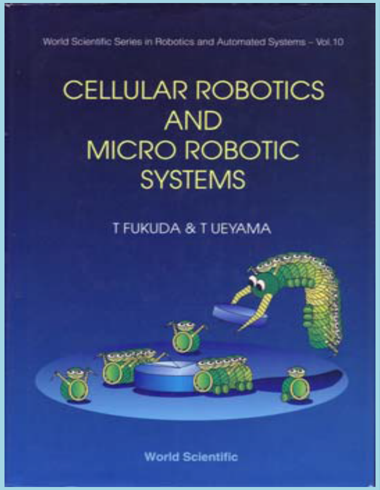
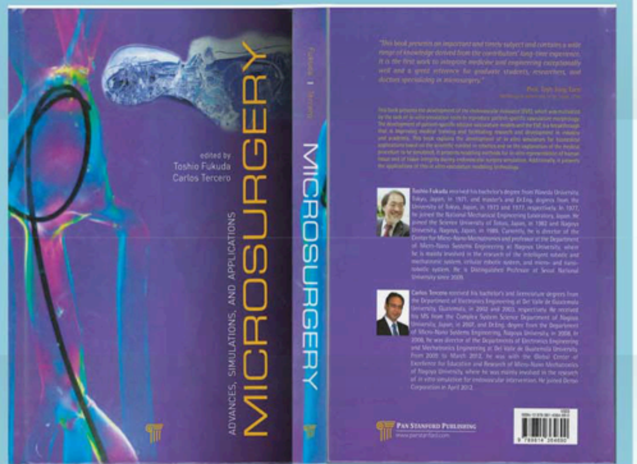
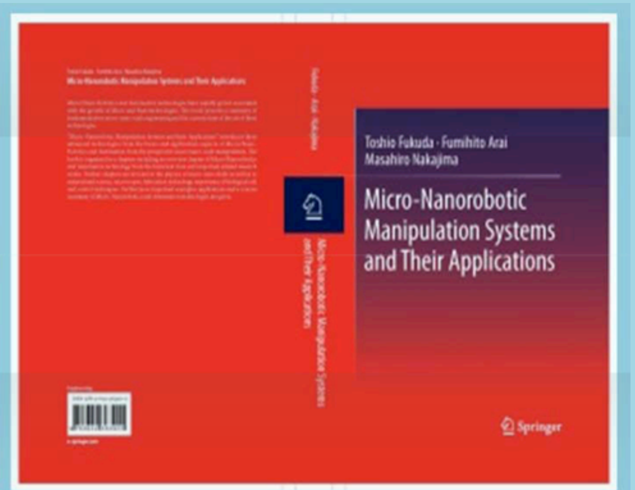
マルチスケールロボティクスの未来







名古屋大学大学院工学研究科
マイクロ・ナノシステム工学専攻
福田敏男

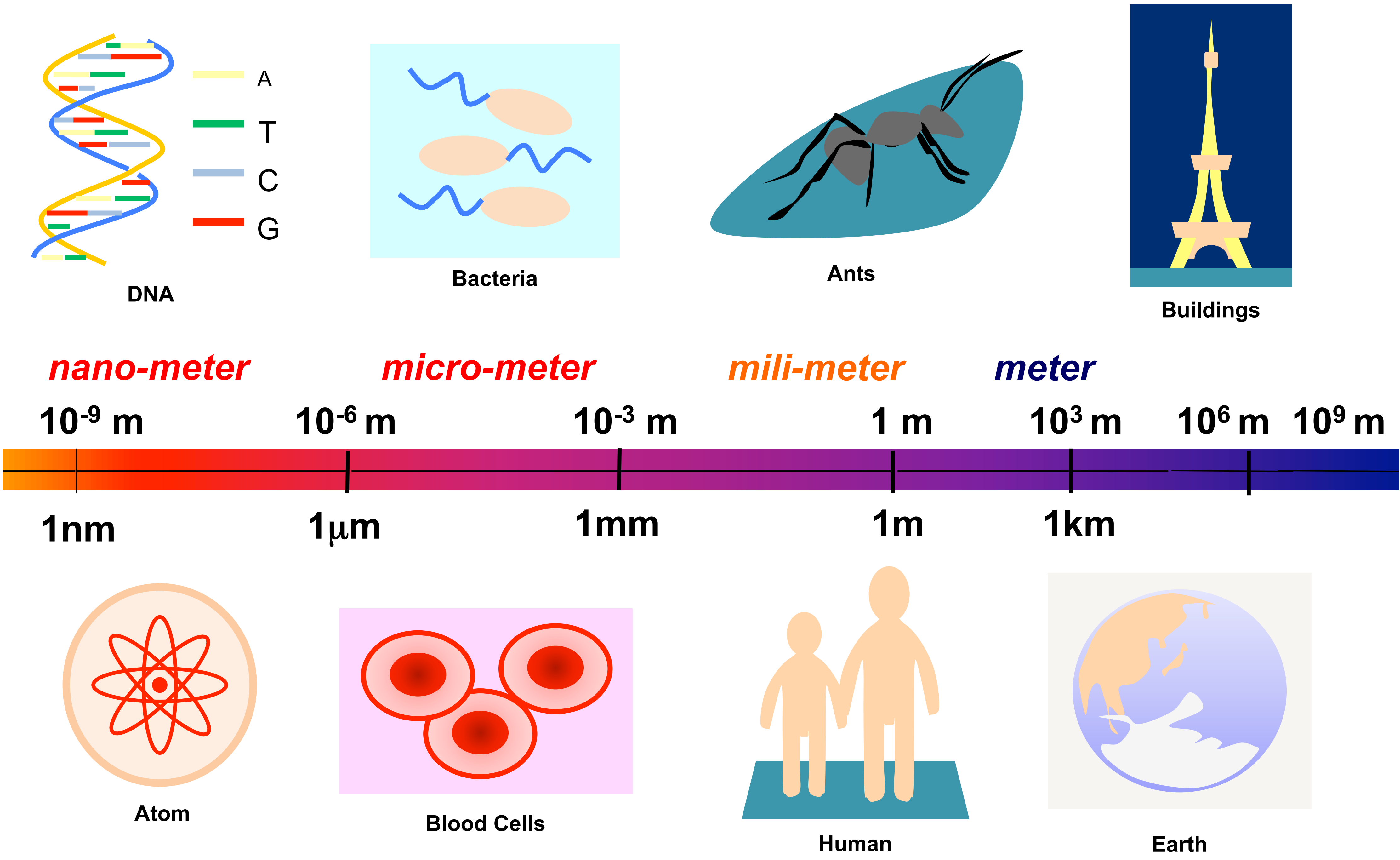
福田敏男 Toshio Fukuda

- President, IEEE Robotics and Automation Society (1998-1999)
- Editor-in-Chief, IEEE/ASME Trans. Mechatronics (2000-2002)
- Director, IEEE Division X, Systems and Control (2001-2002)
- President, Japan Society of Fuzzy Theory and Intelligent Informatics (2003-2005)
- EIC, J. Advanced Computational Intelligence & Intelligent Informatics, J. Micromechatronics, J. Robotics and Mech.
- Founding President, IEEE Nanotechnology Council(2002- 2005)
- Prof. UC Berkeley(2010), Seoul National Univ., CAS IA, BIT, SUT, NCTU, Diakin Univ. , etc.
- Director, IEEE Region 10 (2013-14)

- PhD: 89, Books>= 20: papers>=2,000

鉄腕アトムのロボット学
福田敏男著
集英社 (2003/4/4)

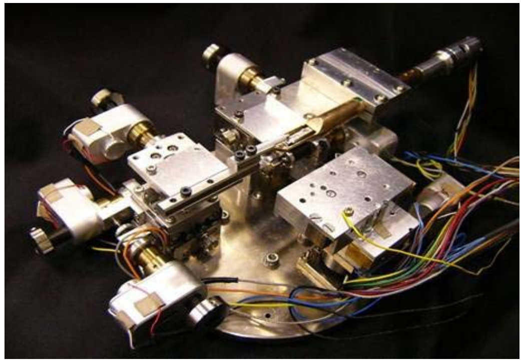
マルチスケール Multi-scale from Macro to Nanometer



福田研究室マルチスケールロボティクス Fukuda Laboratory

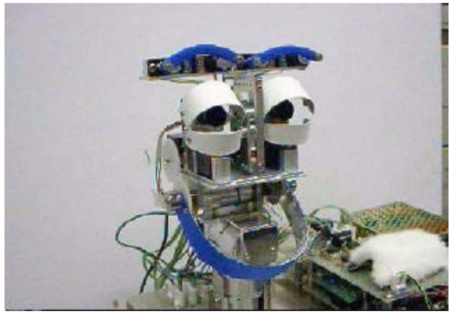
Multi-scale Robotics

nm µm mm cm m



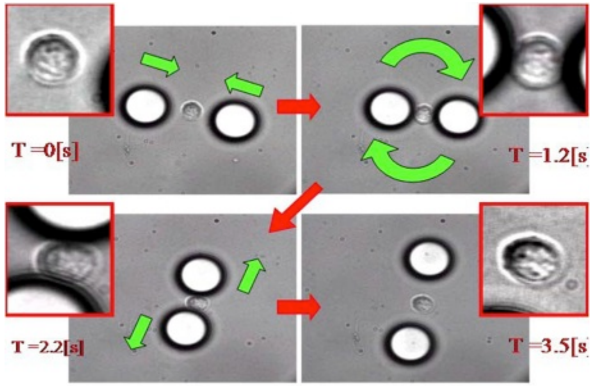
Nanorobotic Manipulation

Catheter Surgery Simulator



Face Robot

Brachiation Robot



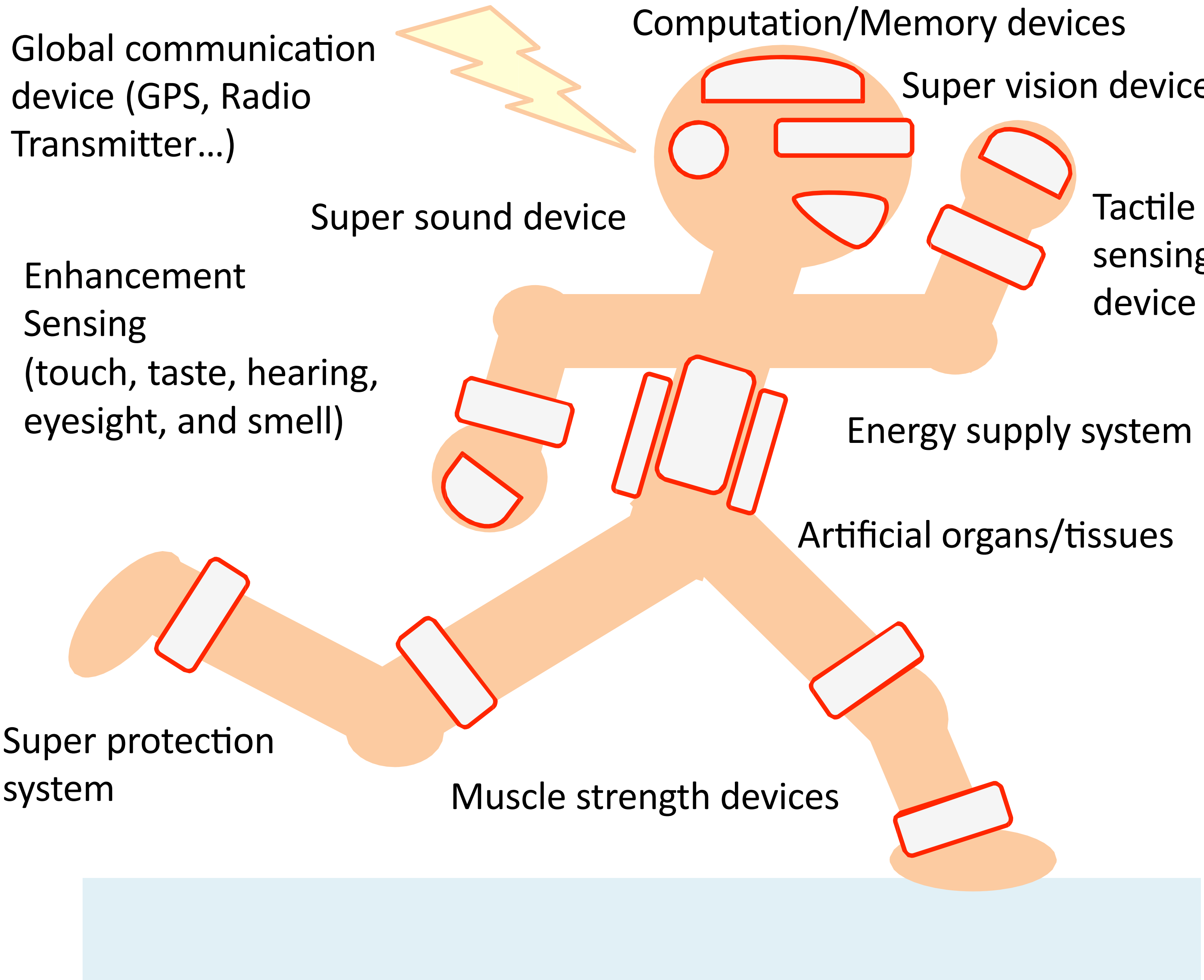
Laser Micro Manipulation

Robotic Manipulation

Multi-mobile Root

Multi-locomotion Robot

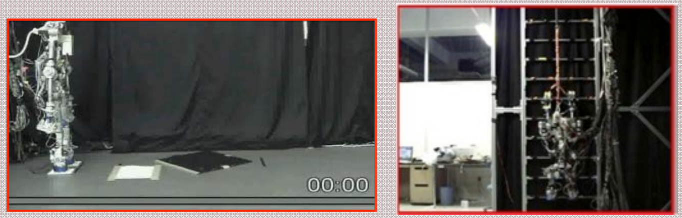
サイボーグのためのデバイス　Devices for Cyborg: Cybernetic organism

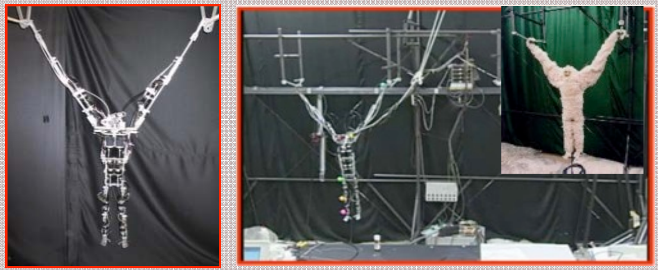


ロボット
（機械）

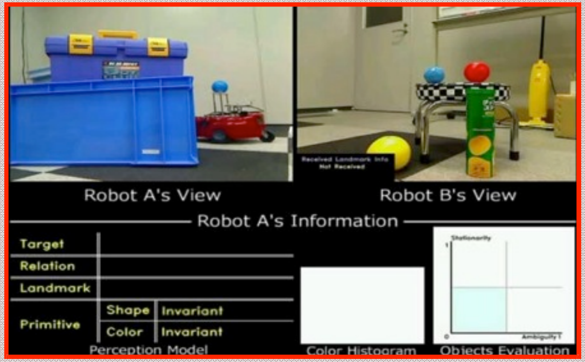
動物
（生物）

マイクロ・ナノ制御工学グループ

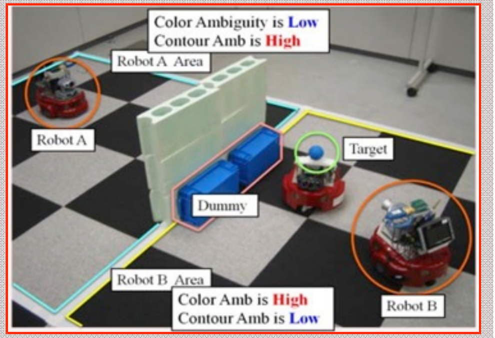




Monkey-type Robot



Multi-task Planning for Multi-robot



Object Tracking Based on Cognitive System

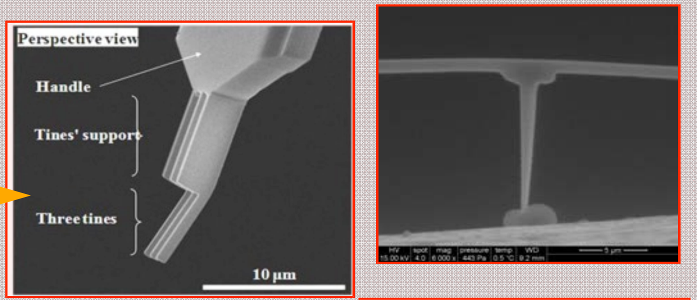
Multi-locomotion Robot

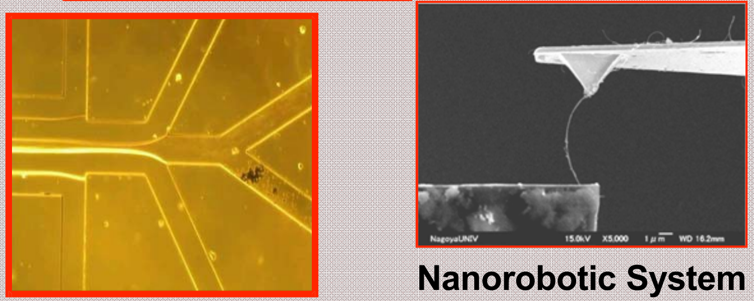
Robotics Human Interface

Micro/Nano Robotic System

Mechatronics

Multi-scale Robotics

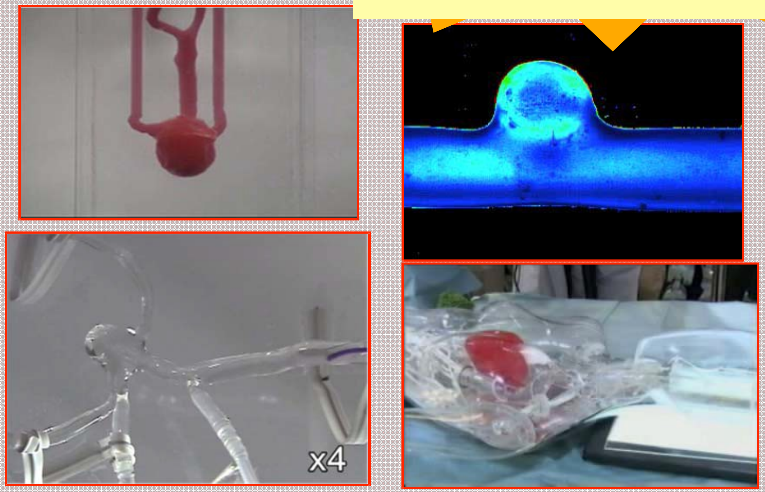




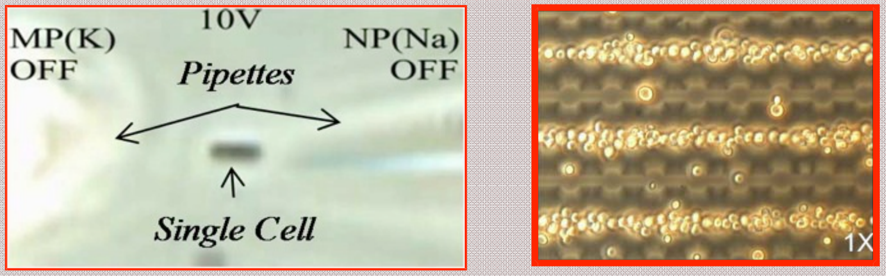
Nanorobotic System

Intelligent Cane

Robot –Human Co-Assembly



Medical Simulator



Single Cell Manipulation/3D Cell Assembly

NHK (Japan)

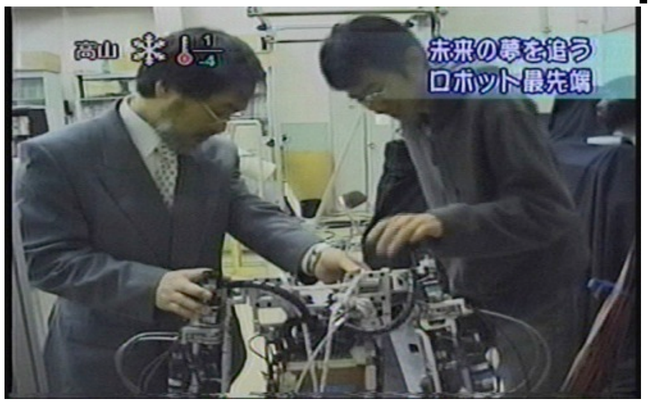
NHK (Japan)

BBC “Robo Monkey” (UK)

社会貢献 Social Activity

KBC “Robot Special” (Korea)

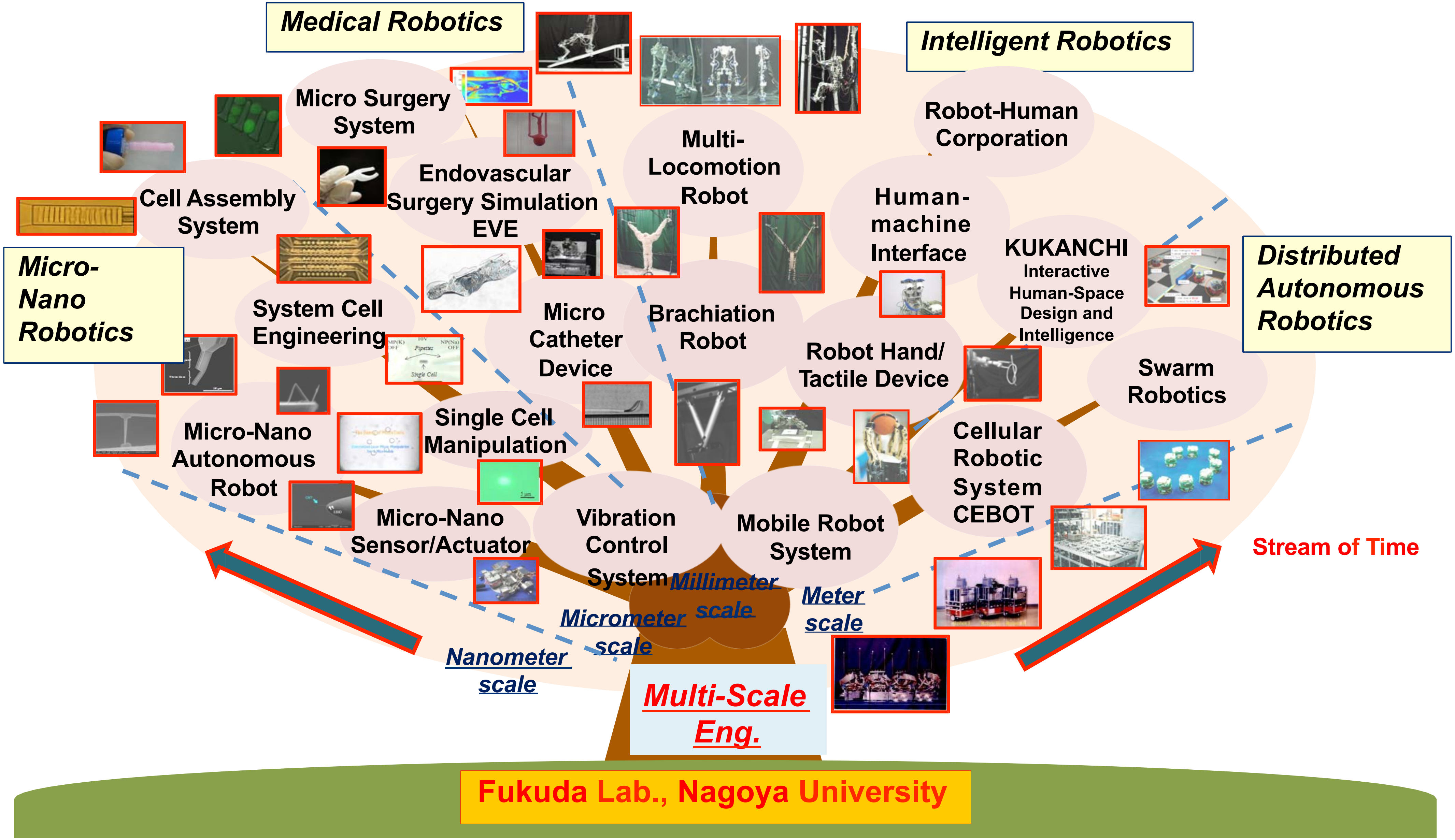
NHK (Japan)



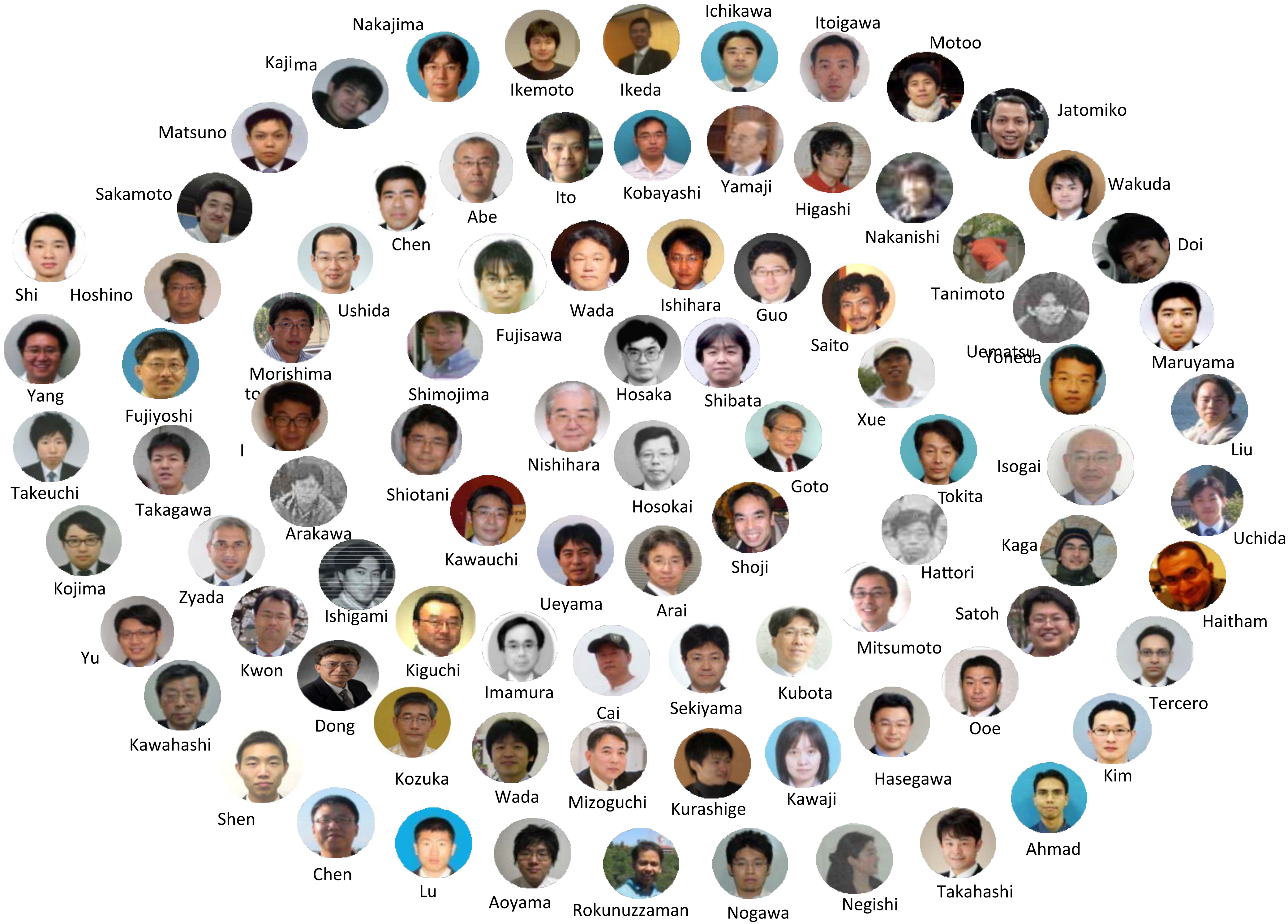
News (Japan)

Live News (Japan)

