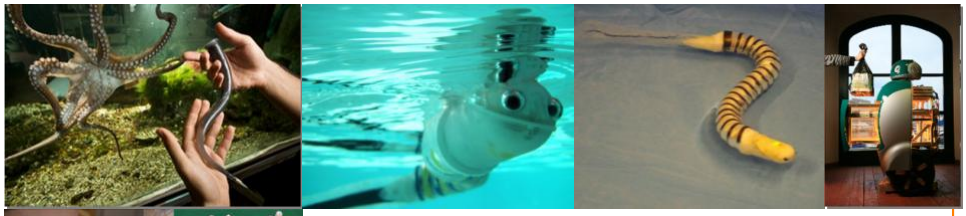
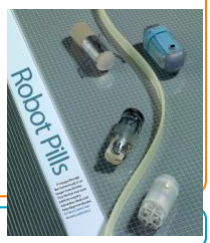
Studiare ingegneria alla Scuola Superiore Sant'Anna
Giornata di orientamento, 15 febbraio 2013, San Miniato (PISA)



# Macchine biorobotiche per la salute

**Arianna Menciassi**
Istituto di BioRobotica
(arianna@sssup.it)

THE BIOROBOTICS INSTITUTE
Scuola Superiore Sant'Anna




## La salute e le macchine?

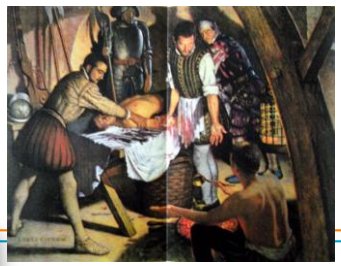
**Quando pensate alla salute pensate a qualcosa del genere?**

**O a qualcosa del genere?**

## La salute e le macchine?

**Quando qualcuno si deve sottoporre a una terapia, preferite un ambiente del genere?**

**O a qualcosa del genere?**



## La salute e le macchine?

**Per descrivere il processo diagnostico, terapeutico o riabilitativo che vi sembra «migliore», usate aggettivi del genere…**

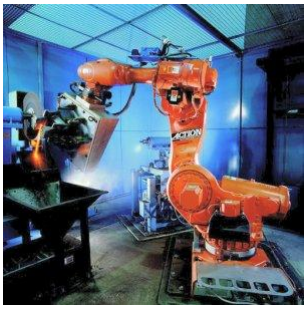
***Accurato, preciso, operatore-indipendente, efficace***

**Oppure qualcosa del genere…**

***Approssimativo, operatore-dipendente, non risolutivo***

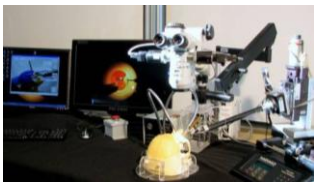
## Perché le macchine (i robot) per la salute?

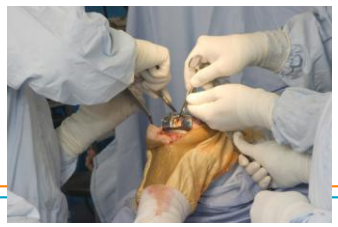
Perché non possiamo ottenere anche in chirurgia, diagnosi e terapia la stessa precisione e accuratezza che caratterizzano i processi di automazione industriale?



Preciso, accurato, ripetibile, veloce

Il contributo delle tecnologie robotiche alle pratiche terapeutiche ed interventistiche.





## Per avere un'idea...

**Arti robotici:**
http://www.youtube.com/watch?v=X85Lpuczy3E

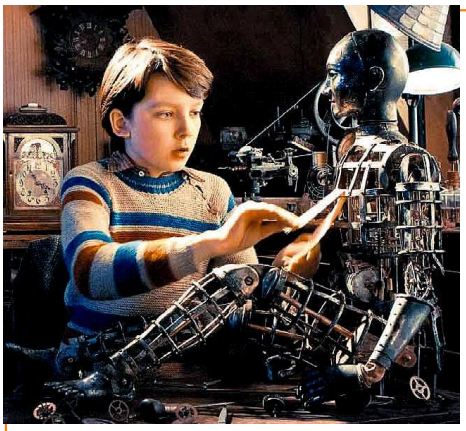
**Macchine per Riabilitazione:**
http://www.youtube.com/watch?v=TwbPchbtLyc
http://www.youtube.com/watch?v=3vxnvIbTiNU

**Macchine per Chirurgia:**
http://www.youtube.com/watch?v=hyPtJzXhRdU
http:// www.youtube.com/watch?v=VJ_3GJNz4fg

# La Robotica

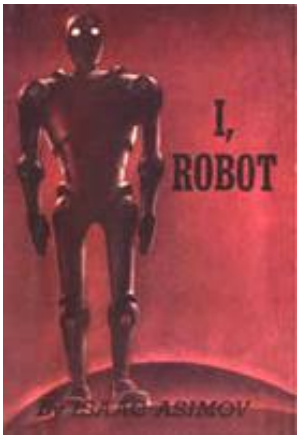
Il termine ***robot*** fu usato per la prima volta dallo scrittore ceco **Karel Čapek**, nel **1920** nel suo romanzo *R.U.R. (Rossum's Universal Robots)*. Deriva dal termine **ceco *robota***, che significa "**lavoro pesante**" o "**lavoro forzato**".
In realtà il vero inventore della parola *robot* fu il fratello di Karl Čapek, **Josef**, anche lui scrittore e pittore cubista, il quale utilizzò la parola "*automat*", (automa), in un suo racconto del **1917**, ***Opilec*** ("L'ubriacone").
Il termine greco ***autòmaton*** significa "che si muove da sé".

# L'attenzione per i «giocattoli» meccanici nei secoli scorsi e … anche in film recenti



## La Robotica

- Il termine "**robotica**" venne usato per la prima volta (su carta stampata) nel racconto di Isaac Asimov intitolato *Circolo vizioso* (*Runaround*, 1942), presente nella sua famosa raccolta *Io, Robot*.
- In esso, egli citava le *tre regole della robotica*, che in seguito divennero le **Tre leggi della robotica**.




First edition cover, December 2, 1950

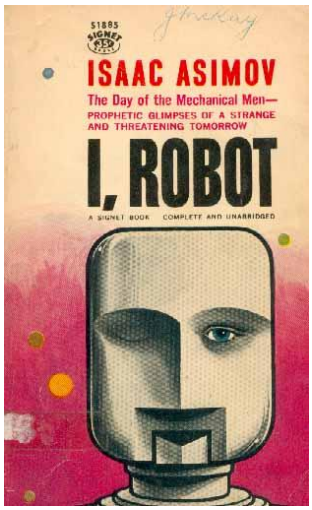
## Definizioni di Robotica

- A robot is a re-programmable, multi-functional, manipulator designed to move material, parts, or specialized devices through variable programmed motions for the performance of a task
- *Un robot è un manipolatore multifunzionale riprogrammabile progettato per muovere materiali, componenti, o dispositivi specializzati, attraverso movimenti variabili programmati per lo svolgimento del compito*

*Robotics Industry Association (~ 1980)*

Jablonsky J., Posey J. 1985. "Robotics Terminology", in *Handbook of Industrial Robotics*, ed. S. Nof, J. Wiley, New York, pp.1271-1303

## Le origini della robotica moderna

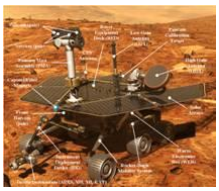



Isaac Asimov
*Scrittore*


*Nel 1960 il primo robot industriale fu installato presso un impianto produttivo General Motors in New Jersey (USA)*

## Dalla Robotica industriale alla robotica di servizio

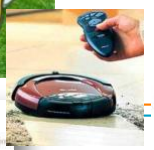
Esplorazioni spaziali



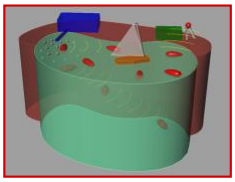
Applicazioni militari

Esplorazioni sottomarine

Applicazioni domestiche



Igiene urbana e monitoraggio ambientale




January 2007

# I robot fuori dalle fabbriche…



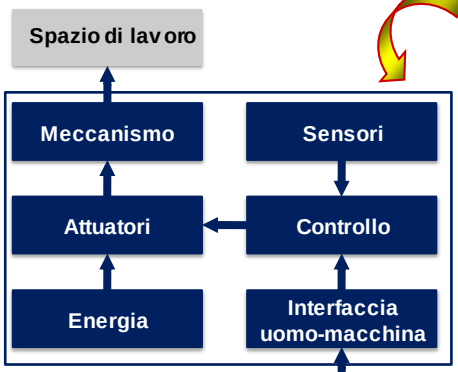

- Condivisione dello spazio di lavoro tra persone e robot
- Maggiori capacità percettive
- Comportamento reattivo

## Meccatronica: il paradigma per la progettazione di robot

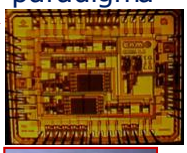
Paradigma "Meccatronico" per la progettazione di macchine

