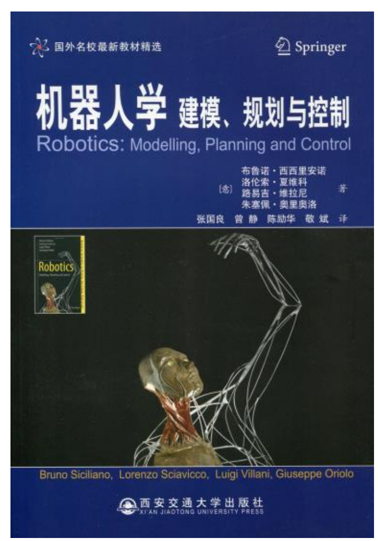
A 5% portion of the final grade will be determined by class attendance and in-class discussions.

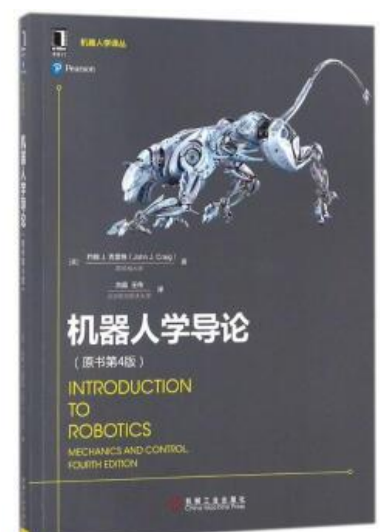
Course Logistics

Textbook and Supplementary Readings

1. **机器人建模和控制（第2版）**，作者：Mark. Spong，Seth Hutchinson，M. Vidyasagar，译者：贾振中 徐静 付成龙. 机械工业出版社, 中国，2023。
2. **机器人学：建模、规划与控制**，作者:Bruno. Siciliano， Lorenzo. Sciavicco，Luigi. Villani，Giuseppe. Oriolo，译者：张国良、曾静、陈励华、敬斌，西安交通大学出版社，中国，2015。
3. **机器人学导论**，翻译，作者:John J. Craig，译者：贠超，王伟，机械工业出版社，中国，2018。

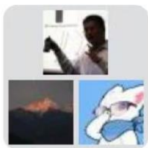






Course Logistics

SUSTech Blackboard **http://bb.sustech.edu.cn**



群聊: 2025-ME331-机器人建模与控制

该二维码7天内(2月22日前)有效，重新进入将更新

我的课程

在课程中您是: 教师

Robot Modeling and Control Fall 2024

Robot Modeling and Control Spring 2024

Robot Modelling and Control Sping 2025

公告:

› Course Logistics

行走机器人 *(当前不可用)*

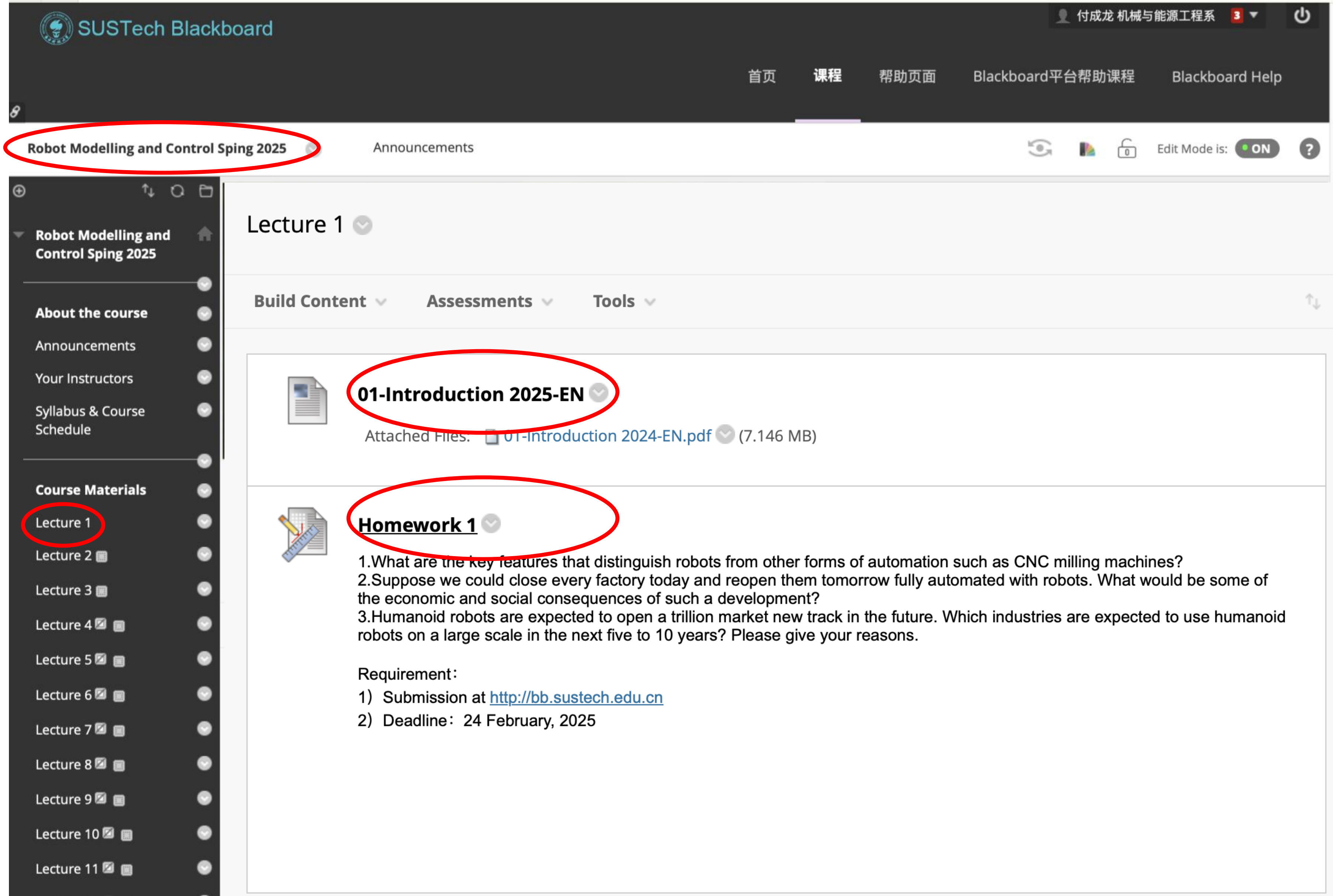
行走机器人（2022春） *(不可用 - 上次可用时间为 2022年7月12日 星期二)*

在课程中您是: 学生

Blackboard help

Blackboard平台操作学习

Course Logistics



Course Logistics

Course Objectives

1. introduce the basic analysis tools that are used in robotics
2. focus primarily on engineering methods to analyze or simulate dynamic movement of animals and robots
3. examine some important tools and principles underlying manipulation and locomotion, which are useful to design and build various manipulators, legged robots, prosthetic devices and exoskeletons