福田研究室の研究の推移 Research Shift of Fukuda Laboratory



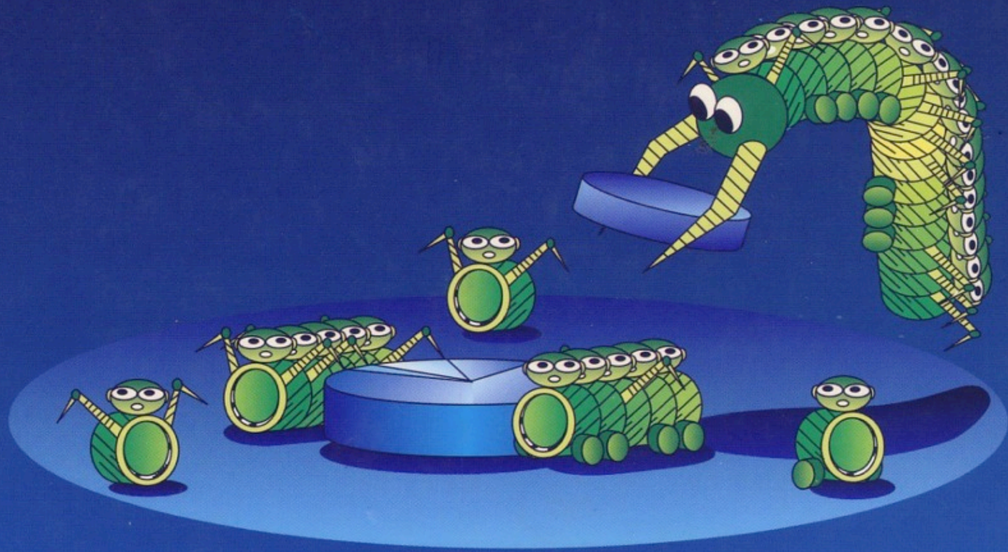
福田研究室の主な研究の進展


Nakajima
Kajima
Ikemoto
Ikeda
Ichikawa
Itoigawa
Motoo
Jatomiko
Matsuno
Sakamoto
Abe
Ito
Kobayashi
Yamaji
Higashi
Wakuda
Nakanishi
Doi
Chen
Shi
Hoshino
Ushida
Fujisawa
Wada
Ishihara
Guo
Saito
Tanimoto
Maruyama
Yang
Fujiyoshi
Morishima
to
Shimojima
Hosaka
Shibata
Xue
Uematsu
Yoneda
Liu
I
Takeuchi
Takagawa
Arakawa
Shiotani
Nishihara
Hosokai
Goto
Tokita
Isogai
Uchida
Kawauchi
Shoji
Hattori
Kaga
Kojima
Zyada
Ishigami
Ueyama
Arai
Haitham
Satoh
Mitsumoto
Yu
Kwon
Kiguchi
Imamura
Cai
Sekiyama
Kubota
Tercero
Ooe
Dong
Kawahashi
Kozuka
Wada
Mizoguchi
Kurashige
Kawaji
Hasegawa
Kim
Shen
Ahmad
Chen
Lu
Aoyama
Rokunuzzaman
Nogawa
Negishi
Takahashi

World Scientific Series in Robotics and Automated Systems – Vol. 10

CELLULAR ROBOTICS AND MICRO ROBOTIC SYSTEMS

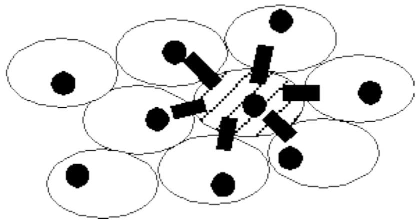
T FUKUDA & T UEYAMA



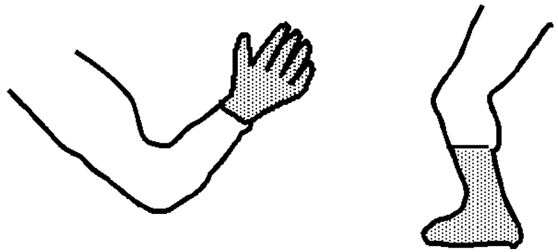
1994

World Scientific

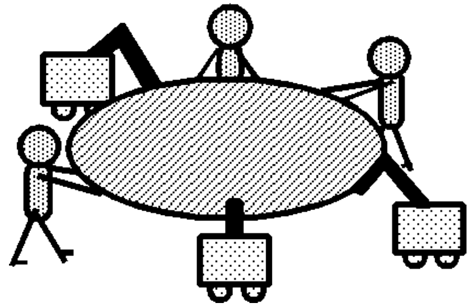
マン-マシン共生 Human Machine Symbiosis



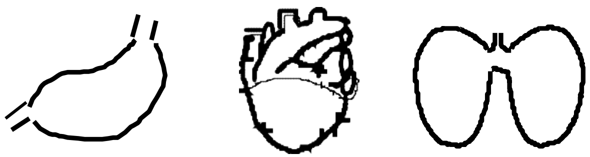
1. Cell Level



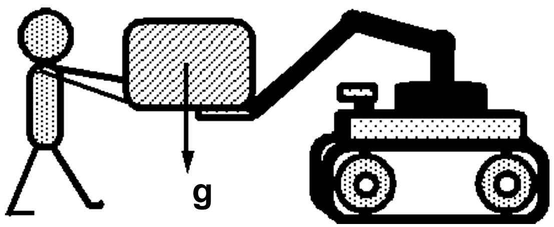
3. Human and Unit Level



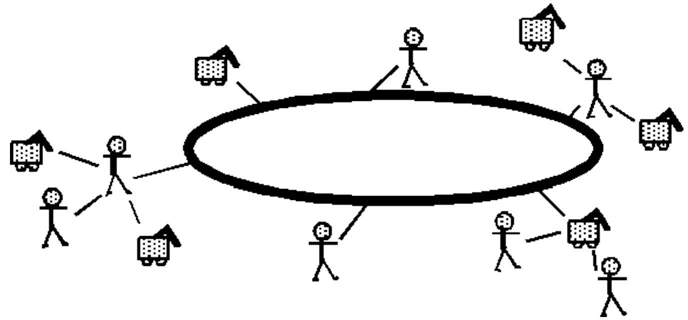
5. “Multi" human and Individual Level



2. Organic Device Level

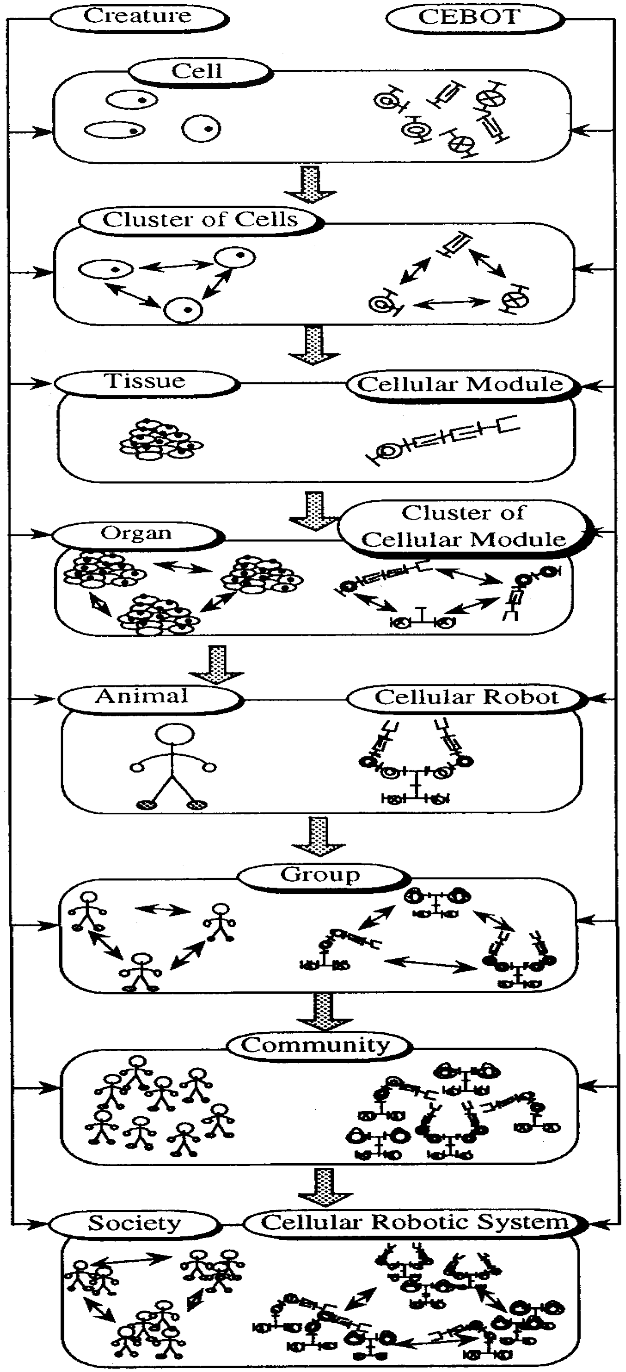


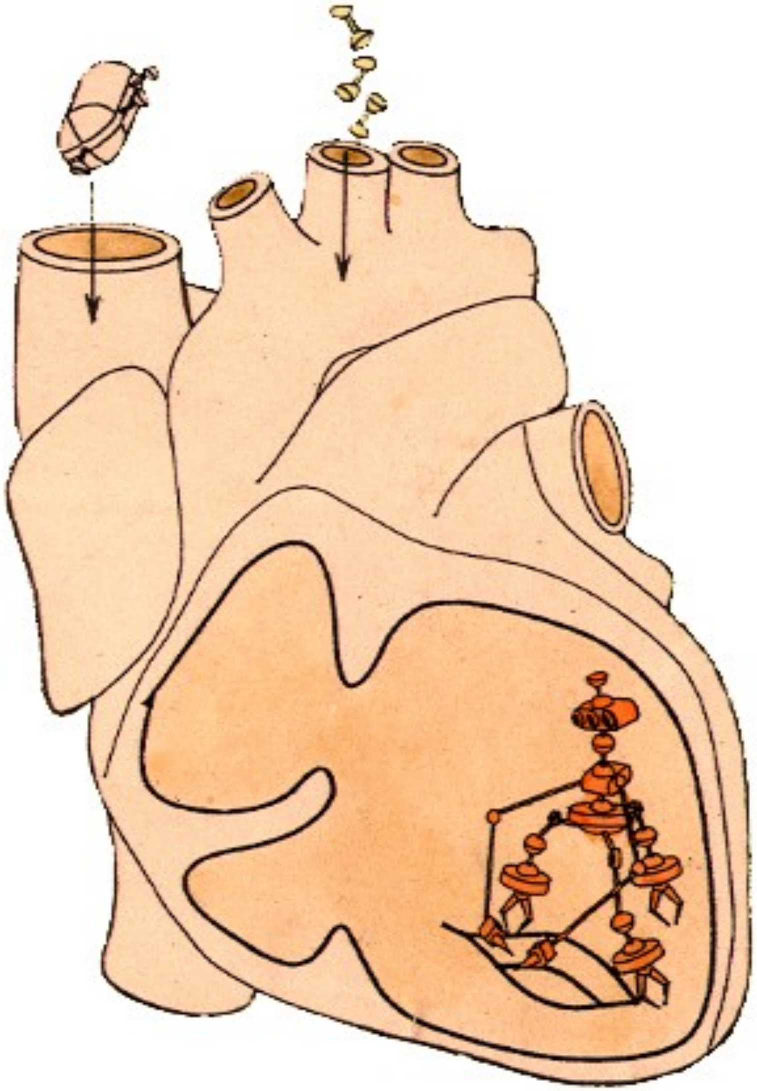
4. Human and Individual Level



6. Network Level

マルチスケールロボティクス　Multi-scale Robotics

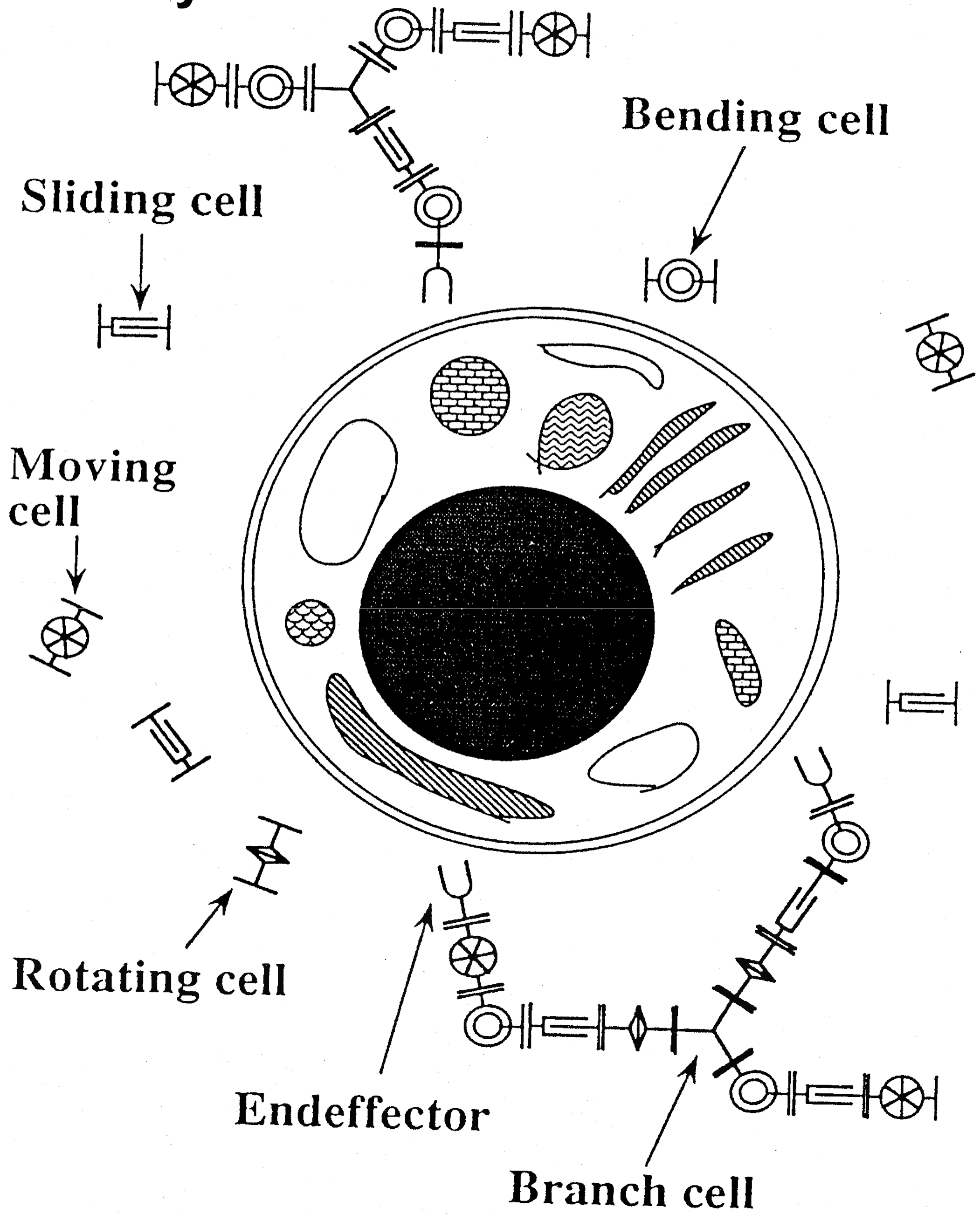




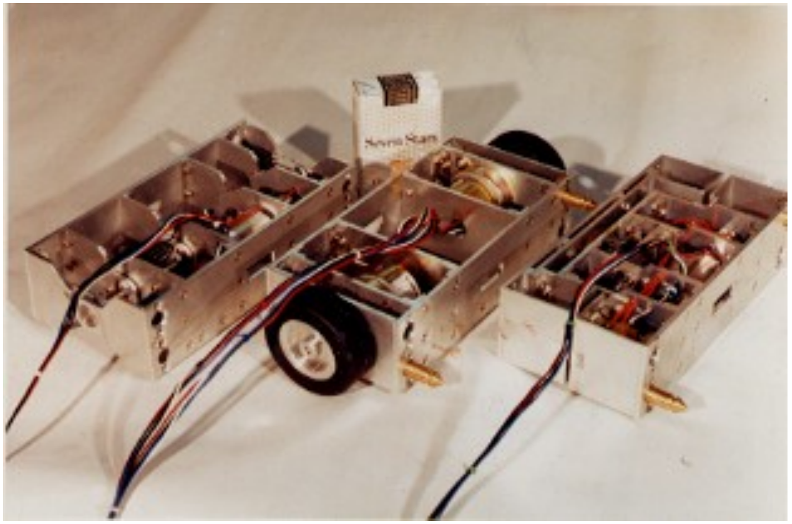
Multi-scale Robotics

セル構造化ロボット　Concept of CEBOT

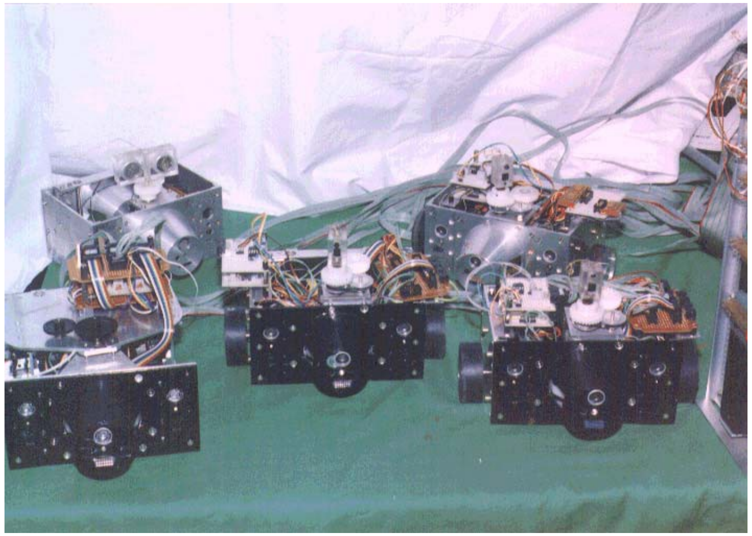
CEBOT: Cellular robotic system



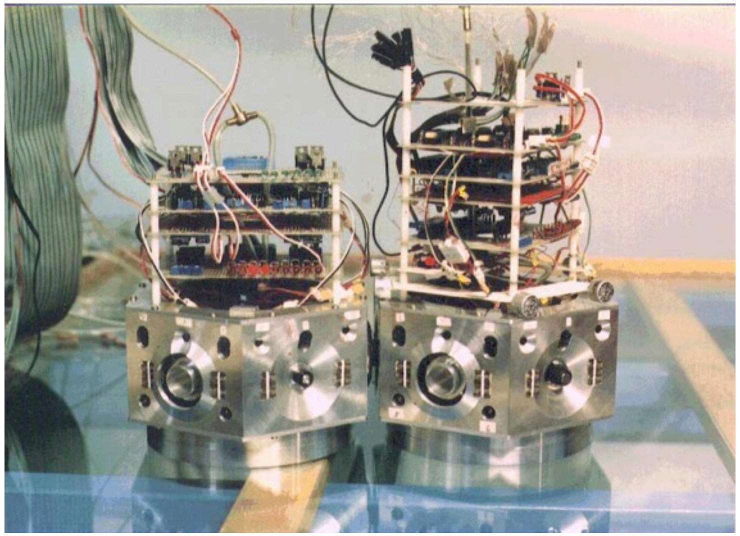
セル構造化ロボット研究　Research on CEBOT



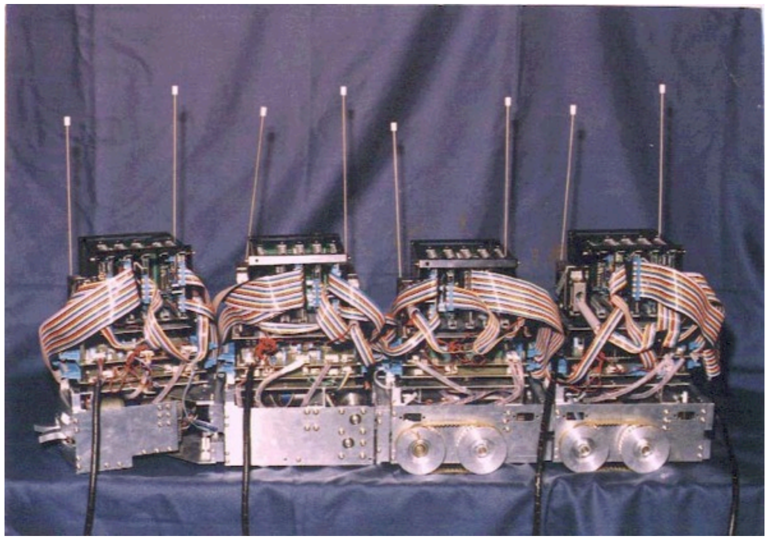
CEBOT mark I (1985)



CEBOT mark II (1988)

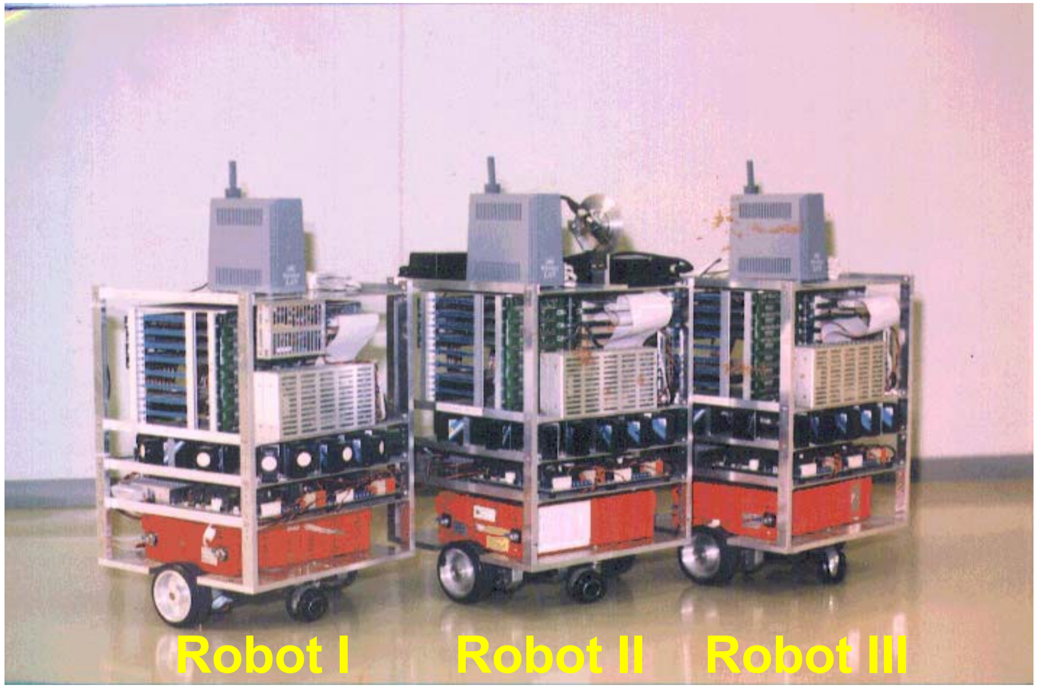


CEBOT mark III (1989)



CEBOT mark IV (1992)

セル構造化ロボット研究 Research on CEBOT



CEBOT mark V (1995)

Computer
- CPU : M68040
- OS : VxWorks (RTOS)
- Bus : VME

Communication
- Wireless LAN
  - Frequency 2471-2497MHz
  - Speed 2Mbps
  - Distance up to 60m

Sensor
- CCD camera (Robot II)
- Ultra sonic (Robot I)
- Infrared (Robot II, III)

Others
- DC motor x 2
- Battery (12V x 2)

自律分散ロボットシステム
Work on Distributed Autonomous Robotic Systems

- Coupling mechanisms

- Structure reconfiguration methods

- Distributed sensing and cooperative navigation

-Swarm Intelligence

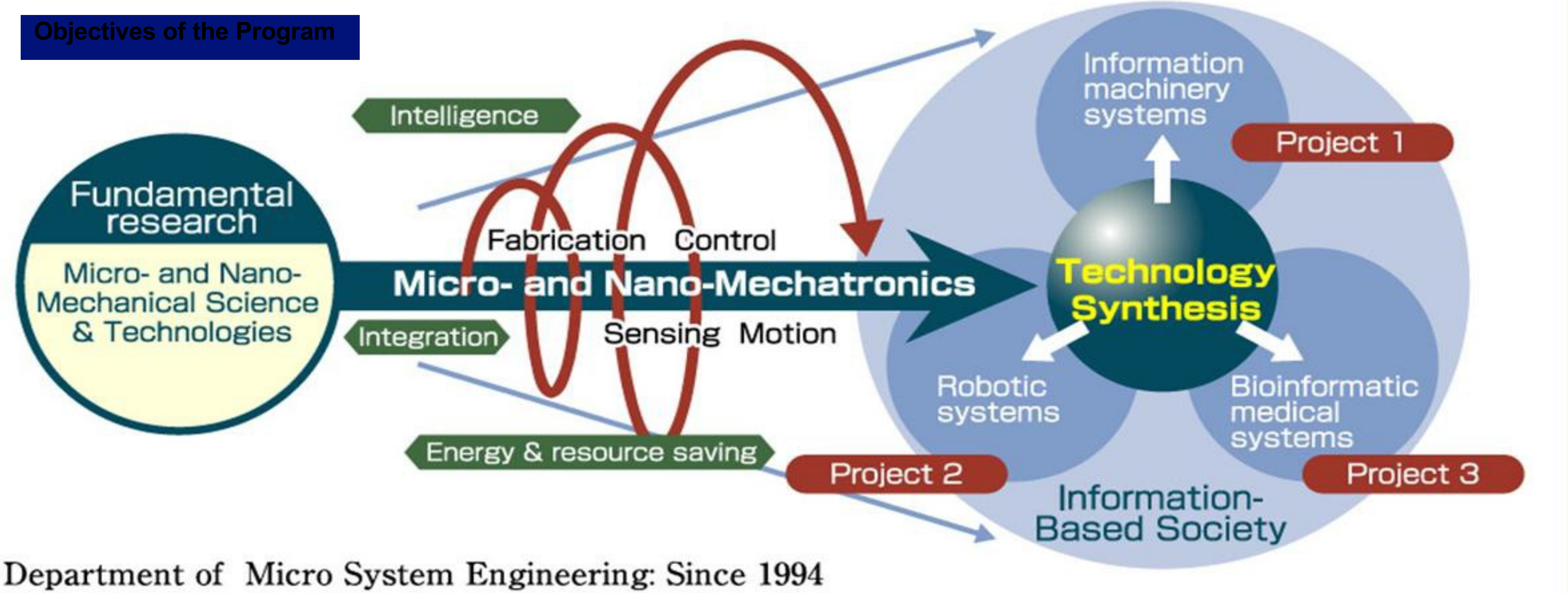
-Micro Autonomous Robotic System (MARS)

CEBOT mark V and Mobile manipulator

Flexible Transfer System(FTS)

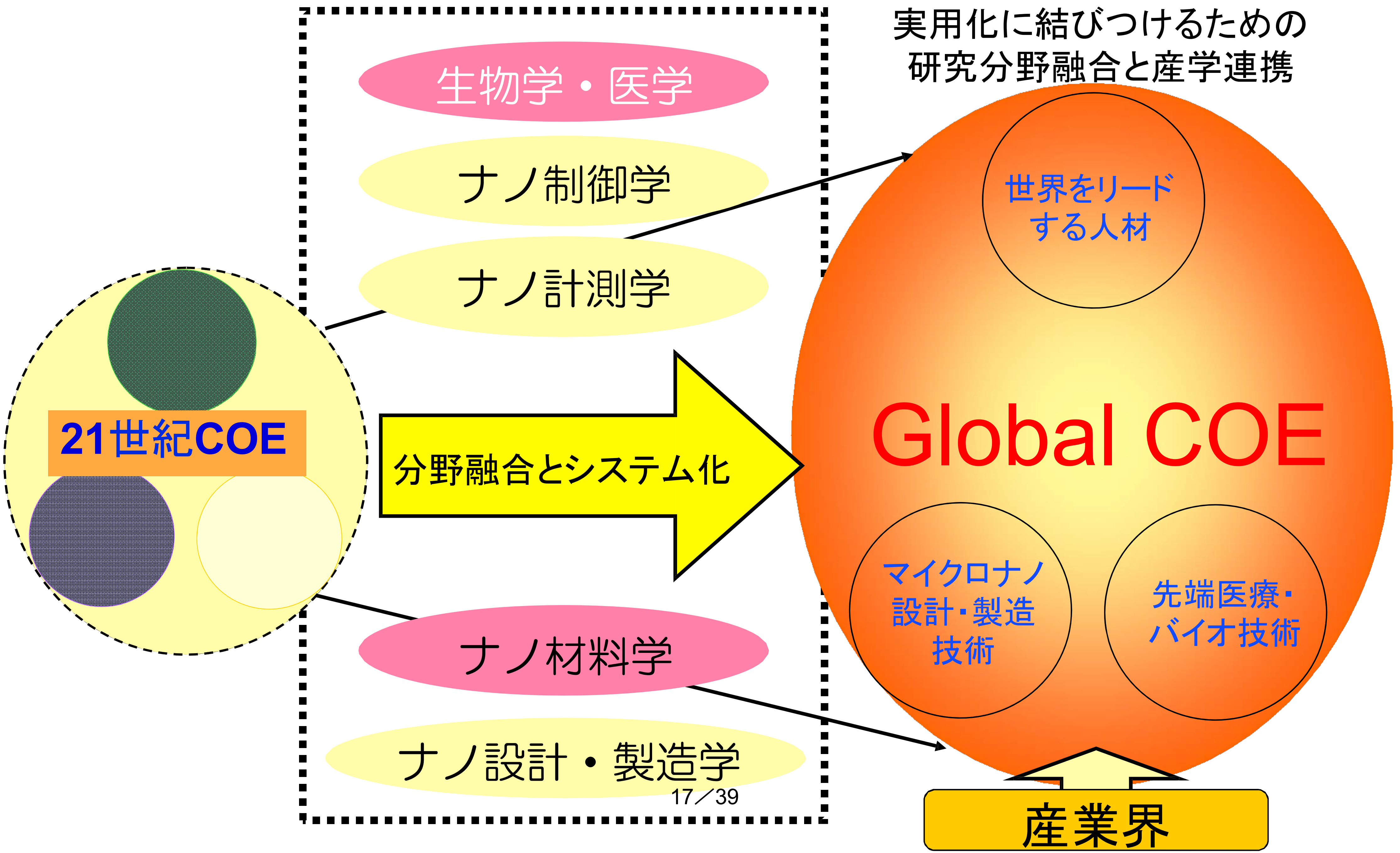
21世紀COEプログラム（2003-2008）

Micro-Nano　Mechatronics for Information-Based Society



We aim to deepen the understanding of the nano-mechanical science (nano sciences in mechanical engineering) and, by combining micro-nano-mechatronics technologies, we will develop systems technology that will become the next generation infrastructure of an advanced information-based society. We will provide seamless support to further research and education in order to establish novel technologies that will apply nano technology to actual devices and systems, especially using mechanical engineering approaches.