Boeing 777

Ferrari - 550 Maranello




Avvento della microelettronica: cambio di paradigma



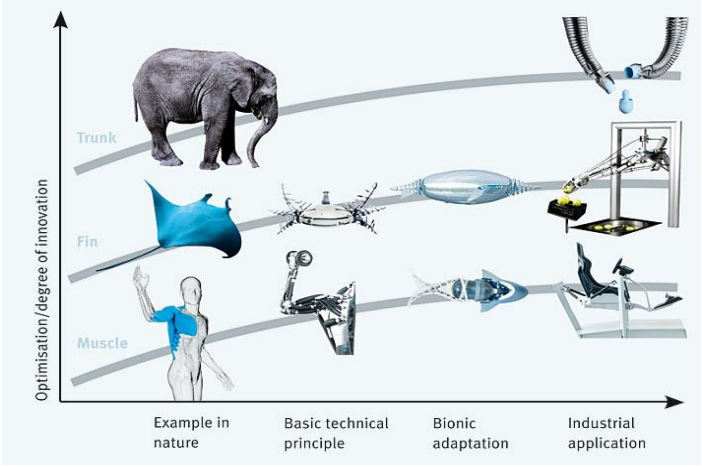
Lavatrice

Telecamera digitale

## Dalla Meccatronica alla BIOmeccatronica

- **Bio***meccatronica*: i sistemi biologici rappresentano un eccellente esempio da imitare
- **Bio***meccatronica*: sistemi meccatronici che hanno una relazione (o un'interazione) con sistemi biologici
- **Bio***meccatronica*: sistemi meccatronici che entrano nel processo di diagnosi, riabilitazione, cura, e reinserimento socio-lavorativo di una persona

# Biorobotics Engineering

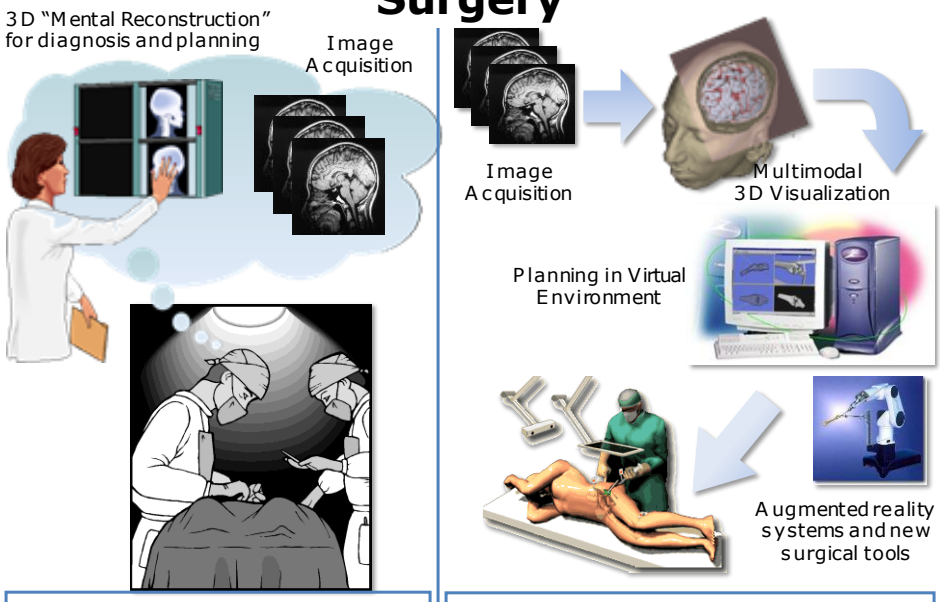


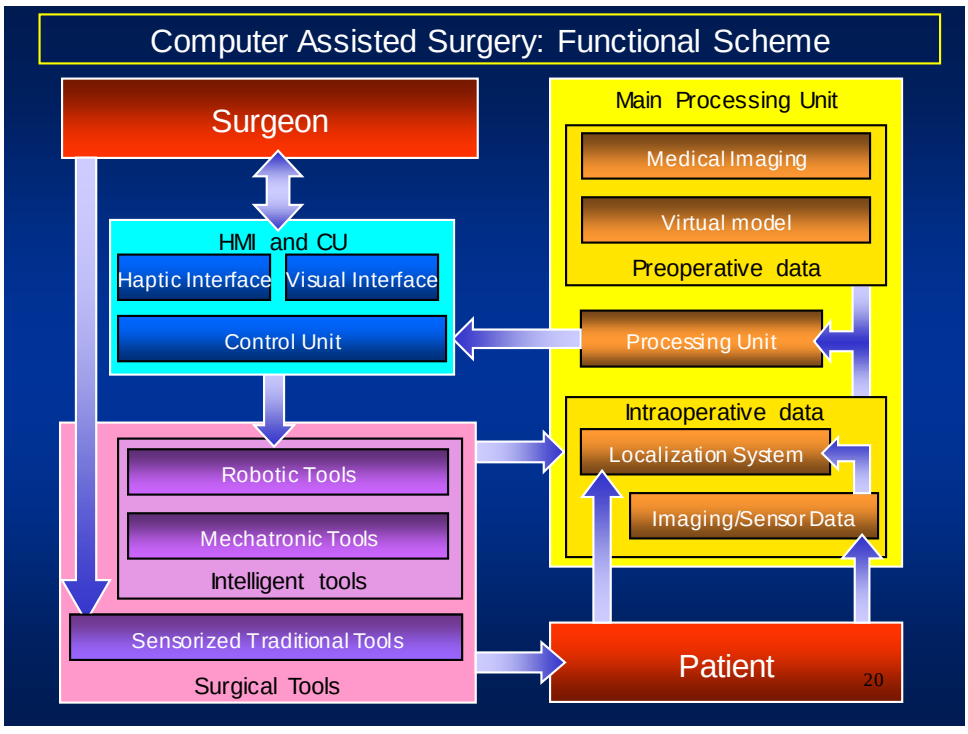

Using **biological principles** of functioning to develop **new application solutions**

Tra le molteplici macchine per la salute…

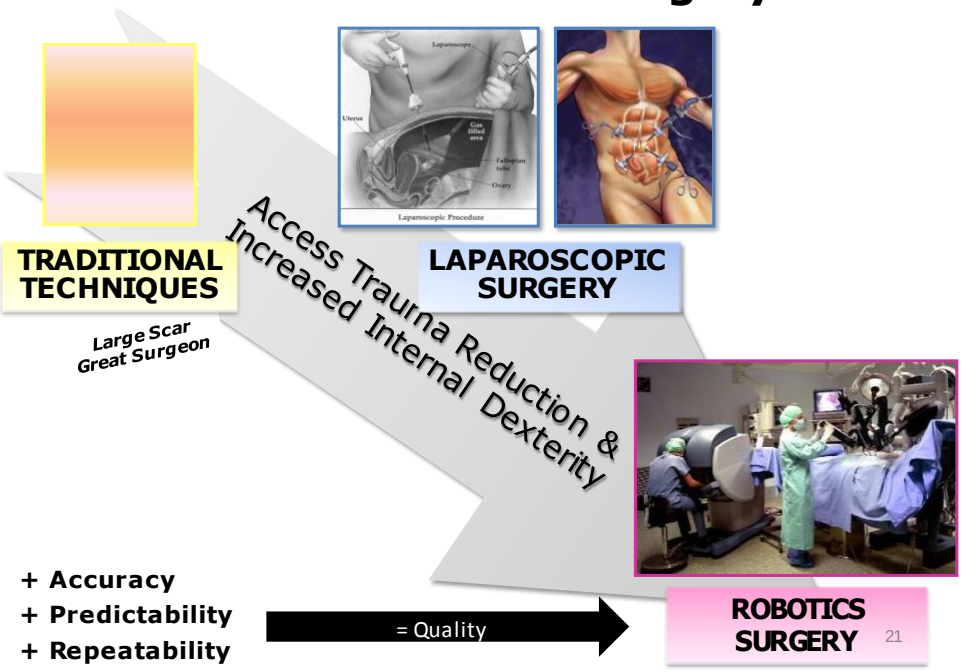
…ci concentriamo sulle macchine per interventi, terapia e chirurgia

# From Traditional to Computer-Assisted Surgery



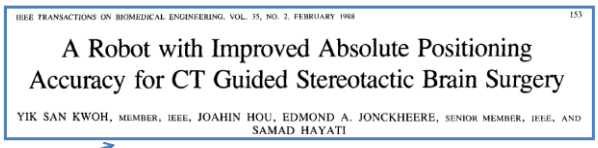
# The Evolution of Surgery




# History of Robotics Surgery

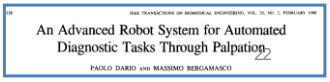
- 1985: Erich Mühe
  1st laparoscopic cholecystectomy
- **1985: Kwoh, Young et al.**
  **1st robot in neurosurgery (Puma 560)**
- 1987: 1st video-laparoscopic cholecystectomy
- **1989: Benabid, Lavallée, Cinquin et al.**
  **1st patient in neurosurgery (Neuromate)**


Neuromate® has been used in thousands of electrode implantation procedures for Deep Brain Stimulation, and Stereotactic Electroencephalography, as well as stereotactic applications in neuro-endoscopy, radiosurgery, biopsy, and Transcranial Magnetic Stimulation.


IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, VOL. 35, NO. 2, FEBRUARY 1988 153

A Robot with Improved Absolute Positioning Accuracy for CT Guided Stereotactic Brain Surgery

YIK SAN KWOH, MEMBER, IEEE, JOAHIN HOU, EDMOND A. JONCKHEERE, SENIOR MEMBER, IEEE, AND SAMAD HAYATI


An Advanced Robot System for Automated Diagnostic Tasks Through Palpation

PAOLO DARIO AND MASSIMO BERGAMASCO

IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, 1988

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- **1991: Davies et al.**
  **1st patient for prostate surgery (Puma 560)**

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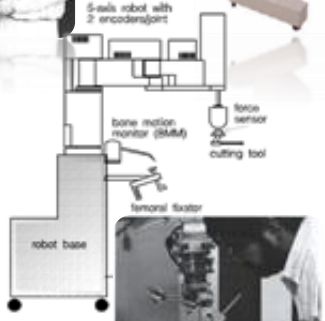
  1st patient in neurosurgery (Neuromate)
- 1991: Davies et al.
  1st patient for TURP (Puma 560)
- **1992: Taylor et al. Integrated surgical systems 1st <u>hip</u> surgery with ROBODOC**

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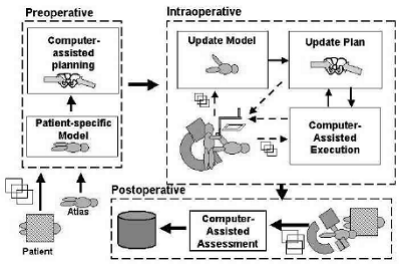
# The ROBODOC Integrated Surgical Systems, Inc.

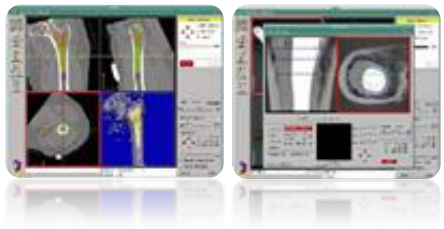



**Bone implant comparison**

Manual broach method
20% contact surface
1-4 mm gap size

RO BODOC method
96% contact surface
0.05 mm gap size

ORTHODOC Pre-surgical planning station



http://www.robodoc.com



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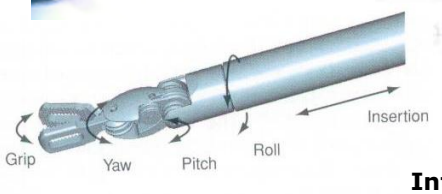
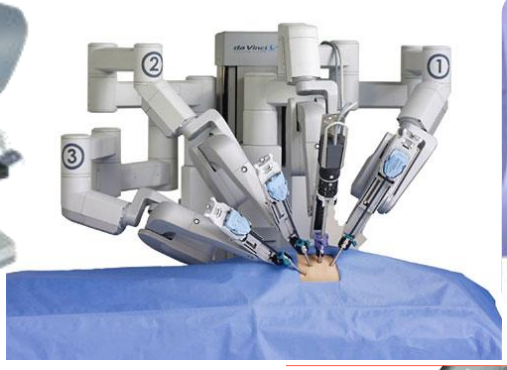
- 1991: Davies et al.
  1st patient for TURP (Puma 560)
- 1992: Integrated surgical systems
  1st hip surgery with ROBODOC
- **1995: Intuitive Surgical Inc. was founded**
- **1998: Intuitive Surgical Inc.**
  **1st totally endoscopic coronary artery bypass grafting using the da Vinci ROBOTIC SYSTEM**

# A success story in surgical robotics: the "daVinci" system

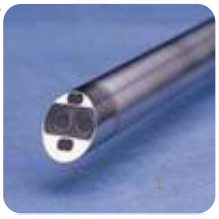



Intuitive "Endowrist"

# The "Secrets" of the DaVinci Robot Success: Accuracy, Dexterity, Intuitiveness




- Outstanding mechanical design
- Excellent optics (2D and 3D vision)
- Smart and friendly interfaces

## The Image-Guided CyberKnife System by AccuRay (Sunnyvale, CA, USA) for Computer-Assisted Radiotherapy

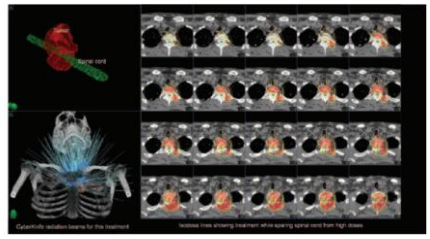



**Figure 4** Top left image: the patient model with the tumour to be targeted and the spinal cord radiosensitive area. Bottom left: CyberKnife radiation beams for treatment. Right: Isodose lines for treatment.

The main reasons for success:

- **Accuracy**
- **Tracking system for motion compensation**


**6MV linear accelerator for X-ray tumor ablation**

**J.R. Adler, M.J. Murphy, S.D. Chang, S.L. Hankock: Image guided robotic radiosurgery, Neurosurgery 44(6), 1299–1306 (1999)**

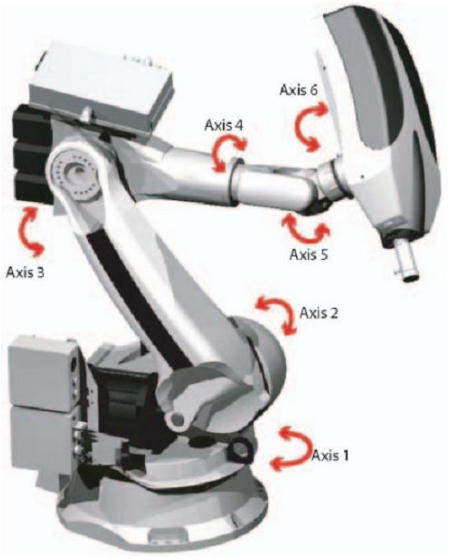
# The CyberKnife Robot

## 6-dof KUKA Robot

- Robotic targeting precision <0.2mm
- Payload: 150 kg
- Max. reach: 2700/2900/3100 mm
- Weight: 1285 kg

## Overall precision of treatment

- <0.95mm for cranial and spinal lesions
- 1.5mm for moving targets with respiratory tracking



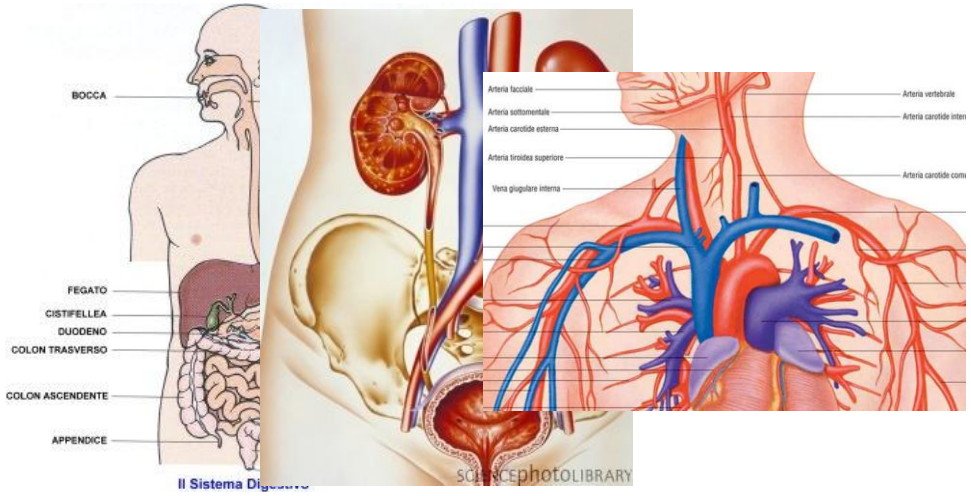
# The Synchrony Tracking System


**1.5mm ACCURACY for moving targets with respiratory tracking**

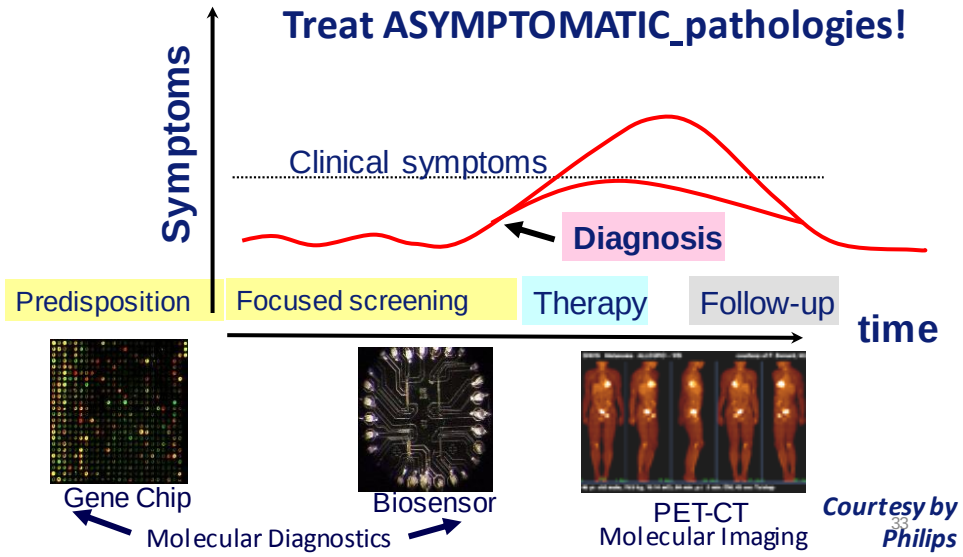
Correspondence model of LEDs and fiducial positions is created intra-operatively. LED position is then tracked in real-time



Perché solo robotica "grande"?
Non si possono ottenere gli stessi vantaggi (precisione, diagnosi precoce, accuratezza) con robot più piccoli, "amichevoli", che non fanno incisioni?