Pre-requisites

- MAE203 Theoretical Mechanics （理论力学 I ）

Course Logistics

Schedule （may be changed in class）

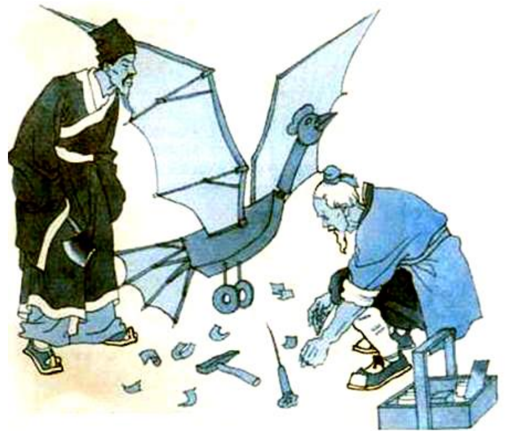
week 01	Introduction to the course, cases of robotics research
week 02	Kinematics I (manipulators, preliminary of kinematics)
week 03	Kinematics II (homogeneous matrix, Euler angle)
week 04	Kinematics III (D-H representation, forward kinematics)
week 05	Kinematics IV (inverse kinematics)
week 06	Kinematics VI (Jacobian calculation and application)
week 07	Kinematics VII (manipulability, trajectory planning)
week 08	Dynamics I (Lagrangian method)
week 09	Dynamics II
week 10	Midterm Test
week 11	Dynamics III
week 12	Dynamics IV（ Final Project Proposal Presentation ）
week 13	Control I
week 14	Control II
week 15	Control III
week 16	Final Project Presentation

Outline

- Ancient dreams of intelligent machines
- Why use robots in modern times?
- Biomimetic robots
- Cases study
- Future trends

1. Ancient Dreams of Intelligent Machines

1) Ancient Automata



Luban Bird
（Sring and Autumn Period）

Ancient Odometer
（The Han Dynasty）

Wooden Ox and Gliding Horse
（Three Kingdoms Period）

Da Vinci's Flapping Design
（Renaissance ）

Japanese Tea Doll
（18th century ）

Swiss writing robot
（18th century）

Ancient Dreams of Intelligent Machines

2. Industrial Manipulators

1954 — George Devol filed a U.S. patent describing an autonomous machine.

1958 — Joseph Engelberger teamed up with Devol and built a prototype.

1959 — They started the first robotics company, Unimation, in USA.

1961 — They put the first Unimate into service at a General Motors plant.

George Devol

+

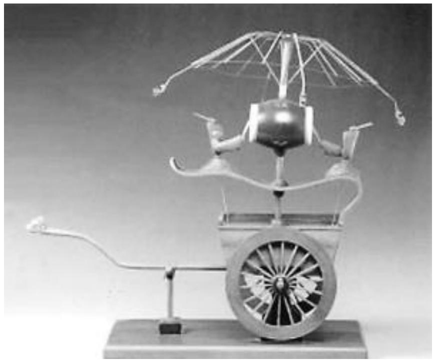
Joseph Engelberger

=

Unimate

Into the 20th century, practical industrial robots have come out. With the advent of robots for various purposes, many dreams have come true.

Ancient Dreams of Intelligent Machines

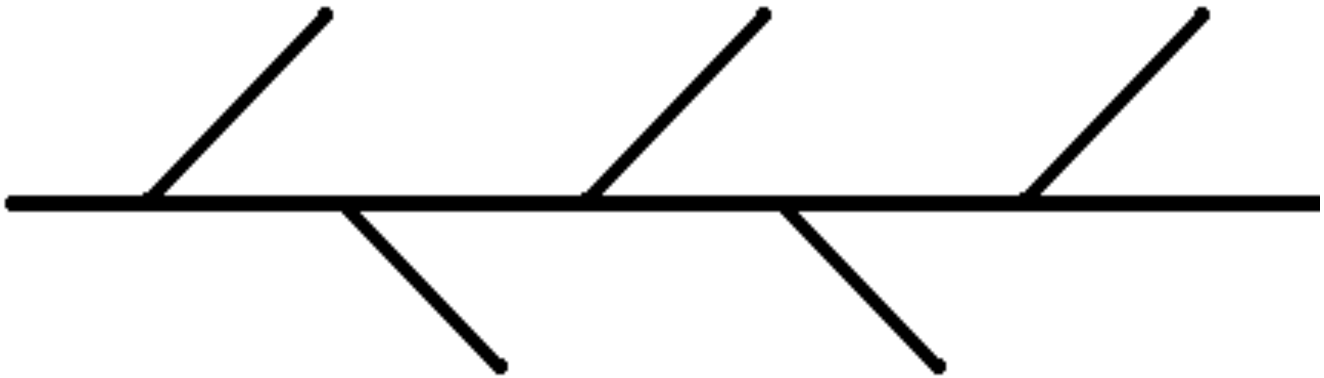


0) Ancient robot

2) Perceptive robot

4) Humanoid robot

Robot Tree



Embodied AI
Brain Science
Biomechanics
Cyborg
……

1) Teaching and playback robot

3) Biomimetic robot

Outline

- Ancient dreams of intelligent machines
- Why use robots in modern times?
- Biomimetic robots
- Cases study
- Future trends

Why use robots in modern times?

- Robot research is becoming a hot spot in global high-tech competition

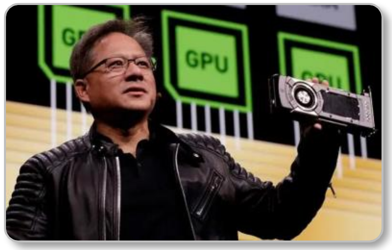
McKinesey
Global Inst.

《Disruptive technologies: Advances that will transform life, business, and the global economy》将**Advanced robotics**列入12项技术之一，预计机器人产业每年将产生 **1.7-4.5 trillion $** 经济效益.

Goldman Sachs
2024

Goldman Sachs Research（投资公司高盛）estimates that the global market for **humanoid robots** may reach at least 6 billion $ in 10 ~ 15 years, potentially expanding to 154 billion $ **（1.1万亿¥）** by 2035 in a blue-sky scenario.

Why use robots in modern times?



Jensen Huang
Nvidia Corp.

At ITF 2023, Jensen Huang: The next wave of AI, known as embodied AI （下一个浪潮是具身智能), refers to intelligent systems that can understand, reason about, and interact with the physical world. Examples include robotics and autonomous vehicles.

Elon Musk
Tesla Corp.

At Tesla’s 2024 annual shareholder meeting, Elon Musk: Humanoid robots could lift the company’s market cap to $25 trillion at an unspecified future date. The value of the entire S&P 500 (标准普尔500指数) is currently $45.5 trillion.

When Tesla humanoid robots Optimus (less than $20, 000) enter the Chinese market, does China have products to compete with them?

Why use robots in modern times?