グローバルCOEプログラム GCOE Program (2008-2013.3)



GCOEの組織　GCOE Organization

Basic research

Nano control engineering

UCLA

T. Fukuda　G. Obinata　F. Arai　C.-M. Ho

Nano measurement engineering

T. Niimi　K. Fukuzawa　Y. Ju　I. Naruse

Nano design and manufacturing

K. Sato　E. Shamoto　N. Umehara　A. Sasoh

Nano materials science

O. Takai　N. Ono　M. Okido

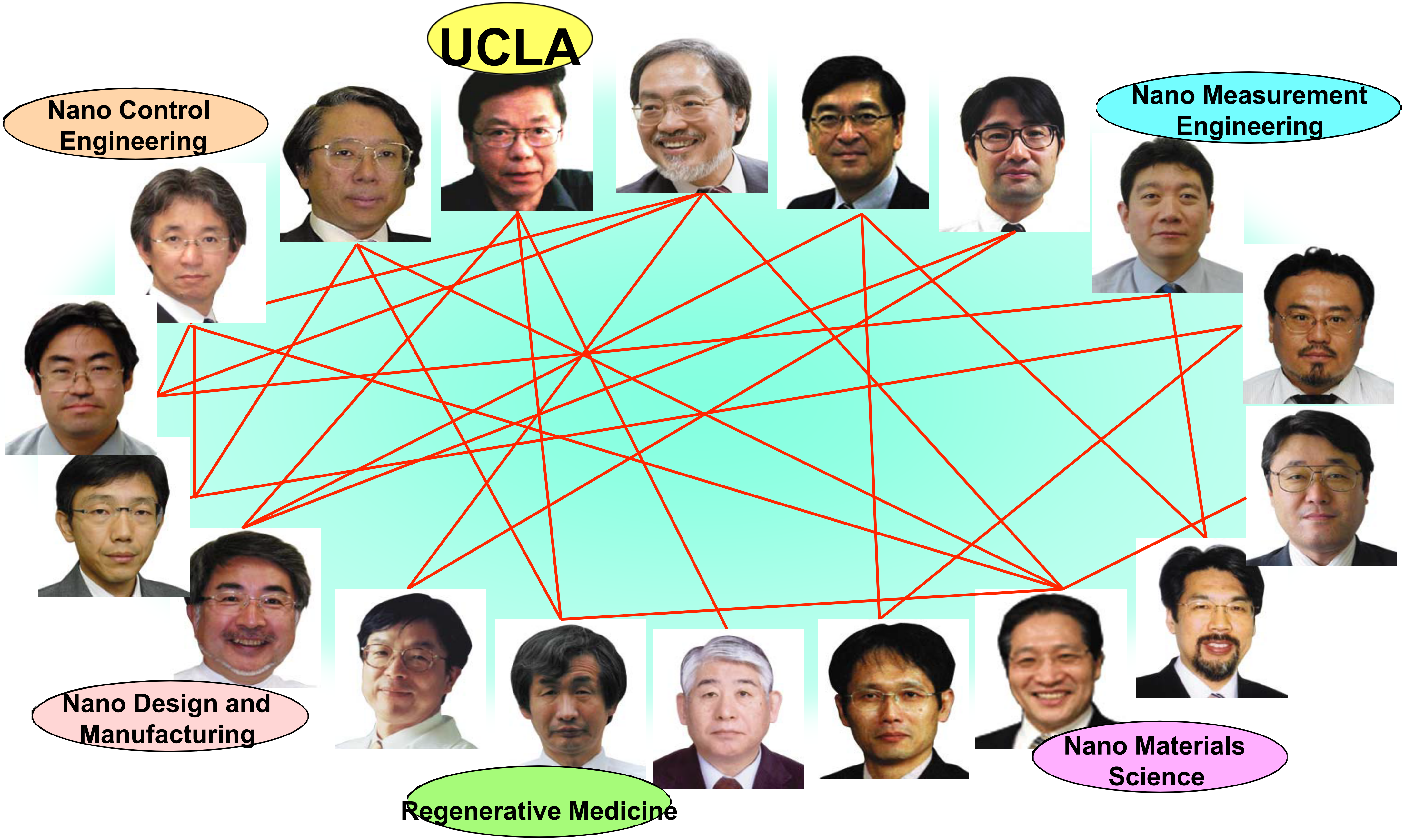
Applied research

Advanced bio/medical technology

M. Ueda　K. Isobe　J. Usukura

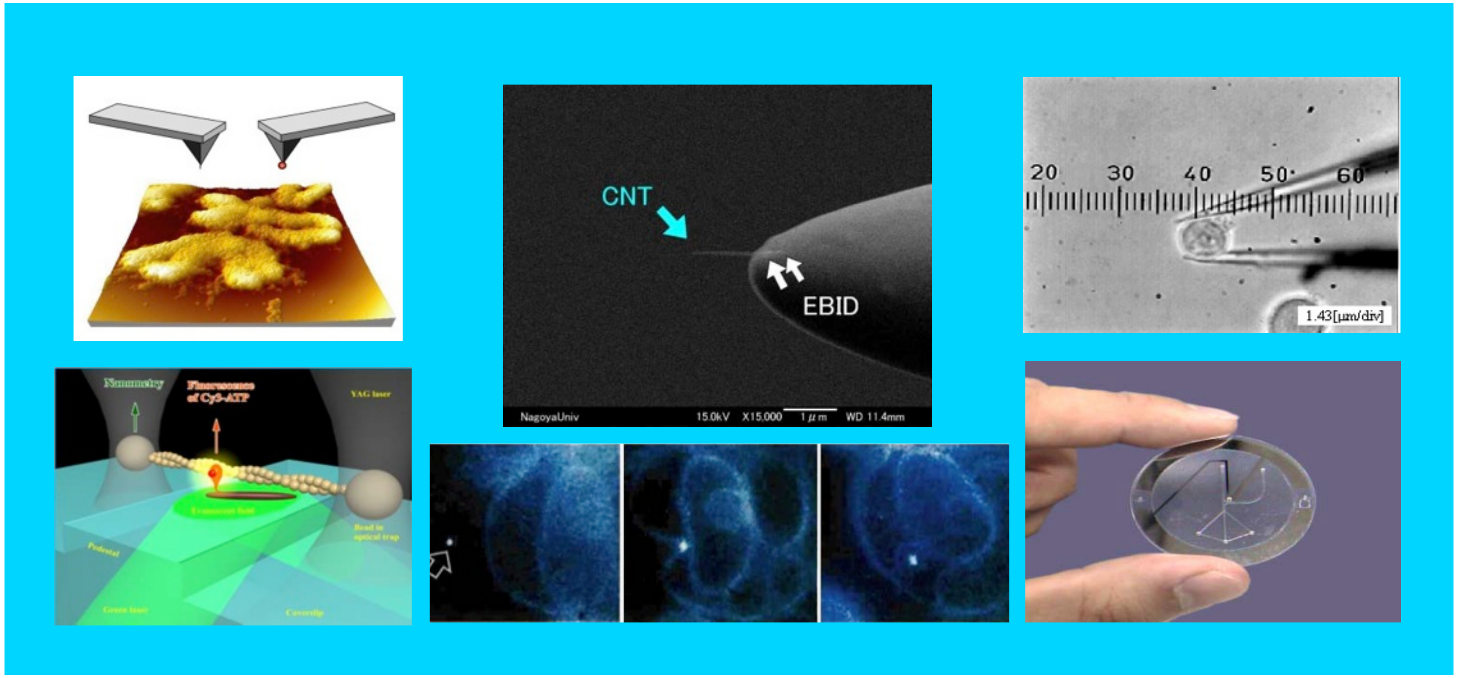
School of medicine

研究者の連携　Collaboration network between members



科学研究費補助金「特定領域研究」
平成17年度発足特定領域
（2005-2009）
申請領域名

マルチスケール操作によるシステム細胞工学



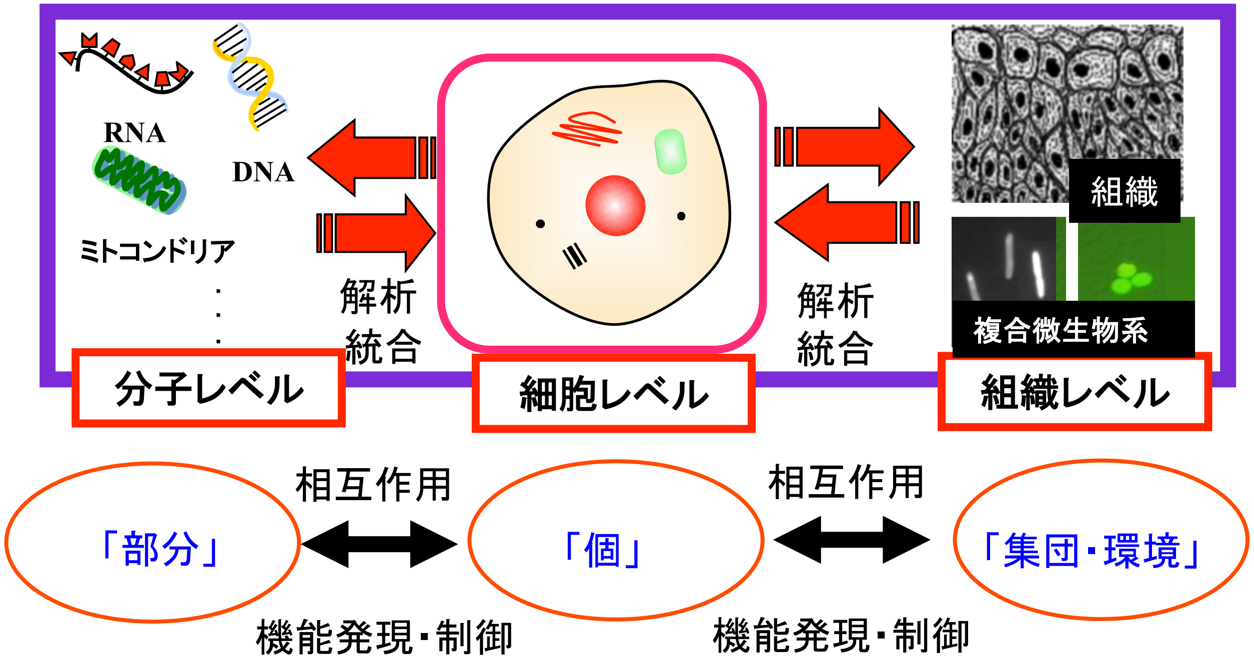
申請代表者

名古屋大学大学院工学研究科／高等研究院

教授・福田 敏男

http://www.chem.scphys.kyoto-u.ac.jp/nonnonWWW/bio/index-j.html

本領域のねらい



「システム細胞工学」

工学技術を基盤として細胞機能の統合的理解を目指す新しい学問領域

1. システム細胞工学を創成する.

2. 細胞を構成する要素の素機能および構成要素の統合機能，制御様式を解明する.

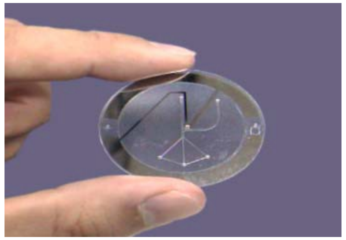
3. 細胞機能を模倣したり，機能を制御するための基礎研究を行う.

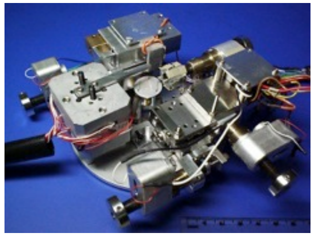
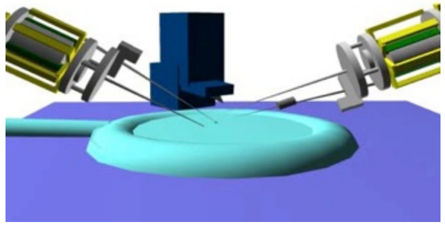
特定領域研究　マルチスケール操作によるシステム細胞工学　成果報告書
http://www.mext.go.jp/a_menu/shinkou/hojyo/chukan-jigohyouka/1301312.htm

本領域の特色：研究体制

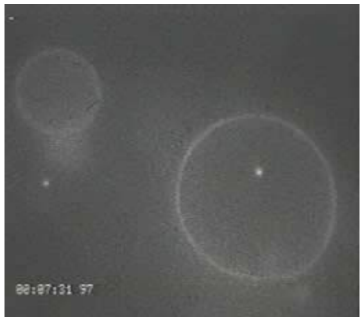
工　学（制御班）

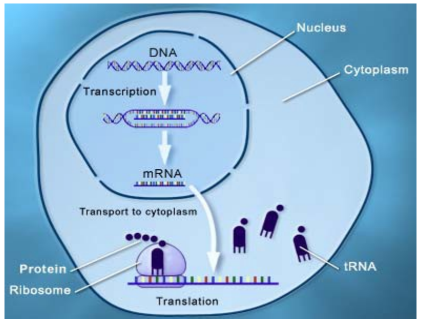
ナノデバイス


バイオチップ



ナノ・マイクロマニピュレータ

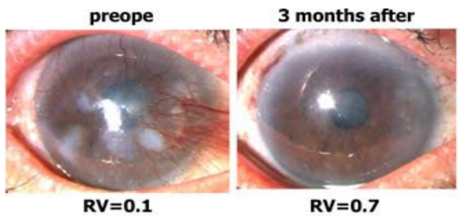
バイオ（再構成班）


リポソーム



蛋白質合成

メディカル（組織班）

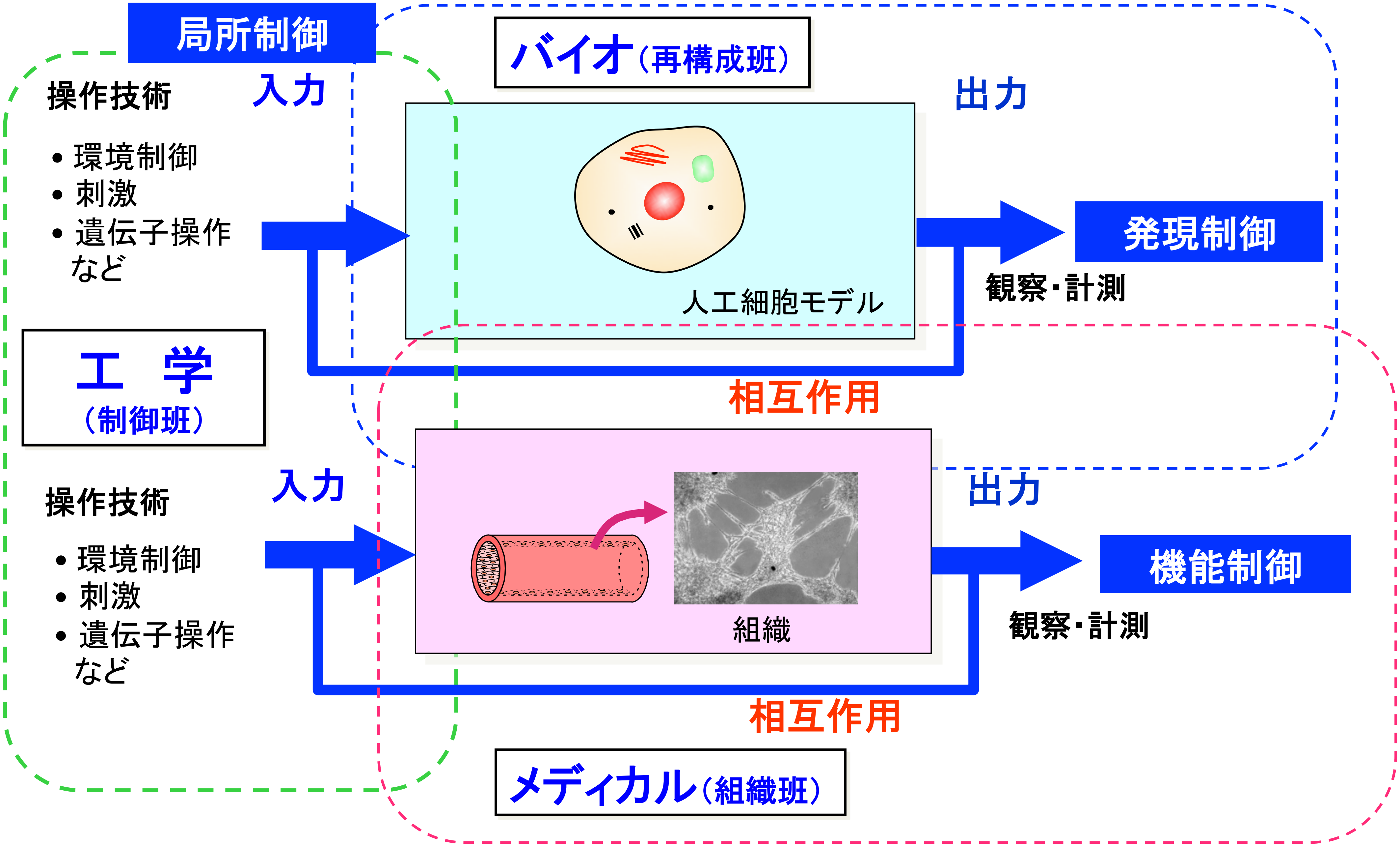


角膜再生

テーラード血管モデル

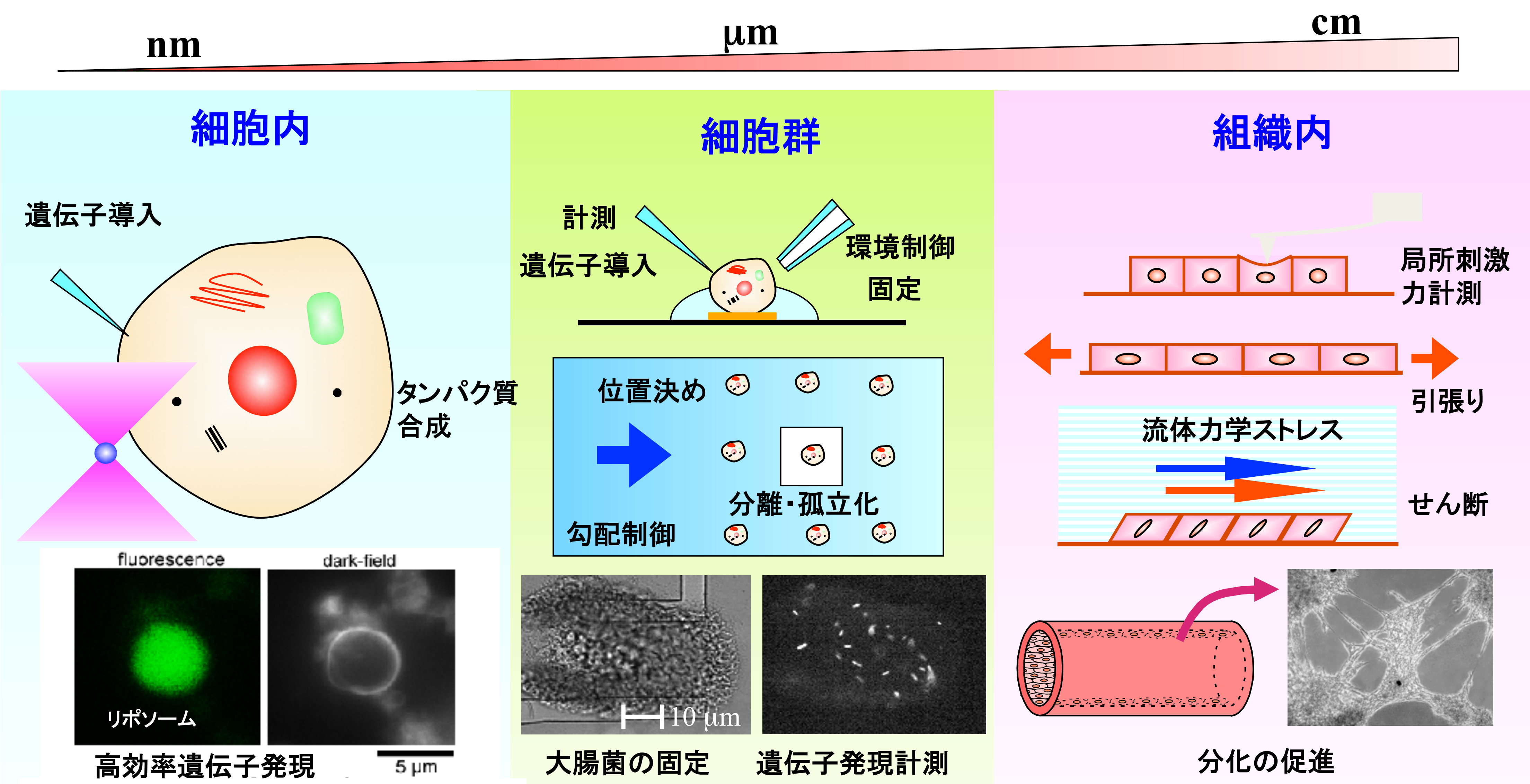
工学を中心とした横断的研究

基盤技術の分担と融合



特定領域研究　マルチスケール操作によるシステム細胞工学　成果報告書
http://www.mext.go.jp/a_menu/shinkou/hojyo/chukan-jigohyouka/1301312.htm

工学に基づく基盤技術



無細胞発現系の構築
1. 発現制御

遺伝子の発現計測と制御
2. 局所制御

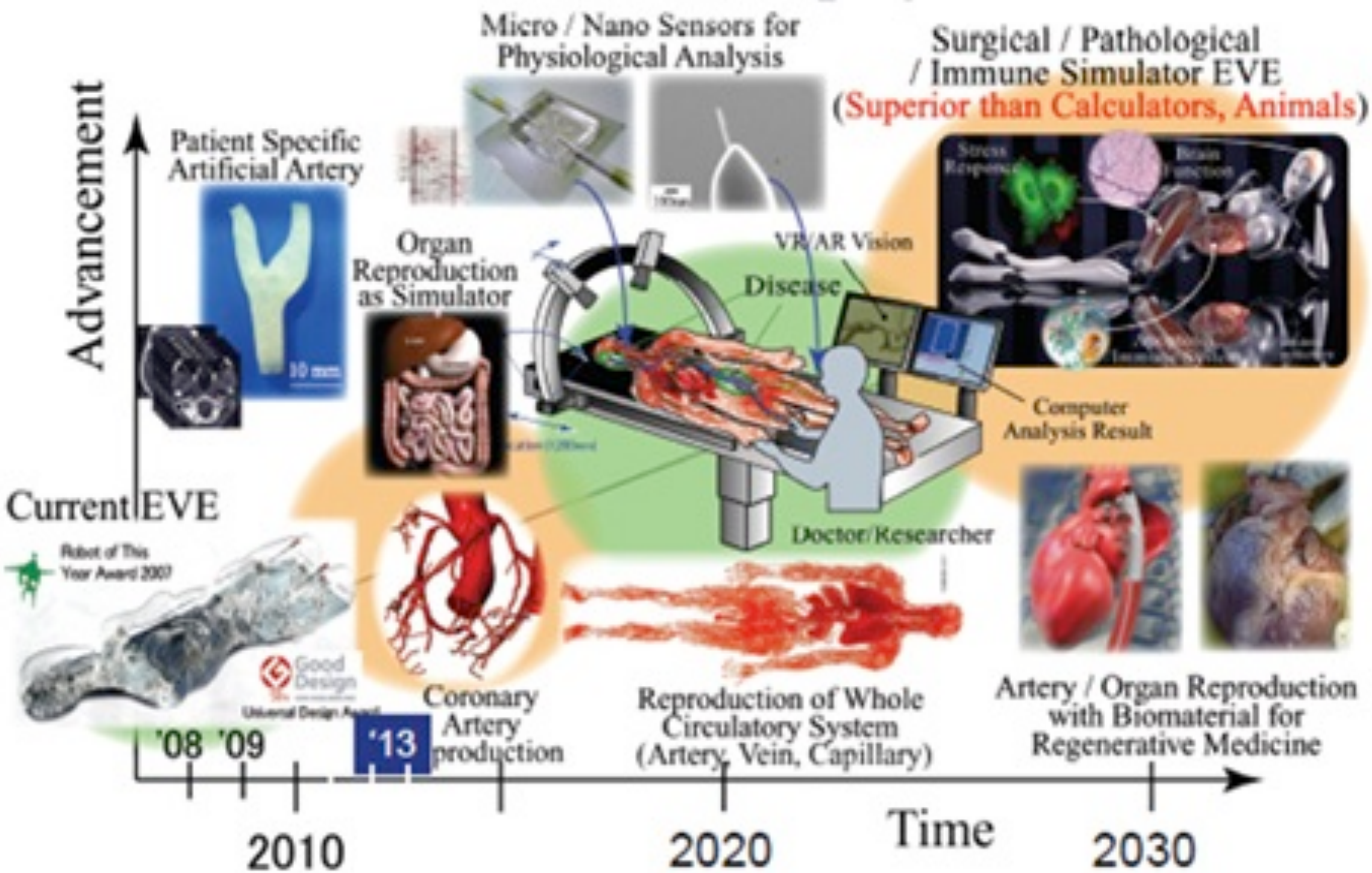
細胞形態・分化誘導
3. 機能制御

特定領域研究　マルチスケール操作によるシステム細胞工学　成果報告書
http://www.mext.go.jp/a_menu/shinkou/hojyo/chukan-jigohyouka/1301312.htm

Future Goal/Direction (Example)

In vitro simulator of In vivo environment

Super-simulator



http://www.micro-nano.jp/en/project.html

福田研究室の研究領域
Research Works of Fukuda Lab

Multi-scale Robotics

m

- Multi-locomotion Robots
- Multi-mobile-robot Corporation

cm

- Interface Robotics
- Grasping, Tactile Sensing

mm

- Medical Robotics -Vascular Model and Scaffold-

µm

- Bio-micro Manipulation for Single Cell Manipulation

nm

- Nanodevice/Nanomanipulation

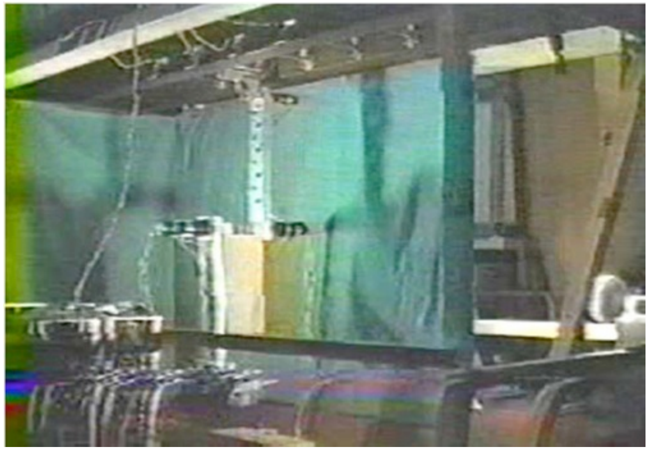
ブラキエーションロボット　Brachiator I~III

What is brachiation?