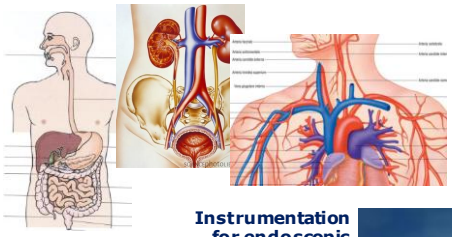


# Prevention: the challenge of modern medicine




## Endoluminal Therapy and Surgery

Endoluminal procedures consist of bringing a set of advanced therapeutic and surgical tools to the area of interest by navigating in the *lumens* of the human body, such as the gastrointestinal tract, the urinary apparatus, the circulatory system, etc.



PillCam for GI tract endoscopy

Clip for endoscopic surgery


Instrumentation for endoscopic surgery and NOTES (Natural Orifices Transgastric Endoscopic Surgery)

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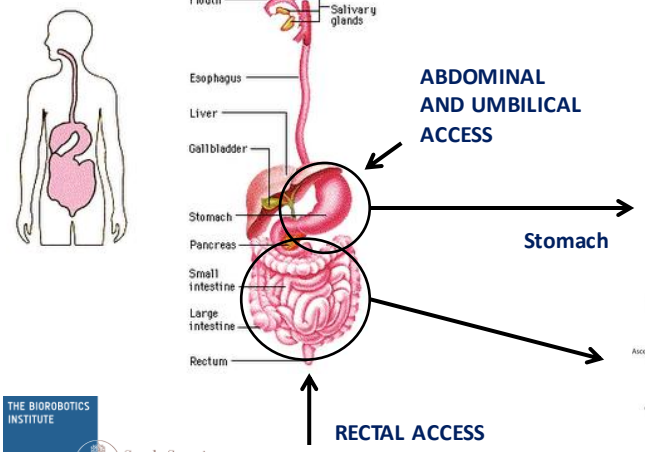
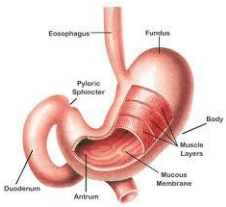
# Endoluminal endoscopy and therapy in the gastrointestinal tract: different possible accesses

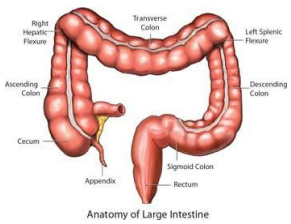
**Gastrointestinal Tract (from esophagus to rectum): Ø = 10 to 30 mm**

Small diameter → Miniaturization
Physiological curvature → Dedicated/Conformable shape
Collapsed tissues → Active mechanism needed for locomotion




Stomach

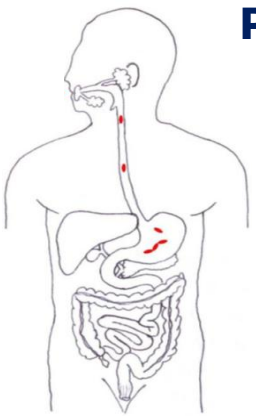



Anatomy of Large Intestine

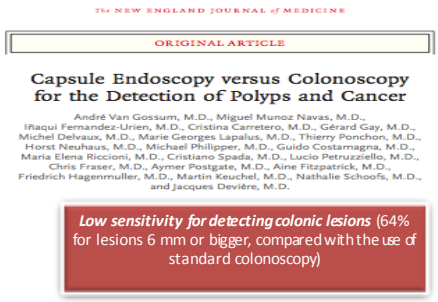
Colon

THE BIOROBOTICS INSTITUTE
Scuola Superiore Sant'Anna

# Passive wireless capsules for gastrointestinal endoscopy




*May 2000: Given Imaging (now PillCam) capsule for endoscopy*


The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

**Capsule Endoscopy versus Colonoscopy for the Detection of Polyps and Cancer**

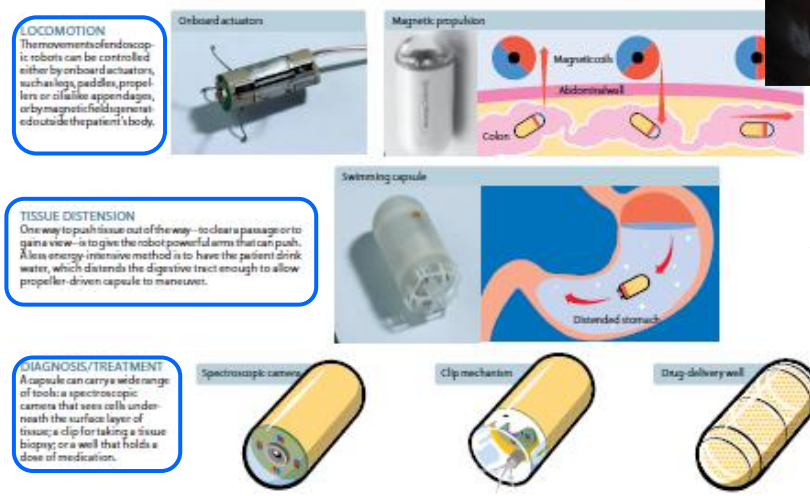
André Van Gossum, M.D., Miguel Munoz Navas, M.D., Iñaqui Fernandez-Urien, M.D., Cristina Carretero, M.D., Gérard Gay, M.D., Michel Delvaux, M.D., Marie Georges Lapalus, M.D., Thierry Ponchon, M.D., Horst Neuhaus, M.D., Michael Philipper, M.D., Guido Costamagna, M.D., Maria Elena Riccioni, M.D., Cristiano Spada, M.D., Lucio Petruzziello, M.D., Chris Fraser, M.D., Aymer Postgate, M.D., Aine Fitzpatrick, M.D., Friedrich Hagenmuller, M.D., Martin Keuchel, M.D., Nathalie Schoofs, M.D., and Jacques Devière, M.D.

***Low sensitivity for detecting colonic lesions*** (64% for lesions 6 mm or bigger, compared with the use of standard colonoscopy)

Benefits:
- Small system dimension
- Low invasiveness procedure
- Access to small bowel

Limitations:
- **Passive locomotion** (no controlled halts: capsule movement by peristalsis)
- Some false negative results

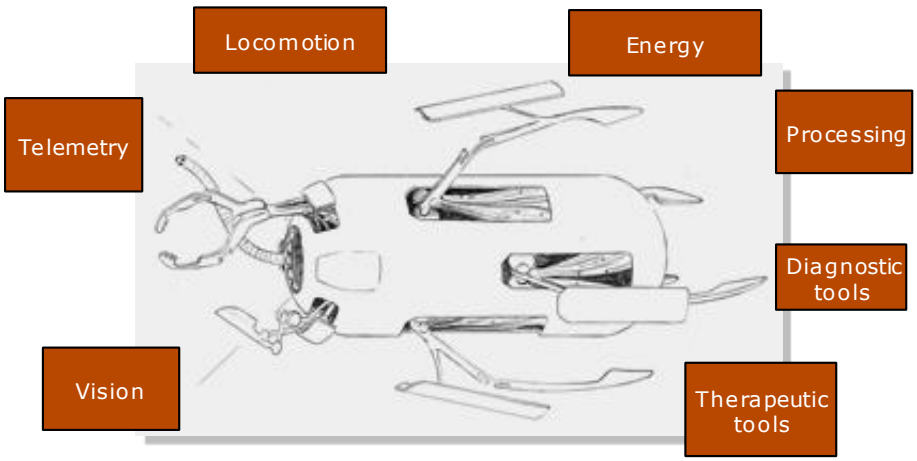
# Overcoming the Limitations of Passive Endoscopic Capsules


*P. Dario and A. Menciassi Scientific American, August 2010*

37

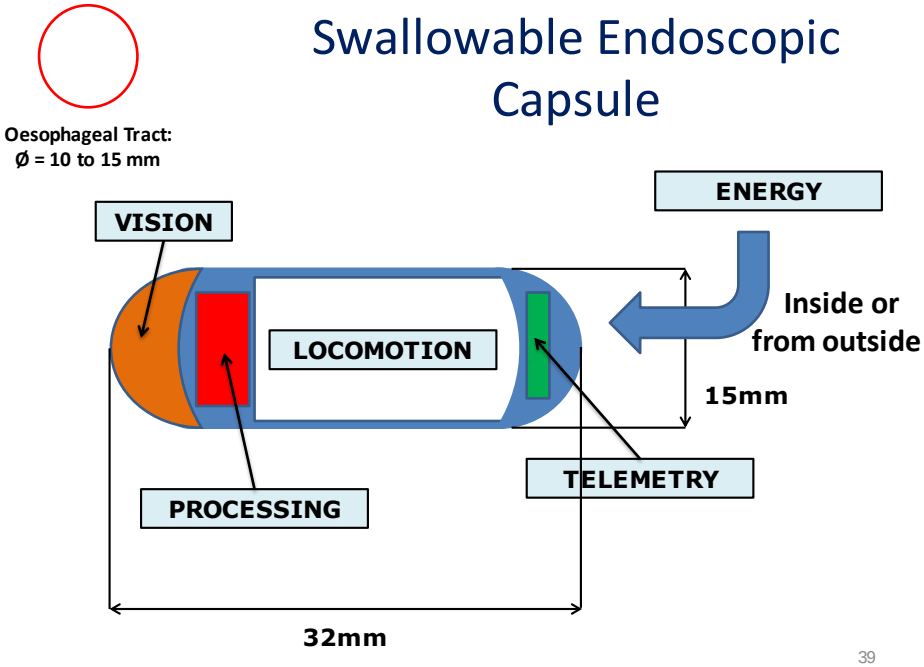
# **ACTIVE** WIRELESS Capsule for Endoscopy