- **Countries are stepping up their efforts to seize the strategic heights of robot development.**

- **USA**： **A Roadmap for US Robotics – Robotics for a Better Tomorrow** 2024 Edition

- **EU**： **Horizon Europe 2024 – AI, Data & Robotics manufacturing, search and rescue, health, homes, transport and logistics, environment and agriculture.**

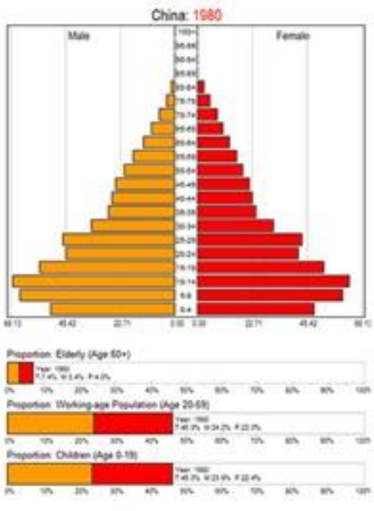
- **Japan**： **《New Robot Strategy》：Japan will become the showcase for the world’s leading robotics。**

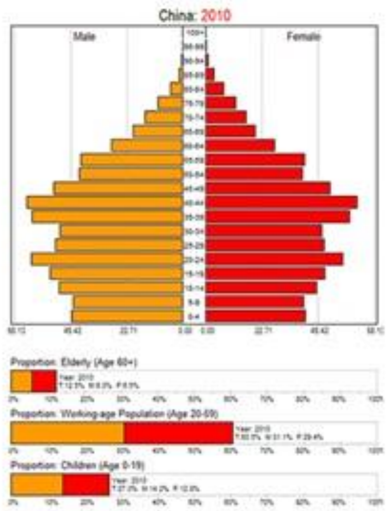
- **China**：**习总书记在中国两院院士大会提出：“不仅要把我国机器人水平提高上去，而且要尽可能多地占领市场”。**

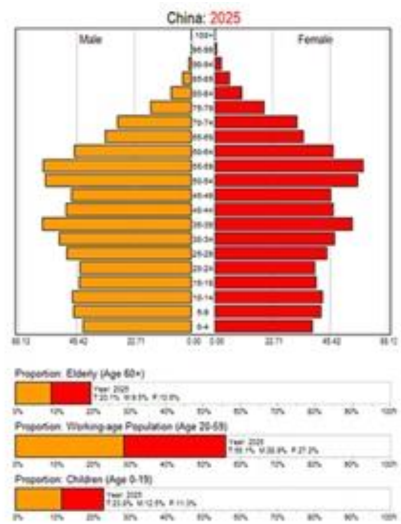
Why use robots in modern times?

❑ Aging Problem

China's aging population is a bigger challenge than its 'one-child' policy.







UN prediction

Media age in 2050:

- **China: 49.6**
- **USA: 42.3**
- **India: 37.5**

Who will care for 250 million elderly people in China?

Why use robots in modern times?

- **Unmanned systems offer versatility functionality, and the capacity to reduce the risk to human life.**

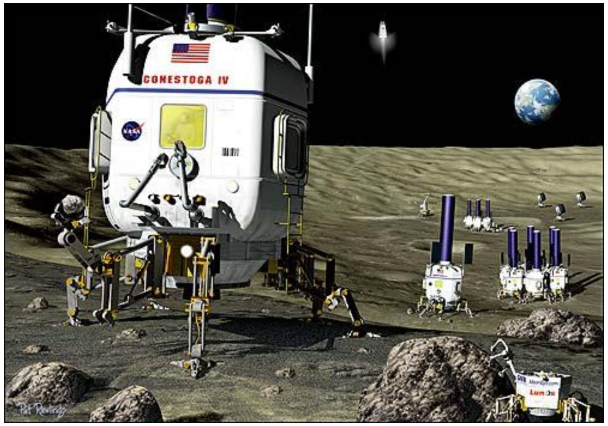
  Unmanned system

  Exoskeleton

  Space robot

  Ocean robot

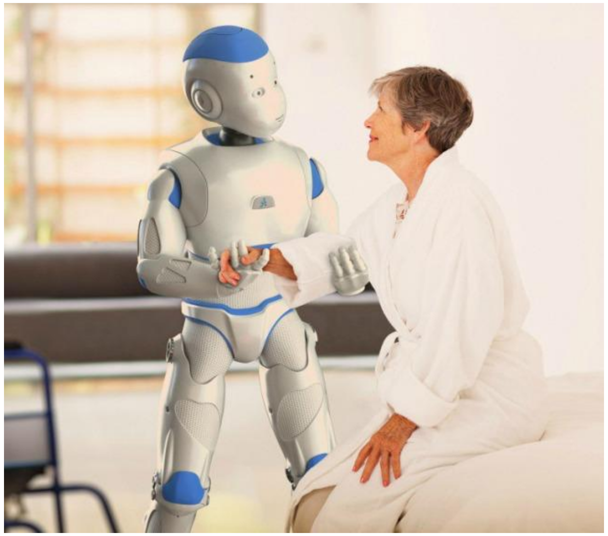
  Robot soldier



Robot is the only choice of replacing humans to work in dangerous, inaccessible areas

Why use robots in modern times?

- **Three factors drive the adoption of robots:**
  - improved productivity in the increasingly competitive international environment;
  - improved quality of life in the presence of a significantly aging society
  - removing first responders and soldiers from the immediate danger/action.

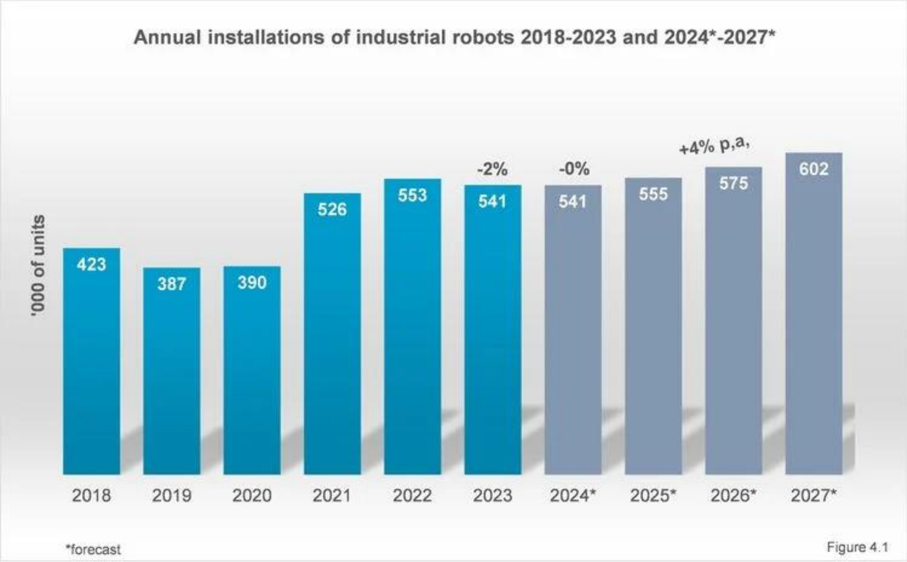


Economic growth, quality of life, and safety of our first responders continue to be key drivers for the adoption of robots.

Why use robots in modern times?

● Robot usage classification and market

Type	Introduction
工业机器人 Industrial robots	ISO: an “automatically controlled, reprogrammable multipurpose manipulator programmable in three or more axes” for use in industrial automation applications.
服务机器人 Service robots	ISO: a robot “that performs useful tasks for humans or equipment excluding industrial automation applications”.