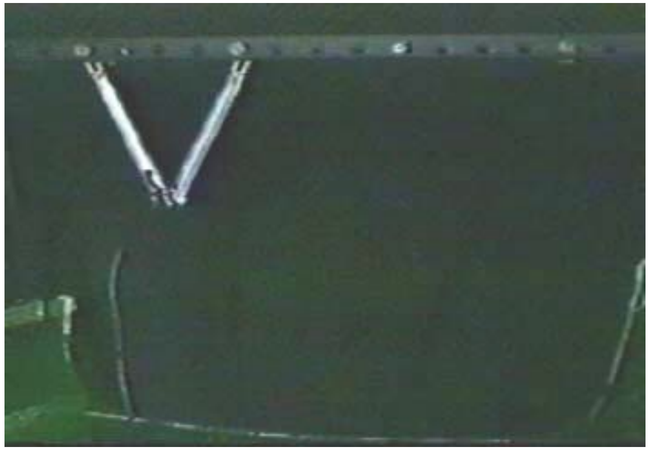
:A interesting form of long-armed apes' locomotion

- **Dynamics of the pendulum**
- **Under-actuated mechanical system**
- **Variable constraint system**

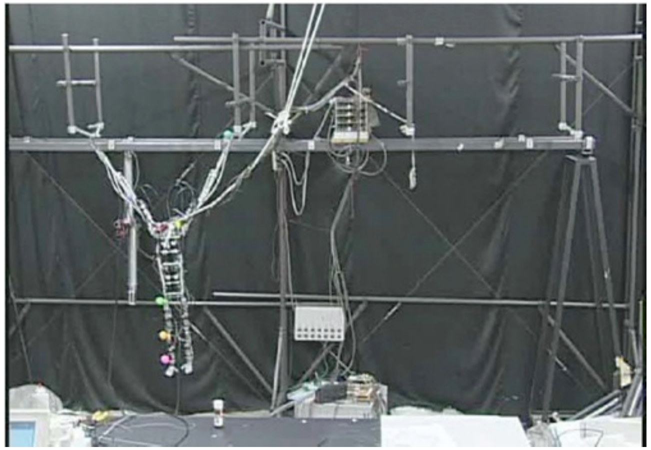
Brachiation



Brachiator
Fukuda et al. (1986)



Brachiator II
Saito et al. (1993)

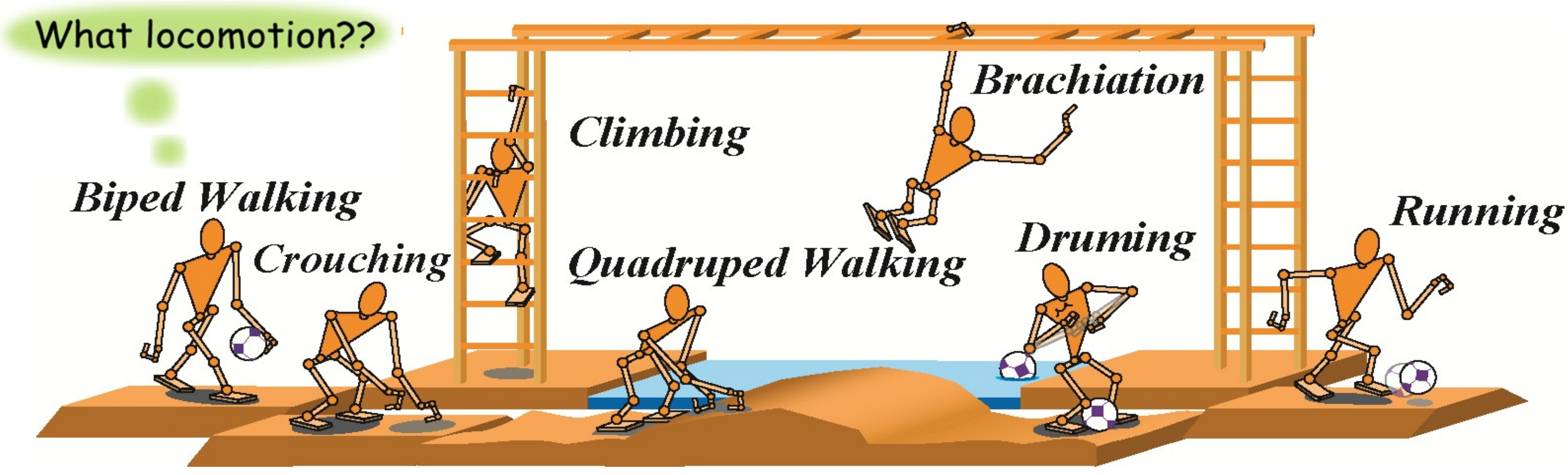


Brachiator III
Saito et al. (1996)

マルチロコモーションロボット
Multi-Locomotion Types

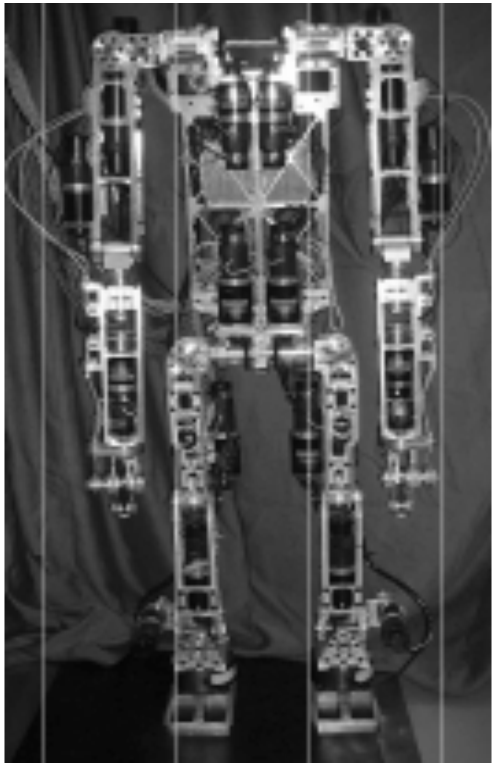
■**In many cases, one creature has multiple types of locomotion in order to improve its mobility.**

■**The motivation of our study is to develop a robot mechanism and a control architecture which can achieve multiple locomotion.**

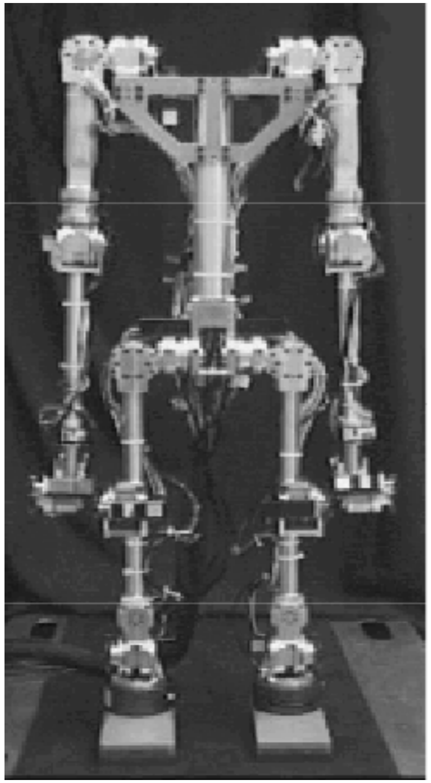


Concept of Multi-Locomotion Robot(MLR)

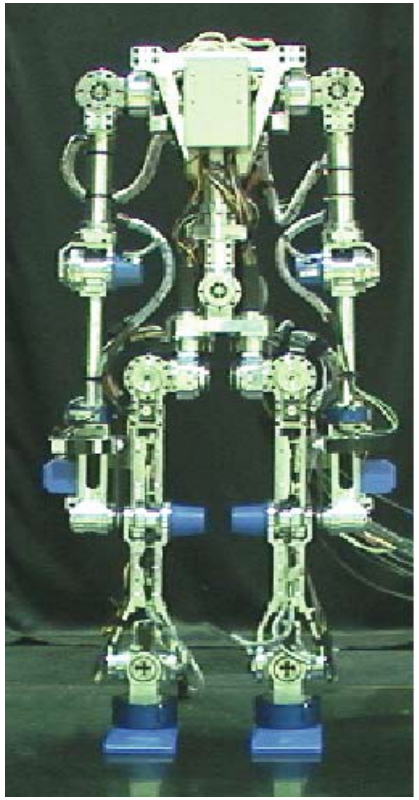
マルチロコモーションロボットの推移
Prototype of the Multi-locomotion Robot



Gorilla Robot I
(2000)



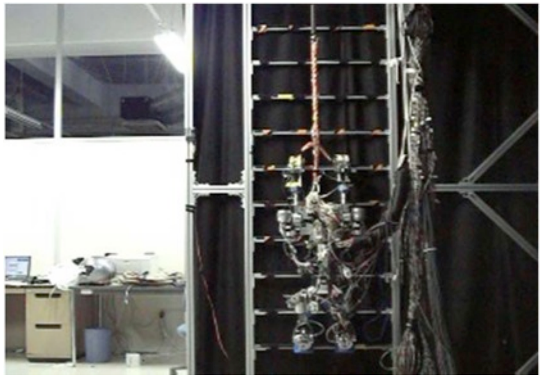
Gorilla Robot II
(2001)



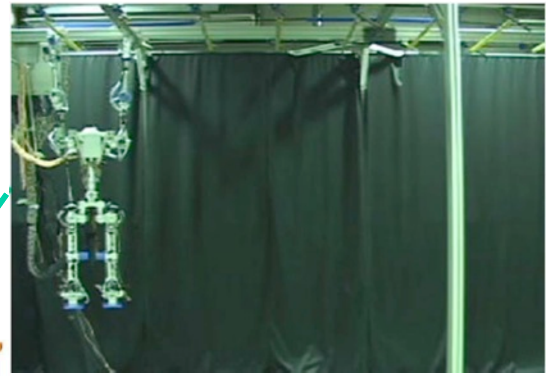
Gorilla Robot III
(2002)

マルチロコモーションロボット
Realization of Multi-locomotion

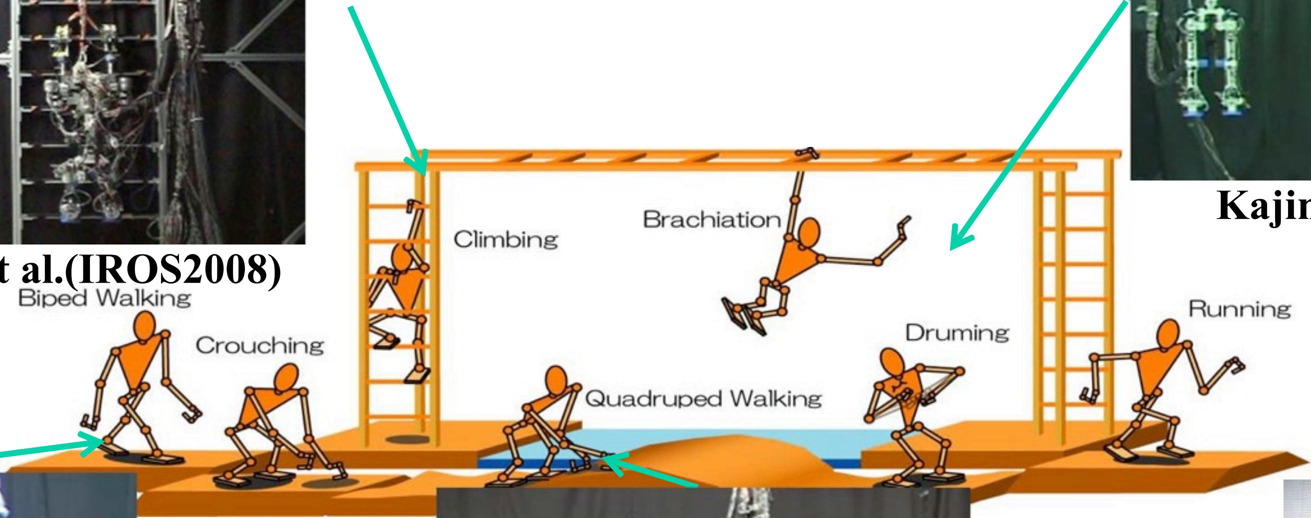
- **In many cases, one creature has multiple types of locomotion in order to improve its mobility.**
- **The motivation of our study is to develop a robot mechanism and a control architecture which can achieve multiple locomotion.**

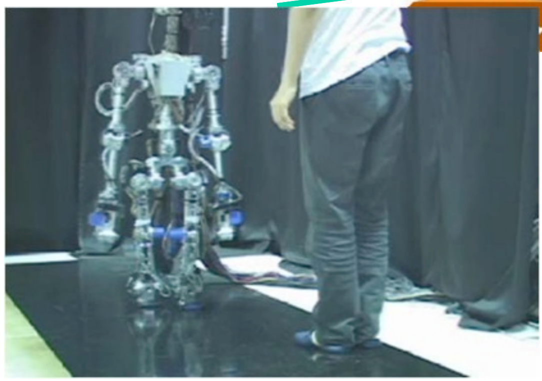


Yoneda et al.(IROS2008)

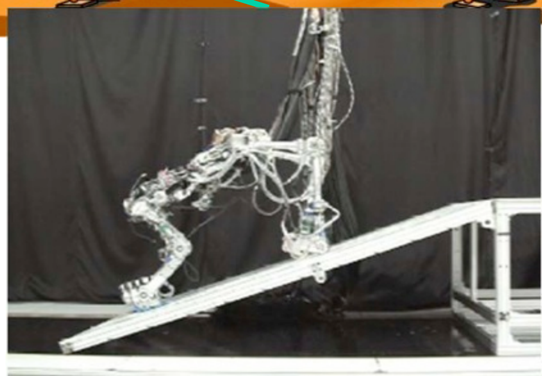


Kajima et al.(IROS2003)





Doi et al.(ICRA2004)



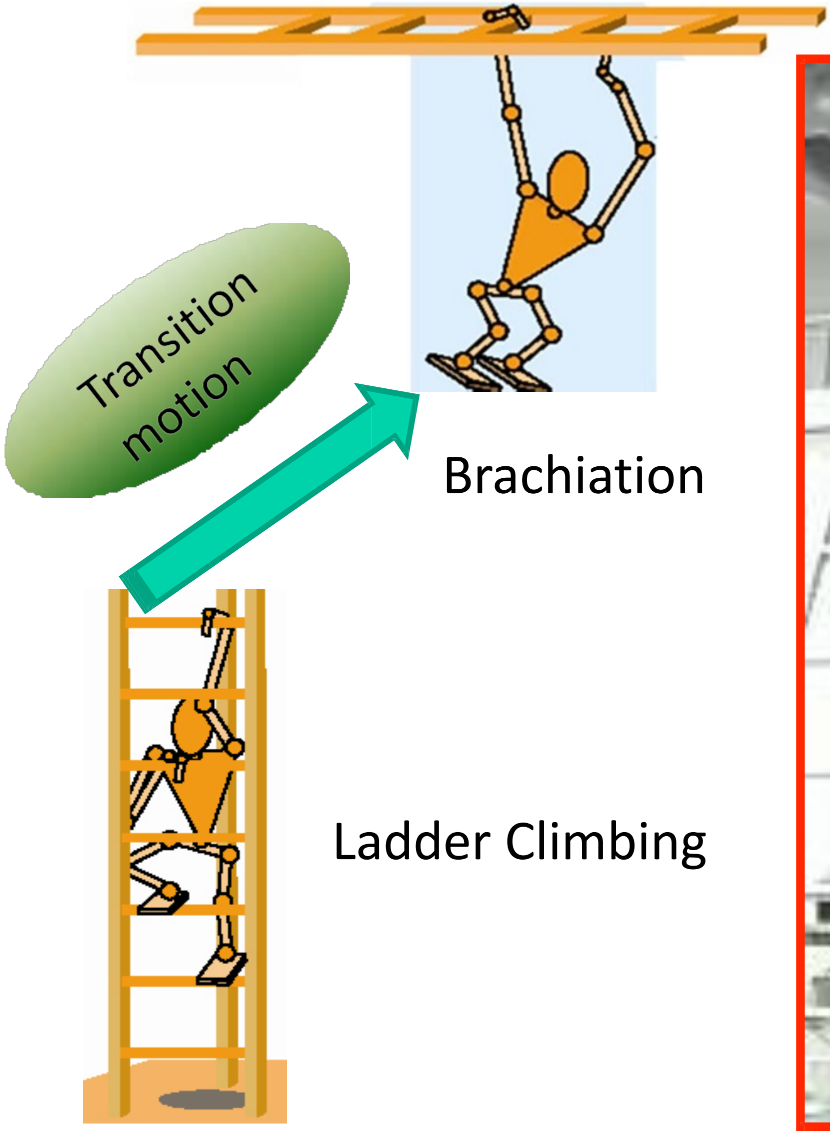
Aoyama et al.(IROS2008)

Lu et al.(IROS2010)

Multi-locomotion Robotics Systems; Fukuda *et al.*; ISBN:978-3642301346

Experimental Video

-from Ladder Climbing to Brachiation



Z. Lu et al., Proc. in Int. Conf. Int. Robots and Systems 2010 (IROS 2010)

Multi-Locomotion Robotic Systems

New Concepts of Bio-inspired Robotics

Toshio Fukuda, Yasuhisa Hasegawa,
Kosuke Sekiyama, Tadayoshi Aoyama

Springer

ISBN 978-3-642-30134-6, May 2012

福田研究室の研究領域
Research Works of Fukuda Lab

Multi-scale Robotics

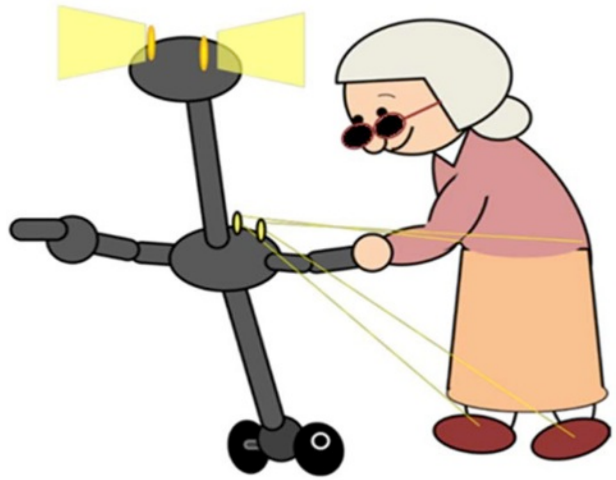
m	• Multi-locomotion Robots
	• Multi-mobile-robot Corporation
cm	• Interface Robotics
	• Grasping, Tactile Sensing
mm	• Medical Robotics -Vascular Model and Scaffold-
µm	• Bio-micro Manipulation for Single Cell Manipulation
nm	• Nanodevice/Nanomanipulation

ケインロボット Cane Robot

- Assistant Functions and Objects
  - Help the elders walking in daily life
  - Assist the patients for recovering the motion function
  - To guide the user for walking and avoiding the obstacles

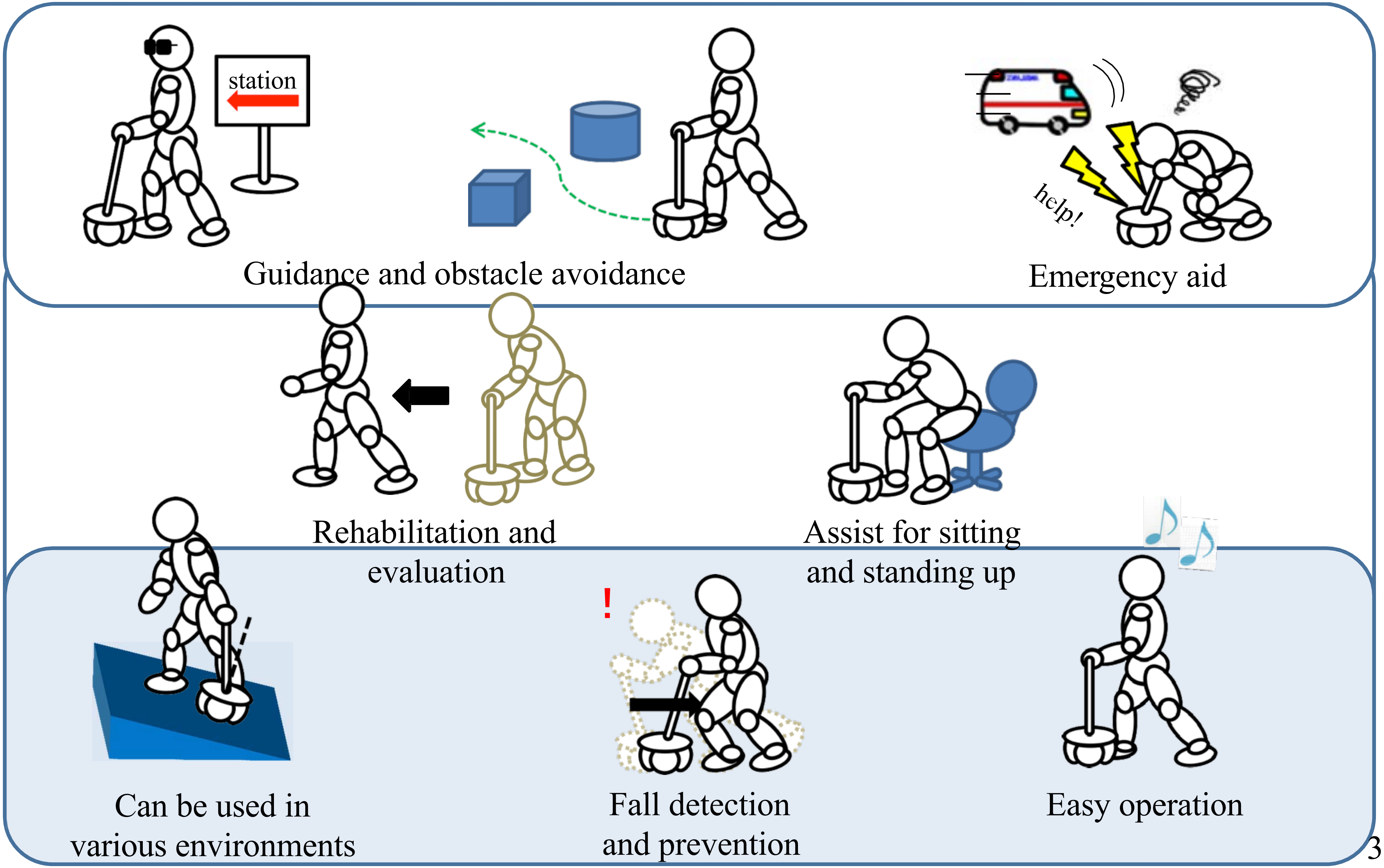
Lower-extremity
Muscle Weakness

Lower-extremity
Rehabilitation



Guide and
Avoid Obstacle

インテリジェントケインノコンセプト
Concept of Intelligent Cane Robot



技術課題　Technical Issues

- **Safety**
  - Hazard Detection
    - Fall Detection 2009
    - Obstacles Detection
  - Hazard Avoidance
    - Fall Prevention 2010
    - Obstacles Avoidance 2012
  - Hazard Reporting
    - Alarm or Vibration
    - Call for Help by Phone
- **Assistance**
  - Walking Assistance
    - Using Comfortable
    - Reduction of Fatigue
  - Navigation
    - Intelligent Guidance
    - Voice and Visualization Guidance
  - Sit/Stand Assistance
    - Assist User to Sit Down
    - Assist User to Stand Up
- **Usability**
  - Human Intention Estimation
    - Intended Direction of Walking 2008
    - Human Behavior Estimation
  - Interface Design
    - Friendly Interface Design 2012
    - Self-Adapted Interface
  - Walking Behavior Learning
    - Human Walking Dynamic Model
    - Disability Level Identification

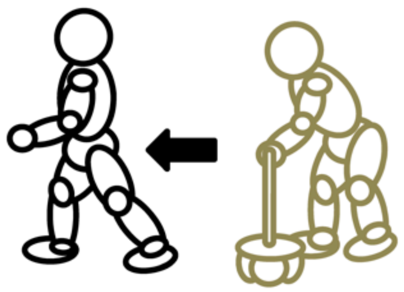
Fall Detection and Prevention

Call for Help by Phone

Navigation

Assist for sitting and standing up

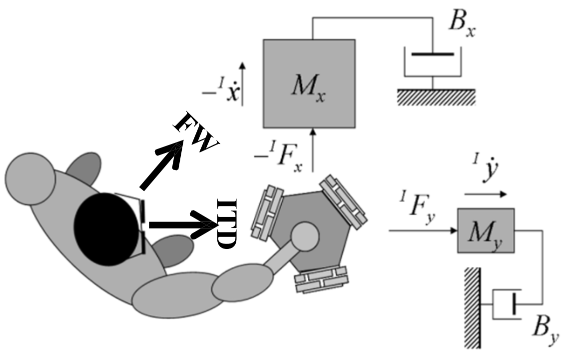
Easy operation



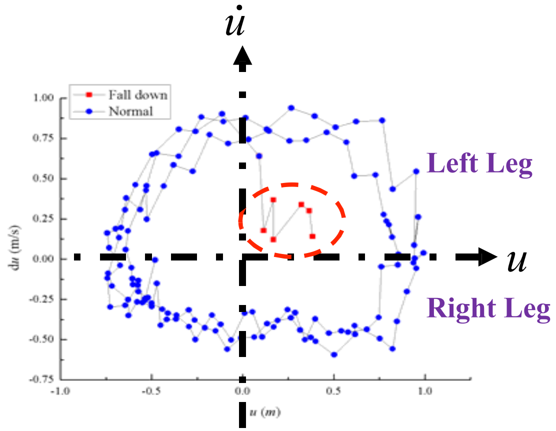
Rehabilitation and Evaluation

現在までの研究活動 Previous research

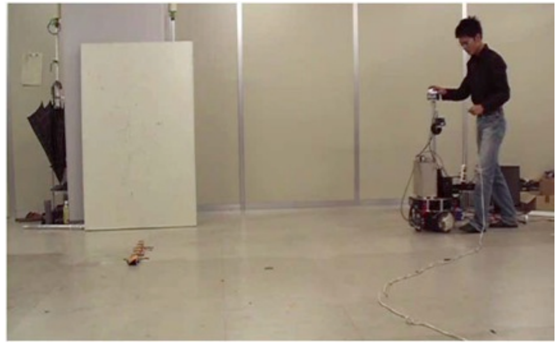
1. Human Walking Intention Estimation (2008)[1]