The engineering design challenge: all components MUST fit in a **swallowable** size (**Ø ~12 mm x L~ 32 mm**)

38

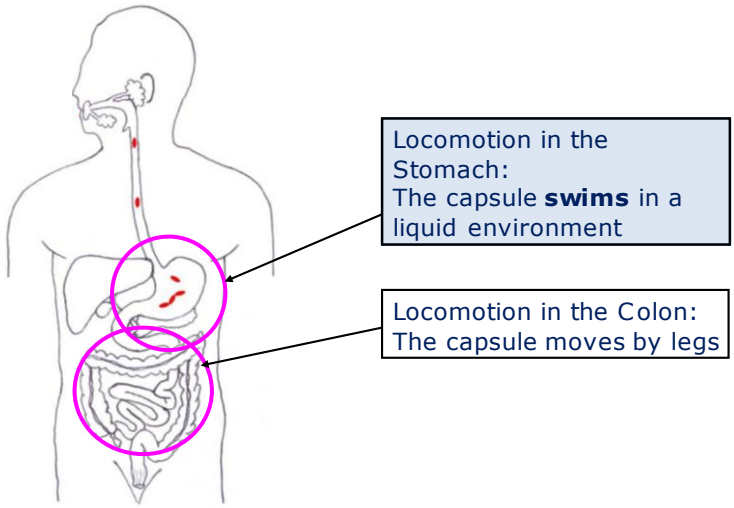
# Swallowable Endoscopic Capsule




39

# Active Endoscopic Capsules

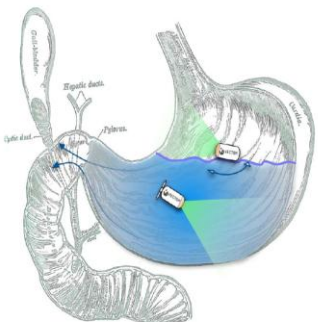
Examples of locomotion strategies optimized for two targeted districts: stomach and colon

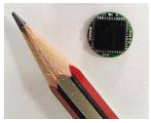


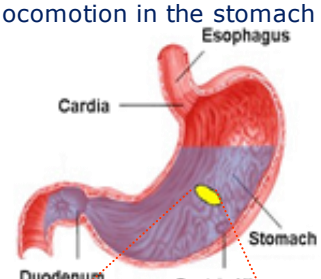

40

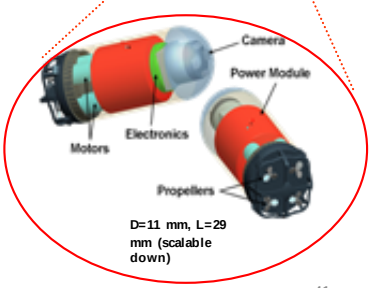
## Wireless Capsule for PAINLESS GASTROSCOPY

Ingestion of liquid in context with the examination allows to obtain organ distension, thus making possible a low power 3D locomotion in the stomach





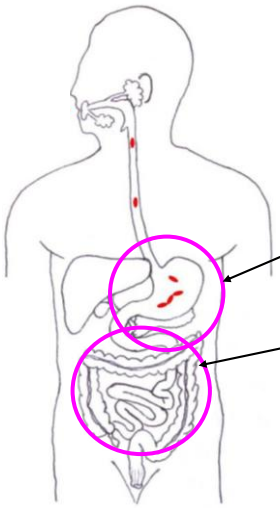



41

## Active Endoscopic Capsules

Examples of locomotion strategies optimized for two targeted districts: stomach and colon



Locomotion in the Stomach:
The capsule **swims** in a liquid environment

Locomotion in the Colon:
The capsule **moves by legs**

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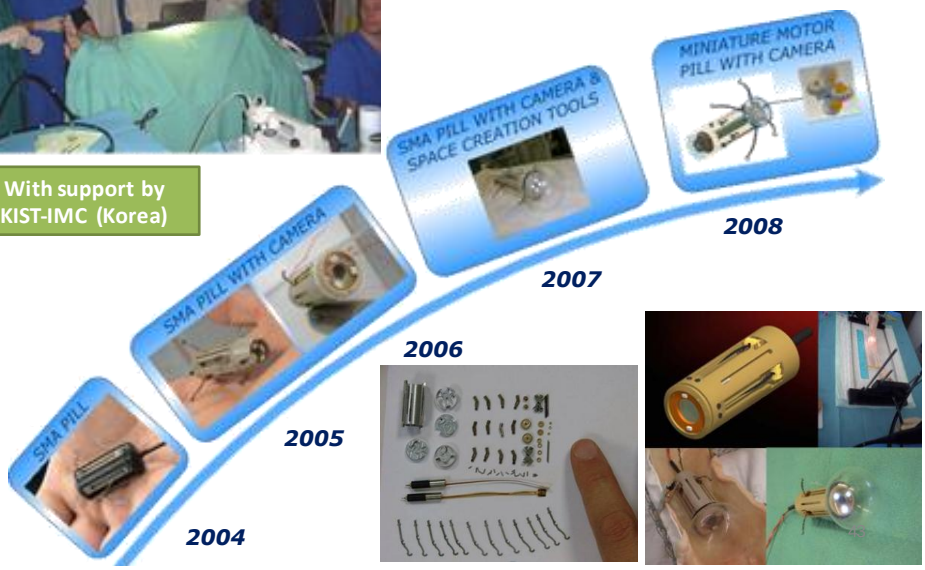
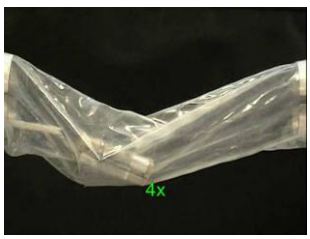
# Developing a Legged Locomotion System

With support by KIST-IMC (Korea)




# Legged Endoscopic Capsules for Tubular Organs

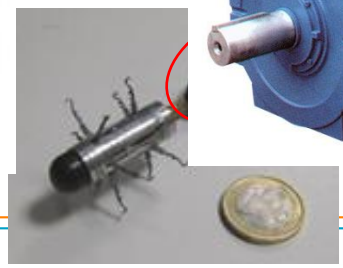
**Features: 12 legs (6 in the front and 6 in the rear part)**
**Dimensions: Φ11 mm; L30 mm**
**Average speed: 5 cm/minute**
**Pulling force: 3.8 N → 0.66 N per leg**

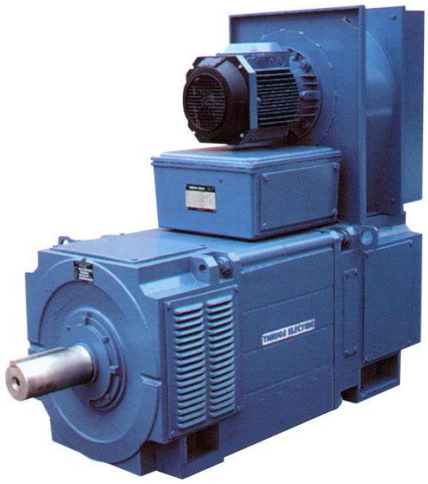





1. A. Moglia, et al. **THE LANCET**, Vol 370 July 14, 2007, pp. 114-116
2. P. Valdastri, R. J. Webster III, C. Quaglia, M. Quirini, A. Menciassi, P. Dario, "*A New Mechanism for Meso-Scale Legged Locomotion in Compliant Tubular Environments*", **IEEE Transactions on Robotics**, 2009, Vol. 25, No. 5, pp. 1047-1057.
3. C. Quaglia, E. Buselli, R. J. Webster III, P. Valdastri, A. Menciassi, P. Dario, "*An Endoscopic Capsule Robot: A Meso-Scale Engineering Case Study*", **Journal of Micromechanics and Microengineering**, 2009, Vol. 19, No. 10, 105007.
4. E. Buselli, P. Valdastri, M. Quirini, A. Menciassi, P. Dario, "*Superelastic leg design optimization for an endoscopic capsule with active locomotion*", **Smart Materials and Structures**, Vol. 18, No. 1, January 2009.