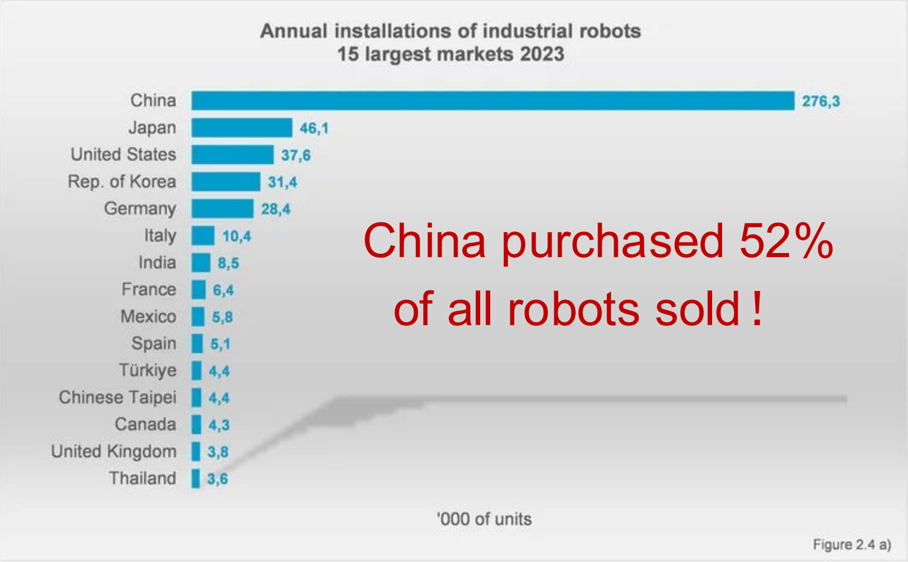


Table 1.1

Classification of service robots by type of movement

Type		Description
A	Ground-based	Robots that move or stand on the ground
A1	Rolling	Rolling on wheels or chains
A2	Walking	Walking on legs
A3	Fixed in place	Immobile, cannot change physical location by itself, standing on the gound, desk or other fixed place, also hanging
A4	Other ground-based	Gound-based but none of the above (A1-A3), e.g. crawling, snakeing, climbing
B	Water-based	Robots that swim or dive (autonomous
B1	Swimming	Swim on the surface of the water, Note: If the robot can both swim and dive, it is counted as diving (B2)
B2	Diving	Dive under the surface of the water
C	Aerial	Robots that move through the air
C1	Fly	Flying in the air
C2	Hover	Hover above ground
D	Wearables	Robots that are worn by people
D1	Exoskeletons	Powered human exoskeletons
D2	Other wearables	Wearable robots other than D1
E	Others	Robots that are not A-D
E1	Other robots	Robots that do not fit into classes A-D, e.g. robots for orbital space Robots that fit into multiple classes, e.g. hybrid robots for water and ground or air

Source: IFR

Table 1.2

Classification of service robots by application

-consumer applications-

Application		Description
AC	Consumer robots	Robots intended for use by everyone. No professional training required.
AC1	Robots for domestic tasks	Robots for housekeeping and similar tasks around the house
AC11	Domestic floor cleaning (indoor)	Wet and dry cleaning of floors, e.g. vacuuming and wiping of floors
AC12	Domestic window cleaning	Cleaning of windows
AC13	Gardening	Gardening tasks, e.g. lawn mowing
AC14	Domestic cleaning (outdoor)	Outdoor cleaning tasks around the home, e.g. pool cleaning, yard cleaning
AC19	Other domestic tasks	Domestic tasks other than AC11 to AC14
AC2	Social interaction, education	Robots with social interaction functions, robots for children and student education
AC21	Social interaction, companions	Main purpose of the robot is to interact with and entertain users at home
AC22	Education	Robots desigend specifically to educate children or students
AC3	Care at home	Robots that support people in need of care (e.g. seniors or handicapped people) in their homes or home-like environments (e.g. retirement homes)
AC31	Mobility assistants	Robotic wheelchairs, robotic rollators/walkers, exoskeletons for walking disabilities. Includes robotic devices.
AC32	Manipulation aids	Robots that support seniors or disabled people in the manipulation of their environment (e.g. meal assistance robot, manipulators mounted to wheelchairs). Includes robotic devices.
AC39	Other care robots	Robots for care at home that do not fit into AC31 or AC32. Includes robotics devices.
AC9	Other consumer robots	Consumer robots that do not fit into any of above classes
AC99	Other consumer robots	Consumer robots that do not fit into any of above classes

Source: IFR

Table 1.3

Classification of service robots by applications

-professional applications-

Application		Description
AP	Professional service robots	Robots intended for use by trained professionals.
AP1	Agriculture	Robots for agricultural and farming applications
AP11	Cultivation	Plowing, seeding, harvesting, weeding, fertilizing, pesticide spraying of/for crop plants and fuit indoors (greenhouse) and outdoors (field, vineyard)
AP12	Milking	Milking
AP13	Other livestock farming	Livestock farming, except milking, e.g. feeding, barn cleaning
AP19	Other agriculture	Agriculture, but none of the above
AP2	Professional cleaning	Robots for professional cleaning applications
AP21	Floor cleaning	Cleaning of horizontal areas, e.g. floors in offices, hotels, public buildings, streets and sidewalks. Note: Robots for barn cleaning are included in class AP13
AP22	Window and wall cleaning	Cleaning of windows, walls and other vertical areas
AP23	Tank, tube and pipe cleaning	Inside cleaning of tanks, tubes or pipes
AP24	Hull cleaning	Outside cleaning of hulls (aircraft, train, other vehicles, tank, container)
AP25	Disinfection	UV, spray, wiping or other disinfection methods
AP29	Other professional cleaning	Professional cleaning other than above
AP3	Inspection and maintenance	Robots for inspection and maintenance
AP31	Buildings and other construction	Outside detection of damage in buildings, plants, bridges, tunnels and other civil construction
AP32	Tank, tubes, pipes, sewers	Inside detection of leakage in tanks, pipes, or sewers
AP39	Other inspection and maintenance	Inspection and maintenance, but none of the above
AP4	Construction and demolition	Robots for construction and demolition
AP41	Construction	Installation of buildings and other constructions, earthwork
AP42	Demolition	Tear-off of buildings and other constructions
AP5	Transportation and logistics	Mobile robots for transportation of goods or cargo and other logistics functions
AP51	Indoor environments without public traffic	Cargo/goods transportation in indoor environments without public traffic only, e.g. warehouses, factories, non-public areas of hospitals, airports, etc.
AP52	Indoor environments with public traffic	Cargo/goods transportation in indoor environments with public traffic, e.g. hospitals, hotels, restaurants
AP53	Outdoor environments without public traffic	Cargo/goods transport in outdoor environments without public traffic only, e.g. harbors, airports
AP54	Outdoor environments with public traffic	Cargo/goods transport in outdoor environments with public traffic, e.g. home delivery, parcel delivery in the streets
AP55	Inventory	Counting and refilling of stock and inventory
AP59	Other transportation and logistics	Mobile robots for transportation and logistics applications not mentioned above. No passenger transportation
AP6	Medical robotics	Robots in medical applications
AP61	Diagnostics	Robotic diagnostic systems. Includes robotic devices.
AP62	Surgery	Robots for invasive therapy (surgery). Includes robotic devices.
AP63	Rehabilitation and non-invasive therapy	Robots for therapy (except surgery) and rehabilitation of patients after surgery or accidents. Includes robotic devices.
AP64	Medical laboratory analysis	Handling or processing of samples in medical laboratories
AP69	Other medical robots	Other robots for medical applications. Note: Robots for transportation in hospitals are included in class AP52
AP7	Search and rescue, security	Robots for emergency situations
AP71	Firefighting	Robots for Firefighting. Includes robotic devices.
AP72	Disaster relief	Robots for detection or rescue of survivors. Includes robotic devices.
AP73	Security services	Robots for security functions, e.g. surveillance, bomb squad support. Includes robotic devices.
AP8	Hospitality	Robots for interaction with guests or visitors
AP81	Food and drink preparation	Robots for food or drink preparation
AP82	Mobile guidance, information, telepresence	Robotic information desks or guides, e.g. in museums, shops, hotel receptions. Robots for virtual participation in real-world events. Note: Telepresence robots specifically designed for the medical field are covered in AP69
AP9	Other professional service robots	Robots that do not fit into any of the above classes
AP99	Other professional service robots	Robots that do not fit into any of the above classes

Source: IFR

Why use robots in modern times?