2. Fall Detection (2009)[2]



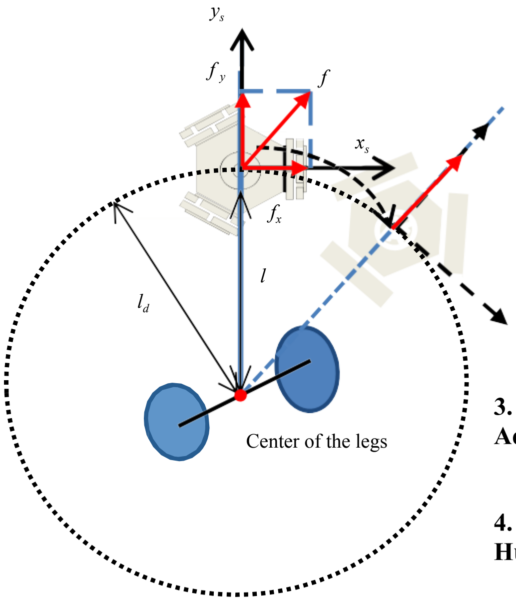
Gait Phase Diagram

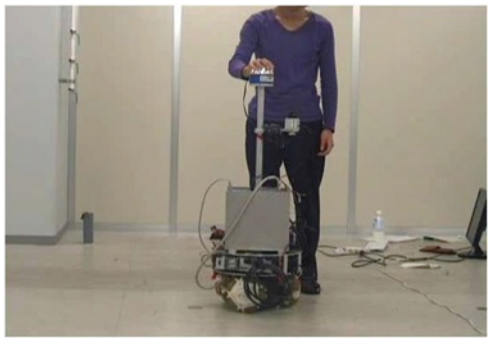


1. Jian Huang, Pei Di, Intelligent Robots and Systems, 2008. IROS 2008. IEEE/RSJ International Conference on

2. Pei DI, Jian Huang, Micro-Nano Mechatronics and Human Science, 2008. MHS 2008. International Symposium on

3. Fall Prevention Strategy (2010)[3]

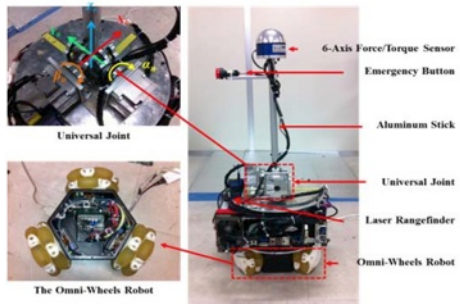


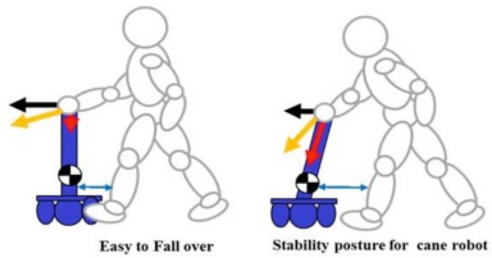


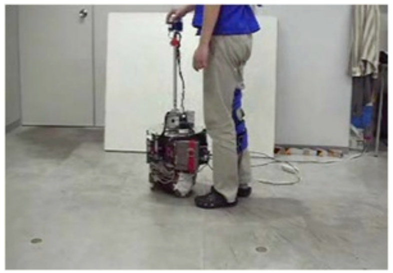
3. Kohei Wakita, Jian Huang, International Conference on Advanced Mechatronics 2010

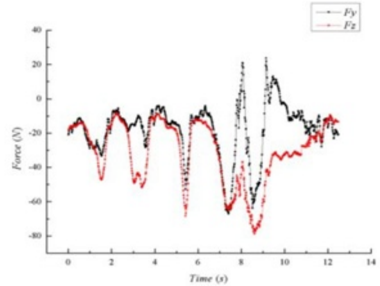
4. Pei DI, Jian Huang, International Symposium on Robot and Human Interactive Communication 2012

4. Optimal Posture Control (2011)[4]









福田研究室の研究領域
Research Works of Fukuda Lab

Multi-scale Robotics

m

cm

mm

µm

nm

- Multi-locomotion Robots
- Multi-mobile-robot Corporation
- Interface Robotics
- Grasping, Tactile Sensing
- Medical Robotics -Vascular Model and Scaffold-
- Bio-micro Manipulation for Single Cell Manipulation
- Nanodevice/Nanomanipulation

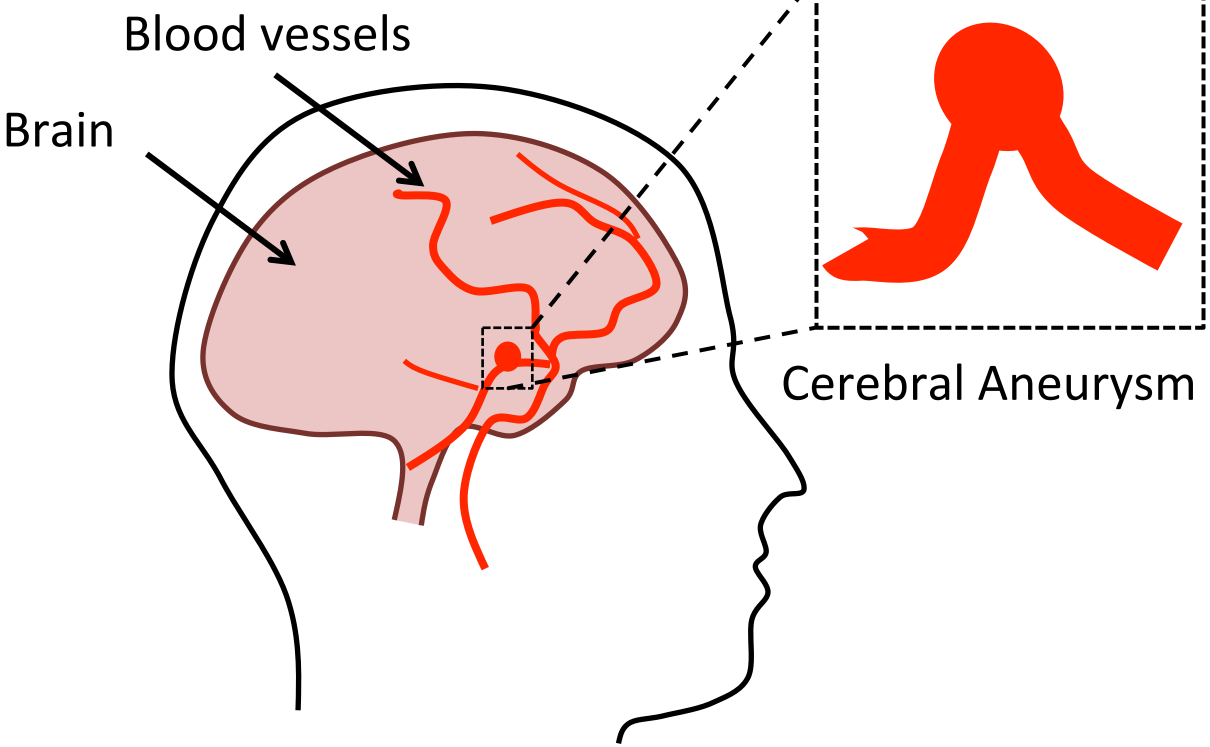
Nagoya University
Micro-Nano Systems Department
Fukuda Laboratory

The EVE project

Challenging the Frontier of the Surgical Simulation since 1989

脳動脈瘤治療　Treatment of aneurysms

Aneurysms



- ◆ Problems
  - ➢ Late identification due to few obvious symptoms
  - ➢ Various morphology due to complex forming reasons
  - ➢ Massive internal hemorrhage; Permanent damage to organs
  - ➢ High death rate after rupture of aneurysms

◆ Open surgical therapy

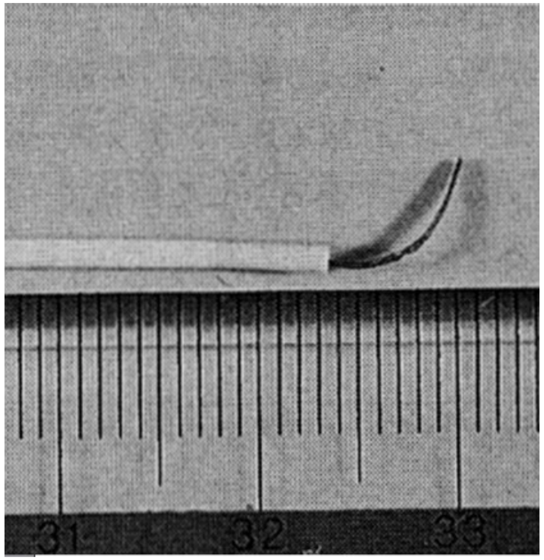
- ➢ Invasive open surgery
- ➢ Intraoperative and postoperative pain and much bleeding, cause large damages to organs, long postoperative stay in hospital, high mortality
- ➢ High risk for complications

◆ Intravascular surgery

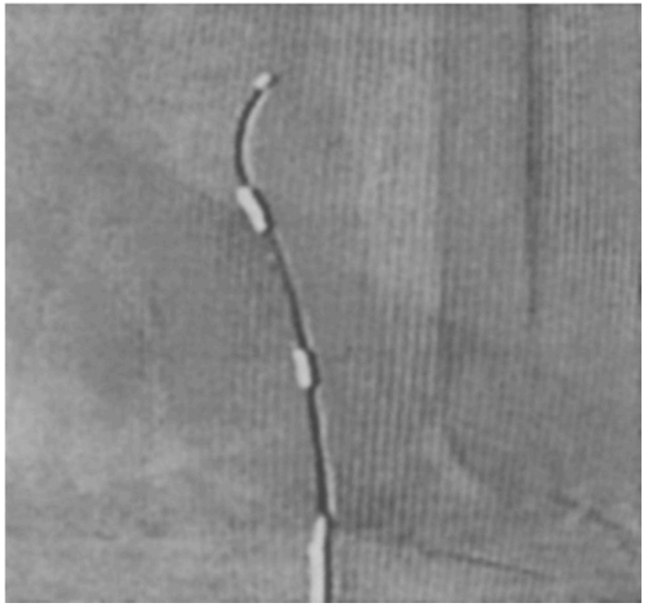
- ➢ Minimal invasion; less bleeding; short operative and recovery time
- ➢ Treatments for various aneurysms with complex morphology
- ➢ Required for high technique for operation

能動カテーテル Active Catheters (1989-1994)

Intravascular Devices



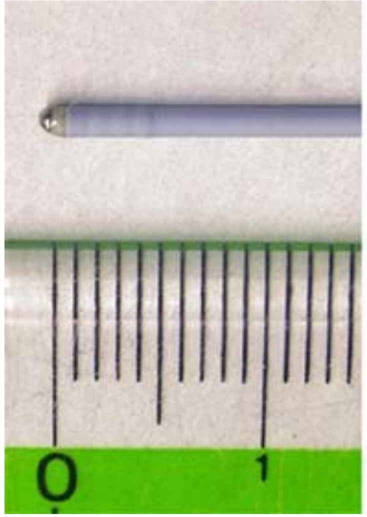
- **Adds maneuverability to the catheter**
- **Endovascular techniques are new in minimally invasive surgery**

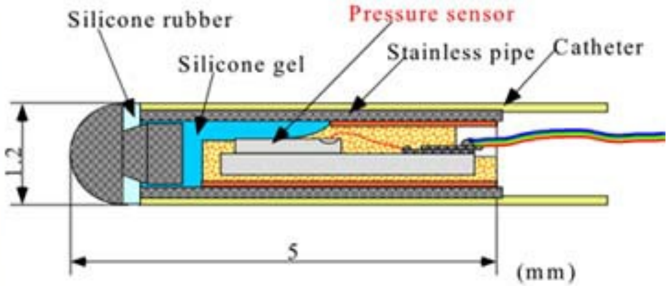


- **Need to be compatible wit Xrays**
- **Requires micro systems as catheters has about 1 mm of lumen**

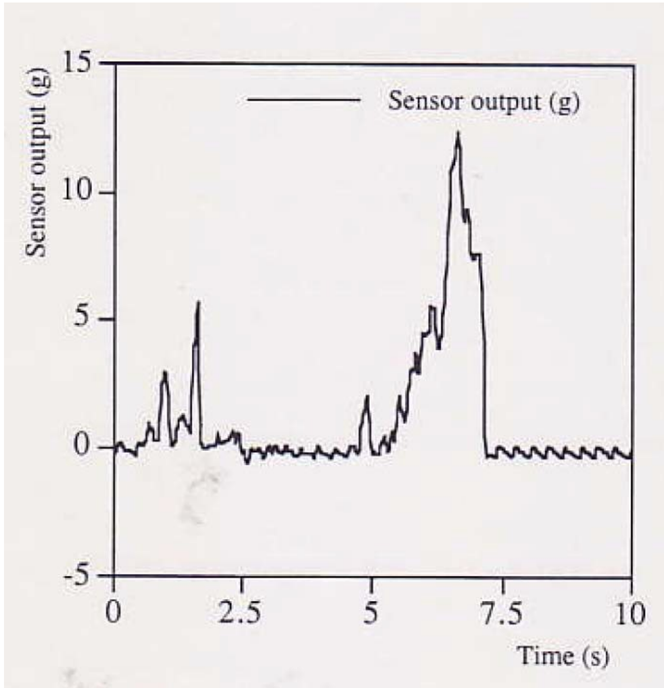
[S.Guo, J. of Robotics Soc. of Japan. 1996]

カテーテル先端への力センサの組込み Force Sensor on catheter tip (1996)





- Prevents the damage of vessel wall
- A pressure sensor detects the force applied to the catheter tip



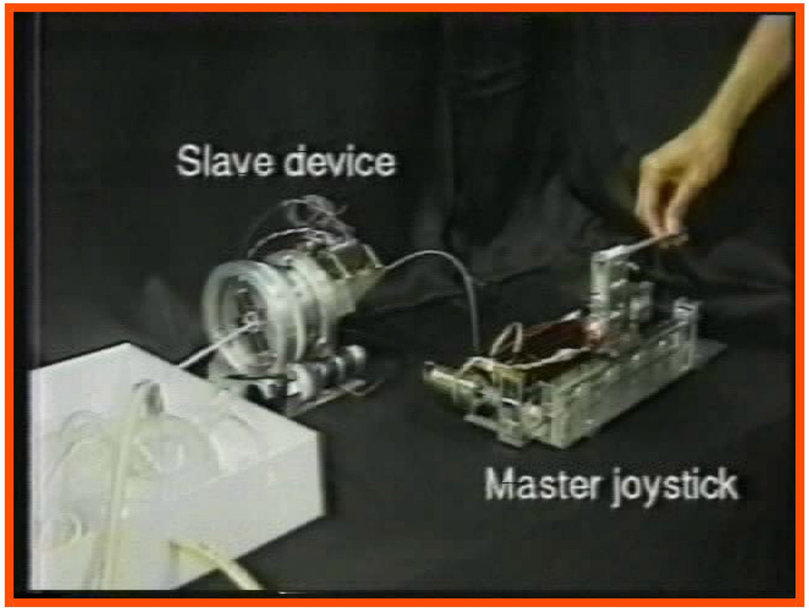
In-Vivo Experiment

- Pressure done by the catheter to an aneurism of canine was measured
- Blood pressure fluctuation was measured

[M. Tanimoto, Trans. of the JSME 1997]

Force Sensor In Vivo Experiment Results

テレサージェリ　Telesurgery (1996)



•**First catheter manipulation mechanism using gum rollers**

•**Master device as human interface for catheter manipulation**

Telesurgery System

•**Reduces the X-rays irradiation to physicians**

•**Manipulated from outside of the surgical room**

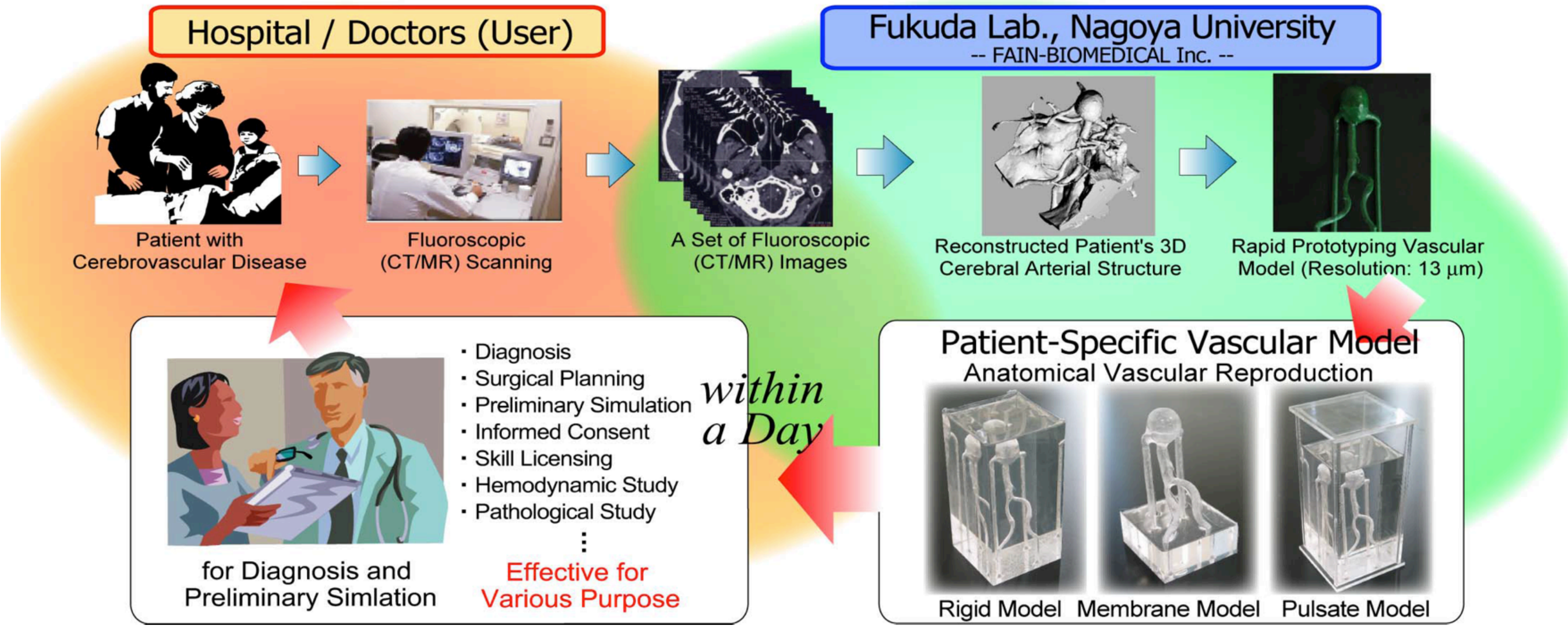
[F. Arai, IEEJ Trans. on Elec. 1997]

Experimentation inside surgical room

シミュレーション・ベイスド・メディスン

Simulation Based Medicine

Patient Specific Vascular Modeling

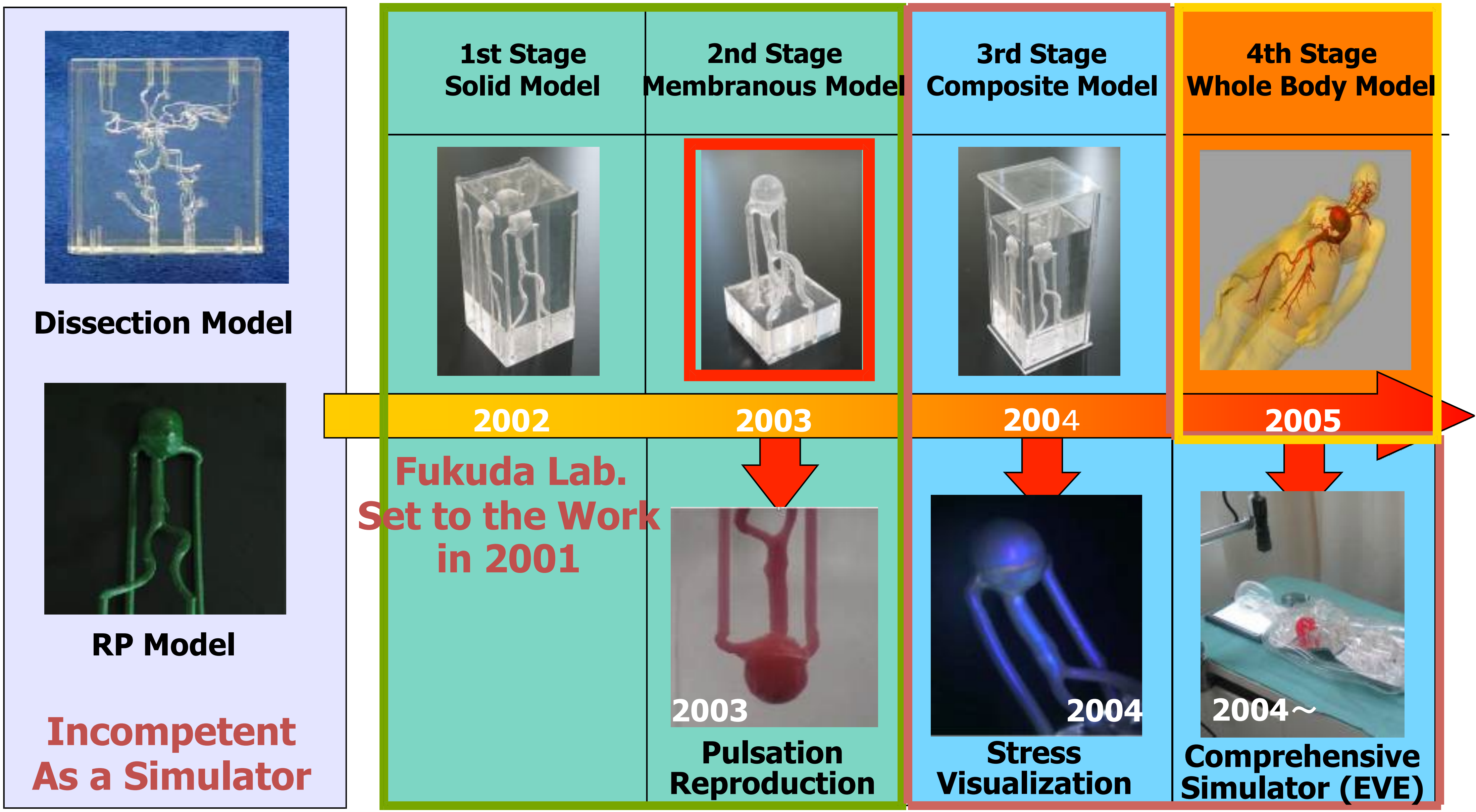


Specification:

- **Information: CT or MRI.**
- **Modeling Resolution: 13 mm**
- **Fabrication Time: < 24 hours**

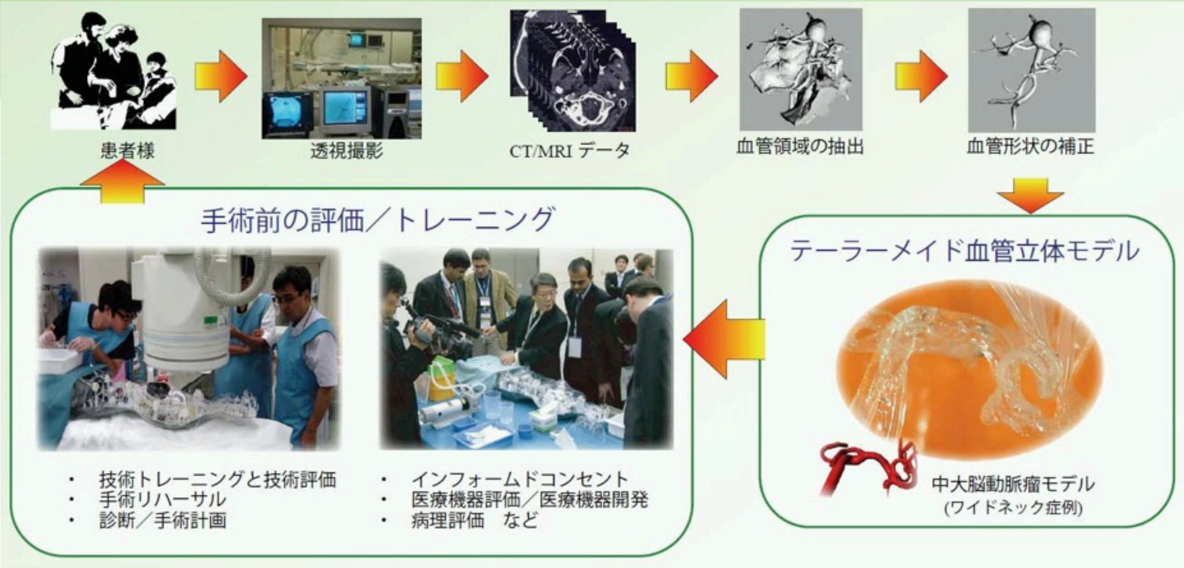
３次元プリンティング技術による人工血管モデルの構築

Vasculature Model Types by 3D printing technology



ファイン・バイオメディカル有限会社

FAIN-Biomedical,Inc.



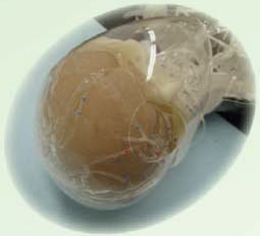
New Release

■ 超精密血管内手術シミュレータＥＶＥ（動脈タイプ）

■ 上肢・下肢モジュール

■ 静脈タイプ

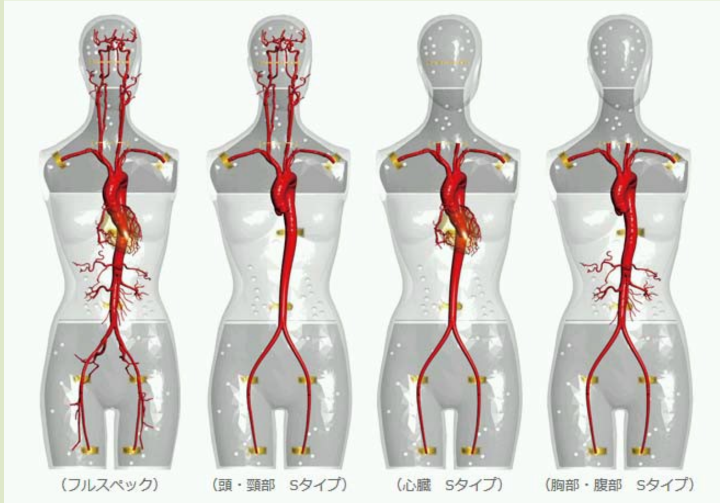
■ 脳モデル

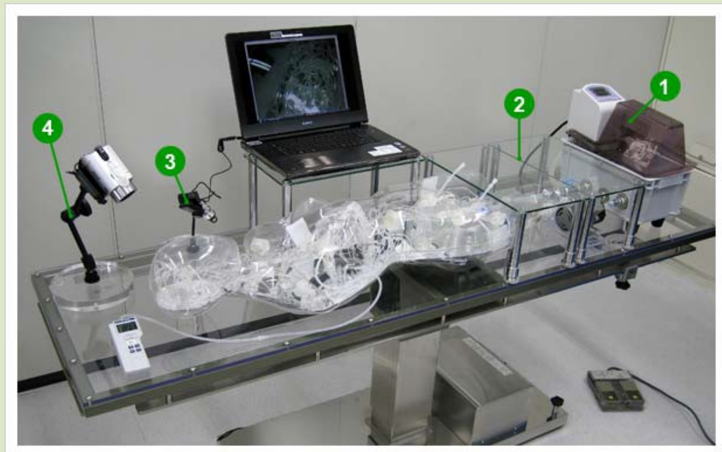


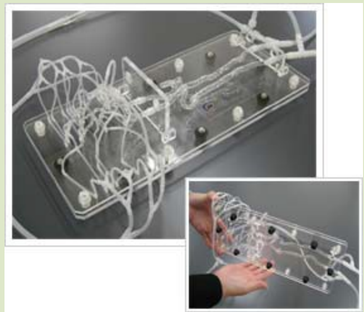
ＥＶＥの主要な特徴：

1．ＣＴから血管を精密に再現　―　現実に即した、幅広い疾患のシミュレーションが可能
2．血管組織の物理特性を再現　―　リアルなカテーテル操作感を実現
3．人体の血液循環（血圧、血流量、温度）を再現　―　血流の影響など詳細な評価が可能
4．Ｘ線透視撮影に適合　―　透視撮影下で迫真のシミュレーションが可能
5．幅広い目的で使用可能
6．軽量構造で持ち運び可能