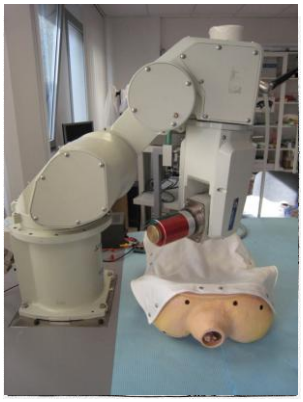
## Il problema dell'energia e dell'attuazione in sistemi miniaturizzati e senza fili



## How adding energy and dragging force from outside?

## Magnetism ⟺ Endoscopy

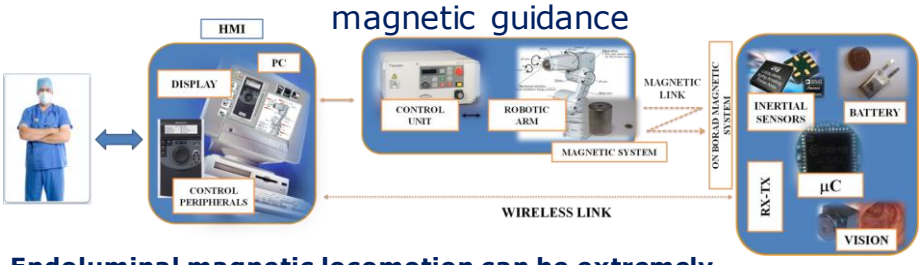


**William Gilbert , 1600**
De Magnete, Magneticisque Corporibus, et de Magno Magnete Tellure *(On the Magnet and Magnetic Bodies, and on That Great Magnet the Earth)*

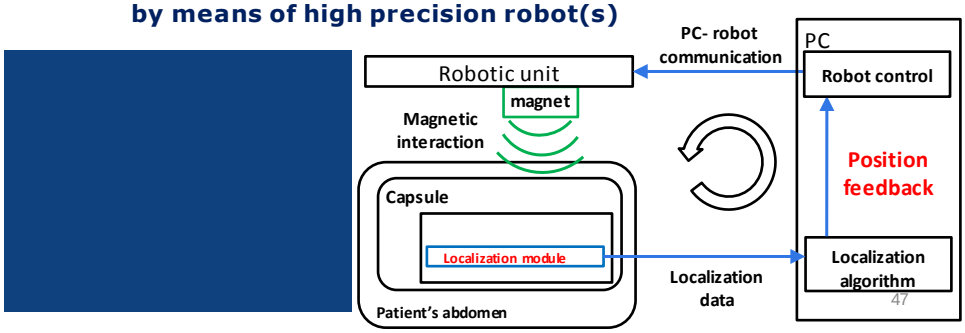
**E.H. Frei, Magnetism and Medicine, J. Appl. Phys. 40, 955 (1969)**

…Present devices include magnets to remove objects from the eye and to facilitate the withdrawal of swallowed safety pins and similar objects… In more sophisticated applications magnetic materials are purposely introduced into the body to accomplish various tasks. Magnetically guided catheters have been used to negotiate the tortuous passageways of blood vessels… magnet inside the stomach is switchable by withdrawing in into a magnetic field… **a ferromagnetic material may be controlled by external magnets, by permitting a more detailed examination of the stomach and small intestine…**

## A possible solution to overcome the energy problem in active capsule endoscopy: robot-assisted wireless magnetic guidance




**Endoluminal magnetic locomotion can be extremely precise when the external magnet (s) is/are moved by means of high precision robot(s)**

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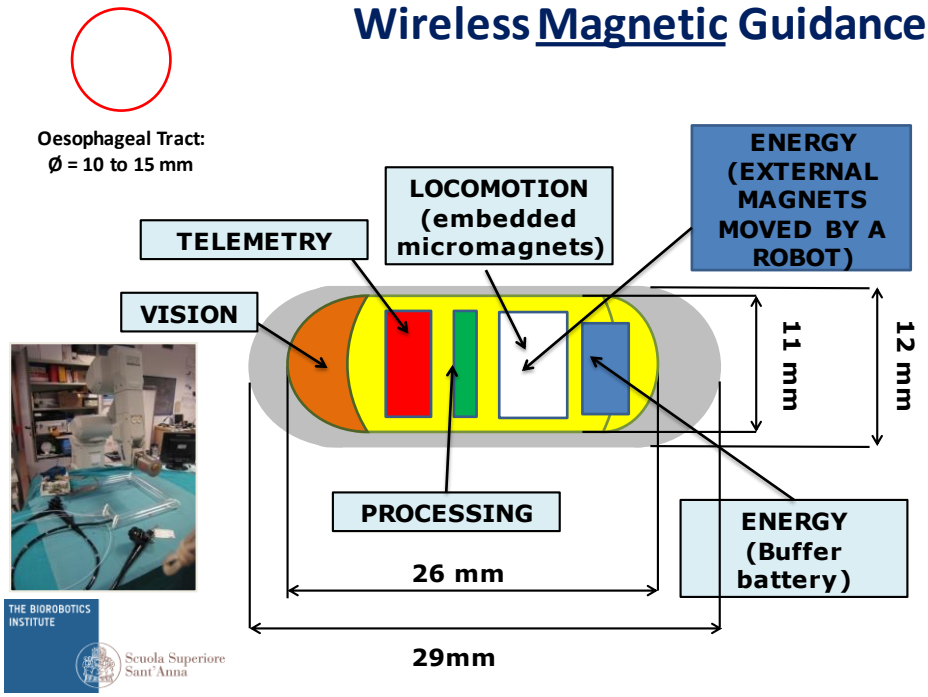
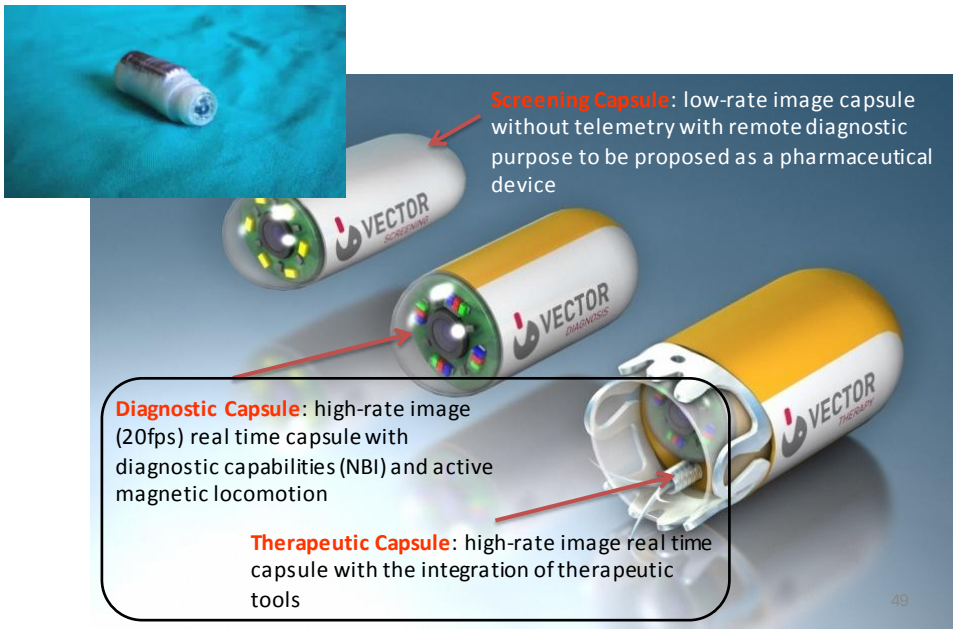
## Wireless Magnetic Guidance



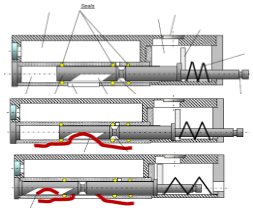
## Swallowable, active endoscopic capsules with additional therapeutic and diagnostic capabilities



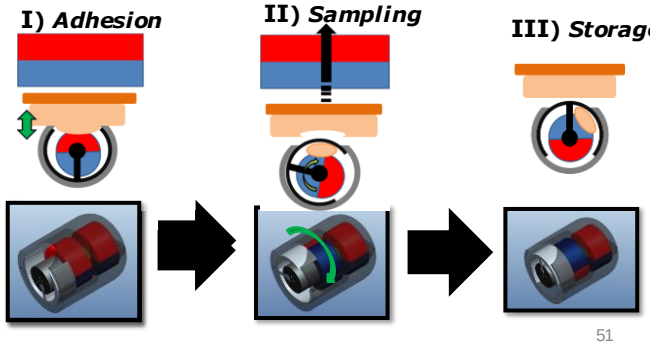

## Swallowable, active endoscopic capsules with additional therapeutic and diagnostic capabilities

# Capsule for wireless biopsy


- **bistable mechanism**
- **activation by external magnetic field**
- **effective adhesion to bowel wall**



-Capable of 10 biopsies
- 11mm x 25 mm

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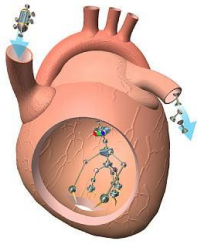
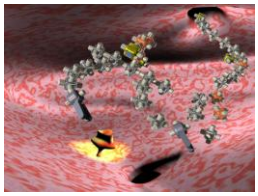
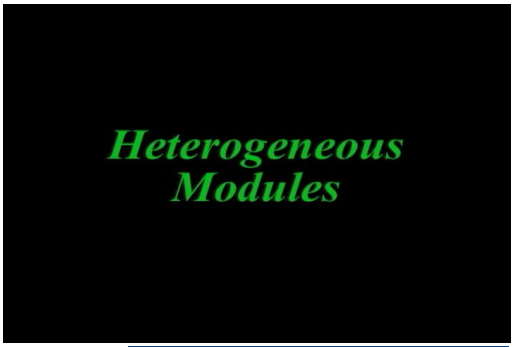
From **Single** Capsules to a **Molteplicity** of Capsules: **Modular** and **Reconfigurable** Surgical Instruments



'CEBOT' concept and prototypes, Professor **Toshio Fukuda**, Nagoya, Japan



**EU ARES Project**, **P. Dario** (SSSA), **Brad Nelson** (ETH), **Jean-Pierre Merlet** (INRIA) and **Josep Samitier** (UB-CBEN)




# Different Accesses

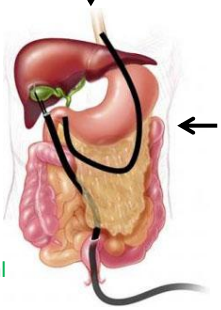
NOTES (Trans-Oesophageal or Trans-Vaginal