- **The challenges in China**
  - The inflection point of demographic dividend is approaching, and the cost of China's manufacturing industry keeps rising;
  - China robot density: 470 robots / 10K employees,

    Korea robot density: 1012 robots / 10K employees；
  - China robot market: the fastest growth, the largest market;
  - More than 70 percent of industrial robots are imported.
- **Robotics as a Key Economic Enabler**
  - Robotics is one of a few technologies that has the potential to have an impact that is as transformative as PC and the Internet. (Bill Gates)

The development of robot technology reflects the national will and strategy!

Why use robots in modern times?

● Chinese government industrial policy

《十四五规划和2035年远景目标纲要》

《“十四五”规划和2035远景目标纲要》： **智能制造与机器人技术、新能源汽车和智能汽车、高端医疗装备**等行业被列入制造业八大核心竞争力中。

《“十四五”机器人产业发展规划》

《“十四五”机器人产业发展规划》：加快推动机器人产业**高质量发展**，**以高端化智能化发展为导向**，面向产业转型和消费升级需求。

中共中央 国务院印发《粤港澳大湾区发展规划纲要》

《粤港澳大湾区发展规划纲要》：以**机器人及其关键零部件**、高速高精加工装备和**智能成套装备**为重点作为国家战略发展重点领域。

《十四五“智能机器人”专项指南》

支撑国民经济主战场、国家**重大需求**、人民生命健康等相关行业/领域自主发展。围绕基础前沿技术、共性关键技术、**工业机器人**、**服务机器人**、**特种机器人等** 5 个技术方向。

Why use robots in modern times?

● Chinese government industrial policy

部　门	时　间	计划名称	计划内容
国务院	2024.12	《深化养老服务改革发展意见》	设立养老服务相关国家科技重大项目，重点推动人形机器人、脑机接口、人工智能等技术产品研发应用。
	2023.08	《河套深港科技创新合作区深圳园区发展规划》	将智能机器人列为欲打造的国际一流科技创新平台之一，推动设立机器人检测认证等中试公共服务平台。
工业和信息化部等十七部门	2023.01	机器人+ 应用行动实施方案	落实《“十四五”机器人产业发展规划》重点任务，加快推进机器人应用拓展，决定开展“机器人+”应用行动。
工业和信息化部办公厅	2023.06	工业和信息化部办公厅关于开展2023年工业和信息化质量提升与品牌建设工作的通知	提升电子装备、数控机床和工业机器人的安全性和可靠性水平，持续推进工业机器人核心关键技术验证平台能力建设。
广东省	2023.11	数字湾区建设三年行动方案	开展智能制造试点建设，统筹用好智能制造试点示范项目成果，培育形成一批智能机器人深度应用场景。
	2022.12	广东省新一代人工智能创新发展行动计划（2022-2025年）	全力将广东打造成为全球新一代人工智能创新发展战略高地，推动智能机器人的发展。

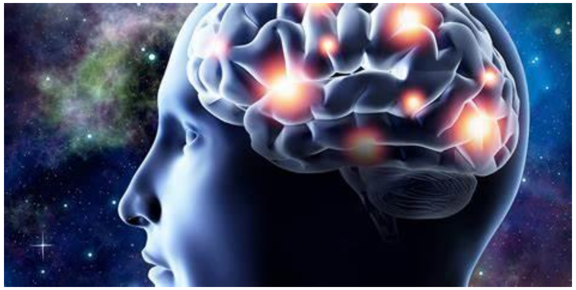
Outline

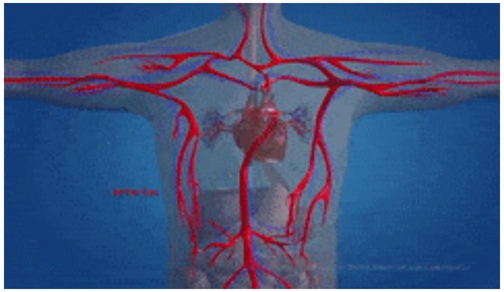
- Ancient dreams of intelligent machines
- Why use robots in modern times?
- Biomimetic robots
- Cases study
- Future trends

Biomimetic Robots

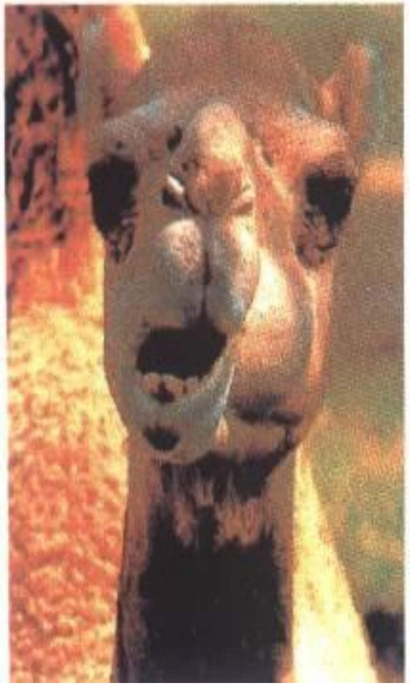
❑ Biomimetics

- Biomimetics is an innovative design concept that draws inspiration from nature and its elements and processes to solve complex human problems.
- The term “biomimetics” is derived from the ancient Greek words “bios” and “mimesis,” which translate to “life” and “imitate,” respectively.
- Nature still has much to teach us.