既製品

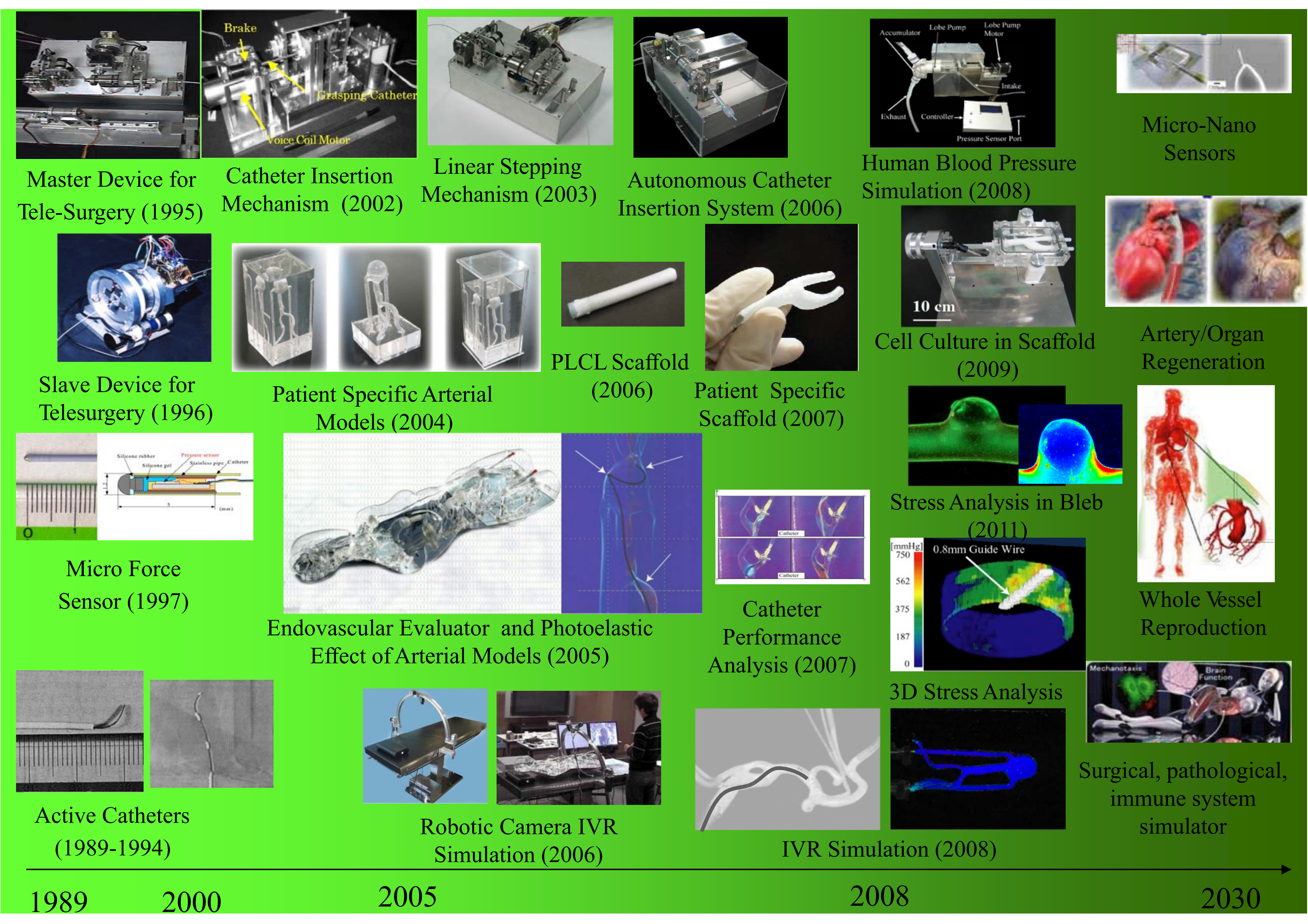






オプション・オーダーメイド

http://www.fain-biomedical.com/


Brake
Grasping Catheter
Voice Coil Motor
Master Device for Tele-Surgery (1995)
Catheter Insertion Mechanism (2002)
Linear Stepping Mechanism (2003)
Autonomous Catheter Insertion System (2006)
Accumulator
Lobe Pump
Lobe Pump Motor
Intake
Exhaust
Controller
Pressure Sensor Port
Human Blood Pressure Simulation (2008)
Micro-Nano Sensors
Slave Device for Telesurgery (1996)
Patient Specific Arterial Models (2004)
PLCL Scaffold (2006)
Patient Specific Scaffold (2007)
10 cm
Cell Culture in Scaffold (2009)
Artery/Organ Regeneration
Silicone rubber
Silicone gel
Pressure sensor
Stainless pipe
Catheter
Micro Force Sensor (1997)
Endovascular Evaluator and Photoelastic Effect of Arterial Models (2005)
Catheter Performance Analysis (2007)
Stress Analysis in Bleb (2011)
[mmHg]
750
562
375
187
0
0.8mm Guide Wire
3D Stress Analysis
Whole Vessel Reproduction
Mechanotaxis
Brain Function
Active Catheters (1989-1994)
Robotic Camera IVR Simulation (2006)
IVR Simulation (2008)
Surgical, pathological, immune system simulator
1989
2000
2005
2008
2030

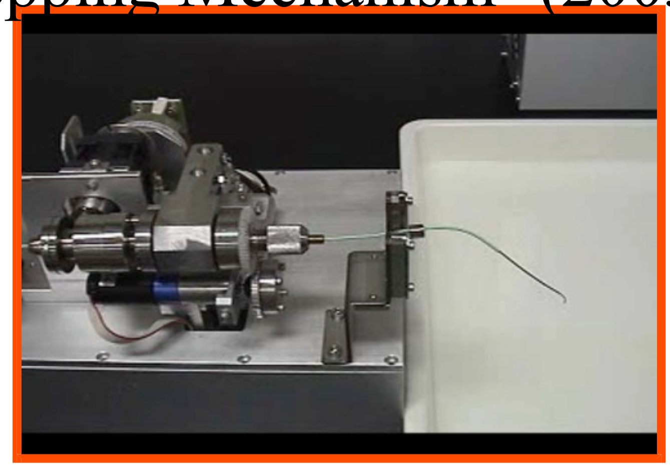
リニアステッピングメカニズム　Linear Stepping Mechanism (2003)

•Variable speed of insertion and extraction of catheter (Feeding force 2N)

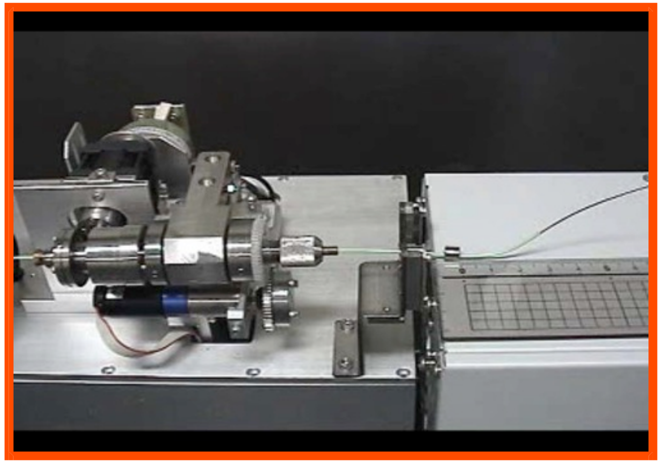
• Variable rotation speed

•High resolution of discrete linear motion of catheter (up to 0.1 mm/cicle)

• Easy to clean

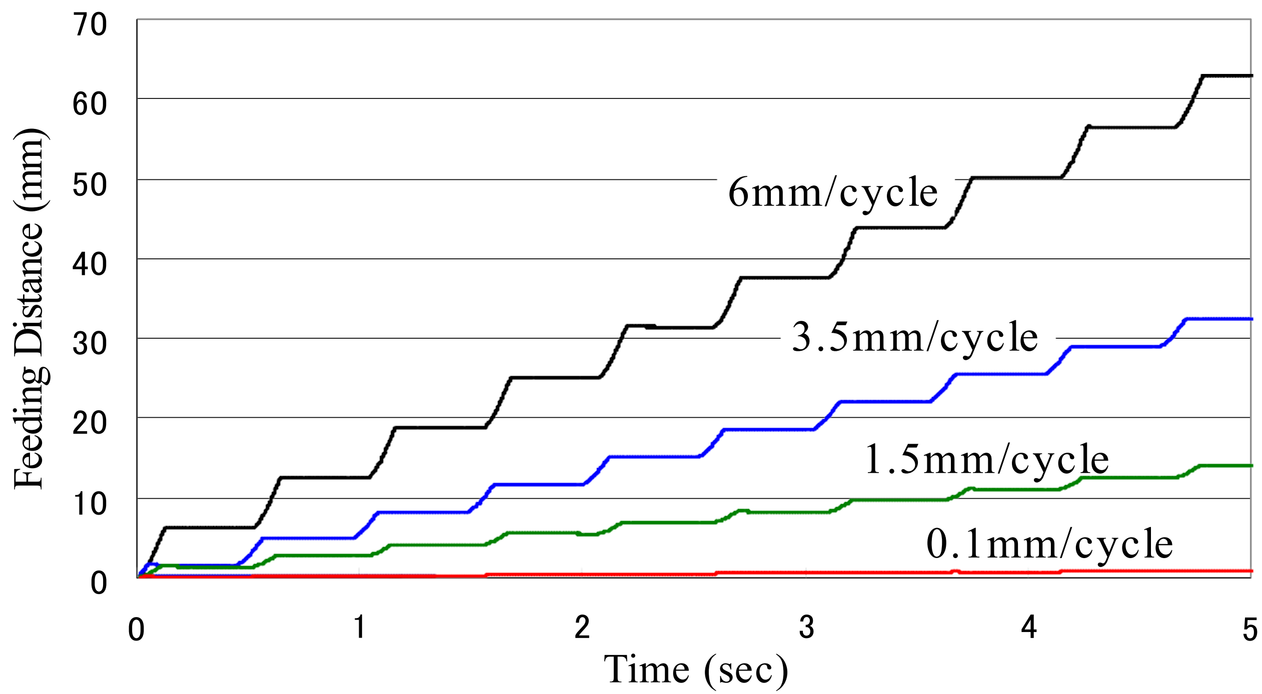


Rotation



Forward

at Variable Speed

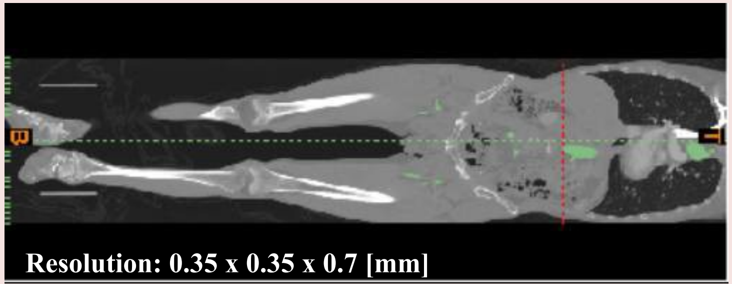


Forward feeding characteristics on several reciprocating distance of grasping unit

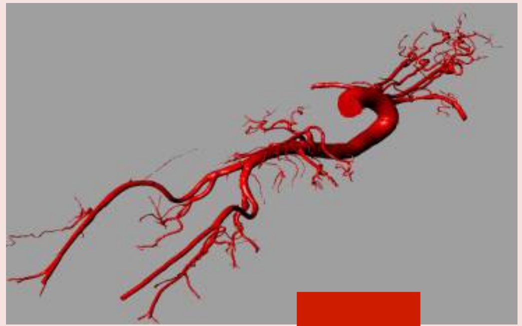
F. Arai et al., ICRA 2002

患者個人に応じた人工血管モデルによるシミュレーション
Simulation using Patient-Specific Vasculature Models

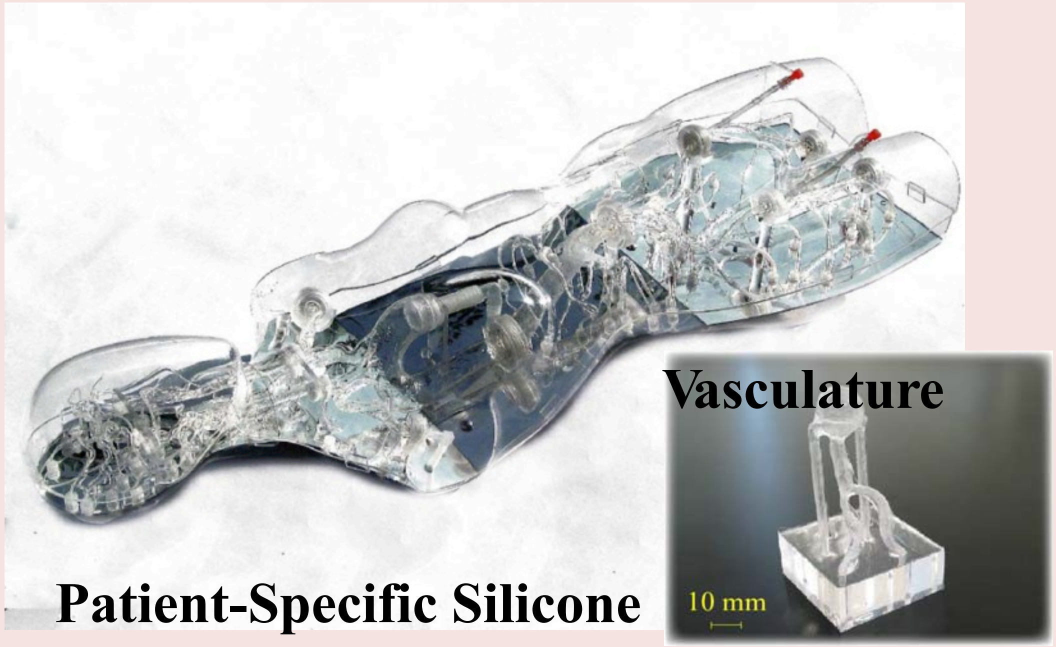
Whole Body Tomogram



Vasculature Morphology Extraction

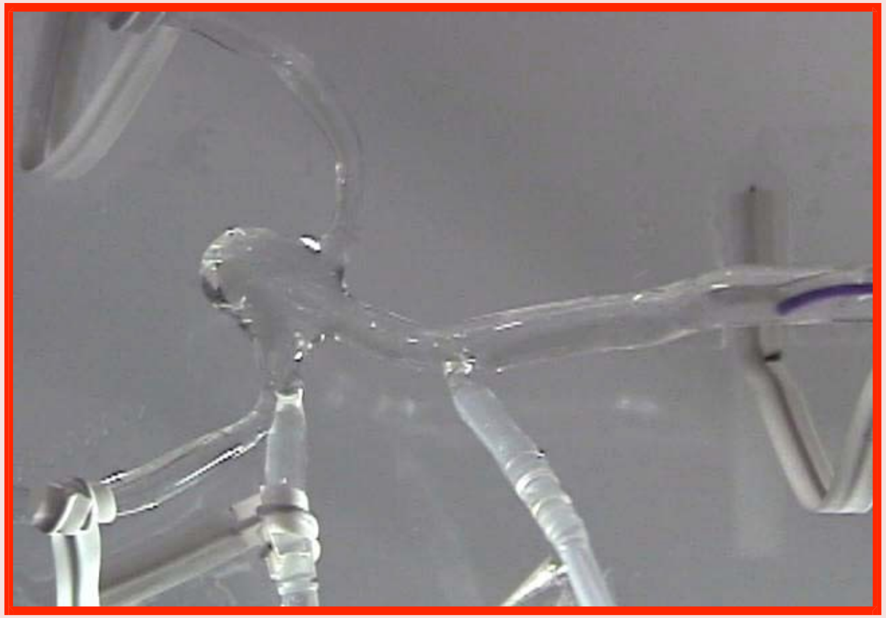


Endovascular Evaluator



[Ikeda, JRM 2005]

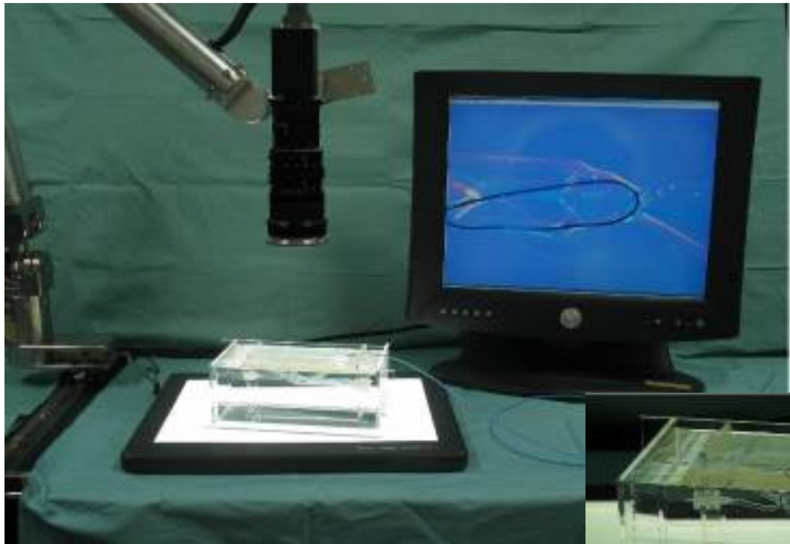
Treatment Simulation



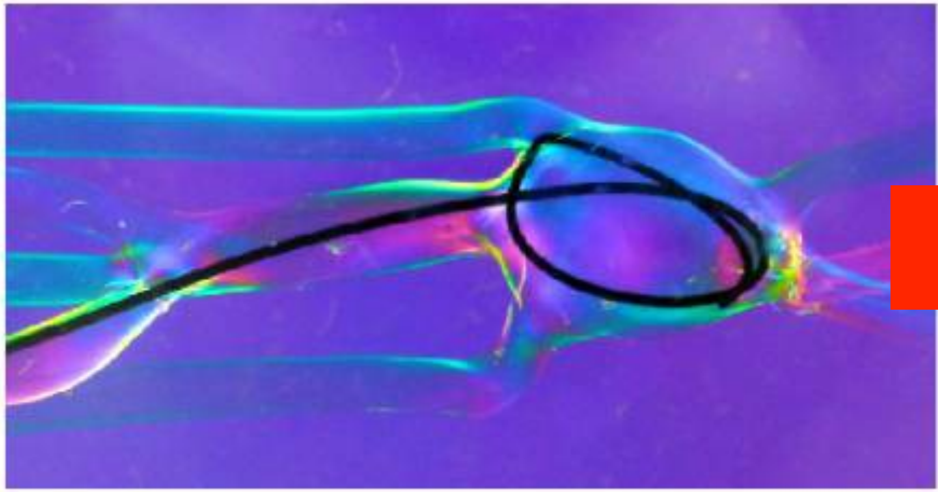
T. Fukuda, C. Tercero, Microsurgery, Pan Stanford Pub.

光弾性効果によるカテーテル操作評価 Photo-elastic Evaluation by Artificial Model

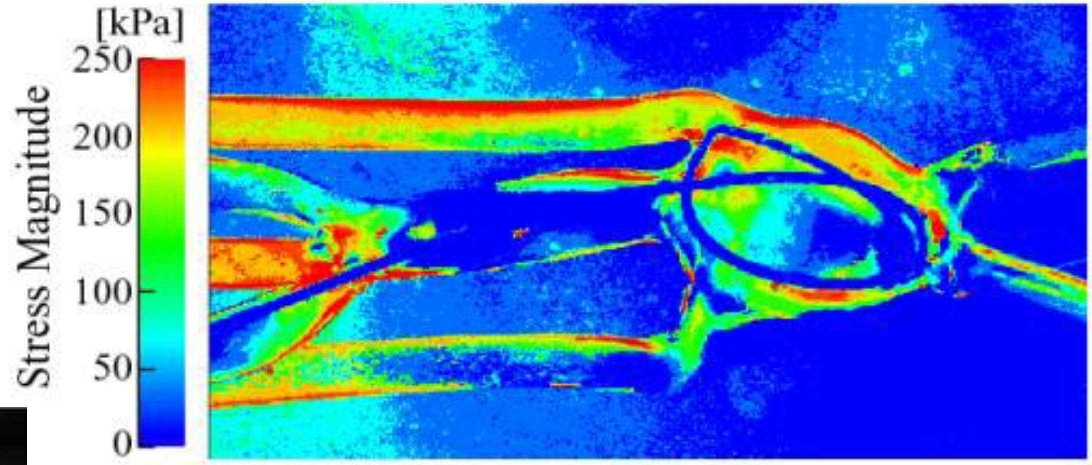
Experimental Result



Hardware Setup

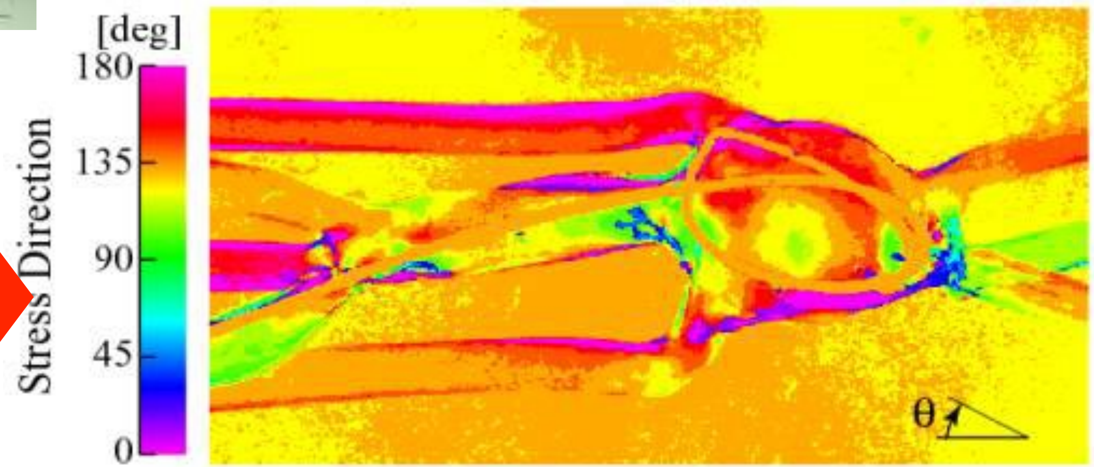


Observed Image



(a) Magnitude of Principal Shearing Stress

(a) Analyzed Magnitude

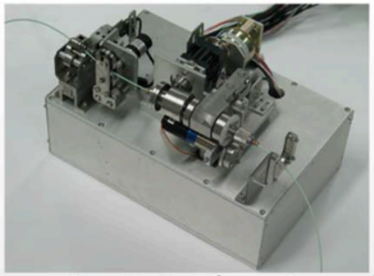


(b) Direction of Principal Shearing Stress

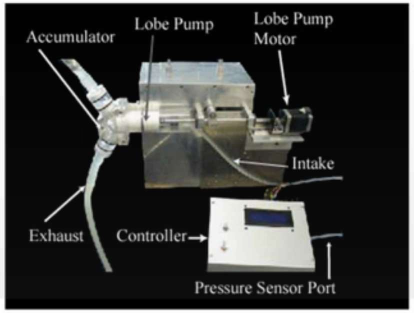
(b) Analyzed Direction

[S. Ikeda, in Proc. of MICCAI 2005]

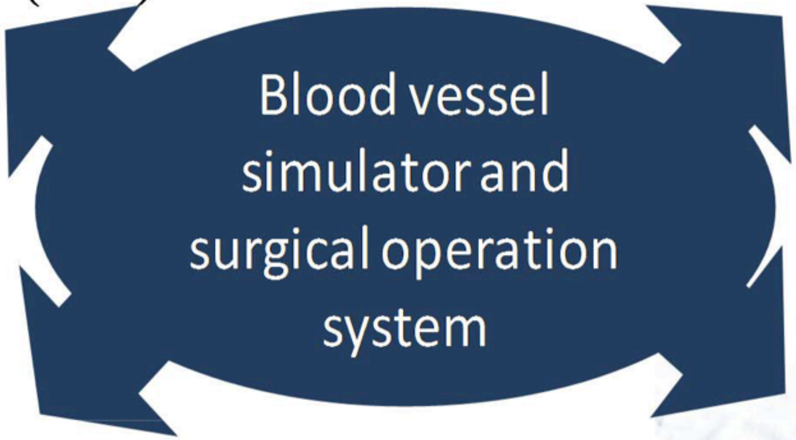
人工血管シミュレータによる手術シミュレータ Blood Vessel Simulator and Surgical Operation System

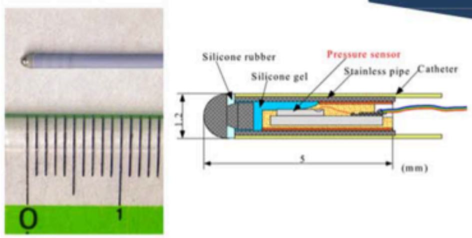


Linear Stepping Mechanism (LSM) for catheter control (2003)

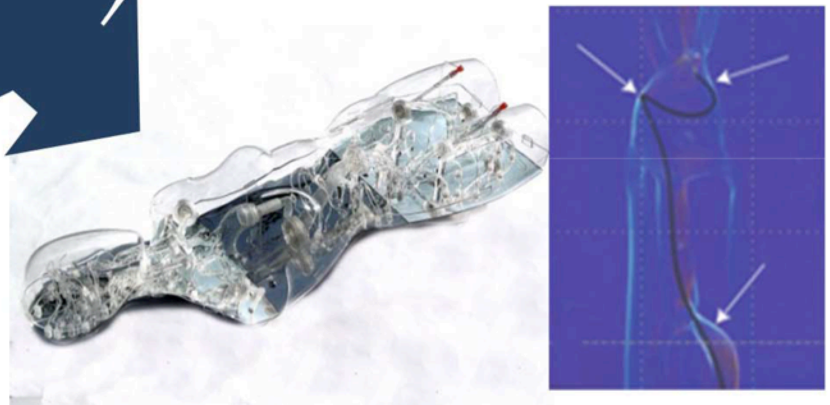


Human Blood Pressure Simulation (2008)



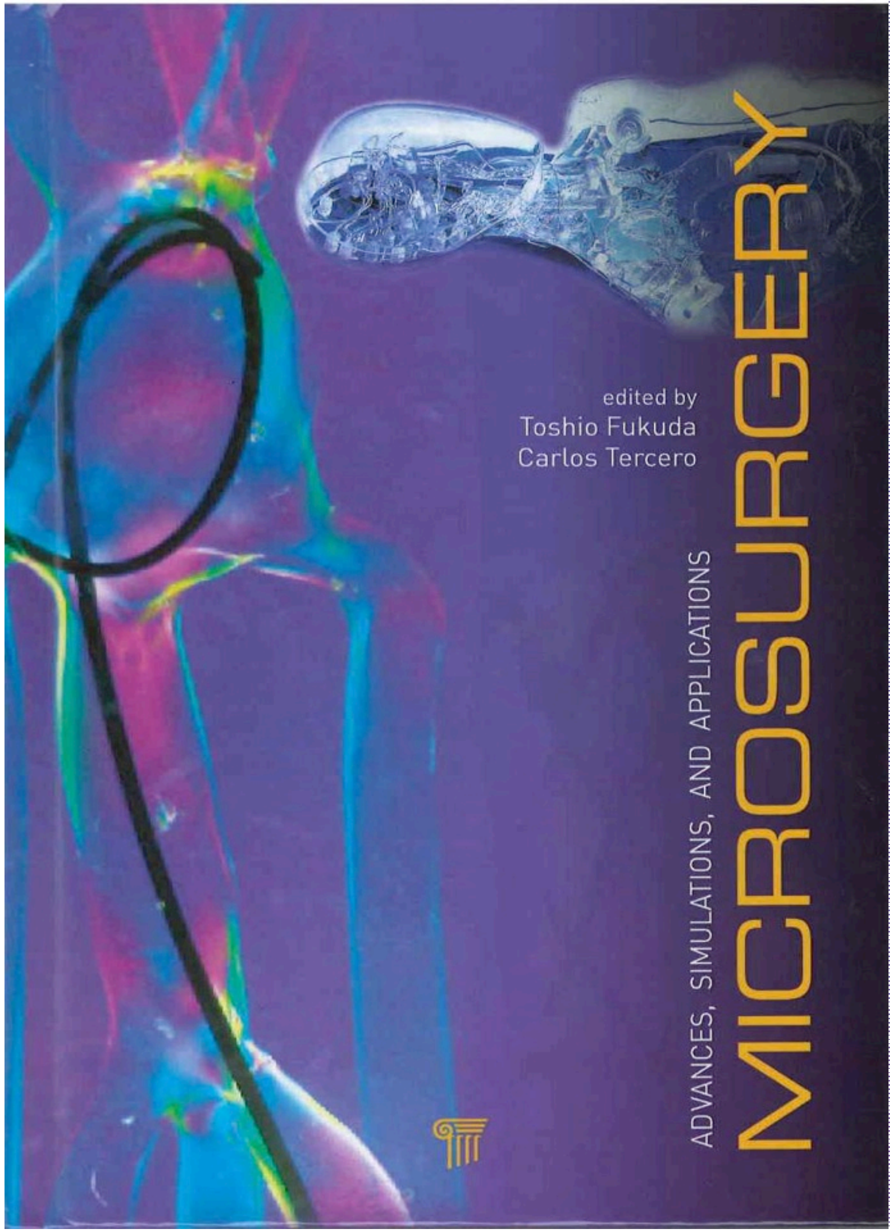


Catheter with Micro Force Sensor (1997)



Endovascular Evaluator and Photoelastic Effect of Arterial Models (2005-)

T. Fukuda et al., IEEE Industrial Electronics Magazine, Vol. 4,pp. 13-22, 2010.



MICROSURGERY

"This book presents an important and timely subject and contains a wide range of knowledge derived from the contributors' long-time experience. It is the first work to integrate medicine and engineering exceptionally well and a great reference for graduate students, researchers, and doctors specializing in microsurgery."