- Small dimension
- Anatomical constraints
- Safety issues

- Totally scarless
- Reduce post-interventional complications

Abdomen by NOTES/Single Port Access access: Ø = 15 to 32 mm

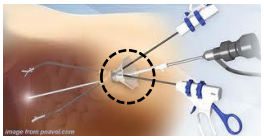
OESOPHAGEAL ACCESS



TRANSVAGINAL ACCESS

UMBILICAL ACCESS

SINGLE PORT ACCESS (Trans-Umbilical)



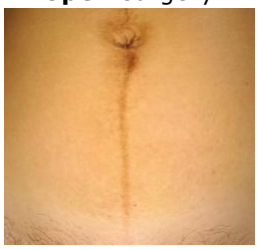
- Fulcrum effect
- Instruments collision
- Triangulation limitation

- Single scarless incision

THE BIOROBOTICS INSTITUTE
Scuola Superiore Sant'Anna

# N.O.T.E.S and **Single Port Laparoscopy**: no visible scars!

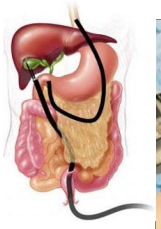
**Open** surgery



Abdominal incision **1 year after open surgery**

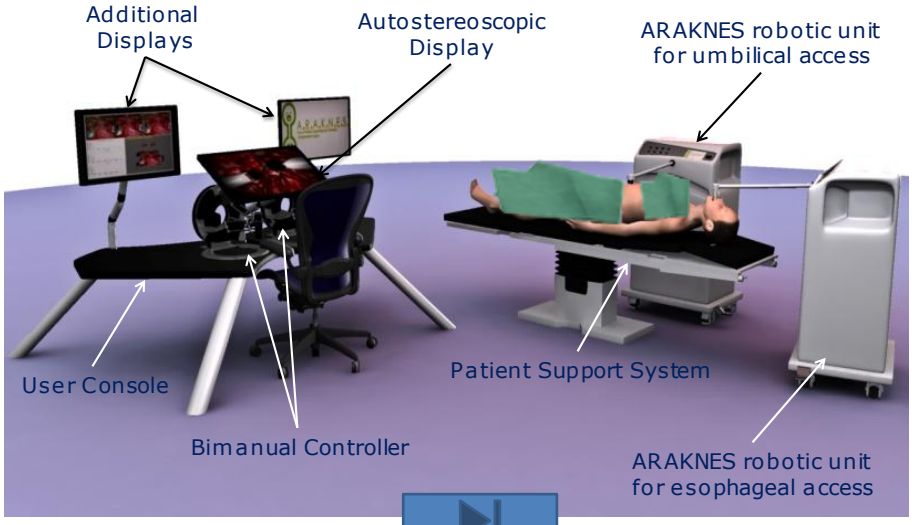
**Laparoscopic** surgery

**Laparoscopic scar after 15 days**



Umbilical incision **3 weeks after single-port nephrectomy** (kidney removal) leaves little to no scarring

## The ARAKNES (Array of Robots Augmenting the KiNematics of Endoluminal Surgery) robotic platform for Single Port and NOTES Surgery

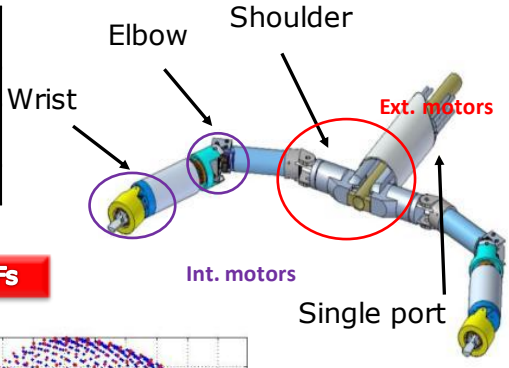



ARAKNES EU-Project 2008-2012 www.araknes.org

## The ARAKNES Internal Bimanual Manipulator

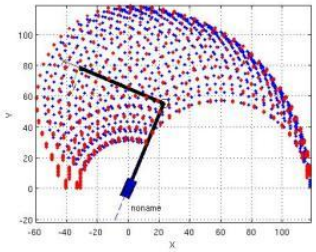
### SPRINT robot - Single-Port lapaRoscopy bImaNual roboT

| | |
|---|---|
| Arm maximum diameter: | 18 mm |
| Tip force: | 5 N |
| Joint rotational speed: | 360-540 deg/s |
| Total lenght: | 130 mm |




**For each arm:** **14 internal DOFs**

- 2 DOFs actuated by **external** motors
- 4 DOFs actuated by **on-board** motors
- 1 DOF Gripper actuated by an **external** motor



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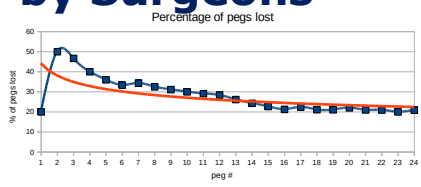
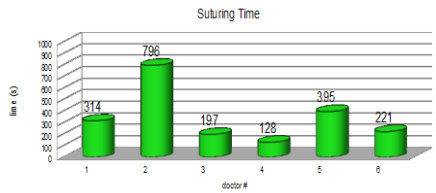
# SPRINT Robot: Mechanisms

# Characterization by Surgeons

**Peg Transfer Task**

**Suturing Task**

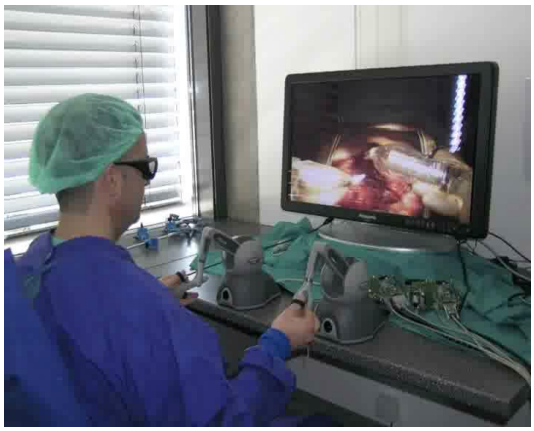



| SURGEON Background | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| AGE | 46 | 49 | 37 | 51 | 70 | 47 |
| SPECIALIZATION | General Surgery | Urology | General Surgery | General Surgery | Laparoscopic Surgery | Gynecology |
| # OF YEARS OF EXPERIENCE | 21 | 20 | 12 | 25 | >30 | 20 |
| EXPERIENCE WITH ROBOTIC ASSISTED LAPAROSCOPY | YES | YES | YES | YES | YES | YES |
| EXPERIENCE IN SINGLE PORT LAPAROSCOPY | YES | NO | YES | YES | YES | YES |

G. Petroni, M. Niccolini, A. Menciassi, P. Dario, A. Cuschieri, *A novel intracorporeal assembling robotic system for single-port laparoscopic surgery,* Surgical Endoscopy, 2012

# SPRINT Robot: In-Vivo Tests



G. Petroni, M. Niccolini, S. Caccavaro, C. Quaglia, A. Menciassi, S. Schostek, G. Basili, O. Goletti, M. Schurr, P. Dario, *A novel robotic system for single-port laparoscopic surgery: preliminary experience,* Surgical Endoscopy, 2012

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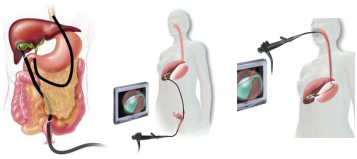
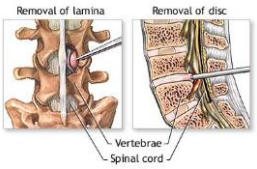
# The Quest for Miniaturization: Integrating Robotics

ABDOMINAL SURGERY



**NOTES (Natural Orifice Translumenal Surgery) SURGERY**
**Reaching** the target (esophagus diameter about 14 mm)
**Bringing** actions to the target

NEURO ENDOSCOPY




**Challenges for neuro endoscopy:**
**Reaching** the target (spinal cord diameter: 4 to 1.5 mm)
**Bringing** actions to the target

VASCULAR SURGERY

**Challenges for vascular therapy:**
**Reaching** the target (Vascular system diameter: 8 to 5 mm)
**Bringing** therapeutic actions to the target

60

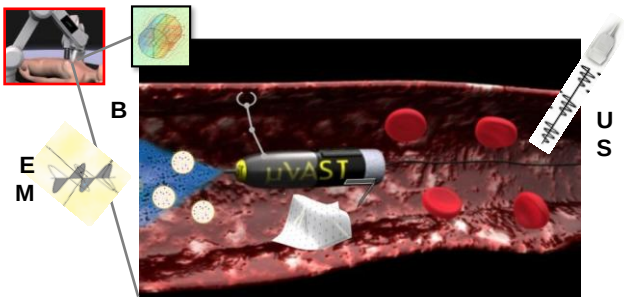
# The problem: finding and destroying the vulnerable plaque in blood vessels

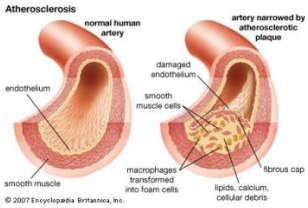
❑ **Cardiovascular disease** is the leading cause of death in industrialized countries (1.9 million deaths in the European Union). Within this group **coronary heart disease (CHD)** is a major cause of death mainly due to **atherosclerotic plaque rupture**, accounts for the largest part