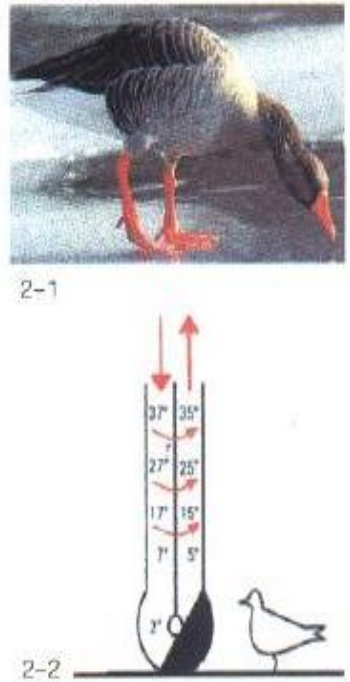




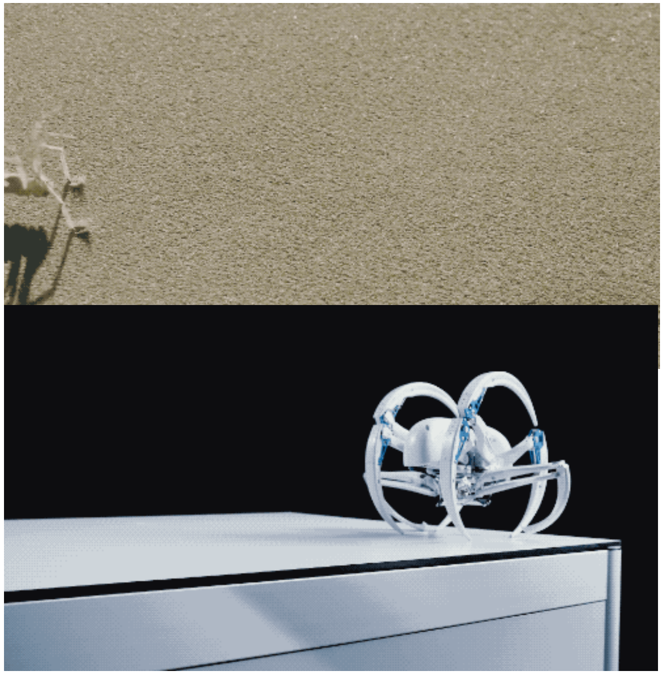
Biomimetic Robots



The camels' elaborate thermoregulation

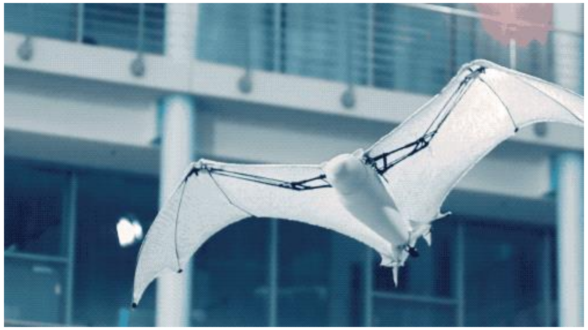


Ice birds cool their feet so they can walk on ice.



A robot that mimics the tumbling of a desert spider

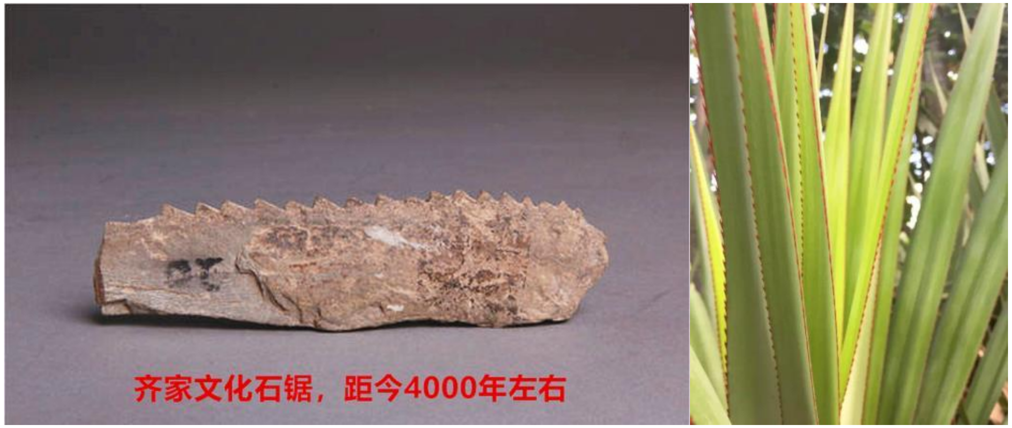
A robotic arm that mimics an elephant trunk



Bat-like robot

The mechanical tentacles like an octopus

Biomimetic Robots



The story of Lu Ban inventing the saw


Flight anti-load suit

Shark-inspired swimsuits

Biomimetic Robots

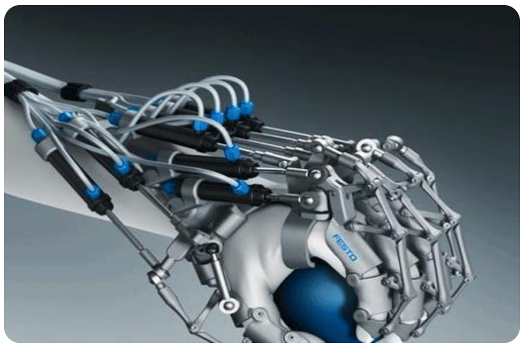
❑ Biomimetic Robotics

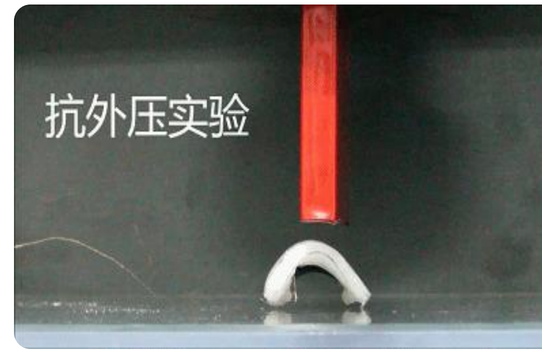
- 近十年来，Science、Nature、PNAS等刊发机器人主题论文50余篇，关注**仿生移动、仿生群体、人机融合、柔软体机器人**等热点
- 2014年，Science 发表机器人特刊 **(soft robots、biomimetic robots)**
- 2016年， Science 杂志创办子刊 **Science Robotics**

《Science Robotics》

Biomimetic Robots

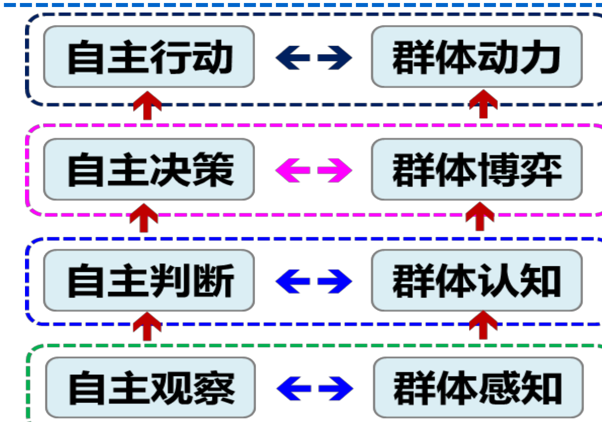
- **Structure: To adapt the environment, the robot needs to have redundant DoF. The development of soft materials to form flexible structures is the research frontier.**





Rigid-flexible **Flexible** **Soft**

- **Swarm: individual autonomy and emergence of swarm intelligence**



Biomimetic Robots

Control： There are two main approaches to developing artificial general intelligence. One is rooted in neuroscience, and attempts to construct circuits that closely mimic the brain. The other is grounded in computer science, and uses computers to execute machine-learning algorithms. In this Nature Cover article, Luping Shi' group reveal the Tianjic chip — an electronic chip that integrates the two approaches into one hybrid platform.