Prof. Tzyh Jong Tarn
Washington University in St. Louis, USA

This book presents the development of the endovascular evaluator (EVE), which was motivated by the lack of *in vitro* simulation tools to reproduce patient-specific vasculature morphology. The development of patient-specific silicone vasculature models and the EVE is a breakthrough that is improving medical training and facilitating research and development in industry and academia. This book explains the development of *in vitro* simulators for biomedical applications based on the scientific context in robotics and on the explanation of the medical procedure to be simulated. It presents modeling methods for *in vitro* representation of human tissue and of tissue integrity during endovascular surgery simulation. Additionally, it presents the applications of this *in vitro* vasculature modeling technology.

Toshio Fukuda received his bachelor's degree from Waseda University, Tokyo, Japan, in 1971, and master's and Dr.Eng. degrees from the University of Tokyo, Japan, in 1973 and 1977, respectively. In 1977, he joined the National Mechanical Engineering Laboratory, Japan. He joined the Science University of Tokyo, Japan, in 1982 and Nagoya University, Nagoya, Japan, in 1989. Currently, he is director of the Center for Micro-Nano Mechatronics and professor at the Department of Micro-Nano Systems Engineering at Nagoya University, where he is mainly involved in the research of the intelligent robotic and mechatronic system, cellular robotic system, and micro- and nano-robotic system. He is Distinguished Professor at Seoul National University since 2009.

Carlos Tercero received his bachelor's and licenciature degrees from the Department of Electronics Engineering at Del Valle de Guatemala University, Guatemala, in 2002 and 2003, respectively. He received his MS from the Complex System Science Department of Nagoya University, Japan, in 2007, and Dr.Eng. degree from the Department of Micro-Nano Systems Engineering, Nagoya University, in 2008. In 2008, he was director of the Departments of Electronics Engineering and Mechatronics Engineering at Del Valle de Guatemala University. From 2009 to March 2012, he was with the Global Center of Excellence for Education and Research of Micro-Nano Mechatronics of Nagoya University, where he was mainly involved in the research of *in vitro* simulation for endovascular intervention. He joined Denso Corporation in April 2012.

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福田研究室の研究領域
Research Works of Fukuda Lab

Multi-scale Robotics

m
- Multi-locomotion Robots
- Multi-mobile-robot Corporation

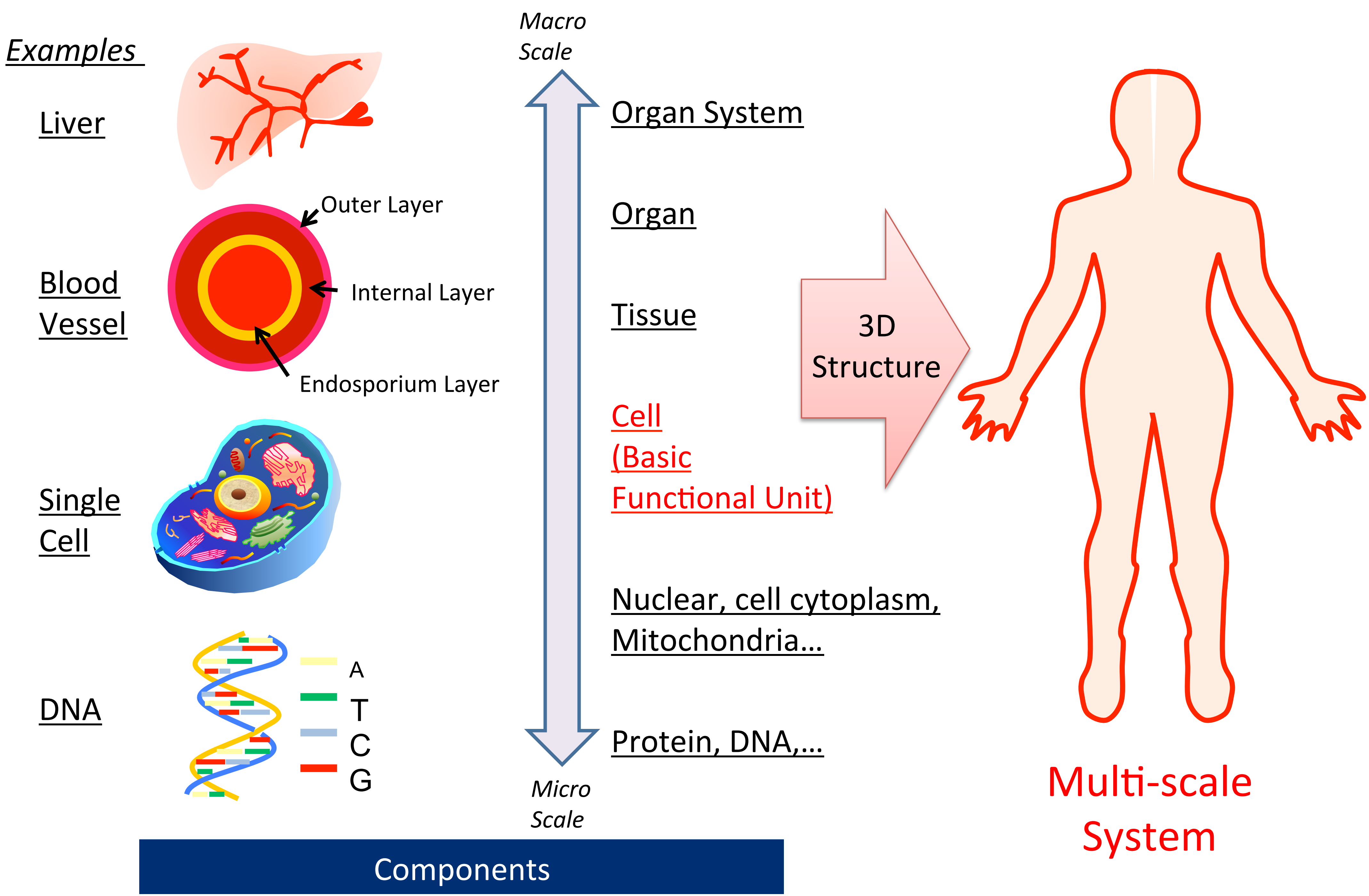
cm
- Interface Robotics
- Grasping, Tactile Sensing

mm
- Medical Robotics -Vascular Model and Scaffold-

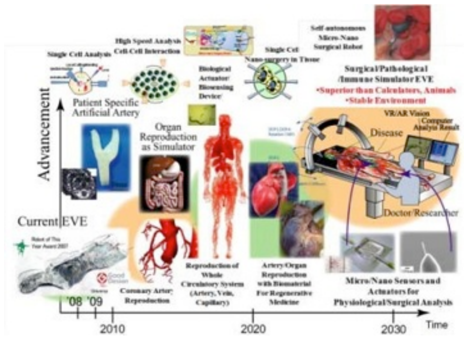
µm
- Bio-micro Manipulation for Single Cell Manipulation

nm
- Nanodevice/Nanomanipulation

3次元細胞構築コンセプト 3D Cell Assembly



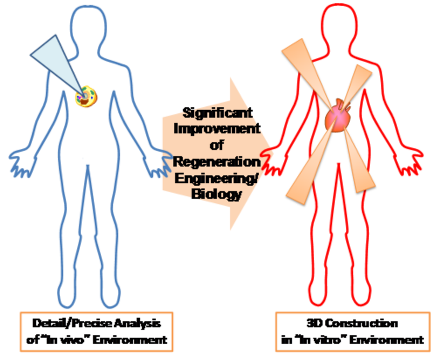
バイオ・シンセシスのためのアプローチ Approach for Biosynthesis



Bio-synthesis in 3D Space

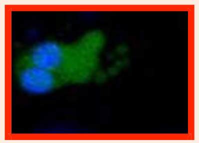
for

- Bionic-simulator
- Regeneration engineering
- Investigation of biological System …



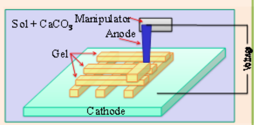
Platelet Production

- Paltelet Production from Megakaryocyte

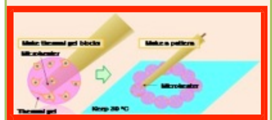


1D Assembly

- Assembly by Electro-deposition

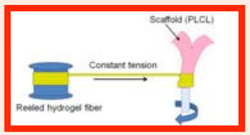


- Assembly by Thermal-gel probe



2D Structure

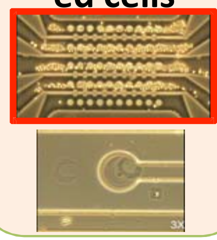
- Rolling up Hydro-gel fibers on scaffold



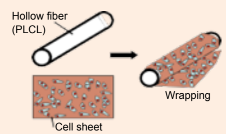
- Direct assembly of magnetic hydro-gel fibers

3D Structure

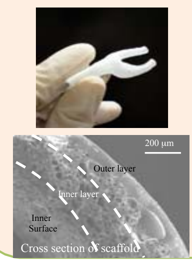
- Assembly of Micro-structures encapsulated cells



- Assembly of Cells sheets in 3D space

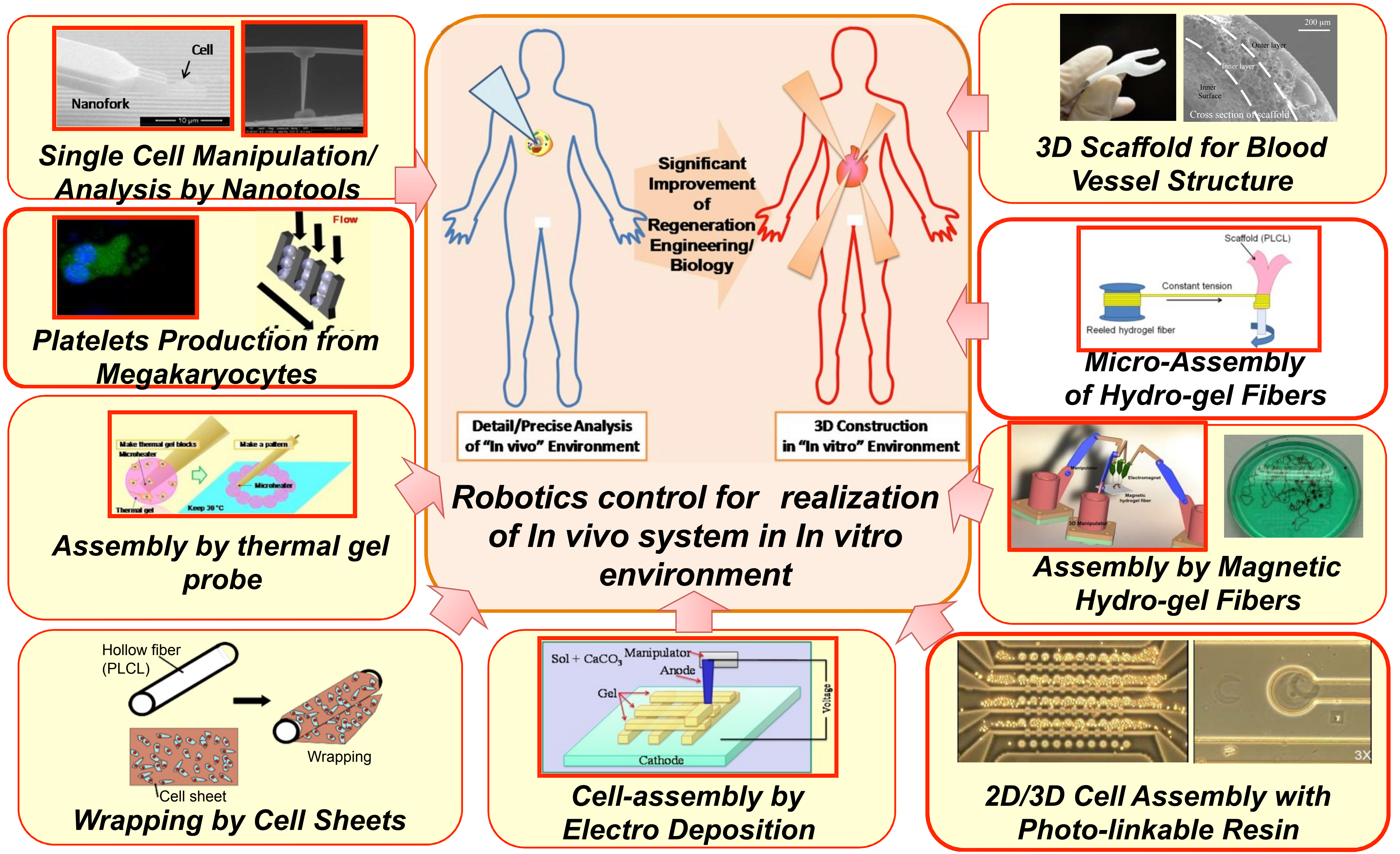


- Biodegradable Scaffold

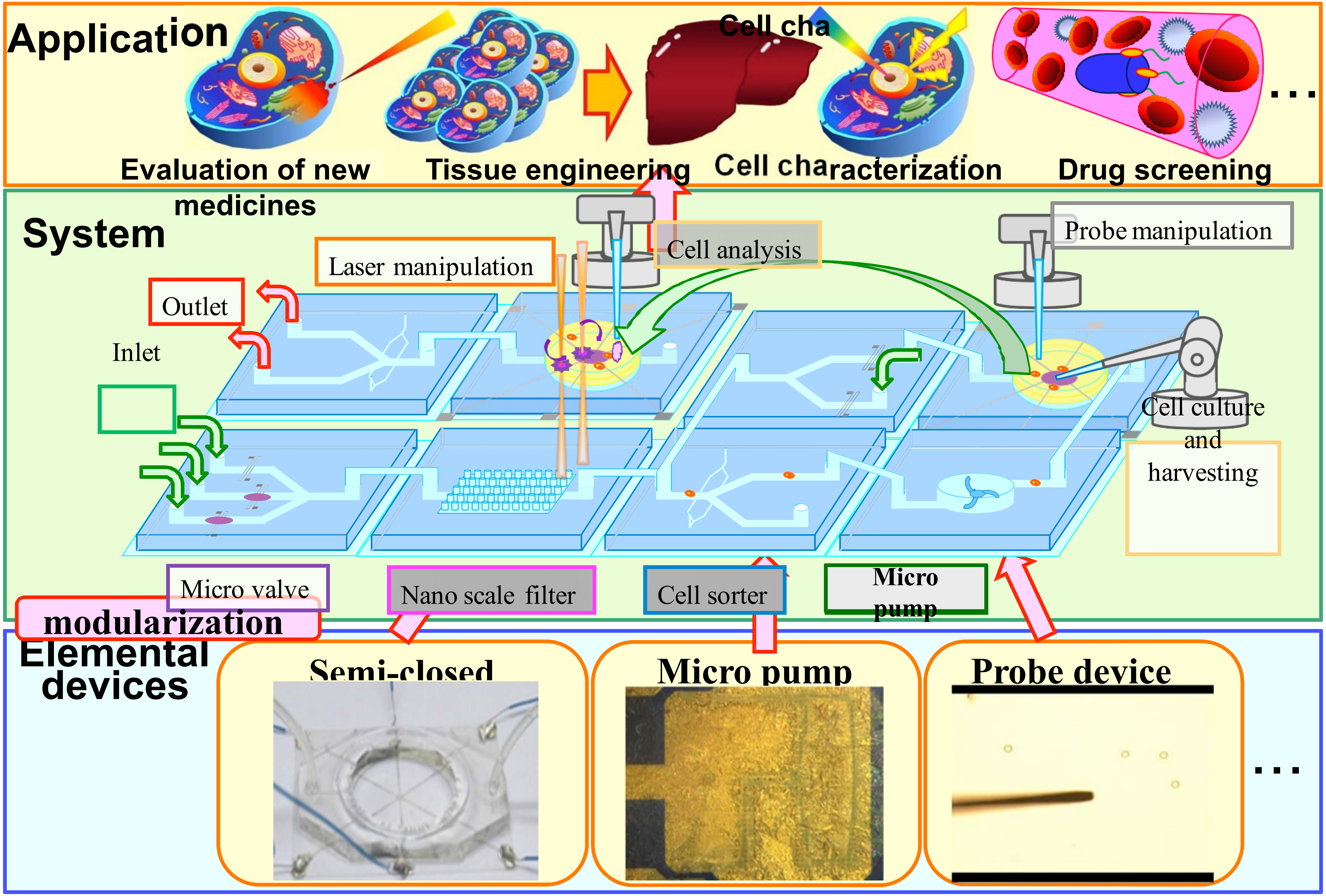


Micro-Nano Fabrication/Measurement/Assembly/Tools…

マイクロナノマニピュレーションによるバイオアセンブリ　Bio-Assembly by Micro-Nano Manipulation



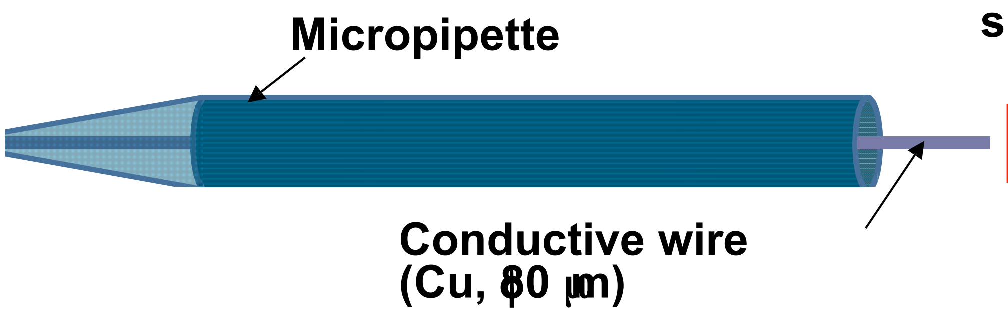
Research objective

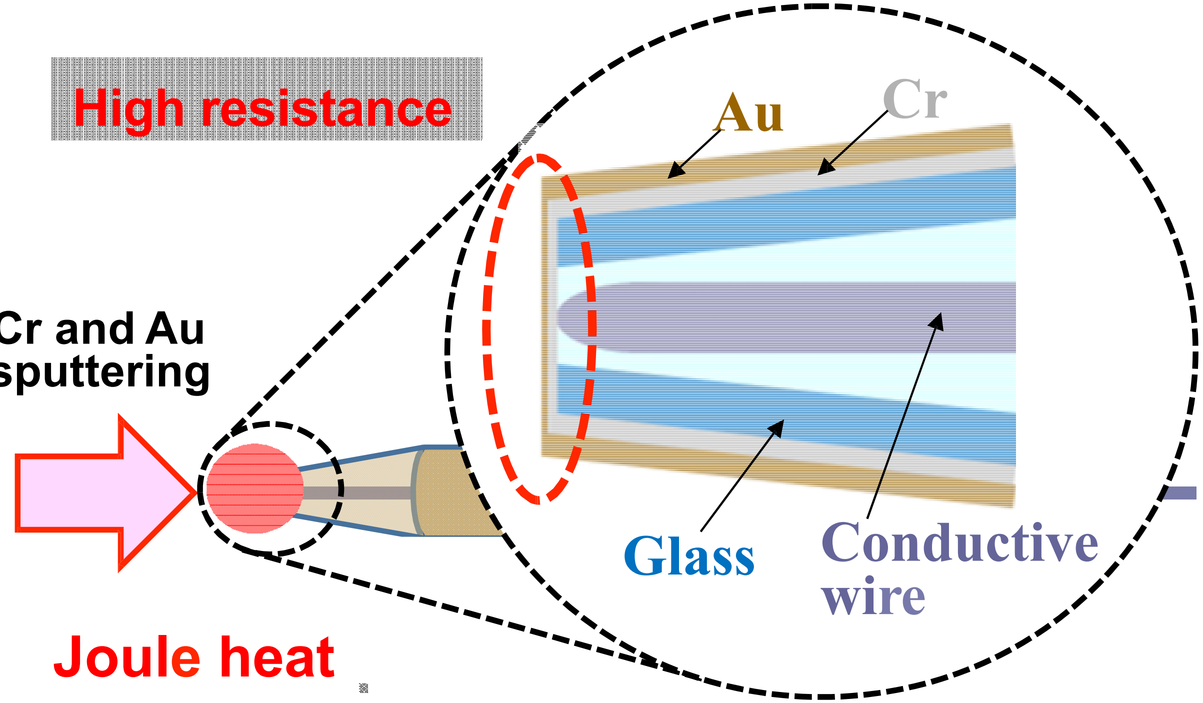


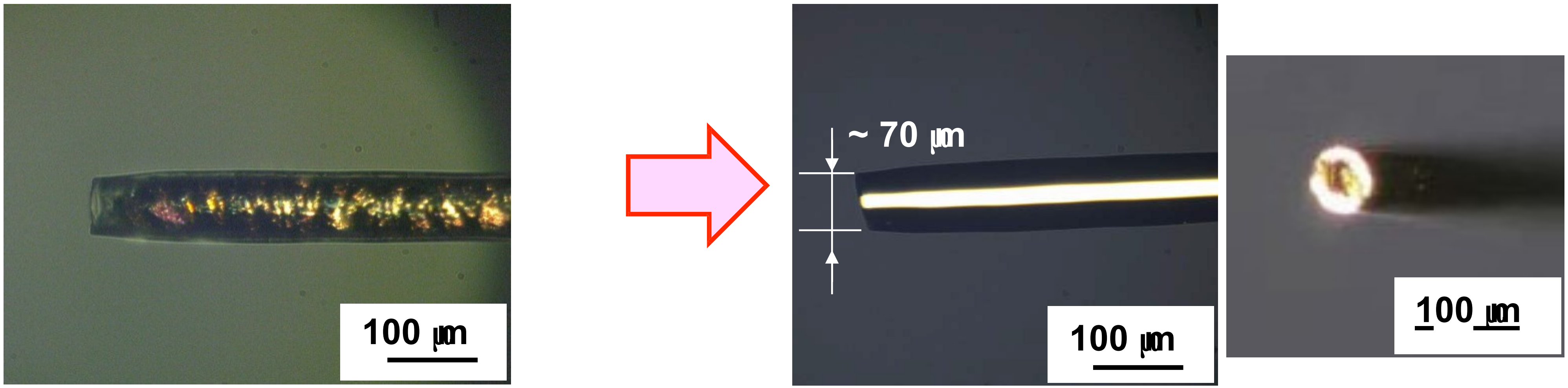
Trans. JSME, 2009 Applied Physics Letters, 2013 J. Micro-Bio Robotics, 2013

Fabrication

Fabrication results of microheater







After pulling glass tubes **After gold sputtering**

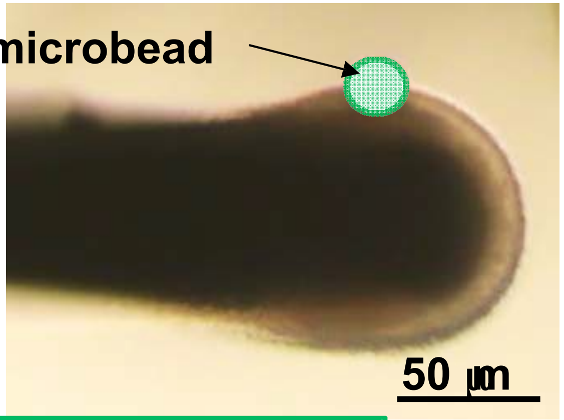
M. Takeuchi, Journal of Micro-Bio Robotics, 2013, DOI:10.1007/s12213-013-0060-x

Fixation force measurement - evaluation -

Fixation force was measured by changing the size of handled micronbead.

- **Microbead size: 20 ㎛ and 50 ㎛**
- **The embedded surface area of the microbead: 25 % to 35 %**

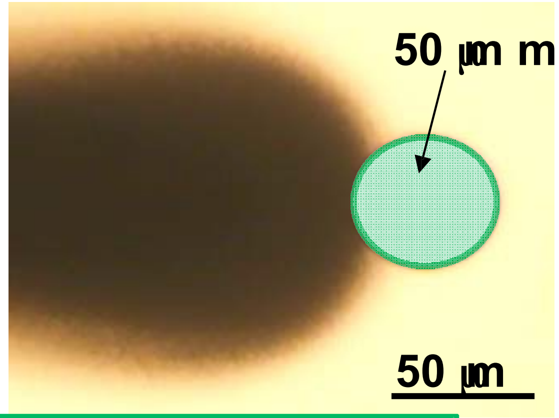
20 ㎛ microbead



Surface area of 20 ㎛ microbead

6.3 times

50 ㎛ microbead



Surface area of 50 ㎛ microbead

Experimental results of fixation force measurement

Handling objects	Fixation force [μN]
50 μm microbead	12.5±3.7
20 μm microbead	2.0±0.8

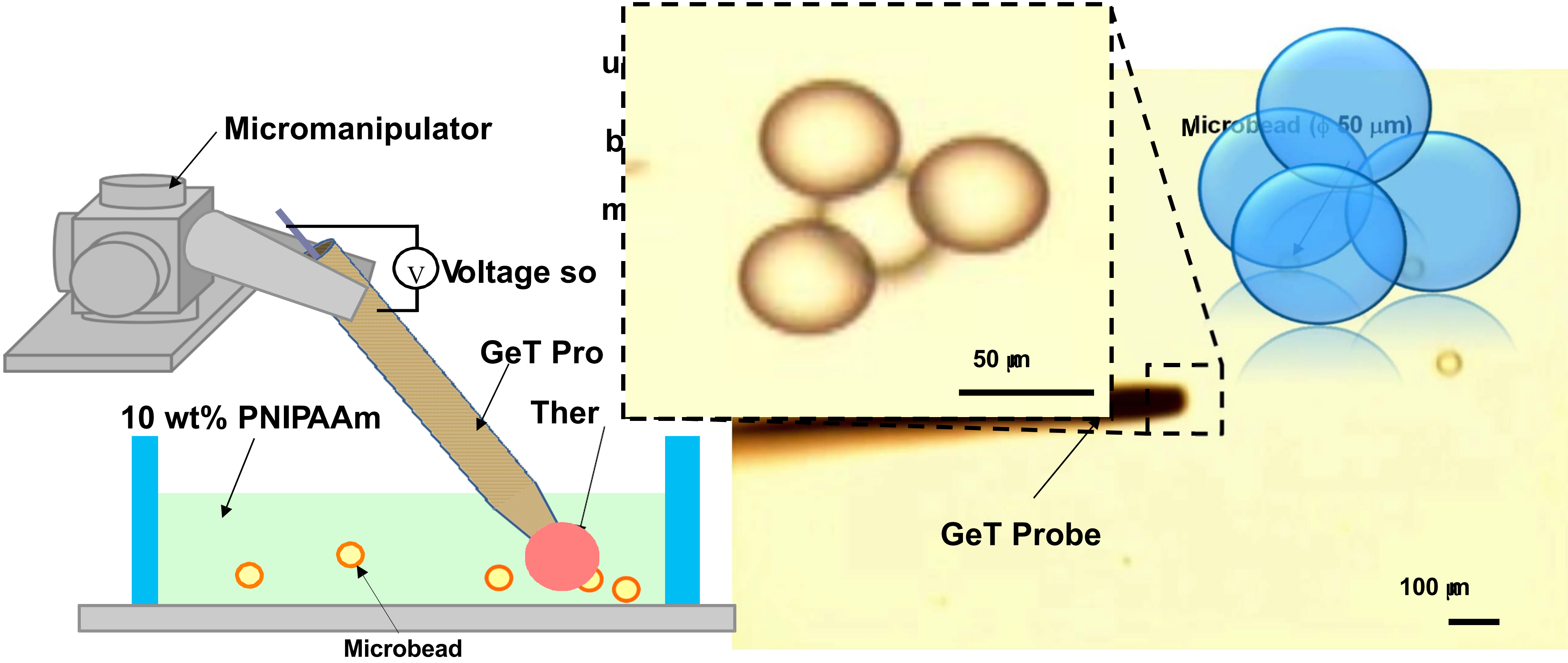
6.3 times

Fixation force is proportional to the embedded surface area to the gel.

M. Takeuchi, Journal of Micro-Bio Robotics, 2013, DOI:10.1007/s12213-013-0060-x

3D assembly of microbeads

3D microstructure was assembled made of ϕ50 ㎛ microbeads.



(replay speed: 10 times faster)

Assembly of 3 dimensional structure was achieved.