❑ **More than 50% of plaque ruptures occur without significantly observable stenosis**. Identification of relevant anatomical structure and definitive therapy for atherosclerotic lesion is still far from being achieved

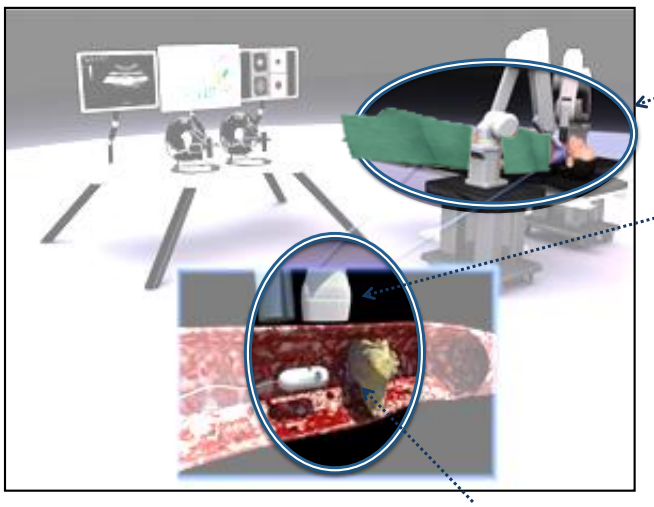
| | | |
|---|---|---|
| 1 | Ischaemic heart disease | 6·3 |
| 2 | Cerebrovascular disease | 4·4 |
| 3 | Lower respiratory infections | 4·3 |
| 4 | Diarrhoeal diseases | 2·9 |
| 5 | Perinatal disorders | 2·4 |
| 6 | Chronic obstructive pulmonary disease | 2·2 |
| 7 | Tuberculosis (without HIV infection) | 2·0 |
| 8 | Measles | 1·0 |
| 9 | Road-traffic accidents | 0·99 |
| 10 | Trachea, bronchus, and lung cancer | 0·94 |

*First ten causes of death worldwide in million of decease (The Lancet, 1997)*




# The Micro-VAST Platform



**Navigation module**: **External robots** holding a permanent magnet and a diagnostic US probe.

**Therapeutic module: Focused US** thrombolysis enhanced by microbubbles released by means of a magnetic internal mechanism

**Debris collection module:** Binding of magnetic particles to thrombus for collection and retrieval of debris.

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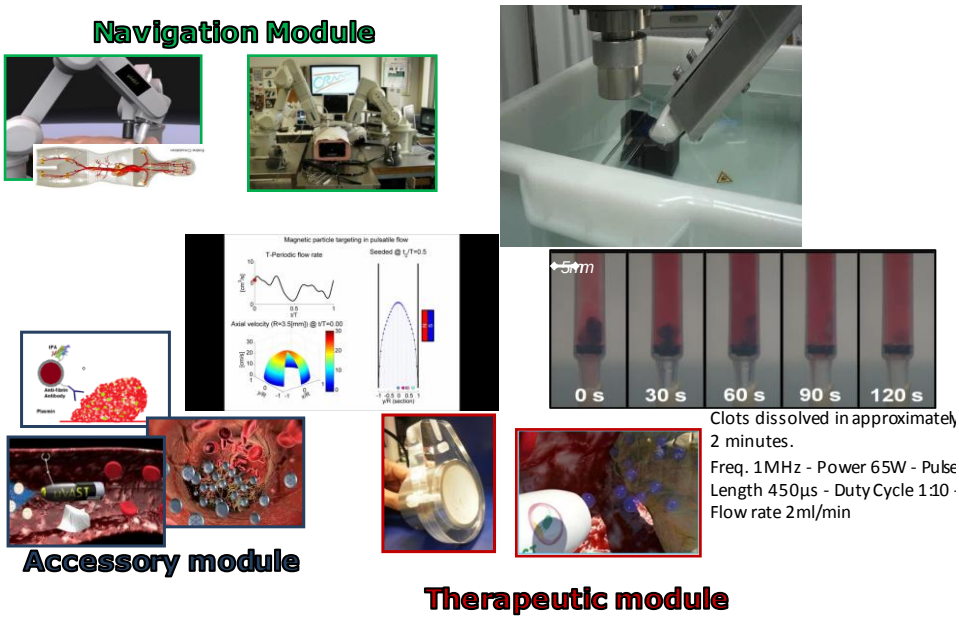
## Micro-VAST Modules: navigation, therapy, post-therapy treatment




Clots dissolved in approximately 2 minutes.

Freq. 1MHz - Power 65W - Pulse Length 450µs - Duty Cycle 1:10 · Flow rate 2ml/min

# Next Grand Challenges for Robotics Surgery

- Transforming (more) dreams into reality


## Next Grand Challenges for Robotics Surgery

- Transforming (more) dreams into reality
- **Dreaming new dreams**

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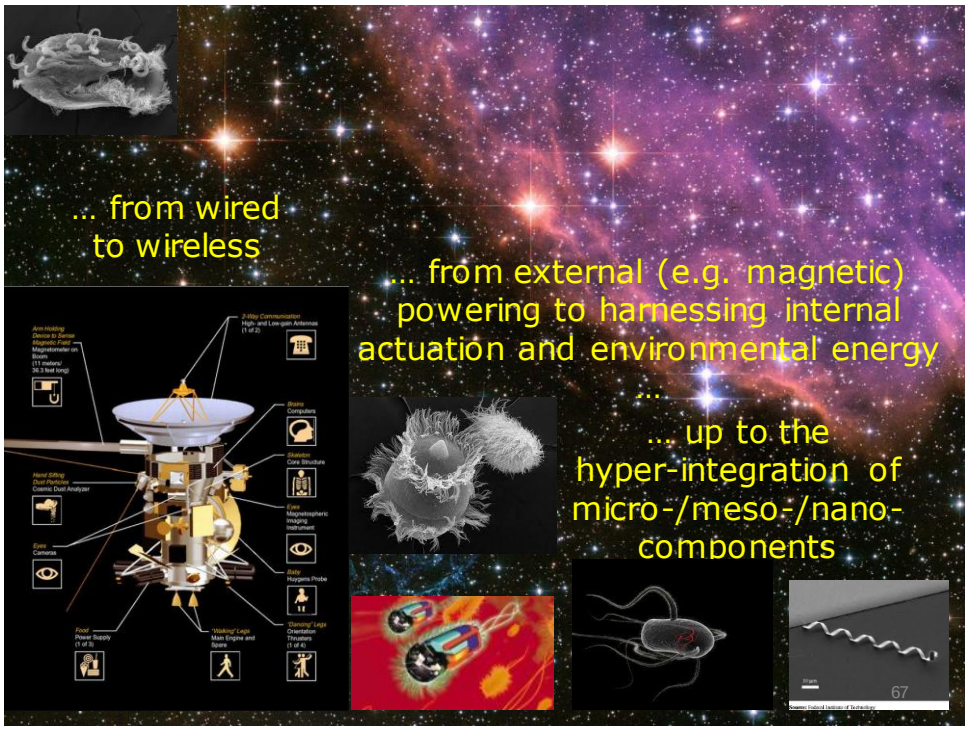
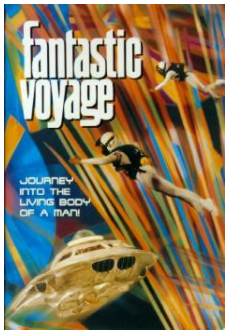



# Is it the time to revisit science fiction?




Isaac Asimov, *Fantastic Voyage*, Bantam Books, Inc., 1966.

FANTASTIC VOYAGE—FROM FICTION TO REALITY

ÉCOLE POLYTECHNIQUE DE MONTRÉAL RESEARCHERS MAKE NEW INROADS FOR CANCER TREATMENT BY USING MRI TO TRACK AND PROPEL DEVICES THROUGH THE BLOODSTREAM.

**By Véronique Barker**

ISSUE #29 // JULY-AUGUST 2007

**PROJECT**

In the same vein as the 1960s classic movie, Fantastic Voyage, where a crew of scientists are miniaturized and injected into the bloodstream, Sylvain Martel [1], director of the NanoRobotics Laboratory at École Polytechnique de Montréal, has successfully made travel through a living animal's bloodstream possible. "This is really what we are doing, except that we

zoom

S. Martel, CANADA 68

# … Current research may not be lagging too behind

❑ **Functions of different modules:**

pilot→ navigation

surgeon→ operation

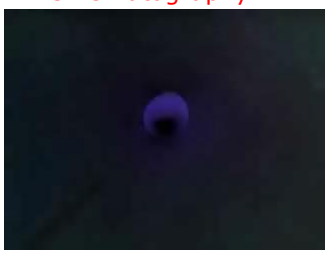
nurse→ assistance tasks

1966 science fiction movie (Dir. R. Fleischer)


❑ **Tasks:**

1. Locomotion
2. Cooperation and Manipulation
3. Therapy

Cinematography



Reality


*S. Martel (2009)*, Ecole Polytechnique de Montreal, Canada

# … Current research may not be lagging too behind

❑ **Tasks:**

1. Locomotion
2. Cooperation and Manipulation
3. Therapy


Cinematography

Reality


*S. Martel (2009)*, Ecole Polytechnique de Montreal, Canada

# … Current research may not be lagging too behind

❑ **Tasks:**

1. Locomotion
2. Cooperation and Manipulation
3. Therapy


Cinematography

Reality (targeted drug delivery )


# Science Fiction Becoming Reality

SCIENCE fiction


REALITY

# The overall vision