Obstacle avoidance

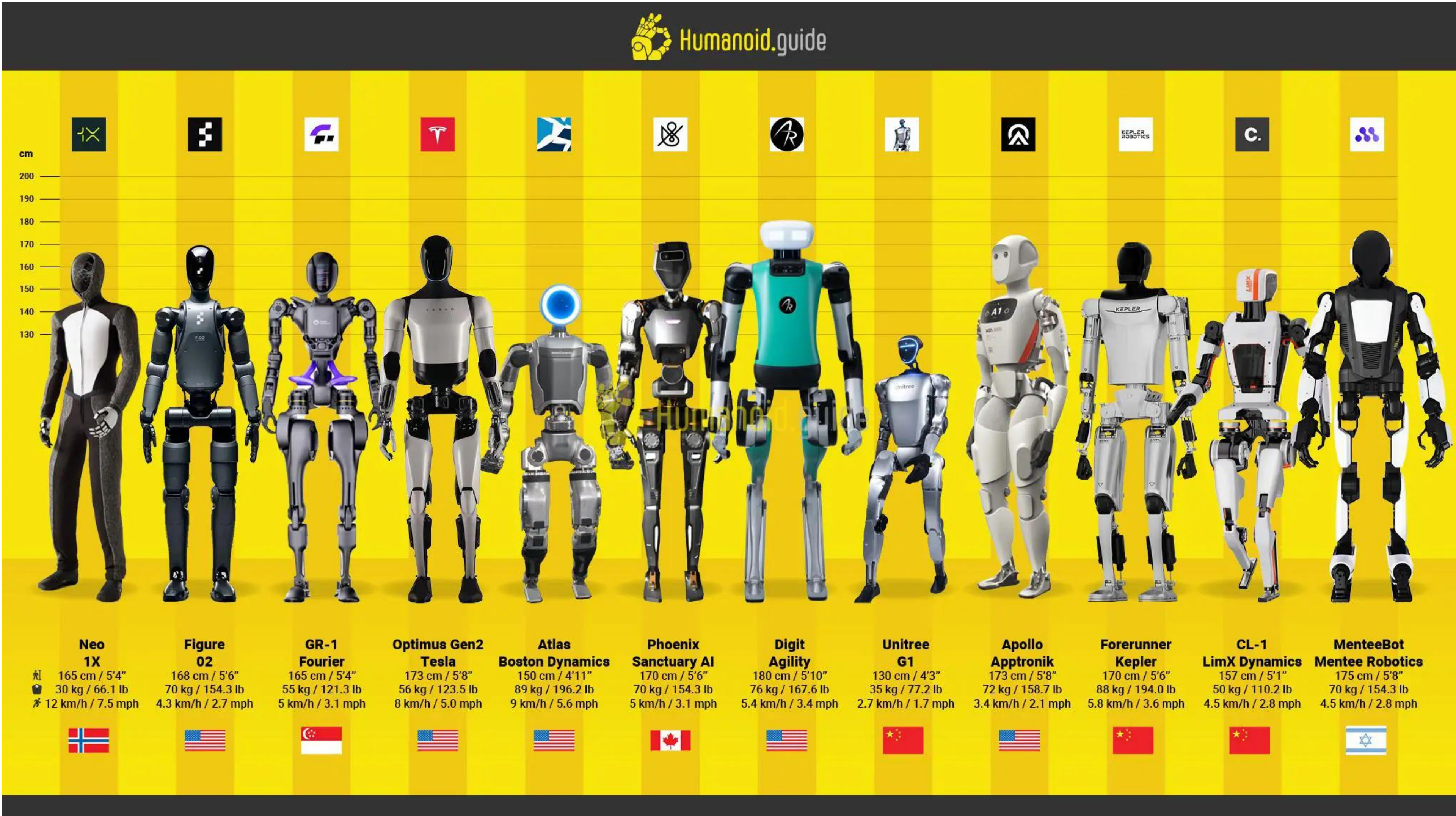
Straight and speed up

Turn left

S-curve

Humanoid Robots

- Humanoid robots are poised to significantly disrupt human labor.
- However, this shift will also create opportunities in robot maintenance, programming, and oversight, requiring a more skilled workforce.

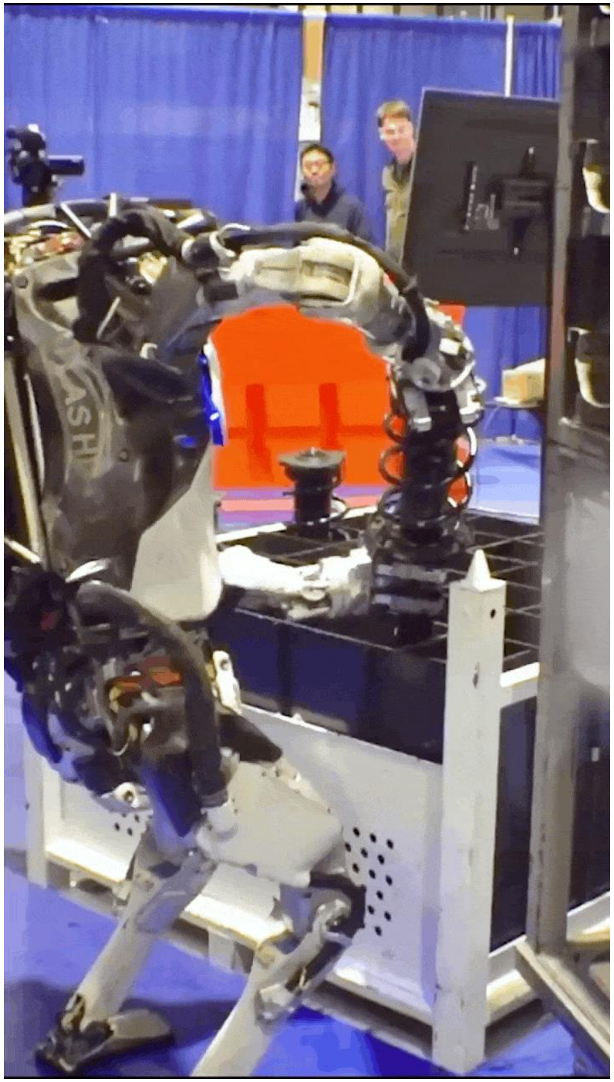


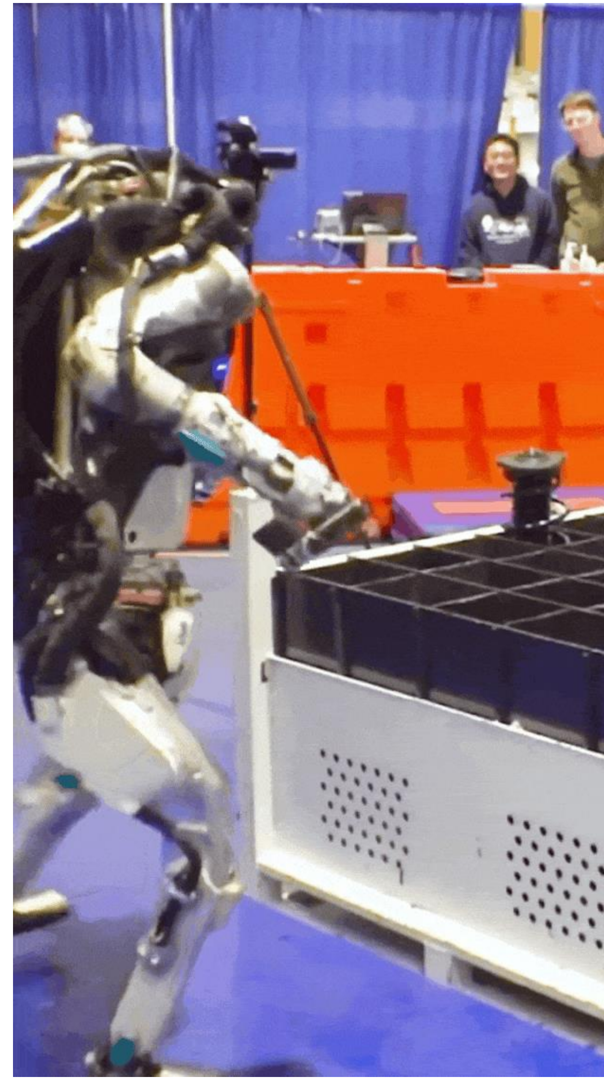
Humanoid Robots

Agility Robot demo at ProMat 2023.COURTESY OF AGILITY ROBOTICS

Humanoid Robots

Boston Dynamics' Atlas picks up a 30-lb car strut and carefully manipulates it.