M. Takeuchi, Journal of Micro-Bio Robotics, 2013, DOI:10.1007/s12213-013-0060-x

福田研究室の研究領域
Research Works of Fukuda Lab

Multi-scale Robotics

m

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- Multi-mobile-robot Corporation

cm

- Interface Robotics
- Grasping, Tactile Sensing

mm

- Medical Robotics -Vascular Model and Scaffold-

µm

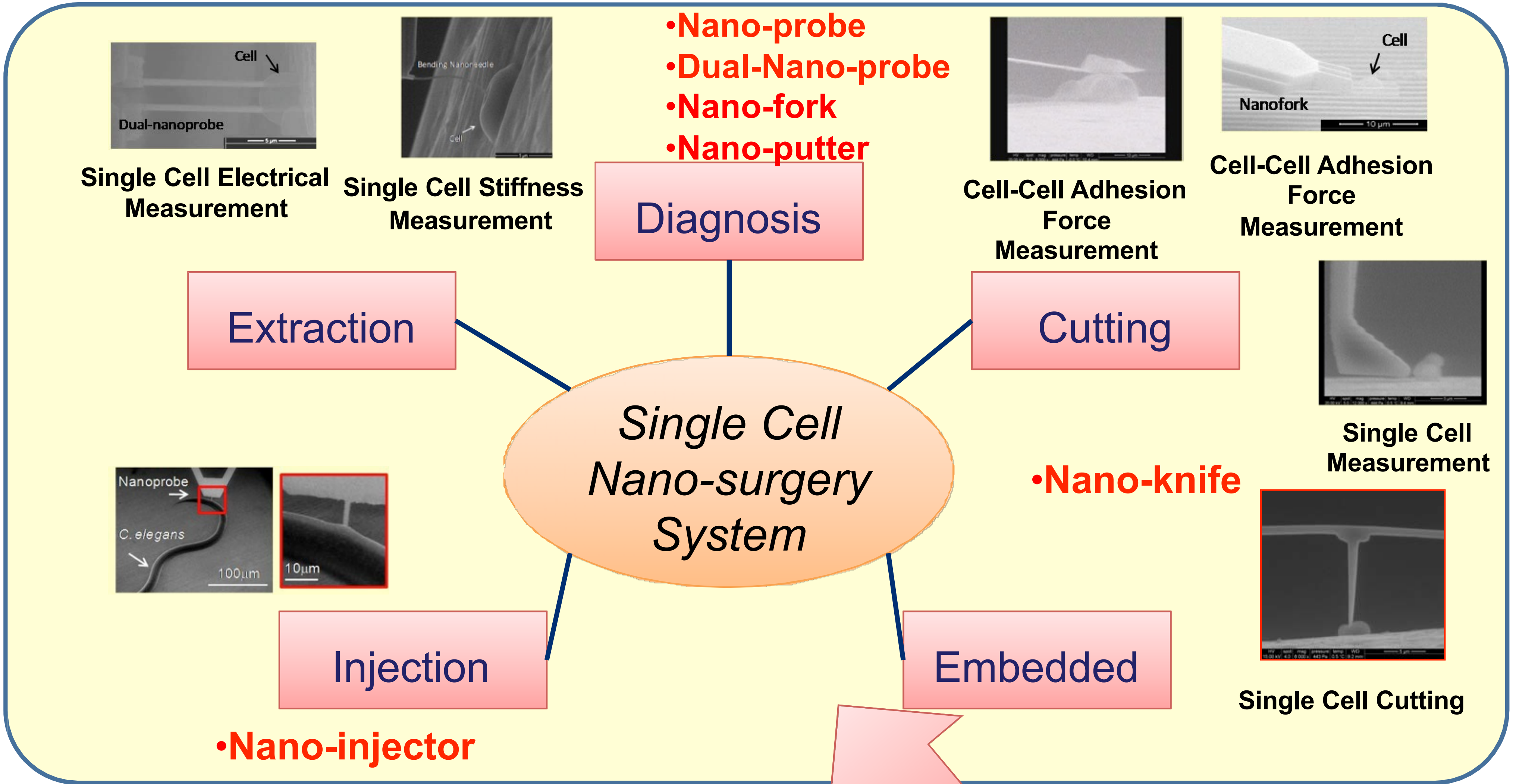
- Bio-micro Manipulation for Single Cell Manipulation

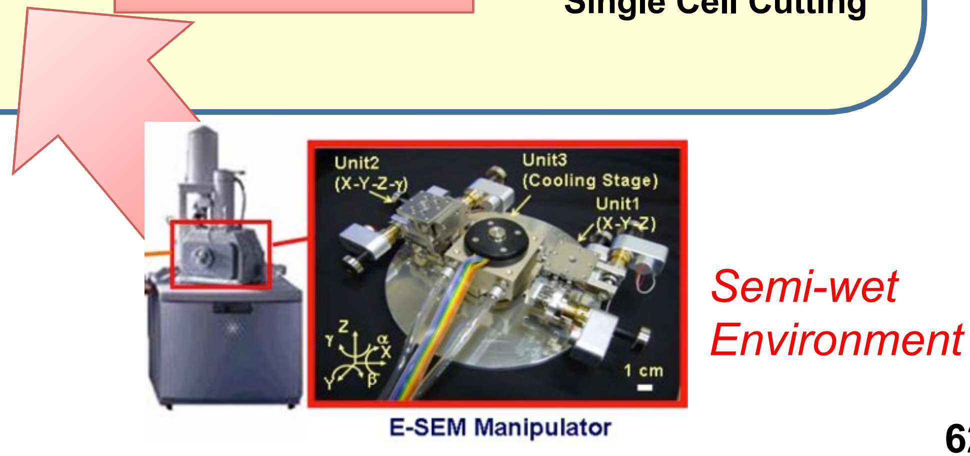
nm

- Nanodevice/Nanomanipulation

ナノマニピュレーションによる単一細胞ナノサージェリシステム

Single Cell Nano－surgery System

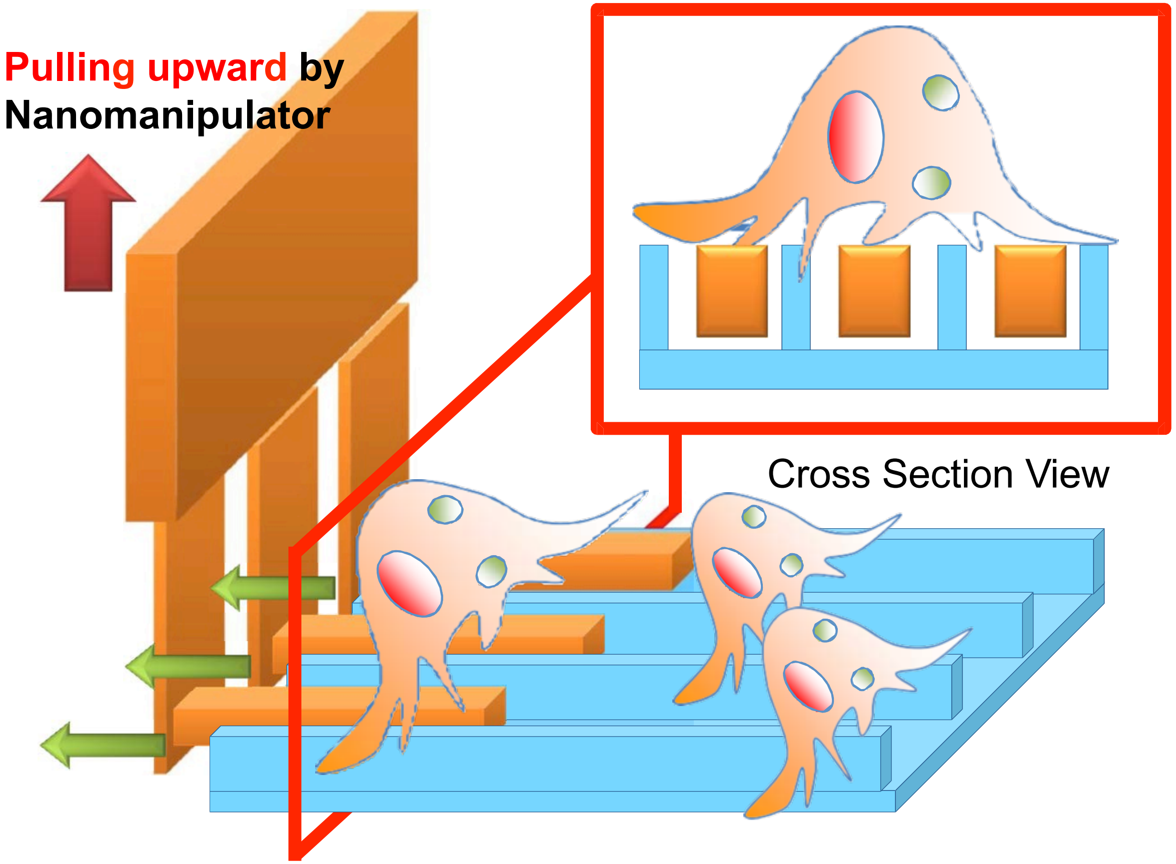


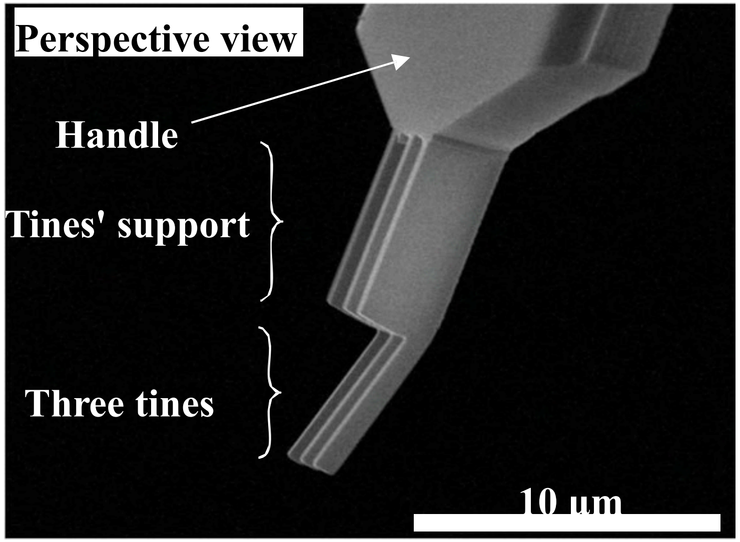


IEEE Transactions on Nanotechnology, Vol. 7 Issue 5, pp. 607-616, 2008
IEEE Transactions on Nanobioscience, Vol. 7 Issue 3, pp. 185-193, 2008
IEEE Transactions on Nanobioscience, Vol. 9, No. 1, pp. 12-23, 2010
Nanotechnology, Vol. 24, Number 14, 145703, 2013
Nanotechnology, vol. 22, No. 30, p. 305701, 2011.
Ultramicroscopy, 111, 8, 1176-1183, 2011
IEEE Transactions on Nanotechnology, Vol. 10 Issue 2, pp. 226-236, 2011
IEEE Transactions on Nanobioscience, Vol. 11 No. 1, pp. 70-78, 2012
IEEE Transactions on Nanotechnology, Vol. 11, No. 2, pp. 298-306, 2012

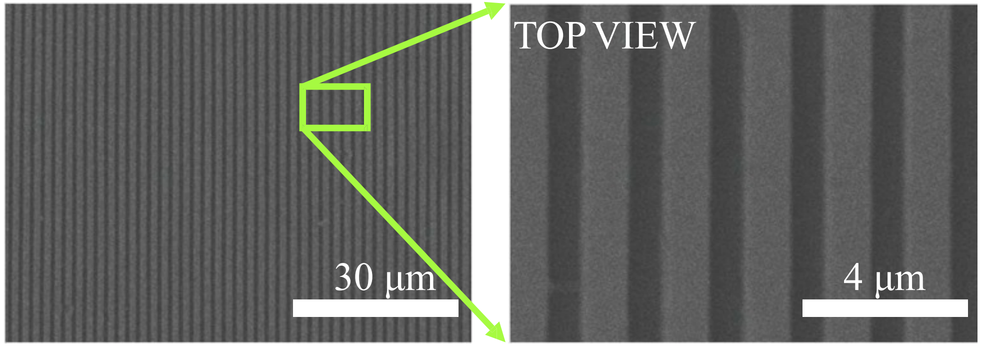
ナノフォークによる単一細胞の付着力計測
Adhesion Force Measurement of Single Cell by Nanofork

Dynamic Sticking Forces Measurement

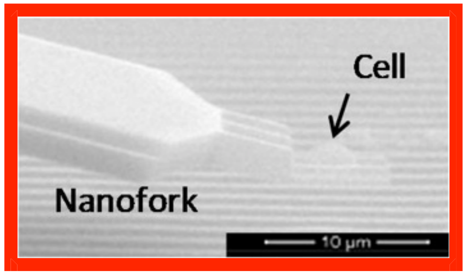




Nano-fork fabricated by FIB



Line-patterned substrate fabricated by Nano-imprinting

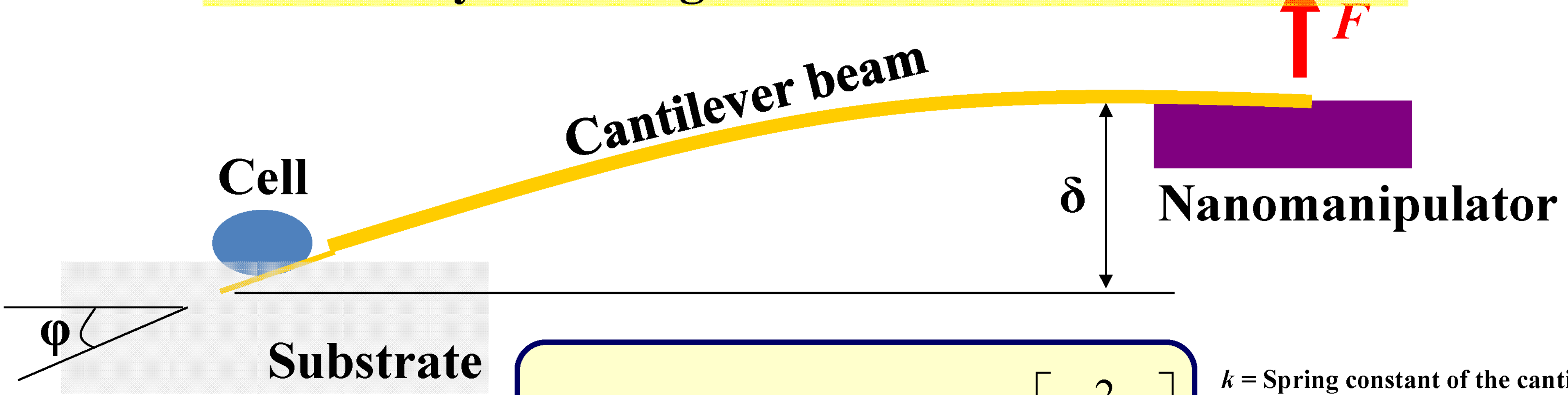


Measuring the sticking forces by the deflection of each cantilevers

M. A. Ridzuan et al., Proc. of IEEE Conf. on Nanotechnology 2010 (IEEE-Nano 2010).

ナノフォークによる単一細胞の付着力計測結果
Results of Single Cell Adhesion Force Measurement by Nanofork

Force Analysis in Single Cell Adhesion Measurement



$$\textbf{Adhesion force} = k * \delta = k\left[\varphi \frac{2}{3} L\right]$$

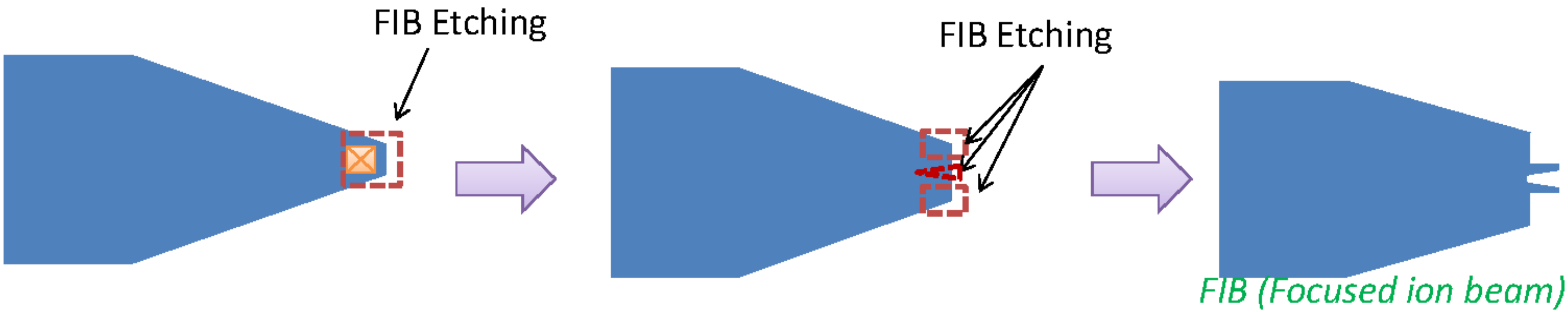
k = Spring constant of the cantilever
L = Length of the cantilever
δ = Deflection length
φ = Deflection angle

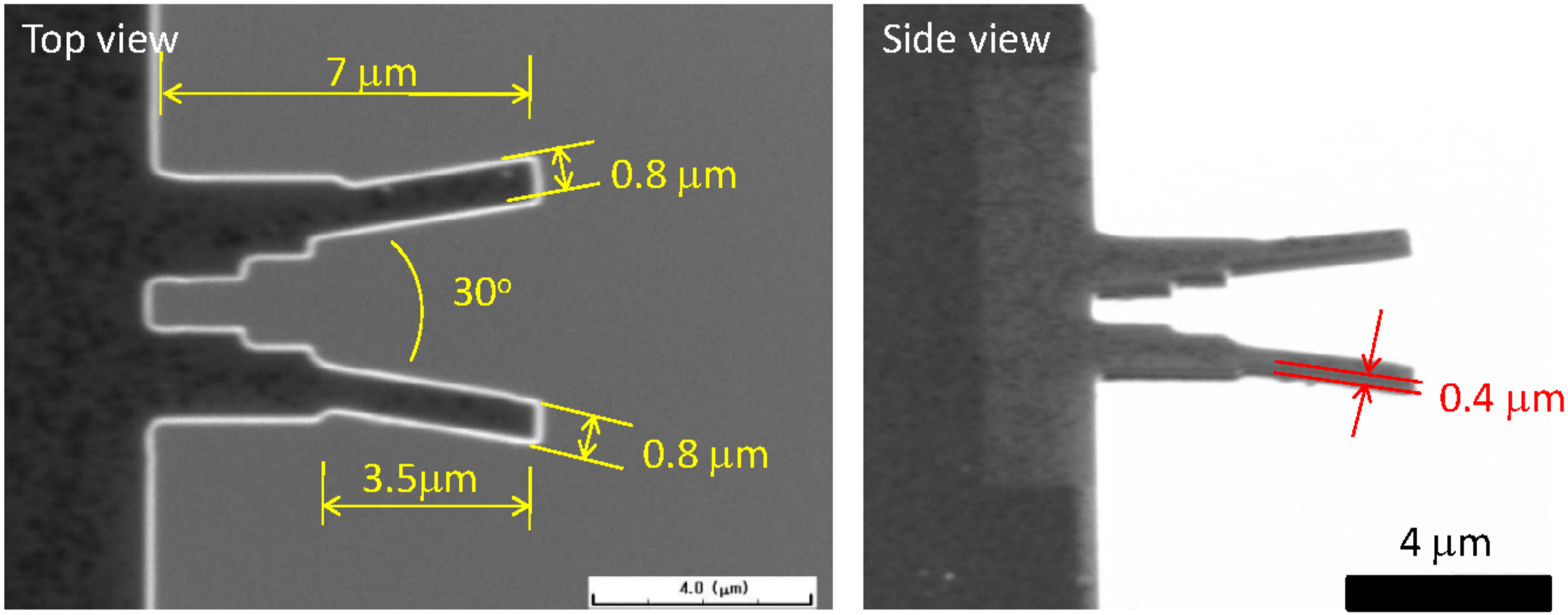
	Parameters for Nanofork		Release Force (nN)
	Spring constant (N/m)	Length (μm)	
Nanofork for 1 μm gap	2.47	192.30	707 ± 106 (n = 2)
Nanofork for 2 μm gap	2.57	191.90	475 ± 87 (n = 4)

M. A. Ridzuan et al., Proc. of IEEE Conf. on Nanotechnology 2010 (IEEE-Nano 2010).

ナノピッカーの作製

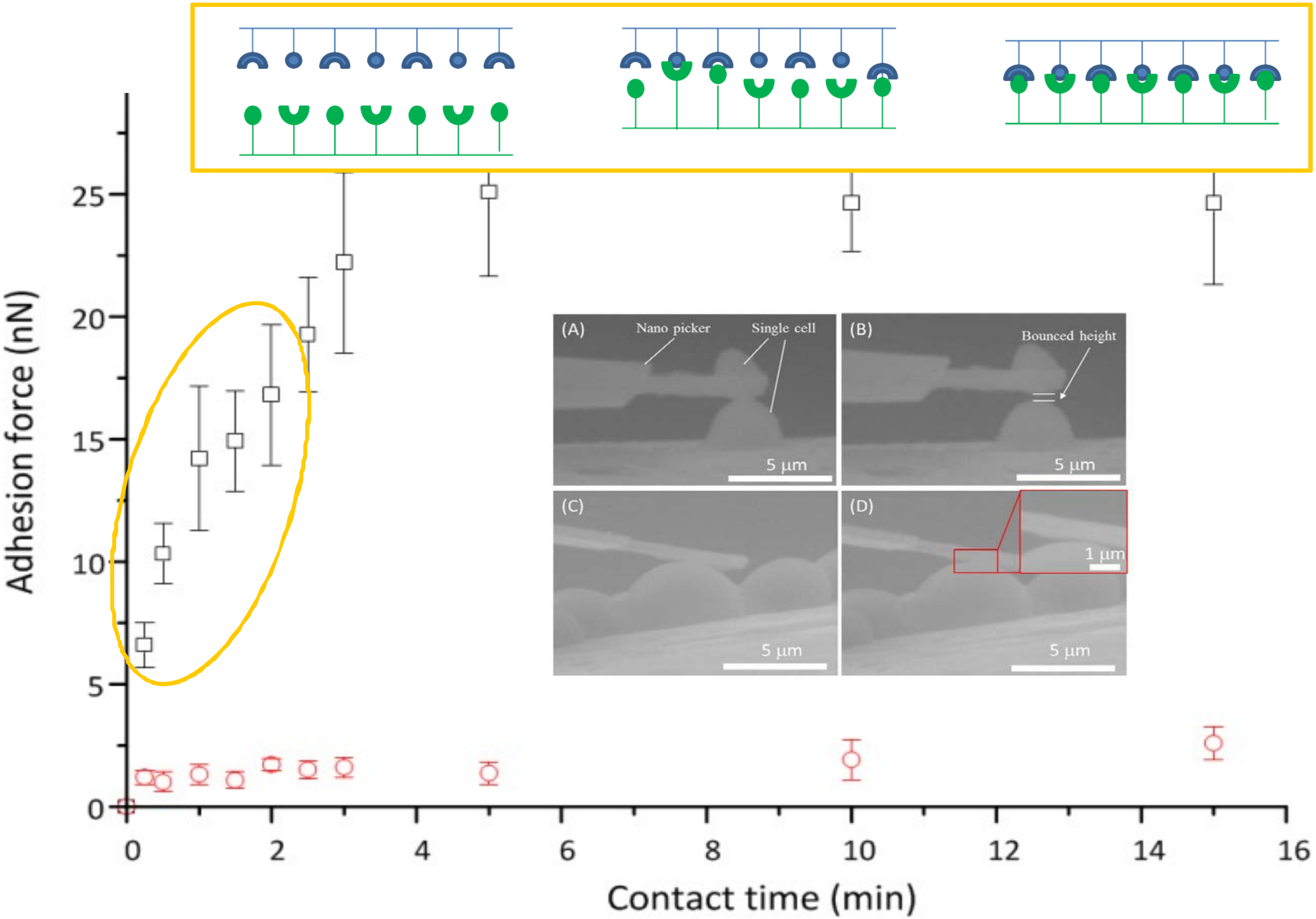
Nano picker fabrication using the cantilever with a spring constant 0.02 N/m





Y. Shen et. Al, Biochemical and Biophysical Research Communication, vol. 409, no. 2, pp. 160-165, 2011.

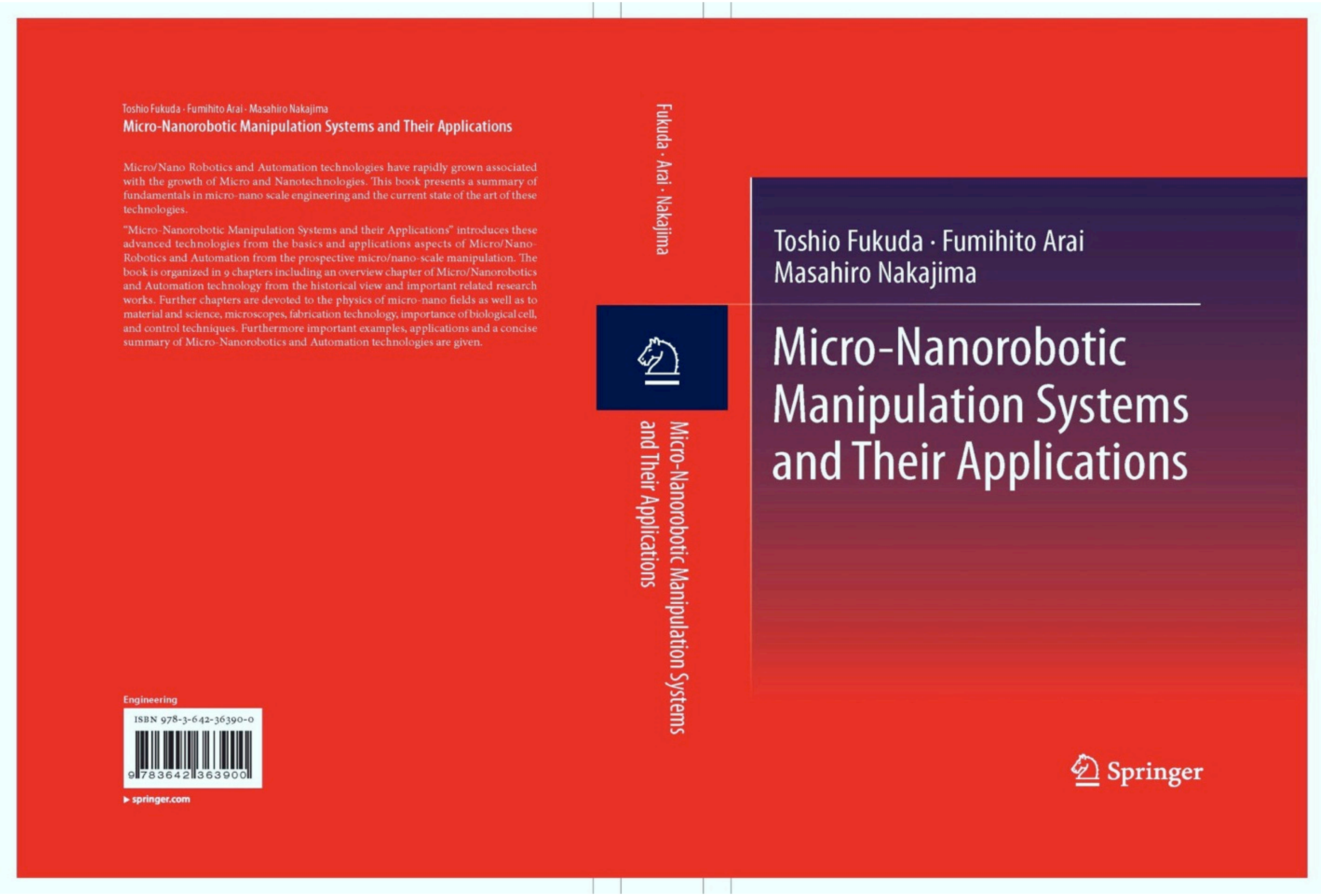
ナノピッカーによる単一細胞の細胞間付着力計測結果



Y. Shen et. Al, Biochemical and Biophysical Research Communication, vol. 409, no. 2, pp. 160-165, 2011.

Micro-Nanorobotic Manipulation Systems and Their Applications

Toshio Fukuda, Fumihito Arai, Masahiro Nakajima, Springer (to be published)



Micro-Nano Mechatronics

- New Trends in Material, Measurement, Control, Manufacturing and Their Applications in Biomedical Engineering-

Edited by Toshio Fukuda, Tomohide Niimi and Goro Obinata, ISBN 978-953-51-1104-7, 364 pages, Publisher: InTech, Chapters published June 05, 2013

Q & A

Acknowledgments

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μ-Mech GEAR
GLOBAL COE PROGRAM

BIO Assembler

Thank you for your attention