Lift heavy things

Recognize irregular objects

Recover after tripping

Humanoid Robots

Unitree Technology's Humanoid Robot (H1) Debuts at CCTV Spring Festival Gala with Performance 'Yang Bot'

Humanoid Robots

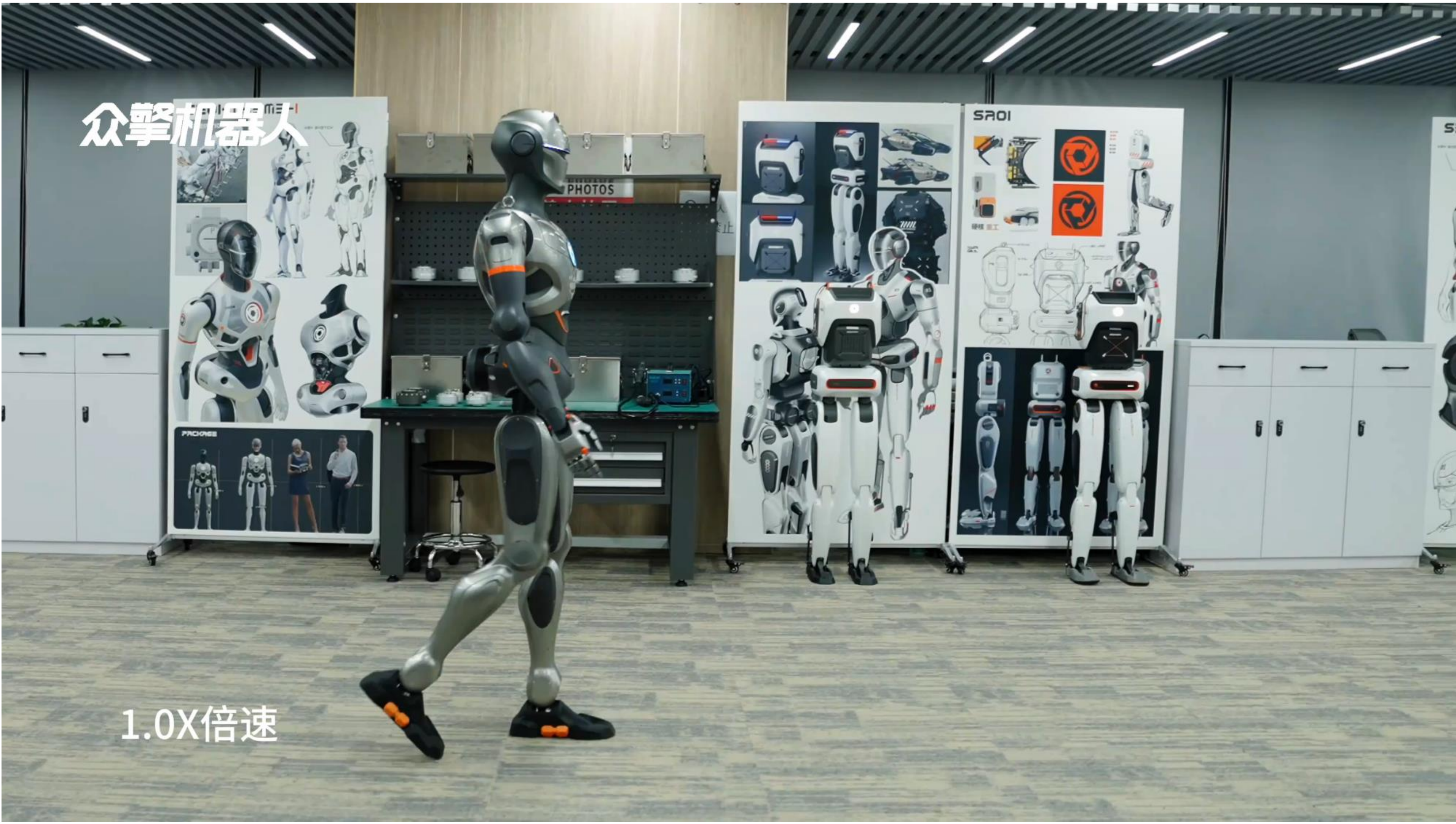
Unitree G1，Humanoid agent AI avatar，Price from $16K

Humanoid Robots

UBTECH's Walker S1 industrial humanoid robot in operation at Foxconn's Longhua facility in Shenzhen

Humanoid Robots

EngineAI Robotics（众擎机器人） SE01 humanoid robot is first to achieve human-like gait.



Challenges

ME、EE、
CS、MSE
Biology

Multidisciplinary intersection

Perception,
actuation,
control

Multifunction unit

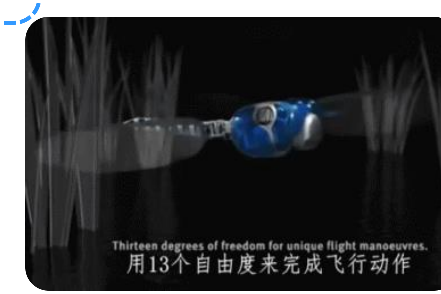
Robots

Multiphysical process

Machinery,
electricity,
liquid,light

Multicontact interface

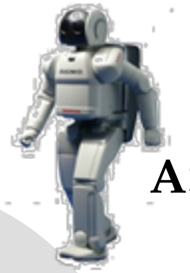
Rigid/Rigid,
Rigid/soft,
soft/soft



Challenge 1：Integrated design of complex systems

The multi-contact interface realization of functional integration, energy conversion and transmission, coupling of material flow/energy flow/information flow among various functional units increase the diversity and complexity of robot system integration design.

Challenges



ASIMO

2

Toyota Prius

0.15

COT

(Cost of transport)

Energy/(Weight*Distance)

0.2

Human

BigDog

15

Robust control of a horse-sized robot need not use 10-20 horsepower.

Challenge 2: Actuation and transmission

How to design bio-inspired joints, optimize the transmission mode, coordinate the timing of joint energy storage, coupling and release, and improve energy utilization efficiency.

Challenges

Challenge 3: Human-machine bidirectional information interaction

Perception: understanding exactly what people do and what they want to do

Behavior: Provide the required movement safely and comfortably (limb extension/enlargement)

Homework 1

1. What are the key features that distinguish robots from other forms of automation such as CNC milling machines?
2. Suppose we could close every factory today and reopen them tomorrow fully automated with robots. What would be some of the economic and social consequences of such a development?
3. Humanoid robots are expected to open a trillion market new track in the future. Which industries are expected to use humanoid robots on a large scale in the next five to 10 years? Please give your reasons.

Requirement：

1）Submission at http://bb.sustech.edu.cn

2）Deadline：24 February, 2025